FAO Fisheries Report No. 389 FIRM/R389

CONTRIBUTIONS TO TROPICAL FISHERIES BIOLOGY

Papers prepared by the participants at the FAO/DANIDA Follow-up Training Courses on Fish Stock Assessment in the Tropics

Hirtshals, Denmark
5-30 May 1986

Manila, Philippines
12 January – 6 February 1986

DENMARK FUNDS-IN-TRUST GCP/INT/392/DEN

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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DENMARK FUNDS-IN-TRUST, GCP/INT/392/DEN
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME 1988

M-42
ISBN 92-5-102707-2

PREPARATION OF THIS DOCUMENT

The papers contained in this document were prepared by participants at two FAO/DANIDA Follow-up Training Courses held at Hirtshals, Denmark, in May 1986, and in Manila, Philippines, in January 1987. All papers were first scrutinized by the lecturers during or shortly after the courses before final editing. A full discussion of the goals and the methods of the courses, organized by the FAO/DANIDA project is presented in an additional paper prepared by the editors.

This document was prepared for printing by FAO at the International Centre for Living Aquatic Resources Management (ICLARM) in Manila, Philippines.

Distribution:

DANIDA
Authors and their Institutes
Participants at the FAO/DANIDA Courses
Institutes specialised in Tropical Fish Stock Assessment
Institutes of Fisheries Education
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FAO Fisheries Department
FAO Regional Fishery Officers

For bibliographic purposes this document should be cited as follows:

Venema, S.C., J.M. Christensen and D.Pauly, 1988 (eds.), Contributions to tropical fisheries biology. Papers prepared by the participants at the FAO/DANIDA Follow-Up Training Courses on fish stock assessment in the tropics. Hirtshals, Denmark, 5 - 30 May 1986 and Manila, Philippines, 12 January-6 February 1987. FAO Fish.Rep., (389):519 p.

ABSTRACT

This document contains 34 papers, produced by the participants at two Follow-up Training Courses on Fish Stock Assessment in the Tropics, organized by the FAO/DANIDA Project "Training in Fish Stock Assessment and Fishery Research Planning" GCP/INT/392/DEN. These are papers on the dynamics of tropical invertebrates (8), demersal (8), and pelagic fishes (11) and on biological and technical interactions in tropical multispecies stocks and fisheries (7). A description of the courses, their methods and goals is given in an additional paper. The document is provided with a species, a geographic and an authors index.

ACKNOWLEDGEMENTS

As manager of the FAO/DANIDA project "Training in Fish Stock Assessment and Fisheries Research Planning" and also on behalf of the course participants, I wish to thank all those people who have made it possible to produce this volume.

The papers could not have been produced without the enormous dedication and inputs of the team of tutors and lecturers: Peder Agger, Ole Bagge, Jan Beyer, Hans Lassen, Niels Axel Nielsen, Daniel Pauly, Per Sparre and Erik Ursin.

Special thanks are due to Djiby Thiam, Mina Soriano and Felimon Gayanilo, who assisted in data processing and programming. The reproduction and duplication of the draft papers at different stages during and after the courses was a gigantic task, requiring a lot of strenuous work on the part of the teams of secretaries. To Anne Marie Nielsen and Jane Ugilt (Hirtshals) and Elvira Carnay, Leah Macantagay, Estrella Makiramdam, Isa Manela, and Nenita Sunglao (Manila) my heart-felt thanks.

Management and staff of the North Sea Centre at Hirtshals, Denmark, and the Hostel of the Philippine Center for Economic Development of the University of the Philippines, Diliman, Quezon City, Philippines, have done everything to make our stay agreeable and our work possible.

ICLARM provided very large inputs in terms of equipment, facilities and personnel. Special thanks to Ian Smith, Director-General; Jay Maclean, Director, Information Program; Leticia Dizon, Managing Editor; Abbie Cruz, Network Secretary; Eloisa Espiritu and Priscilla Catalang, typesetters; and Mark Anthony Go-Oco and Christopher Bunao, draftsmen.

Thanks are also due to the management support team provided by the Government of the Philippines led by Course Director, Inocencio Ronquillo and Coordinating Officer, José Ordoñez. I am specially grateful to Jessica Muñoz and Arlene Legaspi for their management work in Manila.

The references of the papers produced at the Hirtshals course disappeared with my suitcase on returning to Rome. Many thanks to Gloria Soave and Daniel Pauly for having helped me to put them together again.

A team consisting of Jorgen Jensen of DANIDA and Arthur Simpson of FAO started an evaluation of the project during the course in Hirtshals. Their enthusiasm for the concept of the follow-up course has encouraged us very much.

Very special thanks are due to my co-editors Jorgen Møller Christensen, Director of the Hirtshals course and to Daniel Pauly, who has greatly stimulated the production of this volume, and to my secretary Erminia Ronchetti, who has been defending my home-base very well.

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Dynamics of Tropical Pelagic Fishes

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Training in Tropical Fish Stock Assessment: A Narrative of Experience*

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Abstract

A description is given of training courses in tropical fish stock assessment organized by the FAO/DANIDA project "Training in Fish Stock Assessment" (1983-1987), and specifically of the two follow-up courses which led to the 34 other papers included in this volume. Discussed are goals and methods of such courses, as well as the technical content of the curricula and their implementation via appropriate hard- and software.

Introduction

The present contribution represents a narrative and documentation of two follow-up training courses on fish stock assessment in the tropics, organized by a FAO/DANIDA project (GCP/INT/392/DEN), which led to the 34 other papers included in the present volume. This contribution is also intended to reflect on some of the experiences gained during these courses for the benefit of those with interest in further developing and teaching fisheries biology applied to tropical resources.

*ICLARM Contribution No. 422.

The project "Training in fish stock assessment" is funded by the Government of Denmark through the Danish International Development Agency (DANIDA) and executed by FAO under the FAO/Denmark Cooperative Programme (GCP/INT/392/DEN).

The project started on 1 January 1982 with a total budget of US$1,426,000 for six years. It will continue for another five years, with some modifications in the objectives and geographical areas of operation, and an additional budget of US$2,675,000.

From 1982 to 1987, the project's main objectives were to create nuclei of fish stock assessment specialists in tropical developing countries where English is the main language, and to provide them with the means for international contacts and updating of their skills and knowledge.

These objectives were planned to be achieved mainly through a series of training courses and follow-up activities in the form of consultant visits, fellowships and provision of documentation. However, soon after the start of the project it was decided to make use of the "Network of Tropical Fisheries Scientists" set up in 1982 by the International Center for Living Aquatic Resources Management (ICLARM) and its newsletter "Fishbyte" for aspects concerning communication and information (Munro and Pauly 1982; Pauly and Munro 1982). In 1984 it was decided to use the funds initially intended for fellowships to organize, instead, three follow-up courses for selected participants of the first seven courses organized by the project.

A total of 12 courses were organized: (1) seven basic courses in tropical fish stock assessment, of which two were regional and five national; (2) three follow-up courses, of which two were regional and one national, for selected participants from the seven basic courses; and (3) two mini-courses of one to two weeks duration by one lecturer. A detailed list is presented in Table 1. Other major outputs of the project are a new manual based on the collective experience of the lecturers (Sparre 1985), nine thoroughly documented case studies on tropical fish stock assessment and management, and two volumes with papers produced by the participants of the three follow-up courses. The present document includes those papers produced by the 34 participants of the courses in Hirtshals and Manila. The 11 papers produced by 12 participants during the course in India in November 1987 will be published as a separate volume.

Table 1. Training courses held under the FAO/DANIDA Project "Training in fish stock assessment", 1983-87

Regional Courses	
1.	Western and northern Indian Ocean, Mombasa, Kenya, 16 May -17 June 1983
2.	West Africa and Caribbean, Hirtshals, Denmark, 03 - 30 June 1984
National Courses	
3.	India, Cochin, 07 November - 09 December 1983
4.	Indonesia, Semarang, 05 November - 01 December 1984
5.	Malaysia, Penang, 05 November - 01 December 1984
6.	Phuket, Thailand, 04 - 29 November 1985
7.	Manila, Philippines, 13 January - 05 February 1986
Follow-up Courses (Regional/National)	
8.	Hirtshals, Denmark, 05 - 30 May 1986 Participants from courses 1 and 2
9.	Manila, Philippines, 12 January - 06 February 1987 Participants from courses 4 to 7
10.	Cochin, India, 02 - 28 November 1987 Participants from courses 1 and 3
Mini-courses (National) (1 lecturer)	
11.	Kingston, Jamaica, 25 September - 02 October 1985
12.	Port of Spain, Trinidad and Tobago, 05 - 16 October 1987

Courses on Fish Stock Assessment in the Tropics

The seven basic courses in Table 1 were the successors of a series of *ad hoc* courses executed by FAO since 1972 with funds provided by DANIDA, France, CIDA (Canadian International Development Agency) and other organizations, as documented in Venema and Pauly (1982). As such they built on training material already produced for these courses, and a considerable amount of experience gained which led to the identification of the following requirements for the new project:

a) Adaptation of course materials to the specific requirements of fisheries biologists working in the tropics;
b) Training of lecturers through preparatory missions to the tropics and the preparation of case studies. This is necessary because even very experienced fishery biologists from temperate areas are not *ipso facto* qualified to teach tropical fisheries biology;
c) Flexibility with regard to national needs for countries with a larger pool of fishery scientists and regional requirements in the case of grouping of small countries;
d) Adjustment to the different levels of training and experience of the participants;
e) Interactions between trainees and trainers, where possible, before and certainly after the training courses;
f) Continued institutional follow-up after course completion.

The general objective of the seven basic courses was to train fisheries scientists engaged in activities related to stock assessment in the most advanced techniques available for stock assessment in the tropics and to provide them with the means to apply these techniques after the course.

For these purposes it was decided to provide each participant with a programmable scientific pocket calculator (Sharp EL5100S) and to develop a manual with examples from tropical fisheries, containing computational exercises and answers (Sparre 1985). The calculator selected can cope with all calculations needed for the methods taught, while the manual consists of two parts, only one of which contains answers, thus providing a means for self-study and extension.

While the manual was used for a brief introduction in the methods during the first two or three weeks of each four or five week course, actual training in stock assessment was provided in the form of case studies on aspects of tropical fisheries written and selected according to the needs and interest of the participants. A total of nine case studies is now available or in preparation on subjects such as: trawl surveys, coral reef resources, shrimp stock assessment, gillnet selection and data collection and management aspects of a small-scale fishery.

Follow-up Courses

Three follow-up courses were organized by the project, in Hirtshals, Denmark (May 1986, see Appendix I), Manila, Philippines (January 1987, see Appendix II), and Cochin, India (November 1987). Of these, only the first two are considered in this paper.

The objective of the follow-up courses was to assist selected participants from the earlier courses in carrying out a complete scientific (fish stock assessment) study. This comprised processing of data collected in the participants' countries, writing a scientific paper, presenting and discussing it with lecturers and fellow participants, and finally preparing it for publication.

The invited participants were selected by the lecturers of the previous training courses in close collaboration with local course directors or immediate supervisors. The criteria for selection were the following, the participants should: a) be currently engaged in assessment work; b) have a set of data available, preferably collected by themselves; and c) master the techniques taught at the previous training courses.

After selection, but prior to the issuing of invitations, the participants (and their institutions) were visited by one of the lecturers, and the selèction of data for analysis was finalized during such a visit. This enabled the majority of participants to arrive at the course with data considered to be suitable for analysis and the subsequent production of a scientific paper.

Use of Microcomputers

The rapid development and sharp drop in the costs of microcomputers, combined with the increased availability of user-friendly menu-based programs for fish stock assessment of tropical resources, logically led to the decision to make this hard- and software available to the participants at the courses.

An important consideration for this decision was that the number of microcomputers available to fishery scientists in developing countries was increasing rapidly and that the leading scientists should therefore be trained in their use as soon as possible. The courses also formed excellent opportunities to test the user-friendliness and other aspects of the various program packages.

Details on computer use in Hirtshals and Manila are given below:

Hardware

HIRTSHALS COURSE

Five microcomputers and one minicomputer (of the Danish Institute for Fisheries and Marine Research) were used as follows:

(i) Four Apple IIc (128K each): three used to run a test version of the program package for Apple II developed by Sparre (1987), while the fourth equipped with a CP/M card, was used to run the ELEFAN package of Brey and Pauly (1986).

(ii) One Hewlett-Packard HP87 with a two-pen plotter, used to run the graphics-oriented ELEFAN package of Saeger and Gayanilo (1986), and/or to generate graphs of curves estimated using other programs.

(iii) One minicomputer VAX 11/75 was only used to run a very fast version of the ELEFAN I program written by P. Sparre (pers. comm. to Sims 1984), and improved during the course by D. Thiam and P. Sparre (see Thiam 1986).

At this course, there were therefore about three participants per computer.

MANILA COURSE

(i) Five IBM PC's (or compatibles) with printers, on loan from ICLARM, used to run a test version of the graphics-oriented package "The Compleat ELEFAN" (see Pauly and Morgan 1987).

(ii) One mainframe computer of the University of the Philippines, used for a discriminant analysis of the morphometrics of two fish species (Soriano et al., this vol.).

Five participants were assigned per PC, the fifth PC was used mainly for additional programming activities.

Software

Since the first course held in Mombasa in 1983, where an early version of ELEFAN was used with an Apple III computer, great progress has been made in the development of software for fish stock assessment, based mainly on length-frequency data sets. Three packages were available and used in Hirtshals, *viz.*, a) the ELEFAN version of Brey and Pauly (1986) for Apple II with CP/M; b) the graphics-oriented ELEFAN package for Hewlett-Packard 86/87 (Saeger and Gayanilo 1986), and c) the Length-Based Fish Stock Assessment (LFSA) program package developed by Sparre (1987) for Apple IIc.

The diversity of these computer systems was the cause of significant loss of time during the course; the need to re-enter files into different computers proved particularly frustrating. It was therefore decided that the subsequent course would use only one type of computer, and that files created for one type of analysis should be transferable between programs.

The LFSA package was still being developed and numerous interventions and program changes were needed. It is obvious that a course of this type was one of the best testing opportunities for this new software, but that, on the other hand, too much time had to be dedicated to this activity.

For the Manila course the situation was simpler, since only one package was used, a test version of the Compleat ELEFAN package for IBM PC and compatibles. Also, this program package underwent thorough testing during the course, but this time two programmers, Ms. Mina Soriano and Mr. Felimon Gayanilo, Jr. (ICLARM), were present to make the necessary changes and/or to help the participants in making proper use of the package.

During the Hirtshals course the bulk of the duplication in re-entering files was caused by the need for different files for the ELEFAN package on the one hand, and the Bhattacharya (1967) and Gulland and Holt (1959) plot method, which forms the key steps in the FAO package (Sparre 1987), on the other hand. For this reason it was decided that the latter two routines should be incorporated into the Compleat ELEFAN package. Another considerable improvement was that the Compleat ELEFAN package runs in compiled BASIC, hence the problem of extended computing time, such as occurred in Hirtshals, has been resolved.

Overall, the problems related to the software used were:

- Lack of detailed documentation (the manuals provided made numerous tacit, but sometimes, questionable assumptions, see below);
- Participants not reading manuals, and generally ignoring the instructions provided through the program (e.g., via the "instruction box" of the Compleat ELEFAN package).

While the latter is explainable largely by the lack of familiarity of many participants with the use of computers, the former is a serious problem with potentially harmful implications.

Thus, for example, in the case of the method of Wetherall (1986), which is, in slightly modified form (Pauly 1986a) incorporated in the Compleat ELEFAN package, the points used in the linear regression are - as suggested by Wetherall (1986) - weighted by the cumulated frequencies. This gives, however, an enormous weight to the first point included in the regression, i.e., to the very point whose selection (by the participant) is generally very problematic. Thus, the method, although in principle correct, can produce completely misleading results - even when well-sampled data are used - if only one point is not well chosen. The software, it was felt, should therefore (i) provide alternative weighting modes and (2) flash special warnings about the dangers and consequences of erroneous selection of point(s).

Preparation of the Papers

Pre-course

In order to produce the highest efficiency in accomplishing the objectives of the follow-up courses, each participant was given a tutor. For the Hirtshals course, one tutor each was assigned to the four participants from the Caribbean area; the five participants from West Africa and the five participants from East Africa and the South-West Indian Ocean region. (By coincidence, none of the three participants assigned to the fourth tutor came to Hirtshals).

For the second course one tutor was assigned to each of the three largest national groups and one to a group representing all countries.

Prior to the courses, each participant was visited by his/her tutor who stayed for some days and assisted in the selection and presentation of data, and discussed aspects of the work relevant to the preparation of the paper.

Between these preparatory missions and the actual course, tutors and participants maintained close contact through correspondence, while searches for relevant literature were carried out upon request. As a consequence of these activities, some participants arrived at the actual courses with semi-processed data sets and/or draft papers with reference material. Despite this preparatory work several others, however, arrived with large quantities of raw data, sometimes collected at the last moment, which required a lot of processing time.

Course

As the courses reported upon here represented a new form of training for the project, no detailed program was made in advance of the Hirtshals course, i.e., only a rough outline was established within which it developed in the following four phases:

i) In plenum sessions during the first two days the participants presented their data sets and intended methodologies to be followed. Some instructions were given on the use of the microcomputers;

ii) The remaining part of the week one, plus week two were used for data sorting, input and analysis, in close cooperation with the respective tutor;

iii) During the third and fourth week first drafts of the papers were actually written, entered in the word processor and copied to all. The authors then presented their papers at "mini symposia". Lecturers and participants usually offered a number of suggestions for additional data processing and improvement.

iv) After the mini symposia most papers were partly or completely rewritten, reproduced and distributed for final comments.

A number of lectures were given on topics related to problems encountered during the preparation of data and papers, e.g., on the assumptions behind each method.

The Manila course, with a larger number of participants (20), of which about 50% had difficulties in speaking and writing English fluently, the production of a first draft was delayed by about one week. Very few participants had therefore an opportunity to produce a revised second draft of their papers. However, some modifications were made towards the end of the course in close collaboration with the tutors and editors.

Some 17,000 photocopies were made during each course, which indicates clearly the amount of work involved in the production and reproduction of these papers.

Post-course

Subsequent to both courses the papers were reviewed by the tutors and, where necessary, edited versions were sent to their author(s) for comments and/or additional work. The editors, in cooperation with ICLARM's technical staff, notably Mrs. Letty Dizon, then prepared the camera-ready version.

Contents of the Papers

The 34 papers prepared by the participants of the two courses cover a variety of studies, generally closely linked to length-frequency analysis. The papers presented in this volume range from full-fledged assessments, including catch predictions, to preliminary analyses, indicating serious gaps in sampling programs or other constraints, e.g., relatively large mesh sizes used for surveys. All papers contain the basic data which enable the reader to repeat the data analysis, for example, with the help of improved versions of the program packages. The papers can therefore be used straightforwardly as case-study material for training purposes, in addition to their obvious contribution to our knowledge on the various resources. The papers have been arranged in four groups: "dynamics of tropical invertebrates", "dynamics of tropical demersal fish" and "dynamics of tropical pelagic fishes", dealing with estimates of growth parameters and assessments of specific resources, respectively, and "biological and technical interactions in tropical multispecies stocks and fisheries". As might be seen from Fig. 1, the 34 papers included here cover a large part of the intertropical belt.

Basic Structure of Analysis

The bulk of the papers in the first three groups follows this outline:

(*i*) Presentation of basic (length-frequency data), including as needed, their regrouping in space and time, and ponderation (usually by the catch instead of catch/effort, as would probably have been more appropriate);

(*ii*) Estimation of growth parameters using either the ELEFAN I program of Pauly and David (1981), or the Bhattacharya (1967) method of separation of composite distribution, with subsequent linking of mean length and estimation of growth parameters using the method of Gulland and Holt (1959). Also, use of the ϕ' concept (Pauly and Munro 1984, and see below);

(*iii*) Estimation of mortality (Z) under the assumptions of steady state, using a length-converted catch curve (Pauly 1984; Sparre 1985) or mean length(s) in catch samples using the equation of Beverton and Holt (1956) or the method of Wetherall (1986);

(*iv*) Subtraction from Z of an estimate of natural mortality (M) usually based on the empirical equation of Pauly (1980a) to obtain an estimate of fishing mortality (F), through $F = Z - M$ and computation of the exploitation rate $E = F/Z$;

(*v*) Assessment of state of the stock based on the values obtained in *(iv)*, complemented, as permitted by the available data, by additional analyses, e.g., length-cohort analysis (Jones 1984), yield-per-recruit analysis (Beverton and Holt 1966; Pauly and Soriano 1986); surplus production models (Schaefer 1957; Fox 1970; Munro 1980).

A number of participants had insufficient data for all items, from *(i)* to *(v)* to be performed. Some had more, or different data, notably on mesh selection, enabling different analysis to be performed. These may be found in this volume under the section on "Biological and Technical Interactions in Tropical Multispecies Stocks and Fisheries".

The ϕ' concept alluded to above, refers to the fact that given constant units (i.e., with the parameter L_∞ and K of the von Bertalanffy growth function being expressed as total length in cm and $K = \text{year}^{-1}$, respectively) and base for the logarithm (we used Log_{10}), the quantity ϕ' defined by:

$$\phi' = \log K + 2 \log L_\infty$$

is normally distributed within a given fish species with different populations, each of which may have different but mutually compatible values of L_∞ and K (Pauly 1979, 1980b; Pauly and Munro 1984). Thus, growth parameter estimates for a given stock can be usefully compared via

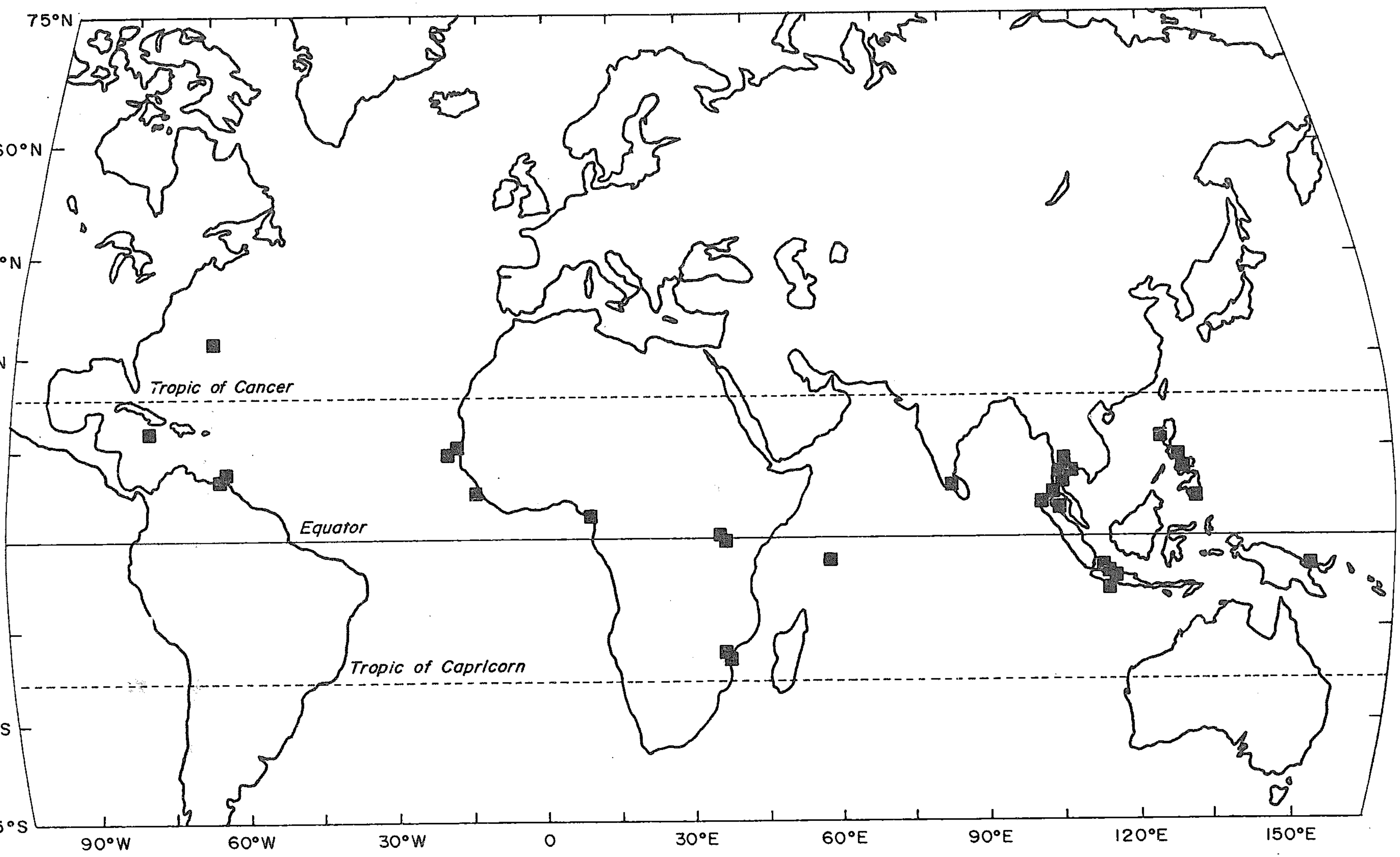

Fig. 1. Geographical distribution of sampling sites for the data analyzed in the 34 other contributions included in this book. Note extensive coverage of the intertropical belt.

ϕ' with those of another stock, and their compatibility assessed. Conversely, when growth data are not available for a specific stock of a given species, a mean value of ϕ' can be estimated from other stocks of that same species, and ϕ' used in conjunction with an estimate of L_∞ obtained through the method of Wetherall (1986) to indirectly obtain an estimate of K (see Pauly 1986b for a first discussion of this approach, proposed at a training course held in Algeria in November 1985). These approaches, as illustrated in a large section of the contributions included in this volume, suggest that the situation should become rare, where an assessment cannot be carried out for lack of growth parameters - at least as far as the most common tropical fish and invertebrate species are concerned.

This matches the situation concerning the estimation of the natural mortality coefficient (M), for use in various models (yield per recruit, cohort analysis). This difficult task was essentially resolved through use of the empirical equation of Pauly (1980a) also used extensively during this course.

Since the papers were considered to be useful training material for future courses and/or self-study, it was decided to expand the methods section of some papers by incorporating descriptions of some of the methods and to make cross references to these sections in other papers, e.g., effects of migration (Sousa), ELEFAN (Thiam), seasonality (Samb), Bhattacharya (Asila and Ogari), swept-area method (Jones and Jones), raising factors (Djama), etc.

Evaluation of the Follow-up Courses and their Output

Generalities on the Courses' Contents

There were some major and minor questions regarding principles which attracted attention during the discussions:

- What to do with incomplete data sets and less than perfect assessments: Should one wait until the "right data" become available, or publish what is there, analyzed in the best possible fashion?
  At the course the second option was chosen in view of the fact that publishing and working should be for fisheries scientists a continuing process rather than a "once-in-a-lifetime-event". Also, the specific situation of many developing countries (problems with publishing, staff fluctuation, difficulties in safe-keeping of data) makes it mandatory to write one's results before opportunities are lost (Pauly 1986c).
- Another example is the variation of methods. The computer programmes are often more sophisticated than the basic method as described in available manuals or textbooks. Example: The length-frequency catch curve normally has ln N/ΔT as the ordinate. The ELEFAN package available at the courses had something more complicated, which required an iterative procedure. The results become less biased (P. Sparre, pers. comm. to Pauly 1984). The users, however, did not know the method, but accepted it. The question is: what are the implications of this attitude, should the instructors be worried about this?
- In general, the scientists of developing countries are not sufficiently motivated by their institutes to write scientific papers. They should be remedied.
- Major problems were observed with regard to insufficient knowledge of relevant literature.

Evaluation of the Hirtshals Course

An evaluation based on a questionnaire filled by the participants of the first course (at Hirtshals) was conducted at the Hirtshals course in order to optimize planning for the second course (in Manila). The results of the evaluation may be briefly summarized as follows.

i) All 14 participants thought that the follow-up course was an excellent (10) or a good (4) way to give high level training following an introductory training course in fish stock assessment.

ii) The tutors' visit prior to the course was very much appreciated and all but one participant found that they had received sufficient guidance on preparation of the data and were given a clear understanding of what was expected of them.

iii) Everybody found it a good idea to start the course with a presentation of each case. All but one liked the "mini-symposium" approach. However, many would have liked to have more time to read the papers before each discussion. The working facilities were (i.e., the North Sea Center, Hirtshals) found to be all right. Half of the participants had sufficient time for the work, the other half did not. Computer facilities were found to be just right by eleven and insufficient by two participants.

iv) Several participants suggested that more data processing (e.g., raising length-frequency data to catch or catch/effort) should be done prior to the course, such as to allow more time for more sophisticated analyses and discussions.

v) A direct question asking for suggestions for improvements was answered as follows (random order):
- More and better instruction in the use of computers;
- More lectures on the implications for management;
- More time for preparation of mini-symposia;
- More tutors, or rather, the time of the tutors should not be taken up for computer programming and debugging.

vi) A specific problem that arose in a few cases was that of conflicting advice or rather different approaches to solve a specific problem being given by the tutor on the one hand and one or more of the other lecturers on the other. This was quickly solved when recognized, but unfortunately not without having caused some stress to the participants. On the other hand, it was a good demonstration of the fact that different approaches are usually equally acceptable in the process of finding out what is happening to a fish stock.

As far as possible, these suggestions and criticisms were used to improve the planning and execution of the second course.

Evaluation of the Manila Course

To a large extent the Manila course went more smoothly than the Hirsthals course among other reasons due to uniformity in the computers and programs, the continuous presence of two additional programmers and easy access to the specialized library of ICLARM.

However, there were two major problems which required a lot of extra inputs from the participants and staff *viz*., the limited English language skills of about half of the participants and a number of large sets of raw data requiring a large amount of processing time. However, these problems were gradually solved and the papers were eventually produced during the course as scheduled.

The Data and the Outputs

After many years of despair because the age of tropical fish could rarely be read from their hard parts, such as scales and otoliths, a new era began when the implications of the fact became fully realized that most length-frequency distributions of tropical fish contain peaks, each representing fish of approximately the same age. More or less sophisticated methods of length-frequency analysis were rapidly presented often in the form of further development of concepts initially proposed by earlier generations of researchers working on length-frequency analysis. They were applied in numerous papers published in the last decade, most of them showing promising results and based on data which had been collected but not published for obvious reasons. This has delayed the development of rigorous criteria for assessing the suitability of data sets for use of methods of length-frequency analysis (but see contribution in Pauly and Morgan 1987).

Some data sets used during the courses were clearly deficient because of inadequate sampling. The papers based on such sets would normally not be given a wide distribution, e.g., as formal publications. They have been incorporated here because they serve as a clear illustration of cases when sampling programs fail and of what needs to be done to improve them. The discussion of these papers may be considered of great importance for training purposes.

Where assessments of stocks of temperate waters are usually based on long series of data collected under national or international sampling programs, data collection in tropical developing countries has been much more limited in time and area due to lack of means and/or long-term planning. Data are often collected under short-term, local projects rather than through national or international sampling schemes. This is an immediate problem but hopefully not a lasting one.

Another problem associated with data collection is that in many cases additional data on total landings and effort of a particular fishery, sample weights and total catch of the vessel sampled were not collected, thus preventing the use of proper raising factors. However, this problem can, of course, be avoided in future sampling schemes to be set up by the participants and their colleagues.

More serious is the fact that some species have length-frequency data with cohorts that are difficult to identify, with one or two modes appearing to remain in the same position for the major part of the year. We assume this is due to an inflow of juveniles from a nursery ground and an outflow of young maturing adults to a different location. These phenomena occurred in several data sets treated at these courses (see e.g. Sousa, this vol.).

Most participants brought data sets for one or two reasonably abundant species. In fact, the "multispecies" problem of tropical demersal fisheries was approached explicitly in only a few papers.

There were also few papers on stock and yield assessment. Does this indicate that most scientists are still busy estimating the basic parameters of growth and mortality, or is it an indication of a still poor relationship between biological research and management needs? The situation will differ from one country to another. During the courses, however, the important role of the fishery scientist *vis-à-vis* the authorities responsible for management and development has been repeatedly emphasized.

Despite the above-mentioned limitations the bulk of the papers included here do represent significant advances, either in terms of assessing specific stocks or at the conceptual level, as in the case of the papers grouped in the section on "Biological and Technological Interactions".

It is thus with considerable pride that we present this volume of contributions to tropical fishery biology.

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Appendix I

FAO/DANIDA FOLLOW-UP TRAINING COURSE IN TROPICAL FISH STOCK ASSESSMENT HIRTSHALS, DENMARK, 5-31 MAY 1986

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Appendix II

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Growth, Mortality and Recruitment of the Asian Moon Scallop *(Amusium pleuronectes)* in the Visayan Sea, Philippines

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Abstract

Growth, mortality and recruitment in *Amusium pleuronectes* were investigated using the shell height-frequency data obtained from the Visayan Sea scallop population. Computer-based methods of length-frequency analysis (particularly the ELEFAN programs) were used. Results obtained gave values of SH_∞ = 100 mm, K = 0.94 and Z = 4.80. The recruitment pattern indicated two spawning peaks, with an interval of about four months between peaks.

Introduction

Scallops (Fam: Pectinidae) make up one of the important shell fisheries of the Philippines. Since 1972 (when the country started exporting these commercial bivalves) a total of some 943 t of scallop meat alone, valued at about P23.2 million or US$1.15 million (US$1 = P20), has been exported (Fisheries Statistics of the Philippines 1972-1984). The shells of scallops also find their way in the export market in the form of finished shellcraft articles.

The country's scallop fishery is primarily based on the species *Amusium pleuronectes*. The industry is totally dependent on natural harvests from several fishing grounds such as, but not limited to, Visayan Sea, Lingayen Gulf, Carigara Bay and Asid Gulf.

Scallops have been extensively studied (Kopinski 1978). However, only a few of the studies made pertain to stock assessment and still fewer deal specifically with the genus *Amusium* . Published reports on *Amusium* include the taxonomic study of *Amusium* species (Habe 1964) and specific studies on *A. balloti* (Heald 1978; Heald and Caputi 1981), on *A. japonicum balloti* (Dredge 1981; Williams and Dredge 1981) and on *A. pleuronectes* (Llana 1979; Morton 1980; Llana and Aprieto 1980; Llana 1983).

A more recent work on *A. pleuronectes* deals with some aspects of growth, recruitment, mortality and reproduction of the species in Lingayen Gulf, Philippines (Del Norte 1986).

This paper attempts to: (1) estimate the growth and mortality parameters of the von Bertalanffy growth formula (VBGF) for *Amusium pleuronectes*, (2) determine the pattern of recruitment of the species in the area of study and (3) compare the results obtained for the Visayan Sea scallop population with those of other studies on *A. pleuronectes* and other *Amusium* species. Comparison of results may be useful since population parameters vary according to locality due to differences in environmental conditions (Bourne 1964; Gulland 1983).

Materials and Methods

The material used for this paper consists of a set of data on shell-height frequency of 1,114 scallop specimens collected during the period June 1976 to March 1977 (Table 1). The data were obtained from the monthly trawl catch of the research vessel *Albacore* (owned by the College of Fisheries, University of the Philippines in the Visayas (UPV/CF)) in the Visayan Sea (Fig. 1). The cod-end of the trawl net used had a mesh size of 15 mm (stretched).

Sampling of the scallops used for this study was part of the sampling scheme adopted by the UPV/CF Institute of Fisheries Development and Research (IFDR) in its project on trawl investigation of the Visayan Sea demersal fisheries in 1976-1977 (Aprieto and Patolot 1977). Fishing tracks and oceanographic stations are given in Fig. 1.

After the catch per drag was landed on deck, all scallops were collected and weighed. Size measurements were done using a Vernier caliper on board the research vessel. Shell height (i.e., the straight-line distance from the hinge to the ventral edge of the shell) and shell length (i.e., the straight-line distance perpendicular to the shell height) were measured. However, for this paper, only the shell height (SH) measurements were considered in the analysis.

Data analysis was facilitated by the use of a computer-based approach to extract growth parameters from length-frequency data. This approach uses the ELEFAN I and II (Electronic LEngth Frequency ANalysis) programs (Pauly and David 1981; Pauly et al. 1982; Pauly 1985, 1986a, 1986b). Sparre (1985) discussed this new approach of length-frequency data analysis. A number of contributions have presented the applications of the ELEFAN programs (Pauly and Ingles 1981; Pauly and Mines 1982; Ingles and Pauly 1984; Pauly et al. 1984; Pauly and Navaluna 1984) including their application to *A. pleuronectes* (Del Norte 1986).

The first step in the computer work was to enter the set of data, using a class size of 3 mm, through the ELEFAN 0 program which allows formatting of data such that they are readable by other ELEFAN routines.

Once the data set has been entered and filed, a shift to the ELEFAN II program was made to estimate the SH_∞ (asymptotic shell height) and Z/K (ratio of the coefficients of mortality and growth) using a modified version of the Wetherall method. This new method of estimating growth and mortality parameters from length-frequency data is presented and discussed by Wetherall (1986) and Pauly (1986a).

The data set was further analyzed in terms of growth using the von Bertalanffy model through the ELEFAN I program. The von Bertalanffy growth formula (VBGF) takes the form (in the ELEFAN I program) of a modified version of the standard VBGF (Pauly and David 1981). The work involved the use of three routines available in the program: (1) response surface generator (to identify the best combination of parameters), (2) direct search for the "optimum" combination of growth parameter values and (3) curve fitting by eye (to fit a growth curve through the restructured sample). These three routines use a new index of the goodness of fit (Rn) to avoid getting negative values of goodness of fit. Rn is computed as equal to 10∧ (ESP/ASP)/10, with ESP (Explained Sum of Peaks) over ASP (Available Sum of Peaks) as a measure of goodness of fit (Pauly and David 1981; Sparre 1985).

Using the values of the growth parameters SH_∞ and K obtained from ELEFAN I, the next step was to shift back to the ELEFAN II program to estimate the total mortality (Z) from a length-converted catch curve, and recruitment pattern. The ELEFAN II program includes, among others, the estimation of Z based on various methods, and the computation of a recruitment pattern by projecting the length-frequency data available backward onto the time axis (Pauly et al. 1984). Total mortality estimation and length-converted catch curves are discussed by Gulland (1983) and Pauly (1983, 1984a, 1984b), while recruitment pattern analysis is illustrated by Pauly and Navaluna (1983).

The steps involved were repeated, adjusting the class size to an interval of 6 mm, and correcting the values using the smooth probabilities of capture obtained from ELEFAN II and based on fitting a logistic curve to probabilities of capture derived from the left, ascending side of a length-converted catch curve. Finally, in order to compare the results on growth of *A. pleuronectes* in the Visayan Sea with those of other studies on *Amusium*, Ø'(an index for comparison of growth performance in animals with the von Bertalanffy type of growth) was

Table 1. Shell height-frequency data on scallops, *Amusium pleuronectes*, collected on board the research vessel *Albacore* in the Visayas sea, Philippines (June 1976–March 1977).

Midpoint (mm)	1976 5 June	4 July	3 Aug.	5 Sept.	11 Oct.	15 Nov.	24 Dec.	1977 20 Jan.	25 Feb.	29 Mar.	*d*	N (cum)
22.5									1		1	1114
25.5											0	1113
28.5						1	1				2	1113
31.5							1			1	2	1111
34.5							1	1			2	1109
37.5	1	2							1		4	1107
40.5		3		1			1		2		7	1103
43.5	3	2	2			1			1		9	1096
46.5	1	5	1	2		2	2	5		1	19	1087
49.5	3	8	2	2			1	2	2	1	21	1068
52.5	5	6	3	4	1	3	1	4	6	7	40	1047
55.5	3	11	7	6	4	6	6	1	4	7	55	1007
58.5	16	14	10	4	2	10	6	8	5	3	78	952
61.5	19	16	22	8	3	3	7	11	2	3	94	874
64.5	26	14	29	7	5	12	12	9	4	1	119	780
67.5	15	20	37	19	8	11	10	20	16	1	157	661
70.5	22	9	30	16	9	9	14	21	32	1	163	504
73.5	13	6	21	27	3	10	20	12	9	1	122	341
76.5	15	8	13	20	3	8	8	6	18	4	103	219
79.5	10	6	4	11	5	3	16	6	9		70	116
82.5	4	4	2	1	1	3	6	1	1	3	26	46
85.5	1		2			3	1	2		1	10	20
88.5	1					2	2	2	1		8	2
91.5				1			1				2	2
d	158	134	185	129	44	87	117	111	114	135	1114	

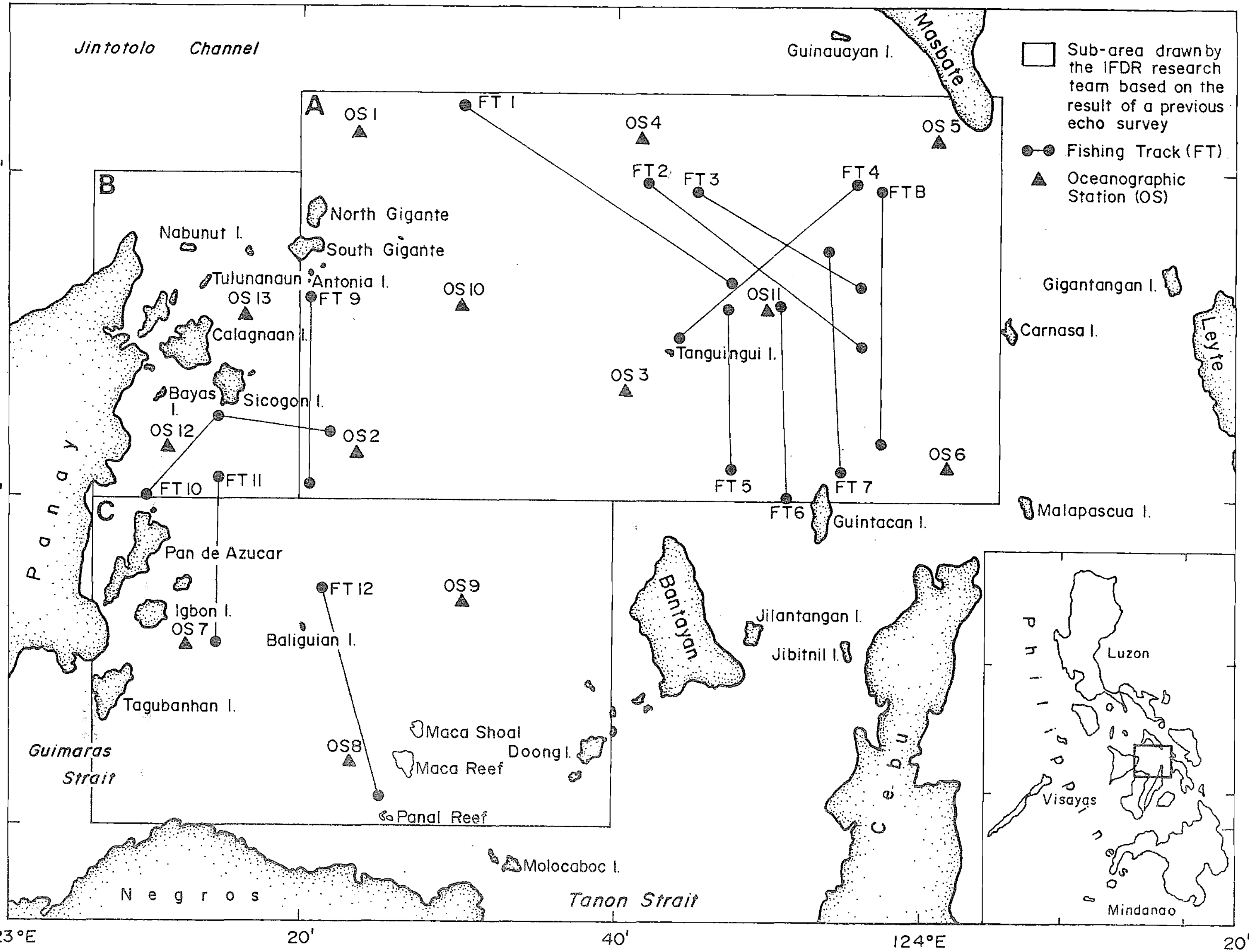

Fig. 1. Map of the Visayan Sea where the scallops used in this study were obtained, showing the fishing tracks and oceanographic stations covered by the research vessel *Albacore* in its trawl survey of the area during the period 1976-1977.

computed. Details on growth comparison using Ø'as an index are discussed in Munro and Pauly (1983) and Pauly and Munro (1984), as well as in several contributions in this volume.

Results

Growth

The Wetherall method of estimating the growth parameter L_∞ from length-frequency data gave an estimate of SH_∞ = 101.8 mm using the uncorrected data in Table 1 but with a class size of 6 mm. The data used for this estimation are presented in Table 2. The regression line started with 72 mm on the x-axis and 5.428 on the y-axis and had a correlation coefficient (r) = -0.979.

Fig. 2 illustrates the von Bertallanfy growth curve for the Visayan Sea scallops using the corrected values of the restructured set of shell height-frequency data. The shell height at which *A. pleuronectes* theoretically ceases growing (SH_∞) was estimated at 100 mm while the rate at which this maximum shell height is approached (K) was 0.94, with Rn value of 0.251. The data in Table 1 using the 6 mm class interval were fitted onto the von Bertalanffy curve by eye, with starting point at sample no. 7 and starting shell height at 39 mm.

Although the growth parameter SH could be estimated using the ELEFAN I program directly, it was decided to use the Wetherall method of estimating L_∞ (which does not require the associated value of K to be known) to facilitate the identification (using ELEFAN I) of a K value compatible with the (fixed) value of L_∞ and which is more reliable than when this parameter is estimated together with L_∞ (Pauly 1986a).

The value of SH_∞ obtained using the corrected data was lower than but still close to both SH_∞ values estimated by the Wetherall method and the von Bertalanffy growth curve based on the uncorrected data. However, the K value increased, suggesting that the correction thus brings the results of the two methods closer together.

Mortality

The Wetherall method also gave an estimate of Z/K = 4.53. The total mortality (Z) of scallops from the Visayan Sea may be calculated using the value of K = 0.94 as obtained from

Table 2. Data for the estimation of the SH_∞ and Z/K values for *Amusium pleuronectes* in the Visayan Sea, using the Wetherall method (1986) as modified by Pauly (1986a).

SH (mean) - SH'	SH'	N (cumulative)
48.876	18.000	1114
42.908	24.000	1113
36.980	30.000	1111
31.103	36.000	1107
25.385	42.000	1096
19.972	48.000	1068
15.000	54.000	1007
10.826	60.000	874
7.348	66.000	661
5.428	72.000	341
4.138	78.000	116
3.600	84.000	20
3.000	90.000	2

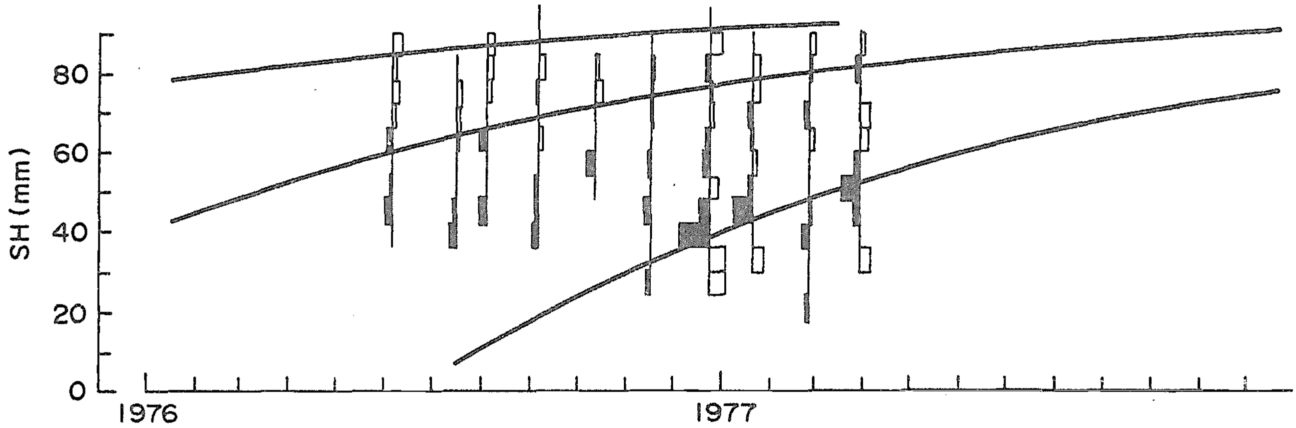

Fig. 2. Growth curve estimated by ELEFAN I from a restructured set of shell height-frequency data on scallops, *Amusium pleuronectes*, from the Visayan Sea area.

the von Bertalanffy growth model; thus Z = 4.26. This value is close to the Z value obtained using length-converted catch curve analysis.

Fig. 3 shows the catch curve constructed from a set of shell height-frequency data on scallops. The total mortality (Z) was estimated at 4.80 from the descending right arm of the catch curve. The points selected for estimating Z by linear regression included at least the points corresponding to the relative ages at which scallops are believed to be fully recruited and vulnerable to the gear employed (i.e., trawl). In this case, the points on the ascending, left arm of the catch curve were not included as they were believed to represent incompletely recruited or selected animals.

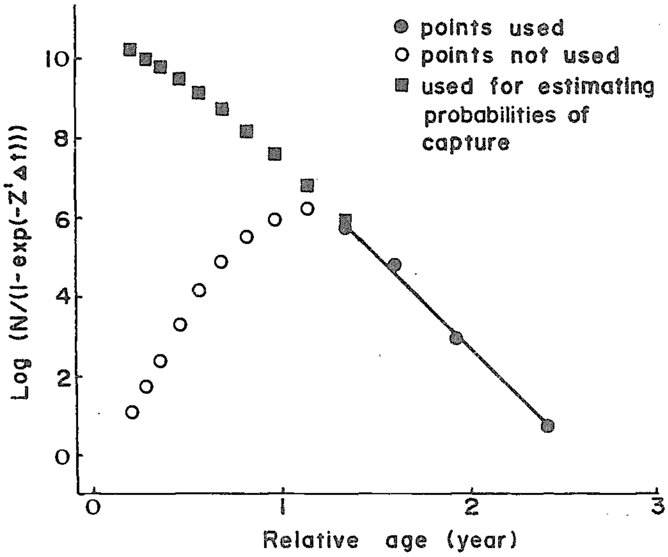

Fig. 3. Catch curve for *Amusium pleuronectes* from the Visayan Sea, estimated by ELEFAN II from a set of shell height-frequency data.

From an estimate of M/K = 1.4 based on values of M/K reported for other bivalves in the literature (Del Norte 1986), M may be computed given the value of K = 0.94 obtained from this study. Thus, M = 1.3; the same value was obtained for *A. pleuronectes* in Lingayen Gulf (Del Norte 1986).

The resultant curve for *A. pleuronectes* from the Visayan Sea is shown in Fig. 4a. This resultant curve is derived from selection and recruitment curves (Gulland 1983; Pauly 1984a, 1984b). The curve is fitted using the logistic transformation (Fig. 4A). The regression estimates gave values of a = 13.6, b = 0.194, and r = 0.998.

Values of L_{25}, L_c (=L_{50}) and L_{75} were also estimated using ELEFAN II. The values obtained were 64.2, 69.9 and 75.6 mm, respectively; these values are close to the values obtained for the same parameters for *A. pleuronectes* from Lingayen Gulf (Del Norte 1986).

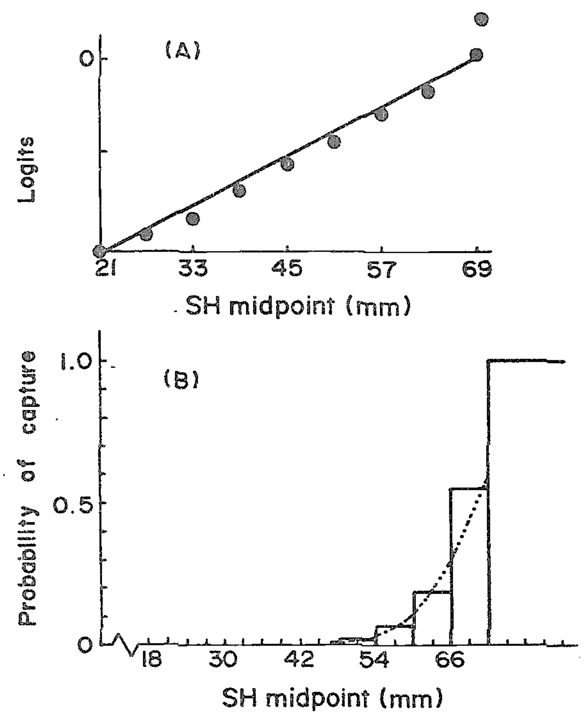

Fig. 4. Incomplete selection/recruitment in small *Amusium pleuronectes* from the Visayan Sea. (A) Logistic transformation of probabilities of capture estimated from length-converted catch curve, with fitted regression. (B) Same values, backtransformed.

Recruitment

Fig. 5 illustrates how *A. pleuronectes* from the Visayan Sea is recruited. Two spawning/recruitment peaks are indicated in this figure, with an interval between peaks of about four months. This pattern of recruitment suggests two recruitment events per year, one shorter and less important than the other.

Discussion

The growth parameters obtained here using ELEFAN I for *A. pleuronectes* from the Visayan Sea as well as the derived ϕ' value compare well with those for the same species from Lingayen Gulf, as well as those estimated for other *Amusium* species using various methods in Australian waters (Table 3). The ϕ' value, obtained by adding the log of K to twice the log of L_∞ (Pauly and Munro 1984), is a measure of the growth performance of fish in terms of length growth but, as demonstrated here, it is also applicable to invertebrates such as scallops.

The mortality estimates obtained here also compare well with those of Del Norte (1986).

The result obtained on the recruitment of *A. pleuronectes* in the Visayan Sea is in agreement with that obtained for the same species in the same area based on gonadal examinations, and with that obtained for the same species in another area in the country.

Llana and Aprieto (1980), based on the histological examination of the gonads from the same set of samples, reported that spawning in *A. pleuronectes* in the Visayan Sea is protracted, with intense spawning taking place from December through February during the colder months, and minor spawning occurring throughout the rest of the year with peaks in June and October.

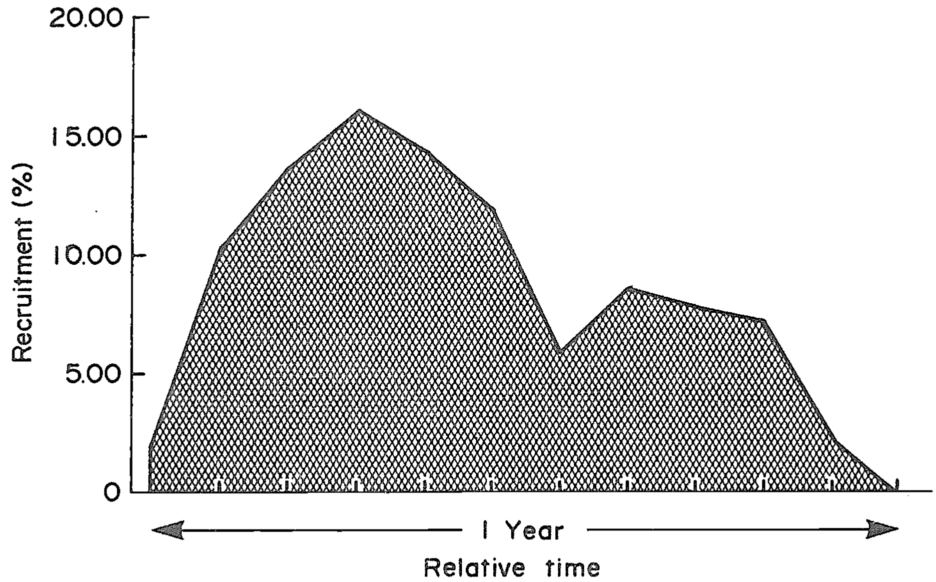

Fig. 5. Recruitment pattern of scallops, *Amusium pleuronectes*, in the Visayan Sea, as obtained from ELEFAN II.

Table 3. Comparison of growth parameter estimates in scallops of the genus *Amusium*.[a]

Species	Locality	SH_∞ (mm)	K(1/y)	Ø'
Amusium japonicum balloti	Queensland,	108	2.00	4.37
	Australia	105	3.06	4.53
	(Source: Williams	109	2.89	4.54
	and Dredge 1981)	102	2.68	4.45
A. balloti	Shark Bay, Western	104	1.42	4.19
	Australia	104	1.29	4.14
	(Source: Heald and	104	2.21	4.38
	Caputi 1981)	95	1.27	4.06
A. pleuronectes	Lingayen Gulf Philippines (Source: Del Norte 1986)	106	0.92	4.01
	Visayan Sea, Philippines (Source: this study)	100	0.94	3.97

[a]Adapted from Table IX in Del Norte (1986); most estimates based on methods of Gulland and Holt (1959), and on ELEFAN I (see text).

Del Norte (1986), using ELEFAN II to analyze a set of shell height-frequency data on *A. pleuronectes* from Lingayen Gulf, concluded that some recruitment occurs throughout the year with two peaks, the major pulse covering 8 months and the minor pulse covering the rest of the year.

Overall, this paper demonstrates that the estimates of the growth parameters, mortality and recruitment patterns from different locations in the Philippines are comparable and compatible with the estimates for the same parameters based on investigations done abroad on scallops.

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Assessment of Indian Squid (*Loligo duvauceli*) and Mitre Squid (*L. chinensis*) in the Gulf of Thailand

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Abstract

The fishery for squid in the Gulf of Thailand is dominated by three gears: otter trawl, pair trawl and light luring. The trawl and light luring fisheries are of approximately equal importance.

Length-frequency data of the squid caught by light luring in the northwestern Gulf of Thailand off Prachuab Khiri Khan in the year 1984, were used in the analysis. The total catch was on average composed of 29% *Loligo duvauceli* and 71% *L. chinensis*. Length-weight relationships of both species, not separated by sex, were found as $W = 0.374216L^2$ for *L. duvauceli* and $W = 0.420666L^2$ for *L. chinensis*.

Asymptotic mantle length of *L. duvauceli*, K and natural mortality were estimated as 26.6 cm, 0.86/year and 0.9/year, respectively. The corresponding values for *L. chinensis* were estimated as 40.9 cm, 0.49/year and 0.5/year, respectively.

The results of cohort analyses and yield-per-recruit analyses are presented for both species.

Introduction

The commercially important species of squid in the Gulf of Thailand fisheries are the Indian squid, *Loligo duvauceli*, and the mitre squid, *L. chinensis*.

The annual Thai landings of squid from the Gulf of Thailand fluctuated around 40,000 tonnes (t) in the period 1972-1981 (Table 1), when the dominating gears were otter trawl and pair trawl. Squid light luring fishing gears were introduced in 1978 and the landings increased to about 65,000 t in 1982-1984 (Table 1). Squids are attracted by light, gather in schools and can be caught by lift nets. By this fishing method, squids of all sizes are caught. Due to the good quality resulting in higher prices and the effectiveness of the method, fishermen gradually changed from otter trawls to light luring. Today 40-50% of the squid landings in Thailand are from light luring vessels. Bannasopit (1981) and Manprasit (1984) described the light luring gear and method.

Ratana-anan (1978 and 1979) reported for both squid species sex ratios, spawning season, length at first maturity, fecundity, length-weight relationship for each sex separately, and stomach contents. Chotiyaputta (1983) studied maturity stages over the year and the relationship between mantle length and ovary weight for both species.

Supongpan and Kongmuag (1981) concluded that the squid stocks in the Gulf of Thailand may already have been overexploited in 1972-1981. The purpose of this study is to estimate the growth parameters, the natural mortality, and to update the earlier assessments through length cohort analysis, as well as through yield-per-recruit and biomass-per-recruit analyses of *L. duvauceli* and *L. chinensis* in the Gulf of Thailand.

Table 1. Landings of the squid by gear from the Gulf of Thailand, Thailand, 1971-1984.[a]

Gear	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Otter trawl	11086	15007	13306	15025	13799	14779	21194	26454	19015	20773	22430	27576	25236	20025
Pair trawl	8149	24049	19416	21606	18336	17385	23757	17561	13815	10962	11248	11902	14131	11399
Squid light luring[b]												23377	30315	25313
Beam trawl	-	18	13	9	17	11	-	-	9	10	29	100	10	15
Push net	-	-	77	207	241	195	520	341	262	285	411	1127	500	467
Bamboo stake trap	630	366	191	575	248	252	364	320	-	75	216	-	101	55
Luring purse seine	-	-	-							96	948	1790	1312	-
Other gears[c]	1375	3081	-	1842	2557	1338	1375	2559	4246	3957	12104	94	56	966
Total	21240	42521	33003	39264	35198	33960	47210	47235	37347	36158	47389	65966	71661	58240

a) Adapted from Fisheries Record of Thailand, 1971-1984

b) Separate records for squid light luring only available from 1982 onwards

c) Other gears include Thai purse seine, encircling gill nets, squid light luring before 1982 and other small gears

Materials and Methods

Monthly samples of squid were collected from squid light luring vessels when landing. The sampling was done at the landing places at Pran Buri (Prachuab Khiri Khan) from December 1983 to December 1984 (Fig. 1). Sampling took place during two days each month. The sample collected was from about 30% of the total landings by light luring vessels on each sampling day.

The data recorded were:

a) Mantle length in 0.5 cm units (on punch cards).

b) Species composition from a subsample.

c) Individual lengths and weights also from a subsample.

d) Total landings of squid by vessel.

e) Data on fishing ground, number of nights fished and days away from port for each month (obtained by interviewing the skippers).

Total annual catches of squid by gear are available from the Fisheries Record of Thailand, 1971-1984.

Average catch rates of squid (kg/hr) by the commercial trawlers in 1976-1981 were available (Supongpan 1984), while catch rates (kg/hr) of squid obtained by the *R/V Pramong 2* and *Pramong 9* were also available for 1966-1981 (Supongpan 1984).

The methods used were: Bhattacharya method (see Sparre 1985) to separate the monthly length compositions into normal components, and then find L_∞ and K from a von Bertalanffy plot; Jones' length cohort analysis (Jones 1981); yield per recruit and biomass per recruit estimation using the Beverton and Holt model and Wetherall plot (Wetherall 1986; Pauly 1986) used to obtain an initial estimate of L_∞ for the ELEFAN I program (Pauly and David 1981).

Results

The Species Composition

The major species of squid caught by squid light luring fishing gear were *L. duvauceli* and *L. chinensis*. These two species were caught on the same fishing ground but their relative contribution to the catch (in weight) varied from month to month (Table 2). The relative weight of *L. duvauceli* varied from 9.87% in December 1983 to 52.71% in April 1984. The annual estimated composition in 1984 is *L. duvauceli* 29% or 16890 t of *L. chinensis* 71% or 41,350 t.

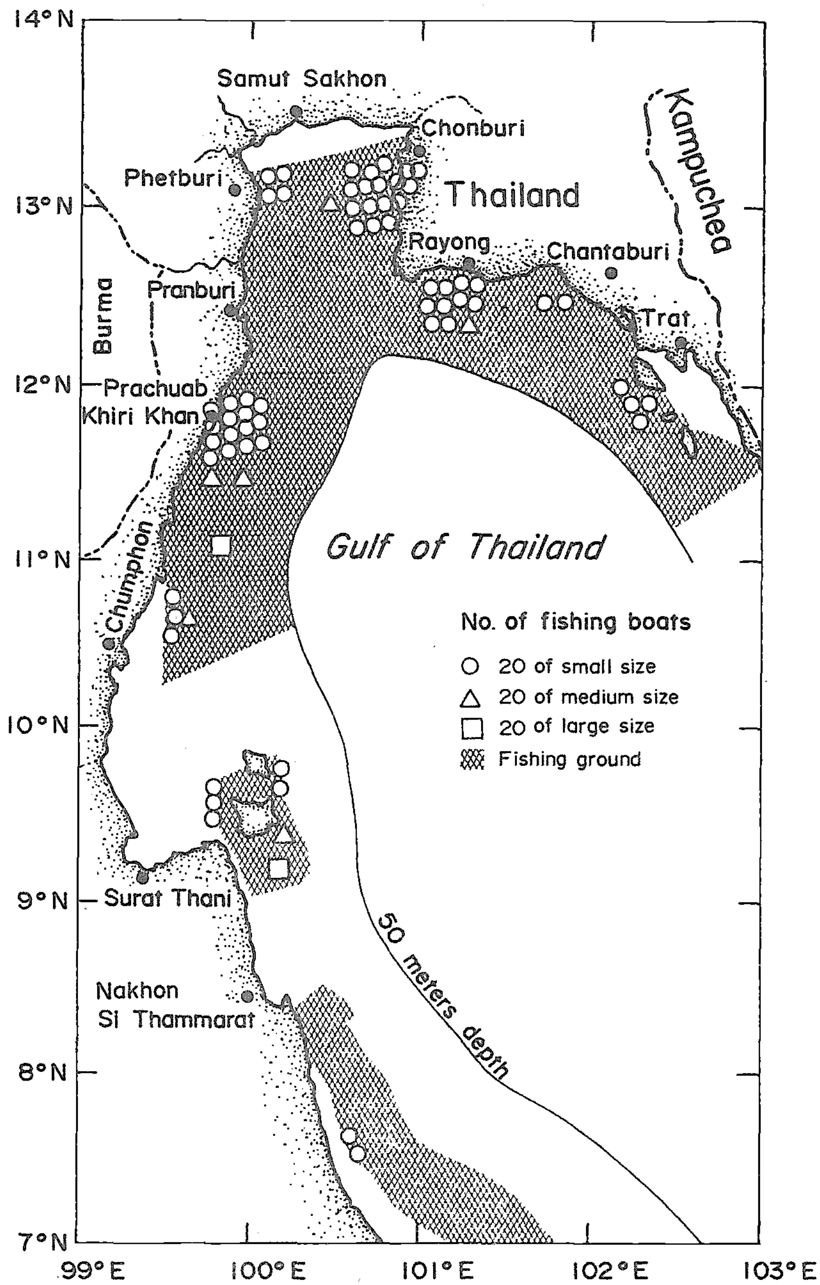

Fig. 1. Light luring squid fisheries in Thailand. Fishing ground and number of vessels by area in the Gulf of Thailand, 1984 (adapted from Supongpan and Kongmuag 1986).

Length-Weight Relationship

The mantle length of *L. duvauceli* and *L. chinensis* was measured individually to the nearest 0.5 cm and their weights in g recorded. The relationship was expressed as

$$W = aL^b$$

Table 2. The species composition by weight of *L. duvauceli* and *L. chinensis* caught by squid light luring at Pran Buri, 1984.

SAMPLE NO.	MONTH/ YEAR	*L. duvauceli* Weight (g)	*L. chinensis* Weight (g)	TOTAL Weight (g)	RELATIVE WEIGHT *L.duvauceli* %	RELATIVE WEIGHT *L.chinensis* %
1	Dec. 83	4 713	43 037	47 750	9.87	90.13
2	Jan. 84	10 710	41 626	52 336	20.46	79.54
3	Feb. "	12 022	12 004	24 026	50.04	49.96
4	1 Mar. "	4 369	10 961	15 330	28.50	71.50
5	29 Mar. "	5 459	14 921	20 380	26.79	73.21
6	Apr. "	7 432	6 669	14 101	52.71	47.29
7	May "	18 392	31 422	49 814	36.92	63.08
8	Jun. "	8 097	26 030	34 127	23.73	76.29
9	Jul. "	8 640	26 627	35 267	24.50	75.50
10	Aug. "	8 303	16 900	25 203	32.94	67.06
11	Sep. "	9 263	21 538	30 801	30.07	69.93
12	Oct. "	5 846	12 094	17 940	32.59	67.41
13	Nov. "	2 576	15 155	17 731	14.53	85.47
14	Dec. "	6 141	17 157	23 298	26.36	73.64
TOTAL		111 963	279 001	408 104		
AVERAGE					29.0	71.0

The results are given in Table 3 *(L. duvauceli)* and in Table 4 *(L. chinensis)*.

The b-value of both species varies from 1.241 to 2.299 for *L. duvauceli* and from 1.403 to 2.093 for *L. chinensis*. Both species have b-values more or less equal to 2. An annual mean relationship was therefore expressed as

$$W = a_o L^2$$

The annual mean relationship was obtained from the monthly estimates by forcing the relationship $W = a_1 L^2$ through the mean length and corresponding weight for each month. This mean length was 10 cm for *L. duvauceli* and 17.5 cm for *L. chinensis* and the weights were calculated from the estimated monthly relationships; a_o was then calculated as the average over all a_1. This procedure was applied instead of simply fitting a joint length-weight relationship through all observations because of restrictions in the computer programs used. The following results were obtained:

L. duvauceli $W = 0.374L^2$ (g-cm)
L. chinensis $W = 0.421L^2$ (g-cm)

These equations apply to the catches with both sexes combined since the length-frequency data are not separated by sex. The purpose of finding an annual average relationship is to calculate the sample weights.

The length samples of each species in each month were raised to the total estimated landings of each species by using the raising factor:

$$\text{Raising factor} = \frac{\text{Total weight of landings (in Thailand)}}{\text{Total weight of sample}}$$

Table 3. Monthly and mean length-weight relationship of the squid *L. duvauceli* caught by squid luring light fishing vessels and landed at Pran Buri, December 1983-December 1984 (mantle length in mm and weight in g).

MONTH	N	a(x10⁻²)	b	r	E
Dec 83	160	1.575038	1.718556	0.901	1.041
Jan 84	420	0.853570	1.841031	0.909	1.074
Feb 84	247	0.935034	1.833387	0.971	1.029
1 Mar 84	120	0.596214	1.923176	0.959	1.039
29 Mar 84	122	0.212158	2.107567	0.973	1.036
Apr 84	160	0.550736	1.912352	0.964	1.038
May 84	408	0.337833	2.013833	0.954	1.045
Jun 84	178	0.185179	2.116566	0.969	1.048
Jul 84	262	0.0863124	2.298800	0.973	1.037
Aug 84	147	1.457604	1.707422	0.963	1.027
Sep 84	179	1.178221	1.718895	0.951922	1.050
Oct 84	135	0.281326	2.04668	0.980	1.045
Nov 84	103	0.193004	2.150272	0.953	1.037
Dec 84	125	12.34281	1.240917	0.791	1.109

The average value

$$W = 0.374216\ L^2$$

(W in g, L is mantle length *changed to cm*)

N number of observations

a = regression - coefficient (intercept)
b = regression - coefficient (slope)
r = correlation coefficient
E = relative error estimate (an experimental error range of E*y to Y/E for a given value of y)

Table 4. Monthly and mean length-weight relationship of the squid *L. chinensis* caught by squid light luring vessels, landed at Pran Buri, December 1983-December 1984 (mantle length in mm and weight in g).

MONTH	N	a (x10⁻²)	b	r	E
Dec 83	316	0.983076	1.851316	0.913	1.043
Jan 84	228	0.979085	1.85506	0.926	1.040
Feb 84	86	0.616402	1.939623	0.946	1.031
1 Mar 84	81	0.542131	1.969177	0.942	1.043
29 Mar 84	76	4.564878	1.541656	0.906	1.029
Apr 84	57	3.576034	1.574547	0.726	1.025
May 84	161	9.603076	1.402591	0.841	1.032
Jun 84	207	0.596468	1.91307	0.926	1.031
Jul 84	169	4.017758	1.558177	0.912	1.023
Aug 84	105	1.293762	1.752815	0.856	1.049
Sep 84	123	2.394291	1.666171	0.924	1.020
Oct 84	178	0.962683	1.806634	0.834	1.028
Nov 84	200	0.256216	2.092696	0.980	1.057
Dec 84	111	2.007709	1.708455	0.939	1.026

The average value

$$W = 0.420666\ L^2$$

(W in g, L is mantle length *changed to cm*)

N = number of observations
a = regression coefficient (intercept)
b = regression coefficient (slope)
r = correlation coefficient
E = relative error estimate (see Table 3)

For example, *L. duvauceli* of December 1983,

$$\text{Raising factor} = \frac{16{,}889.6 \times 10^6}{17{,}173.5} = 0.983 \times 10^6$$

The raising factors for all months (December 1983 to December 1984) are given in Tables 7 and 8 for both species.

Length Composition of the Total Catch, 1984

The sample weights of the length frequencies presented in Tables 5 and 6 were calculated using the length-weight relationships given above.

In 1984 the total landings from the Gulf of Thailand by all gears were 58,240 t (Table 1). The data from the squid light luring fishery are assumed to be representative for the entire fishery. At least the length range from the trawlers corresponds to that of the squid light luring vessels. Supongpan (1984) gives a range of 3 to 22.5 cm for *L. duvauceli* and 4.5 to 40.5 cm for *L. chinensis* in trawl catches, which should be compared with the range of 3 to 26 cm (Table 5) and 6 to 39 cm (Table 6), respectively. Research vessel data are available (Supongpan 1984), which suggest a different species composition of squid in trawls as opposed to light luring. This suggests a difference in efficiency between the two gears *vis-à-vis* the species. This could well also be reflected in the size selectivity.

Table 5. Length-frequency data of *L. duvauceli* caught by squid light luring gear, Pran Buri, December 1983-December 1984 (mantle mid-length in cm, total number = 8,574).

MID-LENGTH (cm)	DATE 1983 12/10	1984 1/3	2/3	3/1	3/28	4/29	5/15	6/30	7/26	8/22	9/27	10/26	11/20	12/17
4														5
5	21	20	13		8	2	3	3	9	10		2	5	27
6	85	118	31	26	69	4	59	26	123	18		10	27	71
7	132	184	22	42	75	7	86	64	161	34		50	60	106
8	126	184	64	31	67	7	55	76	91	29	3	71	76	122
9	76	99	113	27	85	17	47	68	125	49	71	47	81	104
10	55	79	71	19	79	56	82	35	158	81	143	13	70	132
11	33	95	69	24	108	54	72	47	147	33	85	12	19	88
12	49	55	55	14	135	38	82	58	66	18	31	51	4	55
13	14	32	72	9	77	54	73	28	36	53	54	50	1	34
14	4	21	82	2	84	38	76	37	22	95	48	41	1	24
15	3	4	30	1	63	24	34	27	6	54	48	20	0	16
16	0	1	12		20	11	23	25	1	21	15	10	0	2
17	0		19		7	8	9	9		13	7	3	0	5
18	1		10		5	1	4	7		10	4	9	0	7
19	0		3		2	6	5	1		16	2	2	1	9
20	1		1		0		4	1		20	15	4		17
21			1		0		1	1		19	21			21
22					0		2	2		19	26			5
23					1		1			10	30			5
24					1						16			3
25											9			
SUM	600	892	668	195	886	327	718	515	945	602	628	395	345	858

n = 8,574

Table 6. Length-frequency data of *Loligo chinensis* caught by squid light luring gear, Pran Buri, December 1983-December 1984 (mantle mid-length in cm, total number = 5582).

MID LENGTH (cm)	1983 12/10	1984 1/6	2/3	3/1	3/31	4/30	5/31	6/30	7/26	8/22	9/25	10/26	11/19	12/17
6				1									3	3
7	1			0									26	4
8	0			0									54	17
9	1	2		0									46	13
10	5	0		0				1				4	15	8
11	16	1		1				2				41	9	7
12	50	17	3	2				8	3	1		88	16	13
13	87	41	11	19	1	1	1	16	9	1		84	32	19
14	83	81	25	21	4	1	3	37	12	0		64	41	31
15	77	126	15	34	11	9	4	58	8	0		26	41	42
16	67	113	18	23	12	21	19	87	15	6	2	22	41	42
17	57	102	8	25	22	26	36	72	51	52	6	4	33	41
18	38	80	12	20	25	19	48	56	83	62	34		19	87
19	36	63	8	16	19	8	41	48	98	56	47		14	53
20	37	65	17	4	23	1	52	26	64	46	52		13	42
21	23	44	9	4	10		52	20	45	48	38		14	21
22	14	30	5	3	7		43	10	40	28	38		12	18
23	13	34	8	2	10		24	17	33	15	15		8	9
24	12	27	5	4	2		13	9	6	4	11		1	8
25	10	18	3	1	3		16	5	18	9	10		2	2
26	3	16	6	2	5		17	8	15	1	7		3	4
27	3	17	1	2	4		12	1	14	2	7		3	2
28	3	8	1	2	4		9	6	15	9	1		2	0
29	4	7	1	0	1		8	4	11	12	1		1	0
30	3	7	0	3	5		9	1	12	0	6		3	1
31	2	6	2		3		3	1	2	1	0		2	2
32	2	5			2		10	1	0	1	0		1	0
33	2	6			0		0		0	3	1		0	1
34	0	3			0		0		0	2	1		0	4
35	1	1			3		1		1	1	0		0	0
36		1			0		1		0	0	0		1	0
37		1			1		1		0	2	1		1	0
38		1							1	0	1			1
39		1								1				1
SUM	650	924	158	189	177	86	423	494	553	363	279	333	457	496

Growth Parameter Estimates

L. duvauceli

The spawning season is all year-round with a peak in October-December (Supongpan 1984). This makes it difficult to interpret the composition of the length distributions, since the various peaks will not be well defined.

Table 7. Raising factors used for raising monthly length compositions from samples to total landed weight in 1984, using the length-weight relationship from Table 2. The calculated length composition for *L. duvauceli* from the entire landing 1984.

Date 1983/84	Sample Size (numbers)	Sample Total Weight(g)[a]	Mean Weight(g) of squid	Raising factor x 10^6 [b]
Dec	600	17173.5	28.6	0.983
Jan	892	27059.3	30.3	0.624
Feb	668	33081.7	49.5	0.511
Mar 1	195	6092.2	31.2	2.772
Mar 29	886	42263.0	47.7	0.400
Apr	327	18644.9	57.7	0.906
May	718	34838.5	48.5	0.485
Jun	515	23947.8	46.5	0.705
Jul	945	31568.9	33.4	0.535
Aug	602	42034.4	69.8	0.402
Sep	628	49124.6	78.2	0.344
Oct	395	19196.8	48.6	0.880
Nov	345	9862.8	28.6	1.712
Dec	858	38024.8	44.3	0.444

a] $W = 0.374216L^2$ (Table 3)

b] Raising Factor (R.F.) = $\frac{\text{Total landed weight}}{\text{Total weight of sample}}$

Total landed weight of L. duvauceli in 1984 is 29% of 58,240 t = 16,889.6 tonnes (Tables 1 and 2).

$$R.F_{\text{Dec. 83}} = \frac{16889.6 \times 10^6\ g}{17173.5\ g} = 0.983 \times 10^6$$

Table 8. Raising factors used for raising monthly length compositions from samples to total landed weight in 1984, using the length-weight relationship from Table 2. The calculated length composition for *L. chinensis* from the entire landing, 1984.

Date 1983/84	Sample size (numbers)	Sample total weight (g)[a]	Mean weight (g) of squid	Raising factor x 10^6 [b]
Dec	650	24386.1	37.5	1.700
Jan	924	43265.9	46.8	0.956
Feb	158	7074.6	44.8	5.845
Mar 1	189	7320.1	38.7	5.649
Mar 29	177	10052.3	56.8	4.114
Apr	86	3194.3	37.1	12.945
May	423	25960.1	61.4	1.593
Jun	494	20859.8	42.2	1.982
Jul	553	30976.3	56.0	1.335
Aug	363	20454.9	56.3	2.022
Sep	279	16601.4	59.5	2.491
Oct	333	7433.4	22.3	5.563
Nov	457	13645.7	29.9	3.030
Dec	496	20112.9	40.6	2.056

a] $W = 0.420666L^2$ (Table 4)

b] Raising Factor (R.F.) = $\frac{\text{Total landing weight}}{\text{Total weight of sample}}$

Total landed weight of L. chinensis in 1984 is 71% of 58,240 t = 41,350.4 tonnes (Tables 1 and 2)

$$R.F._{\text{Dec. 83}} = \frac{41350.4 \times 10^6\ g}{24386.1\ g} = 1.7 \times 10^6$$

L_∞ was obtained from the Wetherall plot (Fig. 2) and applied to the raised annual length compositions. The estimates are:

L_∞	26.64 cm
Z/K	2.188

K is then obtained by following the best-defined peaks in the length composition. Table 9 shows mean lengths of all peaks found from a Bhattacharya analysis of the length frequencies. The dominating peaks probably correspond to the peak spawning in October-December, which can be traced from December to May. These peaks are marked in Table 9. A von Bertalanffy plot (Fig. 3) of $-\ln(1-Lt/L_\infty)$ *vs*. relative age with $L_\infty = 26.64$ gives the linear relationship:

$$Y = 0.1998 + 0.07198X$$

where

b = 0.07198 is K per month. K per year is therefore 12 x 0.07198 = 0.864.

The growth curve of *L. duvauceli* with L_∞ = 26.64 and K = 0.86 is shown in Fig. 4.

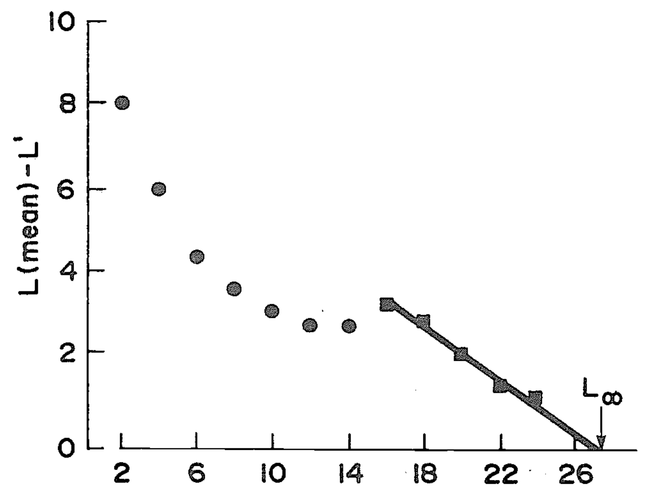

Fig. 2. Modified Wetherall plot of *L. duvauceli*, Gulf of Thailand, 1984.

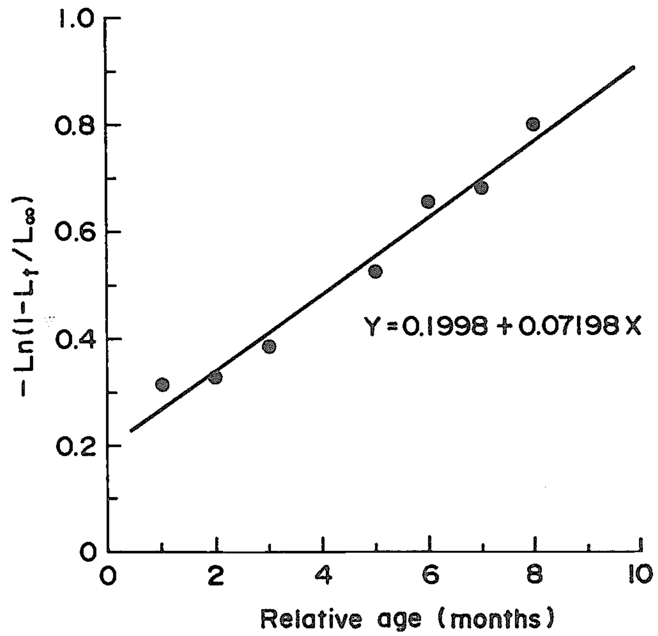

Fig. 3. Von Bertalanffy plot for *L. duvauceli* data in Table 9.

L. chinensis

The monthly length-frequency data of *L. chinensis* with a class interval of 2 cm were used to estimate the asymptotic length (L_∞) and K with the ELEFAN I program. The growth curve is shown in Fig. 5. The estimate of L_∞ was 40.9 cm and K = 0.49/year.

The spawning season peaks in May and November (Supongpan 1984), but with spawning all year-round. The relatively bad fit of the growth curve is probably a result of the spawning all year-round.

Jones' Length Cohort Analysis

The results of raising length frequencies to the number caught in each month of each species were used to calculate the fishing mortality for each length group (Jones 1981). L_∞ and K were

Table 9. Mean length of all peaks from Bhattacharya analysis of the length frequencies of *L. duvauceli*, 1984. Strong peaks (1-8) used in von Bertalanffy plot (see Fig.).

SAMPLING DATE 1983/84	MEAN MANTLE LENGTH (cm)					
Dec		7.20(1)	9.65	12.0	13.38	
Jan	6.04	7.46(2)	10.29	12.13		
Feb	5.42	8.51(3)	10.76	13.07		
Mar 1	6.76	9.01	11.93			
Mar 29	6.16	8.36	10.90(5)	14.00		
Apr		7.25	10.13	12.83(6)	14.51	
May	6.7	9.98		13.25(7)	15.07	18.60
Jun		7.64	11.25		14.64(8)	
Jul	6.15	9.89	12.33			
Aug	6.40	9.52		13.98 (s)		20.04
Sep		9.75	12.83	14.26		21.61
Oct		7.44	12.24	14.31	15.81	
Nov		7.05	9.03			
Dec		9.64	11.86	13.79	18.23	

(n) = peaks used in von Bertalanffy plot (peak 4 not defined).

$-\ln(1-L_t/L_{\infty})$, where L_{∞} = 26.64 cm and L_t peaks 1 to 8, e.g.
$-\ln(1-7.20/26.64) = 0.31$ (see Fig. 3).

Table 10. Length cohort analysis of *L. duvauceli* in the Gulf of Thailand, 1984.

LENGTH GROUP	MID-LENGTH (cm)	CATCHES in x100,000	NO. OF SURVIVORS in x100,000	F	Z	E
12	25	6.72	67.20	0.1000	1.0000	0.10
11	23	31.66	162.57	0.4472	1.3472	0.33
10	21	50.69	296.92	0.5453	1.4453	0.38
9	19	55.84	454.77	0.4926	1.3926	0.35
8	17	98.48	674.74	0.7295	1.6295	0.45
7	15	366.01	1205.63	1.9980	2.898	0.69
6	13	729.39	2188.43	2.5905	3.4905	0.74
5	11	1128.58	3702.89	2.6322	3.5322	0.75
4	9	1463.47	5717.18	2.3912	3.2912	0.73
3	7	1419.87	7854.84	1.7803	2.6803	0.66
2	5	322.03	8990.87	0.3561	1.2561	0.28
1	3	1.11	9824.88	0.0012	0.9012	0.00

Total catch : $5,673.85 \times 10^6$ Natural Mort. M : 0.9/year
Mean E : 0.577   Term. F. Mort. : 0.1
Mean F : 1.230   K : 0.86/year L_{∞} : 26.64 cm

taken as determined in the previous section, while M, the natural mortality, was calculated from Taylor's approximation (Caddy 1983)

$$t_{max} = t_o + 3/K, \text{ hence } M = 3/t_{max}$$

where t_{max} was the maximum age, and where t_o, which is here unknown, but should be low, is set at zero. This gives
for *L.duvauceli* M = 3 ÷ (3/0.86) = 0.9/year

and for *L. chinensis* M = 3 ÷ (3/0.49) = 0.5/year

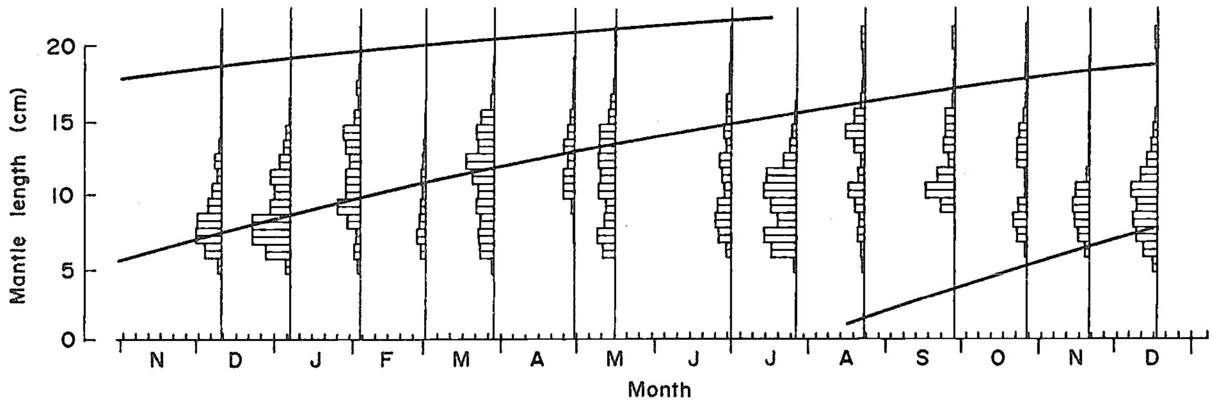

Fig. 4. Length-frequency data with superimposed growth curve of *L. duvauceli*, Gulf of Thailand 1983-1984; the curve has the parameters L_∞ = 26.64 cm and K = 0.86/year.

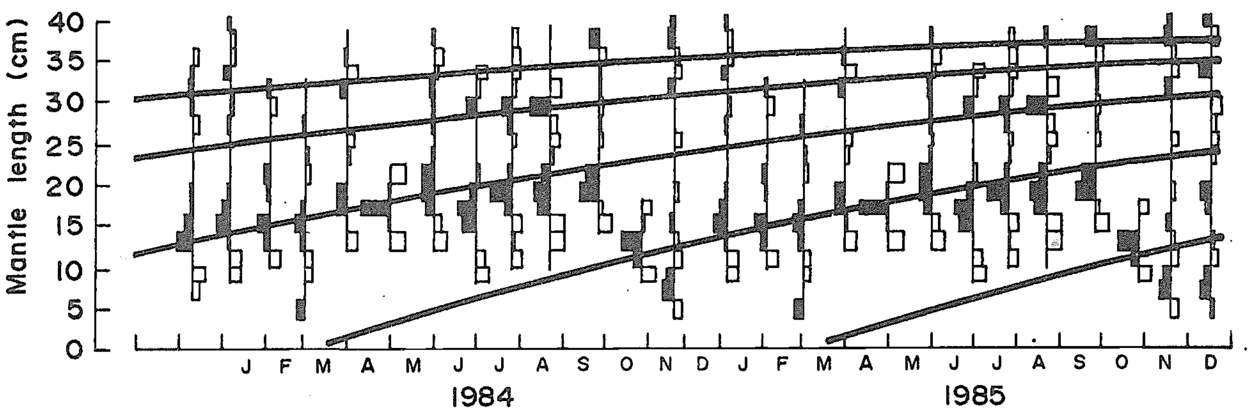

Fig. 5. Growth curve of *L. chinensis*, Gulf of Thailand, 1984 (L_∞ = 40.9 cm and K = 0.49/year) as estimated using the ELEFAN I program.

L. duvauceli

Assuming that the large sizes of *L. duvauceli* are only lightly fished, then the terminal fishing mortality was guessed at 0.1 $year^{-1}$ and used for the length cohort analysis. The results of the analysis are shown in Table 10 and Fig. 6.

L. duvauceli was caught abundantly at lengths between 6 and 16 cm, the fishing mortality increased from 6 cm up to 12 cm length reaching the maximum value of F = 2.63, then declining to F = 2.0 at 15 cm. At 18-24 cm length the fishing mortality seems quite stable at a value of F around 0.5. This abnormal behavior of the fishing mortalities could be a result of the use of jigging gear during the light luring fishery, i.e., the fishermen use jigs while waiting for light to attract the squid. The jigging gear can catch the large size of squid from the bottom up to the surface. If the terminal F was set at 0.6 or 1.3, the terminal curve would move upward as indicated by arrows. The numbers caught and survivors at 6.0-16 cm length would not change.

The exploitation rate E (or F/Z) is very high. From the length between 6 and 16 cm, E is around 0.66-0.75.

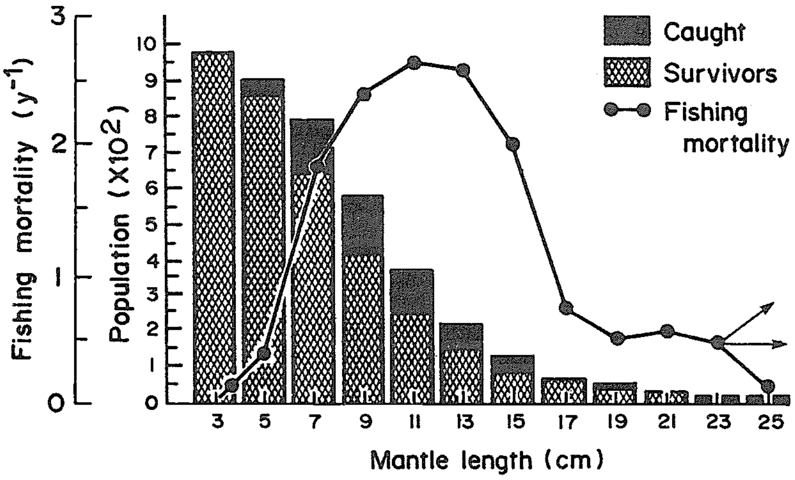

Fig. 6. Length cohort analysis of *L. duvauceli*, Gulf of Thailand, 1984 (L_∞ = 26.64 cm, K = 0.86/year, M = 0.9/year, Terminal F = 0.1, Mean E = 0.577, Mean F = 1.23/year).

L. chinensis

Length cohort analysis of *L. chinensis* is also based on assuming that large sizes of this species were fished lightly, the terminal F was guessed at 0.1 year^{-1}. The results are shown in Table 11 and Fig. 7.

L. chinensis was caught abundantly between 14 and 28 cm length, the F value for this size is between 1.05 and 2.63. The exploitation rate E is also high, i.e., between 0.68 and 0.84.

The fishing mortality of *L. chinensis* fluctuated in the length range 28-38 cm, perhaps for the same reason, i.e., catches of large squid by jigging.

Supongpan and Kongmuag (1986) estimated that jigging contributes about 2% to the total catch.

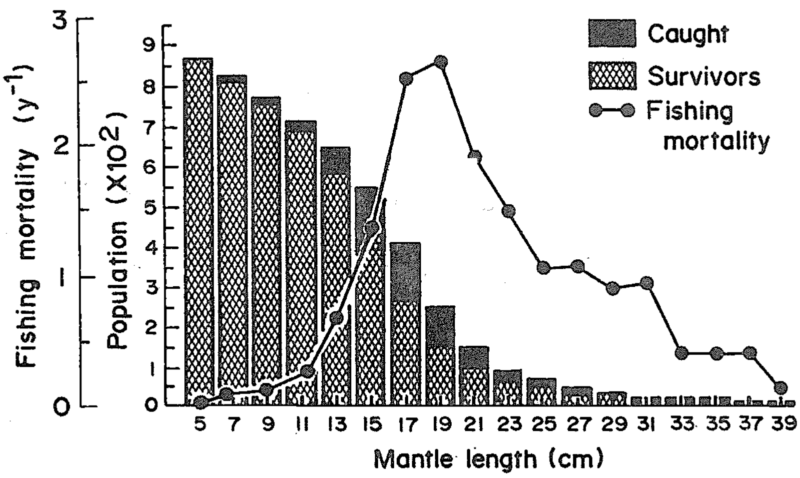

Fig. 7. Length cohort analysis of *L. chinensis*, Gulf of Thailand, 1984 (L_∞ = 42.0 cm, K = 0.49/year, M = 0.5/year, Terminal F = 0.1 Mean E = 0.591, Mean F = 0.723/year).

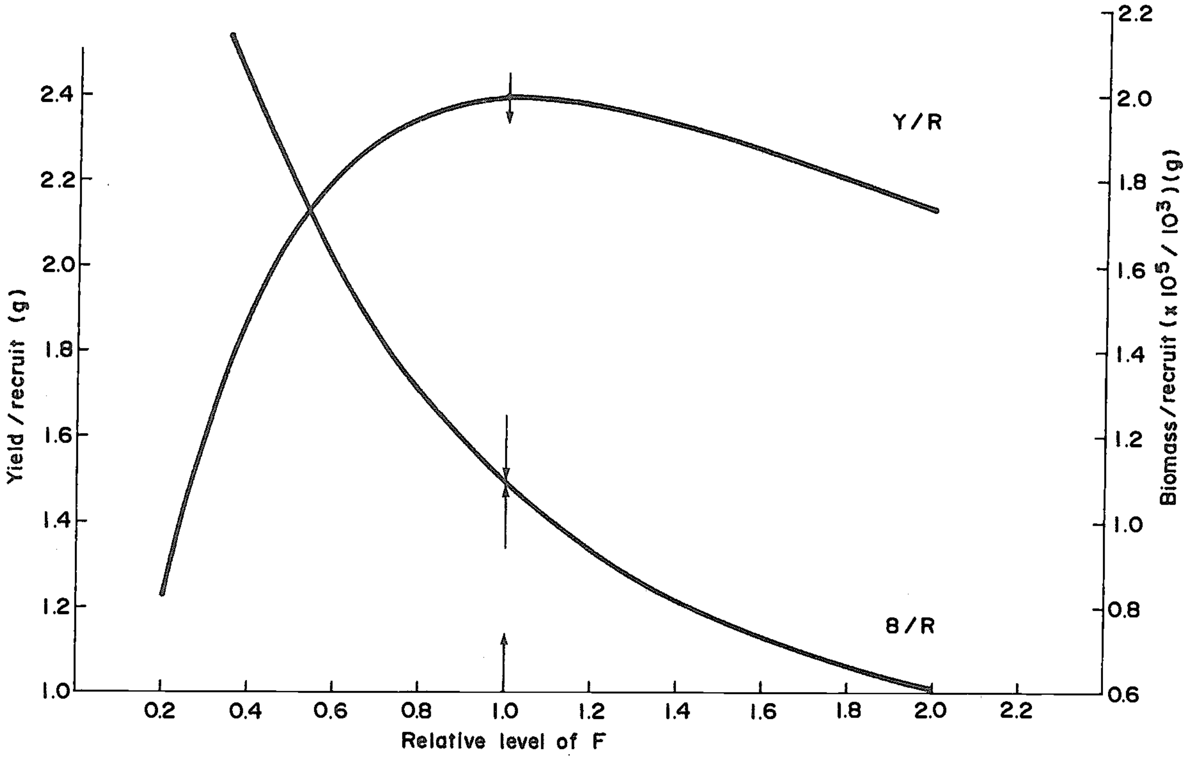

Fig. 8. Yield per recruit and biomass per recruit of *L. duvauceli*, Gulf of Thailand, 1984; arrows indicate optima.

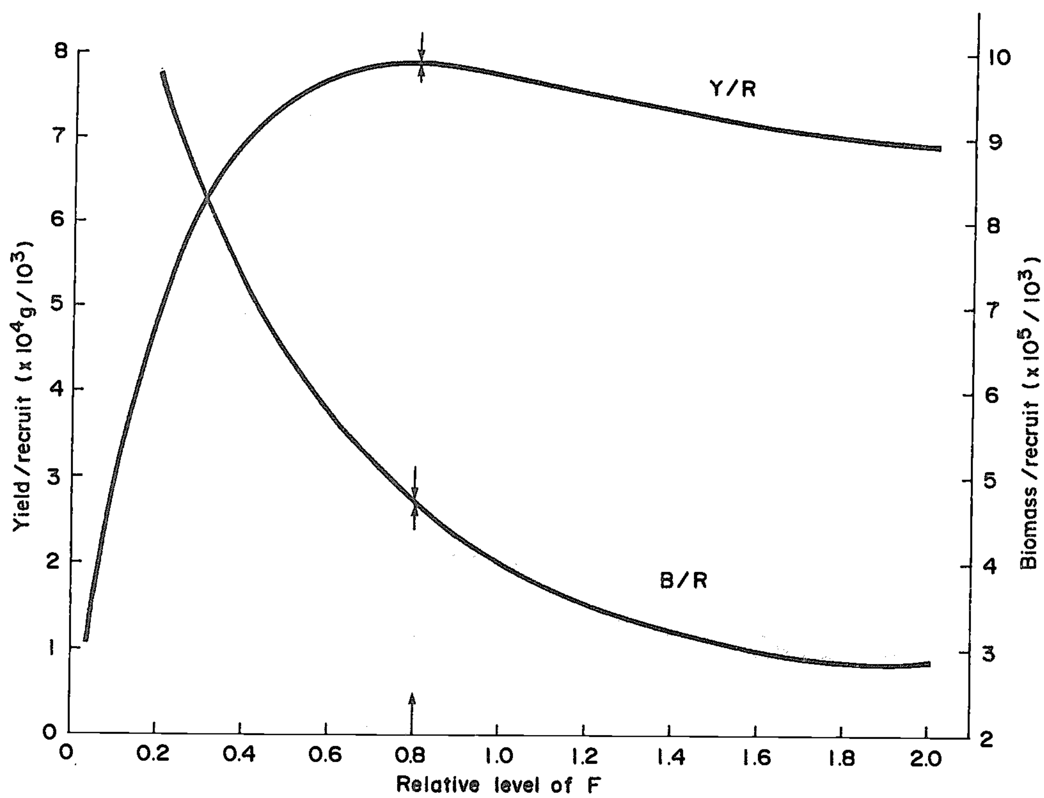

Fig. 9. Yield per recruit and biomass per recruit of *L. chinensis*, Gulf of Thailand, 1984; arrows indicate optima.

Table 11. Length cohort analysis of *L. chinensis* in the Gulf of Thailand, 1984.

LENGTH GROUP	MID-LENGTH (cm)	CATCHES in ($x10^5$)	NO. OF SURVIVORS (in $x10^5$)	F	Z	E
18	39	2.19	13.14	0.1000	0.6000	0.17
17	37	6.63	28.52	0.3790	0.8790	0.43
16	35	8.96	49.35	0.3771	0.8771	0.43
15	33	11.14	75.40	0.3736	0.8736	0.43
14	31	38.28	133.87	0.9482	1.4482	0.65
13	29	50.80	213.23	0.8892	1.3892	0.64
12	27	82.34	334.67	1.0529	1.5529	0.68
11	25	112.60	500.00	1.0678	1.5678	0.68
10	23	215.57	788.08	1.4865	1.9865	0.75
9	21	406.13	1300.17	1.9163	2.4163	0.79
8	19	882.61	2350.54	2.6305	3.1305	0.84
7	17	1347.30	3966.54	2.5071	3.0071	0.83
6	15	985.52	5323.55	1.3264	1.8264	0.73
5	13	621.52	6382.82	0.7099	1.2099	0.51
4	11	208.19	7062.19	0.2209	0.7209	0.31
3	9	97.08	7643.55	0.1002	0.6001	0.17
2	7	61.17	8196.58	0.0622	0.5622	0.11
1	5	3.84	8689.67	0.0039	0.5039	0.01

Total catch: 5,141.869 x 10^6 M : 0.5/year
Mean E : 0.591   Terminal F : 0.1
Mean F : 0.723   K : 0.46/year L_{∞} : 42.0 cm

Yield per Recruit and Biomass per Recruit

Assuming the recruitment of the squid to be constant, the F to be related to the effort and the fisheries to be in a steady state, the Y/R and B/R were calculated from the equations:

$$Y/R = \sum_{L=0}^{L_{\infty}} \exp\left(-\sum_{L_1=0}^{L-1} Z_{L_1}\Delta t_{L_1}\right) \cdot \frac{F_L}{Z_L} \cdot \{1-\exp(-Z_L \Delta t_L)\} \cdot a \cdot L^b$$

$$B/R = \sum_{L=0}^{L_{\infty}} \exp\left(-\sum_{L_1=0}^{L-1} Z_{L_1}\Delta t_{L_1}\right) \cdot a \cdot L^b$$

where R = recruitment (assumed constant and set at 1,000)
L = mid-length of length group [L_{lower}; L_{upper}]
Z_L = total mortality in length group L
F_L = fishing mortality in length group L=M+F_L
Δt_L = time that it takes to grow through length group L, i.e.

$$\Delta t_L = \frac{1}{K} \ln\left(\frac{L_{\infty} - L_{lower}}{L_{\infty} - L_{upper}}\right)$$

where L_{lower} resp. L_{upper} are the lower and upper limits of a length class and where
W = aL^b is the weight-length relationship

Yield per recruit and biomass per recruit were calculated based on M = 0.9 $year^{-1}$ for *L. duvauceli* and M = 0.5 $year^{-1}$ for *L. chinensis*. The F-at-length arrays were those estimated from cohort analysis (Tables 10 and 11 and Figs. 6 and 7). The growth parameters used as in the previous section, Y/R and B/R plotted against a relative level of fishing mortality with 1984 = 1 are given in Figs. 8 and 9 for the two species.

The optima are found for relative level of F = 1 for *L. duvauceli* and for relative level of F = 0.8 for *L. chinensis*. Given the uncertainties in the parameter estimates this probably indicates a fishery close to the MSY level.

Discussion

The Species Composition

Supongpan (1984) reported that the average percentage of the squid caught by *R/V Pramong 4* and *Pramong 5*, during the year 1978-1981, was 44.24% of *L. duvauceli* and 55.76% of *L. chinensis*, while the landings of squid luring fishing vessels at Pran Buri (Prachuab Khiri Khan) are composed of 29% *L. duvauceli* and 71% *L. chinensis*. This could result from differences in gear and/or different fishing grounds.

The commercial trawlers and the squid light luring vessels fish to some extent different grounds (Supongpan 1984) and the assumption made about the species and length compositions obtained from the light luring fishery being representative of the entire fishery is probably not correct. However the differences cannot be evaluated at present.

Length-Weight Relationship

Ratana-anan (1978, 1979) studied the length-weight relationship of both species of *L. duvauceli* and *L. chinensis*. The species were in her study separated by sex with the following results:

L. duvauceli	(females)	$W = 0.0105\ L^{1.773}$	(g-mm)
	(males	$W = 0.0034\ L^{2.043}$	"
L. chinensis	(females)	$W = 0.006973\ L^{1.873}$	"
	(males)	$W = 0.002569\ L^{2.095}$	"

The results obtained in this paper were similar. This is demonstrated for the mean lengths used in this study for each species in Table 12.

Table 12. Comparison of weight estimates obtained through the length-weight relationships of Ratana-anan (1978-1979) and through that obtained here.

	L. duvauceli	*L. chinensis*	Source
Mean month length (cm)	10.0	17.5	Ratana-anan (1978, 1979)
Weight (g)			
females	37.0	111	
males	41.3	128	
both sexes	37.4	129	this study

The Growth Parameters

The asymptotic length (L_∞) of *L. duvauceli* was determined at 26.6 cm and of *L. chinensis* 40.9 cm. The L_∞ of *L. duvauceli* in this paper was smaller than the value from the west coast of India which was 29.0 cm (FAO 1986). Hixon et al. (1981) reported that the maximum size of the squid, *L. peali,* depends on geographic location, sex and size at which maturation occurs. The maximum length of the species mentioned from different locations ranged from 23.6 to 46.5 cm for males and 18.7 to 30.3 cm for females. The L_∞ of *L. duvauceli* and *L. chinensis* may thus change with the location.

The K estimates of *L. duvauceli* and *L. chinensis* were 0.86 and 0.46/year, respectively. These values, while seemingly very different generate values of the growth performance index $\phi' = \log_{10} K + 2 \log_{10} L_\infty$ (Pauly and Munro 1984) that are rather similar (2.78 and 2.91, respectively). Moreover, these growth parameters correspond well with the values in Pauly (1985).

The Length Cohort Analysis

The squid *L. duvauceli* was caught abundantly at 6-16 cm length and there was a small catch at lengths from 16 to 24 cm. This larger size group is probably caught by jigs used during light attraction.

L. chinensis was caught abundantly at 14-28 cm length and there were two small catches at 28-32 and 32-38 cm length.

The larger squid forms about 2% of the total catch (Supongpan and Kongmuag 1986).

Yield per Recruit and Biomass per Recruit

The Y/R analysis shows that the present fisheries are exploiting *L. duvauceli* near the optimum level of fishing mortality and that *L. chinensis* is only slightly exploited, while Supongpan and Kongmuag (1981) reported, based on a Fox model, that the squids in the Gulf of Thailand were already overexploited. Since 1981, when light luring gear was introduced the total landings have increased by 25%. The squid light luring has to some extent caught the squid from the untrawlable fishing grounds. This could mean that squid light luring exploits stocks which were previously either not or only lightly fished. It could also reflect an increased recruitment or simply that the production model fit was not precise. Y/R is a more refined analyses compared with the production model previously used. The yield-per-recruit analysis assumed that recruitment is stable. If this is not so, i.e., if the squid biomass is strongly related to the biomass of fish through predation, then the analysis will not lead to sensible results. There are indications that squid is such an opportunistic species, which can only maintain or even increase its biomass level, because of the high exploitation of the fish stocks in the Gulf of Thailand (Pauly 1985). The estimated values of biomass, mortality and growth would still be valid, but the implications drawn from assuming these parameters to be constant over a time period may well prevent an understanding of the dynamics of the squid stocks.

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Growth Parameters and Mortality of the Deep-Sea Red Crab, *Geryon quinquedens*, off Mozambique

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Abstract

The deep-sea red crab, *Geryon quinquedens*, is a potentially important resource off southern Mozambique. It was fished between 1979 and 1984 by means of arrays of up to 1,000 traps. This paper reviews the literature concerning the main features of this species. Furthermore samples taken from the commercial catches were analyzed in order to estimate von Bertalanffy growth parameters and mortality rates. Although there are several constraints in the analyses, females are believed to have an L_∞ of 15 cm of carapace width and a K-value of 0.86/year. For males, the values adopted are L_∞ = 19 cm and K = 0.45/year.

The mortality estimates are high for both sexes, probably as a result of biased sampling and possibly migration.

Introduction

The deep-sea red crab, *Geryon quinquedens*, has been the object of population studies in several parts of the world for almost 30 years. It has been recorded from the eastern and western slopes of the Atlantic Ocean, from the Indo-Pacific region and off Chile, at depths ranging from 230 m to below 2,000 m (Cayre et al. 1979). Every time it was quoted to be abundant, as well as an accessible resource for new fisheries and details were repeatedly given on distribution and stock composition.

Nevertheless, it seems that commercial problems have always prevented the development of a fishery on this resource (Wigley et al. 1975; Beyers and Wilke 1980).

Fishery For the Deep-Sea Red Crab off Mozambique

In 1979 a Japanese company signed a license contract with the Mozambican Government for deep-sea fishing with traps, operating yearly a single vessel, a factory ship of about 80 m (LOA) capable of full processing of crabs.

Arrays of traps were used, as pictured in Fig. 1. About 1,000 traps were available on board and after an experimental period of about one year, usually 4 or 5 arrays of some 200 traps each were soaked overnight.

The distribution area of the deep-sea red crab overlaps, off southern Mozambique, with that of the spiny lobster, *Palinurus delagoae*, which is also commercially a very important species. For this reason the skipper was easily able to choose the target species according to market value. As shown in Table 1, most of the fishing effort was directed towards the spiny lobster which was caught at depths shallower than 400 m (against a preferential depth for *Geryon quinquedens* ranging from 350 to 1,000 m).

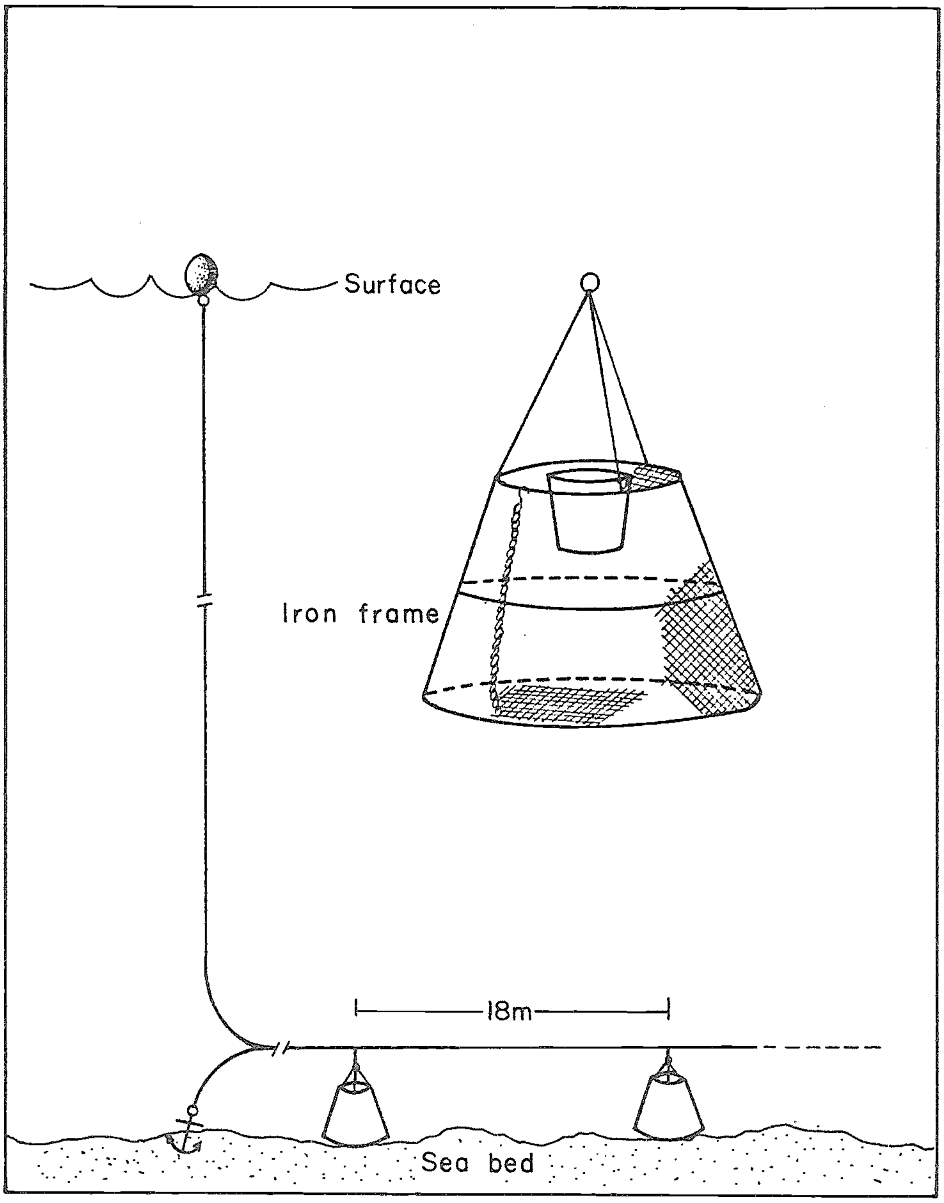

Fig. 1. Trap and long-line arrangement used by the Japanese fishery for deep-sea crustaceans off Mozambique.

Table 1. Nominal catches of deep-sea crustacea by the Japanese trap fishery off Mozambique (tonnes).

Years	Lobster	Crab
1979	193.3	38.8
1980	152.9	15.7
1981	234.7	34.6
1982	294.0	-
1983	135.8	-
1984	134.2	1094.8

Sampling Program

From the start, the Japanese trap fishery was monitored by on-board observers belonging to the Fisheries Research Institute (IIP), who in addition to conducting their research work also ensured that logbooks were properly filled.

Everyday one array of traps was sampled for crabs and for lobsters. The choice of the array sampled was not really random, but the observers were instructed not to take the same order every day. The traps sampled on the other hand were always the first ones hauled in order not to disturb the processing routine.

About 50 crabs/lobsters were observed each day and were sorted by sex and the carapace width measured to the 0.5 cm below. The number and weight of the specimens in each 0.5 cm class were also recorded as well as the number of berried females and animals with soft carapace.

Depth Differentiation in *Geryon quinquedens*

Sex-Ratio

Sex segregation by depth seems to be a general and well documented feature in this species (Dias and Machado 1974; Haefner and Musick 1974; Wigley et al. 1975; Cayre et al. 1979; Beyers and Wilke 1980). Females occupy the upper grounds whereas the males are dominant in deeper waters. Fig. 2 from Cayre et al. 1979) illustrates this phenomenon.

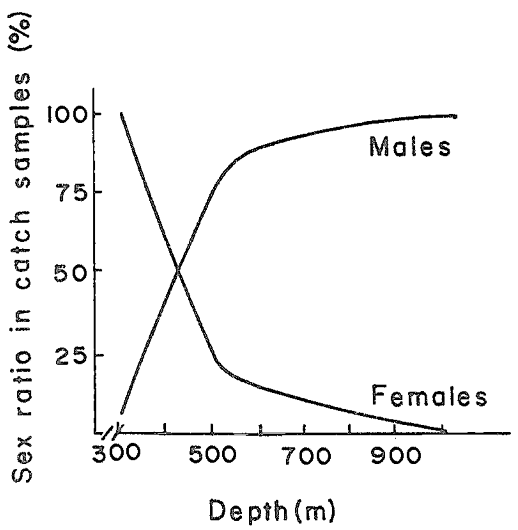

Fig. 2. Segregation of sex by depth in *Geryon quinquedens* (Reproduced from Cayre et al. 1979).

The analysis of the data from the survey period (Paula e Silva 1984) shows that this segregation also occurs off Mozambique and that the depth at which a sex-ratio of 1:1 can be expected lies between 400 and 450 m. However, in a survey conducted in June-July 1974, off the northeastern United States, males dominated over the females in the depth zone of 230-320 m (Wigley et al. 1975).

Size Distribution

As stated by Cayre et al.(1979), "The observations on the size distribution of *G. quinquedens* along the depth (....) seem contradictory". Wigley et al. (1975) described for June/July 1974 off the northeastern United States a steady decrease in the size of the crabs with increasing depth. Beyers and Wilke (1980) report from the southeast Atlantic a reduction in the size of male crabs with depth, while in the females this is not clear. The inverse phenomenon was observed off

Congo (Cayre et al. 1979). Dias and Machado (1974) recorded catches where no depth-related difference in the weight of the males was evident between 300 and 800 m.

From Mozambique (Fig. 3) and along the depths of less than 300 to about 500 m no significant discrimination was found in the mean size of each sex.

Environmental Conditions

Bottom type

As stated in the literature (Wigley et al. 1975; Cayre et al. 1979), *Geryon quinquedens* prefers substrates of a muddy or mud-sandy nature where it digs holes and craters, thus being largely inaccessible to trawling.

Fig. 4 shows the distribution of bottom types off southern Mozambique. Together with Fig. 5 it shows roughly that the substrate between 200 and 1,000 m is adequate for *G. quinquedens*. Some samples for sediment studies were taken off central Mozambique in February-March 1980 which showed that at a depth of 750 m the sediment is composed mainly of clay and silt (Nationalkomitee 1984).

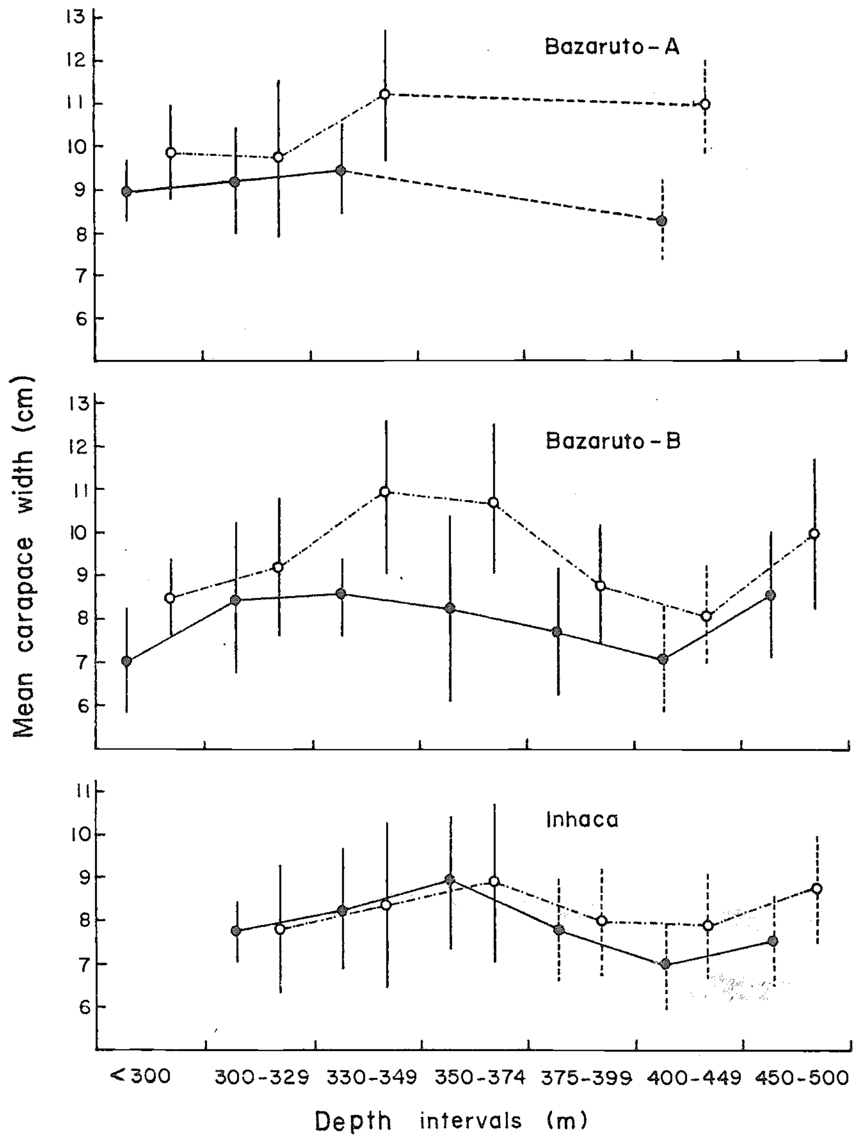

Fig. 3. Average carapace width and standard deviation of *Geryon quinquedens* by depth interval off Mozambique in the period 1979-1980. (o = males; • = females).

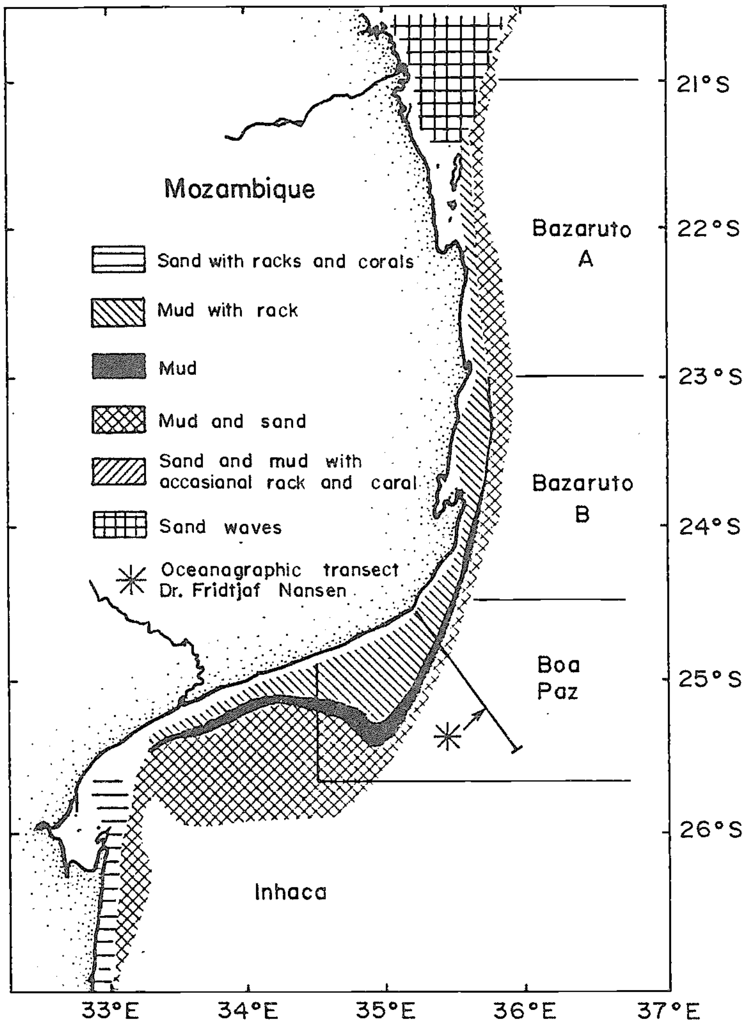

Fig. 4. Bottom types off southern Mozambique (in SIP-Mozambican presentation to the FAO/IOP workshop on the fishery resources of the western Indian Ocean South of the Equator. Mahé, Seychelles, 23 Oct.-4 Nov. 1978).

Temperature

Water temperature has been regularly cited as a possible causative agent for the differential distribution of *Geryon quinquedens* with depth. In general it was found that the area occupied by the species shows a temperature distribution ranging from 10-13°C at the 200-300 m zone to about 4°C at 800-1,200 m (Wigley et al. 1975; Cayre et al. 1979; Beyers and Wilke 1980). In Mozambique the temperatures are somewhat higher than those cited (Table 2). Due to the particular depth distribution of *G. quinquedens*, it has been difficult to correlate this parameter with obvious features of the biology of this crab.

Dissolved oxygen

Abundance of the deep-sea red crab and dissolved oxygen levels measured near the sea bed were found to be positively correlated (Beyers and Wilke 1980). However, Cayre et al. 1979) note that there is probably a preference for low oxygen levels, since off Abidjan, *G. quinquedens*

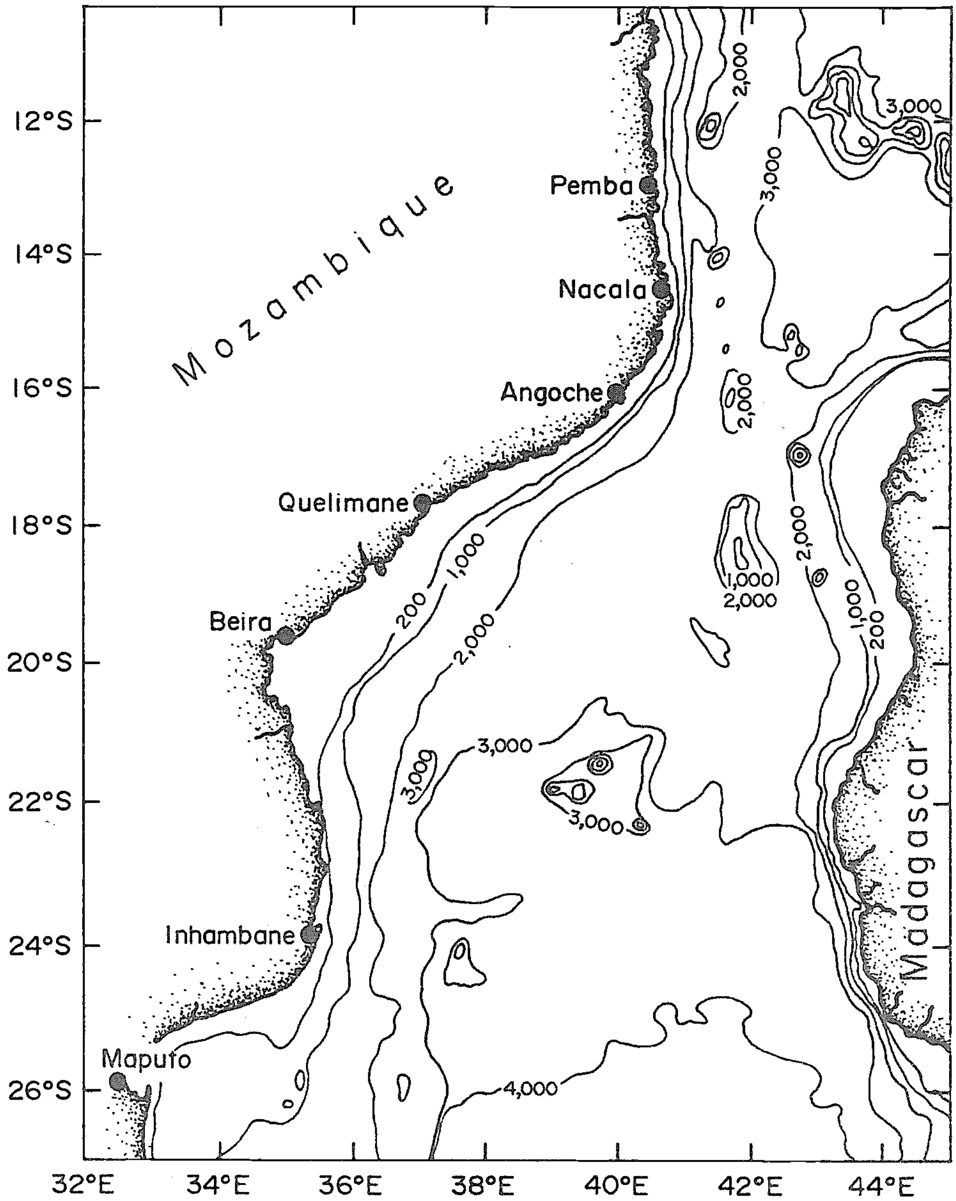

Fig. 5. Bathymetric map of the Mozambique Channel (from: Nationalkomitee für Geodaesie und Geophysik bei der Akademie der Wissenschaften der DDR, 1984. - The oceanological conditions in the western part of the Mozambique Channel in Feb.-Mar. 1980. Geodaetische und Geophysikalische Veroeffentlichungen. Reihe IV, Heft 39. Berlin, German Democratic Republic).

Table 2. Water temperature at the bottom level, deducted from the temperature profiles measured by the R/V "Dr. Fridtjof Nansen" (1977-1978) along the oblique line starting at lat. 24°30'S. (°C) (see Fig. 4).

Depth (m)	Sep. 1977	Nov. 1977	Mar. 1978	May 1978
350	14	13	12	11
500	11.5	10	11	9
800	8	-	8	6
1000	6	-	-	5

is much less abundant at 700 m, where the dissolved oxygen level is somewhat higher. They suggest that this may be due to increased levels of food in the form of decaying organic matter in zones where the oxygen level is low.

Growth and Mortality of *Geryon quinquedens*

Materials and Methods

(a) Materials

Table 3 gives the numbers of monthly samples obtained from the Japanese vessels.

Since the fishing area is extensive and as differences in hydrographic conditions and abundance of spiny lobsters are known to exist, a stratification by area was adopted (Fig. 4) as described by Brinca et al. (1983):

Bazaruto (A): 21° to $23^{\circ}00$'S
Bazaruto (B): 23° to $24^{\circ}30$'S
Boa Paz : $24^{\circ}30$' to $25^{\circ}40$'S (east of $34^{\circ}30$'E)
Inhaca: $25^{\circ}40$'to $26^{\circ}50$'S (and west of$34^{\circ}30$'E)

To compensate for the limited data for some years, all data were pooled in one "synthetic" year with samples at bimonthly intervals. It is this final grouping that is shown in Tables 4 and 5. Fig. 9 shows the total length distribution of all samples combined.

(b) Modal progression analysis

The Bhattacharya (1967) method (explained in Asila and Ogari, this vol.) was applied to the pooled samples (Tables 4 and 5), in order to discriminate different components. These were considered age groups or cohorts and visually linked by hypothetical growth curves. Successive points on these growth curves were used as inputs for a Gulland and Holt plot (as explained in Sparre 1985).

Table 3. Number of monthly samples obtained from the Japanese trap fishery off Mozambique by area.

Year	Bazaruto A	Bazaruto B	Boa Paz	Inhaca	Total
1979	3	5[b]	0	3 (1)	11
1980	7[a]	3 (1)	0	2 (1)	12
1981	4	5	5	4	18
1982	3	1	3[a]	5	12
1983	5	1	3	2	11
1984	4 (4)	0	3	7 (6)	14
Total	26	15	14	23	78

Note: All samples were taken at depths between 300-400 m except:
[a]one sample at less than 300 m.
[b]two samples at less than 300 m.
(1), (4), (6) number of samples taken between 400-500 m.

Table 4. *Geryon quinquedens* - females - carapace width (all years and areas pooled in two month samples).

Carapace width (cm)	Jan/ Feb	Mar/ Apr	May/ Jun	Jul/ Aug	Sep/ Oct	Nov/ Dec	Total
5.0- 5.5	0	0	0	1	0	0	1
5.5- 6.0	0	0	2	13	4	0	19
6.0- 6.5	6	4	1	19	15	0	45
6.5- 7.0	15	19	24	43	39	4	144
7.0- 7.5	19	21	63	58	86	8	255
7.5- 8.0	31	32	102	49	101	18	333
8.0- 8.5	76	44	103	40	127	61	451
8.5- 9.0	129	85	138	69	172	159	752
9.0- 9.5	149	105	222	96	185	293	1050
9.5-10.0	135	107	267	144	213	315	1181
10.0-10.5	119	48	182	119	264	297	1029
10.5-11.0	52	27	125	93	292	216	805
11.0-11.5	24	10	73	75	196	161	539
11.5-12.0	15	2	37	44	109	58	265
12.0-12.5	5	0	21	15	36	12	89
12.5-13.0	2	0	4	4	15	4	29
13.0-13.5	0	0	0	2	3	0	5
13.5-14.0	0	0	0	1	0	1	2
14.0-14.5	0	0	0	0	1	1	2
14.5-15.0	0	0	0	1	0	0	1
Total	777	504	1364	886	1858	1608	6997

Table 5. *Geryon quinquedens* - males - carapace width (all years and areas pooled in two month samples).

Carapace width (cm)	Jan/ Feb	Mar/ Apr	May/ Jun	Jul/ Aug	Sep/ Oct	Nov/ Dec	Total
5.0- 5.5	0	0	0	0	0	0	0
5.5- 6.0	0	0	0	3	0	0	3
6.0- 6.5	2	5	0	13	2	5	27
6.5- 7.0	18	22	4	18	7	10	79
7.0- 7.5	20	34	13	34	20	16	137
7.5- 8.0	20	30	18	39	36	17	160
8.0- 8.5	26	37	24	45	49	46	227
8.5- 9.0	35	41	24	66	87	52	305
9.0- 9.5	61	31	27	63	91	73	346
9.5-10.0	57	11	24	46	75	62	275
10.0-10.5	59	11	65	45	39	80	299
10.5-11.0	45	4	80	39	30	83	281
11.0-11.5	33	15	93	91	21	77	330
11.5-12.0	27	16	131	133	59	46	412
12.0-12.5	17	26	128	207	111	64	553
12.5-13.0	11	21	143	225	146	23	569
13.0-13.5	7	14	101	202	173	18	515
13.5-14.0	2	6	69	143	113	14	347
14.0-14.5	6	2	33	69	48	8	166
14.5-15.0	0	1	11	30	28	1	71
15.0-15.5	0	2	3	5	4	0	14
15.5-16.0	0	0	0	2	3	0	5
Total	446	329	991	1518	1142	695	5121

The initial results were judged to be biased by gear selection. The samples were then corrected by the fractions retained calculated by applying a logistic curve to the length-converted catch curve as described in Sparre (1985). The corrected samples were then reanalyzed for modal progression.

(c) ELEFAN I (Pauly and David 1981)

As described by Thiam (this vol.), the pooled samples were run through the ELEFAN I program to have an alternative estimate of growth parameters. The available version of ELEFAN I could only compute growth curves in which L_∞ is bigger than the largest specimens in all samples.

(d) Wetherall's method (1986)

This method, which estimates L_∞ and Z/K is described by Julien-Flüs (this vol.) and was applied to the pooled bimonthly samples, both with the observed and with relative frequencies (to avoid the weight of the different sizes of the bimonthly samples).

(e) φ' (Pauly and Munro 1984)

The principle involved with this parameter is described by Lablache and Carrara (this vol.). The units used in this case were:

$$\phi' = \ln K + 2 \ln L_\infty$$

with K put on an annual basis and L_∞ expressed in cm.

(f) Length-converted catch curve analysis

The model described in Sparre (1985) was applied to the overall summed sample with relative frequencies, in order to estimate Z, the coefficient of total mortality. Adopted values of L_∞ and K were used as input, as shown in the results. The catch curve was used to calculate the selection factor, as explained in (b) above.

(g) Jones and van Zalinge (1981) method

This method was used to estimate Z. The method, which relies on a cumulation of available length data may be considered an alternative to the length-converted catch curve analysis, which requires the same input.

Results and Discussion

Table 6 shows the summary of all results obtained with the present data and using the methods described above.

Growth Parameters

Figs. 7 and 8 show the distribution of components discriminated by the Bhattacharya method on the uncorrected samples for females and males, respectively. In most samples it was possible to identify two or three components which were considered as distinct age groups or

Table 6. Growth and mortality parameters estimated by different methods for *Geryon quinquedens* from Mozambique.

Sex	Data	Method	L_∞	K	$\emptyset'$[a]	Z	Remarks
	observed	Bhatt. + Gul. & Holt	13.0	0.87	4.99	-	
F	corr. gear selection	Bhatt. + Gul. & Holt	14.8	0.98	5.36	-	L50% = 9.2; L75% = 9.7
E	observed	ELEFAN I	16.25	0.8	5.25	-	best ESP/ASP = 0.426[b]
M	observed	ELEFAN I (season. osc.)	15.7	0.8	5.28	-	best ESP/ASP = 0.457; C = 1.0; WP = 1.1[b,c]
A	observed	Wetherall	14.7	(0.8)	-	3.72	Z/K = 4.66; length groups used: 9.5-12.5[d]
L	relative freq.	Wetherall	15.1	(0.8)	-	4.35	Z/K = 5.44; length groups used: 9.5-13.0[d]
E	relative freq.	Catch curve	(14.5)	(0.8)	-	3.73	length groups used: 9.5-13.0; conf.lim: + 0.83
S	relative freq.	Jones & v. Zalinge	(14.5)	(0.8)	-	4.13	length groups used: 9.5-13.5; conf.lim: + 0.22
	this table	mean	14.9	0.86	5.22	-	-
	observed	Bhatt + Gul. & Holt	18.0	0.44	4.95	-	-
	corr. gear selection	Bhatt + Gul. & Holt	18.0	0.46	5.00	-	L50% = 11.9; L75% = 12.8
M	observed	ELEFAN I	20.0	0.5	5.30	-	best ESP/ASP = 529[b]
A	observed	ELEFAN I (season. osc.)	23.0	0.4	5.35	-	best ESP/ASP = 550; C = 0.9; WP = 0.8[b,c]
L	observed	Wetherall et al.	16.7	(0.45)	-	1.94	Z/K = 4.31; length groups used: 12.5-15.5[d]
E	relative freq.	Wetherall et al.	16.2	(0.45)	-	1.50	Z/K = 3.30; length groups used: 12.0-15.0[d]
S	relative freq.	Catch curve	(19.0)	(0.45)	-	2.75	length groups used: 12.0-15.0; conf.lim: + 1.0
	relative freq.	Jones & v. Zalinge	(19.0)	(0.45)	-	3.35	length groups used: 12.0-14.5; conf.lim: + 0.7
	observed	Pauly (1983)	17.4	-	-	-	$L_\infty = L_{max}/0.95$
	this table	mean	18.7	0.45	5.15	-	-

Note: Figures in parenthesis are input values for the method (provisionally adopted).
[a] $\emptyset' = \ln K + 2 \ln L_\infty$ (K per year, L_∞ cm, ln = natural logarithm).
[b] ESP/ASP: measure for goodness of fit (see Pauly and David 1981).
[c] C: amplitude of seasonal oscillation of growth rate.
WP: winterpoint (time of the year when growth rate is lowest).
[d] length groups used: the length groups used in the regression analysis, i.e., the groups where Z is assumed to remain constant.

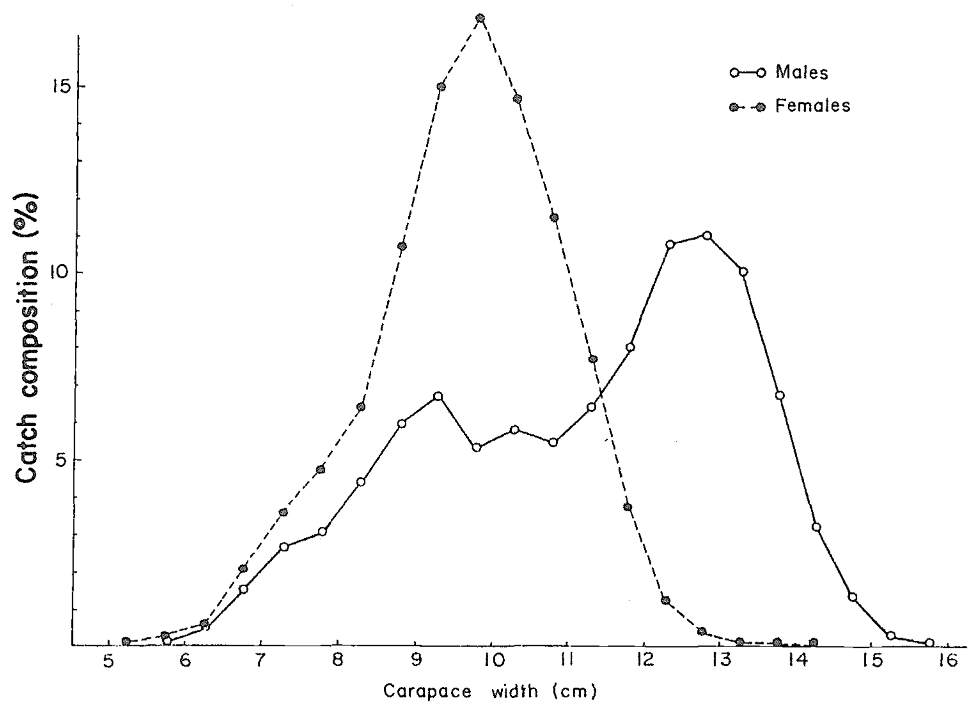

Fig. 6. Size distribution of all *Geryon quinquedens* sampled from the trap fishery off Mozambique, 1979-1984.

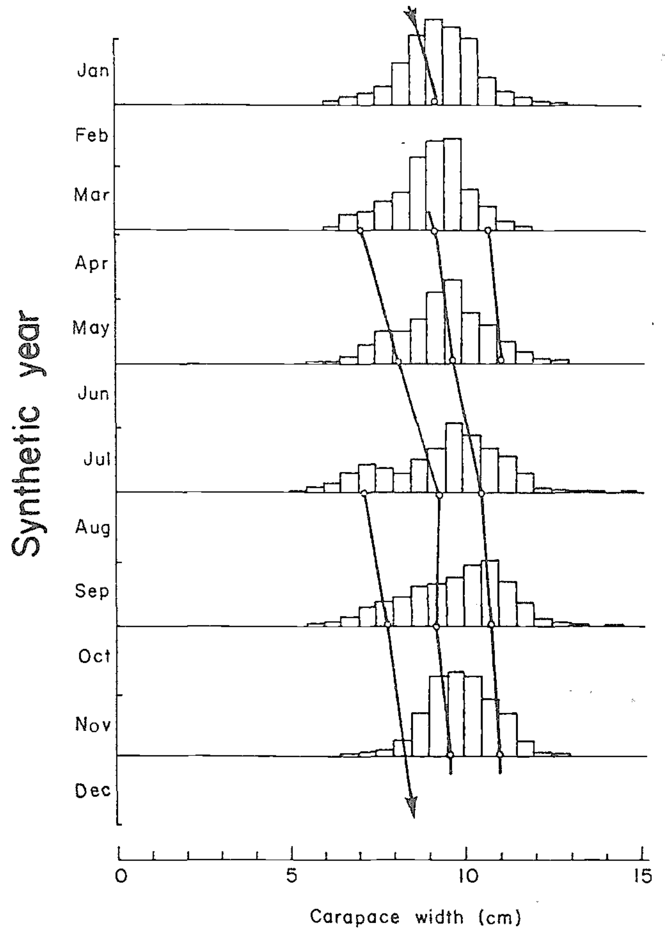

Fig. 7. Distribution of components discriminated the pooled samples of female *Geryon quinquedens* and superimposed growth curves.

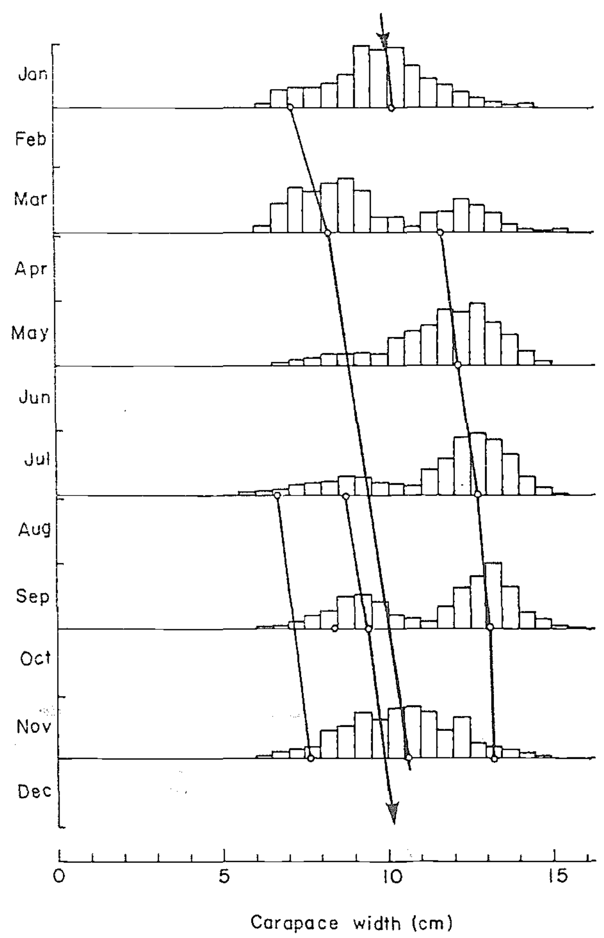

Fig. 8. Distribution of components discriminated by the Bhattacharya method on the pooled samples of male *Geryon quinquedens* and superimposed growth curves.

cohorts. This allowed the construction of assumed growth curves. The resulting Gulland and Holt plots are shown in Figs. 9 and 10 (for females and males, respectively).

It was difficult to trace the modes for the small size groups of crabs. Both in Fig. 7 (males) and Fig. 8 (females) the smaller "cohort" cannot be followed for a long time. (This applies to the recruits identified in January-February and in July-November). It is suggested that this problem arises mainly from gear selection. For this reason, all the analyses were repeated after adjusting the observed frequencies with an estimated selection ogive. The result was that the components (cohorts) that could be followed were reinforced and that a number of modes were found to be spurious.

The Gulland and Holt plot applied to the corrected data resulted in higher values for the curvature parameter, K, especially in the case of the females. The confidence limits can be expected to be very wide, however, and therefore the difference is probably not significant.

With the ELEFAN I program relatively high values for L_∞ were obtained. Since the K values did not differ from the ones obtained with a Gulland and Holt plot (using the raw data), the ϕ' values obtained were also higher.

By running ELEFAN I allowing for seasonal oscillations in growth rate, slightly better fits were obtained. The increase in goodness of fit was very small and was obtained moreover at very high values of the parameter expressing the amplitude of seasonal oscillation.

Judging from the temperature differences observed at each depth level, we would expect, however, only small seasonal oscillations in growth (Pauly 1982).

Figs. 11 and 12 show the plot of Wetherall (1986) of the summed bimonthly samples. It was somewhat difficult to choose the classes where mortality could be assumed to have remained constant. The choice can affect not only the estimation of Z/K (as discussed below), but also the estimate of L_∞. When we used relative frequencies, the results did not deviate very much but it should be noted that the males' estimate of L_∞ decreased while that of the females did not.

The different methods applied resulted in a range of values for L_∞. For the females this range was not very wide. Judging from the literature the biggest females ever caught were

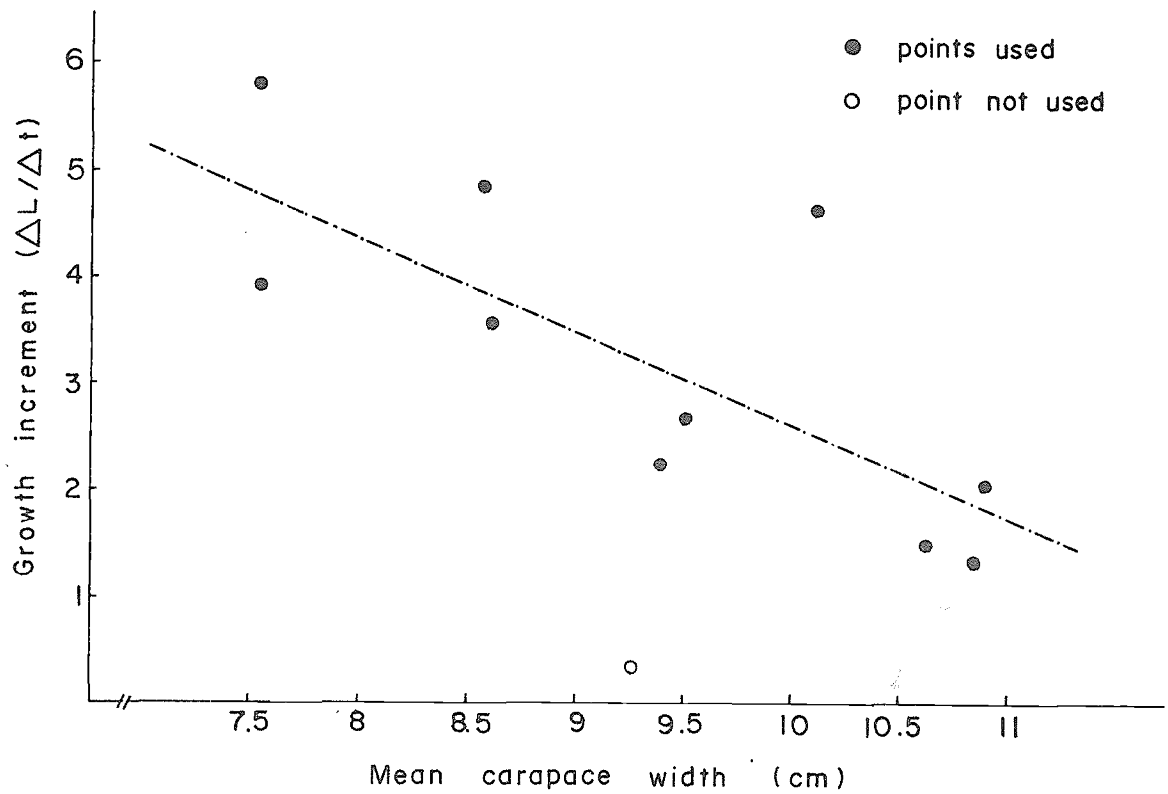

Fig. 9. Gulland and Holt plot, linking the modes discriminated in Fig. 7 in the pooled samples of female *Geryon quinquedens*.

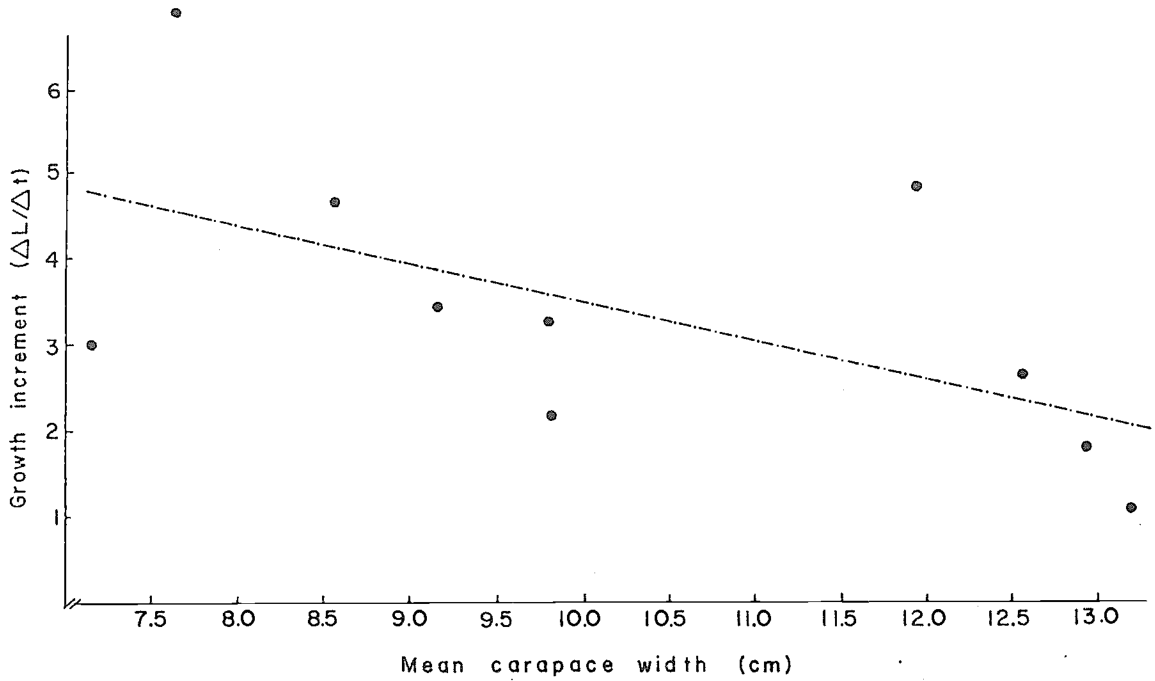

Fig. 10. Gulland and Holt plot drawn linking the modes discriminated in Fig. 8 in the pooled samples of male *Geryon quinquedens*.

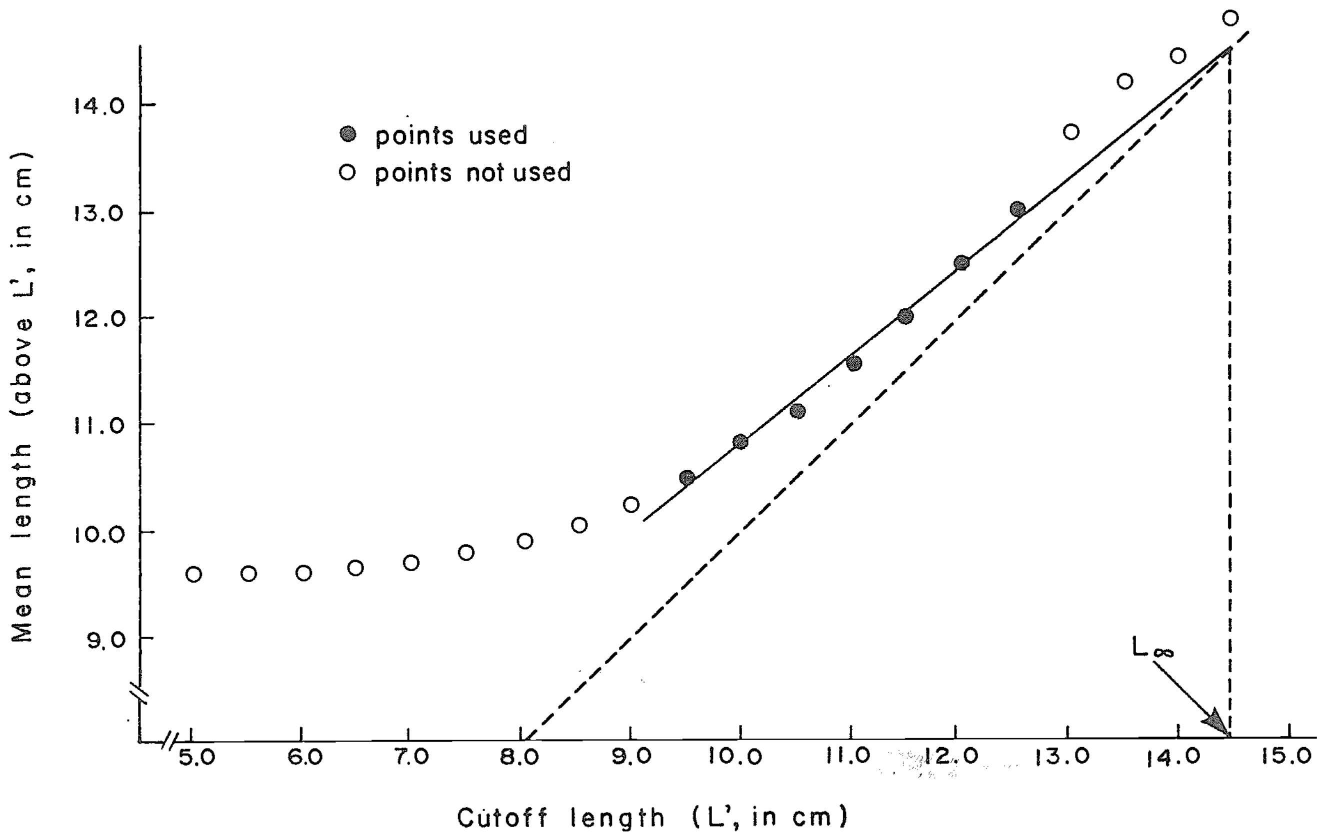

Fig. 11. Wetherall plot of all sampled female *Geryon quinquedens*.

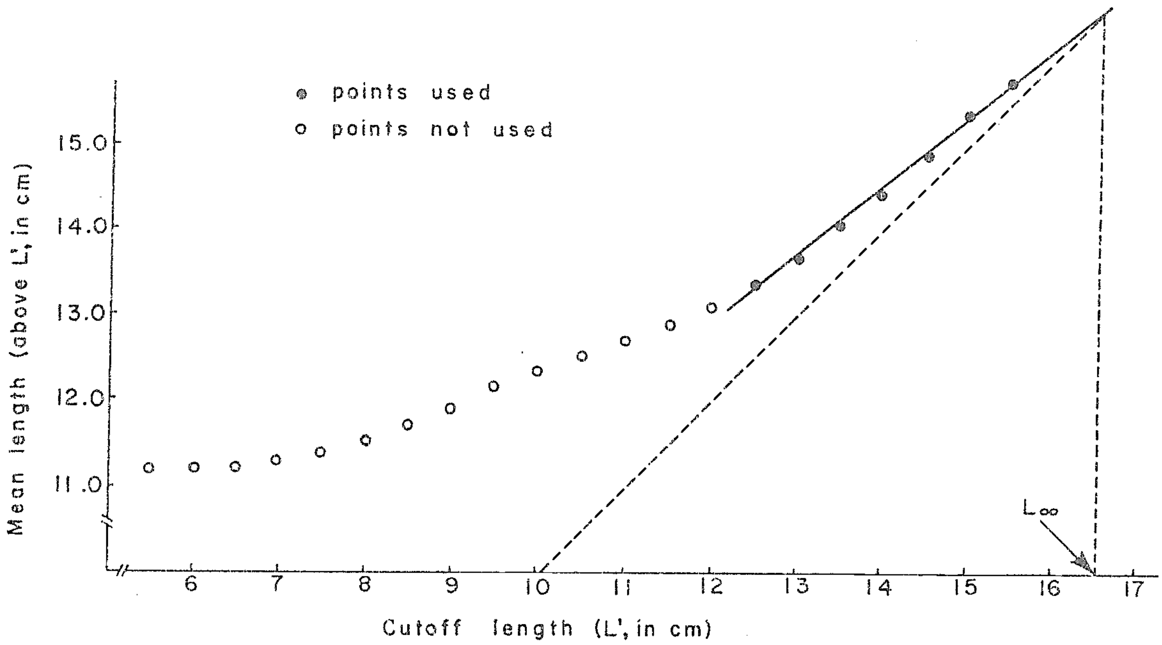

Fig. 12. Wetherall plot of all sampled male *Geryon quinquedens*.

included in the present samples and thus it is different to accept an L_∞ much larger than the largest crab sampled. For the males the range is larger but the value obtained by the Gulland and Holt plot occupies a central place amongst the estimates (Table 6).

The mean values of ϕ' obtained for the two sexes (Table 6) were not significantly different (t-test, 99% level).

If one tries to smoothen out the curves shown in Figs. 7 and 8, a birthday in July-August is reached for both females and males. The small cohort appearing in July-November could also be forced to join the main cohort in March-May. Unfortunately information on the early development of *G. quinquedens* is not available to test these hypotheses.

Mortality

The values obtained by the different models for the coefficient of total mortality Z are difficult to interpret in the light of present knowledge (Table 6).

Firstly the sensibility of these methods to the choice of the length range to be used in the regression analyses must be considered. Then we have values for the females that could be accepted as being similar. The estimates for males, on the other hand, are not consistent.

Furthermore the values obtained would mean that virtually all the crabs in one cohort would have died within the first year of life. This is contradictory to the above interpretation of two cohorts being present in the samples. Also as stated in the introduction, the fishery was never so intense as to allow a high value of fishing mortality.

The reasons for these discrepancies may be explained by biased sampling since only the upper part of the distribution area of *G. quinquedens* was fished and since there was not an even distribution of the sampling effort over the whole geographical area.

Haefner (1977) reported that female *G. quinquedens* matured at about 8-9 cm (carapace width), which is a size covered in this investigation.

The occurrence of sex segregation by depth implies that there should be vertical migrations associated with reproduction. The contradictory observations (from previous studies) on size distribution by depth can be interpreted as seasonal vertical migration. More detailed studies of the reproductive seasons of this species may shed some light on this matter.

Discussion

Sampling from a commercial fishery, where *G. quinquedens* was not the target species, proved to give data which were difficult to interpret for quantitative studies.

Gear selectivity could be an important factor, particularly in the case of traps. It is well known that the vulnerability of many animals to be trapped varies within their life cycle. The fact that the sampling effort was not evenly distributed over the whole habitat of the deep-sea red crab seems also to be important.

Nevertheless the present study indicates differences in the growth parameters of male and female *G. quinquedens*. The males grow bigger than the females, and they do that at a much slower rate. A ϕ' of around 5.2 (in terms of natural logarithms) appears characteristical for this species. Furthermore the average values of L_∞ and K presented in Table 6 are probably close to the real parameters in the stock of *G. quinquedens* off Mozambique.

Recruitment studies should be performed in order to test the hypothesis that the main cohort, originating in July-August, is the major component of *Geryon* catches. Attention should also be paid to an apparently distinct group recruiting from July to November.

An adequate sampling scheme should be set up, covering the whole distribution area of *G. quinquedens* in order to estimate mortality rates. Consideration should be given to the possibility of migrations. In particular, vertical migrations are likely to occur on a seasonal basis in connection with reproduction.

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An Analysis of an Inshore Population of *Penaeus subtilis* in the Gulf of Paria, Trinidad

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Abstract

The results of an inshore trawl survey in the Gulf of Paria, Trinidad, from 1984-1986 are described for the shrimp *Penaeus subtilis* (Penaeidae). An analysis is made of the length frequencies, apparent relative abundance, and relevant commercial statistics including a discussion on the possible sources of bias and limitations of conclusions of such a data set, because of gear selection and immigration/emigration of individuals. It is concluded that estimates of growth and mortality parameters from these data should not be attempted, and hypothesized that the life cycle of the species follows a similar pattern as in French Guiana with spawning related to the onset of the rainy season. Recommendations are made to obtain the necessary data to determine more details on the dynamics of the species and status of the stock.

Introduction

Since 1960 an extensive trawl fishery for penaeid shrimp has developed at the northeast coast of South America between the Orinoco and Amazon rivers. Landings of shrimp have fluctuated between 15,000 and 20,000 t (live weight) per year, involving over 600 vessels from ten countries (Villegas and Dragovich 1984). The principal species in this offshore fishery is the brown shrimp *Penaeus subtilis*, which has its center of abundance between French Guiana and north Brazil (Dragovich et al. 1980), but which also contributes significantly to catches off Venezuela and Trinidad (Novoa 1982). Vessels usually operate at depths between 36 and 72 m, and are of the typical Gulf of Mexico design (21-23 m in length, fishing two otter trawls on outriggers). Inshore populations of *P. subtilis* also support artisanal and semi-industrial fisheries from Trinidad to Brazil. Indications are that stocks of *P. subtilis* harvested by the offshore fishery have declined since the early 1970s.

Attempts have been made to explain the recruitment mechanisms for this species to the offshore fishery, and to model the bioeconomic relationships between the artisanal fishery and the offshore, industrial fishery (Garcia et al. 1984). Information on the juveniles and subadults is however sparse. Such information is essential to ensure that a bioeconomic model produces realistic results, and can also be used to provide short-term forecasts of the relative abundance of the adult stock at sea (Yokel et al. 1969; Berry and Baxter 1969; Caillouet and Baxter 1973; Barret and Gillespie 1973). Additionally, monitoring of the subadult phase can be used as a dynamic management option in determining the opening date of the fishing season and size at first capture as, e.g., in the Gulf of Mexico.

The present study discusses the results of a 1984-1986 inshore trawl survey in Trinidad using the length frequencies and apparent relative abundance of *P. subtilis* obtained, and the implicit problems and biases involved in such surveys for inshore, migratory shrimp populations. A hypothesis for the life history of *P. subtilis* in the waters of Trinidad is also presented.

Description of the Study Area

The Environment

The study area is shown in Fig. 1. It is located off the north-central part of the Trinidad coastline, 1-3 nm from the coast at depths of 2-4 m. The bottom consists of soft mud, with a very gentle slope to the center of the Gulf of Paria. The coastline is bordered by mangrove and shrub vegetation with a number of small rivers discharging into the Gulf. Further inland sugar estates occur and an industrial complex (petro-chemicals and iron/steel smelting) is situated in the south of the study area.

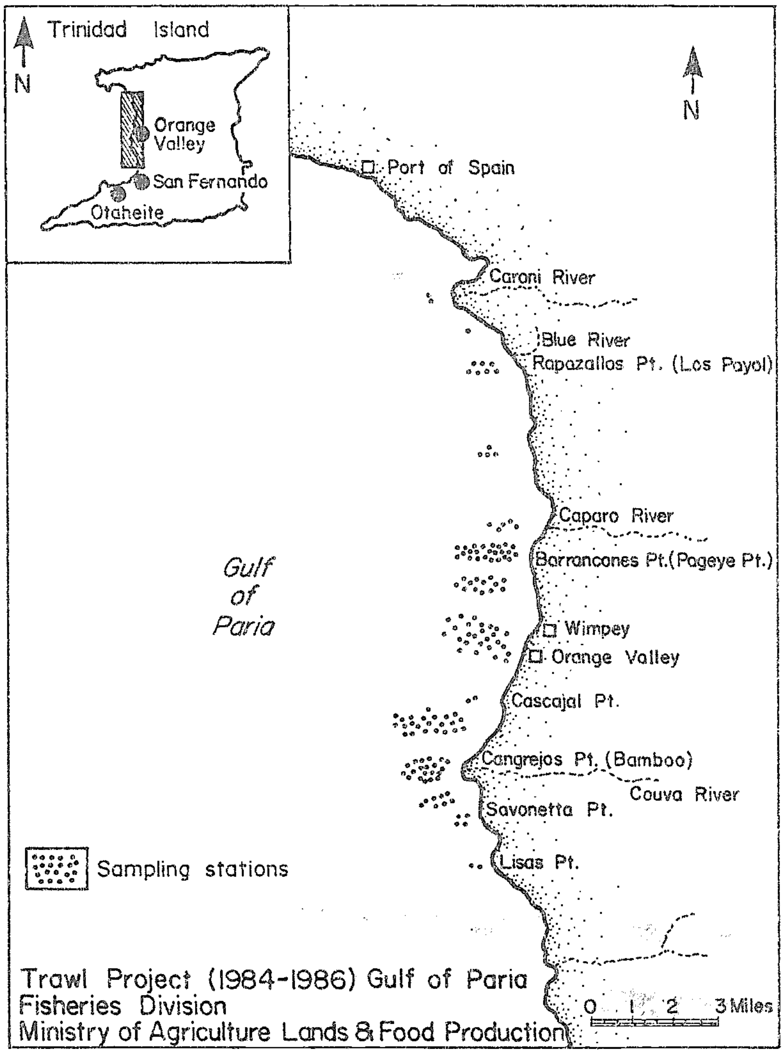


Fig. 1. Location of study area and sampling positions.

The Fishery

An intensive, demersal fishery operates in the inshore waters, with the main fishing center and landing area (Orange Valley) indicated in Fig. 1. There are also a number of lesser landing areas located north and south of Orange Valley in close proximity, and further south significant quantities of shrimp are also landed by the commercial inshore trawlers at San Fernando and Otaheite. Recorded landings of shrimp at Orange Valley, San Fernando and Otaheite totalled 265 t in 1985 with finfish bycatch also landed. There are four types of trawlers operating in the waters of Trinidad:

(a) Inshore artisanal "pirogues", usually 7.5-8.5 m long with outboard engines using a single stern trawl retrieved by hand;

(b) Larger "pirogues", up to 10.5 m with inboard engines operating the same gear;

(c) Mini-stern trawlers from 10.5-12 m with inboard engines operating larger trawl nets from a winch system. These vessels have superstructures with radio, echo-sounder etc.;

(d) Larger shrimp trawlers operating double nets from out-riggers, the vessels being around 22.5 m in length and similar to those operating off the Guianas and northern Brazil in the offshore fishery.

Of the fishing vessels above, all can fish close to shore, except the largest vessels, with the pirogue-type vessels restricted to a maximum of 9 m depth, because of the problems in retrieving nets manually in deeper water. The mini-stern trawlers can fish further offshore, and so "straddle" the inshore and deeper zones. Vessels operate both day and night, with the pirogue-type vessels usually making trips of less than one day. When catch rates are favorable, a number of crews operate the same vessel sequentially. The trawl fishery is Trinidad and Tobago's most important fishery, both in terms of value of catch landed and in volume of landings.

Methods

Field Operations

The data on *P. subtilis* were obtained from a trawl survey designed to monitor the demersal fishery for shrimp and fish from November 1984 to February 1986 in the inshore waters of the Gulf of Paria, Trinidad. The location of stations in the study area is shown in Fig. 1. Two trawl hauls per week, each of 1.5 hour duration on the same day were done from an artisanal-type shrimp trawler, 8.4 m long with two 55 hp outboard engines, using a hand-operated trawl net from the stern of the vessel. The headrope of the trawl net was 8.3 m and the cod-end mesh size 4 cm stretched. The first haul was done at approximately 6:45 a.m., while the second haul started as soon as the second sampling location was reached. Location of sampling stations was determined by sightings of commercial vessels, with hauls taken in the general area of commercial activity. Trawling was done 1-3 nm from the coast, in waters of 4-9 m. On completion of each haul, all shrimp and finfish were separated from trash in the net, put on ice and returned to the laboratory where they were frozen. Identifications were made to the species level, individuals sexed, and length-frequencies taken, to the nearest millimeter below with Vernier calipers of carapace length (CL), measured as the distance from the post-orbital notch of the carapace to the mid-posterior dorsal margin. Monthly details of samples are given in Table 1.

Data Analysis

Sexes were treated separately in all length-frequency analyses, as an initial examination of the size distributions indicated consistently longer carapace lengths for females in each haul. Differences between sexes relating to length-at-age are typical for penaeid shrimp populations and documented in the literature (Garcia and Le Reste 1981). For the analysis of modal length groups, numbers of shrimp were pooled to create an artificial "year", with new monthly sampling "dates" because of relatively few specimens for each sex in certain months during the sampling

Table 1. Sampling details of survey for *Penaeus subtilis* off Trinidad, 1984-1986.

Year	Month	Number of hauls: Total month	Number of hauls: *P. subtilis* present	Numbers (*P. subtilis*)/month: Male	Numbers (*P. subtilis*)/month: Female
1984	Nov.	7	6	791	810
	Dec.	8	8	346	423
1985	Jan.	10	10	260	311
	Feb.	8	7	32	40
	March	8	5	40	40
	April	10	5	8	8
	May	8	5	9	2
	June	8	5	12	29
	July	10	5	7	7
	Aug.	8	1	2	0
	Sep.	8	8	17	85
	Oct.	10	8	17	32
	Nov.	8	6	45	101
	Dec.	8	7	276	318
1986	Jan.	9	7	56	76
	Feb.	8	6	9	26
Totals		136	99	1927	2308

period. This is indicated in Table 2. Individuals were also grouped in 2 mm (CL) size classes to emphasize temporal trends between samples in visual examination. The original carapace lengths (1 mm) were used in the detection of modes within each sample, using the method of Bhattacharya (1967), because of its sensitivity to small incremental changes and the possibility of computing test statistics in the separation of modal distributions. For the analysis of changes in carapace length, arithmetic mean values for weekly hauls were used over the actual sampling time period from 1984 to 1986, and curves fitted by eye and back-projected to the time axis to approximate birthdates. More sophisticated methods of utilizing the size- at-relative age data were not utilized because of the context in which the data were collected and their paucity. Correction for trawl selection was examined but not attempted as treatment of the first sample (November) using a factor obtained from Lhomme (1978) resulted in adjusted frequencies of the smallest size classes appearing unreliable because of the high raising factors used (Fig. 2).

Commercial statistics (landings of shrimp per fishing trip, averaged over the total number of trips made for each month) for the fishing centers of Orange Valley, San Fernando and Otaheite (Fig. 3) were examined for monthly variations to detect any temporal trends. The landings from these three centers represent over 90% of shrimp caught by the inshore fleets in the Gulf of Paria. In the particular case of Orange Valley, situated in the center of the study area (which covers the main area of operation of its inshore commercial fleet) a comparison was made of mean monthly catch rates (survey vessel) with the mean landing per commercial trip, for all shrimp species. A further comparison was made between estimated landing per commercial trip, and the catch of the survey vessel for *P. subtilis* alone (Fig.4). The following are the calculations made for each monthly statistic:

Table 2. Pooled "monthly samples of *P. subtilis* Trinidad, 1984-1986.

Month	Components	Numbers Male	Numbers Female
15th November	November 1984	791	810
	November 1985	45	101
15th December	December 1984	346	423
	December 1985	276	318
15th January	January 1984	260	311
	Janaury 1985	56	76
1st March	February 1985	40	40
	March 1985	8	8
	February 1986	9	26
1st June	April 1985	8	8
	May 1985	9	2
	June 1985	12	29
	July 1985	7	7
1st October	August 1985	2	0
	September 1985	17	85
	October 1985	17	32

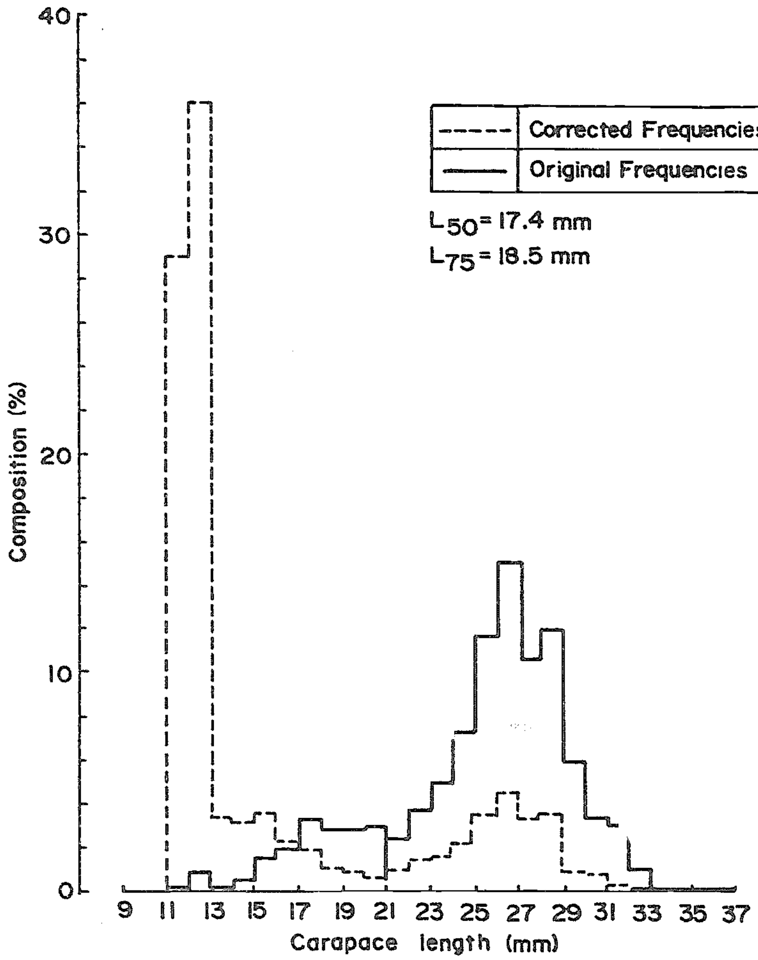


Fig. 2. Correction for trawl gear selection (pooled sample for Nov.).

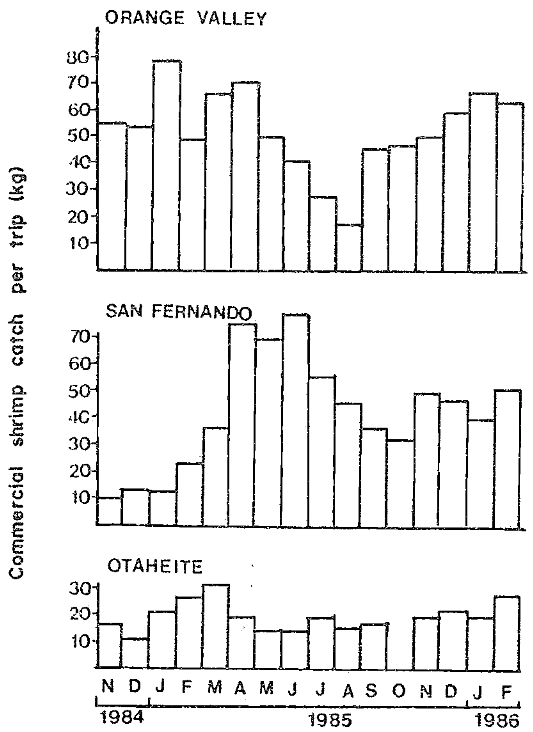
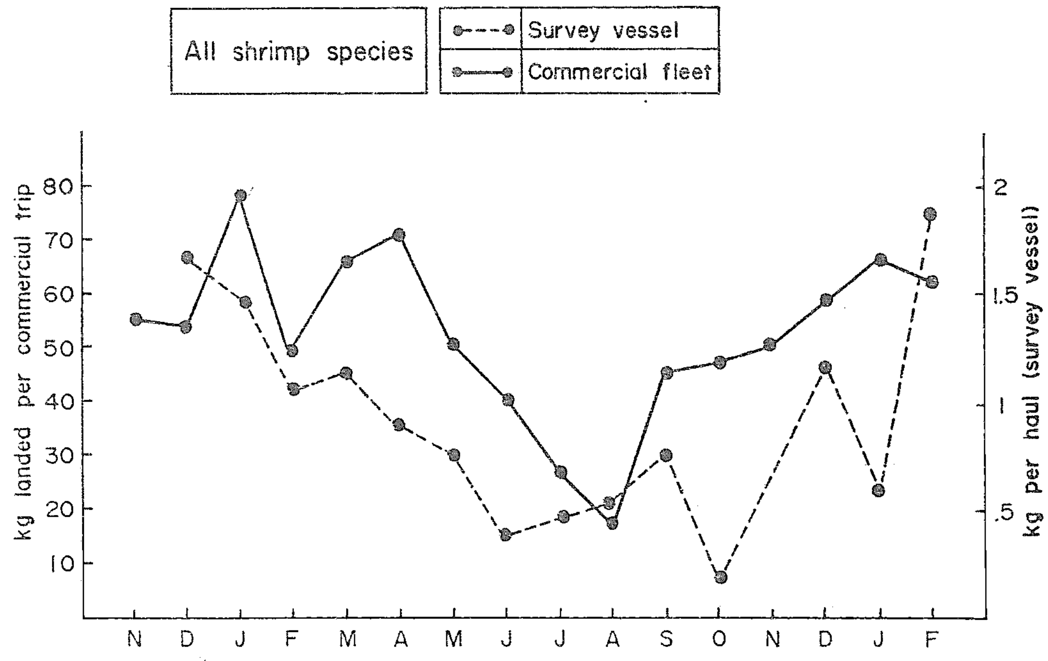


Fig. 3. *Top*. Landings of shrimp (all species) per fishing trip per month for fishing centres in the Gulf of Paria (Nov. 84-Feb. 86).



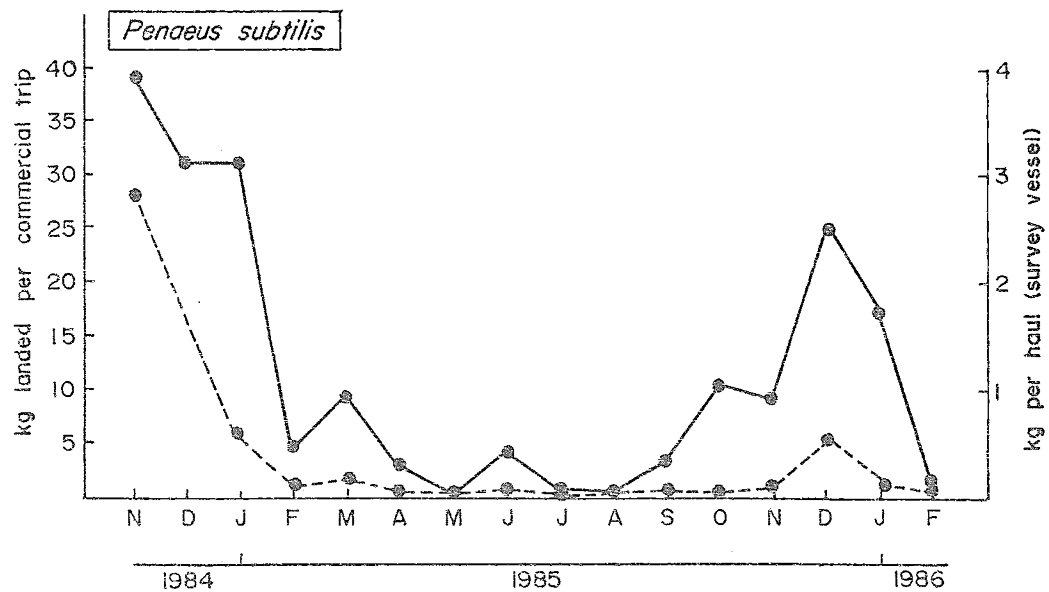


Fig. 4. *Right*. Comparison of commercial landings/trip (Orange Valley) with survey vessel hauls over the same period (Nov. 84-Feb. 86).

Mean commercial vessel landing rate (All shrimp species)	=	Total landings (kg) all vessels / Total number of trips made	= A
Mean survey vessel catch rate (All shrimp species)	=	Total shrimp catch (kg) = B / Total number of hauls made	= B
Estimated commercial vessel landing rate *(P. subtilis)*	=	(A) * Percentage (by weight) of *P. subtilis* in survey vessel catch for same month	
Mean survey vessel catch rate *(P. subtilis)*	=	(B) * Percentage (by weight) of *P. subtilus* in survey vessel catch for same month	

Results and Discussion

Interpretation of temporal trends must consider a number of interacting factors related to behavior of the species and the sampling program. The nearshore area contains emigrating populations, as well as immigrating postlarvae and residential juveniles in various density/time/space scales, depending on its particular use as a nursery and/or staging area for moving offshore. Populations may therefore select for seagrass, algal flats, intertidal mudflats, mud-mangrove banks, or the open channel (Garcia and Le Reste 1981; Staples et al. 1985. Reduced vulnerability of *P. subtilis* to trawling due to burrowing or inactivity may also affect catch rates and composition. The closely related species *P. aztecus* has been documented as predominantly nocturnally active, and therefore less vulnerable to day fishing (Wickham and Minkler 1975; Penn 1984).

A number of other meteorological and hydrological factors (temperature, rainfall, river discharge, salinity, turbidity, currents, wind speed and direction) have been correlated with variations in catchability and abundance, and multivariate models utilized to explain and forecast relationships. These studies are summarized in Garcia and Le Reste (1981) and Witzell and Allen (1983), but forecasts based on these abiotic variables have not been reliable. Rainfall seems to be the single factor most often correlated with catches, either by influencing juvenile migration out of nurseries or by affecting settlement and survival of postlarvae. A consistent relationship between rainfall and recruitment to the offshore fishery in French Guiana for *P. subtilis* could not, however, be established (Garcia et al. 1984, 1985).

Because of the selectivity of the trawl gear, the catch that would be retained would consist of mainly the larger individuals, i.e., faster growing juveniles and emigrants, until they move offshore. The events that trigger emigration have not been understood, however it appears to be forced by a combination of environmental factors in the estuarine area as noted above. The result is variation not only in numbers, but also in sizes of individuals in the emigrating cohort.

Gear efficiency factors may also contribute bias to the samples. The cod-end used of 4 cm stretched mesh (20 mm bar length), as indicated by Fig. 2 will not capture a representative sample of the smallest size classes. Thus both ends of the length distribution will be biased for different reasons. Variation in the trawl efficiency in terms of numbers of individuals captured was shown by Loesch et al. (1976) to vary between 30 and 50% for *P. aztecus* over a ten-day period with a 5 m headrope otter trawl. Finally, because of the relatively few individuals in samples for March, June and October (Fig. 5), a few individuals caught at random can alter conclusions made.

Modal Length Analysis (Pooled Monthly Samples)

Histograms of length frequencies (2 mm CL) for females and males are given in Fig. 5, from 15 November to 1 October. Corresponding modal means as estimated by the method of Bhattacharya (1967) are also given in Fig. 6 with statistics in Table 2. Bimodal peaks are evident in the histograms for both sexes continuously for all sample months, with the smallest size classes of about 19 (males) and 23 (females) mm CL increasingly represented from March to October, especially in June. A significant aspect of Fig. 5 is the appearance for both females and males of the smallest size-classes (< 13 mm CL) in June samples. Providing this is not an artefact of the various factors noted, it may reflect evidence of spawning around this period.

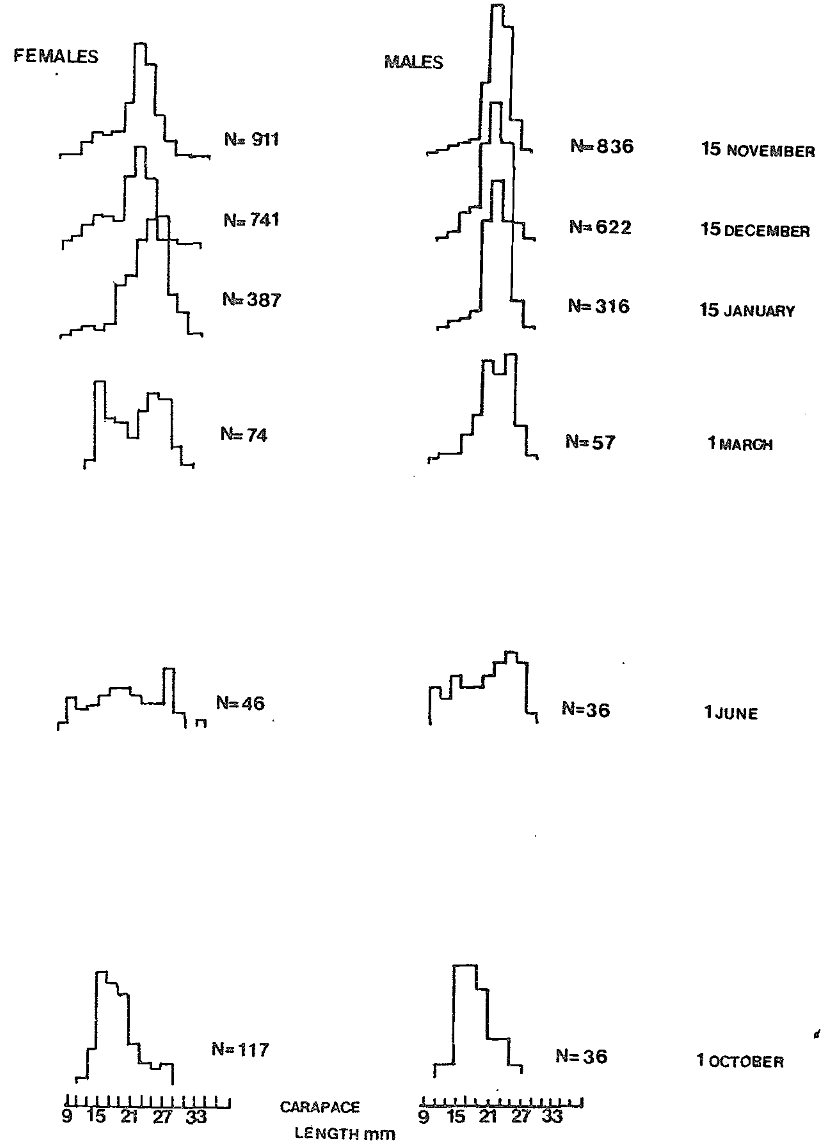


Fig. 5. Histograms of length frequencies of pooled samples (see Table 2).

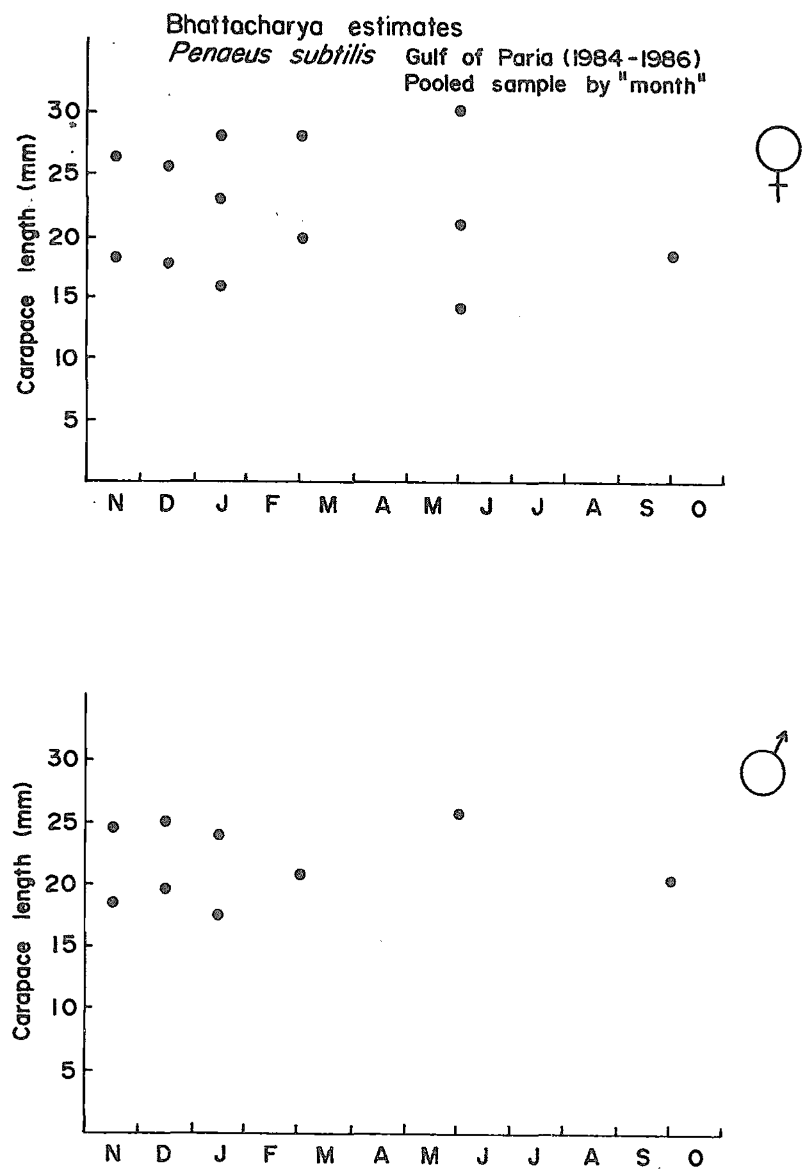


Fig. 6. Results of modal analysis by the method of Bhattacharya on pooled samples of male and female *Penaeus subtilis*.

Bimodality is also reflected in Fig. 6 for November, December and January, but not for March, June and October for male *P. subtilis*. The existence of two such modes could be explained by synchronous spawning at periods over a few months. Evidence for this is not available for penaeid stocks (Crocos 1985).

Bimodality was also found for the length distributions of migrating *P. merguiensis* by Staples (1980) and attributed to individuals from two recruitments. Samb (this vol.), in a study of length frequency samples of the pelagic fish *Sardinella maderensis* from the inshore artisanal fishery of Senegal, also interpreted persistent bimodal peaks in a growth curve for the migrating population. It is suggested that interpretation of length-frequency modes for migratory species, especially when sampling is done only from young, inshore populations must be linked to a clear understanding of its life cycle and habits. Sousa (this vol.) demonstrated the degree of bias for vital parameters estimated from such length frequencies alone and indicated how such bias might arise for the migratory scad *Decapterus russelli* off Mozambique.

Growth Curve Analysis (Weekly Sample Means)

Observed data, with curves fitted by eye are shown in Fig. 7 for both females and males together with reconstructed growth curves using parameters obtained from Parrack (1979) for *P. aztecus*. Values for L_∞ were converted to carapace length. Theoretically, the eye-fitted and

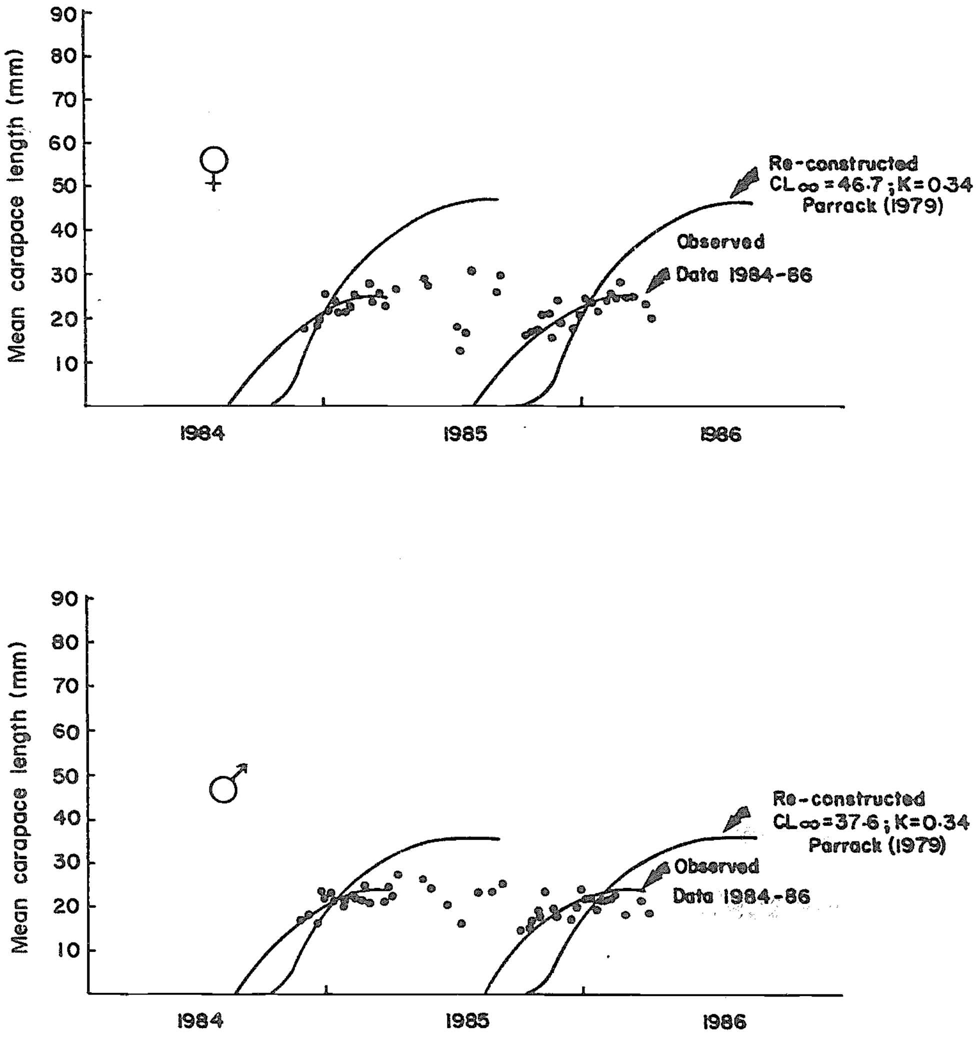


Fig. 7. Observed (1984-1986) and re-constructed growth curves of male and female *Penaeus subtilis*.

reconstructed curves should merge in part. Due to gear selection (smaller individuals are underrepresented), emigration (observed maximum size individuals never approximate L_∞ values known from the literature), the two curves do not merge, however. The phenomenon of "no growth" is probably created by the emigration of individuals after a certain length. The use of such a curve to estimate growth parameters would therefore lead to biased estimates of K and L_∞ as shown by Sousa (this vol.). Use of the length frequencies obtained for a catch curve analysis would also lead to an overestimation of the coefficient of total mortality (Z) due to emigration of the larger individuals. The eye-fitted curve does provide some (biased) information on a spawning/birthdate where it intersects the time axis around July. A later date is more probable, as a correction for gear selection would force the eye-fitted curve to intersect the time axis at a later date.

This would suggest the major spawning event at the height of the rainy season, unlike the proposal of Garcia et al. (1984) that this takes place at the end of the dry season in Suriname. Additional sampling with smaller mesh cod-end trawls over other years, and monitoring of the reproductive state of the adult population are needed to resolve this.

The above results confirm the assessment by Garcia and Le Reste (1981) that observations on growth of migrating subadults are particularly difficult to interpret. The size at emigration for both males and females is approximately 25 mm CL, as indicated in Fig. 5.

Life Cycle Hypotheses (Trinidad Waters)

It is proposed that *P. subtilis* follows a similar life history as outlined for French Guiana and Suriname by Garcia et al. (1984), where spawning is matched to the occurrence of the rainy season. In this scenario, young shrimps enter the coastal (nursery) areas as approximately one month old postlarvae at the beginning of the rainy season, reside there for approximately three months and then emigrate to offshore areas to spawn and repeat the cycle, with a total lifespan of 1 to 1.5 years.

The appearance of the smallest size classes (< 13 mm CL) in June in both male and female *P. subtilis*, indicated by Fig. 5, suggests this as the main rainy season in Trinidad begins approximately at this time. This period also coincides with the lowest number of individuals in samples for the entire survey, a situation consistent with the larger individuals being mainly offshore at this time (Table 1).

Increases, both in the number of individuals per sample (Fig. 5) and the mean sizes (Fig. 6 in October/November 1985), suggest that this period marks the emigration out of the coastal (nursery) areas to offshore, deeper waters where they are lost to the artisanal fishery, but recruited to the industrial shrimp fishery.

The above representation describes a single spawning event. Many tropical penaeid stocks including *P. subtilis* are documented to have two spawnings in their life cycle. Under the present hypothesis, with the present data set, a second spawning is not evident.

An examination of commercial statistics for Orange Valley for the period of the study tends to support this life cycle hypothesis (Figs. 3 and 4). Catch rates (kg of shrimp landed per trip) decline markedly in the mid-year period when the main rainy season is in effect. Estimated catch rates for *P. subtilis* only (Fig. 4) emphasize the absence of the species from commercial catches from April to August with captures increasing from September on. The decline in shrimp landings per trip in the mid-year period is evident also in the adjacent fishing centers of San Fernando (with a lag) and Otaheite to a greater and lesser extent, respectively (Fig. 3). These gross interpretations of commercial statistics need to be refined, so that the landings of the vessels restricted to fishing close to shore (the "pirogues") can be separated from those of the mini-stern trawlers, which can fish further from the coast and catch the larger (older) individuals. This will also allow a more valid comparison of the three fishing areas.

Conclusions and Recommendations

The results of the trawl survey indicate that the present sampling plan does not provide sufficient information to reveal the life cycle or manage the resource of *P. subtilis*, even in a single-species context. It gives rise to a number of hypotheses concerning emigration out of the inshore areas and its timing, seasonal effects in apparent relative abundance, and approximation of a birth/spawning month of the species. Linking of this phase to other stages of its life history, i.e., earlier (juvenile) and later (adult) remains to be done to describe the life cycle. The analysis also reveals that estimation of vital parameters (growth, mortality) from such samples are biased by the emigrations out of the inshore areas, and the selectivity of the gear used. It is likely therefore that a repetition of such a sampling plan will produce similar shortcomings in information.

In order to describe the life history of the species and determine the status of the stock, an integrated program is necessary, involving the following elements:

(a) **Documentation of commercial fishing activities.** Resolution of catch (landing) statistics by time and area together with a sampling of commercial catches for species composition and discards and catches by sizes. Information on fishing habits related to shrimp behavior (gear modification, fishing pattern variation) is also vital in the design of a sampling plan.

(b) **Covered cod-end trials.** Using the same survey vessel and net, utilize a cod-end bag of 11 mm (stretched) to collect the size-classes of shrimp missed by the gear used in the past survey, and therefore correct for gear selection. This will allow reinterpretation of the data.

(c) **Development of an appropriate sampling design.** For the reasons noted in this paper, a continuation of sampling the subadult phase is advisable. To optimize sampling effort, however, a design derived from an analysis of variance of various factors that are considered to affect catches, e.g., day/night, tidal, lunar and hydrological effects, should be implemented. A similar design for the offshore (adult) phase is needed.

Because of the proximity of Trinidad and Tobago to continental countries that also fish for the same migratory species, there is a critical need as well to obtain similar information from these countries and to coordinate sampling programs.

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Estimation of Growth and Mortality in Banana Prawn (*Penaeus merguiensis*) from the South Coast of Java, Indonesia

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Abstract

In 1980, shrimp trawling was replaced by a trammel net fishery on the south coast of Java. Samples of carapace length of *Penaeus merguiensis* were raised to represent the average annual length composition of the monthly landings of banana prawn in Cilacap before and after the change in fishery.

Growth parameters and total mortality by sex, estimated by the ELEFAN program, catch curve and cohort analysis did not change as a result of the trawl ban. The cause of a drop in recruitment as indicated by cohort analysis is unknown but could be an artefact resulting from a change in fishing practice, an increase in the artisanal fishery on the small size shrimp or an increase in the predation pressure due to a possible increase in the fish biomass resulting from the trawl ban.

Female:male ratio of about 1.3:1 as found in the catches could be explained by the cohort analysis if the natural mortality of males was about twice that of females. This is also reflected in a doubling of total mortality from females to males, as found by catch curve analysis, which is difficult to explain in terms of fishing practice, but partly could result from differences in behavior between sexes.

Introduction

Shrimp fishery is one of the most valuable resources in the Indonesian waters. The shrimp fishery has developed rapidly since commercial trawling started around 1966. However, it slowed down and the landings actually decreased since a ban on trawl fishing was imposed in 1980.

Penaeid shrimps are fished in almost all coastal areas of Indonesia with banana prawn *(Penaeus merguiensis)* being the most abundant species (Naamin 1984a). Statistical data show that Indonesian penaeid shrimp production in 1978/1979 reached a maximum of over 5,200 tonnes. Landings of penaeid shrimp have decreased since the trawl ban.

Because shrimp was the target species in the inshore fishing grounds, a conflict was created between the traditional fisheries and the trawl fishery. Trawl fishermen invaded the shallow waters where large numbers of fishermen using traditional gear were operating (Naamin and Martosubroto 1984).

One of the major shrimping grounds is situated on the south coast of Java with Cilacap as the central landing place (Fig. 1). The fishery in this area has developed very rapidly since the start of commercial shrimp trawling in 1971. Official data indicate that the annual production in the Cilacap area reached a peak of about 5,200 t in 1979 and declined sharply to about 1,000 t after the 1980 trawl ban (Table 1).

Since the banning of all trawl fishing, a most important problem has been to find a gear to replace the trawl for catching shrimp. However, no gear has yet been found as effective as the trawl net.

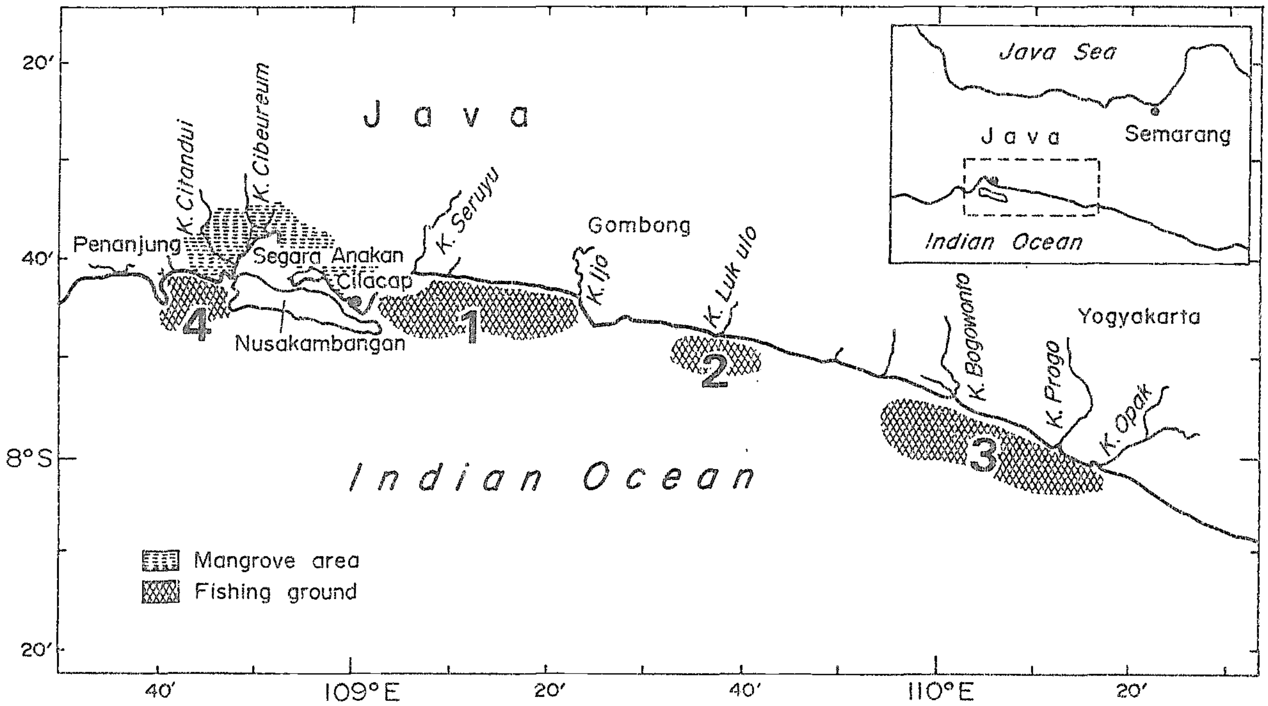

Fig. 1. Distribution of shrimp grounds along the south coast of Java. 1. Teluk Penyu area; 2. Gombong area; 3. Yogyakarta area; 4. Penanjung area.

Table 1. Annual landings of shrimp and fish in Cilacap area, 1969-1983.

Year	Dominant gear	Shrimp (t)	Shrimp (%)	Fish (t)	Fish (%)	Total (t)
1969	Bottom gillnet beach seine	84	2.3	3,519	97.7	3,603
1970	– do –	113	4.6	2,319	95.4	2,432
1971	– do –	195	11.6	1,419	88.4	1,686
1972	Trawl, beach seine	3,798	68.0	1,778	32.0	5,578
1973	– do –	2,487	32.0	7,771	68.0	10,258
1974	– do –	2,911	24.0	12,127	76.0	15,038
1975	– do –	3,005	29.0	10,362	71.0	13,367
1976	– do –	3,054	23.0	13,278	77.0	16,332
1977	– do –	4,900	26.7	13,414	73.3	18,314
1978	– do –	5,205	31.5	16,523	68.5	21,728
1979	– do –	5,242	32.1	16,329	67.9	21,570
1980	– do –	1,614	29.4	3,869	70.6	6,022
1981	Trammel net, beach seine	903	33.4	1,803	66.6	2,706
1982	– do –	1,114	33.1	2,249	66.9	3,362
1983	– do –	866	19.3	3,622	80.7	4,488

Some fishermen started to use trammel nets to catch shrimp, and this is at present the most efficient gear available. Some fishermen use their trawl boats to operate trammel nets, while others use smaller vessels. The trawl vessels using trammel nets were not allowed to fish within three miles off the coast (i.e., fishing area 1 in Fig. 1). The development of the fleet for each fishing area is given in Table 2.

The change in the gear from trawl to trammel net from 1980 to 1981 may have caused changes in the size compositions of the shrimp catch, while the decreasing trend in the catch of large shrimp before 1980 was probably due to increased fishing effort (Naamin and Martosubroto 1984). The differences between trawl and trammel nets are attributed to mesh size.

Table 2. Number of boats by fishing area in Cilacap and adjacent waters, 1978-1984.

Year	Artisanal fishery Area I (0-3 miles)	Artisanal fishery Area II (3-7 miles)	Commercial fishery Area III (7-12 miles)
1978	395	7	89
1979	452	11	89
1980	642	40	89
1981	800	200	46
1982	965	243	50
1983	962	253	60
1984	996	304	89

Source: Cilacap Fisheries Agency

The cod end mesh size of the trawls is about 2 cm, while the trammel nets have mesh size of 3.8 cm. The trammel nets used as bottom shrimp gill nets (active gear) catch shrimp as they become caught with their head or bodies in a mesh of the net or by getting entangled in the net. Fishing occurred in the depth range of 15-30 m. It has three layers of nets, 1.5 inch for inner-net and about 12.75 cm for each outer net.

Knowledge of the selectivity of the commercial fishing nets on the most important shrimp is of considerable value for the interpretation of size composition data from shrimp catch. Several authors have reported that there is hardly any mesh size selection for shrimp due to their shape, where rostrum, antennae and other appendages may hinder passage through the net.

According to Gulland (1972) regulation of mesh size is not effective for penaeids, because the selection is not very efficient. Boerema (1974, cited in Garcia and Le Reste 1981) also indicated that "mesh regulations would not be very effective for regulating the shrimp size."

The most accurate assessment of a shrimp fishery can be made from the analysis of catch-and-effort data combined with information on growth and mortality rates, the basic information needed for shrimp fishery development and management.

Analysis of shrimp commercial catch samples of *P. merguiensis* in the Gulf of Carpentaria was described by Lucas et al. (1979). The resulting estimates of the von Bertalanffy growth parameters (L_∞, K) and the instantaneous rate of total mortality (Z) in banana prawn indicate a L_∞ of almost 40 mm carapace length , a K of about 4 year^{-1} (0.08 week^{-1}) and a Z range from 11 year^{-1} (0.22 week^{-1}) to 18 year^{-1} (0.35 week^{-1}). Later, Gwyther (1982) estimated a high K value of about 7 year^{-1} (0.136 week^{-1}) and a low L_∞ of 30 mm carapace length for males, and a K value of 6 year^{-1} (0.116 week^{-1}) and L_∞ of about 35 mm carapace length for females. In the Arafura Sea, Naamin (1984b) estimated the value of K = 1.6 year^{-1} and natural mortality (M) of 2.1 year^{-1} in banana prawn for both sexes combined. No estimates of K and L_∞, or of mortalities are available for *P. merguiensis* in Cilacap and adjacent waters.

The aim of this paper is to estimate growth and mortality of banana prawn before and after the banning of the trawl fishery. As already indicated, a difference of about 10 to 20% in the growth parameters of male and female in the same population is to be expected (see also Beverton and Holt 1959; Lucas et al. 1979; Garcia and Le Reste 1981). But there seems to be no reason to expect a change in the growth patterns of shrimp by sex before and after the trawl ban. This study therefore focuses on an assessment of the mortalities.

Materials and Methods

Data Source

About 80% of the shrimp caught off the south coast of Java is conveniently landed in Cilacap, this being the only available harbor. The data collection has been concentrated here.

For practical reasons only main types of the shrimp exploitation system were included in the commercial fishery statistics as produced by the Fishery Cilacap Auction. These statistics contained data on the monthly landings, i.e., catch in weight, value and the number of trips by vessel. Effort and other relevant data were also supplied regularly with the cooperation of the ship registration post or "Pos Apung" (before 1980) and Harbour Master's Office (after 1980).

Biological sampling was carried out during 1977-1978 (data collected by N.Naamin). After the trawl ban, this sampling system was extended up to 1982-1984. From the landed catch a sample might be taken for size frequency (carapace length frequency by sex). Sampling of the banana prawn landings was scheduled every month (one or two samples per month). A monthly summary of all these data and estimates of effort in trip/day, catch per trip and total landing was prepared. Each individual shrimp in a sample was recorded on a specially designed form.

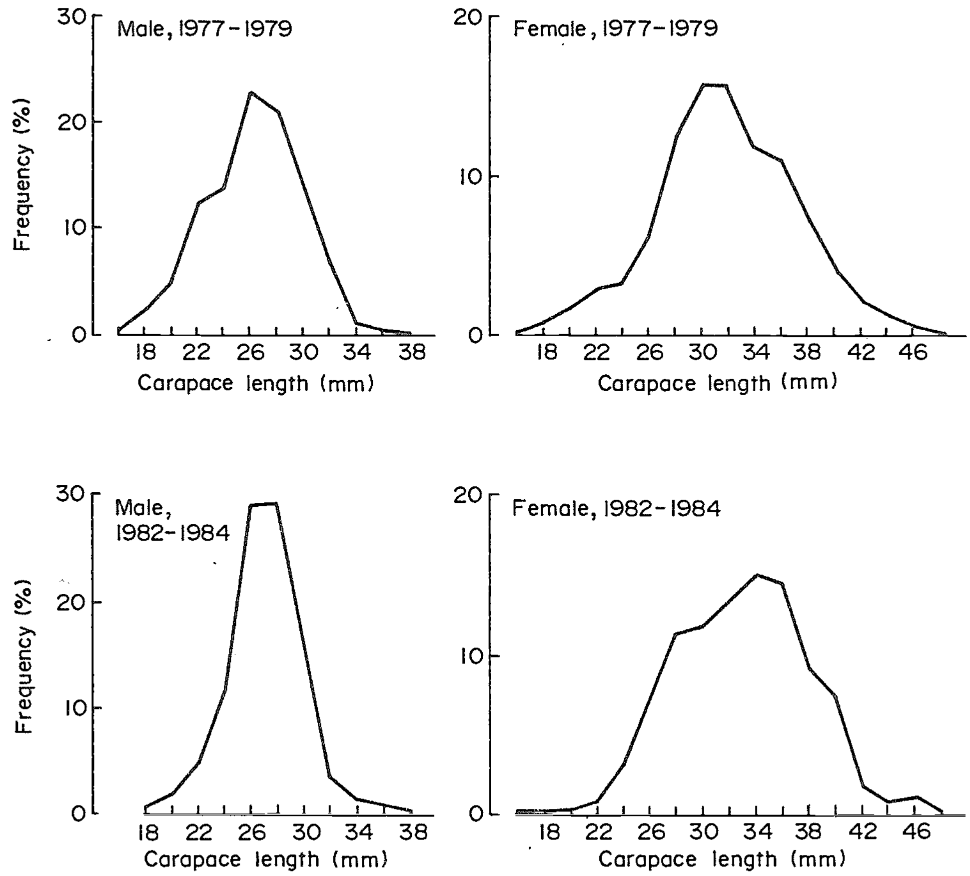

Fig. 2. Average annual carapace length-frequency distribution (by sex) of *Penaeus merguiensis* caught near Cilacap, before and after the trawl ban.

Input Data for Length-Frequency Analysis

Monthly length composition data on males and females caught were provided for each year. Table 3 shows catch per trip, total sample weight and number of prawns by sex at carapace mid-lengths (mm) based on samples taken on board commercial vessels during the periods 1977-1979 and 1982-1984. Information on monthly effort in terms of number of trips, total catch for all trips and catch of sampled trips are given in Table 4. CPUE is also derived. It may be mentioned that each fishing trip is of 5-6 days duration including 1-2 days of sailing. The average number of trawl hauls or trammel net operations is 7 per fishing day.

In order to estimate the length composition by sex and by month of the total landings of banana prawn, the frequency samples were raised in two steps. First, each sample of males and females was raised to total catch of the sampled trip, i.e., by using a first raising factor (Table 3), defined by:

$$\text{Trip raising factor} = \frac{\text{Catch in weight of trip sampled}}{\text{Total weight of trip sampled}} \qquad \ldots 1)$$

Table 3a. Length frequencies by sex of *P. merguiensis* from all trips sampled in Cilacap in 1977.

Carapace midlength (mm)	Jan 1/1	Jan 15/1	Feb 1/2	Feb 15/2	Mar 1/3	Mar 15/3	Apr 1/4	Apr 15/4	May 1/5	May 15/5	Jun 1/6	Jun 15/6	Jul 1/7	Jul 15/7	Aug 1/8	Aug 15/8	Sep 1/9	Sep 15/9	Oct 1/10	Oct 15/10	Nov 1/11	Nov 15/11	Dec 1/12	Dec 15/12
Males																								
16	6																							
18	21	4																						
20	26	6	2																				1	2
22	28	12	3	2			1	1	2	1		12	1	23	1	1			2	2	2		5	2
24	3	4	3	5	3	1	4	4	1	5		12	2	8	5	5	1	2	4	4	5	3	5	4
26	3	17	7	3	6	5	5	9	5	6	1	14	7	23	29	22	8	33	3	16	7	8	2	32
28		10	4	10	7	2	1	13	11	6	1	6	5	15	23	30	16	16	25	20	22	18	1	22
30		3	6	11	6	1		10	14	6	12	2	4	6	15	11	17	10	18	14	56	29	1	6
32		4	3	2	4	6	1	6	5	8	8	4	12	7	11	10	10	4	11	5	22	9	1	2
34				1	1	2		2		1	4			1	1		1	1		2		3		1
36		1	1			2		1		1							1		1					
38						1																		
Females																								
18	7	5																						
20	35	3		1															2					
22	11	8	2	5								1		2	4				1					
24	25	9		2	4		2	1	3	1		7	1	11	4				5					
26	2	5		4	4	1			1			5	1	8	10	6	1	1	7	1				
28	3	7	1	12	18	4		3	3	5	1	10	4	8	14	15	8	11	12	1	2	3	1	3
30	1	8	2	8	16	5	2	6	2	3		6	5	16	14	15	18	16	33	3	13	2	3	
32	1	3	1	4	14	3	3	2	2	5		5	4	7	20	4	8	14	11	13	14	18	1	18
34		10	1	2	11	3	2	8	5	3	3	3	8	5	7	14	13	12	25	12	18	11		23
36	2	4	3	2	7	5		9	5	6	9	3	8	2	10	11	3	5	4	11	44	23	2	28
38	1	2	3	1	1	3	1	3	4	5	9	3	2	1	8	3	5	2	6	7	15	7	7	19
40		1	2			2	1	3	2	3	6	4	1	3	6	3	4	2	4	2	11	7	1	8
42			1					2	1	1	6	2	1		3	2	1	2	1	1				8
44		1						1			3				2	1	1	1		1		2		2
46		1													2	1	1	1				2		
48																						2		
Catch (kg)	25	31	38.5	49	43	35	30	37	49	63	106	38	39.5	55	72	57.5	65	100.5	51	46	83	52.5	49	80
Total sample weight (kg)	1.70	2.70	1.17	1.83	2.60	1.70	0.49	2.18	2.21	1.99	2.57	2.52	1.95	3.0	5.0	4.1	3.7	3.47	4.10	2.95	6.40	4.30	1.04	7.29
Raising factor	14.70	11.50	32.90	26.78	16.54	20.59	61.22	16.97	22.17	31.66	41.25	15.08	20.26	18.33	14.40	14.02	17.57	28.96	12.44	15.59	12.97	12.21	47.02	10.97

Table 3b. Length frequencies by sex of *P. merguiensis* from all trips sampled in Cilacap in 1978.

Carapace midlength (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Males												
16			1									
18	1	5	6	7					3			2
20		12	9	18	2	6	2		12	1		26
22	2	24	29	52	31	23	23	17	54	14	13	35
24	4	20	30	17	16	11	17	39	27	26	24	35
26	9	10	18	36	13	24	20	20	40	22	33	17
28	45	10	7	11	9	20	16	29	9	24	10	2
30	22	2		1	3	8	21	6	11	5	2	1
32	5				3	4	4	1	2	1		
34	1					1	1					
36							1					
Females												
22		11	11	11		2	2		1			
24		7	18	6	1	3	2	6	9	1		
26		13	21	14	2	25	26	8	22	2	15	
28	2	9	14	33	3	13	37	39	49	25	13	1
30	4	4	12	15	22	17	26	50	25	45	31	12
32	3	3	7	13	39	11	12	22	27	38	15	32
34	12	2	4	12	7	4	5	12	16	25	5	45
36	19	2	9	16	5	7	6	7	13	15	4	26
38	10		4	5	3	3	3	4	11	14	3	15
40	9	1		4	2	2	5	3	2	4	3	15
42	7	2		3		2	1	3	1	2	1	10
44	2							1		1		7
46												1
48												1
Catch (kg)	67	135	40	105	72	78	95	97	135	103	87	150
Total sampling weight (kg)	4.30	3.10	6.30	7.50	5.20	5.30	5.70	7.60	6.40	5.40	4.60	8.00
Raising factor	15.58	43.55	6.35	14.00	13.84	14.72	16.67	12.76	19.56	19.07	18.91	18.75

Table 3c. Length frequencies by sex of *P. merguiensis* from all trips sampled in Cilacap in 1979.

Carapace midlength (mm)	Jan 8/1	Feb 8/2	Mar 8/3	Apr 8/4	May 8/5	Jun 8/6	Jul 8/7	Aug 8/8	Sep 8/9	Oct 8/10	Nov 8/11	Dec 8/12
Males												
16	3	7	2	1								
18	1	28	6	9	10	10		1		1		5
20	13	5	19	4	13	12	1	2	2	2	1	
22	5	8	7	26	7	11	2	28	12	37		8
24	6	19	21	15	4	18	7	88	8	88	1	17
26	20	4	35	11	10	5	10	41	109	98	5	8
28	3	1	18	17	7	11	5	89	49	41	2	9
30		2	4	2	11	1	6	3	32	3	1	4
32			3	1	2		1		2		3	3
34				1								1
Females												
16	1											
18	3	6			3							
20	9	14	4		5	8					1	
22	22	11	7	2	9	22	2				2	
24	8	6	17	4	13	9		2	1	2	2	5
26	7	45	3	16	8	24	5	12	2	12	7	7
28	11	32	21	11	9	23	9	38	11	38	15	17
30	10	22	53	9	13	8	7	42	5	41	19	7
32	5	9	19	45	8	10	13	53	19	37	21	6
34	7	6	4	18	17	24	9	64	13	51		8
36	2	2	2	30	12	5	1	12	20	35	1	
38	1	1	1	2	9	4	2	36	8	12	1	4
40		1		1	12		1	4	3	4		2
42				2				7		1		
44								1				
Catch (kg)	70	55	90	72	85	92	67	446	150	69	33	57
Total sampling weight (kg)	2.60	7.20	7.70	7.20	5.80	4.60	2.80	16.30	11.50	7.90	2.70	3.90
Raising factor	26.92	7.64	11.69	10.00	14.66	20.00	23.93	27.36	13.04	8.73	12.22	14.62

Table 3d. Length frequencies by sex of *P. merguiensis* from all trips sampled in Cilacap in 1982.

Carapace midlength (mm)	Apr	May		Jun		Jul		Aug		Sep		Oct		Nov		Dec
	8	1	15	1	15	1	15	1/8	15/8	1/9	15/9	1/10	15/10	8/11	15/11	8/12
Males																
18								1			1					2
20		1					1	2		1			1			1
22		5			1	4		1		4	16	1	4	6		2
24	1	12	1	4	2	2	2	9	3	21	28	12	2	20		1
26	17	8	6	7	5	6	9	17	2	21	7	10	10	7		15
28	15	15	3	10	9	3	4	19	14	14	6	11	20	11		13
30	8	9	4	5	1	1	1	6	6	6	1	16	17	2		4
32	1		1	1		1		3		2		8	1	1		1
34	1	1						1				1				
36	1							1								
Females																
24		1				4						1	6			
26	1	1	1	4	1	4	2			3	2	9	13	8		
28		2	4	5	1	11	6	3		2	2	25	11	9		
30	1	5	6	8		5	9	4	11	1	13	22	7	15		6
32	3	11	11	14	5	6	13	4	6	12	22	11	14	12		7
34	8	5	10	10	8	7	7	15	6	11	11	16	9	10		11
36	10	6	10	4	10	4	3	8	2	7	6	8	11	10		18
38	5	5	6	5	3	5	6	13		1	1	4		4		6
40	6	5	4	7	7	1	1	6	1	2	1	4	1	1		4
42	1	4	2	2		4		5	2	2	1	1	1	1		4
44		1			1	1		6		1	1		1	1		1
46			1					4								
48								1								
Catch (kg)	43.0	47.0	45.0	37.0	59.0	42.0	37.0	81.0	65.0	53.0	32	39.0	44.0	45.0		32.0
Total sample weight (kg)	2.38	2.50	2.89	3.57	3.17	2.40	1.97	5.46	2.17	4.07	4	6.25	4.91	9.08		3.62
Raising factor	18.07	18.80	15.57	10.36	18.61	17.50	18.78	14.84	29.95	13.02	7	6.24	8.96	4.96		8.84

Table 3e. Length frequencies by sex of *P. merguiensis* from all trips sampled in Cilacap in 1983.

Carapace midlength (mm)	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Males								
20	1					3		
22	2		5		1	2	2	1
24	6	19	2	16	7	10	7	23
26	32	69	16	23	38	12	14	17
28	28	138	15	29	52	9	48	35
30	12	55	15	15	18	3	10	30
32	2	2	3	3	9	1	5	2
34	1	2		3	3		1	3
36					2			
Females								
16			5					
18			23					
20			9		2			
22	14		2	1	1			
24	11	13	1	9	8	5	4	
26	50	47	2	19	11	6	11	10
28	106	59	27	48	15	6	23	21
30	64	82	38	23	21	30	36	24
32	24	85	40	29	20	18	46	17
34	24	52	25	23	29	27	28	26
36	5	29	38	23	28	9	26	14
38	7	10	15	20	8	15	19	22
40	6	6	19	2	9	8	17	31
42		1			1	2		4
44						1		1
Catch (kg)	25	18	40	47	67	82	91	73
Total sample weight (kg)	7.51	15.33	8.00	7.0	6.91	4.77	8.20	6.90
Raising factor	3.33	1.17	5.0	6.71	9.70	17.20	11.10	10.60

Table 3f. Length frequencies by sex of *P. merguiensis* from all trips sampled in Cilacap in 1984.

Carapace midlength (mm)	Jan 1/1	Jan 15/1	Feb 1/2	Feb 15/2	Mar 1/3	Mar 15/3	Apr 1/4	Apr 15/4	May 1/5	May 15/5	Jun 1/6	Jun 15/6	Jul 1/7	Jul 15/7	Aug 1/8	Aug 15/8	Sep 1/9	Sep 15/9	Oct 1/10	Oct 15/10	Nov 1/11	Nov 15/11
Males																						
18																			1	3	2	1
20									6							25	6	16	12	4	3	10
22	9		17		3	2	4			1					5	62	39	1	24	2	27	10
24	28		59		12	1	33	1	73	9		5	1	4	17	54	39	15	14	20	24	9
26	147	2	160	8	116	4	136	30	98	7	10	16	3	21	12	18	10	14	1	18	13	1
28	145	1	118	1	133	12	88	7	132	6	8	6	10	15	14	5	6	16		12	19	
30	96	14	115	2	120	16	107	11	39	2	23	6	15	7	1	1		1		22	7	1
32	18	5	25	6	18	6	18	2	6	1	12	2	6	1		2				9	1	
34	5	13	4	6	2	2	1		2		3		1							3		
36	1	3		2	1	2			1			1								1		
38				2		1	4															
Females																						
18																			1			
20			2																3			
22	3		8				2										9		1	7		2
24	16		20		3		10			31	5	1		1	8		26	1	21	28		1
26	54		92		28		54	8		49	7	10	1	5	26		47	2	14	13	1	8
28	69		65		51		67	9	3	76	13	10	1	22	36	9	28	8	18	14	2	23
30	84	6	58	1	124	1	115	15	3	46	7	16	6	7	44	2	27	9	22	7		29
32	59	7	50	2	69	1	50	12	8	58		18	5	9	23	3	13	4	10	1	5	17
34	74	11	44		71	5	43	11	5	32	2	4	4	6	36	5	6	5	8	1	1	27
36	56	18	25	4	40	9	23	10	2	42		7	2	4	37	2	8	6	11		1	15
38	60	6	50	5	59	7	47	4		29	2	4		2	19	4	2	2	4	1	3	16
40		4		3		7	46	1				6	3	2	2	3	2	1	1		1	12
42		4		1				5				1	1	1	1		1	1	2			6
44								3					1			1		1				5
46														1								5
Catch (kg)	94	46	67	32	41	21	58	45.5	64	50.5	41.5	45	51	44	53	69	48	40	63	57	75	68
Total sample weight (kg)	21.90	3.60	19.20	1.60	7.60	3.30	18.10	4.46	15.24	1.40	4.77	2.00	1.70	3.03	2.40	5.90	5.00	2.63	3.06	3.00	8.15	13.60
Raising factor	4.30	12.70	3.50	19.70	5.40	6.30	3.20	10.20	4.20	36.00	8.70	22.50	30.0	14.5	22.1	11.7	9.6	15.2	20.6	19.00	9.2	5.0

Table 4. Effort, total catch in weight, CPUE, catch of sampled trips and monthly raising factor for *Penaeus merguiensis*.

Year	Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977	Effort (number of trips)	962	804	817	813	811	1,014	1,128	991	1,001	706	976	929
	Total catch (t)	38.0	22.9	32.2	54.1	32.4	21.9	71.9	91.1	157.8	154.2	134.4	113.4
	Catch of sampled trips (kg)	56	87.5	78	67	112	144	94.5	129.5	165.5	97	135.5	129
	Raising factor	679	262	413	807	289	152	761	703	953	1,590	992	879
	CPUE (kg per trip)	40	29	39	67	40	22	64	92	158	218	138	122
1978	Effort	1,036	778	865	843	921	911	698	603	462	540	446	402
	Total catch	99.5	27.2	51.5	56.3	70.0	75.8	24.3	35.7	27.6	60.9	40.5	39.3
	Catch of sampled trips	67	135	40	105	72	78	95	97	135	103	87	150
	Raising factor	1,485	201	1,288	536	972	972	256	368	204	591	466	262
	CPUE	96	35	60	67	76	83	35	59	60	113	91	98
1979	Effort	428	391	444	414	442	400	516	633	637	644	574	616
	Total catch	26.0	26.9	25.0	20.9	17.1	17.2	23.3	30.7	17.4	26.8	22.1	19.1
	Catch of sampled trips	70	55	90	72	85	92	67	446	150	69	33	57
	Raising factor	371	489	278	290	201	187	348	69	116	388	670	335
	CPUE	61	69	56	50	39	43	45	48	27	42	39	31
1982	Effort				203	215	230	260	725	780	753	792	117
	Total catch				9.1	11.9	17.5	17.6	44.4	27.3	4.2	10.5	9.4
	Catch of sampled trips				43	92	96	79	146	85	83	45	32
	Raising factor				212	129	182	223	304	321	51	233	294
	CPUE				45	55	76	68	61	35	6	13	80
1983	Effort					485	248	285	291	323	245	331	320
	Total catch					6.6	7.4	18.5	31.1	6.6	9.1	15.8	15.9
	Catch of sampled trips					25	18	40	47	67	82	91	73
	Raising factor					264	411	463	662	99	136	174	218
	CPUE					14	30	65	107	20	37	48	50
1984	Effort	310	280	299	307	292	247	256	100	357	338	240	
	Total catch	11.8	13.9	13.8	19.1	16.5	11.3	23.0	10.0	11.3	20.5	17.4	
	Catch of sampled trips	140	99	62	103.5	114.5	86.5	95	122	88	120	143	
	Raising factor	84	140	223	185	144	131	242	89	128	171	122	
	CPUE	38	50	46	62	57	46	90	109	32	61	73	

Raised frequencies by sex were then added on a monthly basis before raising by the second factor (Table 4), i.e.,

$$\text{Monthly raising factor} = \frac{\text{Total catch in weight of all trips by month}}{\text{Catch of sampled trips by month}} \qquad \ldots 2)$$

Tables 5 and 6 give the raised monthly frequencies after pooling by month for each 3-year sampling period and dividing by 3 (or by the actual number of months sampled) in order to represent the annual average length compositions of prawn catch before and after trawl banning.

Table 5. Calculated annual average monthly catch in numbers ('000) by length groups for males and females of *P. merguiensis* in the south coast of Java during 1977-1979, i.e., immediate before trawl banning.

Carapace midlength (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Males												
16	29.97	8.66	4.66	1.00								
18	91.24	49.62	22.64	26.31	36.63	12.32		0.67	4.00	1.00		11.32
20	145.19	46.95	45.29	48.95	115.88	43.62	5.66	1.33	16.98	5.99	2.66	62.94
22	155.84	93.57	86.58	175.82	72.59	132.53	150.18	52.28	77.92	124.21	46.62	145.85
24	71.26	102.23	113.89	141.53	128.87	93.57	90.58	152.85	63.94	256.08	106.56	166.83
26	189.81	61.27	114.55	223.78	128.21	133.20	198.80	228.77	456.21	344.99	172.83	171.50
28	382.28	65.27	59.94	119.88	84.58	115.55	131.87	279.72	273.06	466.20	201.47	102.56
30	177.16	51.28	20.65	50.28	76.92	58.94	94.91	98.57	217.45	256.08	365.63	41.29
32	48.95	13.32	29.30	44.96	41.29	45.29	102.56	71.60	96.24	117.55	138.86	25.31
34	7.66	2.33	0.67	9.99	3.00	12.99	5.99	3.33	14.65	16.65	11.99	5.00
36	2.66	3.00	5.66	4.66	3.00		1.33		5.66	6.66		
38			3.00									
Sum	1,302.02	497.50	506.83	847.16	690.97	648.01	781.88	889.12	1,226.11	1,595.41	1,046.62	732.60
Females												
16	3.33											
18	79.59	7.33			3.00							
20	154.18	19.65	4.33		5.00	9.99	4.66			13.32	2.66	
22	130.54	63.27	37.63	29.64	8.99	37.63	17.98	13.32	1.33	6.66	5.33	
24	139.86	32.30	76.26	32.30	18.65	30.97	59.27	24.64	12.65	38.96	5.33	7.99
26	42.96	103.23	64.27	50.28	18.98	152.85	93.24	74.26	44.96	75.59	62.94	11.32
28	80.25	97.24	132.20	106.89	43.96	100.23	135.20	185.15	216.78	224.11	109.56	52.61
30	88.25	63.27	145.85	82.25	124.54	95.57	156.18	205.46	283.38	457.54	159.51	72.26
32	50.62	32.30	93.57	98.57	202.46	68.27	259.41	150.18	218.78	364.64	280.72	133.53
34	141.86	20.98	56.94	92.57	67.60	56.94	96.24	129.87	210.79	415.25	136.20	160.51
36	170.16	21.65	42.96	109.89	62.94	60.61	61.61	89.24	89.91	209.46	296.04	160.17
38	88.91	12.32	36.30	32.63	45.95	40.29	21.65	66.27	64.94	167.17	110.22	188.81
40	71.93	9.66	16.65	28.97	33.97	25.31	28.64	37.63	44.96	62.60	83.92	67.27
42	53.95	8.99		18.65	5.33	23.64	6.66	25.97	25.31	23.64	3.00	41.96
44	17.98			4.66		6.33		12.32	14.65	11.99	7.99	17.65
46	2.66							9.99	14.65		7.99	1.67
48											7.99	1.67
Sum	1,317.03	492.19	706.96	687.30	641.37	708.63	940.74	1,024.30	1,243.09	2,070.93	1,279.40	917.42

Table 6. Calculated annual average monthly catch in numbers ('000) by length groups for males and females *P. merguiensis* in the south coast of Java, 1982-1984, i.e., in the trammel net fishing after trawl banning.

Carapace mid-length (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
18								2.00	0.67	4.33	2.66	15.63
20					2.66		1.33	11.66	14.32	20.65	21.31	7.66
22	1.00	2.66	2.00	0.67	6.66	1.00	8.99	26.31	34.63	32.30	43.29	16.32
24	3.33	9.66	5.33	29.97	43.62	12.65	13.99	76.59	78.26	45.95	70.26	25.31
26	18.32	33.63	48.29	433.23	58.28	40.63	64.94	80.59	59.61	30.97	29.30	128.87
28	17.65	20.31	58.94	364.64	64.74	47.95	62.94	125.87	53.61	22.98	58.94	127.21
30	16.65	20.65	55.61	210.46	27.31	27.97	59.27	50.95	15.32	29.97	14.99	54.28
32	4.00	9.66	9.99	27.64	4.66	11.32	19.31	5.33	5.66	11.32	5.99	9.32
34	5.33	5.99	1.67	23.31	2.00	1.67	2.33	4.66	1.00	3.66	0.67	2.33
36	1.33	1.67	1.33	22.98	0.33				0.67	1.00		
38		1.67	0.33	0.67								
Sum	67.61	105.90	183.49	1,113.57	210.46	143.19	233.10	383.96	263.75	203.13	247.41	386.95

Estimation of the Growth Parameters

The parameters of growth L_∞ and K were estimated by the ELEFAN I program using starting values of L_∞ and K obtained from the Wetherall (1986) method and Pauly and Munro's (1984) empirical relationship for L_∞ and K, i.e.,

$$\phi' = \log_{10} K + 2\log_{10} L_\infty \quad ...3)$$

A mean value of ϕ' was derived from the the available set of parameter values (L_∞, K) obtained in other growth studies of *P. merguiensis* (Table 7). Each set of ($L_{\infty i}$, K_i) is associated with a ϕ' value.

Table 7. Growth parameters and mortality rate estimates in *Penaeus merguiensis.*[a]

Year	Growth parameters L_∞ (CL, mm)	K ($year^{-1}$)	ϕ'[b]	Mortality rates ($year^{-1}$) Z	M	F
1969	49.0	1.625	3.591	2.71	2.16	0.55
1974	52.0	1.750	3.675	8.62	1.81	6.81
1975	50.2	1.650	3.619	8.56	2.16	6.40
1976	49.9	1.425	3.550	10.96	1.97	8.99
1977	50.2	1.650	3.619	8.79	2.17	6.22
1978	50.1	1.650	3.617	8.41	2.17	8.99
1979	50.0	1.400	3.544	7.47	1.95	5.52
1980	50.4	1.875	3.678	8.01	2.35	5.66
1981	50.0	1.475	3.567	7.93	2.01	5.92
1982	29.4 ( )	7.07	3.786	3.41	–	–
	35.3 ( )	6.03	3.876	2.81	–	–

[a]All data from Naamin (1984b), except 1982, which stem from Gwyther (1982), and pertains to a stock from the Gulf of Papua.

[b]$\phi' = \log_{10} K + 2 \log_{10} L_\infty$ (see text).

Estimation of Mortality Parameters

With a value of L_∞ and K, Z was obtained from catch curve analysis, while natural mortality was approximated using Pauly's empirical formula. Finally, an estimation of fishing mortalities for each length class was performed based on cohort analysis.

Results

The data for analysis were obtained from the whole length-frequency data, from raised to total commercial landings (Table 5); these were pooled into two parts, i.e., 1977-1979 for trawl fisheries and 1982-1984 for trammel net fisheries with 2 mm carapace length class intervals of each sex.

Growth

First, L_∞ and K were estimated by the ELEFAN I program for the 1977-1979 and the 1982-1984 data sets, separately for each sex. The estimates are given in Table 8. L_∞ and K deviate less than 10% by sex and data for the two time periods were therefore pooled and L_∞ and K reestimated. The results are shown in Table 8. Fig. 3 show the restructured length frequencies and the estimated growth curves. The fit is not convincing, and obviously several peaks (possibly belonging to an extra cohort) are left unexplained. Even so the values L_∞ = 51.5 mm (female), 44.5 mm (male) and K = 1.05 $year^{-1}$ (female), 1.31 $year^{-1}$ (male) are accepted for use in the subsequent analysis.

Table 8. Estimates of growth and mortality parameters for *P. merguiensis* in the south coast of Java. (Growth was estimated by ELEFAN I. Length-converted catch curves, L_∞ and K for 1977-1984 were used for obtaining Z. M was calculated using Pauly's formula with temperature set at 29°C.)

Period	Sex	L_∞ (CL, mm)	K ($year^{-1}$)	Z ($year^{-1}$)	M ($year^{-1}$)
1977-1979	females	53.1	1.15	4.5	–
	males	43.8	1.60	11.1	–
1982-1984	females	53.2	0.90	4.9	–
	males	42.4	1.50	9.5	–
1977-1984	females	51.5	1.05	–	3.1
	males	44.5	1.31	–	3.7
Average		–	–	–	3.4

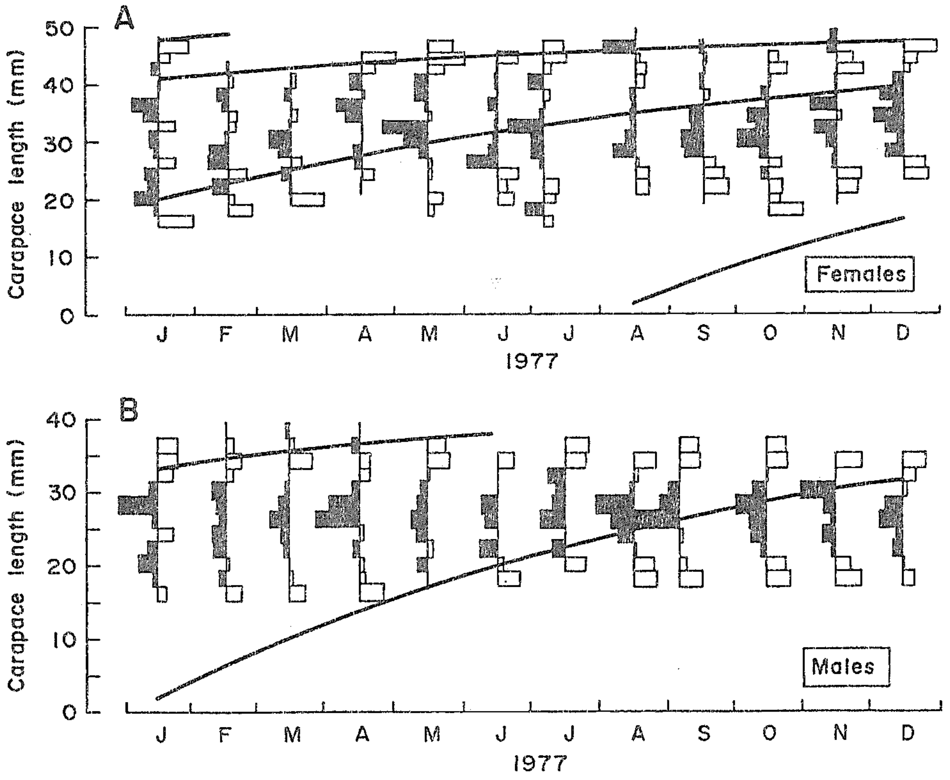

Fig. 3. Restructured length-frequency data for *Penaeus merguiensis* caught off Cilacap, 1977-1984, with superimposed growth curves filled by CIEM (see text).

Mortality estimates

Length-converted catch curve analyses are presented in Fig. 4 for the periods 1977-1979 and 1982-1984 for each sex. The estimated total mortalities are given in Table 8. These total mortalities refer to the largest specimen only. The resultant curve is the difference between the backprojected catches for small size shrimp given that mortality for those fully recruited stock applies and given the actual observed catch by length group. These resultant curves highlight differences in length of first capture. The curves are presented in Table 9 for the two time periods and both sexes. Any change before and after the trawl ban is not evident. This means that the resultant curve is mainly dependent on recruitment to the fishing grounds rather than the selectivity properties of the gear. The cod end in the trawls had a mesh size (stretched) of 2 cm while trammel nets had a mesh size of 4 cm, but selection was probably not very efficient in either of the gears. The total mortality differed markedly between sexes, Z = 4.5-5 $year^{-1}$ (female) and about 10 $year^{-1}$ (male).

A more detailed study of the mortality variation with length was attempted through cohort analysis. This was done separately for each period and for each sex. The necessary input parameters for growth were taken from Table 8, period 1977-1984. The natural mortality was calculated from Pauly's empirical formula using an average annual water temperature of 29°C and L_∞ in mm carapace length.

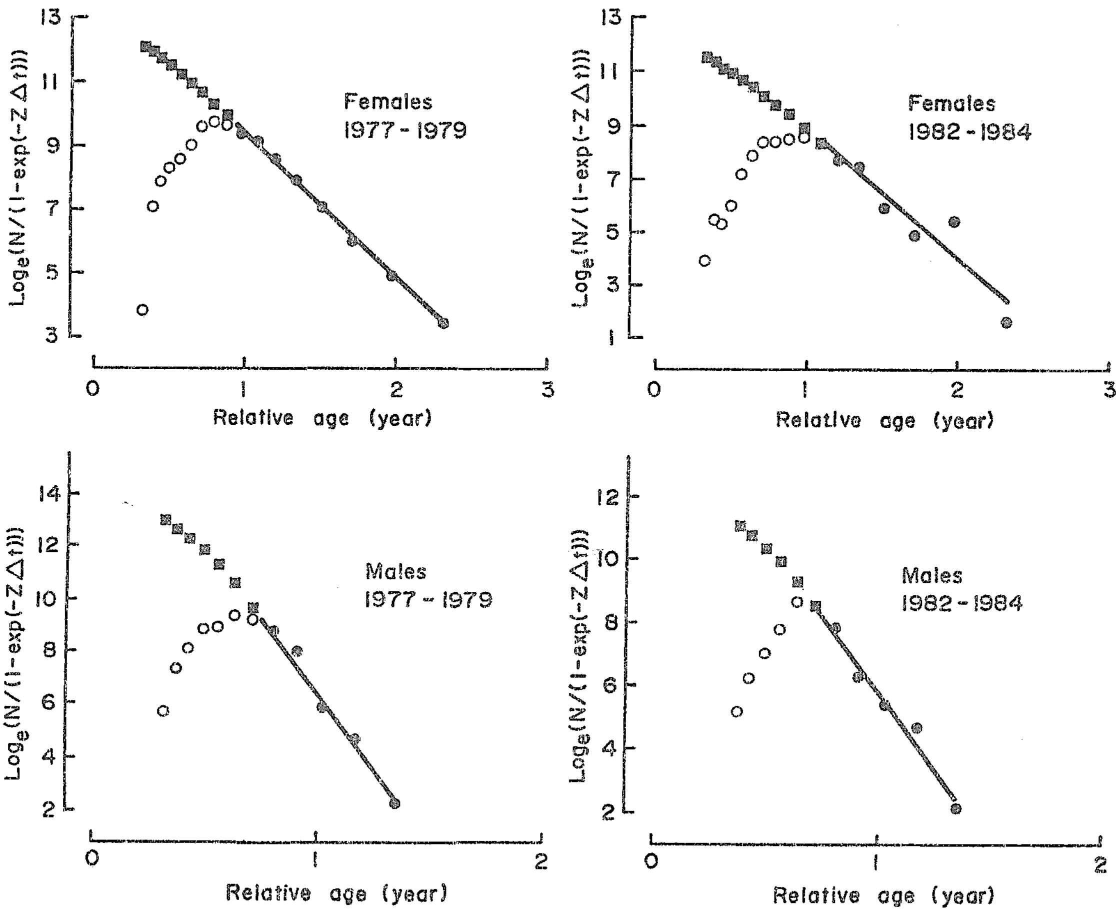

Fig. 4. Catch curve analysis of *P. merguiensis* by sex in the Cilacap commercial trawl fishery (1977-1979) and the trammel net fishery (1982-1984). L_∞ = 44.5 cm and n = 1.31 $year^{-1}$ for males and L_∞ = 5.15 and n = 1.05 $year^{-1}$ for females.

Table 9. Statistics of resultant curves derived from the left-hand side of length-converted catch curves for *Penaeus merguiensis* sampled off Cilacap.

Sex	Time period	a[a]	Statistics of resultant (selection x recruitment) curve b[a]	L_{25}	L_{50}	L_{75}
females	1977-1979	−15.0	0.518	26.9	29.0	31.1
males	1977-1979	−16.9	0.614	25.4	27.2	29.0
females	1982-1984	−14.6	0.452	29.8	32.2	34.7
males	1982-1984	−18.9	0.716	24.9	26.4	27.9

[a]Based on linearized logistic curve and leading to probabilities of capture (P) defined by $P = 1/(1 + \exp(-b(L_P - L_{50})))$.

The calculated natural mortalities are shown in Table 8. A joint value of 3.4 $year^{-1}$ was used in the cohort runs. The terminal fishing mortality was chosen as 1.448 and 1.826 for females and 7.458 and 5.83 for males so as to correspond with Z estimates from the catch curve analysis. The estimated F-at-lengths are plotted against length in Fig. 5. The results do not show any differences in the lower size range between trawl and trammel net fishery. The actual length compositions (Fig. 2) did not show such differences either.

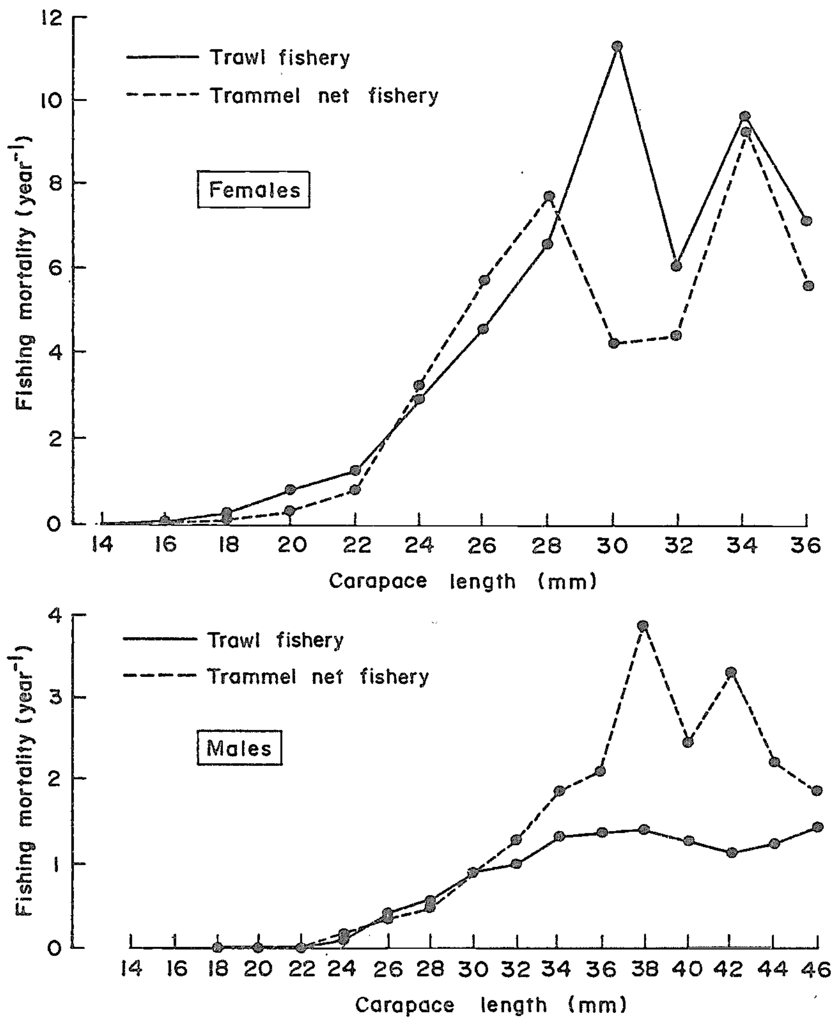

Fig. 5. Relationship between fishing mortality ($year^{-1}$) and length in *Penaeus merguiensis* caught off Cilacap, as obtained by length-structured VPA (see text).

The lack of change in the length compositions was not surprising since both trawl and trammel nets would catch prawns of even small sizes without selectivity. The observed length compositions thus reflected the composition in the stock.

The second result, that the fishing mortality levels have remained constant or have increased, was very surprising since total catch (Table 1) has dropped drastically. Such a situation is only possible if recruitment has changed. Cohort analysis provides an estimate stock-in-number. Table 10 shows the estimated stock in number by sex before and after the trawl ban. Apparently there was a remarkable drop in recruitment level with a factor of 3-4. Also, the sex ratio seemed rather odd. The sex ratio in the catches was about 1.3:1, in general agreement with the biology of the species. The large difference in calculated stock size between males and females is a result of the assumption of natural mortality M = 3.4 $year^{-1}$. Catch-curve analysis (Table 8) yielded Z estimate of 4.5-5.0 $year^{-1}$ for females and around 10 $year^{-1}$ for males. The gear efficiency was dependent on the behavior of the shrimp and there could have been marked differences between sexes. However, at least to illustrate the effect of differentiation in natural mortality, a possible difference in fishing mortality between males and females of the same size was ignored. Using females as the group and looking at the abundant size classes 30-35 mm CL suggested an F around 1 (Fig. 5) which in turn implied M = 8-9 $year^{-1}$ for males. This tipped the sex ratio into an equally unrealistic male dominance. M = 6.5 $year^{-1}$ for females would more or less give a sex ratio of 1:1 in the stock with F = 2-3 $year^{-1}$. This modified stock is shown in Table 10e and 10f. The drop in recruitment was evident, corresponding to the drop in the catches.

The analysis will be taken no further since MSY and Y/R considerations are based on an assumption of constant recruitment which was obviously not met in this case.

Table 10a. Length groups of females of *P. merguiensis* converted into catches. population and F. 1977-1979.

Length class (mm)	Catches (in 000.000)	Population (in 000.000)	F. Mortality
47.00-49.00	9.66	32.34	1.4480
45.00-47.00	36.96	166.97	1.2869
43.00-45.00	93.57	535.12	1.1587
41.00-43.00	237.10	1.383.29	1.3192
39.00-41.00	511.51	3.094.73	1.4494
37.00-39.00	875.46	6,098.29	1.3987
35.00-37.00	1.374.64	10.939.07	1.3484
33.00-35.00	1.585.75	17.735.35	1.0347
31.00-33.00	1,953.05	27.018.67	0.9059
29.00-31.00	1.934.06	38.760.62	0.6705
27.00-29.00	1.484.18	52,764.70	0.4031
25.00-27.00	794.88	68.929.32	0.1758
23.00-25.00	479.18	87.779.53	0.0887
21.00-23.00	352.32	109.730.40	0.0555
19.00-21.00	213.79	135.022.50	0.0290
17.00-19.00	89.92	163.927.00	0.0106
15.00-17.00	3.33	196.746.50	0.0003

Total catch : 12.029.36 Natural mortality : 3.4 K : 1.05
Mean E : 0.0611 Term. F. mortality : 1.448 L_{∞} : 51.5
Mean F : 0.2214

Table 10b. Length groups of females of *P. merguiensis* converted into catches. population and F. 1982-1984.

Length class (mm)	Catches (in 000.000)	Population (in 000.000)	F. Mortality
47.00-49.00	0.67	1.92	1.8260
45.00-47.00	4.67	13.74	2.2223
43.00-45.00	31.98	77.80	3.3875
41.00-43.00	75.27	255.28	2.5041
39.00-41.00	321.03	856.77	3.8918
37.00-39.00	388.29	1.868.70	2.1169
35.00-37.00	598.40	3.566.07	1.8513
33.00-35.00	708.62	6.009.19	1.3891
31.00-33.00	618.39	9.103.90	0.8491
29.00-31.00	528.80	12.918.38	0.5472
27.00-29.00	491.84	17.582.53	0.4008
25.00-27.00	276.74	22.982.42	0.1837
23.00-25.00	125.89	29.229.44	0.0699
21.00-23.00	36.63	36.448.93	0.0173
19.00-21.00	17.32	44.790.77	0.0071
17.00-19.00	19.32	54.367.64	0.0069
15.00-17.00	4.00	65.255.62	0.0012

Total catch : 4.247.86 Natural mortality : 3.4 K : 1.05
Mean E : 0.0651 Term. F. mortality : 1.826 L_{∞} : 51.5
Mean F : 0.2367

Table 10c. Length groups of males of *P. merguiensis* converted into catches, population and F. 1977-1979.

Length class (mm)	Catches (in 000,000)	Population (in 000,000)	F. Mortality
37.00-39.00	3.00	4.37	7.4580
35.00-37.00	32.63	48.19	9.9057
33.00-35.00	94.25	194.43	6.1640
31.00-33.00	775.23	1,199.54	11.4662
29.00-31.00	1,509.16	3,475.87	6.6884
27.00-29.00	2,282.38	7,393.14	4.7465
25.00-27.00	2,423.92	12,554.66	3.0104
23.00-25.00	1,488.19	17,856.81	1.3267
21.00-23.00	1,313.99	23,963.52	0.9322
19.00-21.00	541.44	30,222.77	0.3220
17.00-19.00	255.75	37,047.43	0.1324
15.00-17.00	44.29	44,500.38	0.0203

Total catch : 10,764.23 Natural mortality : 3.4 K : 1.31
Mean E : 0.2419 Term. F. mortality : 7.458 L_∞ : 44.5
Mean F : 1.0848

Table 10d. Length groups of males of *P. merguiensis* converted into catches, population and F, 1982-1984.

Length class (mm)	Catches (in 000,000)	Population (in 000,000)	F. Mortality
37.00-39.00	2.67	4.23	5.8300
35.00-37.00	29.31	43.94	9.5751
33.00-35.00	54.62	139.60	4.5255
31.00-33.00	124.20	360.73	4.3564
29.00-31.00	583.43	1,193.74	7.9478
27.00-29.00	1,025.98	2,815.00	5.8600
25.00-27.00	1,026.66	4,897.92	3.3047
23.00-25.00	414.92	6,779.55	0.9618
21.00-23.00	175.83	8,736.87	0.3356
19.00-21.00	79.59	10,888.26	0.1306
17.00-19.00	25.31	13,273.37	0.0365

Total catch : 3,542.52 Natural mortality : 3.4 K : 1.31
Mean E : 0.2669 Term. F. mortality : 5.83 L_∞ : 44.5
Mean F : 1.2378

Table 10e. Length groups of males of *P. merguiensis* converted into catches, population and F, 1977-1979.

Length class (mm)	Catches (in 000,000)	Population (in 000.000)	F. Mortality
37.00-39.00	3.00	9.50	3.0000
35.00-37.00	32.63	81.38	5.4030
33.00-35.00	94.25	350.29	3.5077
31.00-33.00	775.23	1,840.03	7.0523
29.00-31.00	1.509.16	5,685.87	4.1981
27.00-29.00	2.282.38	13,382.94	2.7399
25.00-27.00	2,423.92	26,009.91	1.5442
23.00-25.00	1,488.19	44,096.48	0.5828
21.00-23.00	1.313.99	70,184.73	0.3447
19.00-21.00	541.44	105,915.24	0.1000
17.00-19.00	255.75	154,359.36	0.0345
15.00-17.00	44.29	218,735.94	0.0045

Total catch : 10,764.23 Natural mortality : 6.5 K : 1.31
Mean E : 0.049 Term. F. mortality : 3 L_∞ : 44.5
Mean F : 0.336

Table 10f. Length groups of males of *P. merguiensis* converted into catches, population and F, 1982-1984.

Length class (mm)	Catches (in 000,000)	Population (in 000,000)	F. Mortality
37.00-39.00	2.67	8.46	3.0000
35.00-37.00	29.31	72.83	5.4333
33.00-35.00	54.62	270.15	2.4880
31.00-33.00	124.20	775.65	2.1172
29.00-31.00	583.43	2,327.03	3.9179
27.00-29.00	1,025.98	5,596.52	2.9725
25.00-27.00	1,026.66	10,893.55	1.5627
23.00-25.00	414.92	18,206.47	0.3910
21.00-23.00	175.83	28,524.71	0.1127
19.00-21.00	79.59	42,875.64	0.0362
17.00-19.00	25.31	62,392.56	0.0084

Total catch : 3,542.52	Natural mortality : 6.5	K : 1.31
Mean E : 0.057	Term. F. mortality : 3	L_∞ : 44.5
Mean F : 0.391		

Discussion

Growth parameters seem not to have been influenced by the trawl ban and L_∞ and K could be obtained although the fit to the restructured length frequencies is not very good. The estimates found here compare reasonably well with other estimates (Table 7). However, these estimates do not distinguish between sex and the L_∞ obtained is in this case probably that of the females.

Cohort analysis assumes among other things that total mortality is composed of a constant natural mortality (M), e.g., due to predation, and of a fishing mortality which varies with length. This interpretation is doubtful in this case. The fisheries represented by these data are only the commercial component while the artisanal fisheries are not documented. The commercial fisheries - trawl in 1977-1979 and trammel net in 1982-1984 - do not operate much outside the 30 m depth contour but the number of banana prawn occurring in deeper water where the grounds are not trawlable is probably low, as prawn prefer sandy and muddy bottom for their habitat. The artisanal fisheries which exploit the coastal zone 0-7 mm is a part of the exploitation which is not documented. These artisanal fisheries probably exploit smaller size banana prawn, i.e., they influence the recruitment to 20-30 m fishing grounds, from which the data analyzed in this paper originate.

The large observed difference in total mortality between males and females could be a result of differences in migration or behavior. Either males are more vulnerable to the fishery than females of the same size, or there is a difference in the natural mortality, which is likely given the observed sex-specific differences in growth parameters.

The observed change in recruitment could have been caused by an increased fishing pressure in the artisanal fisheries as by changed environmental conditions, e.g., the situation of Segara Anakan lagoon. This is related to the impact the trawl fishery had on the demersal fish biomass.

Another possible cause of change in recruitment is related to the impact the trawl fishery had on the demersal fish biomass. Shrimp is an important part of the diet of demersal fish and the trawl ban would be expected to lead to increased fish biomass and hence to increased predation which in turn may lead to a reduced shrimp stock. Such effects have also been postulated for the Gulf of Thailand (Pauly and Neal 1985). Either possibility will need new data for a discussion outside idle speculations.

Acknowledgements

The author wishes to thank Dr. Nurzali Naamin, Director of the Research Institute for Marine Fisheries, Jakarta, Indonesia, for allowing the use of his data on *Penaeus merguiensis* from Cilacap and adjacent waters from 1977 to 1979 and also for his permission to let him attend the FAO/DANIDA course. Thanks particularly go to Mr. Suprapto of the Cilacap Fishery Service for his valuable help in the data collection.

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Growth, Mortality and Exploitation Rates of *Penaeus indicus* in Manila Bay, Philippines and Southeast India

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Abstract

Analysis on the growth, mortality and exploitation rate of *Penaeus indicus* stocks in Manila Bay (Philippines) and Punnaikkayal and Manappad (Tamil Nadu, India) were undertaken.

Results showed that the stocks in these areas are similar with regard to their growth parameters. Relatively high values of total mortality and exploitation rates were obtained which indicate that these stocks are overexploited. Manila Bay and Manappad stocks exhibit one main recruitment pulse per year, while Punnaikkayal stock shows two recruitment pulses per year.

Introduction

Although shrimps greatly contribute to the economy of the Philippines only a very limited number of studies are available. Those that have been conducted (Tiews et al. 1968; del Mundo et al. 1982) concentrated mainly on seasonal distribution, relative abundance and some biological aspects such as sex ratio, maturity stages and feeding habits. So far no studies have been published in the Philippines based on quantitative assessment of shrimp resources, despite their obvious importance. In India, studies on *P. indicus* have been reported upon by Brusher (1972), Devi (1986), Mohamed (1971), Rao (1967) and others.

This paper deals with estimating the growth, mortality, recruitment pattern and exploitation rate of *Penaeus indicus* stocks in Manila Bay-Bataan/Bulacan area (Philippines) using original size-frequency data, and Manappad and Punnaikkayal (southeast India) using the size-frequency data of Manisseri and Manimaran (1981).

The Manila Bay-Bataan/Bulacan area is one of the richest fishing grounds in the Philippines (Fig. 1). The most important among its resources are shrimp, of which the white shrimp species *Penaeus indicus* and *P. merguiensis* are the major ones.

Manappad and Punnaikkayal are two major prawn grounds off Tinnevelly Coast (Tamil Nadu), of which the former has a rich seasonal shrimp fishery dominated by *P. indicus*, while the latter has a year-round fishery dominated by *Penaeus semisulcatus*, but also including *P. indicus*.

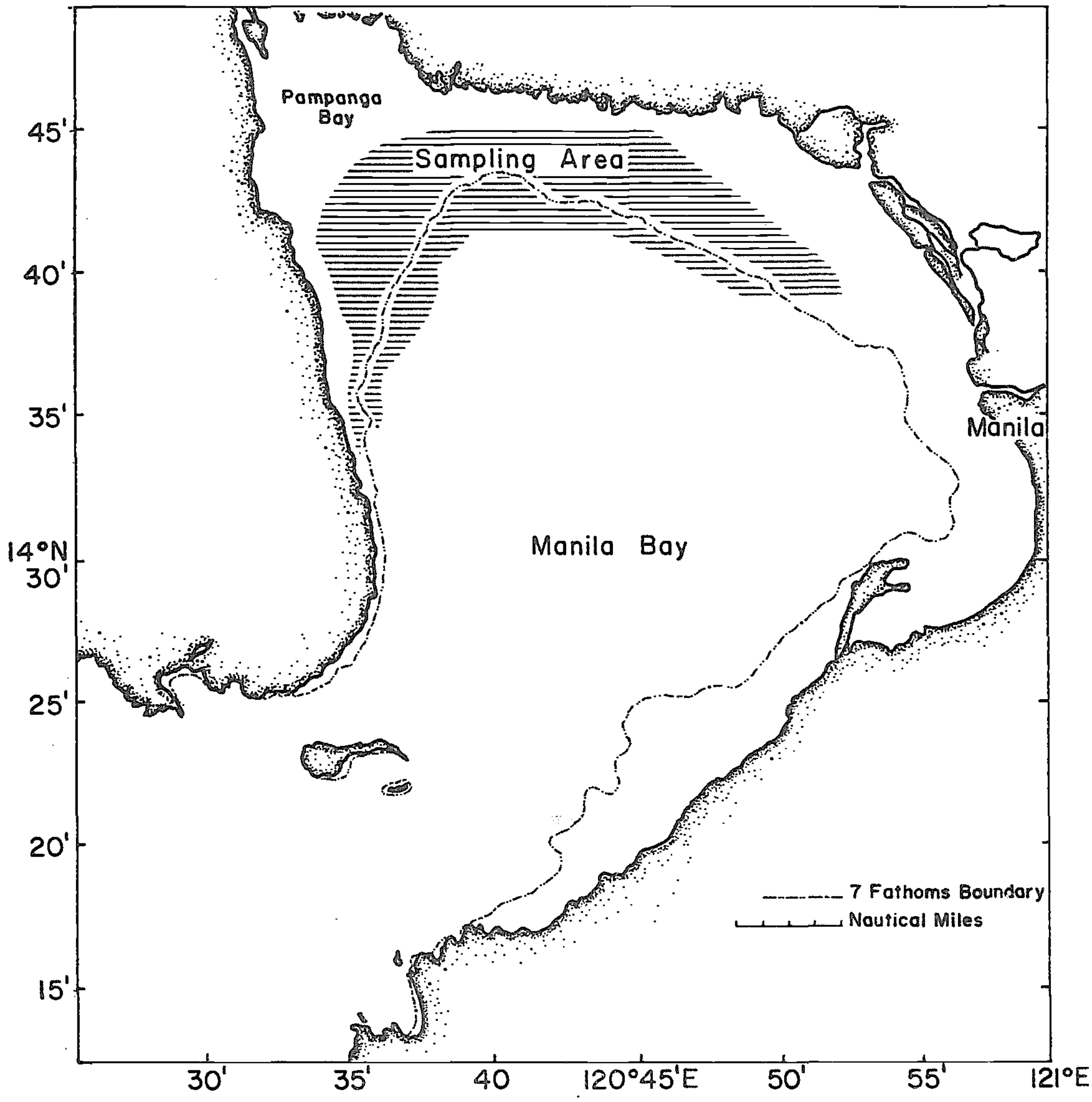

Fig. 1. Map of Manila Bay, Philippines showing sampling area of data in Table 1 and 4 and Fig. 6.

Materials and Methods

Materials

Manila Bay-Bataan/Bulacan area (Philippines)

Samples were collected on board a commercial push netter operating in the Manila Bay-Bataan/Bulacan area from February to December 1982. The total catch for every haul was sorted to determine the weight of every species. All shrimp species were sampled but only data on *P. indicus* were used for this paper.

A total of 1,937 females and 1,251 males were sampled (Table 1); their carapace length was measured in millimeter and grouped in 2 mm length classes. Other samples were brought to the laboratory and their carapace length and total body weight were measured for length-weight analysis by sex. Maturity stages and stomach contents were also recorded.

Table 1. Length-frequency data of female and male *Penaeus indicus* in Manila Bay from pushnet catches, 1982.

Midlength (CL, mm)		M	A	M	J	J	A	S	O	N	D
10	Female	-	1	1	-	-	-	-	-	-	-
	Male	-	-	-	-	-	-	-	-	-	-
12	Female	-	1	1	-	-	1	-	-	-	-
	Male	4	-	-	-	-	-	1	-	-	-
14	Female	-	20	27	-	-	1	-	-	1	1
	Male	-	-	2	-	-	-	-	-	-	2
16	Female	6	89	49	1	8	10	2	5	1	3
	Male	9	2	3	-	-	-	-	-	-	1
18	Female	32	112	111	7	19	8	10	9	15	21
	Male	36	22	11	-	2	-	-	-	10	10
20	Female	39	70	129	11	89	35	14	12	16	27
	Male	95	61	28	4	34	7	18	5	22	10
22	Female	56	38	92	8	49	33	13	2	13	12
	Male	131	52	47	2	40	10	19	3	18	7
24	Female	47	27	103	20	42	17	7	1	13	-
	Male	123	8	50	19	20	6	13	1	3	2
26	Female	53	12	57	13	39	8	3	-	9	-
	Male	95	2	33	20	19	3	2	-	1	1
28	Female	23	1	25	9	5	2	-	-	2	-
	Male	19	-	10	15	1	-	-	-	-	-
30	Female	7	2	16	8	6	-	-	-	-	-
	Male	9	-	11	11	1	-	-	-	-	-
32	Female	2	-	9	2	2	-	-	-	-	-
	Male	4	-	3	1	-	-	-	-	-	-
34	Female	4	-	2	2	1	-	-	-	-	-
	Male	5	-	1	2	-	-	-	-	-	-
36	Female	1	-	-	2	-	-	-	-	-	-
	Male	2	-	1	3	-	-	-	-	-	-
38	Female	2	-	-	-	-	-	-	-	-	-
	Male	2	-	1	1	-	-	-	-	-	-
Sum	(Female)	272	373	622	83	260	115	49	29	70	64
Sum	(Male)	534	147	201	77	117	26	53	9	54	33

Tinevelly Coast (India)

Manisseri and Manimaran (1981) took samples from the landed catch of trawlers operating at the Manappad and Punnaikkayal prawn grounds, off the Tinevelly Coast (Tamil Nadu India) on June-October 1978 and February-December 1978, respectively. They presented their data graphs in the form of % length-frequency distributions, grouped in 5 mm length classes. The data used here were extracted from their figures (3 and 4), reproduced here as Tables 2 and 3.

Methods

Initial values of L_∞ for all stocks were obtained by plotting $\overline{L}$ - L' on L' (Wetherall 1986 as modified by Pauly 1986a), i.e.,

$$\overline{L} - L' = a + bL'$$

where $L_\infty = a/-b$

and $Z/K = (1 + b)/-b$

$\overline{L}$ is defined here as the mean length, computed from L' upward, in a given length-frequency sample, while L' is the limit of the first length class used in computing a value of $\overline{L}$.

The values obtained were used to facilitate the estimation of the parameters L_∞ and K of the von Bertalanffy growth formula through the ELEFAN I program (Pauly 1982).

Length-converted catch curves, based on pooling of % samples were used to estimate total mortality (Pauly 1982).

M values were obtained using Pauly's empirical equation

$$\log_{10}M = -0.0066 - 0.279 \log_{10}L_\infty + 0.6543\log_{10}K + 0.4634\log_{10}T$$

where L_∞ is the asymptotic length in cm, K is put on an annual basis and T is the mean annual temperature (Pauly 1982), set at 27°C in Manila Bay and 25°C in southeast India.

Fishing mortality F was then computed as

$$F = Z - M$$

while exploitation rate, i.e., the ratio of fishing mortality to total mortality, was computed from

$$E = F/Z$$

In the present contribution, if $M \leq F$ (i.e., if $E > 0.5$) then the stock is considered overexploited, as suggested by Gulland (1971).

Recruitment patterns were obtained using the appropriate routine of ELEFAN II program. Since length-frequency data alone do not allow the estimation of t_0, the abscissa of recruitment patterns is not fixed in real time, and is therefore labelled "1 year" (Pauly 1982).

To convert total length (TL) to carapace length (CL) and vice versa, use was made of the relationship derived by Rao (1967) for a *P. indicus* stock from Chilka Lake and Golpapur (India), i.e.,

$$CL = -0.3806 + (0.1986 \times TL)$$, Chilka Lake
$$CL = -0.4044 + (0.2005 \times TL)$$, Golpapur Backwaters.

For any conversion, the mean of the two CL estimates was taken. The inverse form of these equations were used for conversion from CL to TL.

Weight measurements of *P. indicus* in Manila Bay (Table 4) were used to estimate the mean value of "a" in the equation

$$W = a \cdot L^3$$

which was subsequently used to turn our estimates of CL_∞ into estimates of W_∞ (see Table 5).

The growth performance of shrimp in terms of length growth were compared using the formula of Pauly and Munro (1984)

$$\phi' = \log_{10}K + 2 \log_{10} L_\infty$$

where K is the growth constant (yr^{-1}) and L_∞ is the asymptotic length (TL, cm).

Results

The length-frequency data of *P. indicus* in different areas (Tables 1-3) were used to estimate the growth, mortality and exploitation rates for females and males, respectively. The data were also pooled for additional analysis. The data were not raised to the catch because the latter were not available for *P. indicus* separately.

Table 2. Length-frequency data of female and male *Penaeus indicus* in Punnaikkayal, India. 1978.[a]

Midlength (TL, mm)		F	M	A	M	J	J	A	S	O	N	D
100.5	Female	-	-	-	-	-	-	-	-	-	-	-
	Male	2.75	-	-	-	-	-	-	-	-	-	-
110.5	Female	9.01	-	1.10	1.25	3.75	-	-	-	-	1.05	3.75
	Male	9.25	-	-	-	4.50	-	-	1.00	-	7.95	10.25
120.5	Female	2.15	1.65	-	7.55	5.10	-	-	1.05	-	18.44	34.50
	Male	19.50	17.05	2.25	1.65	16.60	-	-	1.01	1.50	6.25	39.98
130.5	Female	18.25	2.75	-	19.15	9.05	-	-	1.25	10.85	31.10	32.99
	Male	19.50	15.70	2.45	19.15	19.10	-	6.75	-	9.95	38.55	34.01
140.5	Female	24.10	7.25	2.25	19.95	17.75	1.50	6.10	6.30	20.01	26.10	20.01
	Male	40.00	19.50	21.05	39.65	35.55	20.50	19.25	4.40	37.75	17.25	7.81
150.5	Female	24.70	19.95	36.10	18.10	29.25	18.60	9.35	17.65	20.01	7.25	1.75
	Male	6.75	40.20	40.10	28.25	20.50	47.75	6.50	20.05	20.05	17.50	2.65
160.5	Female	17.50	38.60	29.05	8.55	27.15	27.50	3.65	8.05	17.95	14.41	1.75
	Male	2.25	6.05	22.90	9.50	4.75	29.25	41.10	19.85	9.25	6.25	3.65
170.5	Female	-	19.25	28.20	18.01	6.20	39.45	19.60	8.75	3.75	-	1.75
	Male	-	-	11.25	0.90	-	2.50	21.40	31.55	10.50	-	2.65
180.5	Female	2.15	7.25	1.10	7.45	1.75	8.75	37.70	26.10	2.50	1.65	1.75
	Male	-	1.50	-	0.90	-	-	-	17.50	9.50	6.25	-
190.5	Female	2.15	1.65	1.10	-	-	2.10	20.15	26.10	8.25	-	1.75
	Male	-	-	-	-	-	-	2.25	4,65	1.5	-	-
200.5	Female	-	1.65	1.10	-	-	2.10	3.45	4.75	9.15	-	-
	Male	-	-	-	-	-	-	2.75	-	-	-	-
210.5	Female	-	-	-	-	-	-	-	-	7.53	-	-
	Male	-	-	-	-	-	-	-	-	-	-	-

[a] as read off Fig. 4 in Manisseri and Manimaran (1981); value do not add to 100%, due to difficulties with accurate interpretation of graphs.

Correction of the original data for gear selection effect (Pauly 1986b) has been tried but the growth parameters obtained from the corrected files were not credible. This is probably due to the very small mesh size (17 mm) of the push netter used in Manila Bay, which probably had caught a wide range of sizes (no mesh size information was available for the Indian data).

The TL_∞ values converted to CL_∞ values and vice versa, and W_∞ values were computed. Results of the analysis are summarized in Table 5 while growth curves, catch curves, resultant curves and recruitment patterns are illustrated in Figs. 2-5.

It was found that the stocks in Manappad and Punnaikkayal have slightly greater values of TL_∞, CL_∞ and W_∞,compared to the Manila Bay stock. Values of K differ between sexes, 1.0 for females and 1.2 for males (1.0-1.1 for the samples of males and females), but are identical for all the three areas for each sex. The computed values of ϕ' as used to compare the growth performance of the stocks, are very similar and, range from 2.64 to 2.71 with a mean of ϕ' = 2.69.

Fishing mortality and exploitation rates are relatively high indicating a high level of exploitation. It should be noted that values for female stocks in Manappad are not given because the available data are not good enough for this analysis.

The recruitment patterns obtained show that the stocks of Manila Bay and Manappad probably have only one pulse of annual recruitment, while two pulses of annual recruitment are observed on the stock of Punnaikkayal.

Table 3. Length-frequency data of male and female *Penaeus indicus*, Manappad, India 1978.[a]

Midlength TL (mm)		Jun	Jul	Aug	Sept	Oct
120.5	Male	-	1.99	-	-	1.25
	Female	-	-	-	-	-
130.5	Male	3.75	1.99	-	-	1.25
	Female	-	-	2.25	1.15	1.55
140.5	Male	18.75	9.75	6.55	10.95	1.25
	Female	5.75	0.95	10.55	1.15	2.55
150.5	Male	38.01	20.25	9.95	21.35	8.25
	Female	18.25	36.50	13.25	2.55	2.55
160.5	Male	29.75	58.25	58.15	19.50	40.35
	Female	17.25	36.15	-	1.15	1.55
170.5	Male	9.75	7.77	23.25	24.85	39.65
	Female	37.50	20.15	21.25	9.55	2.55
180.5	Male	-	-	2.10	23.35	5.50
	Female	18.01	6.25	33.15	10.75	2.75
190.5	Male	-	-	-	-	1.25
	Female	2.75	-	12.55	40.35	20.10
200.5	Male	-	-	-	-	-
	Female	0.50	-	4.50	30.85	46.15
210.5	Male	-	-	-	-	-
	Female	-	-	2.50	2.50	20.25

[a]as read off Fig. 3 in Manisseri and Manimaran (1981); values do not add to 10% due to difficulties with accurate interpretation of graphs.

Table 4. Data for establishing length-weight relationships in female and male *Penaeus indicus* from Manila Bay, Philippines.

Length (CL, mm)	Females N	Females Mean Weight (g)	Males N	Males Mean Weight (g)	Females & Males N	Females & Males Mean Weight (g)
16	1	3.00	-	-	1	3.00
17	1	3.90	2	3.53	3	3.90
18	2	4.45	1	3.70	3	4.45
19	10	5.28	9	4.94	19	5.12
20	7	5.99	5	5.79	12	5.90
21	5	6.14	8	6.62	13	6.43
22	5	6.60	6	7.38	11	7.02
23	7	8.37	2	8.08	9	8.31
24	3	9.57	3	9.20	6	9.38
25	6	9.91	-	-	6	9.91
26	1	12.20	-	-	1	12.20
29	1	16.0	-	-	1	16.00
31	2	15.98	-	-	2	15.98
35	1	2.71	-	-	1	21.70

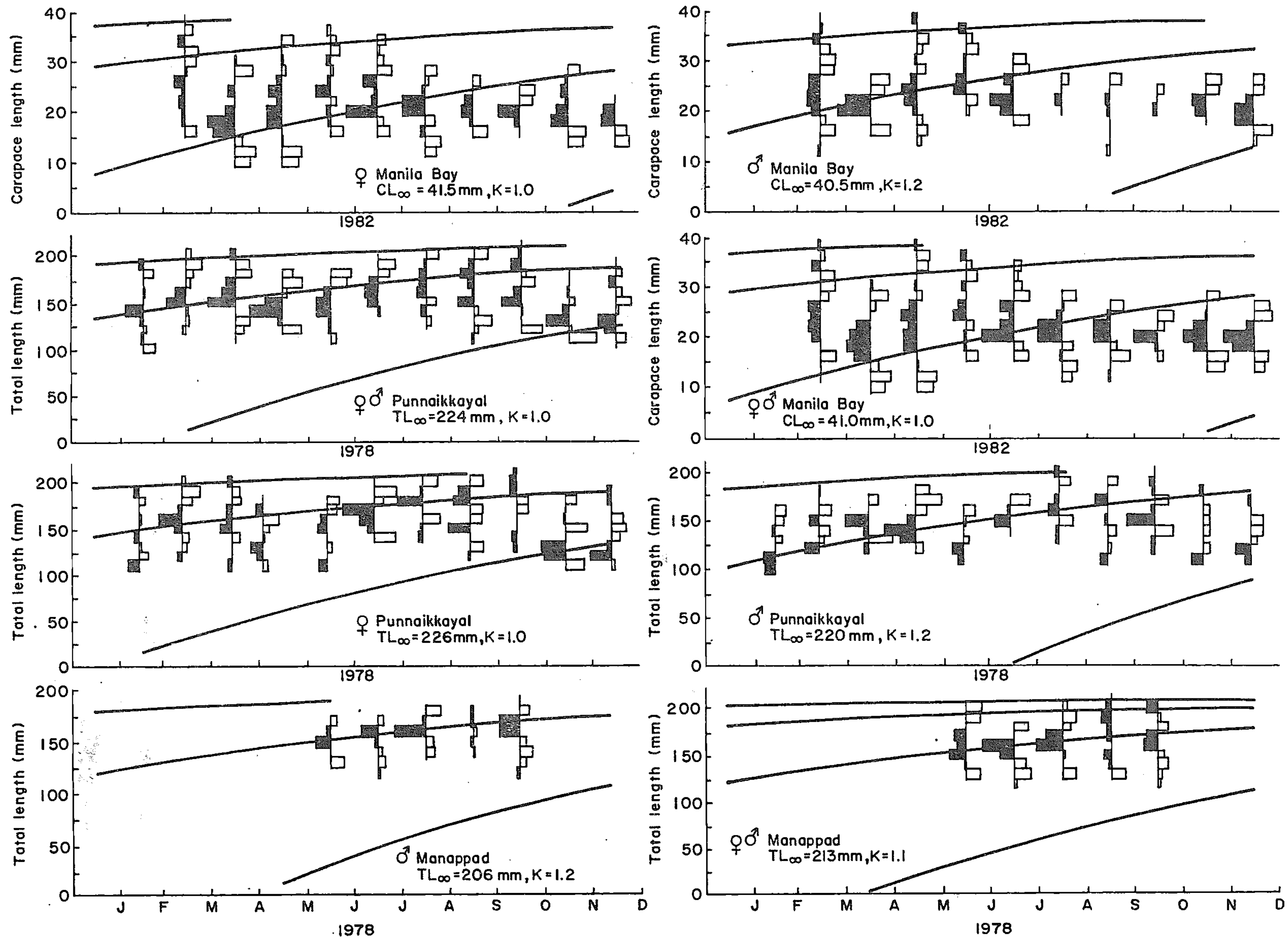

Fig 2. Restructured length-frequency data of female and male *Penaeus indicus* in Manila Bay, Philippines and two fishing grounds in Tamil Nadu, India, with growth curve as estimated using the ELEFAN I program (see also text and Table 5).

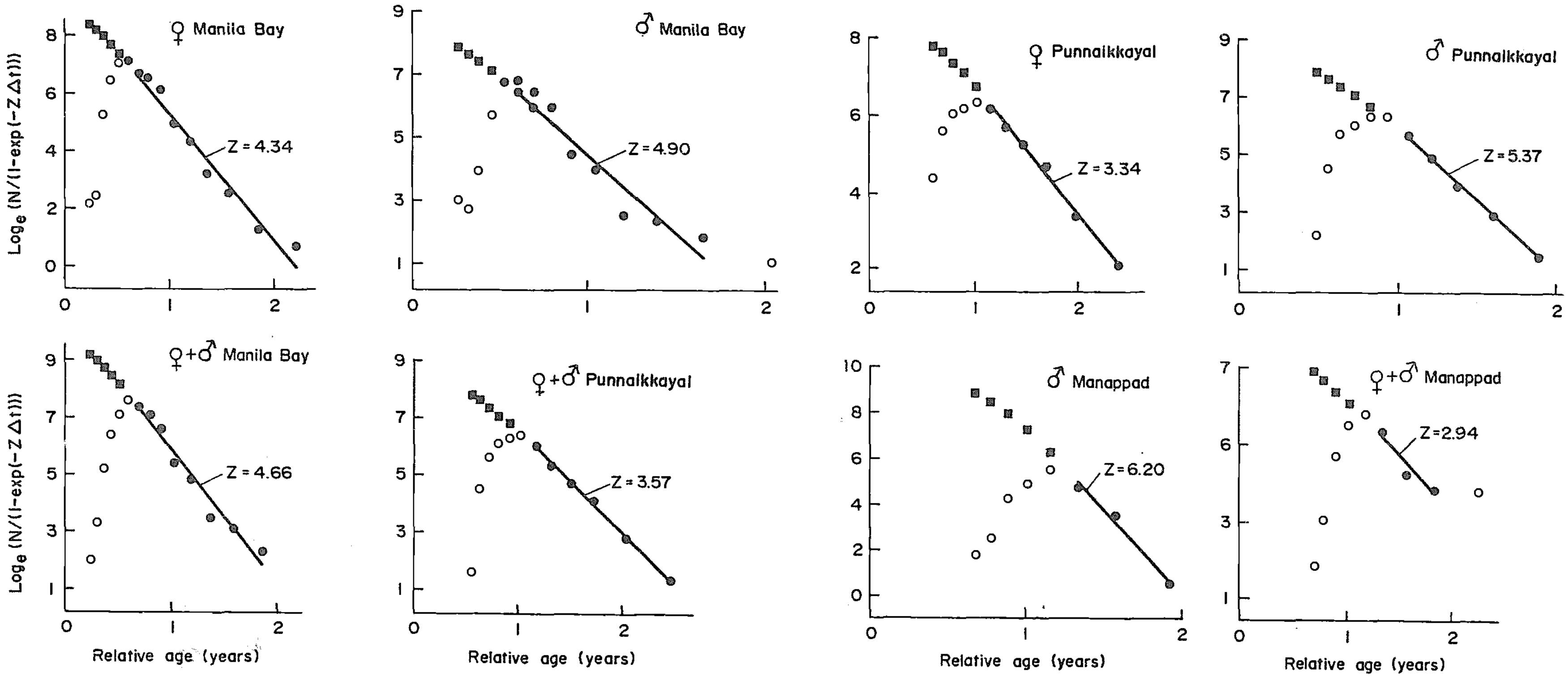

Fig. 3. Length-converted catch curves of female and male *Penaeus indicus* in Manila Bay, Philippines and two fishing grounds in Tamil Nadu, India (see also text and Table 5).

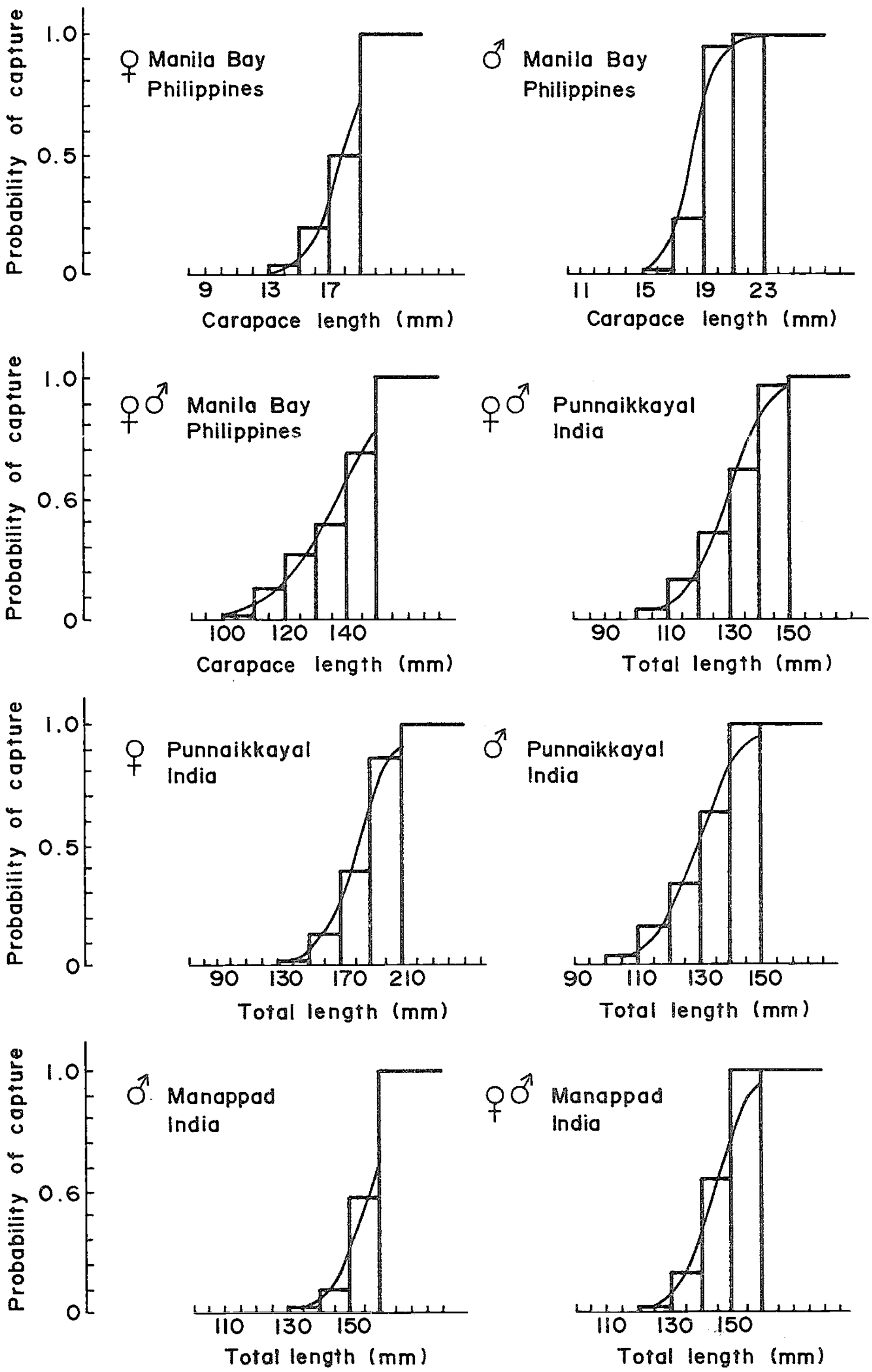

Fig. 4. Probabilities of capture, by length, for female and male *P. indicus* caught by pushnet in Manila Bay, Philippines and by trawlers on two fishing grounds in Tamil Nadu, India.

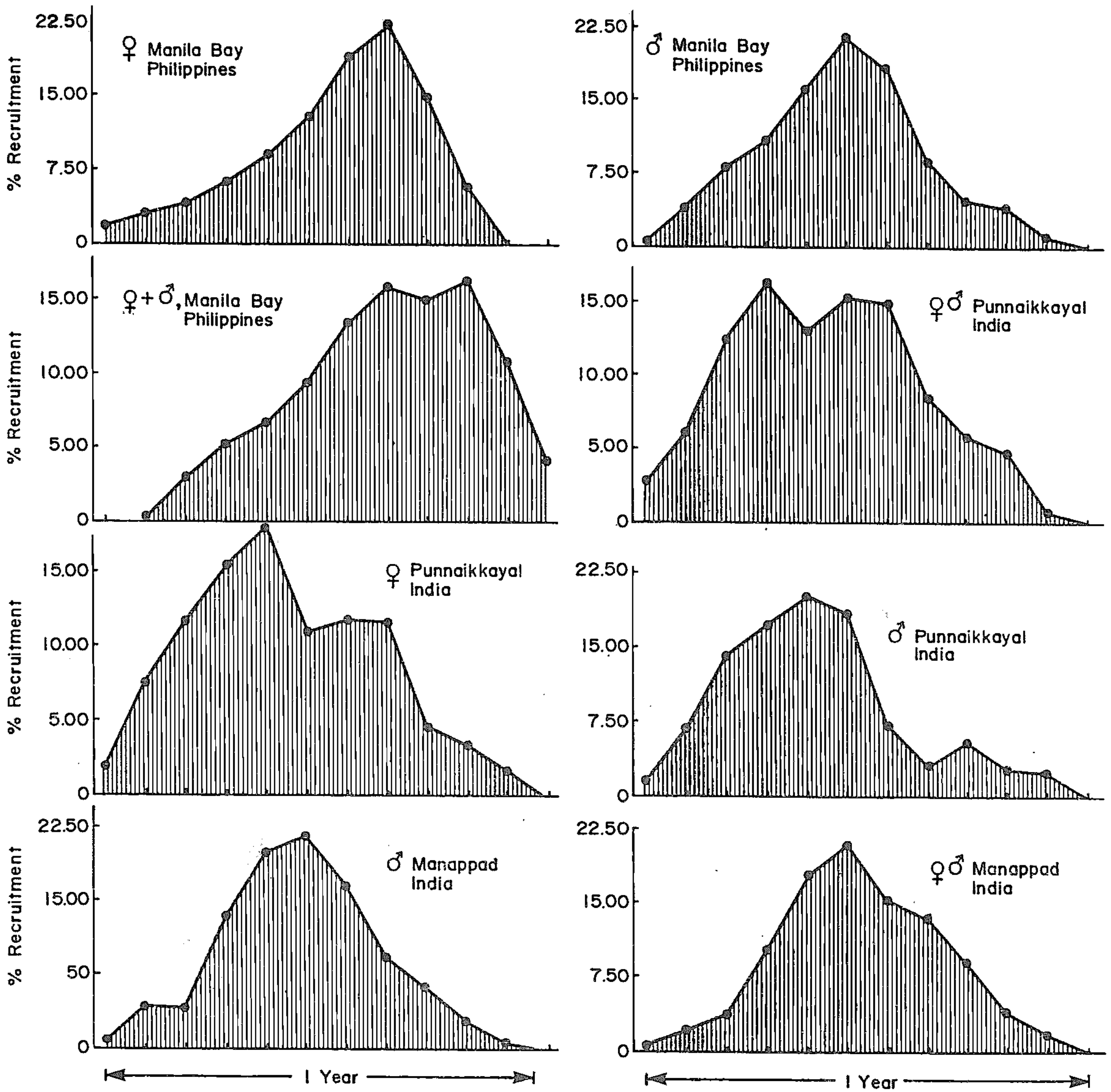

Fig. 5. Recruitment patterns of female and male *Penaeus indicus* in Manila Bay, Philippines and two fishing grounds in Tamil Nadu, India, suggesting local differences in the periodicity of recruitment (see text).

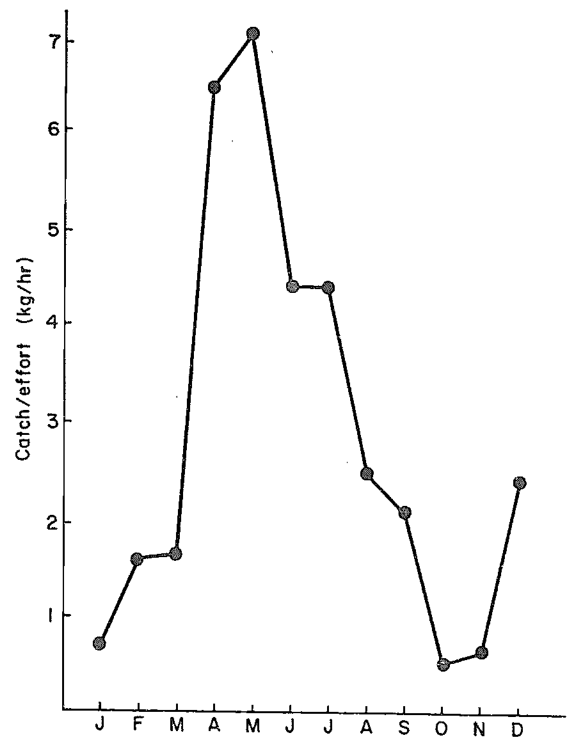

Fig. 6. Relative abundance of white shrimp in Manila Bay (1982), suggesting that annual recruitment of *P. indicus* occurs in one single major pulse.

Table 5. Growth, mortality and exploitation rate of *Penaeus indicus* in Manila Bay, Philippines and two fishing grounds in Tamil Nadu, India.

Area/year	Sex	Growth parameters CL_∞ (mm)	TL_∞ (cm)	W_∞ (g)[c]	K ($year^{-1}$)	ϕ'	Mortality ($year^{-1}$) Z	M[d]	F	Exploitation rate (F/Z)
Manila Bay, 1982	♀	41.5	21.0[b]	6.5	1.0	2.64	4.34	1.94	2.40	0.55
Manila Bay, 1982	♂	40.5	20.5[b]	6.0	1.2	2.70	4.90	2.20	2.70	0.55
Manila Bay, 1982	♀ + ♂	41.0	20.7[b]	6.3	1.0	2.63	4.66	1.95	2.71	0.58
Punnaikkayal, 1978	♀	44.7[a]	22.6	8.0	1.0	2.71	3.34	1.83	1.51	0.45
Punnaikkayal, 1978	♂	43.4[a]	22.0	7.4	1.2	2.75	5.37	2.08	3.29	0.61
Punnaikkayal, 1978	♀ + ♂	44.31[a]	22.4	7.9	1.0	2.70	3.57	1.84	1.73	0.48
Manappad, 1978	♀	42.34[a]	21.4	6.9[e]	–	–	–	–	–	–
Manappad, 1978	♂	40.70[a]	20.6	6.1	1.2	2.71	6.20	2.12	4.08	0.66
Manappad, 1978	♀ + ♂	42.11[a]	21.3	6.8	1.1	2.70	2.94	1.98	0.96	0.33

[a]Converted from total length using TL/CL relationships (see text).
[b]Converted from CL using CL/TL relationships (see text).
[c]Converted from asymptotic length using L/W relationships (see text).
[d]Obtained from TL_∞ (in cm) using Pauly's empirical.
[e]Other values were not computed because of insufficient data.

Discussion

Results on the analysis on growth parameter shows that *P. indicus* stocks in Manila Bay-Bataan/Bulacan area (Philippines) and Manappad and Punnaikkayal (Tinnevelly Coast, southeast India) are similar. Relatively high values of mortality and exploitation rates indicate that all the areas are overexploited. This may be due to a year-round exploitation by commercial push netters using a very small mesh size in Manila Bay and mechanized trawlers in Punnaikkayal and Manappad, for the whole year also and from June-October, respectively. Devi (1986) found extremely high fishing mortalities off Andhra Pradesh (India) and reports high exploitation rates from other Indian stocks of this species, thus confirming the results presented here.

The recruitment patterns of the stock in Manila Bay suggest that there is only one main pulse of annual recruitment and this could be supported by the results of the catch rate analysis in the area, where white shrimps show only one major peak, from April-July (Fig. 6). Del Mundo et al. (1982) reported that a high percentage of ripe females were observed during the months of November and February, while young shrimp entered the fishery in the next months.

The number of annual recruitment pulses in the stock in southeast India coincide with the conclusions drawn by Manisseri and Manimaran (1981) that recruitment of *P. indicus* to the fishery in Punnaikkayal and nearby areas has two pulses, during the months of November-February and May, while in Manappad there is only one pulse, in June-July.

Acknowledgements

The authors wish to thank the owner of *F/B St. Dominic II* for allowing us to board his vessel; the crew, for their generous help during the data collection; and Ms. Araceli A. Bandala for her tireless effort during the survey.

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An Assessment of Jinga Shrimp, *Metapenaeus affinis* (Penaeidae), in Ban Don Bay, Gulf of Thailand

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Abstract

Metapenaeus affinis is the dominant shrimp species in Ban Don Bay (western Gulf of Thailand). Length-frequency and catch per trawl data collected by research vessels at 29 fixed stations fished monthly in 1981, are used to estimate growth parameters K and L_∞, mortalities and monthly biomass. An assessment of MSY is also presented based on catch and effort data from commercial fisheries in the area.

Introduction

Ban Don Bay located off Surat Thani Province in the western Gulf of Thailand (Fig. 1) is one of the most productive shrimp fishing grounds of Thailand (Vibhasiri 1984). There were 1,205 fishing boats operating here in 1981, mostly small boats, using small gears like shrimp gill nets and push nets, fishing along the coast at most 3 km offshore (Lowsawatgoon 1986). Bigger trawlers (otter, beam and pair) are working in areas further offshore.

Metapenaeus affinis is the dominant species among the penaeid shrimps occurring in Ban Don Bay, of which the spawning grounds and seasons were described by Thubthimsang (1981). Gravid females of *M. affinis* were found year-round, but dominated in January, March and October. Other knowledge on the biology of *M. affinis* in this area is still scarce; however, a study on a similar species, *M. mutatus*, is available (Chaitiamvong and Thaiprayoon 1977). Ramamurthy et al. (1975) studied the fishery and population dynamics of *M. affinis* along the Mangalore coast, India. Pauly et al. (1984) estimated the growth parameters of *M. affinis* off Versova, India, based on data in Mohamed (1967).

The present paper estimates growth parameters, mortalities, biomass, and yield per recruit of *M. affinis* based on length-frequency data and catch data from research vessel surveys. An assessment of the maximum sustainable yield is also presented based on catch and effort data from commercial fisheries in the same area.

Materials and Methods

Data from Research Vessels

Monthly length-frequency data and catch data were collected by research vessels *Pramong 2, 4, 5* and *9* from January to December 1981. These research vessels, wooden stern trawlers, LOA 23 m of a similar general design, fished with a polyethylene otter trawl of German design, with a 20-25 mm mesh cod-end (see also Yoo-Sook-Swat, this vol.). The headrope and ground rope were 34.8 and 43.9 m, respectively. Trawling speed was about 2.5 knots and the haul duration one hour. Monthly survey operations were carried out at night, between 18 and 06 hours, 4 hauls per night, 20-29 hauls per month, at fixed stations (Fig. 1).

The catches of shrimp were identified to species level and by sex. The entire catches of *M. affinis* were measured. Total length, from tip of rostrum to tip of telson, was measured in mm, and later grouped into 0.5 cm classes. The length compositions are given in Table 1.

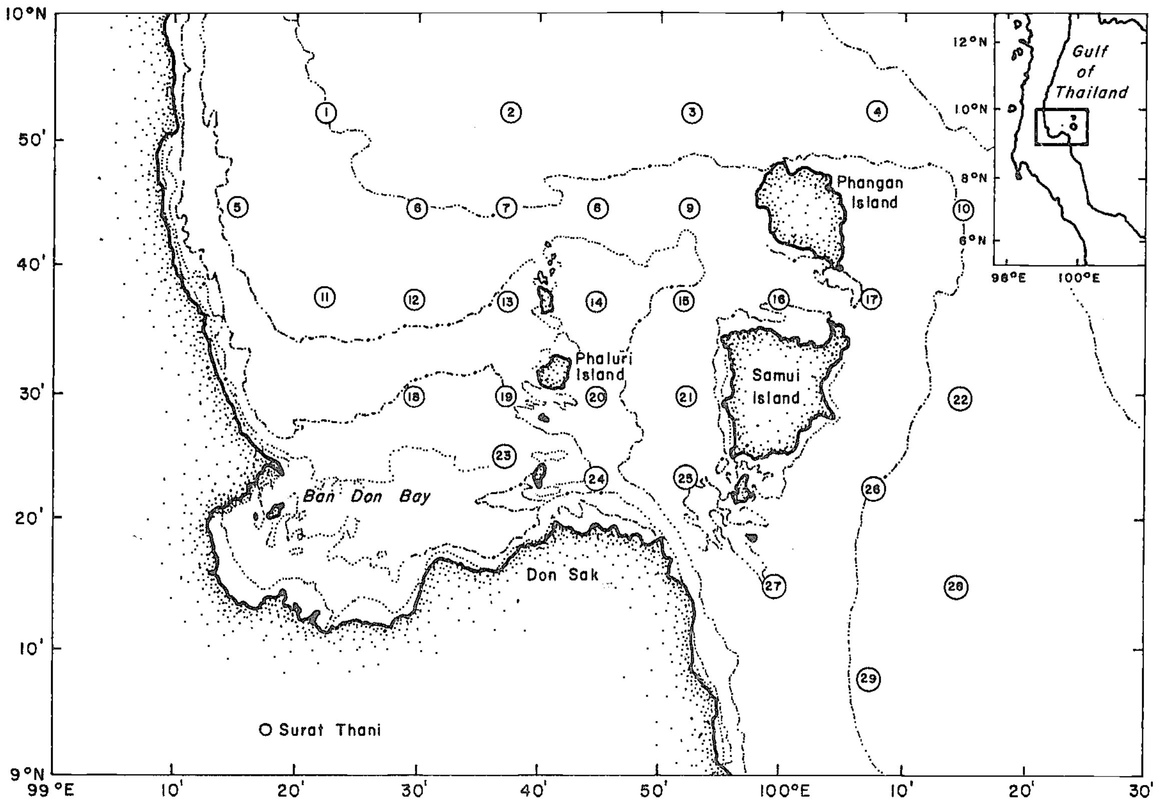


Fig. 1. Map of Ban Don Bay, Surat Thani Province in the Gulf of Thailand showing the stations under study.

Data from Commercial Fisheries

Landing data, total catches and effort by year by fleet were collected and processed by the Fisheries Statistics Unit of the Department of Fisheries. These data are published annually as Fisheries Record of Thailand.

Statistics for *Metapenaeus* spp. are not given at species level, but the survey data from the same area contain this information (Vibhasiri et al. 1985). Annual landings of *M. affinis* has thus been derived from the total landings of all *Metapenaeus* species (Table 2) using the survey data.

Otter trawlers (LOA < 18m) accounted for about 65% of the shrimp catches (Vibhasiri 1984). Effort data from the otter trawlers, in hours, were used as the standard gear for calculation of total fishing effort in this fishery.

The total effort for all vessels engaged in the shrimp fisheries in a particular year expressed in terms of otter trawlers, was estimated by dividing the total annual catch in that year by the CPUE of otter trawlers (Gulland 1969). Total catch, CPUE of otter trawlers and total effort, in otter trawl hours, for 1976-1983 are given in Table 2.

Table 1. Monthly length frequency data of female and male *Metapenaeus affinis* from research vessel surveys in Ban Don Bay, 1981.

Total midlength (cm)	Date 1/17 Female	Male	2/13 Female	Male	3/25 Female	Male	4/14 Female	Male	5/25 Female	Male	6/25 Female	Male
4.25											1	
4.75											5	2
5.25					1						22	8
5.75	7				1				2		46	20
6.25	3				3	1			0		36	25
6.75	7		1		5	2	2	1	14	3	57	34
7.25	16		3	1	7	1	5	3	18	10	40	33
7.75	21	11	6	5	12	2	7	3	28	15	58	45
8.25	33	26	13	9	15	9	8	9	20	15	60	65
8.75	64	34	18	15	18	9	9	12	31	18	57	73
9.25	74	83	26	39	7	16	8	9	28	26	49	62
9.75	80	129	26	70	4	13	6	10	37	54	38	58
10.25	76	123	25	105	8	28	7	19	28	51	24	60
10.75	110	158	50	88	12	68	10	32	37	49	22	70
11.25	164	152	79	75	16	49	9	48	25	17	26	52
11.75	160	67	69	21	22	22	20	31	22	10	25	10
12.25	174	25	81	5	40	6	20	1	14	4	44	5
12.75	143	3	36	1	44	3	33		10	1	28	1
13.25	65		13	1	21		15		12	0	10	1
13.75	39		4		10		13		14	1	7	
14.25	15		2		9		7		11	0	3	
14.75	6		1		4		3		4	1	1	
15.25	2								1		2	
RF[1]	2.977		5.480		3.517		4.062		5.311		4.162	

Total midlength (cm)	Date 7/26 Female	Male	8/18 Female	Male	9/15 Female	Male	10/17 Female	Male	11/25 Female	Male	12/21 Female	Male
4.25												
4.75					2	1	1			6	4	
5.25	1	1			39	4	20	7	24	7	17	2
5.75	11	5	4		72	16	53	14	91	20	31	10
6.25	20	20	7	2	70	32	43	22	153	58	98	31
6.75	38	41	14	2	42	39	72	36	358	139	190	99
7.25	36	21	14	9	12	41	49	36	354	144	233	174
7.75	43	75	22	12	15	44	57	48	263	98	230	237
8.25	42	78	19	27	31	55	40	33	215	158	169	169
8.75	35	60	31	27	23	47	35	42	124	133	154	154
9.25	31	47	37	33	9	34	43	58	76	117	118	171
9.75	15	35	27	32	11	31	29	57	91	167	115	189
10.25	14	40	21	34	13	29	27	43	63	158	100	162
10.75	8	35	14	18	18	20	37	16	67	137	104	200
11.25	18	20	21	13	20	24	42	7	52	61	106	88
11.75	14	6	23	3	22	3	24	1	42	10	95	44
12.25	9	3	17	1	16		19	2	36	3	63	3
12.75	10	4	8	1	10		8	1	33	1	51	
13.25	3		3		6		4		23	0	27	
13.75	7		0		1				11	1	25	
14.25	3		3						3		5	
14.75	1		2						0		2	
15.25			1						1			
RF[1]	5.425		4.594		4.960		4.607		3.444		2.770	

n = 8,869 n female = 8,869
n male = 7,251

[1]RF = Raising factor to raise numbers sampled to numbers caught by the whole fleet in thousands. Pooled data used in cohort analysis (Table 4).

Table 2. Total estimated landings of *Metapenaeus affinis* (in tonnes) and CPUE (kg/h) of commercial otter trawlers (<18m) and total estimated effort in otter trawl units ('000h), in Ban Don Bay, 1976-1983.

Year	1976	1977	1978	1979	1980	1981[a]	1982	1983
Catch (tonne)	598	545	505	614	751	859	750	640
CPUE (kg/h)	0.307	0.313	0.261	0.375	0.283	0.246	0.181	0.191
Effort (000'h)[b]	1941	1741	1935	1637	2654	3492	4144	3351

[a]Year of the trawl survey.
[b]Effort by all gears expressed in otter trawl hours.

Raising to Total Catch

Before the length frequencies of the samples of *M. affinis* could be raised to the total catch of *M. affinis* in Ban Don Bay in 1981, the sample weights had to be obtained from length-weight relationships, presented by Chaïtiamvong and Thaiprayoon (1977), for each length class.

females $W = 0.00000724\ L^{3.050}$

males $W = 0.00005293\ L^{2.618}$

where L is total length in mm; W is weight in g.

The length frequencies were further raised to the total catch by a raising factor given in Table 1 for each month:

$$R.F = \frac{\text{total weight from entire catch}}{\text{sample weight}}$$

The sample weights for males and females were pooled and raised to total catch for cohort analysis and catch curve analysis.

Estimation of Growth Parameters

The ELEFAN I program (Pauly et al. 1984) and the Bhattacharya method (based on Sparre 1985) were used for determining growth parameters L_∞ and K from length-frequency data. This procedure assumes that

- the length-frequency data are representative of the population;
- the growth patterns are repeated from year to year;

- the von Bertalanffy Growth Formula (VBGF) describes the mean growth in the population; and
- all shrimp in the samples have the same growth parameters.

The Wetherall (1986) method was used to estimate L_∞ and Z/K.

Estimation of Total Mortality

Total mortality was found from length-converted catch curve analysis (Pauly et al. 1984). This method estimates Z/K, and K is estimated as mentioned earlier.

Biomass Estimation

The monthly biomass or standing stock of *M. affinis* in Ban Don Bay was estimated using the "swept area method" (Sparre 1985). The research vessels trawled 20 to 29 fixed stations each month covering the entire distribution area of the shrimp stock (Fig. 1).

The area swept per hour (a) expressed in km^2 is:

$$a = 2.5 \times 1.852 \times 34.8/1000 \times 0.5$$

$$= 0.080562 \text{ km}^2$$

The total survey area (A) encompasses 115 grids of 5 by 5 nm or

$$A = 115 \times 5^2 \times 1.852^2 = 9{,}861 \text{ km}^2$$

The biomass is then calculated from CPUE (kg/h) x A/a x 0.5, where 0.5 is the retention coefficient.

Maximum Sustainable Yield

Fox's (1970) model was used to estimate the maximum sustainable yield (MSY) of *M. affinis*. This assessment is based on the assumption that the examined stock represents a single entity, while the interaction between stocks is disregarded.

Results

Growth Parameter Estimates

The length-frequency data used are given in Table 1. Usually, such data should be corrected for gear selectivity. Promsaka (1983) presents a selection ogive for *Metapenaeopsis* spp. obtained with a shrimp trawl operating at night. He gives a selection factor of 1.58. Accepting that this ogive can be applied to *Metapenaeus affinis* then a cod-end mesh size of 2.5 cm suggests that the portion of the length composition above 6.5 cm TL is unaffected by mesh selectivity. Table 1 contains only a few observations below this limit. Since the selection ogive for *Metapenaeus affinis* is not known, but guessed by making an analogy with *Metapenaeopsis* spp., it was decided not to correct for mesh selection. With the mesh size used, size classes as small as 4.0 cm should be present; however, such small shrimp were not found in the catches of the research vessels and they are probably not yet present on the fishing grounds.

First estimates of the asymptotic length (L_∞) and the ratio between the coefficients of mortality and growth (Z/K) were obtained for the largest male and female shrimp based on the annual length-frequency distributions with the Wetherall plot:

	males	females
L_∞	15.2	16.5 (cm)
Z/K	6.938	4.434

The graphs showing the selected points are given in Fig. 2. Subsequently these estimates for L_∞ were used in ELEFAN. The restructured data and the growth curve fitted by ELEFAN I are shown in Fig. 3. The parameters estimated by this method are:

	males	females
L_∞	15.0	17.4 (cm)
K	0.85	0.84 (per year)

The fit is not very good (ESP/ASP ≈ 0.2).

More insight in the identification of cohorts was gained by splitting the length distributions into normal components using the Bhattacharya method. The components and their time allocation are given in Table 3 . Two cohorts were identified: cohort A which recruits to the fishery in March and which seems to originate from a single recruitment burst and cohort B, which seems to have a more extended recruitment period between June and September. The randomly varying mean lengths obtained for cohort B in these months can be interpreted as a continuous recruitment to the fishery. Cohort A and B cannot be distinguished after about 1 year in the fishery, which is the likely cause for the apparent drop in mean length. A von Bertalanffy plot was used to obtain another estimate of the growth parameter K using L_∞'s from the Wetherall plot and the mean lengths by month and cohort from Table 3. The points belonging to the peak of cohorts were transformed by $-\ln(1-L/L_\infty)$ and plotted against the relative age. The plots are presented in Fig. 4. The slopes (K) are respectively:

	males	females
K	0.77	0.66 (per year)

These estimates of K are lower than the ones obtained from ELEFAN I, for both males and females.

Mortality Estimates

Catch curve analysis is feasible, assuming that total mortality is constant from some length upwards. This assumption could be violated by migration out of the fishing area of mature shrimp or avoidance of the trawl by the larger shrimp. For an estimate of total mortality based on the length compositions obtained by the research vessels it has to be assumed that they are representative of the commercial fisheries. The research vessels used a commercial shrimp trawl with the same mesh size and operated at night like the commercial fleet. Length-frequency data from commercial trawlers are also similar to the ones from research vessels used here (Technical reports in Thai, from the Marine Fisheries Division, Bangkok, Thailand).

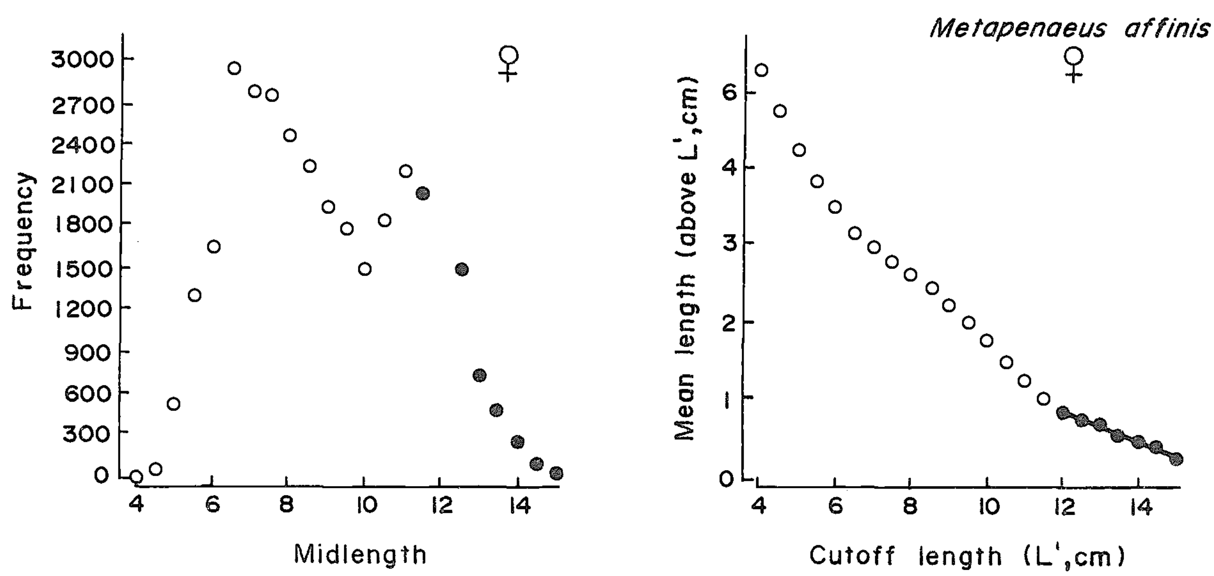


Fig. 2a. Estimation of L_∞ and Z/K using the method of Wetherall for female *Metapenaeus affinis*.

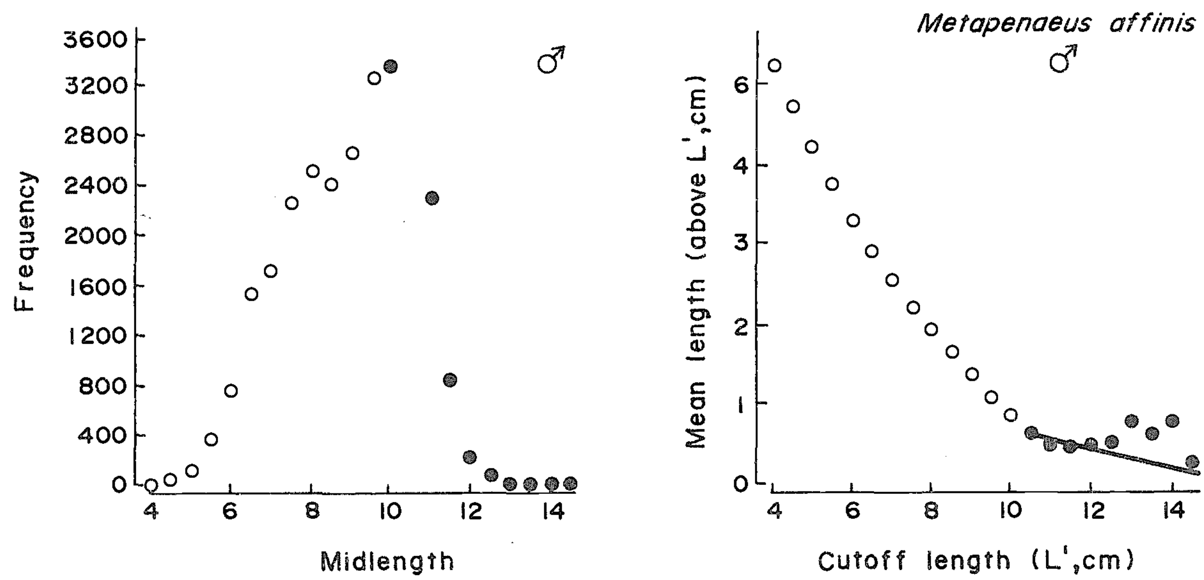


Fig. 2b. Estimation of L_∞ and Z/K using the method of Wetherall for male *Metapenaeus affinis*.

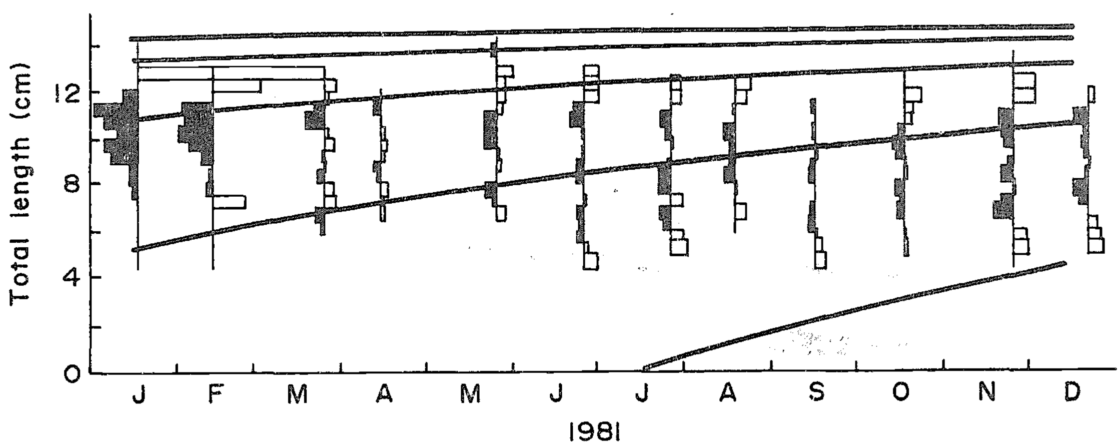


Fig. 3a. Growth curve identified by ELEFAN I for male *Metapenaeus affinis* in Ban Don Bay.

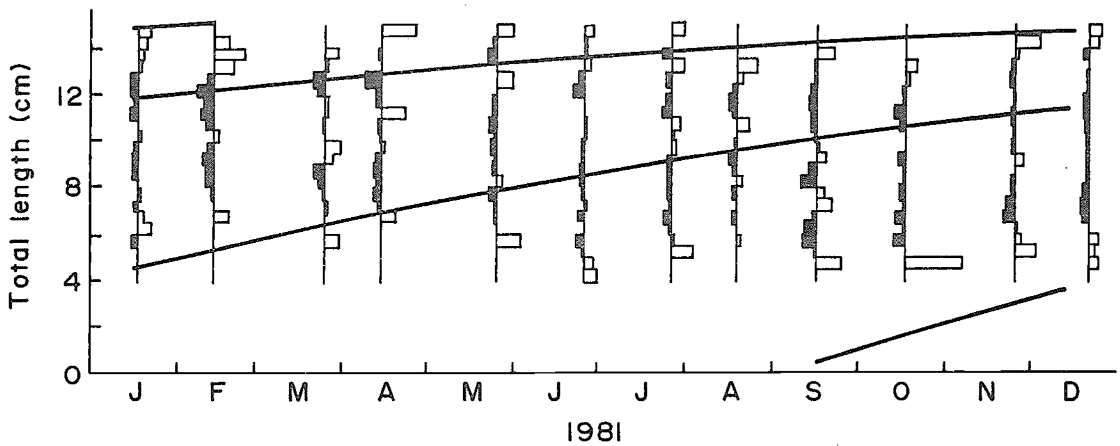
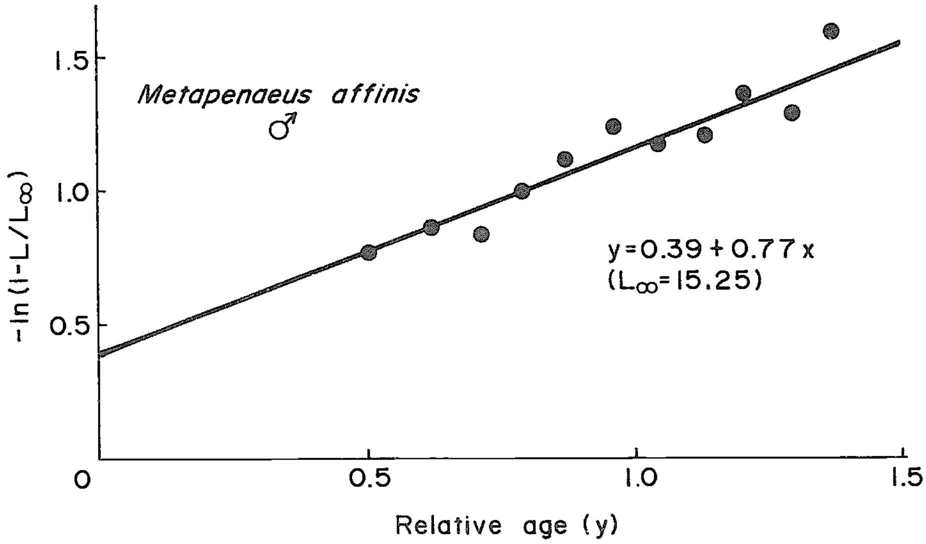


Fig. 3b. Growth curve identified by ELEFAN I for female *Metapenaeus affinis* in Ban Don Bay.



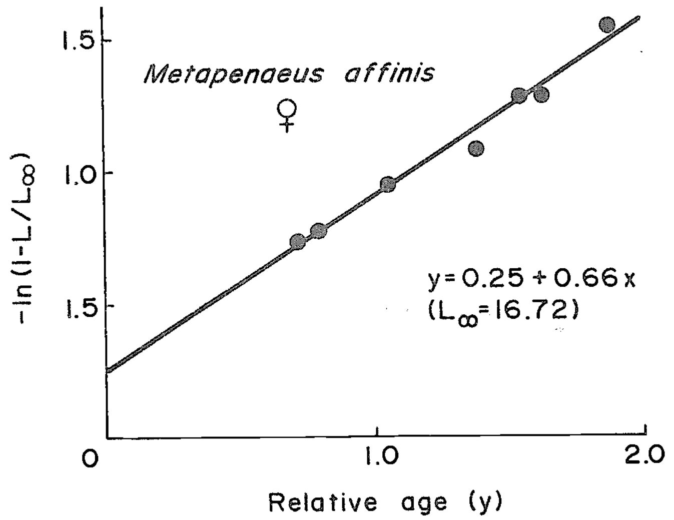


Fig. 4. Von Bertalanffy plot for male and female *Metapenaeus affinis*.

Table 3. Mean length of male and female cohorts of *Metapenaeus affinis* obtained by Bhattacharya Method.

Month	Cohort A Males		Cohort A Females		Cohort B Males	Cohort B Females
Jan	-	10.58	-	10.25	-	
Feb	-	10.72	-	9.87	-	
Mar	7.00	11.33	8.31	12.50	9.51	
Apr	7.75	11.06	8.86	12.82	9.04	
May	8.20	11.83	11.05		10.36	
Jun	9.07	10.89[a]	8.80	12.30[a]	7.06	6.21
Jul	8.41	10.94	8.74	12.07	7.09	7.11
Aug	8.82	10.41	9.90	12.12	-	8.10
Sep	8.64	10.61	8.75	11.43	6.89	6.44
Oct	10.00	-	9.03	11.62	7.72	6.79
Nov	10.28	-	10.73	13.15	7.48	7.75
Dec	10.06	10.87	11.04	-	7.95	7.75

[a]From this point onwards this peak includes both cohort A and cohort B.

Length-converted catch curves are presented in Fig. 5. Applying the growth parameters as obtained using ELEFAN I (females $L_\infty = 17.4$, $K = 0.84\ y^{-1}$; males $L_\infty = 15.0$, $K = 0.85\ y^{-1}$), the following total mortalities were estimated

	males	females
Z	7.0	5.23 (per year)

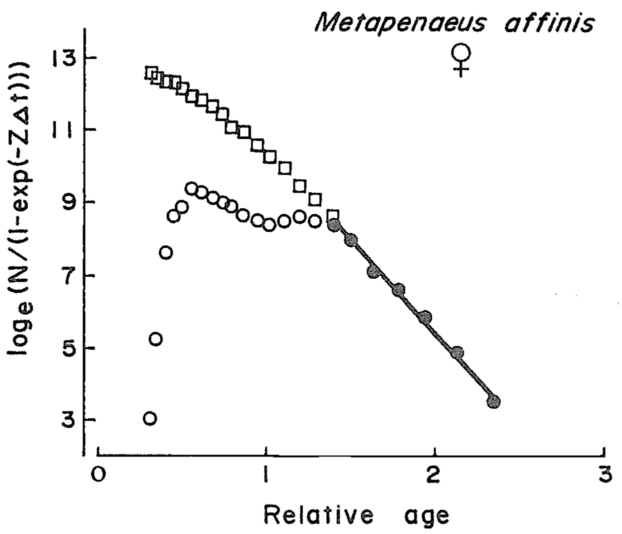


Fig. 5a. The length converted catch curve of female *Metapenaeus affinis*.

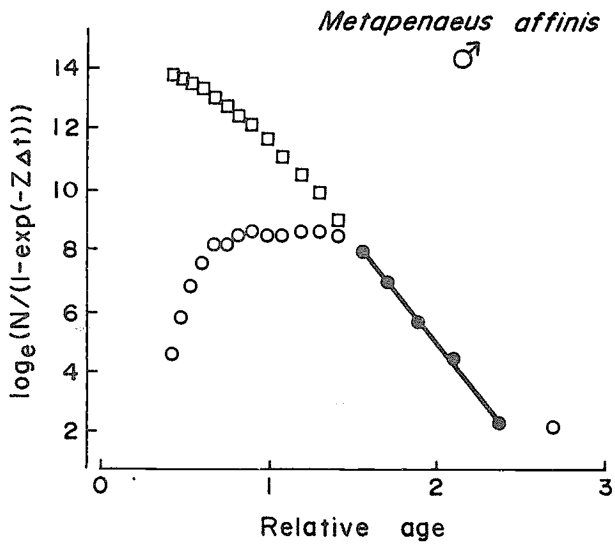


Fig. 5b. The length converted catch curve of male *Metapenaeus affinis*.

Cohort Analysis

Cohort analysis is based on length classes being converted into age intervals by the inverse of the von Bertalanffy equation.

$$t(L1) = t_0 - 1/K \ln (1 - L_1/L_\infty),$$

$$\Delta t = t(L2) - t(L1)$$

$$= 1/K \ln (L_\infty - L_1 / L_\infty - L_2)$$

The normal sex ratio of *M. affinis* in the landings is about 1:1 (Chaitiamvong and Thaiprayoon 1977). The samples presented in Table 1 show a sex ratio females:males of 8,869:7,251 or 1.2:1. A set of growth parameters for pooled data should be about the mean of the parameters estimated for each sex and this set was chosen as

$$L_\infty = 16.25 \text{ cm}$$

$$K = 0.85 \text{ year}^{-1}$$

The natural mortality (M) is unknown. Total mortality for the largest specimens was found to be Z = 5 for females and Z = 7 for males ($year^{-1}$). The *Metapenaeus affinis* stock is probably heavily exploited with an exploitation rate much higher than 0.5. This suggests M to be in the range M = 1 to M = 3 ($year^{-1}$). Garcia (1985) summarizes the available knowledge on M for adult *Penaeus* spp. to be around M = 2.4 ($year^{-1}$) and *M. affinis* will probably experience at least that level of natural mortality. A value of M = 3 $year^{-1}$ was therefore used in the subsequent analyses.

The inputs and outputs of the cohort analysis are presented in Table 4. The calculated F-at-length array is depicted in Fig. 6a. This graph shows a rather wide length interval over which F increases. This is probably not reflecting changes in the gear efficiency, but rather recruitment to the stock over this length range, since selection would not affect these size ranges.

Yield and Biomass per Recruit

The yield-per-recruit curve (Fig. 7a) was calculated assuming a natural mortality M = 3 $year^{-1}$. The curve is based on the F-at-length array presented in Table 4 and Fig. 6a which represents 1981. The terminal F was set at F = 0.5, in order to obtain a flat topped F at length for larger size shrimp.

Biomass Estimation

The CPUE, CPUA and calculated biomasses for each month (January to December, 1981) are presented in Table 5. The mean biomass for 1981 only for this area is only 130 t, using a retention factor of 0.5. The monthly biomasses are also shown in Fig. 8, which shows a low peak around June and a high one around December. The peaks correspond with the two monsoons as indicated on the graph.

Maximum Sustainable Yield

Table 2 gives total annual catches and CPUE for the commercial otter trawlers of class <18 m LOA and the derived effort (=catch/CPUE) in otter trawl units. These data were used in a Fox (1970) model.

Table 4. Cohort analysis of pooled data of *Metapenaeus affinis*, Ban Don Bay, 1981.

Midlength (cm)	Catches (in 000)	Population (in 000)	F
15.25	27.61	193.27	0.5000
14.75	100.47	801.58	0.5935
14.25	240.85	2304.90	0.5723
13.75	488.30	5356.05	0.5716
13.25	746.79	10642.20	0.4935
12.75	1582.60	19641.75	0.6401
12.25	2251.38	33327.65	0.5907
11.75	2877.79	52822.31	0.5196
11.25	4525.45	80562.18	0.5848
10.75	5203.39	117138.66	0.4976
10.25	4869.58	162836.41	0.3578
9.75	5033.42	219401.81	0.2930
9.25	4610.93	287555.00	0.2177
8.75	4676.27	369116.31	0.1825
8.25	5001.98	465823.94	0.1636
7.75	5012.15	578890.25	0.1392
7.25	4494.66	709275.56	0.1071
6.75	4445.83	858968.81	0.0918
6.25	2424.71	1027431.75	0.0438
5.75	1655.95	1217305.75	0.0264
5.25	636.35	1429861.88	0.0090
4.75	80.36	1667135.25	0.0010
4.25	4.16	1931292.00	0.0000

Total catch : 60990.98
Mean E : 0.032
Mean F : 0.098
Natural mort.: 3
Term.F. mort.: .5
K = 0.85
L_{∞} = 16.25

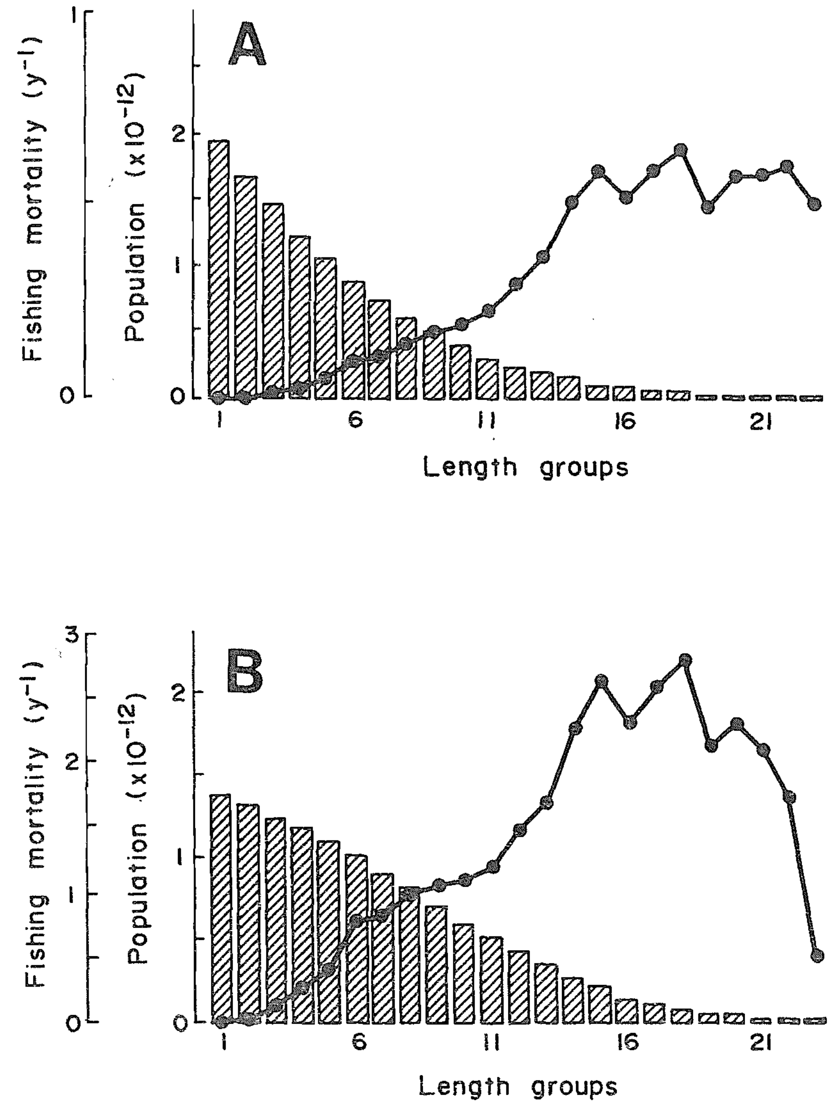


Fig. 6a and 6b. Cohort analysis of *Metapenaeus affinis* in Ban Don Bay, L_{∞} = 16.25 K = 0.85
A) M = 3, terminal F 0.5
B) M = 1, terminal F 0.5

Fig. 9 shows annual yield plotted against effort and CPUE plotted against effort; ln (CPUE) is assumed linearly related to effort and the fitted curves are shown in the graph.

The estimated MSY of *M. affinis* in Ban Don Bay was found as 763 t. This yield corresponds to an annual standard fishing effort (f_{msy}) of 4,309 x 10^3 hours. This analysis does not suggest any overexploitation of this species.

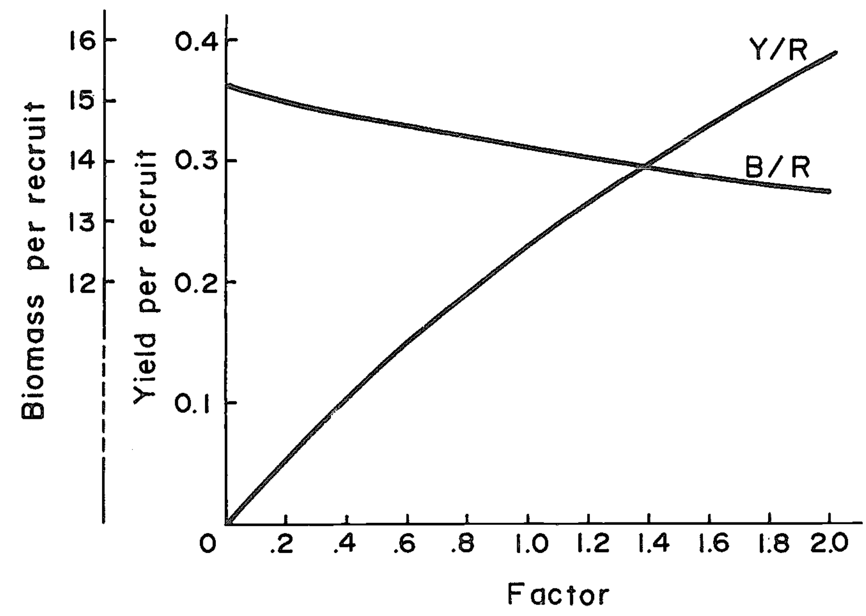


Fig. 7a. Yield per recruit (Y/R) and biomass per recruit (B/R) calculated from the F-at-length array obtained with M = 3 and terminal F = 0.5 (see Fig. 6a).

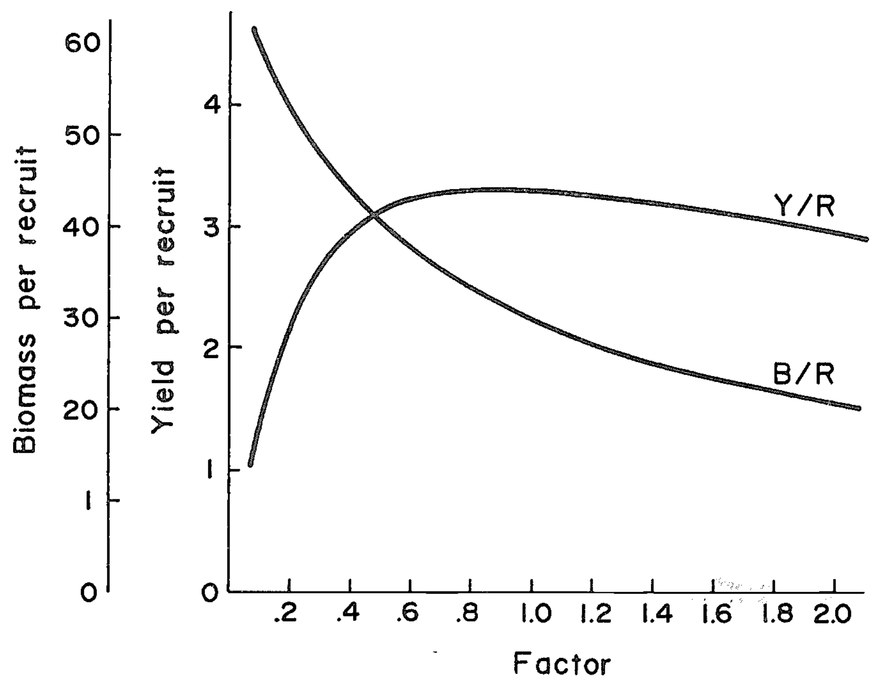


Fig. 7b. Yield per recruit (Y/R) and biomass per recruit (B/R) calculated from the F-at-length array obtained with M = 1 and terminal F = 0.5 (see Fig. 6b).

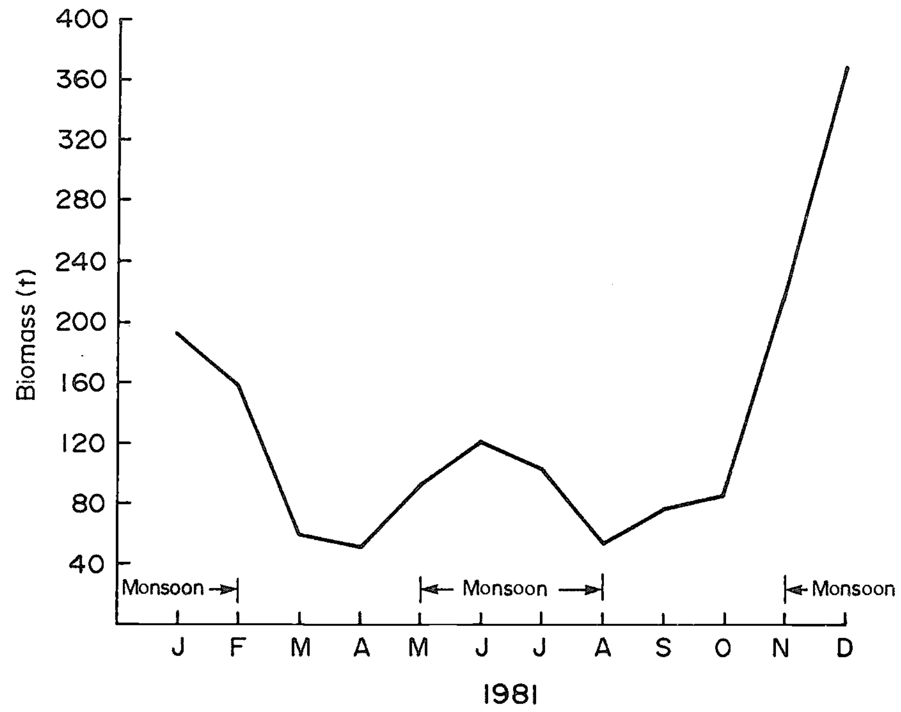


Fig. 8. Monthly biomass of *Metapenaeus affinis* in Ban Don Bay, estimated from R/V data for 1981 (See also Table 5).

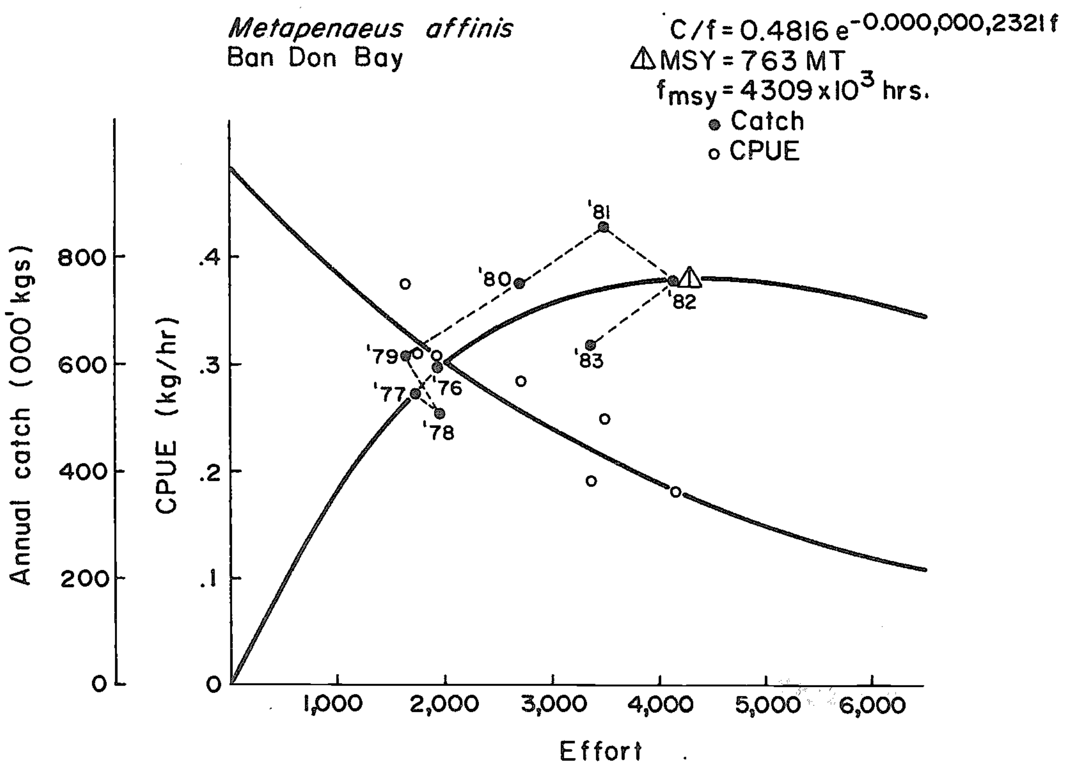


Fig. 9. Annual catch by *Metapenaeus affinis* by all gears and CPUE by commercial otter-trawlers of 18 m length, *vs*. the estimated total effort in Ban Don Bay.

Discussion

The estimated values of L_∞ and K of *Metapenaeus affinis* compare well with the results given by Ramamurthy et al. (1975) (Table 6). Ramamurthy only gives K with one digit, the K value obtained in this study and their estimates are well within the implied accuracy. There is a reasonable agreement in the ϕ' values (Pauly and Munro 1984).

The total mortality Z obtained in this study and that at the Mangalore coast of southwest India are also similar, neither estimate being precise. However, both studies suggest a natural mortality M = 3 ($year^{-1}$) or less since both stocks are subject to an intense fishery.

The growth parameters in this study were obtained through a combination of several methods some of which provide estimates of the same parameters, but based on different basic assumptions. The Wetherall method was used to estimate L_∞, but this estimate and the corresponding K depend critically on the choice of points on the curve which is considered, e.g., for males including one length group less, i.e., start at 11 cm will give a negative Z/K, while including one length group more will change Z/K from 6.9 to 2.9. This also affects the L_∞ estimate but to a lesser extent, i.e., from 15.25 cm to 13.1 cm. This latter value is out of line with the general impression from the length composition and therefore the 15.25 cm was accepted.

Results of the ELEFAN I program compare well with those of the Bhattacharya analysis, although, as should be expected the L_∞ obtained from ELEFAN was slightly larger than the L_∞ obtained through the Wetherall analysis. The Bhattacharya analysis will break down in the upper range of the length distributions where many cohorts fall into the same peak and the number of observations is small.

The F-at-length array (Fig. 6) shows a steadily increasing F between 4 and 10 cm. This increase is a reflection of recruitment over this length range rather than increased efficiency with length. Migration out of the fishing grounds of larger specimens is possible, but there is no evidence for it in this data set.

The fluctuations in monthly biomass as shown in Fig. 8 and Table 5 are probably not reflecting real changes in biomass of the stock, but rather a change in vulnerability to the gear. During the monsoon, shrimps do not stay at the bottom but may be feeding higher in the water column, resulting in a smaller fraction being caught in shrimp trawls. The actual portion of shrimps retained may be much lower than 50%, even in the non-monsoon seasons. The apparent discrepancy between the low average biomass of 130 t and the annual estimated landings of 859 t can be at least partly explained by this factor. Another problem is that the quantities of *M. affinis* landed were estimated and not measured. Further, it is likely that the landings from the fishery came from a larger area than that covered by the survey. In particular the contribution to the landings from the unsurveyed shallow waters may have been considerable. While this trawl survey may not have given a good indication of absolute abundance, the results are still useful for a better understanding of seasonality in the landings.

Table 5. Monthly biomass estimates of *Metapenaeus affinis* in Ban Don Bay, based on research surveys in 1981 at fixed stations.

Month	Total Catch (kg)	No. of haul n	CPUE	s.e.	N	Catch per unit of area (CPUA)*	Biomass (ton)
Jan	22.87	29	0.789	0.237	115	9.794	193
Feb	13.10	20	0.655	0.107	115	8.130	160
Mar	7.01	29	0.242	0.121	115	3.004	59
Apr	4.26	20	0.213	0.085	115	2.644	52
May	10.88	29	0.375	0.023	115	4.655	92
Jun	9.77	20	0.489	0.270	115	6.070	120
Jul	12.19	29	0.420	0.174	115	5.213	103
Aug	4.45	20	0.223	0.101	115	2.768	55
Sep	9.15	29	0.316	0.136	115	3.922	77
Oct	6.92	20	0.346	0.059	115	4.295	85
Nov	25.45	29	0.878	0.133	115	10.898	215
Dec	29.98	20	1.499	0.581	115	18.607	367

*A = 9861 km^2; a = 0.080562 km^2 (area swept per haul).

Table 6. Summary of estimates of L_∞, K, Z and ϕ' for male and female *Metapenaeus affinis*.

Author/ Method	Sex	L_∞ (cm)	K ($year^{-1}$)	M ($year^{-1}$) (guessed)	Z ($year^{-1}$)	ϕ'
Ramamurthy et al. (1975)	male	17.4	0.84	—	3.76	2.41
	female	18.8	0.72		2.50	2.41
This paper/ ELEFAN	male	15.0	0.85	—	—	2.28
	female	17.4	0.84			2.41
Wetherall (L_∞) and von Bertalanffy plot (K)	male	15.25	0.77	—	—	2.25
	female	16.72	0.66			2.27
Cohort analysis	pooled	16.25	0.85	3	3.5[a]	2.35

[a]mean Z over the length range 10.25 - 14.75 (midlength) see Table 4.

The yield per recruit shows no optimum, contrary to the Fox model analysis. The data points available for the latter analysis, however, make the exact position of the optimum doubtful. Also the yield-per-recruit analysis is not on very firm ground, M is guessed, actually in the upper end of the likely range and a different M would change the yield-per-recruit curve substantially. For a demonstration of the effect of a different M value, a cohort analysis was carried out with M = 1 ($year^{-1}$) (see Fig. 6b) and the F-at-length array was used as a basis for the yield-per-recruit curve presented in Fig. 7b. It is considered that the apparent difference is rather a result of noise in the data and uncertainty about essential parameters than reflecting any real difference. It is also obvious that the lack of an optimum on the yield-per-recruit curve does not lead to the conclusion that an unlimited fishery is permissible, since recruitment will be affected at high mortality levels, an element not included in the yield-per-recruit model.

Acknowledgements

Thanks are due to Mr. Wannakiat Thubtimsang for allowing the use the length-frequency data of *Metapenaeus affinis* in Ban Don Bay, 1981, for this study and to Ms. Mina L. Soriano and Mr. Felimon C. Gayanilo Jr. for faithfully adapting some computer programs to this author's everchanging needs.

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An Assessment of the Southern Velvet Shrimp *(Metapenaeopsis palmensis)* (Penaeidae) off the Coast of Rayong Province, Gulf of Thailand

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Abstract

Shrimp trawl surveys by the research vessel *Pramong 5* were undertaken off the northeastern coast of the Gulf of Thailand between Kor Chuang and Laem Yah, Rayong Province, from January to December 1982. Catches and length composition by sex of *Metapenaeopsis palmensis* obtained during these surveys were analyzed and used to estimate biomasses.

Introduction

The southern velvet shrimp *(Metapenaeopsis palmensis)* is widely distributed in tropical and warm temperate waters of the Malay archipelago and northern Australia (Grey and Dall 1983). It is also found in the Gulf of Thailand, where it is caught by beam trawlers and push netters. These fleets actually fish for larger shrimp species while small shrimps, of which *M. palmensis* is one of the main components, are taken as bycatch. The small shrimps are sold as a dried product. The size of *M. palmensis* in the Gulf of Thailand varies between 3 and 9 cm total length. Coastal mud-sandy beds at depths between 5 and 22 m are its preferred habitat (Thubthimsang et al. 1982). Grey and Dall (1983) also indicate muddy to sandy bottom and 5 to 30 m depth as preferred habitat. The species, being of minor commercial importance, has not been studied much. The maximum total length is 105 mm for females and 85 mm for males.

Under the Thai Government's Economic Development Plan No. 5 (1982-1986), which aims at developing industries and natural resorts along the eastern coast of the Gulf of Thailand, the area between Amphur Sattahip and Amphur Muang, Rayong Province has been declared an industrial zone. Hence, industrial wastes will probably affect the marine environment along the Rayong Province coast. Because of the importance of the marine resources along this coast, their general status was investigated (Thubthimsang et al. 1982). Data on *M. palmensis* from this January-December 1982 survey are analyzed in this paper to obtain biomass estimates.

Materials and Methods

The research vessel *Pramong 5* (LOA 23 m, 350 hp) made a trawl survey off the coast of Rayong Province in 1982. The surveyed area was broken down into twenty-five rectangles of 5 x 5 nm^2, while each rectangle was assigned a number called a station. Of these 25 stations, 13 were selected as fixed stations, namely, 9 in the 10-19 m stratum and 4 in the 20-30 m stratum. These 13 fixed stations were fished once a month, for one hour, at night between 1800 and 0600. The trawl used was a German-designed otter trawl of polyethylene, with a headrope of 34.8 m and a groundrope of 43.9 m. The cod-end mesh size was 25 mm. Catches were sorted into species and the total catch of each species was recorded. The length composition, by sex of a subsample of *M. palmensis* was recorded, together with the weight of the subsample. The length was measured from the tip of rostrum to the end of the telson. Tables 1 and 2 present the CPUE by station, while the length frequencies, grouped in 0.5 cm intervals by month and station for each sex separately are given in Tables 3 and 4.

One station (No. 13) showed no catch of *M. palmensis* at any time and has been excluded from the analysis.

The total surveyed area between 10 and 19 m is 18 x 25 nm^2 and between 20 and 30 m is 7 x 25 nm^2. Station No. 13 is assumed to represent one square of 25 nm^2 which is subtracted from the 10-19 m stratum. Therefore, the surveyed area becomes 17 x 25 nm^2 = 425 nm^2 or 1,458 km^2 for the 10-19 m stratum and 175 nm^2 or 600 km^2 for the 20-30 m stratum.

The biomass estimates were made using the swept area method, as described in Sparre (1985). The swept area per hour, a, is calculated from the length of the head rope (h), the trawling speed (s) and duration of the haul (d) as:

$$a = s \cdot d \cdot h \cdot 0.5 \quad km^2$$

The average swept area (km^2/h) of *Pramong 5* was

$$a = 2.5 \cdot 1.852 \cdot 34.8/1{,}000 \cdot 0.5 \quad km^2$$

$$= 0.080562\ km^2$$

The catch per unit of area (CPUA) was calculated from

$$CPUA = CPUE/a$$

Of the monthly biomass from stratum j B_{mj}, the variance is calculated from

$$B_{mj} = \frac{\overline{CPUA}_{mj} \cdot A_m}{X1}$$

$$Var.(B_{mj}) = \frac{A_j^2}{X_1^2} \cdot Var(\overline{CPUA}_{mj})$$

where A_j is the total area of each stratum.

The retention coefficient X_1 was set at 0.5.

The monthly total biomass B_m is the sum of the two biomasses in the two strata:

$$B_m = B_{m\,10\text{-}19} + B_{m\,20\text{-}30}$$

Results

Selectivity

The monthly length compositions in Tables 1 and 2 show very little change with time. This could be an effect of trawl selection. Promsaka (1983) presented data for *Metapenaeopsis* spp. and derived a selection factor of 1.58 from a cover cod-end experiment. From Fig. 5 in Promsaka it appears that length compositions below 6.5 cm are seriously affected by selection.

The length compositions obtained from this survey, however, do not seem to cover the lower length range and this could indicate that *M. palmensis* smaller than 6 cm were not present in the survey area but rather in the more shallow coastal zones or in the mangroves. As no small specimens were not found in the survey area, correction for selectivity was not appropriate in this case.

Table 1. Catch rate (kg/hr) of male, *M. palmensis* caught by shrimp trawl during Jan.-Dec., 1982. Station 13 in the depth range 10-19 m station never showed any *M. palmensis.*

Station no.	Depth: 10-19 m								Depth: 20-30 m			
Month	12	15	16	17	18	20	21	22	23	24	25	26
Jan	0.460	0.916	0.0	0.183	0.018	0.0	0.421	0.733	0.0	0.538	0.402	0.583
Feb	0.226	0.456	0.0	0.0	0.0	0.303	0.076	0.377	0.0	1.127	0.300	0.227
Mar	0.526	0.0	0.0	0.459	0.0	0.198	0.463	1.314	0.0	0.049	0.331	0.577
Apr	0.0	1.022	0.0	0.0	0.0	0.0	1.083	0.0	0.356	0.0	0.129	0.258
May	0.0	0.770	0.582	0.0	0.0	0.117	0.585	1.048	0.020	0.378	0.113	0.429
Jun	0.0	0.0	0.0	0.0	0.483	0.271	0.161	0.111	0.0	0.267	0.018	0.177
Jul	0.0	0.840	1.470	0.0	0.0	0.0	0.0	0.0	0.0	0.206	0.0	0.0
Aug	0.0	0.0	0.030	0.0	0.0	0.0	0.0	0.069	0.0	0.0	0.050	0.0
Sep	0.0	0.253	0.052	0.0	0.505	0.0	0.455	0.051	0.0	0.0	0.164	0.032
Oct	0.0	0.0	0.0	0.141	0.0	0.0	0.432	0.433	0.0	0.852	0.429	0.597
Nov	0.082	0.120	0.085	0.062	0.040	0.0	0.080	0.104	0.0	0.245	0.124	0.062
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.206	0.0	0.0	0.033	0.081

Table 2. Catch rate (kg/hr) of female, *M. palmensis* caught by shrimp trawl survey during Jan.-Dec., 1980. Station 13 (depth range 10-19 m) in station never showed any *M. palmensis.*

Station no.	Depth: 10-19 m								Depth: 20-30 m			
Month	12	15	16	17	18	20	21	22	23	24	25	26
Jan	0.700	2.564	0.0	1.007	0.832	0.090	0.969	0.917	0.0	0.538	0.402	0.583
Feb	1.054	0.304	0.0	0.0	0.0	0.227	0.604	0.603	0.0	1.127	0.300	0.227
Mar	0.724	0.0	0.0	0.591	0.0	0.132	0.357	1.446	0.0	0.049	0.331	0.577
Apr	0.0	1.278	0.0	0.0	0.0	0.0	1.657	0.0	0.614	0.0	0.129	0.258
May	0.0	3.080	0.698	0.0	0.0	0.703	0.935	0.932	0.020	0.378	0.113	0.429
Jun	0.0	0.0	0.0	0.0	1.047	0.239	0.129	0.079	0.0	0.267	0.018	0.177
Jul	0.0	1.260	1.470	0.0	0.0	0.0	0.0	0.0	0.0	0.206	0.0	0.0
Aug	0.0	0.0	0.060	0.0	0.0	0.0	0.0	0.021	0.0	0.0	0.050	0.0
Sep	0.0	0.758	0.258	0.0	0.505	0.0	0.885	0.509	0.0	0.0	0.164	0.032
Oct	0.0	0.0	0.0	0.379	0.0	0.0	0.648	0.217	0.0	0.852	0.429	0.597
Nov	0.288	0.020	0.025	0.208	0.160	0.0	0.160	0.186	0.0	0.245	0.124	0.062
Dec	0.0	0.140	0.0	0.0	0.0	0.0	0.0	0.824	0.0	0.0	0.033	0.081

Table 3a. Length-frequencies of female *M. palmensis* in depth 10-19 m.

ML/Date	1/15/82	2/15/82	3/15/82	4/15/82	5/15/82	6/15/82	7/15/82	8/15/82	9/15/82	10/15/82	11/15/82	12/15/82
3.25					1							
3.75			4		3							
4.25			8	1	7					3		1
4.75		1	20	3	12	4			3	2	7	1
5.25	12	10	28	21	16	8	7	1	6	8	18	5
5.75	21	10	27	22	12	8	8	1	13	10	29	3
6.25	21	11	24	20	11	9	7	0	6	9	23	2
6.75	30	10	7	9	14	6	6	0	5	7	14	5
7.25	19	10	3	12	9	6	1	1	4	4	1	1
7.75	10	4	2	8	12	2	1	1	3	1	1	
8.25	3	1		2	3					1	0	
8.75	1				2						1	
9.25												
9.75												
Sum	117	57	123	98	102	43	30	4	40	45	94	18
Sample wt (g)	386	185	247	230	272	93	65	11	88	115	256	70

n = 771

Table 3b. Length-frequencies of female *M. palmensis* in depth 20-30 m.

ML/Date	1/15/82	2/15/82	3/15/82	4/15/82	5/15/82	6/15/82	7/15/82	8/15/82	9/15/82	10/15/82	11/15/82	12/15/82
3.25										1		
3.75	1				1	1				1		
4.25	2		7		2	1				8	1	
4.75	3	2	7	1	12	2	1			15	8	2
5.25	7	11	13	7	7	2	0	1	2	23	11	8
5.75	12	11	9	27	2	8	2	1	4	20	12	16
6.25	11	15	6	22	9	9	1		5	8	19	10
6.75	10	6	1	10	9	8	0			6	6	4
7.25	7	2	3	5	1	3	0			2		2
7.75	4	3		1	1	1	1			0		
8.25										1		
8.75												
9.25												
9.75												
Sum	57	50	46	73	44	35	5	2	11	85	57	42
Sample wt (g)	143	140	85	170	95	80	90	3	25	150	125	100

n = 507

Table 4a. Length-frequencies of male *M. palmensis* in depth 10-19 m.

ML/Date	1/15/82	2/15/82	3/15/82	4/15/82	5/15/82	6/15/82	7/15/82	8/15/82	9/15/82	10/15/82	11/15/82	12/15/82
2.25	2											
2.75	1											
3.25	3		1									
3.75	0		5		1					1		
4.25	0		16		2					12		
4.75	1	3	30	4	11	3		1	3	24	9	
5.25	6	11	42	18	22	5	7	0	3	17	26	1
5.75	17	18	23	22	20	8	16	2	9	9	16	5
6.25	25	9	11	18	4	8	5	3	4	6	5	1
6.75	6	4	4	8	5	5	2		1		1	
7.25	2	1		0	3	1			2		2	
7.75	0	0		1								
8.25	1	1										
8.75												
9.25												
9.75												
Sum	64	47	132	71	68	30	30	6	22	69	59	7
Sample wt (g)	149	95	225	165	133	64	35	14	52	93	140	15

n = 605

Table 4b. Length-frequencies of male *M. palmensis* in depth 20-30 m.

ML/Date	1/15/82	2/15/82	3/15/82	4/15/82	5/15/82	6/15/82	7/15/82	8/15/82	9/15/82	10/15/82	11/15/82	12/15/82
2.25												
2.75												
3.25												
3.75					1	1				1		
4.25	1		4		3	0			2	9	1	
4.75	3	1	16		8	2			4	14	2	
5.25	8	5	16	12	10	7	2	2	0	19	6	8
5.75	18	17	8	23	17	6	1	1	1	13	10	4
6.25	13	11		9	12	5	0		1	6	7	1
6.75	8	4		6	2		1			1		
7.25				0	1							
7.75				1	1							
8.25												
8.75												
9.25												
9.75												
Sum	51	39	44	53	55	21	4	3	8	63	26	13
Sample wt (g)	99	110	58	115	99	26	15	5	12	110	70	35

n = 380

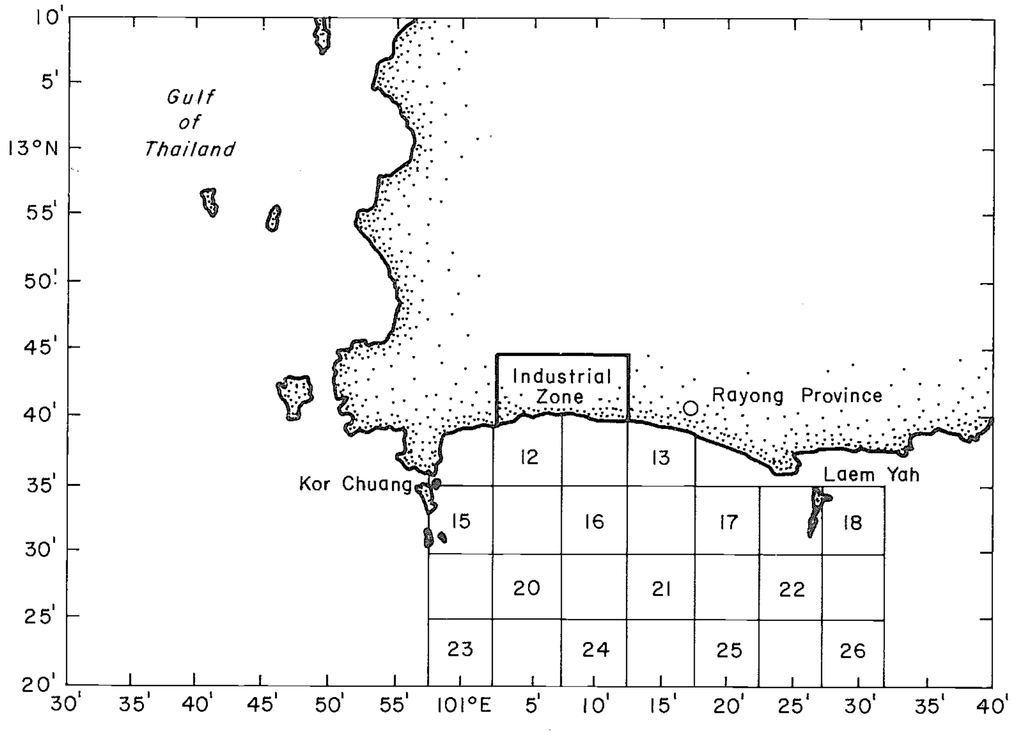

Fig. 1. Map of the survey-area from Laem Chabung, Chouburi Province to Laem Yah, Rayong Province.

Biomass and Stock in Numbers

The survey results were averaged monthly and converted into CPUA, by sex and depth statum, as shown in Fig. 2. Biomass (B) by depth strata for each sex of *M. palmensis* was calculated and the results are given in Tables 5 and 6. The biomasses were then added and raised to total stock number by applying the numbers per kg calculated from Tables 3 and 4. Station 13 is excluded from these calculations. The total areas of the two strata are, respectively, 17 x 25 = 425 nm^2 for the 10-19 m stratum and 7 x 25 = 175 nm^2 for the 20-30 m stratum, or 1,425 and 600 km^2, respectively.

The biomass estimates showed considerable scatter and it was not obvious that these estimates reflected any real variation in the biomasses. The scatter in the stock number was even higher because of the small sample sizes. The temporal changes came out more clearly after taking running averages of 3 months (Figs. 4 and 5). The main feature seemed to be a rather high level in the first half of the year and a drop of a lower level around August. Whether this low level is part of a seasonal cycle is not known.

Fig. 2 shows the abundance with depth. The CPUA is not much different. The *M. palmensis* seems evenly distributed in this area.

The mean lengths are calculated for the combined length distribution by sex and by depth stratum. The results are:

	Females		Males	
Depth (m)	10-20	20-30	10-20	20-30
Mean length (cm)	5.52	5.57	6.07	5.83
Std. Dev. (cm)	0.76	0.69	0.94	0.82

There does not seem to be any size stratification by depth in this area.

The sex ratio female:male is 1,278:985 or 1.3:1 suggesting a slight dominance of females.

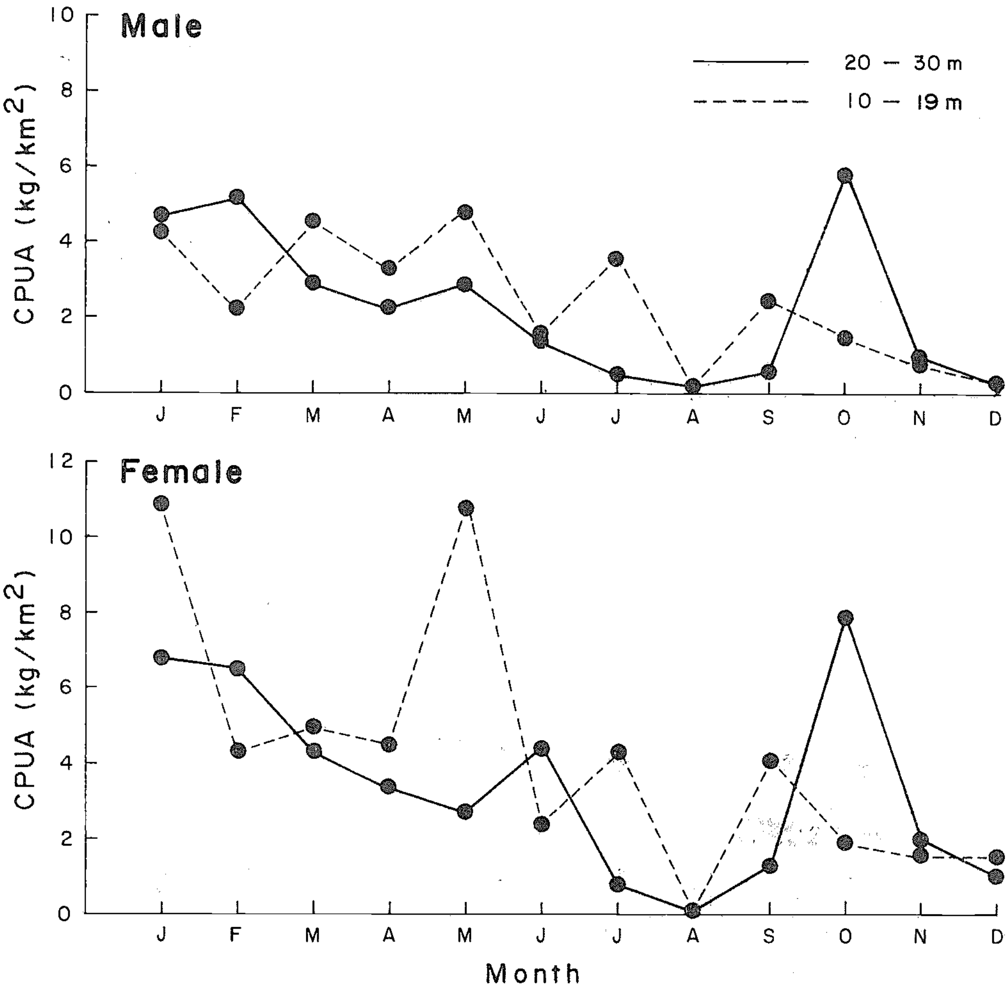

Fig. 2. Monthly mean CPUA with depth in male and female *M. palmensis*.

Table 5. Estimated monthly biomass of male *M. palmensis* in depth 10-19 m and 20-30 m.

Month	Depth 10-19 m		Depth 20-30 m		Biomass (tonnes)		
	$\overline{CPUA}$	$\sqrt{Var}$ / $\overline{CPUA}$	$\overline{CPUA}$	$\sqrt{Var}$ / $\overline{CPUA}$	Depth[a] 10-19 m	Depth[b] 20-30 m	Total
Jan	4.24	1.54	4.72	1.65	12.36	5.67	18.03
Feb	2.23	0.81	5.13	2.16	6.50	6.16	12.66
Mar	4.59	1.94	2.97	1.67	13.38	3.57	16.95
Apr	3.27	2.14	2.30	0.96	9.53	2.76	12.29
May	4.81	1.80	2.91	1.23	14.02	3.49	17.51
Jun	1.59	0.76	1.43	0.80	4.64	1.72	6.36
Jul	3.58	2.46	0.64	0.64	10.44	0.77	11.21
Aug	0.16	0.12	0.16	0.16	0.47	0.19	0.66
Sep	2.44	1.11	0.60	0.48	7.11	0.72	7.83
Oct	1.56	0.86	5.83	2.23	4.55	7.00	11.55
Nov	0.89	0.17	1.06	0.52	2.59	1.27	3.86
Dec	0.32	0.32	0.35	0.24	0.93	0.42	1.35

[a]Area 1,458 km^2.
[b]Area 600 km^2.

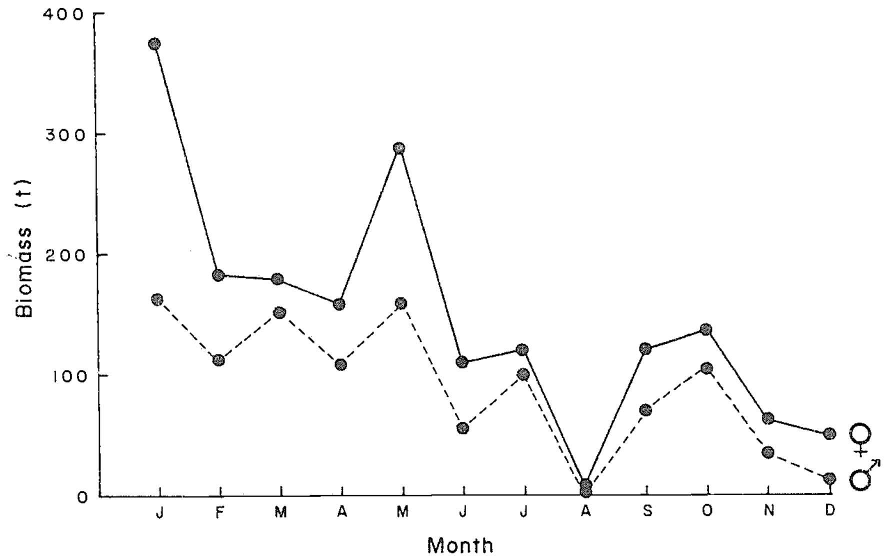

Fig. 3. Monthly estimated biomass of male and female *M. palmensis* off Rayong Province, 1982.

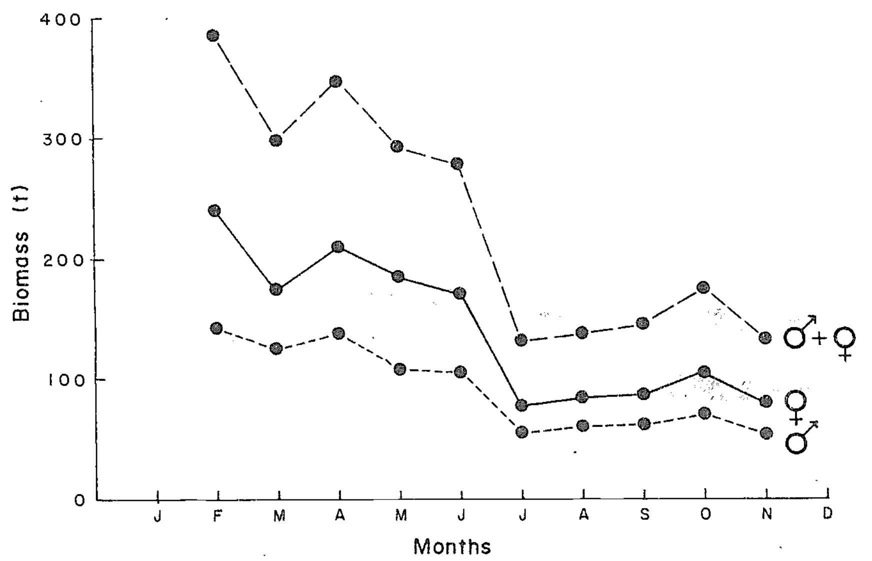

Fig. 4. Monthly estimated biomass (running average of 3) of male and female *M. palmensis* in depth 10-30 m off Rayong Province, 1982.

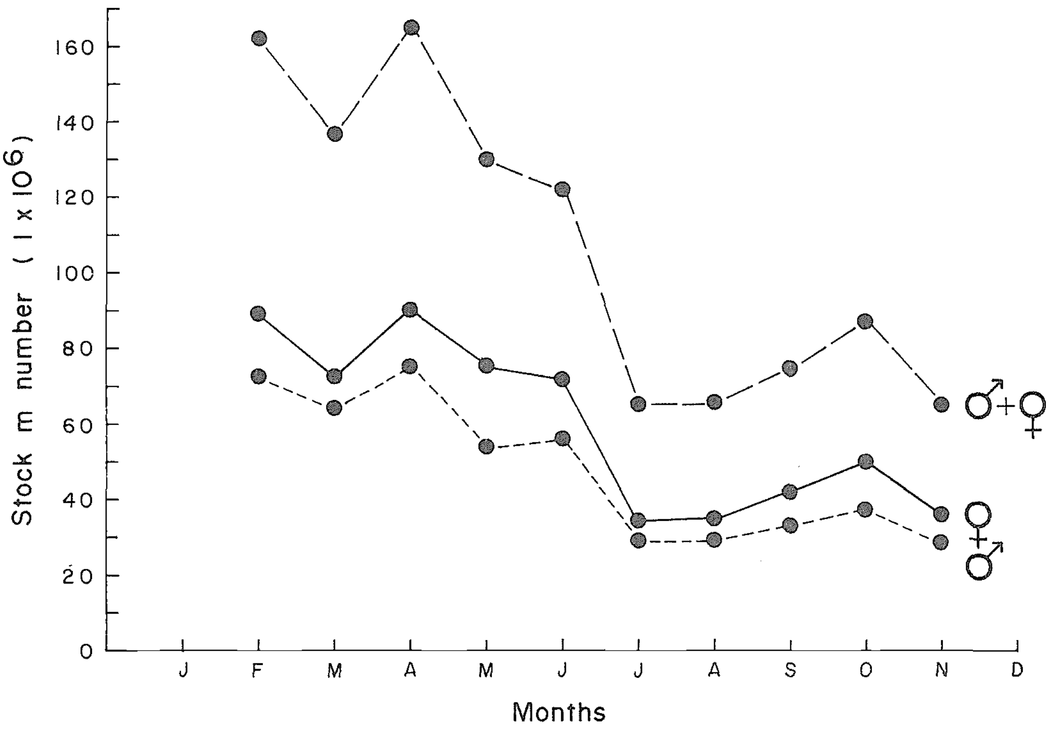

Fig. 5. Monthly stock in number (running average of 3) of male and female of *M. palmensis* in the depth 10-30 m off Rayong Province, 1982.

Table 6. Estimated monthly biomass of female *M. palmensis* in depth 10-19 m and 20-30 m.

Month	Depth 10-19 m		Depth 20-30 m		Biomass (tonnes)		
	$\overline{CPUA}$	$\sqrt{Var\ \overline{CPUA}}$	$\overline{CPUA}$	$\sqrt{Var\ \overline{CPUA}}$	Depth 10-19 m	Depth 20-30 m	Total
Jan	10.98	3.44	6.82	3.18	32.01	8.19	40.20
Feb	4.33	1.67	6.54	3.10	12.62	7.85	20.47
Mar	5.04	2.22	4.35	1.53	14.69	5.22	19.91
Apr	4.55	3.01	3.41	1.62	13.27	4.09	17.36
May	9.85	4.43	2.80	1.17	28.72	3.36	32.08
Jun	2.32	1.57	4.40	1.85	6.76	5.28	12.04
Jul	4.24	2.79	0.85	0.85	12.36	1.02	13.38
Aug	0.12	0.09	0.09	0.09	0.35	0.11	0.46
Sep	4.12	1.71	1.26	0.68	12.01	1.51	13.52
Oct	1.93	1.07	7.95	2.95	5.63	9.54	15.17
Nov	1.62	0.45	1.89	0.66	4.72	2.27	6.99
Dec	1.50	1.27	1.01	0.61	4.37	1.21	5.58

Table 7. Estimated monthly stock of male *M. palmensis* in depth 10-19 m and 20-30 m.

Month	Depth 10-19 m No/kg	Depth 10-19 m Stock (1×10^6)	Depth 20-30 m No/kg	Depth 20-30 m Stock (1×10^6)	Total stock (1×10^6)
Jan	430	5.31	515	2.92	8.23
Feb	495	3.22	354	2.18	5.40
Mar	587	7.85	759	2.70	10.55
Apr	430	4.10	461	1.27	5.37
May	511	7.17	556	1.94	9.11
Jun	467	2.17	808	1.39	3.56
Jul	545	5.69	267	0.20	5.89
Aug	428	0.20	600	0.12	0.32
Sep	423	3.01	667	0.48	3.49
Oct	742	3.37	573	4.01	7.38
Nov	421	1.09	371	0.47	1.56
Dec	466	0.44	371	0.16	0.60

Table 8. Estimated monthly stock of female *M. palmensis* in depth 10-19 m and 20-30 m.

Month	Depth 10-19 m No/kg	Depth 10-19 m Stock (1 x 10^6)	Depth 20-30 m No/kg	Depth 20-30 m Stock (1 x 10^6)	Total stock (1 x 10^6)
Jan	303	9.70	399	3.26	12.96
Feb	308	3.89	357	2.80	6.69
Mar	498	7.32	541	2.83	10.15
Apr	426	5.65	429	2.87	8.52
May	375	10.77	463	1.56	12.33
Jun	462	3.13	438	2.31	5.44
Jul	462	5.71	250	0.26	5.97
Aug	364	0.13	667	0.07	0.20
Sep	455	5.46	440	0.67	6.13
Oct	391	2.20	567	5.41	7.61
Nov	367	1.73	456	1.03	2.76
Dec	257	1.12	420	0.50	1.62

Discussion

Monthly mean length size of male and female *M. palmensis* is nearly constant all year-round (about 5-7 cm) and independent of depth. Females are slightly bigger than males in agreement with other studies (Grey and Dall 1983).

Shrimps and prawns, in general, migrate between areas (nursing, feeding and spawning). The maximum sizes of *M. palmensis* are 105 mm for females and 85 mm for males (Grey and Dall 1983). The length-frequency data for both male and female here lack both the smaller and the upper range. It may be possible that the small ones migrate to the survey area and then as they grow, migrate to other areas. This process has a high turnover, so the mean length remains constant all year-round.

Metapenaeopsis palmensis seems to be very evenly distributed over the entire survey area; also no difference in density seems apparent.

The data show a rather wide scatter making estimates about mortalities and growth a futile effort.

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Population Dynamics of *Nemipterus japonicus* (Pisces: Nemipteridae) off Kedah State, Malaysia

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Abstract

Length-frequency data for 1985, derived from the combination of commercial and "trash" size fish sample from trawl landings were used to estimate the growth parameters and exploitation rate of *Nemipterus japonicus* in the waters off Kedah State. The growth parameters L_∞ and K were estimated using the ELEFAN method and total mortality estimation and correction for gear selection, based on a length-converted catch curve. The following estimates were obtained: $L_\infty = 31.4$ cm, K = 0.55 ($year^{-1}$), Z = 3.72, M = 1.21, and F = 2.51 (all $year^{-1}$), respectively. The estimated mean size at first capture is 7.35 cm. *N. japonicus* is recruited into the fishery through a single annual pulse.

Introduction

The fishes of the family Nemipteridae, popularly known as threadfin breams or "Ikan Kerisi" in Malay, are a fairly important group of demersal fish, both in terms of their commercial value as well as relative abundance. They are caught by trawlers operating in areas about 5-20 nautical miles off the Kedah coast. (Fig. 1). Fishing concentrates around the island of Langkawi but reaches as far as Perak Island. Two types of trawl nets are used: fish trawls (high opening net) and prawn trawls (low opening net). The minimum legal cod-end mesh size is 38 mm, but the effective mesh size of the cod-end of the prawn trawl is probably lower. Therefore the trawl catches include a considerable quantity of small-sized individuals, landed as "trash" fish which is used for fish meal. Commercial sized nemipterids are sold fresh or are processed into fish balls.

Nemipterids contribute about 5% to the total trawl landings and make up about 13% of the total landings of demersal species off Kedah State. *Nemipterus japonicus* is one of the important species and forms about 40% of the total landings of Nemipteridae in Kedah State.

According to Senta and Tan (1975), *N. japonicus* is a relatively large nemipterid, mostly ranging from 14 to 20 cm (standard length). It is also geographically the most widely distributed species indicating its adaptability to different environmental conditions. It was, for example the only nemipterid caught by *R/V Changi* in the Andaman Sea, where the fishing grounds were shallow and less saline because of river inputs. Eggleston (1972) found that *N. japonicus* occurs from very shallow waters to a maximum of 30 fathoms (about 50 m). The small-sized fish are mostly found in less than 15 fathoms (25 m), whereas the big ones occur at depths greater than 25 fathoms (45 m). Weber and Jothy (1977), reported similar distributions off Sabah and Sarawak. *N. japonicus* is thus clearly an inshore species.

There have been few attempts to estimate the growth parameters of *N. japonicus*. Weber and Jothy (1977) estimated mortality rates based on size (age) groups identified using the Cassie method. Based on their data, Pauly (1978) estimated the growth parameters of *N. japonicus* from the northern part of Borneo. Other growth parameter estimates may be found Krishnamoorthi (1971) and Lee (1975).

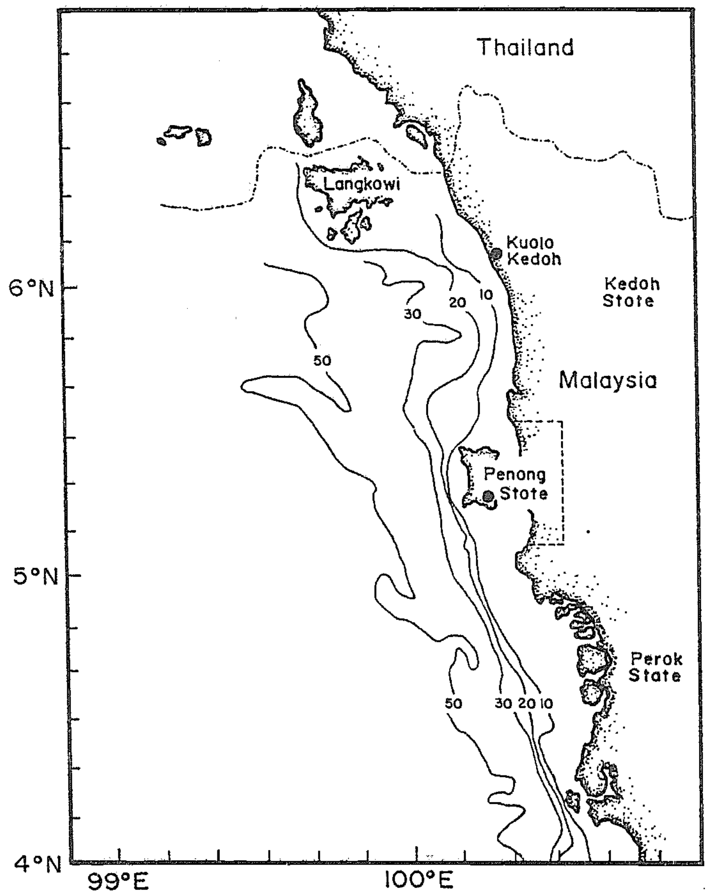

Fig. 1. Coasts of Kedah, Penang and Perak States, Malaysia (all depths in fathoms).

This present analysis utilizes data on *N. japonicus* collected in Kuala Kedah in 1985 and attempts to determine growth parameters and exploitation rate. Kuala Kedah was chosen because it is an important landing center of Kedah State. Fishing is carried out throughout the year, except during festivities and regular monthly data are available. The biological study carried out is part of the monitoring sampling program of the Fisheries Research Institute, Glugor, Penang.

Materials and Methods

The material was largely drawn from the data collected regularly at Kuala Kedah. The samples were taken monthly for three consecutive sampling days. The landings figures were obtained from trawls landings at the jetty. The samples were grouped into single species and a trash fish component consisting of a mixture of species.

Length Measurements

Since the upper lobe of the caudal fin in *N. japonicus* proceeds into a long filament, the length measurement (to cm below) were taken as total length, defined as the length from the tip of the snout to the tip of the lower lobe of the caudal fin. Contrary to common practice, the lower lobe was not bend towards the center when measuring. This means that the slight difference in length measurements between the length frequency data presented here and those obtained elsewhere should be taken into account.

Type of Data Used for the Analysis

For the analysis, there are two different data sets collected both for a biological study of length-frequency distribution of *N. japonicus* and for a trawl catch species composition study, which allowed the total catch of *N. japonicus* to be calculated.

Length-frequency data -- the biological study

Data for commercial category samples of *N. japonicus* consist of the length measurement for the months of January to December 1985, obtained from the combined landings of several boats irrespective of vessel size. For every month, about 200-300 specimens were measured using a weighing balance (up to 5 kg). The sampling procedure is outlined in Fig. 2.

The trash fish landing is not sorted into species. It contains fish species not used for human consumption and also commercial fish species below market size. For each month during 1985, approximately four to five samples of about 5 kg of trash fish were taken and sorted into species. The sorted samples of *N. japonicus* were measured in units of 1 cm. Fig. 2 describes the sampling procedure.

Species composition data

In order to estimate the total monthly catch of *N. japonicus* (and other species of *Nemipterus* spp.) a regular species composition program was carried out by the Fisheries Research Institute, Penang. The total monthly landings of *Nemipterus* spp. and trash from trawl landings for the state of Kedah were obtained from the Annual Fisheries Bulletin at Fisheries Headquarters. The data are reported by species groups and landings are subdivided into 4 vessel groups according to tonnage. The regular sampling program for species composition was conducted using only the following three categories of trawlers since the two smallest vessel groups have been pooled:

i) vessel size < 25 gross tons (gt), using mainly prawn trawls;
ii) vessel size 25-40 gt, using mainly both fish and prawn trawls;
iii) vessel size > 40 gt, using mainly fish trawl net.

The composition study provides data for January to December 1985 and allows to determine the percentage of *N. japonicus* in the total catch of commercial nemipterids and trash landings. The sampling was carried out at three different places in Kuala Kedah. The commercial-sized catch of *Nemipterus* spp. and trash catch were sorted and weighed. For the small trash size of *N. japonicus,* a 500 g weighing balance was used to obtain precise estimates of the sample weight.

The total landings of *Nemipterus* spp. and trash were recorded at every sampling month. Fig. 3 shows the sampling technique. Since the sample size of the length-frequency samples of the biological study varies from 150 to 250 per month, it was attempted also to use the length-frequency samples from the composition study. The monthly length-frequency samples of commercial-sized *N. japonicus* from the biological study and from the composition study are shown in Table 1. In order to check whether the two data sets represent the same length distribution, a statistical test for identical distrubtion was carried out for each month. The X^2 statistic is given for each month in the bottom row of Table 1 (Snedecor and Cochran 1967). Each statistic is X^2 distributed with one degree of freedom and the 5% significance level corresponds to a value of 3.84. It appears from Table 1 that the four samples are significantly

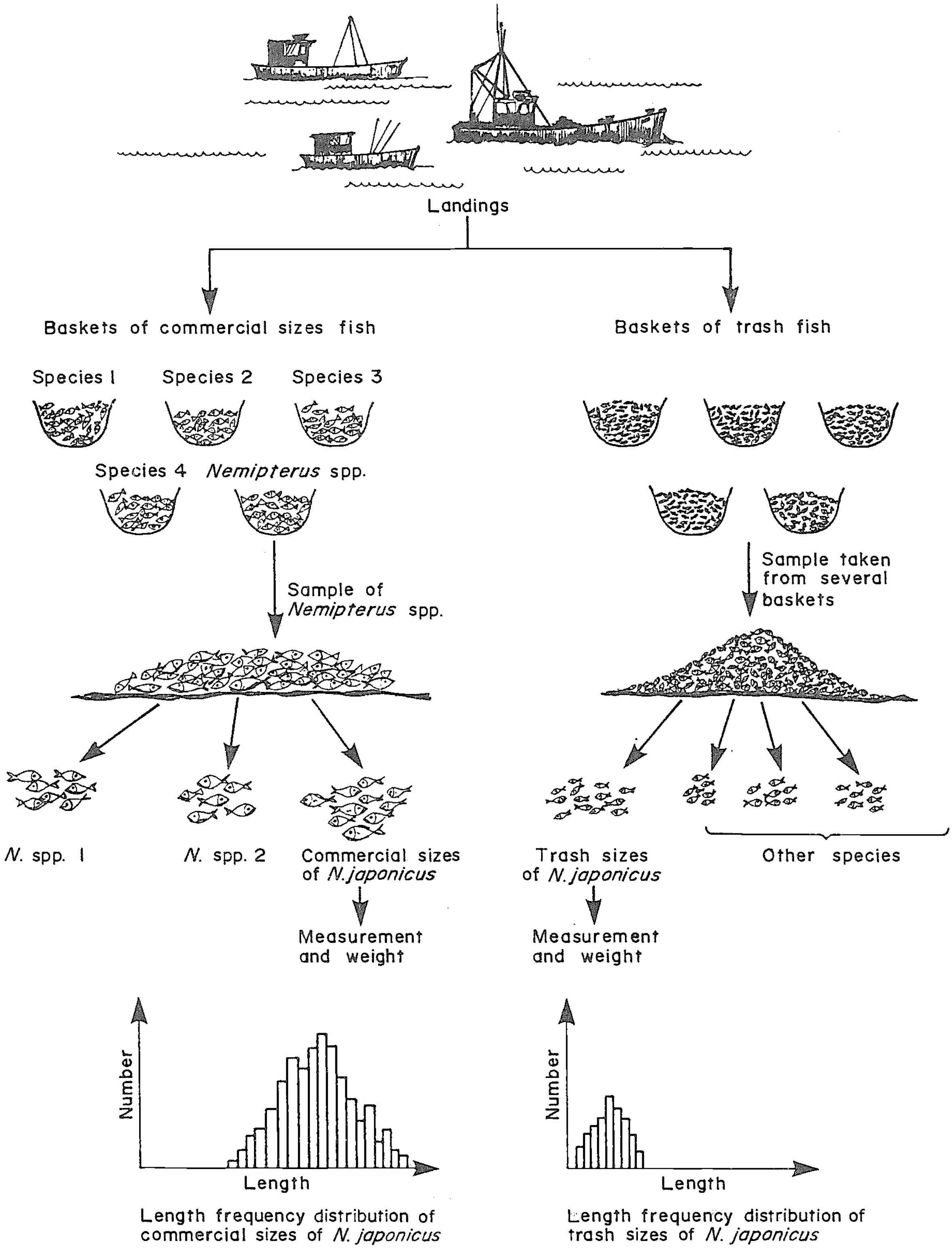

Fig. 2. Representation of the sampling scheme for length-frequency data from several trawlers of different sizes in Kuala Kedah, Kedah State, Malaysia.

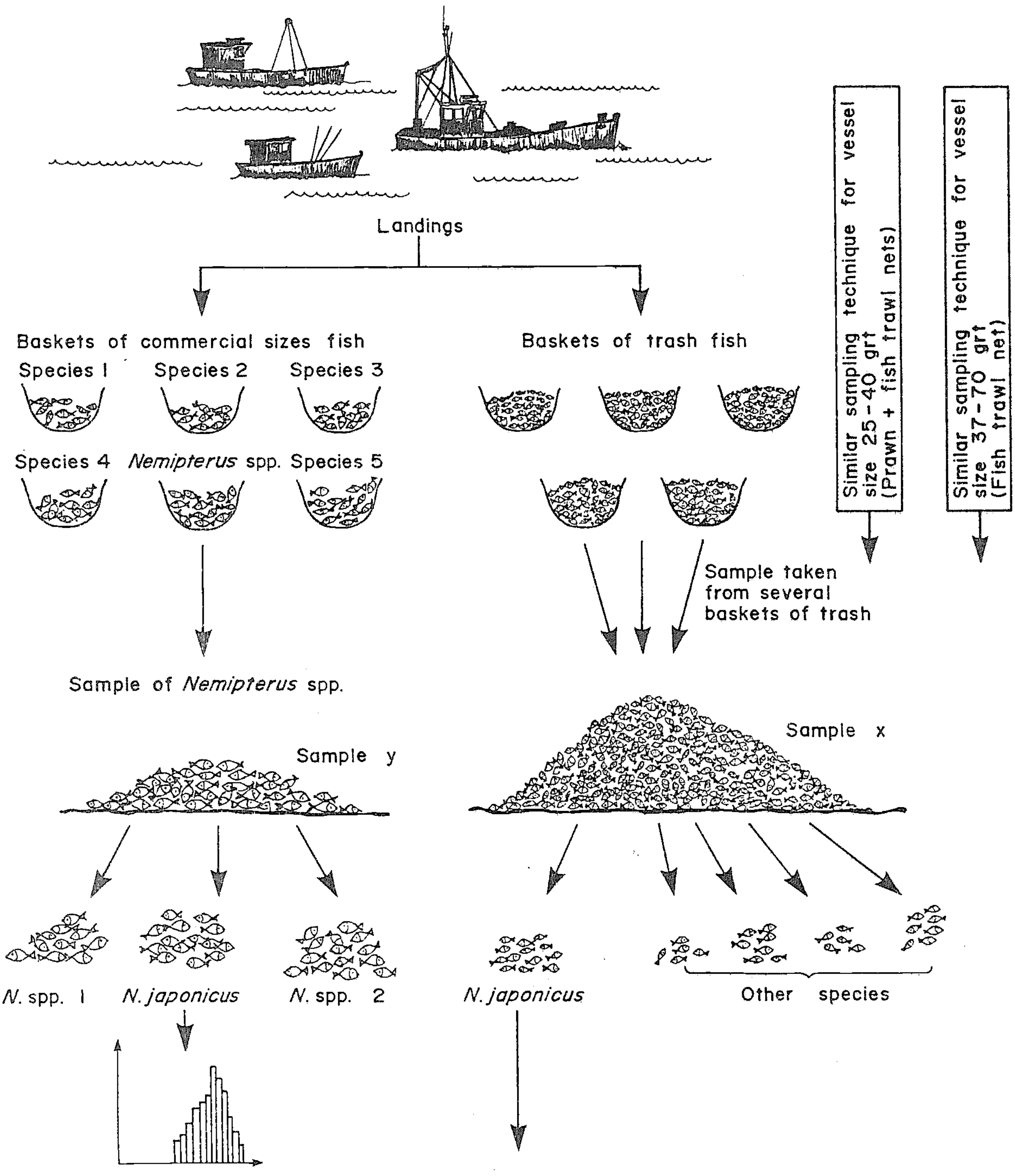

Fig. 3. Sampling procedure for the species composition of *N. japonicus* in the commercial size and trash size trawl landing with respect to vessel size group in Kuala Kedah, Kedah State, Malaysia.

Table 1. The use of Chi-squared method to differentiate two sets of length-frequency data of *N. japonicus* sampled from both biological and catch composition studies in Kuala Kedah, Kedah State, Malaysia, 1985. (February, April and June are omitted for lack of comparable samples).

Mid-length (cm)	Jan		Mar		May		July		Aug		Sep		Oct		Nov		Dec	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
10.5	2							1	2	2		1		1			1	
11.5	24		13		1				2	2	3		17	2	1		13	2
12.5	53	2	30	2	22		6	4	17	7	13	2	29	2	9	1	32	2
13.5	36	2	75	1	52		20	7	28	3	26	1	32	2	14	1	27	3
14.5	57	3	54	6	48	2	26	5	14	6	53	1	31	1	12	2	35	2
15.5	32	7	16	7	27	2	21	5	26	4	34	3	18	3	8		29	
16.5	20	6	6	10	25	2	34	4	45	7	20	2	22	2	5	1	17	1
17.5	16		5	1	7	1	44	5	40	5	13	2	19	5	3		24	
18.5	16	1	2		8		24	1	11	1	9	4	23	6	4	1	19	
19.5	13				5		16	1	5	1	14	4	7	4	1	1	15	
20.5	11				1		6	1	3	1	5	2	6	6	1	2	14	6
21.5	5				1		3	1	4		5		1	2	1	3	6	3
22.5	2						2				1		3				3	3
23.5	1				2			2	1	1	3	1				1	2	
24.5	1				2												1	2
25.5	1				1													1
26.5																	1	1
TOTAL # OF SAMPLES	290	21	201	27	202	7	202	39	198	40	199	22	208	35	59	13	238	27
X^2	0.1377		39.69		0.004		1.63		3.02		11.21		12.86		11.75		0.86	

X^2 = 81.164 (d.f. = 9)

A - Length frequency from biological data.
B - Length frequency from composition study.

different in March, September, October and November 1985. The combined test statistic for all months is 81.2 (d.f. = 9) which is clearly significant at the 5% level which critical value = 16.92.

The above result shows that the composition study gives higher average lengths than the biological study. It was concluded that this might be caused by a very low sample size in the composition study. It often appears that a small sample size leads to biased samples of relatively large fish. Hence in this study, only length-frequency data from the biological study will be used.

Combination of Samples

The proper method for calculating the catch data of *N. japonicus* would be to apply the average percentage of *N. japonicus* in the landings of *Nemipterus* spp. within each vessel group. For the trash landings, the average percentage of *N. japonicus* should be multiplied with the total trash catch for each catch vessel group separately. However, during the processing of data it was noted that species composition samples were missing for some vessel groups in some months. Samples from an adjacent vessel group could be used, but this would involve a considerable amount of regrouping of vessels. The percentage of *N. japonicus* varied very little from one vessel group to another. Therefore average monthly percentages of *N. japonicus* in the *Nemipterus* spp. and in trash landing were calculated. Multiplying these to the total catch of commercial-sized *Nemipterus* spp. and to the total catch of trash fish, the catch of *N. japonicus* in the trawl landings of Kedah State was derived.

The length-frequency data of *N. japonicus* from the commercial and trash catch were raised separately, before being combined. The length frequency of the commercial size was first raised to the total weight of *N. japonicus* in the *Nemipterus* spp. group, whereas for the trash size it was raised to the total trash landings. Then the two sets of frequency data were pooled. This then became the basic estimate of the length distribution of *N. japonicus* in the catch and the basis for the estimation of growth parameters and exploitation rate. The data are given in Table 2.

Table 2. Length-frequency data of *N. japonicus* from the commercial size (C) and trash (T) landings of trawler from one landing center of Kuala Kedah, Kedah State.

Month	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Mid-length	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
3.5		1																						
4.5		3		1				1		1										4				1
5.5		11		1		1		1						2						10		5		1
6.5		5		3		1		3					1	8						4		2		1
7.5		2		2		14		3		4		1		6						6			2	8
8.5		2		2		17		11		5				1		1				6				4
9.5		4				14		11		2		2		8		2				3		3		3
10.5	2	6	1			15		17		10		5		8	2	3				2				5
11.5	24	3	6		13	3		11	1	12	3	4		8	2	2	3		17	2	1		13	4
12.5	53	3	35		30	2	9	6	22	12	20	1	6	3	17	4	13	1	29		9		32	3
13.5	36	1	67		75	1	10	1	52	2	37	1	20		28		26		32		14		27	2
14.5	57	1	69		54	1	5		48		23		26	1	14	1	53		31		12		35	
15.5	32	1	49		16		10		27		14		21		26	1	34		18		8		29	
16.5	20		35		6		4		25		17		34		45		20		22		5		17	
17.5	16		18		5		12		7		9		44		40		13		19		3		24	
18.5	16		14		2		13		8		19		24		11		9		23		4		19	
19.5	13		5				1.1		5		9		16		5		14		7		1		15	
20.5	11		6				13		1		5		6		3		5		6		1		14	
21.5	5		6				9		1		1		3		4		5		1		1		6	
22.5	2		2				5						2				1		3				3	
23.5	1						5		2		1				1		3						2	
24.5	1						1		2														1	
25.5	1		1				1		1															
26.5																							1	
Total sample size	290	34	314	9	201	69	108	65	202	48	158	14	202	45	198	14	199	1	208	37	59	10	238	32
Total sample weight (g)	11470	429	15483	64	9962	947	12134	1051	8514	900	9717	199	16873	608	9456	184	12471	28	12894	236	5226	59	22477	483
Average weight (g)	39.55	12.61	49.31	7.10	49.56	13.72	112.35	16.17	42.15	18.74	61.50	14.22	83.53	13.51	47.76	13.15	62.67	27.50	61.99	6.37	88.57	5.94	94.44	15.10
Total catch of *N. japonicus* (kg)	45058	82644	43340	34539	51430	165282	26673	163009	14038	33006	18291	43050	38672	86466	31711	13877	32293	51915	20663	25895	1816	18056	10330	32754

Methods Used for the Analysis of Growth Parameters and Exploitation Rate

i) The Wetherall method was used to estimate the L_∞ and Z/K (Wetherall 1986; Pauly 1986a)

ii) The growth parameters L_∞ and K of the von Bertalanffy equation for growth in length were then estimated using the ELEFAN I program (Pauly and David 1981). The method restructures the length-frequency data and the growth curve which has the best fit to the peaks is identified.
estimates of L_∞ and K. The catch curve analysis allows the total mortalilty Z to be calculated. The initial values of L_∞ and K were used as inputs in the empirical equation given by Pauly (1980) together with environmental temperature to estimate natural mortality M. From the estimate of Z and the estimated value of F the exploitation rate E = F/Z can be derived.

iv) The resultant curve was estimated from the catch curve following the procedure recommended by Pauly (1986b). The routine smoothes a set of probability of capture over different length classes, so that a resultant curve is established. The estimated mean size at first capture is derived. Correcting each length class for mesh selectivity, a new set of length-frequency data was derived.

v) Using the new corrected length-frequency data, procedures (ii) and (iii) were repeated. A new set of growth parameters, corrected for selection was identified and used to draw a new catch curve.

vi) The ELEFAN software package also provides a description of the recruitment pattern using the final growth parameters obtained in (v). The recruitment pattern is obtained by projecting a set of length-frequency data backward onto a one year time axis (Ingles and Pauly 1984).

vii) Finally, the optimum level of the exploitation rate (E) was estimated, using the relative yield/recruit model of Beverton and Holt (1966) as modified by Pauly and Soriano (1986).

Results

Estimates of L_∞ and Z/K

The raised length-frequency data were added for all months. The Wetherall plots were made for both 1 cm and 2 cm intervals. The 2 cm class interval seems to reduce the "noise" in the data and gives a better fit to a straight line. Using all points above 13.0 cm, the estimates of L_∞ and Z/K are 34.2 cm and 7.123, respectively (Fig. 4).

Estimates of the von Bertalanffy Growth Parameters

The growth curve fitted by ELEFAN gave different values of L_∞ and K for the 1 cm class interval (Fig. 5A) and for 2 cm class interval (Fig. 5B). The 2 cm class interval gave better estimates of L_∞ and K, because the peaks in the restructured length-frequency data were more clearly outlined and this enabled a good fit of the growth curve to be obtained. The best estimates of L_∞ and K for the 2 cm class interval are L_∞ = 31.5 cm and K = 0.53, respectively.

Length-Converted Catch Curve and the Resultant Curve

The Pauly formula for M, used with L_∞ = 31.5 cm, K = 0.53 and T = 29°C, gave an M = 1.18. Using the estimated values of L_∞ and K and M, a length converted catch curve was constructed in order to estimate probabilities of capture by length (Fig. 6A).

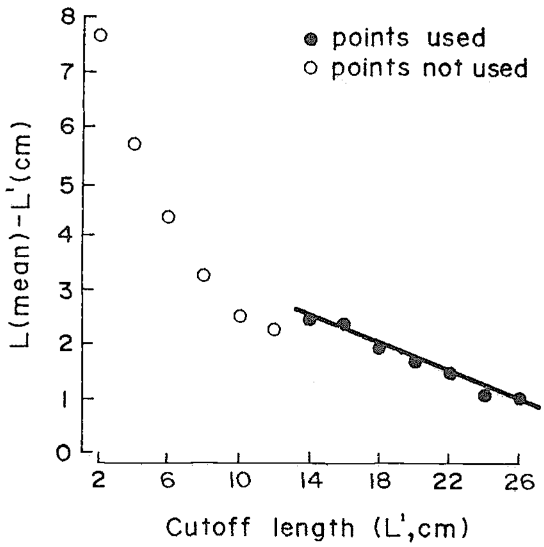

Fig. 4. Estimation of L_∞ = 34.2 cm and Z/K = 7.123 in *N. japonicus* from northwest Penang, Malaysia, using the modified Wetherall plot.

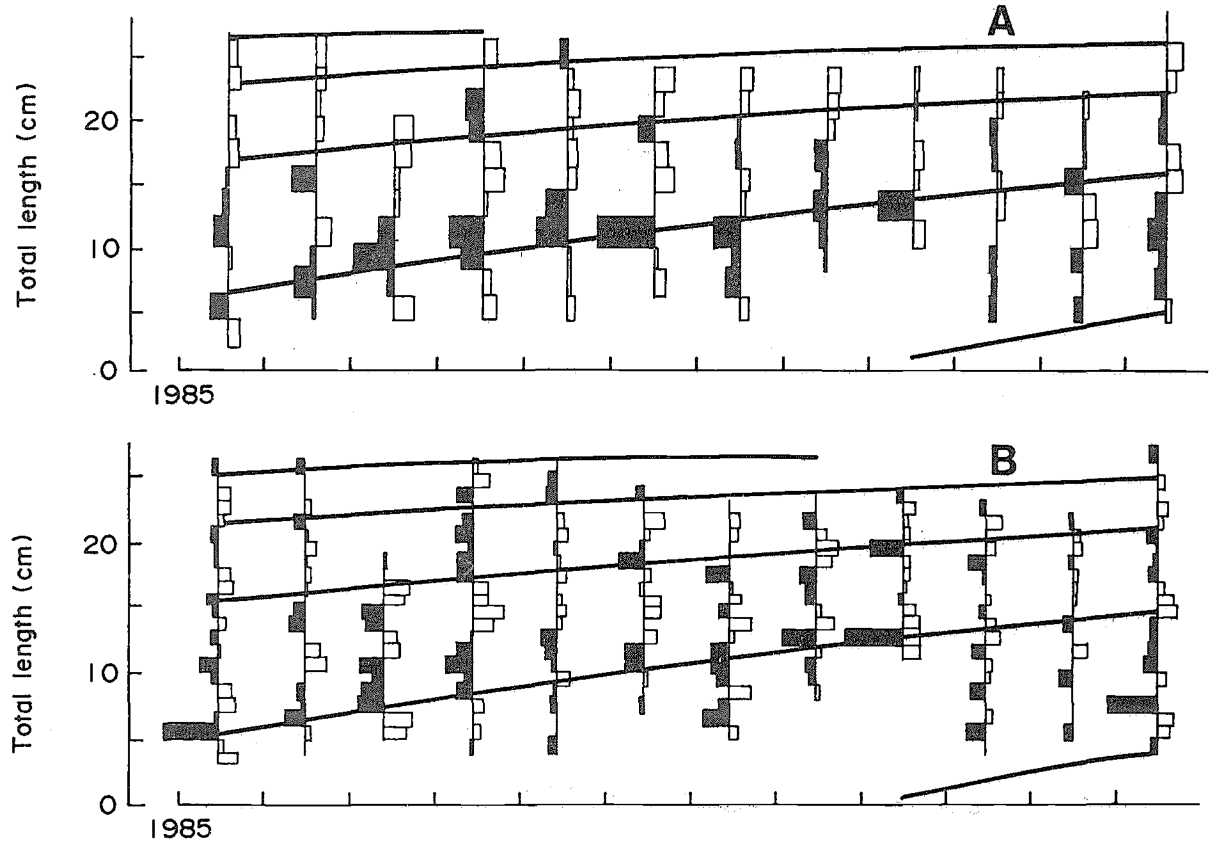

Fig. 5a. Restructured length-frequency data (ELEFAN I) and superimposed growth curve for *N. japonicus* using a class interval of 1 cm, as derived from uncorrected data. Estimated values are L_∞ = 30.5 cm and K = 0.51 with starting sample (SS) = 9 and starting length (SL) = 12.50. b. Restructured length-frequency data (ELEFAN I) and superimposed growth curve for *N. japonicus* using a class interval of 2 cm, as derived from uncorrected data. Estimated values are L_∞ = 31.5 cm and K = 0.53 with starting sample (SS) = 6 and starting length (SL) = 11.00.

The selection curve resulting from the combined effect of mesh selection and recruitment curves was then derived. Using a logistic transformation, the set of probability of capture was smoothed and the smoothed probabilities (Fig. 6B) used to correct the 2 cm length-frequency data file.

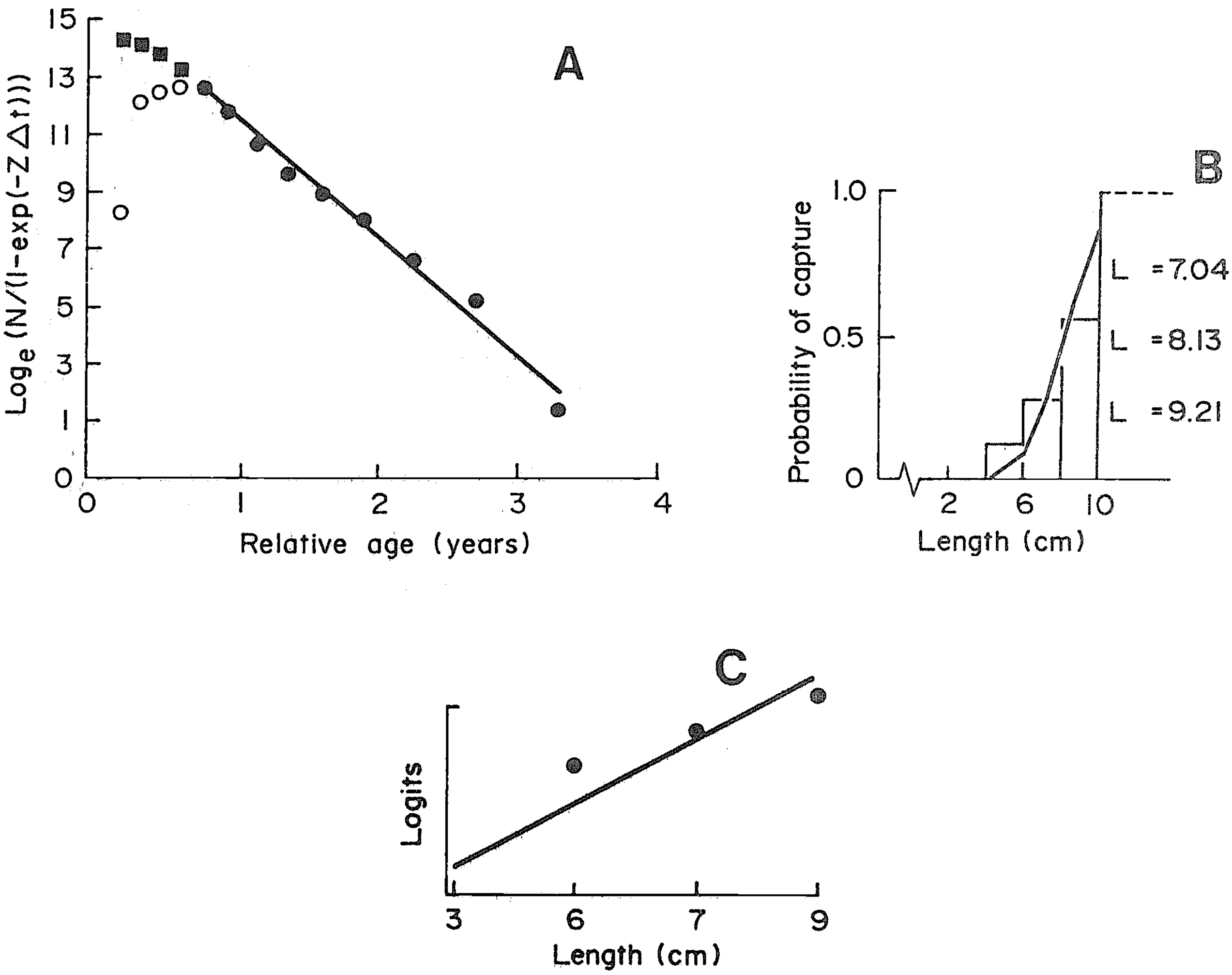

Fig. 6a. Length-converted catch curve of *N. japonicus* as derived (from uncorrected data) to estimate the mortality rate using growth parameter estimates of L_∞ = 31.5 cm, K = 0.53 (y^{-1}) and a temperature of 29°C. The estimated values are M = 1.18, Z = 4.02 and E = 0.706. b. The corresponding resultant curve. c. Logistic transformation of B.

Estimated Values of L_∞ and K After Correction for Selection Pattern

The values of L_∞ and K obtained from the corrected length-frequency data and the ELEFAN program were 31.4 cm and 0.55, respectively. The growth curve is shown in Fig. 7 superimposed onto the restructured data.

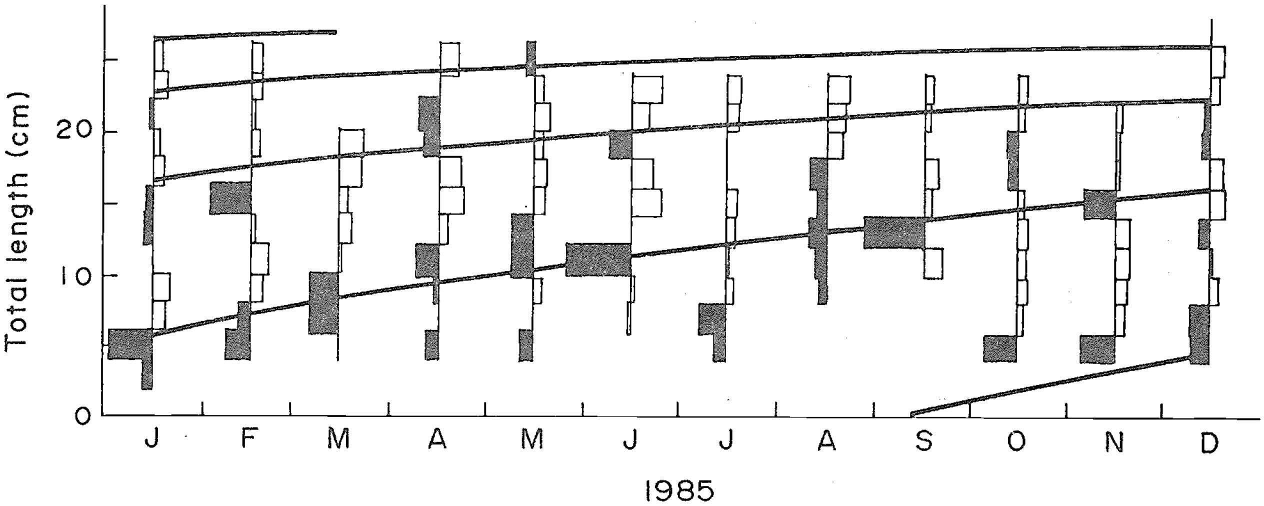

Fig. 7. Growth curve of *N. japonicus* as derived from corrected data. The estimated values are L_∞ = 31.4 cm and K = 0.55 with starting sample (SS) = 6 and starting length (SL) = 11.00 cm.

Length-Converted Catch Curve and the Resultant Curve Using the Final Values of L_∞ and K

Fig. 8 shows the length-converted catch curve using the final values of L_∞ and K. The values of Z, F and E obtained are: Z = 3.72, F = 2.51 and E = 0.68. The new estimate of M obtained from Pauly's formula is M = 1.21, and the estimated mean size at first capture is 7.4 cm (Fig. 8).

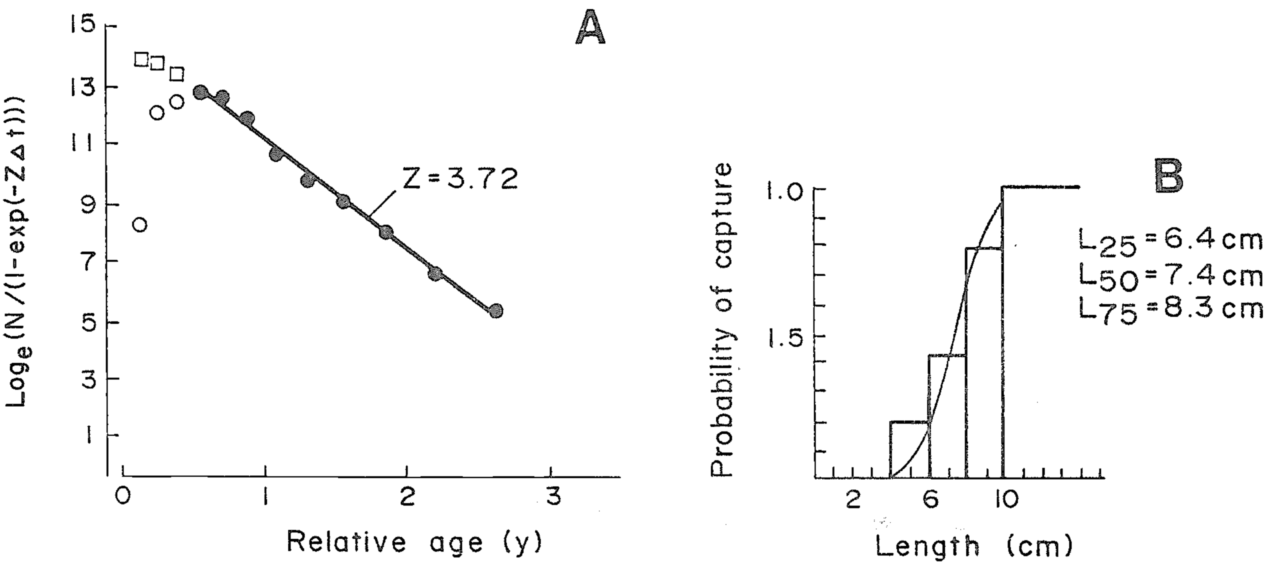

Fig. 8. Length-converted catch curve (A) and resultant curve (B) for *Nemipterus japonicus* off northwest Penang, Malaysia. Based on L_∞ = 31.5, K = 0.55 and M = 1.21.

Recruitment Pattern

Fig. 9 shows the recruitment pattern of *N. japonicus* using L_∞ = 31.4 cm and K = 0.55. The figure suggests that there is only one recruitment pulse per year.

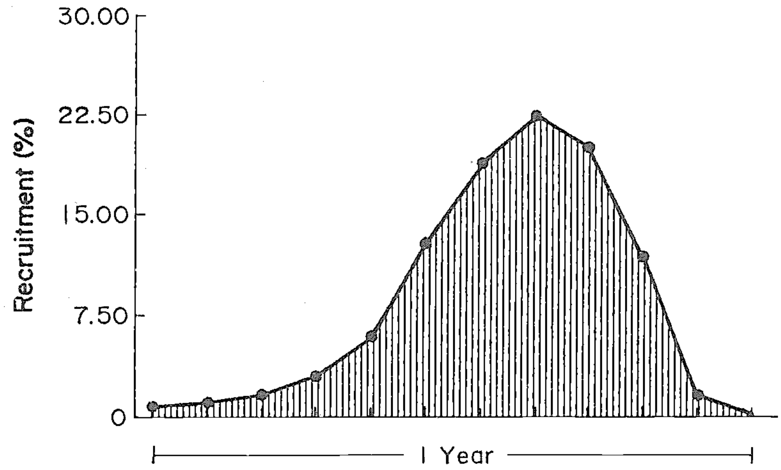

Fig. 9. Recruitment pattern of *N. japonicus* off Kedah State, showing single annual pulse of recruitment.

Yield per Recruit and Biomass per Recruit

Using the final values of L_∞ and K together with the probabilities of capture obtained from the selection curve, yield per recruit and biomass per recruit were computed as shown in Fig. 10A and Fig. 10B, respectively. As might be seen, yield per recruit reaches a maximum at the exploitation rate of 0.46. As the exploitation rate increases beyond this value, yield per recruit decreases.

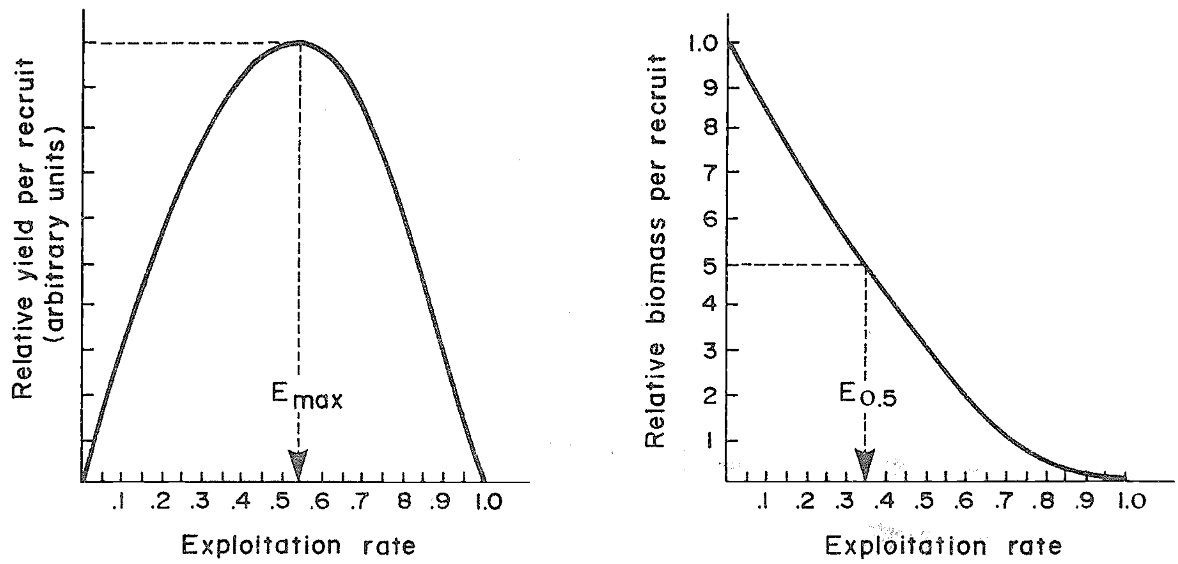

Fig. 10. Relative yield per recruit and biomass per recruit as a function of exploitation rate (E = F/Z) in *Nemipterus japonicus* from northwest Penang, Malaysia. Used were L_∞ = 31.4 cm, K = 0.55, M = 1.21, the smoothed probabilities of capture in Fig. 8b and the method of Pauly and Soriano (1986).

Discussion

Class intervals of 1 and 2 cm of *N. japonicus* were used to estimate L_∞ and Z/K values using the revised version of Wetherall's method. The 2 cm class interval gives a better estimate.

The index of fish growth performance of Pauly and Munro (1984), ϕ' obtained in this study from the uncorrected length-frequency data is quite close to that obtained in Manila Bay (as shown in Table 3). Comparison of the growth parameters as estimated from the corrected length-frequency data is difficult, because most of the estimates obtained from other authors have not been corrected for selection (D. Pauly, ICLARM, pers. comm.). In this study the value of L_∞ obtained from the corrected data decreases slightly and the K value increases slightly compared to an analysis on uncorrected data, as would be expected. The growth parameters obtained after correction for selection probably give better estimates provided the selection is estimated correctly. The method depends on three basic assumptions: a) the gear used creates trawl type selection curves, b) the smallest fish are subjected only to natural mortality and that 3) the mortalities for the length groups which are not fully exploited can be calculated by interpolation (Pauly 1984).

Table 3. Growth parameter estimates, mortality rate and exploitation rate of *N. japonicus* in various areas of the Indo-Pacific[a].

Areas	L_∞	K	Ø	Z	F	M	E	L_c	Remarks	Authors
India (Andhra-Orissa)	30.5	0.314	2.47	0.37	0.01	0.36	0.03	N.A	1964-1965	Krishnamoorthi (1971)
	20.9	0.648	2.45	0.57	0.01	0.56	0.02	N.A	1965-1966	"
	30.3	0.294	2.43	0.61	0.02	0.59	0.03	N.A	1966-1967	"
Hongkong	34.1	0.190	2.34	1.32	N.A	N.A	N.A	N.A	Females	Lee (1975)
	38.2	0.130	2.28	1.43	N.A	N.A	N.A	N.A	Males	"
Manila Bay, Phil.	30.0	0.700	2.80	3.31	1.90	1.41	0.51	14.8	1978-1979	Ingles and Pauly (1984)
Carigara Bay, Phil.	23.5	0.730	2.61	2.49	0.98	1.52	0.39	12.6	1981-1983	Corpuz et al. (1985)
Samar Sea Phil.	26.5	0.600	2.62	2.09	0.80	1.29	0.38	12.0	1981-1983	"
Northern Burma	37.0	0.235	2.51	0.92	N.A	N.A	N.A	12.7	1979-1982	Pauly and Sann Aung (1984)
Southern Burma	37.0	0.243	2.52	0.94	N.A	N.A	N.A		1979-1982	"
Northern Borneo, Malaysia	28.9	0.470	2.59	2.28	N.A	N.A	N.A	N.A		Weber and Jothy (1977); Pauly (1978)
Kedah State, Pen. Malaysia	31.5	0.530	2.72	4.02	2.84	1.18	0.71	8.13	uncorrected for selection	This study
	31.4	0.550	2.73	3.72	2.51	1.21	0.68	7.35	corrected for selection	"

N.A: Not available.
[a]All analyses are based on length-frequency data except for Hongkong stock, which are based on scales and otoliths.

The length at first capture is very small as compared to other findings, as shown in Table 4. The value of L_C obtained in this study is rather small, about 7.4 cm, as compared to the one obtained from Manila Bay (Ingles and Pauly 1984), which is about 14.8 cm (Table 3). Using a selection factor obtained from Jones (1976), L_C was calculated as follows:

$$\begin{aligned} L_C &= \text{S.F. x mesh size} \\ &= 3.3 \times 38 \\ &= 12.5 \text{ cm} \end{aligned}$$

As earlier mentioned, the actual mesh size is probably much lower than 38 mm, therefore the estimated L_C obtained from the length-frequency data is more or less similar to the one obtained using Jones' selection factor. These results support the selection curve that was applied and thus support the estimated growth parameters.

The estimates of mortality and exploitation rates obtained are lower after correction for selection. The values for Z before and after correction are 4.02 and 3.72, respectively (Table 4). Together with the high value of E of about 0.68, these rates indicate that the stock is overexploited in the area studied. The optimum exploitation rate is much lower at E = 0.53 (Fig. 10A).

The recruitment pattern of *N. japonicus* as shown in Fig. 9 suggests the occurrence of a single pulse of recruitment per year. This is similar to other areas, especially in the Samar Sea and Carigara Bay (Philippines) (Corpuz et al. 1985).

The approach of using length-frequency data to estimate the growth parameters and exploitation rate of *N. japonicus* off Kedah State gives acceptable results. The accuracy of the estimates, however, depends solely upon the length-frequency data used. It is therefore recommended that sampling be increased in order to cover all vessel groups on a regular monthly basis.

Table 4. The mortality rate and exploitation rate of *N. japonicus* in various areas of the Indo-Pacific.

AREAS	Z	F	M	E	L_c	REMARKS	AUTHORS
India (Andhra-Orissa)	0.366	0.0113	0.3550	0.031	N.A.	1964-1965	Krishnamoorthi (1971)
India (Andhra-Orissa)	0.574	0.0105	0.5638	0.018	N.A.	1965-1966	Krishnamoorthi (1971)
India (Andhra-Orissa)	0.609	0.0168	0.5925	0.028	N.A.	1966-1967	Krishnamoorthi (1971)
Hongkong	1.320	N.A.	N.A.	N.A.	N.A.	Females	Lee (1975)
Hongkong	1.430	N.A.	N.A.	N.A.	N.A.	Males	Lee (1975)
Northern Borneo	2.283	N.A.	N.A.	N.A.	N.A.	1972	Pauly (1978)
Manila Bay	3.310	1.900	1.410	0.510	14.80	1978-1979	Ingles and Pauly (1984)
Northern Burma	0.915	N.A.	N.A.	N.A.	12.70	1979-1982	Pauly and Sann Aung (1984)
Southern Burma	0.944	N.A.	N.A.	N.A.		1979-1982	Pauly and Sann Aung (1984)
Carigara Bay	2.493	0.976	1.517	0.392	12.61	1981-1983	Corpuz et al. (1985)
Samar Sea	2.088	0.798	1.290	0.382	11.99	1981-1983	Corpuz et al. (1985)
Malaysia	4.021	2.839	1.182	0.706	8.126	Uncorrected for selection pattern	This study
Malaysia	3.725	2.513	1.212	0.675	7.351	Corrected for selection pattern	This study

* N.A. Data not available.

Acknowledgements

The author wishes to express her sincere gratitude to the Director General of Fisheries, Y. M. Tengku Dato' Ubaidillah bin Abdul Kadir and the Director of the Fisheries Research Institute, Mr. Mohd. Shaari bin Sam Abdul Latiff for their permission to let her attend the FAO/DANIDA course; to all her staff, especially the Resource Section of FRI, who contributed a tireless effort in collecting, compiling and processing of the data. Special thanks are also due to the fishermen and the owners of the boats at Kuala Kedah, for their cooperation and patience and last but not least to the two programmers of ICLARM, Ms. Mina S. Soriano and Mr. Felimon C. Gayanilo, Jr., for their great help in the use of the computer. To the Secretariat, she extends her love and indebtedness.

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Population Dynamics of Big-Eye Croaker (*Pennahia macrophthalmus*, Sciaenidae) off Kedah, Penang and Perak States, Malaysia

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Abstract

Length-frequency distribution data from commercial and "trash fish" categories of *Pennahia macrophthalmus* caught by trawlers off the coast of Kedah, Penang and Perak States were pooled to obtain a length-frequency distribution for the northern part of the west coast of Peninsular Malaysia.

The ELEFAN I program and Wetherall method were used to estimate growth parameters. Total mortality was estimated by catch curve analysis, while natural mortality was estimated using Pauly's empirical relationship. The estimated rate of exploitation exceeded the optimum rate of exploitation obtained in yield-per-recruit analysis. The recruitment pattern, i.e., the back transformed length-frequency data suggested a single, protracted pulse of recruitment per year.

Introduction

The inshore fisheries are and will probably remain the most important component of the fisheries sector in Malaysia, contributing approximately 90% of the total landings of fish.

The Malacca Strait, off the northern part of the west coast of Peninsular Malaysia, is a well-established fishing ground for the inshore fishery. More than 85% of the demersal fish in Peninsular Malaysia is landed on the west coast. The big-eye croaker, *Pennahia macrophthalmus*, Family Sciaenidae, locally called "Gelama", is one of the most common species found in the coastal area within 30 nautical miles (about 50 km) from the coastline. This fish is exploited by both fish and prawn trawls and by other gears. The legal minimum mesh size for the cod-end of trawl nets is about 38 mm for the prawn trawl and 50 mm for the fish trawl, but in the actual fishing operations the mesh size used is probably smaller. Therefore, *P. macrophthalmus* always forms part of the trawl catch, especially in the small-sized fish ("trash" fish). Although the same species is also found in Thailand, Indonesia, Burma and the Philippines, very few specific studies have been carried out and only a few scientific papers deal with it.

A monthly random sampling program for the trawl fishery at three major landing centers in the northern part of the west coast of Peninsular Malaysia was used to obtain monthly length-frequency data on *P. macrophthalmus*. These data were used to estimate the von Bertalanffy growth curve parameter (L_∞ and K) and mortality rates. They were also used to estimate the recruitment pattern, yield per recruit and present level of exploitation of this species.

Materials and Methods

The trawl fishery using fish and shrimp trawls was studied intensively from January to December 1985, by sampling three different size classes of trawlers, namely, <25, 25-40 and >40 gross tons (gt) at three major landing centers: Kuala Kedah (State of Kedah), Batu Maung (State of Penang) and Pangkor Island (State of Perak) (Fig. 1). Sampling programs were conducted for both trawl catch categories, namely, a) commercial fish and b) trash fish.

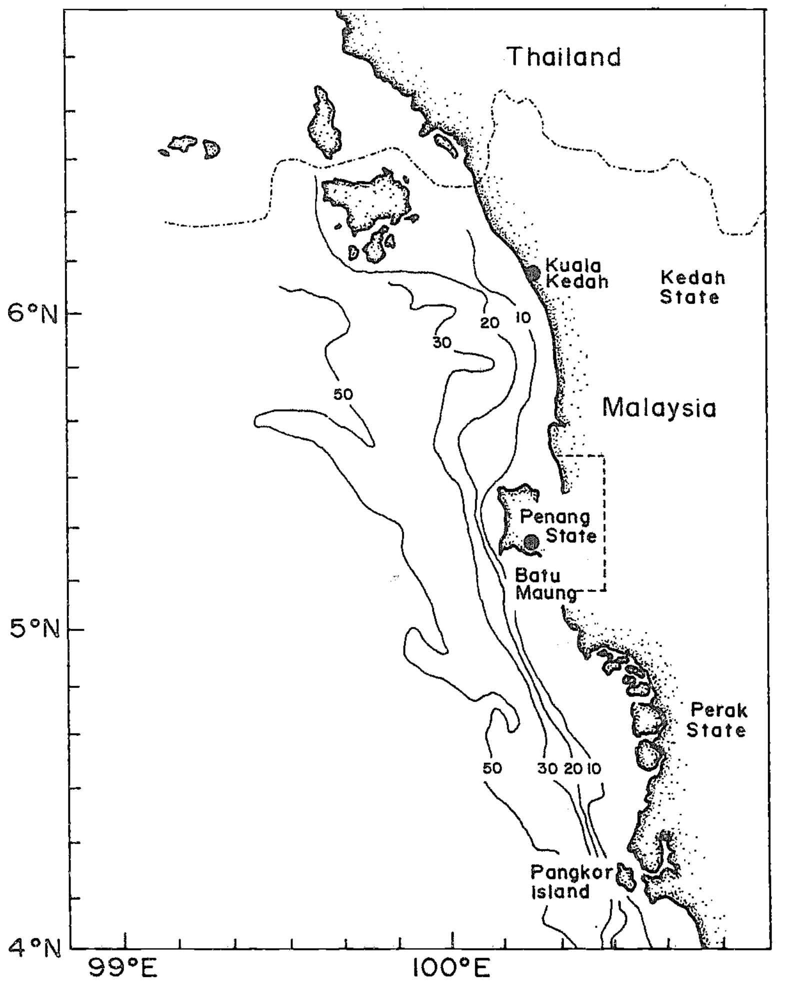

Fig. 1. Coast of Kedah, Penang and Perak States, Malaysia (all depths in fathoms), showing Kuala Kedah, Batu Maung and Pangkor Island sampling sites.

This study makes use of data obtained through two different sampling programs. The first was intended to provide data on the composition at species level of the trawl catches in both categories. The second sampling program provided length-frequency data of individual species; in this case, *Pennahia macrophthalmus*, also for both categories. The results of the first program were used to raise the length-frequency samples to the total catch in numbers by state and the area as a whole. Use was also made of statistical data collected by the Statistical Section of the Department of Fisheries (Kuala Lumpur) for the monthly total landings by state.

The sampling systems used have been described in detail by Mahyam b. Mohd. Isa (this vol.). The length-frequency samples taken from January to December 1985 are presented for each state, by category, in Tables 1 to 3 separately.

The length-frequency data were actually collected separately for three size classes of trawlers. However, the probability of the largest trawlers (>40 gt) to be sampled during the three

Table 1. Length-frequency distribution of *Pennahia macrophthalmus* in the commercial (C) and trash size (T) in 1985, Kedah State, Malaysia (Source: Fish. Res. Inst. Penang).

MONTH	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
CLASS/SIZE	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
3																1		1						
4		2								5						1		3		1		1		
5		2						1		13						3						5		1
6		1		1				1		19						6				1		3		
7				1		3		1		7		3				13						1		
8		7				3		1		7				1		19							2	3
9		6		1		4		5		5		2				7								
10	18	2				3		12	1	2		2		1	1	2			3	1	12	1	2	4
11	33				1	1	10	1	10	3	4		9		5	6		1	28	2	15		19	1
12	20		2		6		12		40	5	25	2	50	1	6	2	9		61	1	54		16	
13	20		39		26		42		33		45	7	54		41	1	12		48	1	48		12	
14	17		17		31		39		36		65		66		70	1	43		43		21		8	
15	20		13		16		8		44		18		18		55		55		30		11		18	
16	38		14		23		21		25		14		1		25		38		10		8		32	
17	54		27		42		31		15		9				13		19		5		1		66	
18	39		25		25		27		7		8				5		14		5		2		31	
19	18		14		22		12		4		5				1		8		1				26	
20	6		6		8				2		3												17	
21	4		2						2														9	
22																							2	
23																							1	
24																								
total sample (no.)	287	20	271	3	200	14	202	22	219	66	195	16	198	3	221	67	198	5	287	7	172	11	261	9
average weight (g)	28	14	50	6	57	9	42	14	40	10	97	17	35	22	37	8	55	14	83	19	90	6	55	14
total catch (kg x 10^2)	233	608	404	130	408	279	226	135	119	61	307	182	137	129	433	244	204	98	218	76	295	85	138	150

Table 2. Length-frequency distribution of *Pennahia macrophthalmus* in the commercial (C) and "trash" sizes (T), in 1985, in Penang State, Malaysia (source: Fish. Res. Inst. Penang).

MONTH	JAN		FEB		MAR		MAY		JUN		JUL		AUG		OCT		DEC	
CLASS	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
3		5																
4		5	1															
5		9	8	3	1													
6			11	5									1					
7			6	5	7						14	2	1					3
8			6		31	3					6		1					
9		2	5	5	41	4			8		18	3	14					1
10		3	10	9	9	3	2		35		71	3	27					2
11	40	1	13	4	6	2	14		20		46	2	24				3	2
12	128	6	34	7	11	4	22		17		25	3	16		7		13	2
13	93	3	45	7	34	2	28		21		14	1	25		9		30	2
14	46	1	31		56	12	56		41		28	1	24		19		33	1
15	36		45		48	14	62		42		21		28		15		28	1
16			26		39	2	32		24		13		21		7		35	
17	22		27		9	4	9		21		15		2		4		43	
18	35		12			1	20		3		13		2		3		21	
19	5		3						2		24		1		1		8	
20	2		1Y				9		2		10						8	
21											4		2					
22	1										1				1		1	
23											1							
24											3							
TOTAL SAMPLE (NO)	451	35	284	45	293	49	280		236		327	15	189		66		228	14
AVERAGE WEIGHT (g)	60	17	50	14	60	14	65		60		74	20	50		60		70	15
TOTAL CATCH ($kg \times 10^2$)	77	58	71	25	112	149	148		99		142	14	105		186		96	81

Table 3. Length-frequency distribution of *Pennahia macrophthalmus* in the commercial (C) and "trash" sizes (T), in 1985, Perak State, Malaysia (source: Fish. Res. Inst. Penang).

MONTH	JAN		FEB		MAR		APR		MAY	JUN		JUL	AUG		SEP		OCT	NOV		DEC	
CLASS/ SIZE	C	T	C	T	C	T	C	T	C	C	T	C	C	T	C	T	C	C	T	C	T
3								4													9
4								3													5
5				1				10													28
6		1	1					13								1					51
7		2	6	2				13						1		1					31
8		1	2	1				2			2			1		1					49
9			2			1		1			2			1					2		14
10		1	2	1		4	2			13	3		3	1				14	4		4
11	4		10		3	2	23	1	8	37	13	7	10	2	1			34			3
12	25		49	1	21		14	1	30	27	5	22	21	1	2			43		4	1
13	31	1	89		34		104		54	43		37	56		2			58		15	1
14	30		42		33		85		93	19		36	40					18		56	
15	48		9		34		9		21	31		40	18		4			1		42	
16	53		11		45				5	16		29								19	
17	23		17		57				1	7		20			1					3	
18	7		10		19					3		8			1					1	
19	2		2		7					4											
20												1									
21																					
22																					
23																					
TOTAL SAMPLE (NO)	223	6	252	6	253	7	237	48	212	200	25	198	148	7	11	3		168	6	140	196
AVERAGE WEIGHT (g)	60	14	60	12	60	18	40	14	40	80	16	60	60	16	60	16	60	60	14	60	12
TOTAL CATCH ($kg \times 10^2$)	345	155	382	282	343	199	534	139	423	709	1196	693	609	572	849	180	171	940	196	90	4083

consecutive sampling days were very low and even if they were sampled the number of fish available was very limited. Therefore, length-frequency distributions of the catches of the three different vessel classes were compared in order to check whether the length-frequency distributions were identical or not (Table 4). The X^2 statistic (Snedecor and Cochran 1967) for identical distribution test gave a value of 3.44 with 5 degrees of freedom, which implies that there was no significant difference (at 95% level) between the two vessel categories. Therefore, the length-frequency distributions of all sampled trawlers were pooled.

Samples of 150 to 450 specimens of *P. macrophthalmus* were taken from the commercial category irrespective of vessel classes and the total length measured to the cm below. Similarly, samples of the trash fish category were measured after sorting into species. The number of fish measured in this category was much lower, 10-80, due to the labor-intensive sorting and measuring required for many species, to which *P. macrophthalmus* contributed approximately 5% in weight.

Table 4. Length-frequency distribution of the sample from the landings of two vessel classes, ≥ 40 gt and < 40 gt for the trash size of *Pennahia macrophthalmus*, 1985.

Length	Vessel size[a] ≥ 40 gt	< 40 gt	
*4	11	7	The X^2 test
5	15	10	for identical
6	13	16	distribution:
7	6	4	$X^2 = 3.44$
8	12	12	d.f. = 5
9	8	3	
Total	65	52	

[a]Number of vessels sampled in each vessel class is 3.

The length frequencies thus obtained were first raised to the total catch in numbers for the particular month by category and state. Total length frequencies for both categories were then pooled to obtain the total length-frequency distribution by state. Combined data from the three states gave the total length-frequency distribution for the northern part of the west coast of Peninsular Malaysia (Table 3).

Estimates of L_∞ and Z/K were obtained through the Wetherall method (1986) modified by Pauly (1986a). The values of L_∞ and K obtained from ELEFAN I were used to correct the data for selection of the gear (Sparre 1985). The total mortality coefficient, Z, was estimated using a length-converted catch curve, while the natural mortality, M, was obtained through Pauly's (1980) formula. The recruitment pattern was obtained by projecting length frequencies backward onto a one-year time scale (Pauly 1982) to show numbers of recruitment pulses per year. The estimation of yield per recruit and biomass per recruit was done using the relative yield-per-recruit model of Beverton and Holt (1966) as modified by Pauly and Soriano (1986) to account for a wide selection ogive.

Results and Discussion

The estimation of the growth parameters was at first carried out using the length-frequency data grouped into 1 cm class intervals. Overall, it was found that 2 cm class intervals produced modes which were easier to interpret. Therefore 2 cm classes were used to estimate the growth and related parameters.

Growth Parameters (L_∞ and K)

Wetherall's method (1986) gave the estimates $L_\infty = 34.8$ cm and Z/K = 10.6 (Fig. 2). The L_∞ estimated through this method was 9.8 cm larger than the maximum length recorded in the sampled fish.

Running the same length-frequency data through the search routines provided in the ELEFAN I program gave best estimates of $L_\infty = 34.5$ cm and K = 0.42. In order to avoid bias due to gear selectivity, length-frequency data used for ELEFAN I estimates of growth parameters should be corrected. For this purpose the length-converted catch curve was applied along with an estimate of M, following the method of Pauly (1986b) (Fig. 3). This method gives a

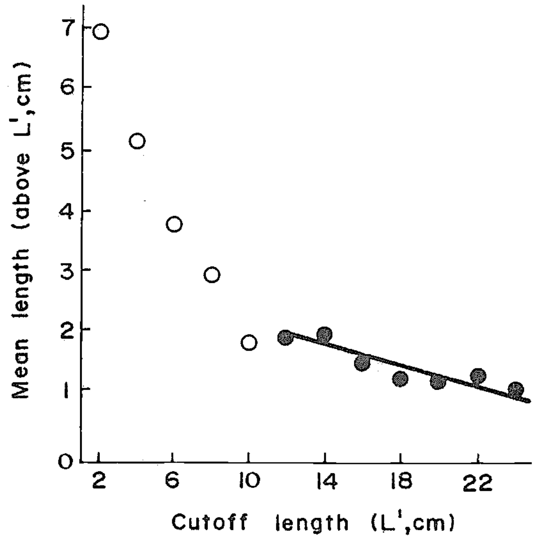

Fig. 2. Estimation of L_∞ and Z/K in big-eye croaker *Pennahia macrophthalmus* (northwest coast of Penang, Malaysia) based on the modified Wetherall method; parameter estimates are y = 2.99-0.086X, L_∞ = 34.8 cm and Z/K = 10.6.

resultant curve and also the values of the probability of capture corresponding to each length (Fig. 4). The estimated probability values were then applied to the original length-frequency data. The corrected data were then run in the search routine in the ELEFAN I program. Fig. 5 shows the fitting of the growth curve at the estimated values of L_∞ = 34.8 cm and K = 0.53 as derived from the corrected data. These values were then applied to the original (uncorrected) length-frequency data for the calculation of all other parameters (see below).

The value of L_∞ estimated from the corrected data was found to be very close to the one estimated by the Wetherall method. It may be concluded that both methods gave the same value of L_∞ which is 34-35 cm. However, this value remains high compared to the largest size of fish in the samples.

Mortalities, Exploitation Rate and Length at First Capture

The values of the total mortality coefficient, Z = 7.28, and the natural mortality, M = 1.15, estimated by a new length-converted catch curve and the Pauly formula (1980), respectively gave a value of fishing mortality, F = 6.13. The resultant curve derived from the new catch curve provided an estimate of L_C = 10.2 cm.

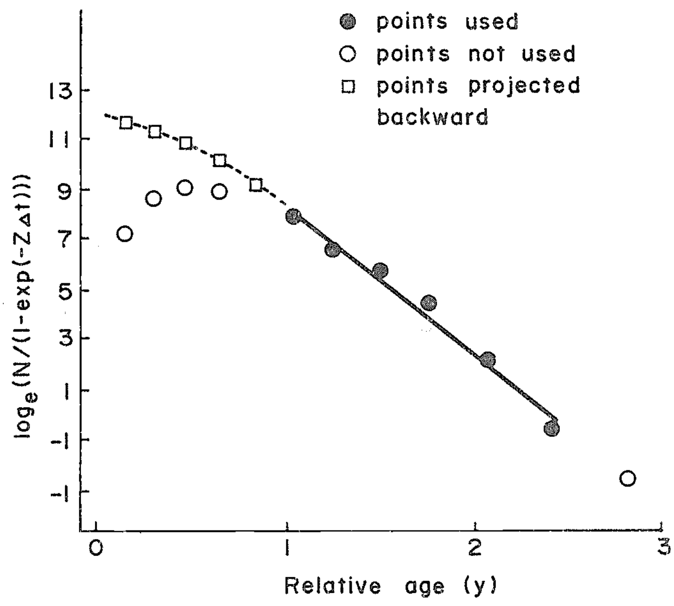

Fig. 3. Catch curve of big-eye croaker *(Pennahia macrophthalmus)* derived from the growth parameters obtained from uncorrected length-frequency data, northwest coast of Peninsular Malaysia, 1985. The curve is based on preliminary values of L_∞ = 34.5 cm and K = 0.42.

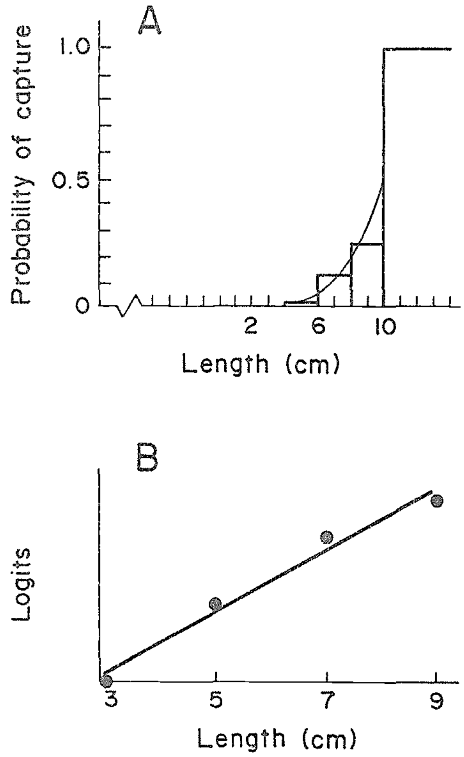

Fig. 4. The resultant curve (A) and logistic transformation (B) derived from preliminary catch curve (Fig. 3), as used to correct the original length-frequency data of big-eye croaker *(Pennahia macrophthalmus)* on the northwest coast of Peninsular Malaysia, 1985.

Recruitment Pattern

The annual recruitment pattern was obtained by projecting the 12 months worth of length frequency backward onto a one-year time axis. The value of t_0 used in the calculation was zero, therefore the exact time of recruitment cannot be determined. From the pattern shown in Fig. 6, it may be inferred that recruitment occurred in the form of two pulses of unequal strength.

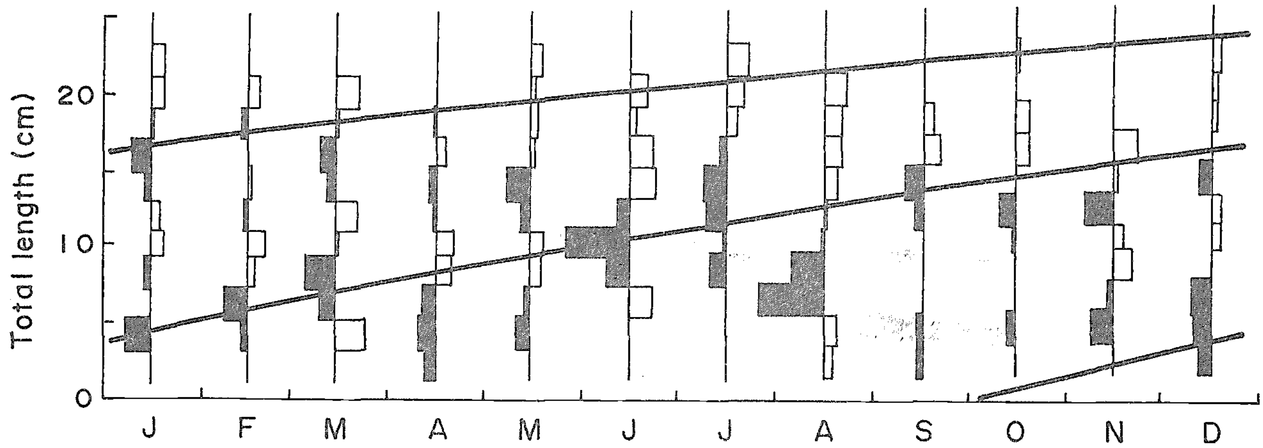

Fig. 5. Restructured (corrected) length frequency of big-eye croaker *(Pennahia macrophthalmus)* from the northwest coast of Peninsular Malaysia, 1985. The best fitting of growth curve is determined by the growth parameters $L_\infty = 34.8$ cm and $K = 0.53$ per year.

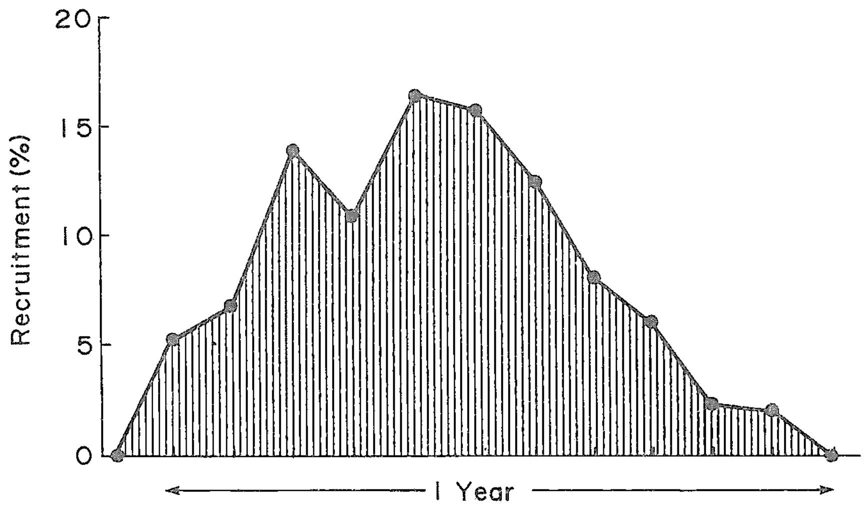

Fig. 6. Recruitment pattern for *Pennahia macrophthalmus*, northwest coast of Peninsular Malaysia.

Yield per Recruit and Biomass per Recruit

The estimation of yield per recruit (Y/R) gives an optimum level of exploitation rate at E = 0.53. The curve is shown in Fig. 7. Fig. 8 shows biomass per recruit (B/R) at different values of E.

Discussion

The present exploitation rate E = F/Z = 0.84 of *Pennahia macrophthalmus* is very much higher than optimum level. This shows that the species is presently overexploited.

The high value of Z is due to the high value of F. This indicates that this fish is very vulnerable to the gear used or, in other words, the gear used is very selective towards this fish. The fishing intensity in the area is also known to be very high as more than 70% of all trawlers in Peninsular Malaysia operate on the west coast especially in the study area. This supports the estimated value of E which is extremely high. The high exploration rate and the low L_c value are in accordance with the large quantity of small size of fish found in the "trash" size composition

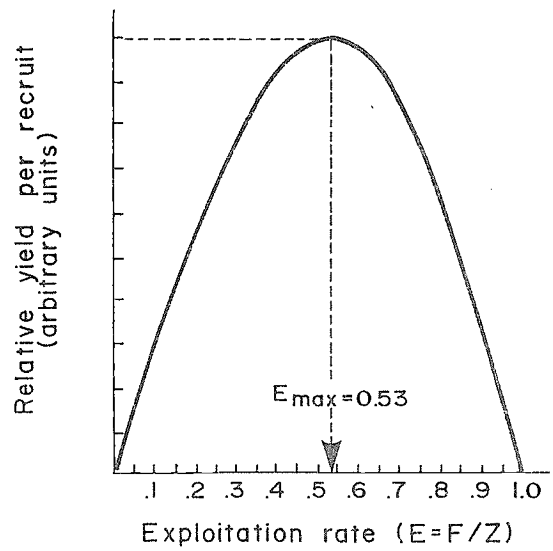

Fig. 7. Estimation of the exploitation rate (E) leading to maximum yield/recruit for big-eye croaker *(Pennahia macrophthalmus)* on the northwest coast of Peninsular Malaysia, 1985.

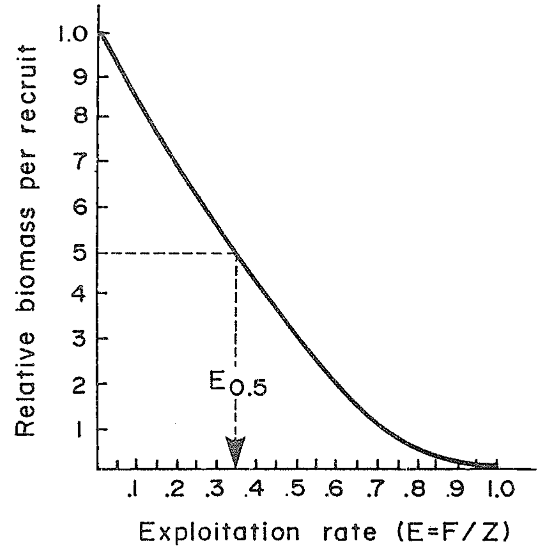

Fig. 8. Relationship between relative biomass per recruit and exploitation rate in big-eye croaker *(Pennahia macrophthalmus)*, showing E value at which relative biomass per recruit (and hence c/f) become half of its value in the unexploited stock (= $E_{0.5}$).

(Tables 1 to 3). Besides, accepting the value of L_∞=34.8 cm implies that the chance of the fish to grow larger than 25 cm is very low, hence no sample of fish with that size was found in the 12 months sample.

Estimated values of the asymptotic length (L_∞) obtained in this study shows that there is agreement between the values obtained by the Wetherall method and through the search routine in the ELEFAN I program.

Other estimates of growth parameters for this species in the Strait of Malacca are not available. However, there are two studies on this species, one conducted in Manila Bay and another in San Miguel Bay, Philippines (Ingles and Pauly 1984). The comparison between the various values is shown in Table 6. Apparently, there is no good agreement between the two results obtained in Philippine waters. The value Ø'= 2.99 for the study in Manila Bay is much higher than the Ø' value 2.38 for the San Miguel Bay. However, the Ø' value of 2.67 derived from the present study in Malaysia is equal to the mean of the two values from the Philippines. Therefore, one could conclude that the Ø' obtained from this study is neither contradicting nor supporting the Ø' values found in the Philippines.

Both L_∞ values obtained from the two bays in the Philippines are low. According to early FAO species identification sheets (Fischer and Whitehead 1974), this fish could attain a size of about 17 cm. However, in a more recent version of these sheets (Fischer and Bianchi 1984) a higher maximum size of at least 30 cm was given. This latter value agrees better with our findings.

There are two possible reasons for the absence of fish >25 cm in the samples. As indicated in this study, the exploitation rate at 0.84 is really very high compared to the optimum level of yield per recruit which reached the rate of 0.53. Therefore, the chances for the fish to grow bigger are very low, since they are caught at a very small size (L_c = 10.2 cm). The second possible reason is that probably the bigger size fish migrate from shallow to deeper waters. As catches from the vessel class >40 gt was rarely incorporated in the samples, the chances of the bigger-sized fish to appear were small.

If this is the case, the value for Z is overestimated. Further studies on these species are necessary to give a satisfactory explanation for the gap between L_{max} in the samples and L_∞. In a new sampling scheme, sampling of larger vessel classes and, consequently, bigger-sized fish should be emphasized.

Table 5. Length-frequency distribution of the total landings of *Pennahia macrophthalmus* in the northwest part of Peninsular Malaysia from January to December 1985 (N x 10^3).

Midlength (cm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.5	483			28,930				478	1,767			31,277
4.5	4,801	5		21,697	459			478	5,303	572	1,309	17,367
5.5	5,188	4,079	6	72,756	1,193			1,436	0	0	6,546	98,589
6.5	4,004	7,471	0	94,454	1,744			11,768	0	572	5,878	177,240
7.5	3,690	15,416	6,243	94,454	642	1,979	175	76,582	0	0	1,309	108,892
8.5	16,962	4,002	7,150	14,896	642	59,804	1,994	88,339	0	0	1,600	174,178
9.5	13,149	7,467	11,114	9,386	459	61,367	245	64,970	0	0	1,829	49,040
10.5	1,277	4,374	13,344	5,282	213	92,613	2,514	55,523	0	1,913	2,844	22,530
11.5	1,280	474	5,844	9,228	647	390,894	950	114,905	3,054	4,632	4,203	13,424
12.5	2,174	5,664	1,632	8,344	1,640	152,837	4,528	56,952	2,741	5,598	4,928	5,951
13.5	3,696	3,914	2,357	6,992	1,504	7,711	3,367	6,764	2,797	6,947	5,814	6,751
14.5	1,586	1,724	4,833	5,840	2,372	3,054	3,630	7,185	802	3,055	1,889	7,777
15.5	2,453	841	4,700	265	1,423	3,175	2,818	4,450	6,173	1,135	245	5,880
16.5	3,065	826	2,530	564	675	1,759	1,789	1,553	709	441	19	2,849
17.5	1,798	1,371	3,729	833	291	1,225	1,255	708	1,641	244	38	1,262
18.5	807	1,059	1,553	725	257	421	543	286	1,548	197		547
19.5	241	483	950	322	192	302	140	63	149			298
20.5	17	184	287		100	149	116	0				211
21.5	0	59			67		23	22				116
22.5	2				24		5					25
23.5					8		5					9
24.5							17					

Table 6. Estimated values of growth and related parameters in *Pennahia macrophthalmus* in three different fishing grounds of Southeast Asia.

Area	Parameters[a]						
	L_∞	K	L_c	Z	M	E	ϕ'[d]
Manila Bay,[b] Philippines	26.50	1.40	13.10	5.55	2.30	0.58	2.99
San Miguel Bay,[b] Philippines	20.00	0.60	11.20	2.28	1.40	0.37	2.38
N/W Pen.,[c] Malaysia	34.20	0.40	10.26	5.50	0.96	0.84	2.67

[a]All lengths in cm, all rates in year $^{-1}$
[b]From Ingles and Pauly (1984)
[c]This study
[d]$\phi' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro 1984)

Acknowledgements

The author expresses thanks to Y.M. Tengku Dato Ubaidullah b. Abd. Kadir, Director General of Fisheries, Malaysia, and Mr. Mohd. Shaari b. Sam Abd. Latiff, Research Director of Fisheries Research Institute, Penang, for allowing him to participate in the FAO/DANIDA course. He also thanks the staff of the Resources Section of the Fisheries Research Institute, Penang, for their participation in the collection of the data used here, especially Ms. Mahyam b. Mohd. Isa and Mr. Alias b. Man.

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Estimation of Growth Parameters and Mortality of Longneck Croaker (*Pseudotolithus typus*) in Cameroon

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Abstract

Length-frequency data on *Pseudotolithus typus* (Sciaenidae) were collected in 1984 from the commercial fishery at the Douala (Cameroon) landing site. The catch of two fishing companies was sampled and the frequencies were raised to total catch using a CPUE calculation.

Nothing has been published before on the biology of *P. typus* in Cameroon waters. The ELEFAN and Bhattacharya methods were applied to the data. The final estimates of growth parameters and total mortality were obtained via a new method developed by J.A. Wetherall and the growth performance index ϕ' of D. Pauly and J.L. Munro.

The values of the results presented here may be biased because large fish were missing in the samples and possibly also because of relatively constant recruitment results in the absence of evident modes. The results presented here should be confirmed by age reading on hard parts.

Introduction

This study on growth and mortality rate of the longneck croaker (*Pseudotolithus typus*) gives an insight into the biology of one of the most important species exploited by the commercial fishery in Cameroon.

To date nothing on the biology of the species in Cameroon waters has been published. However, growth parameters of the species have been estimated in Congo and in Nigeria (see Table 1).

Cameroon opens to the Atlantic Ocean to a distance of 360 km (Fig. 1). The coast is characterized by mangrove swamps, an important river system opening into the ocean and a high rainfall (6 months on the north coast). The commercial fishery began in 1912 with a German steam trawler, but it was only in the 1950s that commercial fishing became significant. From three trawlers in 1954, the fleet increased to 31 units in 1983. The finfish fishery is localized in the estuaries at depths of 10-30 m, and is directed towards the sciaenid community as described by Longhurst (1963). Higher catches were observed with the increase of effort until the early 1980s, but from 1983 there is obviously a decline in the catch from the demersal stock.

As a result of this decline, a research program for the study of the biology of the most important commercial species was initiated by the Institute of Animal Research. The Fisheries Research Station at Limbe implemented a sampling program in 1983 for the collection of length frequencies. The data analyzed here are therefore from a commercial fishery.

Table 1. Available estimates of growth parameters for *Pseudotolithus typus* and the corresponding ϕ' values on a $\log_{10}$ basis.

Sampling location	Sex	L_∞ (cm)	K ($year^{-1}$)	ϕ'	Source
Congo					
Congo River	male	61.1	0.346	3.11	Poinsard (1973)
mouth, 10 m	fem.	77.4	0.255	3.18	Poinsard (1973)
idem, 20 m	both	61.3	0.42	3.20	Pauly (1978, based on Poinsard and Troadec 1966)
Pointe Noire	both	89.7	0.16	3.11	Poinsard (1973)
Nigeria					
Off Lagos, 20 m	both	105	0.217	3.38	Pauly (1978, based on Federal Fisheries Service 1963)
Off Lagos, 20 m	both	103	0.29	3.49	Bayagbona (1969)
Nigeria	both	61.2	0.37	3.14	Longhurst (1963)[a]
Average ϕ'				3.23	

[a]An estimate of Z = 1.25 is also available for this stock.

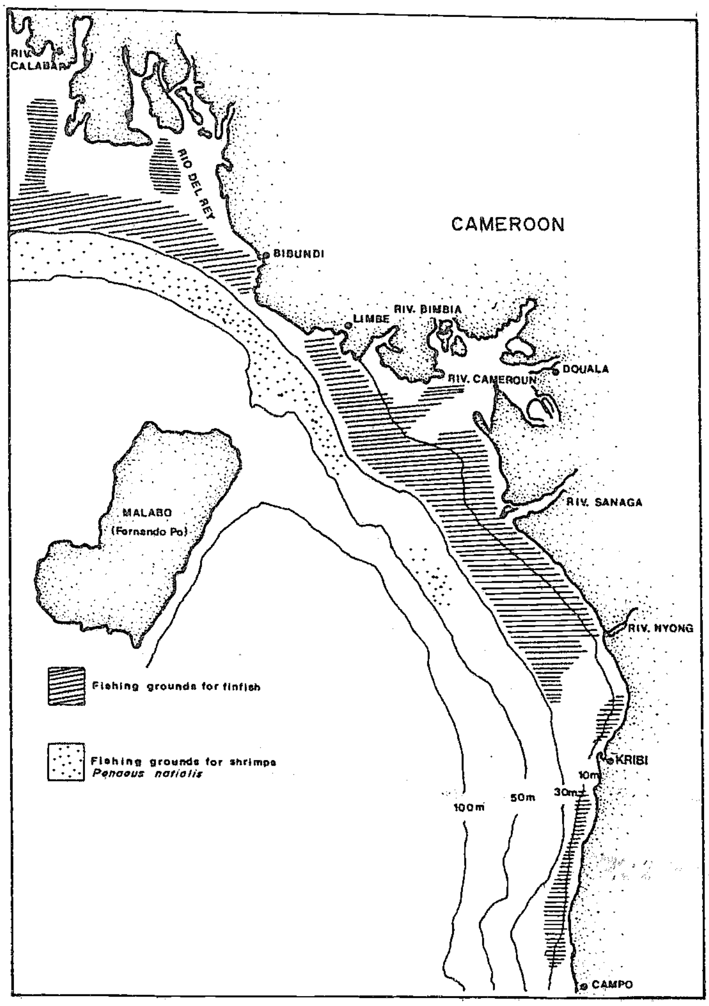

Fig. 1. Major fishing grounds for fish and shrimp along the Cameroon coast.

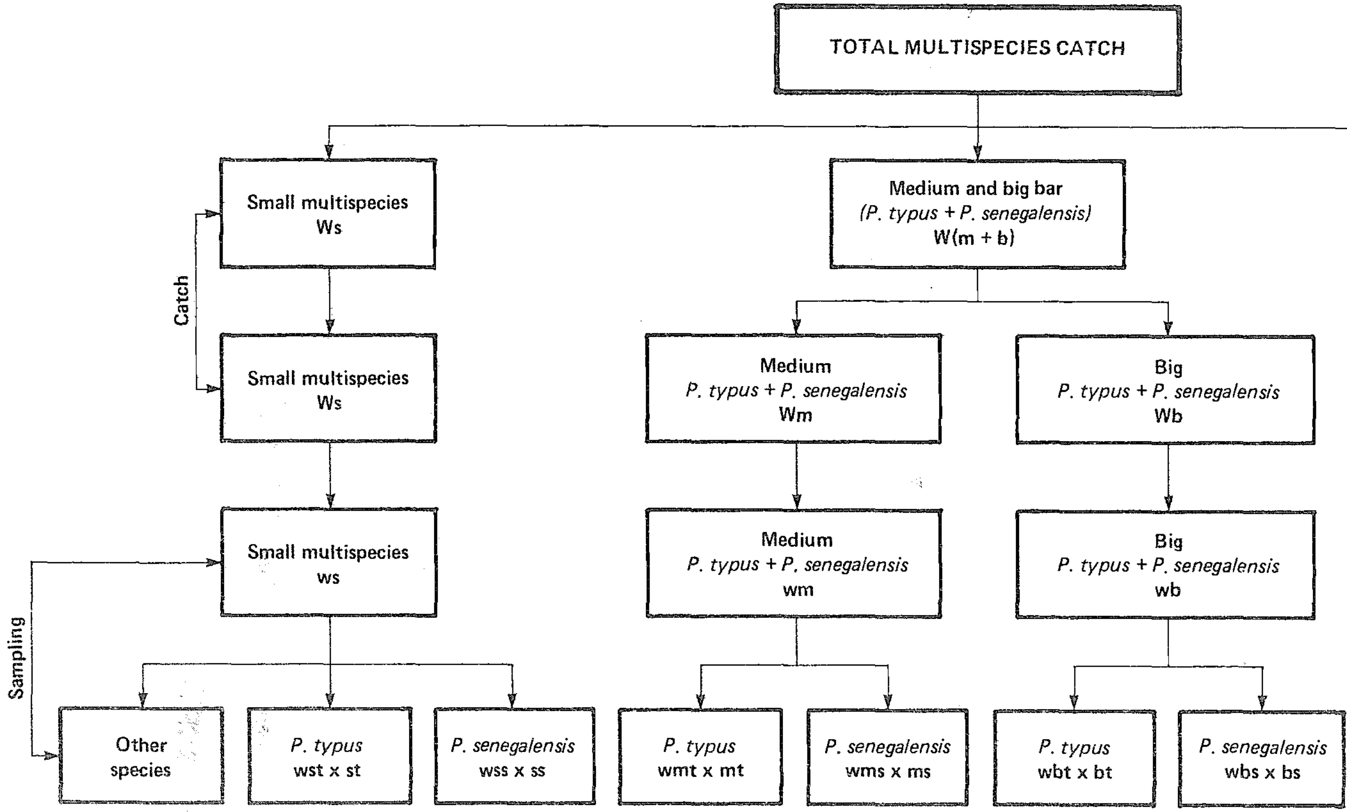

Fig. 2. Sampling method applied to the commercial catch of *P. typus* and *P. senegalensis* by the companies CHALUTCAM and COTONNEC in 1984.

Materials and Methods

Basic Features of the Fishery

The Cameroon industrial fishery is based on demersal fishes and operates at depths between 10 and 50 m (see Fig. 1). Whereas there is a relatively important stock of shrimps *Penaeus notialis*, the finfish stock consists mainly of croakers: *Pseudotolithus elongatus*, *P. typus* and *P. senegalensis*.

Five fishing companies operated in 1984: CHALUTCAM, COTONNEC, CRECAM, COPEMAR and PECAM, all of which landed their catch in Douala. In this study fishing effort is measured in boatdays * horsepower and the five companies may then be grouped into three categories. The gear used was a trawl with a stretched mesh of 30-41 mm in the cod-end.

Sorting the Catch and Sampling Method

The multispecies catch is sorted on the trawler into commercial categories (Fig. 2). "Gros" comprises all fish larger than approximately 60 cm. This multispecies category is only recorded by catch in numbers (N_l) and not by catch in weight (W_l). Big- and medium-sized fish (25-60 cm) of *P. typus* and *P. senegalensis* are sorted into one category called "bar". The landings of "bar"(W(m + b) kg) is further divided into a new "bar" category of big fish (30-60 cm) and "nylon" comprising medium size fish (22-30 cm). All small fish (9-22 cm) are put in the "friture" category. The categories "bossu" (*P. elongatus*) and "divers" do not contain *P. typus* or *P. senegalensis*.

The landings of *P.typus* from one fishing trip are therefore contained in four categories comprising Ws kg small fish (multispecies), Wm kg medium fish (*P. typus* and *P. sengalensis*), Wb kg big fish (*P. typus* and *P. senegalensis*) and N_l large fish (multispecies) (Fig. 2).

Samples were collected from one to four fishing trips per month from February 1984 to November 1984. All sampling was done only from the landings of trawlers belonging to the companies CHALUTCAM and COTONNEC. From each trip sampled the material consisted of samples from the categories small (Ws), medium (Wm) and big (Wb). Weights of *P. typus* in the subsamples were recorded and each fish was measured to the cm below. From the trips sampled a few large *P. typus* were measured when available from the small registered landings of the "gros" category. A total of 8,524 *P. typus* were measured including only 242 large individuals (Table 2) with lengths between 60 and 118 cm. For the determination of the length to weight relationship of *P. typus* total body length and weight of 650 fish were measured (Table 3).

Table 2. Sample of large *Pseudotolithus typus* for 1984.

Class interval (cm)	Numbers
60–	1
65–	4
70–	22
75–	48
80–	41
85–	35
90–	35
95–	34
100–	14
105–	4
110–	1
115–	3
Total number	242

Table 3. Data for length-weight relationship from 1984 on *Pseudotolithus typus*. Based on the measurement of total length to cm below and body-weight to nearest gramme of 650 fish.

Class No	Class mid-length (cm)	Mean body weight (g)
1	13.5	15.2
2	14.5	17.7
3	15.5	18.7
4	16.5	23.6
5	17.5	31.8
6	18.5	32.6
7	19.5	45.3
8	20.5	56.0
9	21.5	61.8
10	22.5	70.0
11	23.5	81.6
12	24.5	92.4
13	25.5	105.3
14	26.5	121.4
15	27.5	131.3
16	28.5	153.6
17	29.5	166.0
18	30.5	187.7
19	31.5	189.7
20	32.5	221.9
21	33.5	264.8
22	34.5	264.4
23	35.5	301.1
24	36.5	333.5
25	37.5	323.3
26	38.5	372.1
27	40.5	473.2
28	42.5	558.3
29	43.5	594.2
30	44.5	595.8
31	45.5	648
32	47.5	732
33	48.5	785.1
34	49.5	843.1
35	50.5	920.2
36	51.5	991
37	55.5	1,160
38	63.5	1,804
39	64.5	1,895
40	67.5	2,146

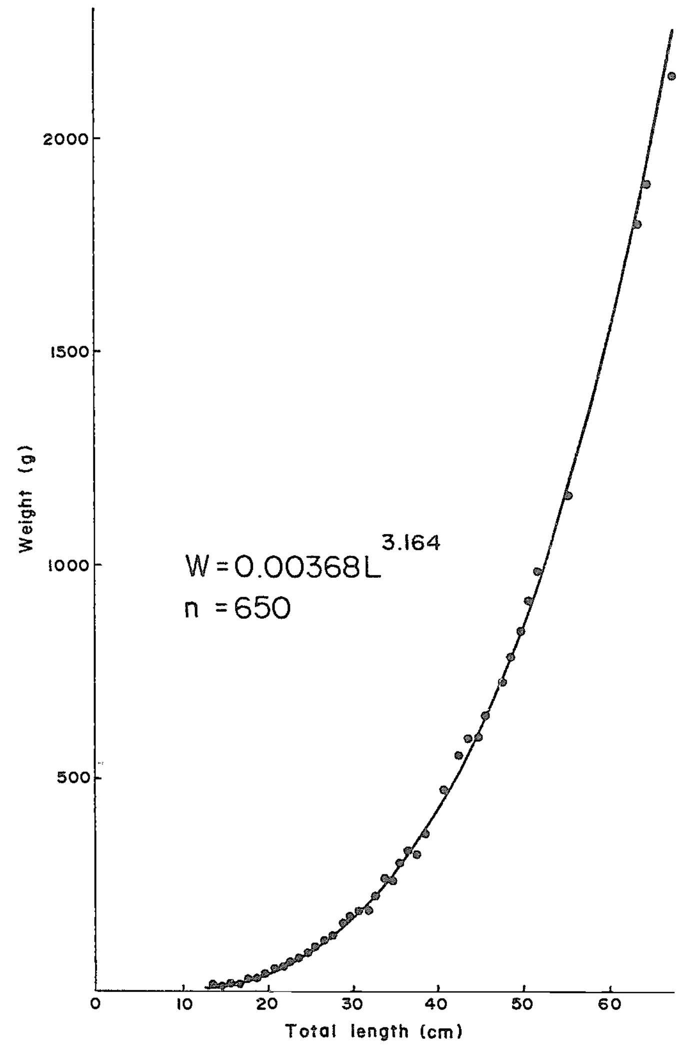

Fig. 3. Length-weight relationship of *Pseudotolithus typus* in Cameroon.

Raising Samples to Total Catch in Numbers by Length Group

The starting point for the raising procedure is the number of *P. typus* by length group for each size category in the trips sampled, i.e., in the case of length group No i for trip No j, xstj(i), xmtj(i) and xbtj(i) for the categories small, medium and big, respectively (see bottom of Fig. 2). The aim is to raise these numbers by appropriate factors in order to estimate the monthly catch in numbers by length group of *P. typus* in the multispecies fishery by the total fleet of trawlers in Cameroon. This raising procedure is carried out in several steps. The end result consists of monthly length frequencies (Table 8) which represent the data available for estimating growth and mortality in this study. Large fish were excluded because the fraction of *P. typus* in the "gros" category could not be estimated from the data available (Table 2).

Raising to catch per trip sampled

The length frequencies of *P. typus* in the multispecies sample (weight wsj) of the total catch of size category small (weight Wsj) of trip j was raised to the total by the factor Wsj/wsj (Fig. 2).

The same procedure could not be applied to the size categories "medium" and "big" because the individual catches in weight of "medium" (Wmj) and "big" (Wbj) were not available for this study. Only the combined weight is known:

$$W(m+b)j = Wmj + Wbj \tag{1}$$

The same raising factor W(m + b)j/(wmj + wbj) was used to raise the "medium" and "big" samples. The estimate Nj(i) of the total number of *P. typus* in length group No i from trip No j was then obtained by adding the calculated contributions from each of the three size categories, i.e.,

$$Nj(i) = \frac{Wsj}{wsj} * xstj(i) + \frac{W(m+b)j}{wmj+wbj} * [xmtj(i) + xbtj(i)] \tag{2}$$

Raising to monthly catch by the CHALUTCAM and COTONNEC group of trawlers

Raised length frequencies per sampled trip (the Nj's Eq. (2)) were added on a monthly basis to estimate the number caught by length group in all sampled trips per month. Raising to the monthly catch in numbers by length groups for the CHALUTCAM and COTONNEC companies was then done by applying the raising factor (Table 4):

$$\text{First monthly raising factor } (R_1) = \frac{\text{Total no. of company trips in the month}}{\text{No. of trips sampled in the month}} \tag{3}$$

All trips in 1984 for this group of trawlers were of 7 days duration.

Table 4. Raising factor to total catch of *Pseudolithus typus* per month by the companies CHALUTCAM and COTONNEC.

Month	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov
Total trips	36	37	36	36	38	39	35	37	37
Sampled trips	1	1	1	3	4	2	1	1	1
R_1	36	37	36	12	9.5	19.5	35	37	37

R_1 = Total trips/sampled trips

Raising to catch per month by total fleet

The two other groups of trawlers from which no sampling was done catch more shrimp than finfish. Total registered landings of "friture" and "bar" was taken as a measure of the catch of *P. typus* by company category. Effort was measured by total number of boatdays in 1984 (Table 5) multiplied by horsepower. A coefficient of CPUE for *P. typus* in 1984 was then derived by normalizing to the company category from which samples were taken, in 1984, namely CHALUTCAM/COTONNEC = 1 (Table 6). The distribution of the annual catch of *P. typus* by company category over months was assumed proportional to monthly effort. A second raising factor (R_2) was therefore obtained as follows:

Second monthly raising factor (R_2) =

$$R_2 = \frac{\Sigma\text{Monthly effort} * \text{CPUE}\ \text{all companies}}{\text{monthly effort} * \text{CPUE}\ \text{one company (CHALUTCAM/COTONNEC)}} \quad (4)$$

To facilitate computations, the "coefficient of CPUE" from Table 6 was used instead of CPUE in the calculation of the raising factor (R_2) from Eq. (4). Table 7 gives raising factor R_2 and also total raising factor $R_1 * R_2$ to total catch of *P. typus* per month by all companies.

Table 5. Company boat days in 1984.

Company	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CHALUTCAM/COTONNEC	259	252	259	252	252	252	266	273	245	259	259	252
COPEMAR/PECAM	128	111	121	112	152	134	146	151	143	166	169	155
CRECAM	213	222	248	203	218	182	204	187	184	179	128	164

Table 6. Computation of coefficient of standardized CPUE for finfish by company categories.

1984	CHALUTCAM/COTONNEC	COPEMAR/PECAM	CRECAM
Friture (kg)	1,540,372	40,304	1,359,675
Friture (kg)	1,546,374	7,920	
Bar (kg)	1,038,146	141,660	1,288,488
Bar (kg)	844,846	19,680	
Total catch (kg)	4,969,738	209,564	2,648,163
Total boat days	3,080	1,688	2,332
Horsepower per trawler	430	650	520
Effort (boat days * horsepower)	1,324,400	1,097,200	1,212,640
CPUE (kg/boat – days/horse-power)	3.752	.191	2.184
Coefficient of CPUE	1	.0509	.5821

As an example, the total raising factor ($R_1 * R_2$) to total catch of *P. typus* in February for all companies was calculated as

$$R_1 * R_2 = 36 * 1.654 = 59.54$$

where R_2 was obtained as follows:

$$R_2 = \frac{\Sigma\text{boat days} * \text{horsepower} * \text{coefficient CPUE (all company categories)}}{\text{boat days} * \text{horsepower} * 1\ \text{(CHALUTCAM/COTONNEC category)}}$$

$$= \frac{252 * 430 * 1 + 111 * 650 * .0509 + 222 * 520 * .5821}{252 * 430 * 1} = 1.654$$

The raised length frequencies per month in units of 100 fish are presented in Table 8.

Bhattacharya method

The frequency distribution of lengths obtained from a sample of fish is skewed and polymodal in many cases. Sometimes the modes correspond to individual age groups, the frequency distribution of any such component is usually assumed to be normal (Bhattacharya 1967). Therefore the difference between successive logarithms of numbers plotted against the upper limits of size classes must give a straight line and the intercept of the regression line with the x-axis gives the mid-length of the age group. The next step after the Bhattacharya plot is the modal progression analysis which hopefully allows to draw the growth curve, and give estimates of L_∞ and K by a Gulland and Holt (1959) plot.

ELEFAN I method

The ELEFAN I program was developed by Pauly and David (1981). The idea behind the method is to split a composite distribution into peaks and troughs, and to find the best growth curve passing through the maximum number of peaks and avoiding troughs as far as possible. Goodness of fit is assessed by a ratio ESP/ASP. Details on the method are described by Saeger and Gayanilo (1986) whose version of the ELEFAN I program (and ELEFAN II) was used for several analyses. ELEFAN I thus helps identify "best" values of L_∞ and K.

Wetherall method

Wetherall (1986) using the classical Beverton and Holt (1956) Z equation:

$$Z = K(L_\infty - L)/(L - L') \qquad (5)$$

expressed L as a linear function of L'

$$L_i = a + b\,L'_i \qquad (6)$$

where L_i is the mean length of fully selected fish, computed from L'_i upward (and L'_i is the lower limit of the first length class used in computing L_i). From (6) we have

$$L_\infty = a/(1-b) \qquad (7)$$

and $$Z/K = b/(1-b) \qquad (8)$$

To obtain a and b only the straight part of the plot of L_i on L'_i should be used for the regression analysis. Because L_∞ is estimated via division by a small difference (1-b), care must be taken not to truncate the value of "b" prior to computation of L_∞. This new approach is attractive as it estimates L_∞ and Z/K.

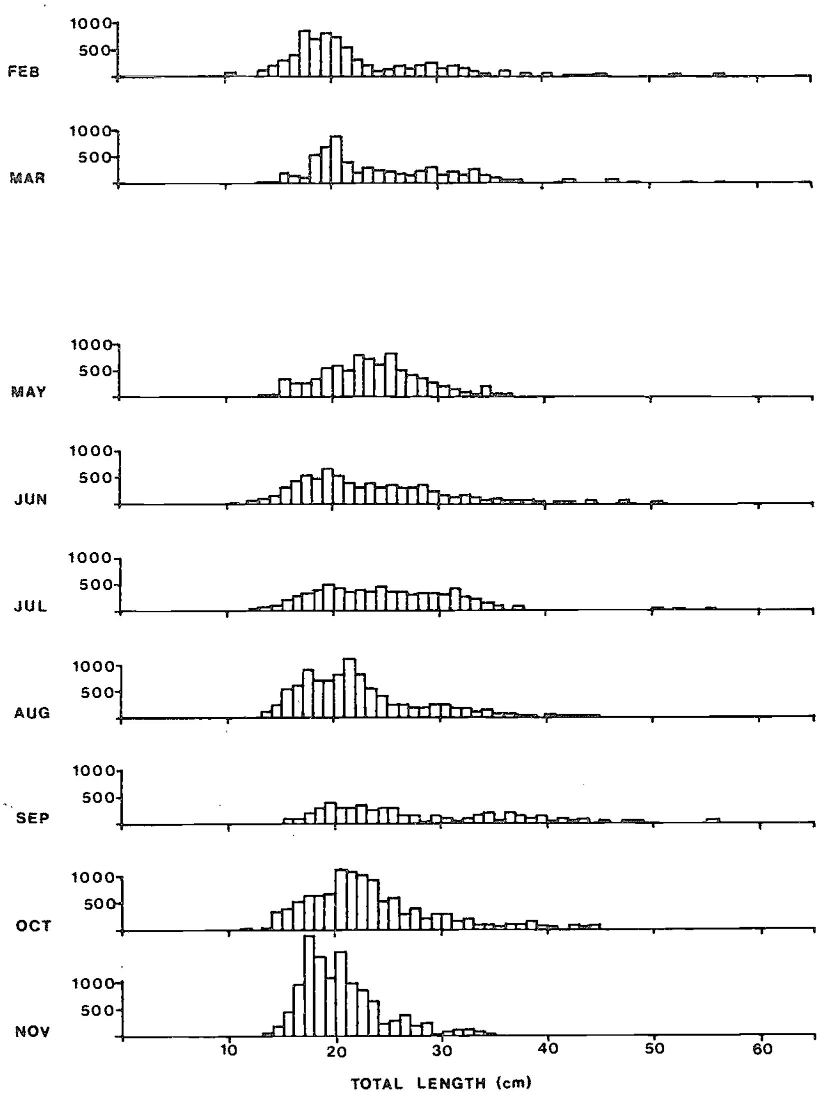

Fig. 4. Total catch-at-length data for *Pseudotolithus typus* caught off Cameroon in 1984 (see text for comments concerning the absence of large fish).

Pauly and Munro's (1984) ϕ' equation

Empirical investigations have shown that the quantity

$$\phi' = \log K + 2 \log L_\infty \qquad (9)$$

is approximately normally distributed within taxa provided of course that the same units are used for K, respectively, L_∞ in the calculations of the individual ϕ' values (see Lablache and Carrara, this vol. for further details). Table 1 lists available (K, L_∞) estimates of *P. typus* from the literature giving an average $\phi' = 3.23$.

Analyses of data were done using three computers (VAX II/750, Apple IIc, HP 87 XM) at the North Sea Centre (Hirtshals, Denmark).

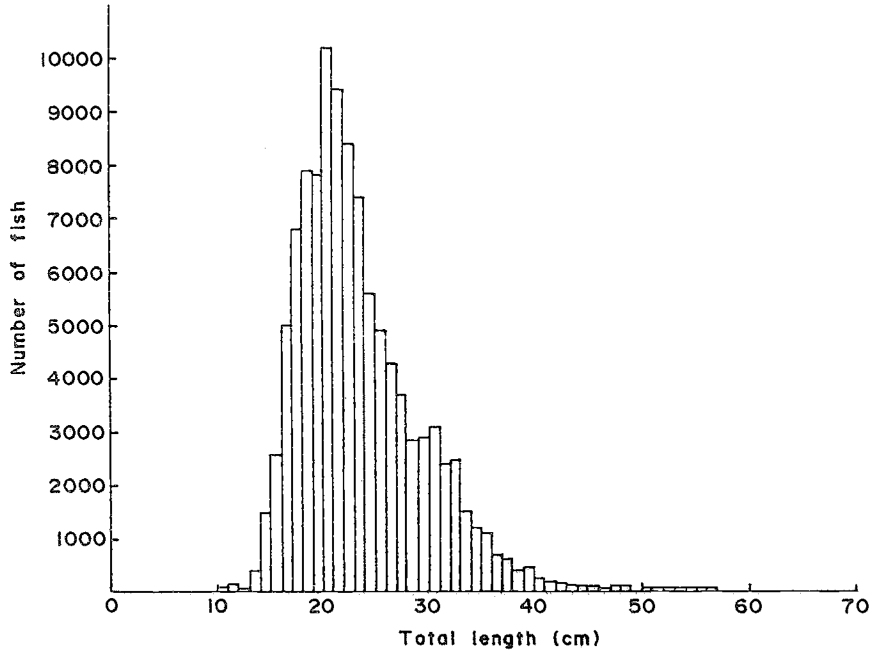

Fig. 5. Combined length-frequency samples of *Pseudotolithus typus*, raised to total catch of Cameroon in 1984.

Results

Length-Weight Relationship

As mentioned earlier in the introduction, no specific study has been carried out on this species in Cameroon waters. It was therefore thought that it would be useful to include the relation between length and weight in this paper.

In general the weight of a fish can be expressed as a function of its length by the equation:

$$W = aL^b \tag{10}$$

W = weight; L = length; a and b being constants to be estimated from length/weight data pairs

Eq. (10) on a logarithmic scale gives:

$$\log W = \log a + b \log L \tag{11}$$

i.e., on a logarithmic scale the plot of weight against length gives a straight line with slope b and an intercept of log a.

A total number of 650 fish were measured to the cm below (total length) and weighed to a decigram digit. Grouping was made in 40 one cm length classes using midpoints (Table 3 and Fig. 3). The regression equation obtained from this data set is:

$$Y = -2.434 + 3.164X$$

or

$$W = 0.003681\ L^{3.164} \tag{12}$$

where the 95% confidence interval (with 38 d.f) of the power (b) is 3.12 and 3.21.

Bhattacharya and ELEFAN I Results

The data used for the Bhattacharya analysis on an Apple IIc and the ELEFAN I runs on a VAX 11/750 are the 9 months of length frequencies in 1 cm classes (Table 8) corresponding to the histograms in Fig. 4. The results from the Bhattacharya analysis are summarized in Table 9. Three normal distributions were identified for each month. The mean lengths of these groups are shown by arrows on the restructured data plot from ELEFAN I in Fig. 6. It was not possible to obtain convincing results based on the available data. Some modes from the Bhattacharya analysis could apparently be related in various ways and the ELEFAN produces very "flat" response surfaces (with the highest ESP/ASP ratio around $L_\infty = 60$ cm and $K = 0.1$/year).

As an indication of recruitment to the fishery, Fig. 7 plots numbers explained by the first component of the Bhattacharya analysis divided by effort on months (Table 11). Effort was calculated from the 2nd raising factor (Table 7) multiplying by monthly effort (boatdays * horsepower) for the CHALUTCAM and COTONNEC companies, cf. Eq (4).

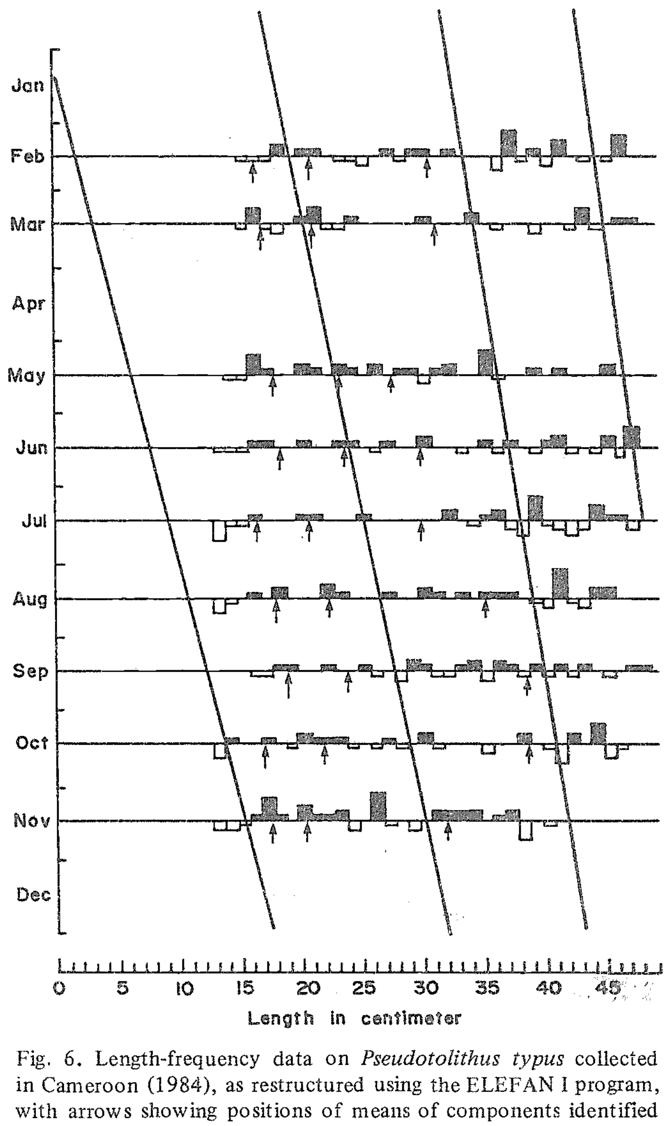

Fig. 6. Length-frequency data on *Pseudotolithus typus* collected in Cameroon (1984), as restructured using the ELEFAN I program, with arrows showing positions of means of components identified using Bhattacharya's method and with a superimposed growth curve with parameters $L_\infty = 82.7$ cm and $K = 0.25$ (year^{-1}). Note lack of agreement between these elements (see also text).

Table 7. Raising factor to total catch of *Pseudotolithus typus* per month by all companies.[a]

	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov
R_2	1.654	1.710	1.655	1.549	1.582	1.525	1.574	1.536	1.398
Total raising factor $R_1 * R_2$	59.54	63.27	59.58	18.59	13.03	29.74	55.09	56.83	51.73

[a] R_2 = second monthly raising factor, see Eq. 4.
R_1 = (See Table 4)

Table 8. Raised ($R_1 * R_2$) length frequencies for *Pseudotolithus typus* per month in 1984 (in units of 100 fish).

length class (cm)	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
10–	102									102
11	51			27				74		152
12	51									51
13	204			53	14	17		74		443
14	254	109	55	117	101	171		517	244	1,568
15	305	109	55	232	160	331	136	540	650	2,518
16	508	326	493	497	314	755	136	762	1,299	5,090
17	610	272	439	633	361	837	248	960	2,518	6,878
18	1,271	218	439	756	480	1,323	474	960	2,030	7,951
19	1,119	836	493	682	543	1,042	565	1,034	1,543	7,857
20	1,221	1,093	854	964	711	1,042	452	1,671	2,193	10,201
21	1,119	1,498	893	771	646	1,156	468	1,569	1,299	9,419
22	840	681	743	822	568	1,674	506	1,495	1,145	8,474
23	495	364	1,224	879	595	1,127	423	1,392	914	7,413
24	264	560	1,134	785	582	806	441	784	314	5,670
25	136	447	888	615	665	557	447	796	403	4,954
26		392	1,165	461	497	384	237	460	578	4,174
27	267	314	756	535	496	366	221	591	164	3,710
28	217	294	676	442	475	246	50	341	158	2,899
29	298	314	515	432	469	247	198	409	62	2,944
30	325	432	434	505	485	321	149	432	87	3,170
31	244	294	306	365	445	290	99	250	110	2,403
32	298	333	257	272	594	209	149	273	114	2,499
33	190	275	209	181	395	231	215	182	101	1,979
34	163	412	177	186	307	176	297	182	89	1,989
35	136	216	290	174	305	181	83	91	50	1,526
36	27	157	64	107	282	134	297	136	39	1,243
37	190	118	64	123	104	115	231	136	29	1,110
38	54	98		80	57	69	149	182	4	693
39	108	20	32	61	124	46	165	114	8	678
40	27	39		85	37	21	83	91	2	385
41	108		16	106	24	60	116	23	2	455
42		20		33	9	17	50	114		243
43	27	59			9	9	66	68		238
44	27	20		10	16	17		114		204
45	27		16	19	10	17	17	23		129
46	54	39		5	9			23		130
47	27	59		24	3		17			130
48	27			5			17			49
49	27	39		4						70
50				18	7		17	23		65
51										
52				5						5
53	27				7			23		57
54		20								20
55							17	23		40
56		20			7			23		50
57	27	20		5						52
Total	11,472	10,507	12,687	12,076	10,913	13,994	7,236	16,955	16,230	112,080

Note: Large fish were excluded because their fraction could not be estimated from the data available (See also Table 12).

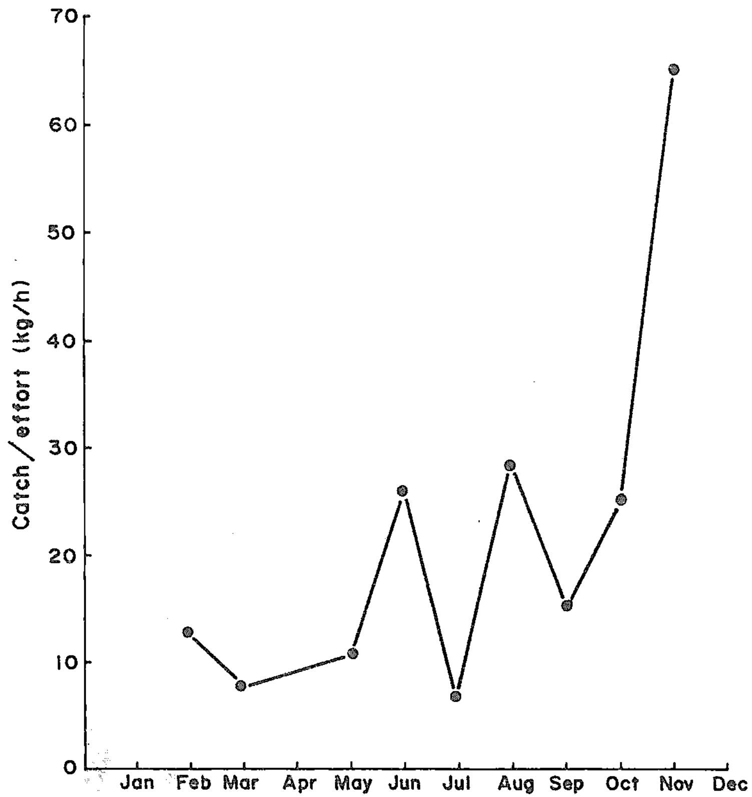

Fig. 7. Catch/effort of small specimen of *Pseudotolithus typus* off Cameroon (1984). Estimates based on numbers in first normal components of length-frequency samples, as identified using Bhattacharya's method.

Table 9. Mean length, standard deviation and number of fish for each of the three normally distributed components resulting from the Bhattacharya analysis.

Sample date	Mean length (cm) I	II	III
1984 Feb 15	16.656	21.342	31.037
1984 Mar 15	17.393	21.318	31.712
1984 May 15	18.396	24.163	28.041
1984 Jun 15	18.787	24.151	30.369
1984 Jul 15	17.034	21.233	30.325
1984 Aug 15	18.206	23.109	32.028
1984 Sep 15	19.520	24.379	35.582
1984 Oct 15	17.385	22.189	38.805
1984 Nov 15	18.137	22.401	32.583

Sample date	Standard deviation (cm) I	II	III
1984 Feb 15	1.937	1.937	3.156
1984 Mar 15	2.270	1.417	3.553
1984 May 15	1.278	1.635	2.938
1984 Jun 15	2.317	2.299	2.400
1984 Jul 15	1.374	2.031	4.304
1984 Aug 15	1.577	2.250	4.572
1984 Sep 15	1.843	1.901	3.140
1984 Oct 15	1.643	1.791	3.510
1984 Nov 15	1.825	1.300	3.106

Sample date	Cohort size (numbers) I	II	III
1984 Feb 15	2,252	5,958	2,385
1984 Mar 15	1,529	4,529	3,369
1984 May 15	1,880	5,077	4,529
1984 Jun 15	4,311	4,457	2,589
1984 Jul 15	1,224	3,516	5,589
1984 Aug 15	4,916	7,162	2,878
1984 Sep 15	2,483	2,262	1,912
1984 Oct 15	4,245	7,805	1,227
1984 Nov 15	10,124	3,595	832

Wetherall Results and the ϕ' Index

Data for a Wetherall plot were obtained (Table 12, Fig. 8) by adding all monthly length frequencies to represent the "mean" frequency distribution for 1984 (Table 8 and the histogram in Fig. 5). The regression equation obtained without weighting by numbers is:

$$Y = 8.6761 + .8951X$$
$$r = 0.998$$

giving L_∞ = 82.7 cm and Z/K = 8.53

Using the mean value of ϕ' = 3.23 for *P. typus* values of K = 0.25/year and, hence, total mortality Z = K * 8.53 = 2.1/year were obtained. A growth curve with K = 0.25/year and L_∞ = 82.7 cm is shown in Fig. 6.

Table 10. Total number of fish described by the identified normal components compared to total number in the raised samples.

Sample date	Total number in the three cohorts	Total number in the raised sample
Feb	10,595	11,472
Mar	9,472	10,517
May	11,486	12,687
Jun	11,357	12,076
Jul	10,329	10,913
Aug	14,956	13,994
Sep	6,657	7,236
Oct	13,277	16,955
Nov	14,551	16,230

Table 11. Calculated CPUE based on the size of the first component from the Bhattacharya analysis and monthly effort.

Sample date	Cohort I numbers	Effort boatdays * horsepower	CPUE
Feb	2,252	179	12.6
Mar	1,529	190	8.0
May	1,880	179	10.5
Jun	4,311	168	25.7
Jul	1,224	181	6.8
Aug	4,916	179	27.5
Sep	2,483	166	15.0
Oct	4,245	171	24.8
Nov	10,124	156	64.9

Table 12. Data for Wetherall plot based on catch numbers C (Table 5) of *Pseudotolithus typus* for 1984 in 2 cm intervals. Points used for the regression are marked by "*".

L' (cm)	L mid (cm)	C	L (cm)
10	11	254	23.9
12	13	494	24.0
14	15	4,191	24.0
16	17	11,968	24.4
18	19	15,808	25.3
20	21	19,620	26.6*
22	23	15,887	28.4*
24	25	10,624	30.3*
26	27	8,075	32.1*
28	29	5,843	33.7*
30	31	5,573	35.1*
32	33	4,058	36.8*
34	35	3,515	38.4*
36	37	2,353	40.4*
38	39	1,371	42.6*
40	41	840	44.7*
42	43	481	46.9*
44	45	333	48.7*
46	47	260	50.5*
48	49	119	52.8*
50	51	65	54.4*
52	53	62	55.4*
54	55	60	56.3*
56	57	102	57.0*

Table 13. Calculation of stock in steady state with two cohorts per year. As an example, 1 million recruits of age 1 is used.

Age (year)	Numbers	Mean length (cm)	Body weight (g)
1	1,000,000	18.4	36.7
1.5	349,938	26.0	110
2	122,457	32.7	227
2.5	42,852	38.6	385
3	14,996	43.8	575
3.5	5,248	48.4	789
4	1,836	52.5	1,018
4.5	642	56.1	1,255
5	225	59.2	1,493
5.5	79	62.0	1,728
6	28	64.5	1,954
6.5	9.7	66.7	2,171
7	3.4	68.6	2,375
7.5	1.2	70.3	2,566
8	0.47	71.8	2,742
8.5	0.15	73.1	2,905
9	0.051	74.3	3,054
9.5	0.018	75.3	3,190
10	0.0062	76.2	3,313
•	•	•	•
•	•	•	•
•	•	•	•
	0	83	4,344

Z = 2.1 $year^{-1}$, K = 0.25 $year^{-1}$, L_∞ = 83 cm, t_0 = 0 and W = 0.003681 * $L^{3.164}$

Discussion

This preliminary study indicates that the growth parameters of *P. typus* in Cameroon waters are in the order of L_∞ = 83 cm and K = 0.25/year. These results are based on a Wetherall analysis of the pooled monthly length frequencies raised to total catch of *P. typus* in 1984 (Table 8, Fig. 5) giving L_∞ and Z/K = 8.53. In order to obtain a value of K it was necessary to apply Pauly and Munro's ϕ' equation. The seven available (L_∞, K) estimates from the literature (Table 1) gave rise to a ϕ' = 3.23 from which the estimate of K was obtained and, hence, a total mortality of Z = 2.1/year. Table 1 shows that the estimates of L_∞ vary from around 60 cm to 100 cm. The two estimates of a high L_∞ (105 cm and 103 cm, see Table 1) alone give a ϕ' = 3.43 implying K = 0.27/year for L_∞ = 100 cm. The three estimates of a low L_∞ (61.1, 61.2 and 61.3 cm in Table 1) alone produce ϕ' = 3.15 implying K = 0.39/year for L_∞ = 60 cm. This could indicate that large *P. typus* are not found in shallow waters (e.g., mouth of Congo river) and, hence that 60 cm is an underestimate of L_∞ and 0.4/year correspondingly an overestimate of K.

In Cameroon, the trawlers are not built to go far offshore. The catches of "gros" (multispecies, large fish) vary greatly from a few fish to several hundred per trip. The maximum size of *P. typus* of the 242 fish sampled in 1984 is 118 cm (Table 2). From this information alone, recalling that L_∞ in the von Bertalanffy growth equation is defined as the mean length of infinitely old fish, we would expect an L_∞ in the order of 100 cm. The mean length of the 242 large *P. typus* is 87 cm which is an underestimate of L_∞ because these fish must comprise

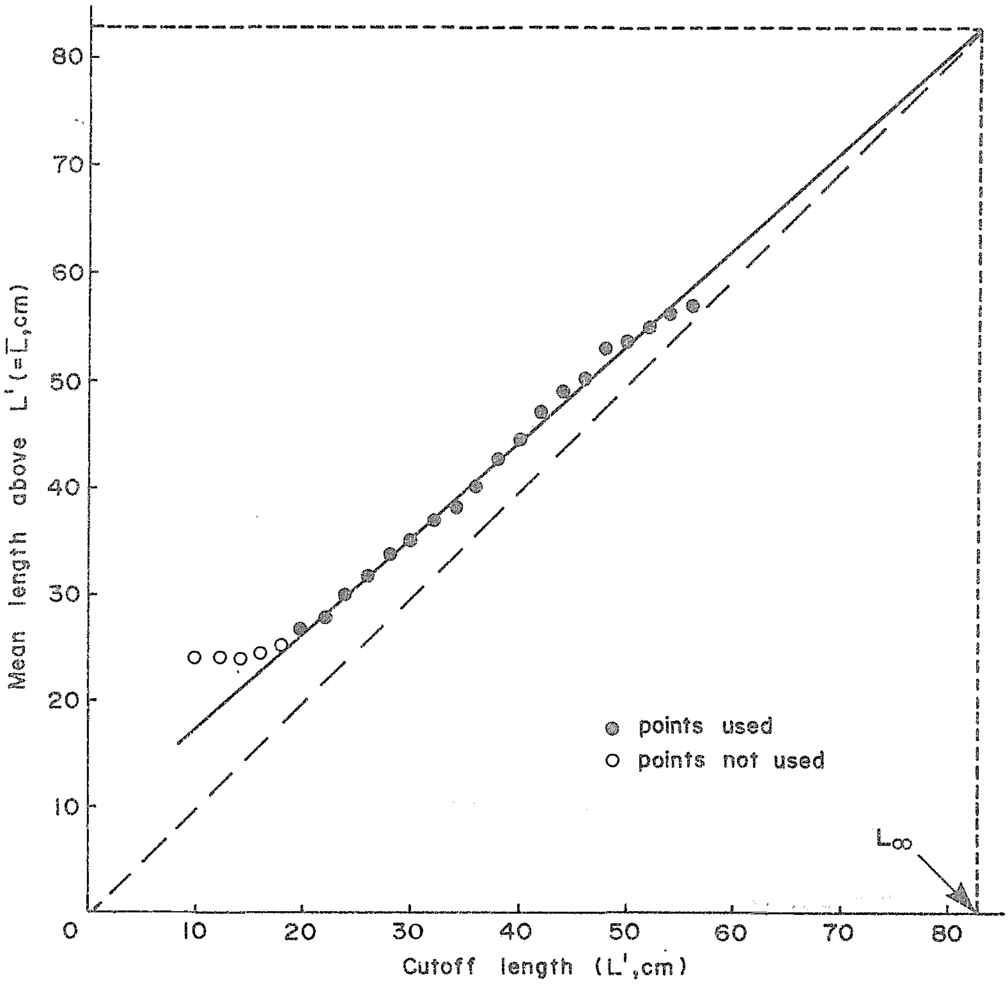

Fig. 8. Wetherall plot for the estimation of L_∞ and Z/K in *Pseudotolithus typus* from Cameroon, based on length frequencies obtained in 1984 (see text).

several old age groups. Omitting the large fish from the analysis, as has been done in this study (because of lack of sampling comparable to that of the smaller fish) is likely to introduce serious bias in the estimation of growth parameters.

It may be noted that the length-weight relationship in Eq. (12) also seems to apply to the large *P. typus*. Some large fish (body weight up to around 12 kg) were weighed to ± 1/2 kg and no deviation from Eq. (12) could be detected (data not presented here).

It is not sure that the large fish are poorly represented in the sample. To elucidate this point we assume that the stock of *P. typus* is in steady state, i.e., the stock remains constant from one year to the next due to constant parameters of recruitment, growth and mortality. The composition of the stock may then simply be calculated by considering a cohort during its lifespan (Beverton and Holt 1957; Sparre 1985). This is done in Table 13 assuming two cohorts per year. As an example, 1,000,000 fish recruiting to the fishery at age 1 year with a mean length of 18.4 cm obtained from the von Bertalanffy growth equation (L_∞ = 83 cm, K = 0.25/year, t_o = 0 year) shall be assumed:

$$L_t = 83\ (1 - e^{-0.25\ t})$$

Total mortality is Z = 2.1/year, i.e., S, the fraction of the cohort surviving half a year becomes:

$$S = e^{-Z\Delta t} = e^{-2.1\ *\ 0.5} = 0.35$$

so the numbers at age in Table 13 are simply obtained by multiplying by S for every half year. The total stock of fish one year or older becomes

$$N_{total} = 1{,}000{,}000\ (1 + S + S^2 + S^3 + ...) = \frac{1{,}000{,}000}{1 - S} = 1{,}538{,}314$$

or, approximately 50% larger than the recruitment number. This stock comprises 1,537,969 fish of length 56 cm or smaller (age groups 1 to 4.5 years), 346 fish of length 60-70 cm (age group 5 to 7.5 years) and 0.635 fish of length 72 cm or bigger (age group 8+). The first group of small fish corresponds roughly to the estimated catch of *P. typus* in 1984 of 11.2 million fish (Table 8). Using the considerations above we would expect to catch approximately

$$11.2 * 10^6 * \frac{346.635}{1{,}537{,}969}$$

or 2,500 fish of 56 cm or bigger in 1984. This may well be in accordance with the sample of 242 large *P. typus* before raising with some unknown factor to total catch in 1984 by all companies. However, the considerations above also indicate that we should expect to catch many more fish (346/0.635 ≈ 500 times) of length 60-70 cm than of length 70 cm or bigger. But the sample of large *P. typus* shows the opposite trend (5 fish compared to 237 large fish). This absence of fish between 50 and 70 cm from the samples suggests migration to deeper waters outside the present fishing ground. The estimate of total mortality is therefore likely to include a part due to migration.

A major difficulty in this work is due to the "noise" present in the length frequencies which makes it difficult to determine modes or peaks from most histograms. This reduces the chance, e.g., for a proper modal progression analysis. Analyzing Bhattacharya results and ELEFAN I restructured length frequencies indicates a permanent mode composed of individuals of 17-19 cm for all months sampled. This may suggest a constant recruitment to the fishable stock and explain why the histograms are very difficult to dissect with the Bhattacharya method and give "very flat peaks" with ELEFAN I.

In this context, two points must be emphasized. First, the rather complicated raising procedure (which was necessary because of narrow and overlapping commercial length categories) may have caused bias in some months (one trip sampled), bias in the raising procedure due to the absence of Wm and Wb (catch in weight of "nylon" and "bar") and the necessary exclusion of large fish. The second point concerns the interpretation of the "recruitment picture" in Fig. 7 based on the first component from the Bhattacharya analysis. To investigate this point, the results of the Bhattacharya analysis in Table 9 shall be considered further. The standard deviations for the first components are more or less constant which may indicate that the first component represents one age group and not a mixture of several age groups (as probably is the case for the third component with much higher variability in both mean lengths and standard deviations). The complexity of the cohort dynamics may be elucidated by considering the first "cohort" of November 1984. CPUE of this cohort is proportional to 64.9 (Table 11). Multiplying by, say, 10 one may consider the cohort to comprise 649 fish of mean length 18.137 cm (Table 9). In the same way, one finds that the October cohort comprises 248 fish of length 17.385 cm. The fraction exp (-Z/12) = exp (-2.1/12) = 0.839 or 0.839 * 248 = 208 fish are expected to be alive in November and to have increased in length by

$$\Delta L = (L_\infty - L)(1 - e^{-K\Delta t})$$

$$= (83 - 17.385)(1 - e^{-0.25/12}) = 1.353 \text{ cm}$$

that is to length 17.385 + 1.353 = 18.7 cm. Thus these fish are likely to be included in the November cohort. Going back to September, one finds that the fish surviving two months increase from mean length 19.5 cm to mean length 22.1 cm in November, which is close to the mean length of the second cohort of November. Thus, in a first approximation one may consider the 649 fish in the first cohort of November to be composed of 208 fish recruited to the fishery in October and 649 - 208 = 441 new recruits with a mean length of X = 17.85 cm obtained from the requirement

$$649 * 18.137 = 208 * 18.738 + 441 * X$$

These considerations indicate the importance of obtaining separate and reliable information on spawning and recruitment patterns in order to be able to make the correct interpretations of the modes resulting from a Bhattacharya analysis. In the present context, the "peak" of November in Fig. 7 should be reduced by a factor of 441/649 = 0.68. Correction factors for the other months may be obtained in the same way (except for the fact that some months were not sampled).

Conclusions

This study has allowed first estimates of growth parameters and total mortality rate of *P. typus* in Cameroon waters. Useful information has been provided regarding the need for further investigations. In particular, some corrections and extensions of the sampling methods are needed in order to reduce the "noise" which made it difficult to determine true modes or peaks from the length frequencies of this study. The present analysis indicates the possibility of two cohorts per year. This needs to be supported by e.g., gonad analysis to obtain a rough estimate of the spawning peaks. There is a need for collecting separate biological data on *P. typus*; in particular, some age readings on hard parts will be useful to support the estimation of growth parameters. Future investigations must also put focus on the assessment of the large fish. This will require trawling offshore.

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Population Dynamics of Emperor Red Snapper *(Lutjanus sebae)*, with Notes on the Demersal Fishery on the Mahé Plateau, Seychelles

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Abstract

Growth parameters of emperor red snapper (*Lutjanus sebae*, Fam. Lutjanidae) were estimated from length-frequency data collected during trawl surveys carried out on the Mahé Plateau, Seychelles, from 1977 to 1981. The von Bertalanffy growth parameters were estimated as K = 0.23/year and L_∞ = 96 cm. The relationship between gutted weight (kg) and total length (cm) can be expressed as $W = 0.0000525\ L^{2.77}$ or $W = 0.0000198\ L^3$.

From data on gonad maturity stages, one major spawning season from February to April and a second period of sexual activity around September to October were suggested.

Mortality rates were estimated from length composition data of the commercial handline fishery (September 1983 to August 1984) using two methods: length-converted catch curve and Jones' length cohort analysis. The two methods gave similar results of Z = 0.73, F = 0.25/year and Z = 0.78, F = 0.3/year. respectively, for the exploited part of the population, with M = 0.48 as estimated by Pauly's empirical formula.

Length cohort analysis gave a density of 1.2 t/nm^2 (0.35 t/km^2) for *Lutjanus sebae* on the offshore banks of the Mahé Plateau. An estimate of 4.4 t/nm^2 (1.29 t/km^2) was obtained for the overall fishery.

Thompson and Bell yield analysis was applied based on results obtained from the length cohort analysis. Long-term predictions of yield and biomass were attempted for varying changes in fishing mortality.

Munro's version of the surplus production model was applied to catch and effort data from the schooner handline fishery.

Introduction

Handlining is by far the most important method of fishing in the Seychelles waters accounting for 60% of all landings. In 1974 this fishery was extended to the offshore banks and periphery of the Mahé and Amirantes Plateau, with the introduction of larger boats locally known as schooners.

Emperor red snapper (*Lutjanus sebae*), locally called "bourgeois", represents 8% of the total landings by the artisanal fishery in Seychelles and 28% of the schooner landings.

In view of its economic importance both for domestic consumption and for exports, a study was started in 1983 by the Research Section of the Fishing Development Company (FIDECO) in collaboration with the UNDP/FAO South-West Indian Ocean Project. The main objective of the project was to assess the state of exploitation of this species on the offshore banks of the Mahé Plateau. This work is now being continued through the assistance of the Institut Français de Recherche Scientifique pour le Developpement en Cooperation (ORSTOM) (see Marchal et al. 1979, 1981).

In this paper, we present the data available on the biology of the principal species caught by this fishery, *Lutjanus sebae*. Growth and mortality estimates for this species are also given for the offshore banks of the Mahé Plateau, Seychelles, along with a preliminary estimate of biomass and potential yield.

Due to the lack of long series of historical data on this offshore demersal fishery, an attempt has been made to evaluate the stock accessible to handline fishery by using a comparative approach (Munro and Thompson 1973; Gulland 1979). This study is based on two years' data collected from the fishery during the period 1982 to 1984. A rough assessment of the fishable biomass for this fishery is also attempted using cohort analysis.

Description of the Fishery

Total landings by the artisanal fishery in Seychelles is around 4,000 t annually and has remained stable for the past few years. The fishery can be divided into two broad categories: the inshore and offshore fisheries.

Inshore fishing is carried out by small open boats ranging from 5 to 8 m mostly equipped with outboard engines, and open whalers (7-9 m) powered with inboard engines.

The most common inshore gear used are handlines (60%), traps (35%), gill nets and beach seines. Two-thirds of the production is landed by inshore boats, with bourgeois representing only 5% of their catches.

The offshore fishery contributing the remaining one-third of the landings is practised by larger decked boats ranging from 9 to 12 m and known locally as schooners. These boats of wooden construction are equipped with inboard engines (27 to 37 horsepower mostly) and usually carry a Marconi sail rig. The facilities on board include a cabin for 4-6 crew and an insulated hold with a capacity of 1-2 t of ice and fish.

The fishing method practised is handlining. The fishing gear consists of a cotton main line and a monofilament leader with several branch lines with 2/0 to 4/0 size barbed hooks. The main line is weighed at the bottom with about 700 g of iron. The number of hooks varies according to the target species; for larger species, such as snappers and big groupers, 4-8 hooks are used.

Fishing activity is mostly concentrated on banks situated near the periphery of the Mahé and Amirantes Plateau. The navigation equipment on board the schooners is limited to a compass. Fishing grounds are generally out of sight of land. Fig. 1 shows a map of the fishing grounds divided into statistical sectors.

General Features of the Biology of Lutjanus sebae

Lutjanus sebae, the emperor red snapper or bourgeois, belongs to the family Lutjanidae. This species is widely distributed along the coasts of the Indian Ocean (Druzhinin 1970). In the Seychelles, unlike other coastal countries in the region, it is better represented in the catches than the blood snapper (*Lutjanus sanguineus*), a similar species.

According to Allen and Senta (1984), the juveniles inhabit shallow mangrove and seagrass areas while the adults may be found down to a depth of 100 m.

No study has been conducted in Seychelles on the distribution of juveniles but small individuals are occasionally trapped around the reef areas. Adults are caught in depths ranging from 20 to 50 m only, on substrates characterized by large scattered coral heads.

However, no precise information is available on depth distribution of smaller age groups and the migration of this species. A common belief of the local fishermen is that the bourgeois tends to congregate on shallow coral heads during the spawning season (around March to April) and is then more vulnerable to the gear.

Though the bourgeois seems to prefer rough substrates, significant numbers are also caught in trawl catches on more even grounds.

Analyses of the stomach contents of the bourgeois (Marchal et al. 1981) show that it has a carnivorous diet consisting cf fish and crustaceans in similar proportions. Cephalopods were also present.

Results of trawl surveys indicate that the sexes can be differentiated at lengths greater than 20 cm; eggs are usually first observed in females of 50 to 60 cm and milt in males of 60 cm (Tarbit 1980). However, fully mature gonads have occasionally been observed in much smaller fish (de Moussac, pers. comm.). *L. sebae* is reported to reach a length of over 100 cm (Allen and Senta 1984).

Materials and Methods

Data on catch, fishing grounds, duration of trip and number of fishermen were recorded for each trip during the period September 1982 to August 1984 on FIDECO schooners. Since all the fish are gutted on board, all catches are expressed as kg or tonnes of gutted fish.

Fishing Areas

The Mahé Plateau has been divided into 10 sectors (Fig. 1). The boundary of each sector was chosen so as to enclose one major bank or related groups of banks. Sector I is not included in this study as the stock there is almost exclusively exploited by open boats (Lablache and Carrara 1984).

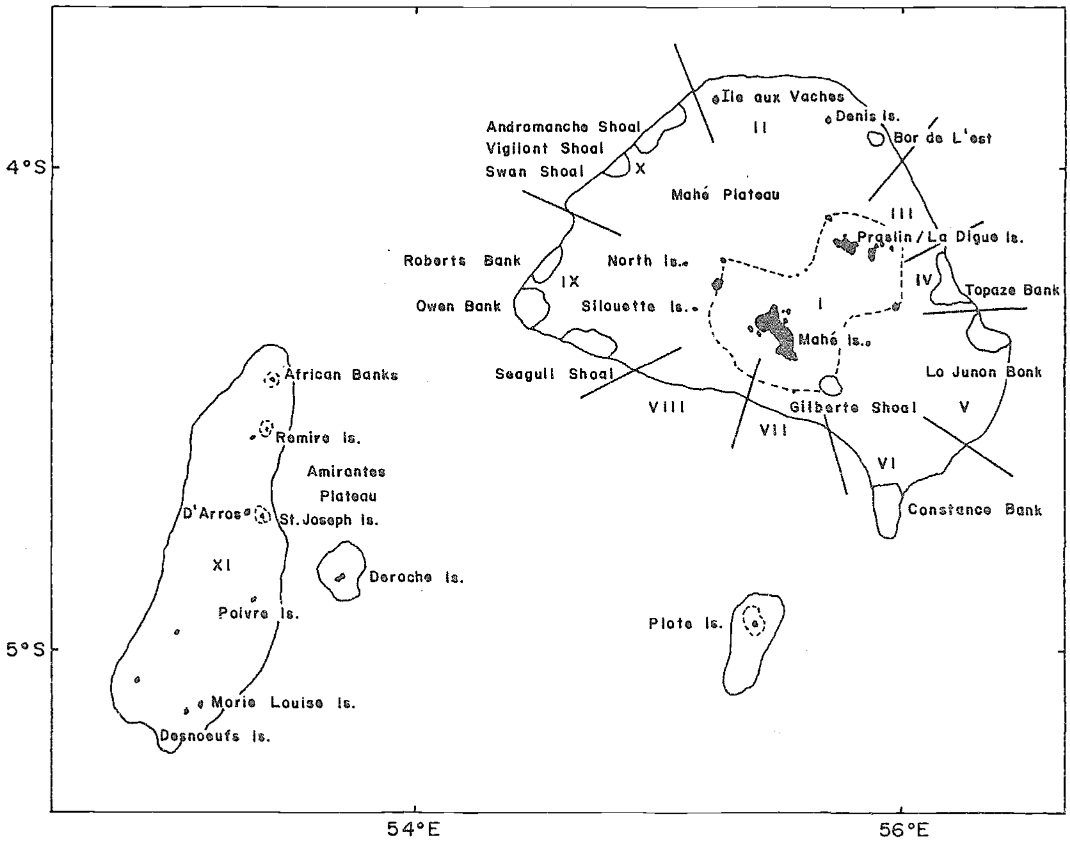


Fig. 1. Fishing sectors. I: Inner Islands area; II: Bird, Denis, North edge; III: NE edge; IV: Topaze Bank; V: La Junon Bank; VI: SE edge, Constance Bank; VII: South edge; VIII: SW edge; IX: Owen, Robert's, Seagull Banks; X: NW edge; XI: Amirantes Plateau.

The surface of the fishing banks and associated plateau edges have been estimated using the Admiralty Charts of the Seychelles group and interviewing skippers. Altogether a total of 1,920 nm^2 have been estimated to be exploited by the offshore fishery; the fishing areas are located mostly near the edges of the Mahé Plateau.

Previous estimates for the Mahé Plateau, presented here for comparison, are:

"Fishable area 3,000 nm^2" (Wheeler and Ommaney 1953)
"Edge zone 3,800 nm^2" (Steinberg et al. 1982)
"Suitable for line fishing - 35 to 65 m 1,600 nm^2" (Gulland 1979)
"Shelf and Bank areas - 20 to 50 m - 1,950 nm^2" (Birkett 1979)

Considering that the first two estimates have been calculated as a "peripheric ribbon" containing the fishing areas, our estimate of the actually fished area seems reasonable (see also Azov-Black Sea Research Institute of Marine Fisheries and Oceanography 1979; Marchal et al. 1979, 1981; Löwenberg et al. 1984).

Catch and Effort

Catch and effort data collection started in September 1981 on the parastatal fishing company (FIDECO) schooners (Nageon n.d.; Lablache and Carrara 1984). Since 1982, estimates have also been made for the privately operated schooners:

- September 1982 to August 1983 for the schooners operated by FIDECO which runs 47% of the fleet; estimates for the remainder of the fleet are based on two months' worth of data, collected during October and November 1982 (Lablache and Carrara 1984).
- September 1983 to August 1984 for the FIDECO schooners; with partial coverage by month, for the remainder of the fleet.

The mean catch rate in the different fishing sectors for FIDECO schooners was calculated from all trips carried out during the study period. Comparing the average catch rate for October-November 1982 for the rest of the fleet with the mean catch rate for FIDECO schooners during the same months, the latter was observed to be 34% lower. A similar difference of 32% was also observed for data collected in the second year of the study period.

Applying this percentage to the FIDECO figures in each sector, we estimated the corresponding catch rates for the rest of the fleet. The overall catch rate in each sector was taken as the weighted mean (by number of boats) of the two fleets. The results are shown in Table 1.

The effort exerted by the rest of the fleet during the study period was calculated as shown in Table 2, and the distribution by fishing sector was assumed to be similar to that of FIDECO schooners (Table 1).

Gonad Analysis

Since the fish are gutted at sea, only few specimens of *L. sebae* could be examined for gonad activity. The data obtained by the authors were combined with data from trawls surveys, data collected by ORSTOM staff (1984 to 1985) and other data from the files of the now renamed Fisheries Division (1976 to 1977) and are shown in Table 3 (see also Fig. 2).

Weight-Length Measurements

The gutted weights of 70 specimens of *L. sebae* for a wide range of lengths were taken during the study period (see Fig. 3).

Tarbit (1980) gives a graph of weight against fork length for males and females; they suggest no difference in length-weight relationship with sex.

Table 1. Catch and effort data by fishing zone, September 1982 to August 1984 (C/M/D: catch (kg)/man/day).

Zone	Catch FIDECO	Catch others	Catch overall	C/M/D FIDECO	C/M/D[1] overall	% of Bourgeois	Effort FIDECO	Effort[3] others	Total effort
1982-1983									
II	11,791	19,957	31,748	30.90	36.46	30.97	440	482	922
III	51,419	92,844	144,263	42.31	49.93	27.59	1,495	1,637	3,132
IV	37,006	64,097	101,103	46.07	54.36	29.57	948	1,038	1,986
V	43,400	75,386	118,786	52.63	62.10	37.82	976	1,069	2,045
VI	83,298	130,713	214,011	51.04	60.23	33.77	1,745	1,911	3,556
VII + VIII	20,609	33,513	54,122	41.14	48.55	18.20	555	608	1,163
IX	65,637	105,892	171,529	48.19	56.78	30.83	1,501	1,644	3,145
X	13,842	20,688	34,530	39.37	46.46	29.47	358	392	750
Mahé Plateau	327,002	543,090	870,092	46.10	54.40	29.78	8,018	8,781	16,800
Amirantes Plateau	45,500	72,094	117,594	34.18	40.33	1.42	1,437	1,577	3,011
Total	372,502	615,184	987,686				9,455	10,358	19,811
1983-1984									
II	6,304	9,268	15,572	24.55	28.18[2]	27.25	257	286	543
III	17,909	30,098	48,007	23.47	26.94	24.97	873	972	1,845
IV	5,621	8,931	14,552	27.02	31.01	29.32	225	250	475
V	9,808	16,141	25,949	42.26	48.50	31.57	260	289	549
VI	28,813	43,841	72,654	36.44	41.82	35.97	819	911	1,730
VII + VIII	4,975	8,061	13,036	20.10	23.07	33.40	273	304	577
IX	93,355	158,856	252,211	51.13	58.68	19.19	2,115	2,354	4,469
X	9,015	13,499	22,514	32.13	36.88	27.08	286	318	604
Mahé Plateau	175,800	288,695	464,495	38.80	44.53	28.59	5,108	5,685	10,793
Amirantes Plateau	93,899	168,711	262,610	46.05	52.85	4.81	2,494	2,775	5,269
Total	269,699	457,406	727,105				7,602	8,460	16,062

[1]((C/M/D FIDECO * 16 boats) + (1.34 * C/M/D FIDECO * 18 boats))/34.
[2]((C/M/D FIDECO * 14 boats) + (1.32 * C/M/D FIDECO * 12 boats))/26.
where boats = mean no. of boats in operation/month.
[3]Effort distribution assumed to be similar to FIDECO boats (applied to the estimated total from Table 2).

Table 2. Estimation of effort by non-FIDECO schooners of the schooner fleet (see text).

Year	Men/ boat	Days fishing per trip	Trip/ month	Mean no. of boats fishing	Annual effort man days
1982-1983	4.8	3.7	2.7	18	10,358
1983-1984	5.0	4.7	2.5	12	8,460

Table 3. Gonad activity for *Lutjanus sebae* on the Mahé Plateau, Seychelles.

Maturity stage	II	Male IA	Male A	Male AR	Male R	Male S	Male N	Female IA	Female A	Female AR	Female R	Female S	Female N
Jan	8	6	12		1		19	11	8		8		27
%		31.6	63.2	0	5.3	0		40.7	29.6	0			
Mar	252	20	140	53	5	13	231	20	149	131	28	23	351
%		8.7	60.6	22.9	2.2	5.6		5.7	42.5	37.3	8	6.5	
Apr		6	10		8	1	25	16	8		14	3	41
%		24	40	0	32	4		39	19.5		34.1	7.3	
May	8	1	2		2		5	7	2		1	9	19
%		20	40	0	40			36.8	10.5	0	5.3	47.4	
July	7	7	2				9	3	7				10
%		77.8	22.2					30	70				
Sep	36	45	11		9	7	72	50	29	5	32	15	131
%		62.5	15.3		12.5	9.7		38.2	22.1	3.8	24.4	11.5	
Oct	36	19	13		1	2	35	25	18	9	9	2	63
%		54.3	37.1		2.9	5.7		39.7	28.6	14.3	14.3	3.2	
Nov	6	34	29				62	45	27				72
%		54.8	46.8					62.5	37.5				
Dec	5	7	17		4		28	10	12		4		26
%		25	60.7		14.3			38.5	46.1		15.4		

II = Immature, IA = Inactive, A = Active, AR = Active Ripe
R = Ripe, S = Spent, N = Number of fish examined

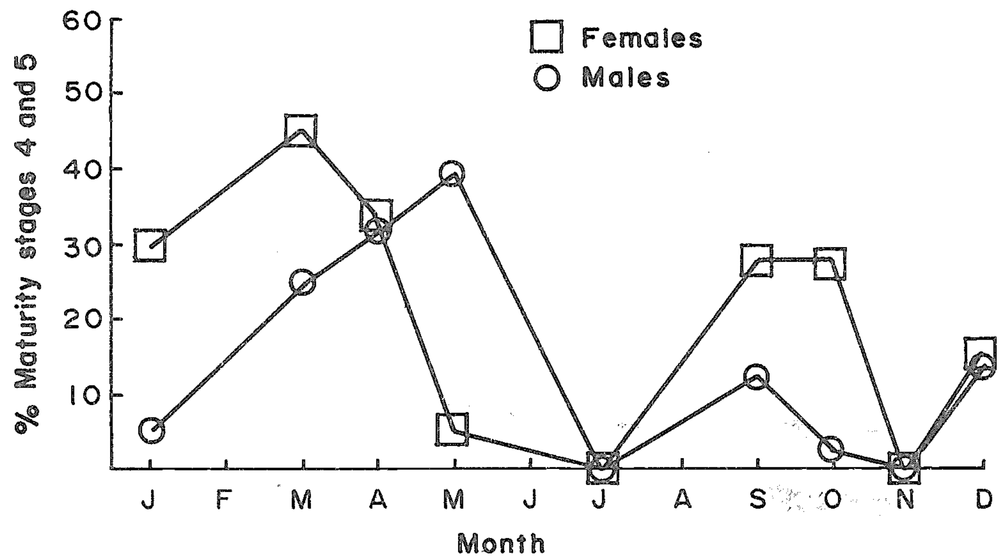


Fig. 2. Percentage maturity stages, AR and R, against month. *(Lutjanus sebae)*

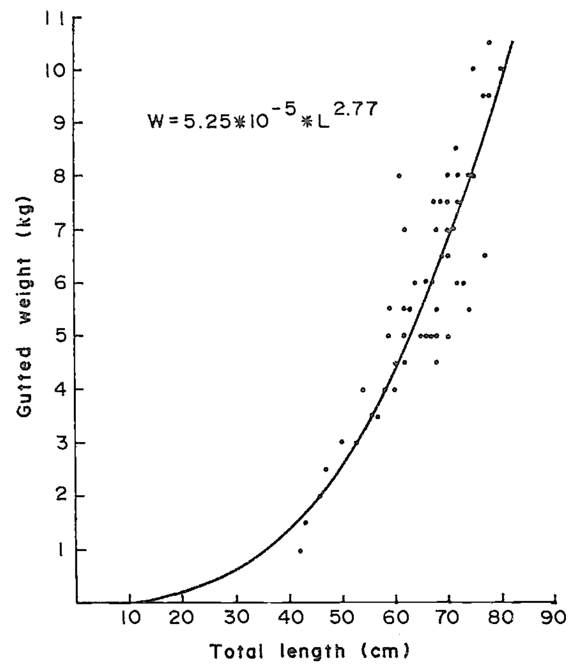


Fig. 3. Plot of gutted weight (kg) against total length (cm) for *Lutjanus sebae*.

Growth

The length-frequency samples taken from the fishery do not include the smaller age groups due to the selectivity of the gear and are therefore not suitable for estimation of growth parameters. These growth parameters have been estimated from data collected by trawl surveys carried out on the Mahé Plateau by *R/V Professor Mesyatsev,* October 1977 (Birkett 1979); *Nauka*, February to April 1979 (Azov-Black Sea Research Institute of Marine Fisheries and Oceanography 1979); and in the frame of a bilateral project with the Federal Republic of Germany, March to November 1981 (Steinberg et al. 1982). The samples used in the analysis are given in Table 4 and Fig. 4 for males and females combined. Length measurements were taken as total lengths to the cm below.

The modes in each sample were identified by separating the available length-frequency samples into their component distributions using the Bhattacharya (1967) method. By plotting the difference between consecutive logarithmic values of the number caught against length, a normal distribution is transformed into a straight line. In this manner, by visually inspecting the obtained plot, the first group can be separated and the number of fish belonging to this first group is calculated and subsequently subtracted from the sample. The process is repeated until the whole sample has been divided up into its component distributions (see also Asila and Ogari, this vol.).

The means of each group identified were plotted against time as shown in Fig.4. The most probable progression of these means was then visually identified.

The von Bertalanffy growth parameters were obtained by the Gulland and Holt (1959) method as described in Sparre (1985). This requires a plot of the difference in length between consecutive means over difference in time ($\Delta L/\Delta t$) against the mean length between the two corresponding mean lengths. By undertaking a regression analysis of the available data pairs (Fig. 5) the growth parameters L_∞ and K were estimated. These values were then used as initial values of L_∞ and K for the ELEFAN I (Electronic LEngth-Frequency ANalysis) as described by Pauly and David (1981) and implemented by Saeger and Gayanilo (1986).

Growth parameters obtained were then compared to results available on the same and/or related species.

Since growth is not linear, growth comparisons in two fish populations using L_∞ and K separately may be misleading (Pauly 1979; Kimura 1980; Merona 1983; Moreau et al. 1986).

Table 4. Percent length-frequency samples of *Lutjanus sebae* from trawl surveys in Seychelles waters.

Class midlength (cm)	MESYATSEV 14-28 Oct 1977	NAUKA 12 Feb-12 Mar 1979	German survey Mar-May 1981	Sep-Nov 1981
7.5	0	0	0.60	0
10.5	0	0	1.61	0
13.5	0	0	4.43	0
16.5	0	0.12	1.01	0.10
19.5	0	0.14	0.40	1.40
22.5	0	0.18	0.40	1.60
25.5	0	0.22	0.00	0.80
28.5	0	0.24	0.60	0.80
31.5	0	0.30	2.11	0.10
34.5	0	0.32	1.41	0.70
37.5	0	0.36	0.40	1.10
40.5	0.4	0.80	0.81	1.50
43.5	0.4	1.02	0.81	1.10
46.5	0.8	0.78	1.61	1.20
49.5	2.9	1.18	3.63	1.60
52.5	2.0	1.99	2.32	2.71
55.5	5.7	2.39	2.32	4.21
58.5	4.1	2.59	5.84	6.42
61.5	11.5	4.34	5.94	13.24
64.5	20.5	6.61	11.38	17.45
67.5	15.6	11.14	12.19	13.74
70.5	7.4	14.48	15.61	9.53
73.5	6.1	16.14	7.96	8.63
76.5	8.2	7.65	3.02	6.02
79.5	11.1	6.75	4.53	3.31
82.5	3.3	4.94	3.83	2.01
85.5	0	5.62	3.02	0.60
88.5	0	5.96	2.01	0.10
91.5	0	2.05	0.20	0
94.5	0	1.43	0	0
97.5	0	0.18	0	0
100.5	0	0.06	0	0
No. sampled	224	1,009	471	729

Pauly and Munro (1984) proposed that growth performance can be expressed by an index ϕ' defined by:

$$\phi' = \log K + 2 \log L_\infty$$

where K is expressed on an annual basis and L_∞ in cm.

When originally deriving this formula, Pauly (1979) started from the von Bertalanffy growth equation

$$W = W_\infty (1 - \exp(-K(t - to)))^3$$

The highest growth rate according to this equation is:

$$dw/dt_{max} = 4/9\ KW_\infty \qquad (1)$$

Pauly (1979) and Munro and Pauly (1983) used this maximum growth rate as an index of growth performance. However, based on both biological and empirical considerations (Pauly 1979 and see Moreau et al. 1986), W_∞ was replaced by an arbitrary surface of the fish $AW^{2/3}$ (where A is a constant).

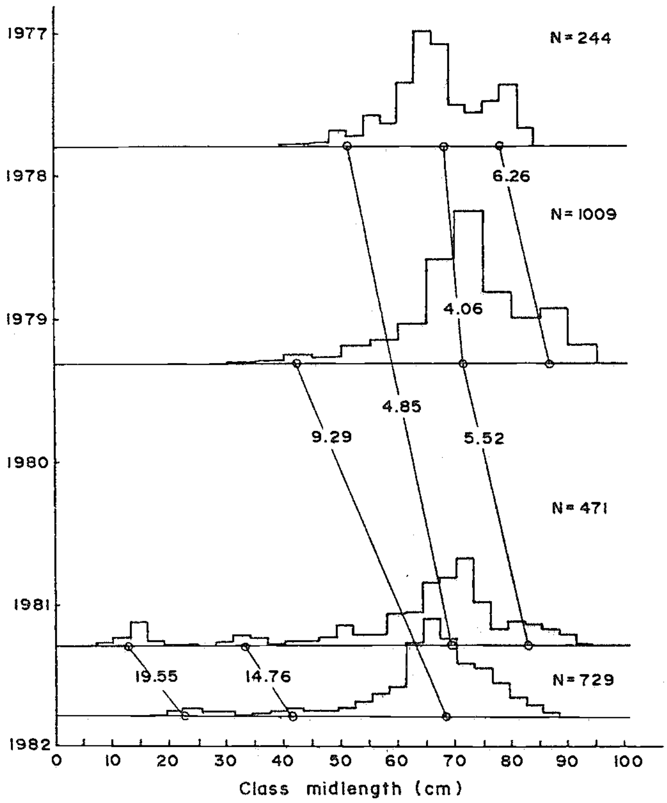


Fig. 4. Plot of modal midlengths against time and progression of the modes *(Lutjanus sebae)*. N = sample size. Growth rates in centimeters per year are listed above each progression.

This leads to

$$4/9\ KAW^{2/3}$$

as index of growth performance.

Converting W_∞ into length by $W_\infty = qL_\infty{}^3$ gives the expression

$$4/9\ Aq^{2/3}KL_\infty{}^2 \qquad (2)$$

For the purpose of statistical analysis the logarithm of expression (2) is preferred, and thus defining the index ϕ_O of growth performance

$$\phi_O = \psi + \log K + 2 \log L_\infty$$

$$\text{where } \psi = \log 4/9\ Aq^{2/3}$$

The term can be shown to remain approximately constant within small taxonomic groupings; it depends on the condition factor q and the weight/surface conversion factor A (Moreau et al. 1986).

Thus within species, and between closely related taxa, the index of growth performance

$$\phi' = \phi_O - \psi = \log K + 2 \log L_\infty$$

can be assumed to remain fairly constant.

Mortality

Length-frequency samplings of *L. sebae* landed by the schooners were taken on a quarterly basis for the different fishing sectors. The total length of the fish was measured to the nearest cm below. Table 5 presents the cumulated length composition samples, raised to the total catch in each sector for *L. sebae*. Data for Sector X have been omitted due to insufficient data.

The total mortality coefficient, Z, was calculated from catch-at-length data by combining all sectors for which data were available for the period 1983 to 1984 (Table 5). Two methods were used, the length-converted catch curve (Pauly 1983) and Jones' length cohort analysis (Jones 1984).

Table 5. Total catch by sector of *Lutjanus sebae* Sep 1983-Aug 1984 (in numbers) excluding sector X.

Length group (T.L., cm)	Sector[a] II	III	IV	V	VI	VII + VIII	IX	Total
24.5-29.4	0	41	0	0	0	0	0	41
29.5-34.4	9	41	0	12	40	10	83	195
34.5-39.4	57	20	11	48	189	14	208	546
39.5-44.4	57	102	22	95	388	20	706	1,391
44.5-49.4	76	286	11	95	388	54	665	1,575
49.5-54.4	104	449	60	131	518	81	1,329	2,673
54.5-52.4	161	469	99	357	588	78	1,703	3,455
59.5-64.4	180	469	198	417	827	118	2,451	4,660
64.5-69.4	161	428	258	393	1,235	183	1,703	4,362
69.5-74.4	114	510	93	226	866	146	1,205	3,160
74.5-79.4	85	286	60	119	388	64	1,122	2,125
79.5-84.4	28	184	44	24	269	47	291	887
84.5-89.4	19	82	5	0	129	34	83	352
Total number	1,051	3,367	863	1,917	5,826	850	11,549	25,442
Sample size (number)	111	165	157	161	585	251	278	1,708
Total catch (gutted weight, kg)	4,243	11,987	4,267	8,192	26,134	4,354	48,399	107,576

[a]See Fig. 1.

In the absence of any other information on the fishery, the natural mortality coefficient M was estimated using the approach proposed by Pauly (1980). The formula given below correlates natural mortality coefficient, M with the von Bertalanffy growth constants and the annual mean water temperature, T (in ^oC)

$$\ln M = - 0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.463 \ln T$$

where $\ln = \log_e$ replaces $\log_{10}$ used in the original version of this equation.

Biomass and Yield

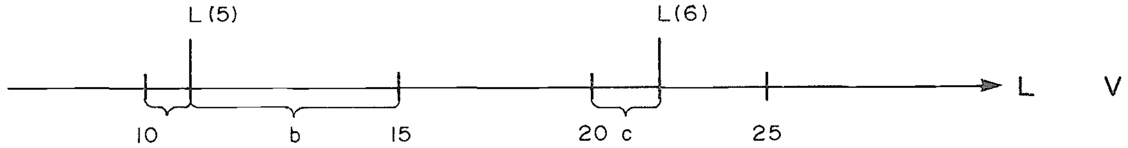
An estimate of stock size was obtained from the length cohort analysis as modified below.

Short-term prediction

The method proposed by Thompson and Bell (1934) was modified to accept length-frequency data as input:

(a) Stock numbers, N calculated by length cohort analysis are transformed into age-frequency data with help of the growth curve:

Age group (a, a + 1) corresponds to the length interval (L(a), L(a + 1)), where L is the input to the von Bertalanffy equation:



The figure above shows a hypothetical example. In this case the entire length group of 15-20 cm, the fraction b/5 of length group 10-15 cm, and the fraction c/5 of length group 20-25 cm, will be transferred to age group 5.

Fishing mortalities by length group are transferred to age groups in a similar way, taking into account the time period used to grow through a length class.

(b) Stock numbers, N, for the next year are calculated by:

$$N(y + 1, a + 1) = N(y,a)\ \exp^{-Z(y,a)}$$

where y is the index of year and a an index of age; N(y,a) are the numbers estimated from cohort analysis, and Z is the sum of F and M which are the mortalities from cohort analysis.

The following Table shows a hypothetical example:

Results from Jones' length cohort analysis

Length group (cm)	Stock number by length group	Fishing mortality by length group
5-10	N (5-10)	F (5-10)
10-15	N (10-15)	F (10-15)
15-20	N (15-20)	F (15-20)
20-25	N (20-25)	F (20-25)
.	.	.
.	.	.
.	.	.

Conversion of length groups into age groups by the von Bertalanffy growth equation →

Modified Thompson & Bell analysis

Age group[a]	1984 Stock number at beginning of 1984	1984 Fishing mortality during 1984 (Fishing pattern)	1985 Stock numbers at beginning of 1985
1[a]	N (84, 1)	F (84, 1)	N (85, 1) = N (84,1)
2	N (84, 2)	F (84, 2)	N (85, 2) = N (84, 1) exp (−Z(84, 1))
3	N (84, 3)	F (84, 3)	N (85, 3) = N (84, 2) exp (−Z(84, 2))
4	N (84, 4)	F (84, 4)	N (84, 4) = N (84, 3) exp (−Z(84, 3))
.	.	.	.
.	.	.	.
.	.	.	.

[a]As absolute ages were not available the ages given here are relative ones, i.e., the age corresponding to the lower limit of first length group is (arbitrarily) assigned the value 1 year.

(c) The mean stock number $\overline{N}$ during the year y + 1 is then calculated:

$$\overline{N}(y + 1,a) = N(y + 1,a)\ [1 - e^{-Z(y + 1,a)}] / Z(y + 1,a)$$

e.g., $\overline{N}(85,a) = N(85,a)\ [1 - e^{-Z(85,a)}] / Z(85,a)$

(d) The number caught in year y + 1 is calculated by:

$$C(y + 1,a) = F(y + 1,a)\ \overline{N}(Y + 1,a)$$

e.g., $C(85,a) = F(85,a)\ \overline{N}(85,a)$

(e) Yield in year y + 1 is calculated by:

$$\sum_a C(y + 1,a)\ W(a)$$

where $W(a) = q\,L(a + 0.5)^b$

(f) Biomass in y + 1 is calculated by

$$\sum_a \bar{N}(y + 1,a)W(a)$$

The procedure described above predicts the status quo catch and stock in 1985, i.e., the catch and stock in case of unchanged fishing pattern, e.g., from 1984 to 1985:

$$F(85,1) = F(84,1)$$
$$F(85,2) = F(84,2)$$
$$F(85,3) = F(84,3)$$
.
.
.

To simulate a change in the overall level of effort in 1985 compared to 1984 a constant factor, X_L, is applied to the 1984 fishing pattern:

$$F(85,1) = X_L\ F(84,1)$$
$$F(85,2) = X_L\ F(84,2)$$
$$F(85,3) = X_L\ F(84,3)$$
.
.
.

Thompson and Bell long-term yield prediction

This model is essentially the same as the short term prediction model. The difference is that the stock is assumed to be in a steady state (all parameters are assumed to have remained constant during a long period, e.g., constant recruitment). The recruitment estimate used is N(84,1).

Results

Spawning Season

The monthly gonad activity for *L. sebae* is given in Table 3 and Fig. 2. A plot of percentage maturity stage (AR to R) against month, as represented in Fig. 2, shows two peaks: a marked one around February to April and a smaller peak around September to October.

Weight at Length

A plot of gutted weight in kg (W') against total length in cm (L) for males and females combined is given in Fig. 3. The regression of the log-transformed weights against log-transformed lengths gives the following relationship:

$$W' = 0.0000525\ L^{2.769}$$

Assuming that the growth can be expressed by $W' = qL^3$, the following relationship between W' (kg) and L(cm) was obtained

$$W' = 0.0000198\ L^3$$

Growth

The modes identified using the Bhattacharya method and linking of the modes are shown in Fig. 4. Using the Gulland and Holt method (Fig. 5), the growth constants L_∞ and K were obtained as 96 cm and 0.23/year, respectively. These estimates shall be used for all further computations.

The ELEFAN I program gave the best fit for L_∞ = 100 cm and K = 0.25/year. The restructured samples used in the ELEFAN I analysis, with superimposed growth curve are shown in Fig. 6.

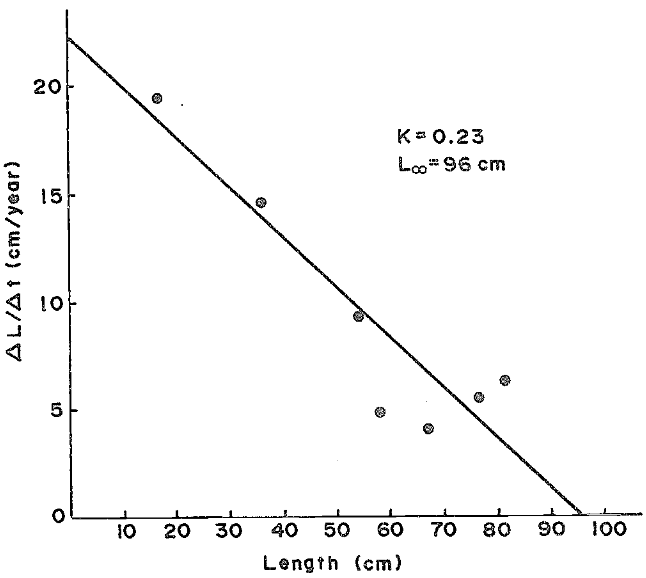


Fig. 5. Gulland and Holt. *(Lutjanus sebae).*

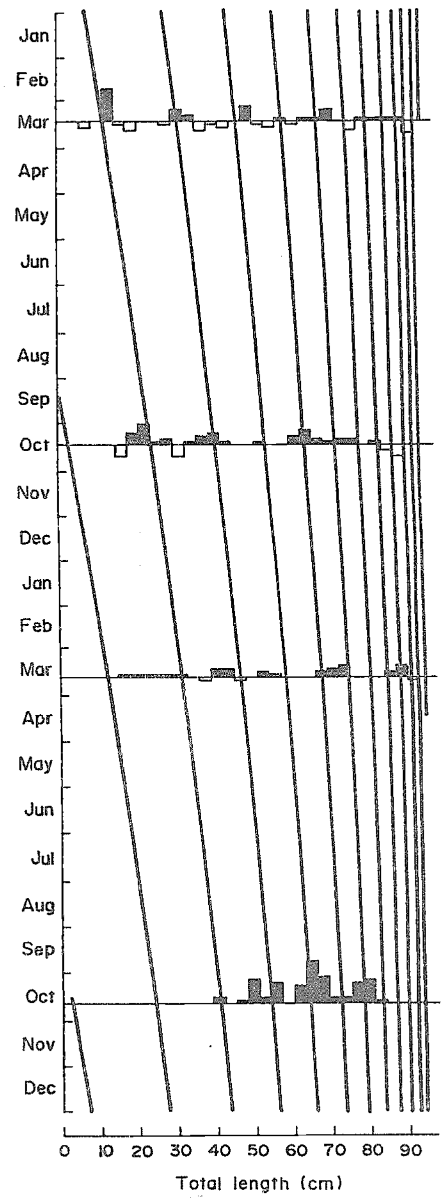


Fig. 6. Restructured length-frequency samples for *Lutjanus sebae* (Mahé Plateau, Seychelles) using ELEFAN I and superimposed growth curve.

Mortality

Using an L_∞ of 96 cm and K of 0.23/year, the length-converted catch curve gave a Z value of 0.73 (Fig. 7).

Tarbit (1980) compiled hydrological information on the Mahé Plateau, from which the mean temperature for depths ranging from 40-60 m is given as 24°C. This value introduced, along

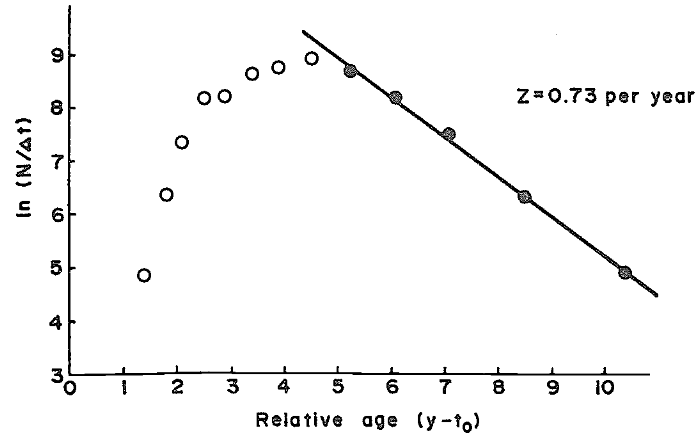


Fig. 7. Length converted catch curve for *Lutjanus sebae* (Mahé Plateau, offshore banks) for L_∞ = 96 cm, K = 0.23 per year.

with the growth parameters $L_\infty = 96$ cm and K = 0.23 into Pauly's formula leads to an estimate of M = 0.48/year.

The fishing mortality coefficient can therefore be estimated as F = 0.25.

Using length-converted cohort analysis (Table 6) with M = 0.48 a similar result was obtained. The mean F (weighted by stock numbers) for the fully exploited part of the stock (L > 64.5 cm) was 0.28.

Thus, the estimated M, F and Z appear to be consistent.

The terminal exploitation rate, F/Z, of 0.4 in Table 6 was chosen as the value giving a constant F/Z in the last length groups.

Fitting a logistic curve to the left hand side of the catch curve gave an estimate of $L_c = 41$ cm (L_c = the length at which 50% of the fish are available to the fishery and are caught if encountering the gear, i.e., the 50% length in the resultant curve).

Table 6. Jones' length cohort analysis for *Lutjanus sebae* (Mahé Plateau, offshore banks) for K = 0.23 per year, L_∞ = 96 cm and M = 0.48 per year.

Interval L (i) L (i+1) (cm)	C	X_L [a]	N	F/Z	F	Z	W (kg)	N*W
4.5- 9.5	0	1.0604	352,700	0.000	0.000	0.480	0.009	3,000
9.5-14.5	0	1.0641	313,700	0.000	0.000	0.480	0.038	12,000
14.5-19.5	0	1.0683	277,000	0.000	0.000	0.480	0.103	29,000
19.5-24.5	0	1.0731	242,700	0.000	0.000	0.480	0.218	53,000
24.5-29.5	41	1.0786	210,800	0.001	0.001	0.481	0.399	84,000
29.5-34.5	195	1.0850	181,200	0.007	0.003	0.483	0.66	120,000
34.5-39.5	546	1.0925	153,700	0.022	0.011	0.491	1.01	156,000
39.5-44.5	1,391	1.1015	128,300	0.058	0.030	0.510	1.48	190,000
44.5-49.5	1,575	1.1125	104,500	0.073	0.038	0.518	2.07	217,000
49.5-54.5	2,673	1.1260	83,000	0.134	0.074	0.554	2.80	233,000
54.5-59.5	3,455	1.1434	63,100	0.194	0.115	0.595	3.68	233,000
59.5-64.5	4,660	1.1662	45,200	0.292	0.198	0.678	4.74	215,000
64.5-69.5	4,362	1.1976	29,300	0.349	0.257	0.737	5.98	175,000
69.5-74.5	3,160	1.2438	16,800	0.373	0.286	0.766	7.42	124,000
74.5-79.5	2,125	1.3181	8,300	0.414	0.339	0.819	9.07	75,000
79.5-84.5	887	1.4575	3,200	0.387	0.305	0.785	10.95	35,000
84.5-89.5	352		900	0.400	0.320	0.800	13.07	11,000
Total number			2,214,400	Gutted biomass (kg) (Sectors I-IX)			=	1,965,000
				Whole biomass (kg) (All sectors)			=	2,358,000[b]

$*X = ((L_\infty - L(Z))/(L_\infty - L(i+1)))^{M/2K}$

[a] $X_L = ((L_\infty - L_i)/(L_\infty - L_{i+1}))^{M/2K}$.
[b] Biomass has been raised by 5% to account for sector X and by 15% to account for gutting effect.

Stock Size Estimates

Using length cohort analysis the biomass of *L. sebae* on the offshore banks of the Mahé Plateau was estimated as 2,360 t; corresponding to a density of 1.2 t/nm^2 (0.36 t/km^2) for a fishable area of 1,900 nm^2 (Table 6).

In the absence of similar information on other principal species exploited by the schooner fishery, a rough biomass assessment was made for the overall fishery based on the assumption that *L. sebae* (representing 28% of the catch) is representative of all fish in this fishery. An overall biomass of 8,400 t and a density of 4.4 t/nm^2 (1.29 t/km^2) were estimated.

Thompson and Bell Yield Analysis

The stock number and fishing mortality by length groups obtained from the cohort analysis were converted to relative age groups, using the von Bertalanffy equation as described in the section on short-term prediction and the results are given in Table 7.

Table 7. Data input for the Thompson and Bell yield per recruit model (by age group) for *Lutjanus sebae* (Mahé Plateau) with K = 0.23 per year, L_∞ = 96 cm, M = 0.48 per year and W = 0.0000198 L^3 (kg, cm).

Age group	Stock no.	Fishing mortality	Weight (kg)
1	1,126,500	0.000	.002
2	565,400	0.004	.251
3	282,400	0.033	1.107
4	136,800	0.097	2.491
5	59,100	0.219	4.178
6	26,400	0.274	5.962
7	10,500	0.322	7.696
8	4,300	0.320	9.292
9	2,000	0.305	10.706
10	900	0.320	11.927
Sum	2,214,400	–	–

Figs. 8 and 9 show the variation of the short-term yield and equilibrium yield, respectively, together with biomasses for different changes in fishing mortality.

To test the reliability of the Thompson and Bell analysis, the 1984 data were applied to predict the 1985 catch. The model predicts a catch of 115 t for a 40% reduction in effort for 1985. This seems consistent with the situation observed in 1985, where the overall fleet, reduced from 34 to 21 schooners landed approximately 120 t (round weight) of *L. sebae*.

The long-term equilibrium model (Fig. 9) seems to indicate that if the 1984 level of effort is maintained, the long term annual yield of *L. sebae* would be around 380 t.

Analysis of CPUE and Effort per Area Using the Surplus Production Model

From the estimated catch and effort figures obtained for the overall fishery (Table 1), the effort per nm^2 and the catch per nm^2 for the different fishing sectors were calculated as shown in Table 8.

These figures, applied to the surplus production model (Munro and Thompson 1973; Gulland 1979) are shown in Fig. 10.

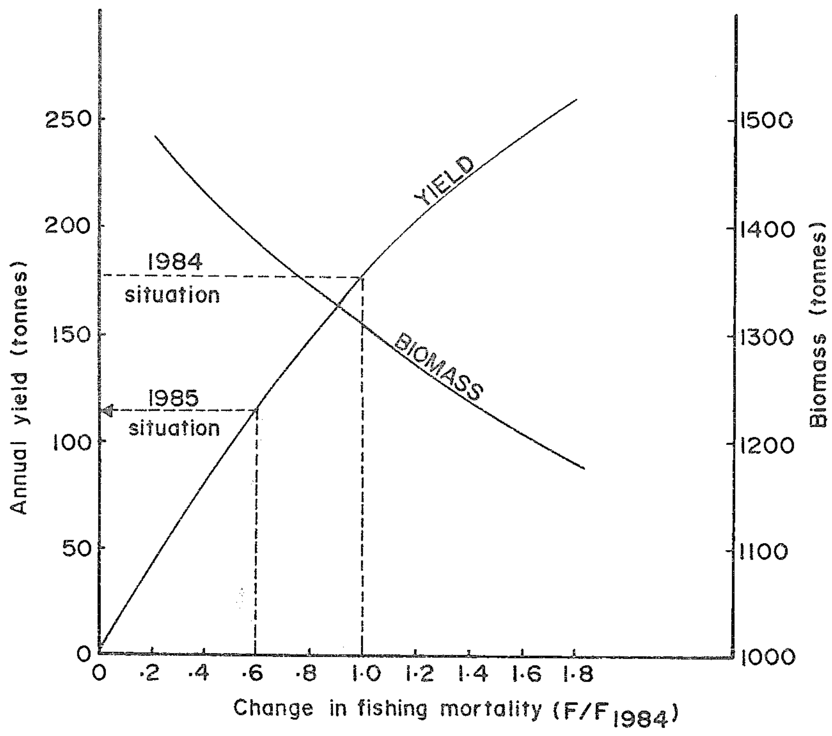


Fig. 8. Thompson and Bell short term model for *Lutjanus sebae* (Mahé Plateau, off-shore banks) for L_∞ = 96 cm, K = 0.23 per year, M = 0.48 per year and W = 0.0000198 L^3 kg.

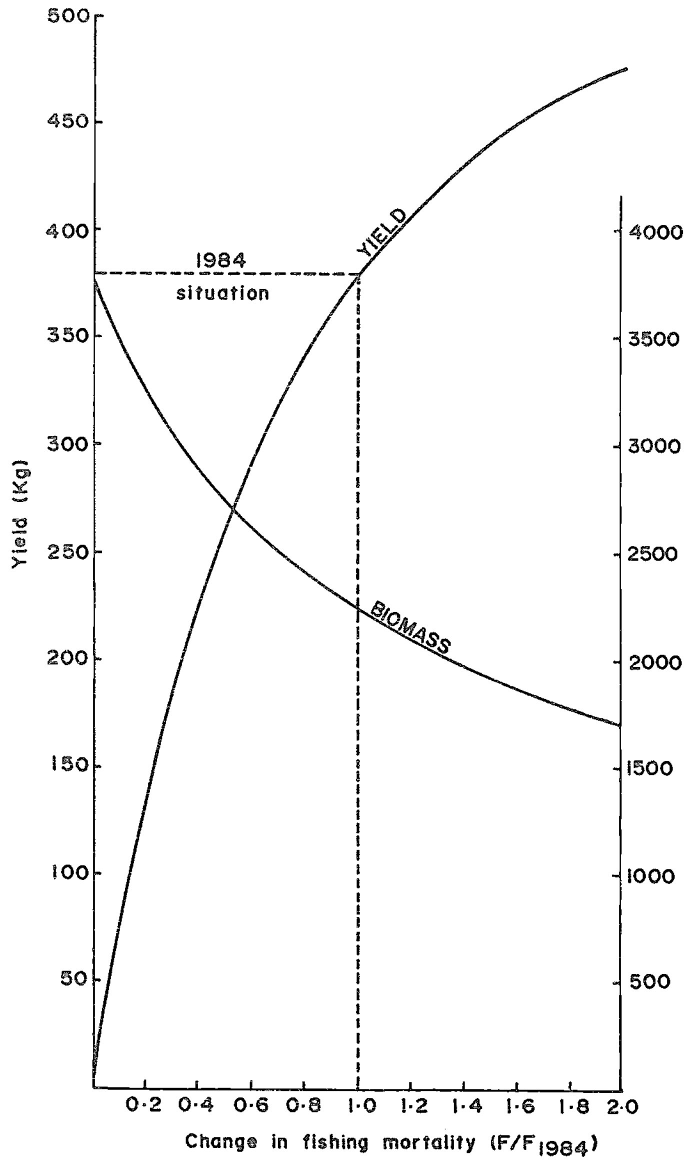


Fig. 9. Thompson and Bell long term equilibrium model for *Lutjanus sebae* (Mahé Plateau, offshore banks) parameters as in Fig. 8.

Table 8. Summary of catch rate and effort/nm^2 by fishing sectors (Mahé Plateau, Seychelles) September 1982 to August 1984. (C/M/D = catch per man per day, M*D/nm^2 = man days per square nautical mile.

Fishing zone	Area (nm^2)	Sep 1982-Aug 1983 C/M/D (kg)	Sep 1982-Aug 1983 M*D/nm^2	Sep 1983-Aug 1984 C/M/D (kg)	Sep 1983-Aug 1984 M*D/nm^2
II	80	36.	11.5	28.6	6.8
III	160	49.9	19.6	26.9	11.5
IV	224	54.4	8.9	31.0	2.1
V	225	62.1	9.1	48.5	2.4
VI	496	60.2	7.4	41.8	3.5
VII + VIII	256	48.5	4.5	23.1	2.2
IX	400	56.8	7.9	58.7	11.2
X	80	46.5	9.4	36.9	7.5

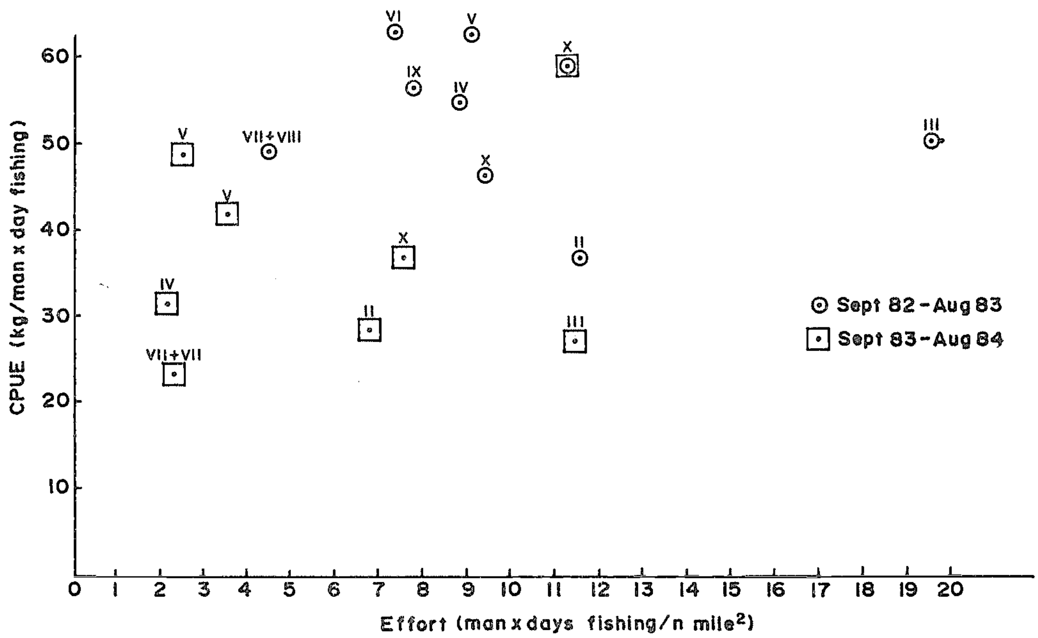


Fig. 10. Plot of CPUE (kg) man*days fishing against effort (man*days fishing/nm^2) by fishing sectors.

Discussion

Lutjanus sebae

The two spawning seasons identified correspond to the intermonsoon periods. Tarbit (1980) proposes that the main spawning season may extend from December/January to April, on the basis of data collected from April to November.

The values of L_∞ and K obtained in this study compares relatively well to other estimates obtained for *L. sebae* and similar Lutjanidae (Table 9). The ϕ' values obtained are consistent with other estimates.

Table 9. Comparison of growth estimates for *Lutjanus sebae* and some related species.

Species	K ($year^{-1}$)	L_∞ (T.L., cm)	ϕ'[a]	Area	Method	Sources
L. malabaricus (m)	0.19	102	3.30	Great Barrier Reef, Australia	Otoliths (ageing)	McPherson et al. (1985)
L. malabaricus (f)	0.25	86	3.27		Otoliths (ageing)	
L. malabaricus	0.31	60	3.05	Vanuatu, S. Pacific	ELEFAN I	Brouard & Grandperrin (1984)
L. malabaricus	0.168	83	3.06	Australian Water (Arafura Sea)	Scales & vertebrae	Edwards (1985)
L. purpureus	0.096	96.7	2.95	Off Recife, Brazil	Non-linear regression	Pauly (1978, based on Fonteles-Filho 1970)
L. sanguineus	0.236	89	3.27	Djiboutian Waters Red Sea, Gulf of Aden	Scales & vertebrae	Reference not available (UNDP/FAO, Red Sea and Gulf of Aden project)
L. sebae (m)	0.14	114	3.26	Great Barrier Reef Australia	Otoliths	McPherson et al. (1985)
L. sebae (f)	0.21	90	3.23			
L. sebae	0.23	96	3.33	Mahé Plateau, Seychelles	Bhattacharya/Gulland Holt Figs. 4 & 5. Values used for further analysis	Present investigation
L. sebae	0.25	100	3.40	Mahé Plateau, Seychelles	ELEFAN I (Fig. 6)	Present investigation

[a] $\phi' = \log_{10} K + 2 \log_{10} L_\infty$.

A difference in growth between males and females of *L. sebae* was observed in Australian waters. McPherson et al. (1985) noted that males were significantly larger than females at lengths greater than 50 cm, whereas younger fish did not show a significantly different growth. Tarbit (1980) states that adult males of *L. sebae* are substantially larger than females. In the absence of length-frequency data by sex, growth parameters estimated in this study indicates the average growth for the males and females of *L. sebae*.

The total mortality coefficient, Z, obtained using the length-converted catch curve is similar to that obtained from the length cohort analysis.

Estimates of M obtained for similar species, e.g., *L. malabaricus* in Vanuatu (Brouard and Grandperrin 1984) and *L. sanguineus* in Djiboutian Waters, Red Sea and Gulf of Aden correspond to 0.545 and 0.51, respectively, compared to 0.48 obtained in this study. However, these estimates have all been derived using Pauly's empirical formula. The value of M = 0.48 obtained corresponds however to M = 2 x K (= 0.46) as found by Ralston (1987) for groupers and snappers.

Similar values of Z obtained from the catch curve and length cohort analysis would seem to indicate that the estimated M value is reasonable.

The density of *L. sebae* estimated for the offshore banks of the Mahé Plateau is comparable to those given by various authors, for trawlable grounds, except for the estimates given by Künzel et al. (1983) which are lower (Table 10).

Biomass estimates given in this report apply only to the offshore banks of the Mahé Plateau since data for the central zone of the plateau were not included. Therefore it has been assumed that no fishing mortality is applied on the smaller length groups in both the cohort analysis and the Thompson and Bell model. Furthermore, the biomass estimate obtained for the offshore banks analysis of the Mahé Plateau is not the actual fishable biomass accessible to the schooner fishery due to the selectivity of the handlines. A reduction of about 30% should be applied to the results in order to remove fish smaller than L_c (= 41 cm) (compare Table 6).

Table 10. Comparison of some density estimates of *Lutjanus sebae* in Seychelles waters.

Estimated density tons/nm²	t/km²	Area and sources
0.6[a]	0.18	Mahé Plateau edge zone Künzel et al. (1983)
0.3[a]	0.09	Central zone Künzel et al. (1983)
1.4[a]	0.41	Trawlable area Mahé Plateau Tarbit (1980)
1.0[a]	0.29	Trawlable area Mahé Plateau Marchal et al. (1981)
1.2[b]	0.35	Hard bottom Mahé Plateau (offshore banks, this study)

[a]Observed % of total density estimated using the swept-area method on trawlable grounds.

[b]Length cohort analysis for estimation of population size.

The Overall Fishery

The total biomass for the Mahé Plateau was estimated to be 42,000 t by Birkett (1979), 75,000 t by Marchal et al. (1981), 80,000 t by Tarbit (1980) and 51,000 t by Künzel et al. (1983). It should be noted that these biomass estimates comprise also species not normally exploited by the handline fishery such as Scaridae, Nasidae, Gatherinidae, some shark species and small nonmarketable fish species. These results are also for the whole of the Mahé Plateau, including the central area of the plateau, the plateau edge at depths greater than 60 m and sandy bottom areas.

The density estimates of demersal fish accesible to handlining (see Table 11 for definition) on the offshore banks of the Mahé Plateau are comparable to estimates obtained previously through the use of the swept area method on trawlable grounds. Künzel et al. (1983) obtained a lower value whereas estimates given by Tarbit (1980) and Marchal et al. (1981) were higher (Table 11). The last two papers were expected to give overestimates since it was not possible to extract all the unwanted species from the overall density estimates given.

The potential yield of the offshore banks of the Mahé Plateau for the species actually exploited by the schooner handline fishery is to date not known. Künzel et al. (1983) estimate the MSY for large growing species, for the edge zone of the Mahé Plateau (3,800 nm^2) to be 2,600 t which corresponds to an MSY of 0.68 t/nm^2 (0.2 t/km^2). This figure also includes the above mentioned species not normally caught by schooners (see Löwenberg et al. 1984 and Künzel et al. 1983). By excluding these species, the estimated MSY for offshore demersal fishery will be 0.55 t/nm^2 (0.16 t/km^2).

The nonconformity of our data to the surplus production model used could indicate that this model is inappropriate and/or the data are inadequate. The lack of fit between model and data could be explained by the following:

Table 11. Comparison of some density estimates of demersal fish[a] in Seychelles waters.

Estimated density tons/nm^2 All species[a]	Species not caught by handline excluded	Reference area and survey period	Remarks
0.8 2.7	0.5 2.1	Mahé Plateau Central zone 8740 nm^2 edge zone 3800 nm^2 1981	actual density were estimated using the swept area method from trawlable grounds and extrapolated to the whole area (incl. hard bottom) Source: Künzel et al. (1983)[a]
5.3[f]	5.0[f]	trawlable area of Mahé Plateau 4176 nm^2 1976-1979	density estimates using swept area method on trawlable grounds (no extrapolation to non-trawlable grounds Source: Tarbit (1980)[b]
4.8[f]	4.5[f]	trawlable area of Mahé Plateau 7000 nm^2 1980	density estimates using swept area method on trawlable grounds Source: Marchal et al. (1981)
4.4[d]	4.4[d]	hard bottom off Mahé Plateau (offshore banks) 1900 nm^2 1984-1985	length-cohort analysis for estimation of population size, length to weight conversion. Whole stock assumed to be represented by *L. sebae* Source: this study

[a]Big fish species. See Table 5 in Künzel et al. 1983 for definition.
[b]Some species groups as in Künzel et al. 1983 (extrapolated from Table in Tarbit 1980).
[c]Some species groups as in Künzel et al. 1983 (extrapolated from Table 3.3 in Marchal et al. (1981).
[d]Density estimates = D/0.28 assuming that *L. sebae* (= 28% of the catch) is representative for all fish.
[e]For comparison with density estimates based on handline data only.
[f]This figure is an overestimate because density estimates are given only for some selected species and the overall fishery. Therefore some unwanted fish species could not be subtracted for lack of data.

- ***Diversity of the species in the catch.*** Catch rates are influenced by the species sought by the fishermen due to pricing strategy. Fishermen have the choice of the type and the number of hooks to be used and the type of substrate and depth.

- ***Man-days fishing may not correctly reflect the fishing mortality exerted on the stock.*** The number of hooks used per line may change and the number of hours fishing per day changes. Time spent searching for fish and other factors affecting the number of hours fishing per day cannot properly be assessed.

- ***There is a sharp drop in catch rates during the bad weather season (May to August).*** This is probably due to the fast drift of the boat and related difficulty in keeping the line close to the bottom, limitation in the choice of fishing grounds and time spent waiting for improvement of weather which cannot be properly accounted for (Lablache and Carrara 1984). Catch rates cannot therefore be compared on a yearly basis if we are to account for the above drop in catch rates and the fact that some areas are visited more during either the good or bad weather season.

- ***Information on the fishing grounds may have been misreported.*** Though the skippers of the company had no real reason for giving false reports, the boats may move to adjacent fishing sectors. Furthermore the distance of the fishing grounds and the lack of navigational aids may render it difficult to obtain correct information on the fishing grounds.

Some of these factors such as the variation in catch per man x days fishing with changes in crew size, duration of fishing trip, weather conditions and fishing location have already been demonstrated by Lablache and Carrara (1984). Some of the bias in the data, mentioned above, could be corrected through the application of a multivariate statistical analysis, by which the different factors other than fishing intensity, influencing the catches per trip could be quantified. This approach applied on a single species and groups of species basis could improve the overall results (Ralston and Polovina 1982). The present study sets the stage for future research, which should entail a more detailed analysis on the existing data, aimed at identifying these variables which are significantly affecting catch rates.

Conclusion

This is the first time that such a study has been attempted on demersal stocks of the Mahé Plateau, and it has been based on limited data. Therefore results obtained here are only preliminary and should be reassessed by further research. Furthermore, consideration must be given to the fact that the schooner fishery is based on a multispecies resource. Before any management measure can be recommended, a similar study must be carried out on other important species exploited by the fishery.

The Thompson and Bell model has so far found little application to tropical fish stocks. The findings of our analysis seem to indicate that such a model could be usefully applied. It should, however, be further tested against observed data. Actually length cohort analysis should preferably be applied to data summed over several years (Jones 1984) which was not the case in the present study. Further, the Thompson and Bell model assumes constant recruitment. The estimate of this recruitment should preferably be the average value observed over several years. In the present study the recruitment was based on a value estimated for one year only. The very high value predicted as the long-term yield when applying the 1984 level of effort might be due to an outstanding high year class recruiting to the fishery in 1984.

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Growth, Mortality and Biomass Estimation of Goat Fish *(Upeneus sulphureus)* in the Java Sea, Indonesia

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Abstract

Growth parameters, mortality and biomass of *U. sulphureus* in the southern Java Sea inshore area (0-50 m) were estimated from trawl surveys in 1977-1979 carried out by the Indonesian-German Demersal Fisheries Project.

The biomass was estimated on an annual basis by the swept-area method, correcting for mesh selection and post stratifying in depth zones. The estimated biomass in 1979 was less than one-fourth of the estimated biomass in 1977.

Growth and mortality parameters were estimated by the ELEFAN method and catch curve analyses. The underlying length frequencies by depth zones were corrected for mesh selection and weighted by the proportion of estimated biomass in each zone.

The limitations in the methods used and lack of information on the fisheries are discussed and recommendations are made for further work to be done in this area.

Introduction

Goat fish *(Upeneus sulphureus)* is one of the many demersal fish in the Java Sea. Significant quantities of this fish are caught between 10 and 50 m depth, and the catch rate increases significantly with increasing depth (Beck and Sudradjat 1978).

The stock in 1976 in the offshore area in the southern Java Sea, has been estimated at about 58,000 tonnes, while in the north of coast central Java Sea it was approximately 9,000 t (Badrudin 1978). Estimates of biomass immediately before the trawl ban in 1980 are not available and the biomass of *U. sulphureus* in the inshore areas has apparently never been estimated.

Before the trawl ban, effort expended on the demersal stocks was mainly based on trawlers. In the north of Java, the number of trawlers was approximately 600-1,000 (Losse and Dwiponggo 1977). The trawlers usually operated inshore and conflicts with the artisanal fishery could not be avoided.

After the trawl ban, the demersal fisheries effort has mainly been based on trammel nets with shrimp as the target species. The effect of the trawl ban on the stock of demersal fishes has not been evaluated.

Stock density, potential yield and growth studies in the southern Java Sea were carried out by the Indonesian-German Demersal Fisheries Development Project.

Previous estimates of growth parameters of *U. sulphureus* were presented by Beck and Sudradjat (1978) and Dwiponggo et al. (1986) based on data collected in the inshore area of the southern Java Sea. The aim of this study is to reestimate the growth parameters of *U. sulphureus* in the same inshore area and, in particular, to obtain estimates of mortality and biomass in the period 1977-1979. Length-frequency samples and catch per unit of effort from the trawl surveys form the data source of this study. Such an assessment of *U. sulphureus* in the period immediately before trawl banning constitutes the first step in providing the basis for biological advice on future stock management. However, an important problem in this assessment and therefore in the present work is due to the use of a mesh size of 40 mm in the cod-end (stretched) during the entire survey. The small fish escape through such big meshes and it becomes difficult to perform reliable assessments of the small demersal fish species based on the trawl catches.

Material and Methods

Material

Material for analysis in this paper was obtained during surveys made by the Indonesian-German Demersal Fisheries Development Project in 1977, 1978 and 1979. A mesh size of 4 cm was used in the cod-end (see Mulyadi, this vol., for more details on gear and rig).

The raw data, including length frequencies, operational aspects, catch composition, and catch rates were obtained from Dwiponggo and Badrudin (1978, 1979, 1980).

Length-frequency samples of *U. sulphureus* from individual one-hour hauls by depth zone (I = 0-20 m; II = >20-40 m; III = >40 m) and by area (A, B, C) are given in Table 1. The positions of these hauls are shown in Fig. 1.

The weights of *U. sulphureus* samples were calculated based on the length-weight relationship given by Beck and Sudradjat (1978),

$$W = 0.009\, L^{3.193} \qquad \text{...1)}$$

with W in g and L, total length in cm.

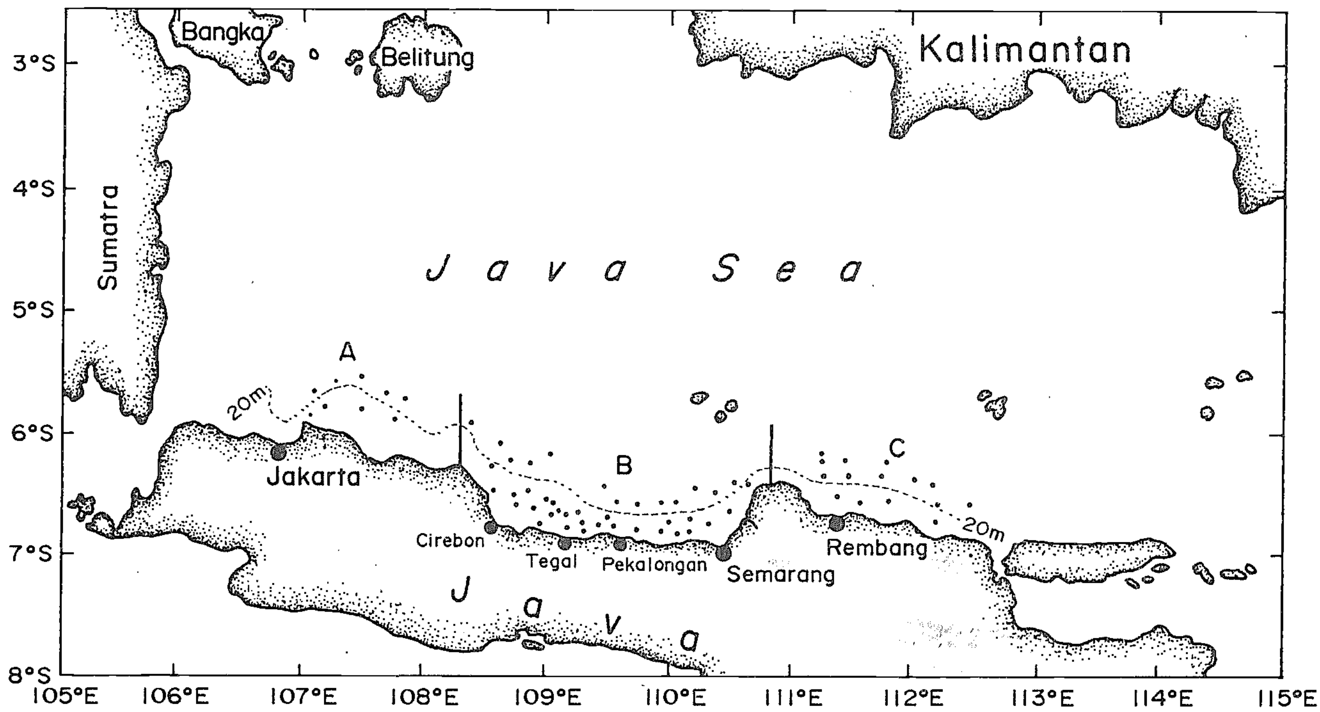

Fig. 1. Distribution of trawl hauls by area and depth zones by *R/V Mutiara IV* survey from 1977 to 1979. Only hauls positive for *U. sulphureus* are shown. The 20 m isobath has been added for the north coast of Java only.

Table 1. Length-frequency samples of *Upeneus sulphureus* by depth and area zones from the *R/V Mutiara 4* trawl survey in the Java Sea, 1977-1979, with raising factor to total catch in each of the one-hour trawl hauls (see also text).

Mid-length (cm)			1977 Apr								1977 Jul					
	22	22	22	23	23	21	21	21	21	22	23	26	27	27	27	27
4.75																
5.25																
5.75	3	2	1		1				1							
6.25	4	6	0		0				1							
6.75	10	5	4		0	4		1	7		1		1			
7.25	19	21	7		0	20	1	9	25	2	8		1	4		
7.75	23	14	12		0	16	12	24	35	1	28	4	1	15	1	1
8.25	42	15	41	3	2	21	44	36	18	4	24	9	22	16	3	3
8.75	42	9	42	0	0	6	41	24	15	3	19	35	40	24	3	2
9.25	28	5	34	0	0	7	29	18	8	7	24	17	27	11	3	2
9.75	8	2	24	1	1	4	10	21	13	3	6	3	17	13	4	9
10.25	1	1	11	4	1	5	3	5	5	2	8	1	6	4	7	4
10.75	2	0	5	16	9	2	1	1	0	17	1	1	3	0	20	9
11.25		1	11	24	23	4		0	1	16			1	1	21	12
11.75		0	7	21	26	2		0	0	8					16	17
12.25		2	6	20	15	2		2	0	11					5	8
12.75		0	0	9	5	2		1	1	3					3	3
13.25		1	2	4	7	0			0	1					0	7
13.75		1		1	3	0			2						1	0
14.25					3	2										1
14.75					3											
15.25					1											
15.75																
16.25																
16.75																
17.25																
Sample size, n_j	182	85	207	103	100	97	·141	142	132	78	119	70	119	88	87	78
Sample weight, w_j (kg)	1.46	0.68	2.38	2.35	2.53	1.00	1.30	1.34	1.11	1.46	1.06	0.67	1.23	0.82	1.67	1.64
Catch, W_j (kg)	12.0	1.4	2.8	2.5	14.6	1.7	13.2	22.5	26.0	9.1	34.5	19.9	25.0	17.9	4.5	28.0
Raising factor, W_j/w_j	8.22	2.1	1.2	1.1	5.8	1.7	10.2	16.8	23.4	6.2	32.5	29.7	20.3	26.7	2.7	17.1
Depth zone	I	II	II	II	III	I	I	II	II	II	II	I	II	II	II	III
Area zone	B	B	C	B	B	B	B	B	B	B	B	B	B	B	B	B

Table 1. Continued

Mid-length (cm)	1977 Sep						1977 Oct			1977 Nov						
	8	9	9	11	11	11	14	15	16	28	29	29	29	29	30	30
4.75																
5.25								1								
5.75								6								
6.25								2		12		3				
6.75								1		16		14				
7.25								0		13	1	25				
7.75								0		6	0	25	1			
8.25								17		1	1	15	2		3	1
8.75		3	9		1		1	44	2		0	4	4		0	0
9.25	1	24	10	6	10	1	7	18	3		3	3	2		1	3
9.75	1	29	19	14	26	4	26	6	8		22	0	9	5	6	21
10.25	12	12	5	18	34	9	17	2	5		54	2	27	30	38	59
10.75	12	15	11	10	5	7	15		12		25	2	29	25	40	21
11.25	16	3	12	10	2	9	6		7		13	2	6	38	25	17
11.75	10	2	17	3	1	17	6		8		1	1	2	18	12	6
12.25	16	2	8	1	1	16	7		5				1	5	4	2
12.75	3	2	7	1	1	7	6		15				1	6	1	0
13.25	2	0	2	0	1	3	2		19				0	2	1	4
13.75	2	1	5	0		1	1		9				0			
14.25	0	1	1	1		1	1		11				1			
14.75	1			0		1	1		3							
15.25				0					3							
15.75				1												
16.25																
16.75																
17.25																
Sample size, n_j	76	94	106	65	82	76	96	97	110	48	120	96	85	129	131	134
Sample weight, w_j (kg)	1.70	1.42	8.09	1.13	1.22	1.78	1.78	0.86	3.16	0.21	1.88	0.66	1.39	2.55	2.36	2.26
Catch, W_j (kg)	2.0	1.6	74.0	3.1	45.2	54.0	80.0	19.3	48.6	1.3	14.1	1.8	12.8	39.6	12.8	16.6
Raising factor, W_j/w_j	1.2	1.1	35.4	2.7	37.0	30.3	44.9	22.4	15.4	6.1	7.5	2.7	9.2	15.5	5.4	7.3
Depth zone	II	II	III	II	II	III	II	I	I	I	II	II	II	II	II	II
Area zone	B	B	B	B	B	B	C	C	C	B	B	B	B	B	B	B

Table 1.-Continued

Mid-length (cm)	2	2	2	2	2	3	3	3	3	3	1977 Dec 4	4	5	5	5	15	15	15	16	16	16
4.75	2					1															
5.25	14					16															
5.75	28					47							2					1			
6.25	36					38	1						0	1			1	0			
6.75	6					12	17	1					0	0			0	1			1
7.25	21	1				28	59	0					2	1			0	0		1	2
7.75	7	2	1			8	40	2		1		1	9	7			3	5		4	5
8.25	5	6	0			2	10	0		0		2	26	22	1		17	13		15	13
8.75	2	0	0			1	4	0		0		0	44	36	2	3	31	20		12	2
9.25		0	2		3	0	0	0		0	1	0	22	16	2	0	30	28		9	3
9.75		0	3	3	9	0	0	5	1	13	0	0	5	4	0	2	5	9		3	1
10.25		2	19	13	37	0	0	24	12	37	7	2	1	0	1	8	0	2		0	
10.75		19	39	17	19	0	7	22	37	32	16	19	0	1	12	21	2	8	2	0	
11.25		33	20	37	17	1	4	24	23	29	37	25	0	2	15	15	1	7	1	1	
11.75		18	8	9	3	0	2	11	18	7	11	22	0	4	15	10	1	3	9		
12.25		12	2	6	7	0	0	6	11	2	15	11	1	1	14	6			12		
12.75		2		1	0	1	0	1	2	2	8	10	1	0	4	1			6		
13.25		0		2	3		0	1	1	2	7	2	0	0	4				3		
13.75		2					1	1	3	1	7	3	0	0	5				13		
14.25		1						0	0	1	6	4	0	0	1				3		
14.75		0						0	2		6		0	2	5				2		
15.25		1						1	2		3		1		2						
15.75		1						0			0										
16.25								1			1										
16.75																					
17.25																					
Sample size, n_j	121	100	94	88	98	155	145	100	112	127	125	101	114	97	83	66	91	97	51	45	27
Sample weight, w_j (kg)	0.44	2.15	1.70	1.77	1.56	0.58	1.02	1.97	2.46	2.68	3.36	2.38	1.10	1.05	2.16	1.28	0.91	1.13	1.61	0.41	0.21
Catch, W_j (kg)	7.7	5.0	18.5	13.3	60.0	3.6	14.8	26.9	44.6	21.9	26.8	11.6	2.7	3.0	14.8	2.5	7.8	6.9	9.0	2.7	0.8
Raising factor, W_j/w_j	17.6	2.3	10.9	7.5	34.1	6.2	14.5	13.7	18.1	8.2	8.0	4.9	2.4	2.8	6.9	2.0	8.6	6.1	5.6	6.6	3.8
Depth zone	I	I	II	II	II	I	I	II	II	II	II	II	I	I	II	II	II	II	III	I	I
Area zone	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	B	B	B	B	B	B

Table 1. Continued

Mid-length (cm)	16	17	17	17	17	17	17	17	17	1977 Dec 18	19	19	19	20	20	20	21	21	21	21
4.75							1													
5.25							0													
5.75		1					0							1				1		
6.25		0				1	8	1		2				1				0		
6.75		0				2	43	0		5				0				1		
7.25		8	1			2	86	1		5			8	3				0		
7.75		43	1			14	56	14	1	10			14	2				0		
8.25		86	0		2	18	14	27	3	35			17	3	1			2		
8.75	1	56	1		1	7	3	8	2	27			14	5	5			22		
9.25	1	14	0		1	1	1	2	6	12	1		11	0	23			39	1	
9.75	10	3	0		0	0		0	2		0		9	1	8			30	1	
10.25	19	1	9		1	1		0	11		4		10	5	7		4	6	12	
10.75	12		13	6	17			0	13		15	1	13	6	4	4	2	2	29	5
11.25	8		21	11	19			1	9		27	2	70	15	4	11	6	3	25	7
11.75	2		16	13	19				4		10	10	1	5	4	23	11	1	16	6
12.25			8	14	14				2		15	9	2	7	3	23	7		0	8
12.75			1	7	13				1		9	5	1	2	1	17	11		3	2
13.25			0	2	7				0		7	3	1	7		9	17		1	3
13.75			2	3	4				2		6	7		1		7	5		3	3
14.25			2		4						1	3				4	3			
14.75			0		0											4	3			
15.25			0		2												6			
15.75			1														3			
16.25																	3			
16.75																	1			
17.25																				
Sample size, n_j	53	212	76	56	104	46	212	54	56	96	95	40	171	64	60	102	82	107	91	34
Sample weight, w_j (kg)	0.86	1.69	1.66	1.41	2.64	0.34	1.13	0.42	0.98	0.76	2.32	1.19	2.58	1.25	0.87	2.92	2.83	1.25	1.85	0.87
Catch, W_j (kg)	14.3	3.9	114.4	29.4	47.5	0.4	3.9	13.2	47.5	4.9	74.0	5.8	7.7	36.0	4.0	24.0	6.7	9.0	25.5	37.0
Raising factor, W_j/w_j	16.6	2.3	68.9	20.8	18.0	1.2	3.5	31.4	48.7	6.4	31.9	4.9	3.0	28.8	4.6	8.2	2.4	7.2	13.8	42.5
Depth zone	II	II	II	III	III	I	I	I	II	I	II	III	II	III	II	II	III	I	II	II
Area zone	B	B	B	B	B	B	B	B	B	B	B	B	B	A	B	B	C	A	A	A

Table 1. Continued

Mid-length (cm)					1978 Jan										1978 May					
	10	10	10	13	14	14	16	16	16	19	19	19	20	20	20	21	21	21	22	23
4.75																	3	1	1	
5.25										1	1	3	8	1	3	2	6	3	0	1
5.75										0	1	7	20	4	3	6	4	6	1	1
6.25										1	1	4	5	4	3	8	5	6	0	2
6.75										4	1	5	12	3	3	9	18	13	2	4
7.25										9	6	5	16	5	11	19	11	13	5	9
7.75										26	9	11	14	7	18	9	4	6	1	4
8.25	2							1		13	6	9	13	13	24	6	5	5	1	9
8.75	4		1					1		7	4	6	13	18	14	4	0	4	5	3
9.25	12		0	1	1			2		0	3	2	5	11	17	2	1	3	3	3
9.75	20		1	2	2	1	1	3	1	2		4	3	11	21	3	4	4	3	6
10.25	33	7	2	2	3	0	7	6	1	1		2	6	6	6	4	5	3	3	10
10.75	22	31	17	1	14	3	24	5	10	1		2	5	1	1	9	11	4	12	10
11.25	12	32	34	13	11	5	23	28	15	1			4		0	5	3	5	5	4
11.75	5	22	37	13	16	15	20	18	16	1			0		0	0	1	2	13	3
12.25	1	14	15	15	9	12	4	19	14				0		1	2	0	1	4	
12.75	0	7	14	9	2	12	0	7	8				0		1		1	1	1	
13.25	1	8	4	2	6	2	2	5	8				1					1	1	
13.75	1	1	1	5		2		1	1									1		
14.25	1	1	1	3		2		3										1		
14.75				1																
15.25																				
15.75																				
16.25																				
16.75																				
17.25																				
Sample size, n_j	114	123	127	67	64	54	81	99	74	67	32	60	125	84	126	88	82	83	61	69
Sample weight, w_j (kg)	1.84	2.77	2.97	1.76	1.44	1.44	1.66	2.32	1.82	0.49	0.21	0.41	0.90	0.74	1.14	0.89	0.81	0.94	1.16	0.92
Catch, W_j (kg)	14.8	15.1	45.0	7.8	24.2	5.2	98.5	17.2	14.4	3.12	1.5	4.5	3.5	8.50	11.25	18.5	49.0	26.5	7.8	21.8
Raising factor, W_j/w_j	8.0	5.4	15.2	4.4	16.8	3.6	59.3	7.4	7.9	6.3	7.1	10.9	3.9	11.5	9.9	20.8	60.7	28.3	6.7	23.7
Depth zone	II	II	III	III	II	III	II	II	II	I	I	I	II	II	II	II	II	II	II	II
Area zone	B	B	B	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	B

Table 1. Continued

Mid-length (cm)	1978 May							1978 Oct			1978 Nov						
	23	23	24	24	24	25	25	31	31	31	2	2	3	3	4	4	4
4.75																	
5.25		2			1		3										
5.75		6	2		0	5	9										
6.25		2	2		0	5	11										
6.75	1	2	3	1	0	3	13										
7.25	5	10	2	1	0	15	7										
7.75	11	9	3	3	0	13	13										
8.25	4	9	7	1	1	8	4										
8.75	7	2	2	2	0	14	8										
9.25	1	5	4	1	5	3	8		3					3		1	
9.75	1	3	4	3	2	9	3		2	19	13		3	3	2	2	3
10.25	2	1	3	0	2	3	3	1	12	25	6	1	8	15	5	6	7
10.75	8	7	6	8	14	5	1	2	7	12	3	0	11	18	5	8	6
11.25	9	9	11	11	20	4		0	3	3	5	1	10	20	1	6	6
11.75	7	4	11	9	15	1		1	4	2	2	4	2	4	0	0	0
12.25	2	3	3	4	15	4		2	6		7	0	2	3	7	7	4
12.75	3	1	2	3	7	1		0	5		5	4	1	1	2	3	1
13.25	2	1	5	1	5	1		6	9		2	3	1	0	1	6	3
13.75		1	2					3	1		0	0		0	0	3	1
14.25			2					1	3		1	1		0	1	0	1
14.75								1			1			1		1	
15.25																	
15.75																	
16.25																	
16.75																	
17.25																	
Sample size, n_j	63	77	74	48	87	94	83	17	55	61	45	14	38	68	24	43	32
Sample weight, w_j (kg)	0.95	0.92	1.33	0.91	1.92	0.95	0.52	0.54	1.31	0.95	0.96	0.40	0.73	1.28	0.54	1.04	0.70
Catch, W_j (kg)	12.3	23.5	4.2	3.5	4.3	2.2	2.5	0.56	2.1	1.1	2.2	0.4	0.8	1.4	1.5	4.8	0.8
Raising factor, W_j/w_j	12.9	25.5	3.2	3.8	2.2	2.3	4.8	1.0	1.6	1.2	2.3	1.0	1.2	1.2	2.8	4.6	1.1
Depth zone	II	II	II	II	II	II	II	II	II	II	III	III	II	II	II	II	III
Area zone	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B

Table 1. Continued

Mid-length (cm)							1979 Jun											1979 Feb			
	12	13	13	13	13	13	14	14	15	16	17	18	18	18	18	19	19	20	20	20	20
4.75																					
5.25																					
5.75																					
6.25							1				1										
6.75							0				1										
7.25							0	1	2		2										
7.75							0	0	5	2	5										
8.25	1	2	1	1			2	1	15	11	1						1				
8.75	3	16	0	0			8	5	17	5	17	1	5				0		3		
9.25	6	22	10	7		6	17	21	24	15	32	13	20	3	7		1		24		
9.75	8	26	12	10	4	6	15	33	11	19	28	15	30	8	19	4	2	3	21		
10.25	9	22	23	5	9	19	10	32	7	9	7	15	22	28	17	8	7	3	33		3
10.75	6	12	16	2	22	29	3	8	2	1	20	14	10	21	20	12	33	18	21	5	14
11.25	1	2	15	3	8	11	1	2	1		2	9	1	15	9	15	31	32	18	6	13
11.75		1	8	3	12	10		0			1	3	3	17	4	3	18	17	11	5	31
12.25			1	0	1	1		0			1	1	3	4	1	2	9	6	9	5	29
12.75				1	2	2		1				1	0	1	3	3	5	3	1	6	11
13.25					0							0	0	2	1	0	2	5	3	3	1
13.75					1							1	1	0	1	1		2	4	1	3
14.25														1				2		1	
14.75																		1	2	1	
15.25																				1	
15.75																					
16.25																					
16.75																					
17.25																					
Sample size, n_j	34	103	86	32	59	84	57	104	84	62	118	73	95	100	82	48	109	92	150	34	105
Sample weight, w_j (kg)	0.47	1.35	1.43	0.49	1.15	1.49	0.70	1.42	0.88	0.71	1.48	1.17	1.34	1.89	1.40	1.09	2.24	2.39	3.10	0.93	2.55
Catch, W_j (kg)	1.6	6.0	8.8	1.8	11.4	10.0	0.80	1.6	6.6	2.1	10.8	5.4	1.6	2.4	11.5	1.9	15.5	23.4	31.8	7.1	18.4
Raising factor, W_j/w_j	3.4	4.4	6.2	3.7	9.7	6.7	1.1	1.1	7.5	3.0	7.3	4.6	1.2	1.3	8.2	1.7	6.9	9.8	10.3	7.6	7.2
Depth zone	II	II	II	II	III	III	II	II	II	II	II	II	II	II	II	I	III	II	II	II	II
Area zone	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C

Table 1. Continued

Mid-length (cm)	20	20	21	22	22	22	1979 Feb 23	23	23	24	24	24	24	27	1979 Apr 27	28	30
4.75																	
5.25				5							2					1	
5.75				9							1			3	2	2	
6.25				19		1					4			20	2	5	1
6.75				12	2	0					7	1		40	8	10	1
7.25					4	0					9	0		10	6	3	4
7.75					0	1					10	0		3	0	0	2
8.25					0	0					5	0		4	0	0	0
8.75			1		2	1					2	0		3	1	1	1
9.25	3		1	3	2	1					0	0		3	1	0	2
9.75	24		4	10	24	2	4	1	1		0	0		5	2	1	0
10.25	21		11	20	33	5	11	4	3		5	5	3	7	2	2	5
10.75	33	19	18	22	35	16	16	13	8		5	15	14	7	8	0	10
11.25	21	30	22	14	35	29	8	21	21		10	24	23	9	8	1	10
11.75	18	20	6	22	25	22	16	22	18		6	13	24	9	6	2	7
12.25	11	23	23	18	22	19	11	16	14		7	17	19	6	3	2	7
12.75	9	13	8	1	10	5	4	0	8		0	13	7	4	1	1	4
13.25	1	5	6	5	4	5	3	2	11		1	9	7	0	0	1	8
13.75	3	6	2	2	1	1	2	2	3			4	1	0	2	0	2
14.25	4	1	3		0	2	2	3	4			3	1	2	0	1	
14.75	0	3	1		2	1	2	1	3			0	2	1	1		
15.25	2	1	1		0			1				1	1				
15.75		0			1			2					2				
16.25		0											0				
16.75		1											0				
17.25													1				
Sample size, n_j	150	122	107	117	202	111	79	88	94	49	74	105	105	136	53	33	64
Sample weight, w_j (kg)	3.10	3.16	2.53	2.78	4.03	2.53	2.08	2.18	2.49	0.16	0.94	2.69	2.73	1.50	0.83	0.36	1.36
Catch, W_j (kg)	31.8	23.8	22.0	5.3	15.9	20.6	7.7	4.7	16.9	0.6	2.2	9.5	20.0	1.7	1.9	1.4	1.6
Raising factor, W_j/w_j	10.3	7.5	8.7	1.9	3.9	8.1	3.7	2.2	6.8	3.8	2.3	3.6	7.3	1.1	2.3	3.9	1.2
Depth zone	II	III	III	II	II	III	I	II	II	II	II	II	II	II	II	II	III
Area zone	C	C	C	C	C	C	C	C	C	C	C	C	C	B	B	B	B

Table 1. Continued

Mid-length (cm)	1979 May 20	21	21	22	22	23	23	24	24	1979 Sep 5	5	6	7	7	1979 Oct 14	14	16	16	17
4.75																			
5.25	2		1			1	1												
5.75	7	11	3		1	0	6		3										
6.25	11	14	6	1	1	2	2		0										
6.75	12	5	9	3	5	1	4	1	1										
7.25	15	23	39	5	7	1	17	0	4										
7.75	33	29	34	14	21	4	29	4	13										
8.25	33	33	28	31	25	9	21	7	10										
8.75	8	17	11	14	40	6	9	3	15					1			1		
9.25	3	4	2	10	12	3	2	6	2	6	2			6	2	2	7		1
9.75		2	1	1	7	0	1	1	2	21	0		1	25	15	12	23	2	3
10.25		1	1			2		2	4	17	4		1	18	25	21	30	8	8
10.75								3	10	18	4	16	4	23	24	12	16	1	9
11.25								11	29	19	9	26	4	25	2	7	17	5	2
11.75								20	32	12	13	25	5	22	1	3	14	4	2
12.25								24	8	14	10	21	7	18		5	20	0	1
12.75								23	10	8	9	8	4	12		4	13	1	1
13.25								19	3	4	6	7	12	5		1	6	3	
13.75								20	2	1	2	5	8	4		0	2		
14.25								3	1	2	4		6	1		0	2		
14.75								2			2		3	1		1			
15.25								1			5		1	1					
15.75											2			1					
16.25																			
16.75																			
17.25																			
Sample size, n_j	124	129	135	79	119	29	92	150	149	122	72	108	56	153	69	68	151	24	27
Sample weight, w_j (kg)	0.74	0.85	0.84	0.61	0.97	0.23	0.58	4.03	2.70	2.47	2.13	2.65	1.79	3.36	1.09	1.23	3.0	0.50	0.50
Catch, W_j (kg)	1.9	7.5	4.4	2.6	5.2	1.0	2.1	4.4	8.3	11.0	21.8	5.3	3.4	21.0	6.4	15.6	3.0	2.4	18.6
Raising factor, W_j/w_j	2.6	8.9	5.3	4.2	5.4	4.4	3.6	1.1	3.1	4.5	10.2	2.0	1.9	6.2	5.9	12.4	1.0	4.8	39.1
Depth zone	I	I	I	I	I	I	I	III	III	II	III	II	II	III	II	II	I	II	II
Area zone	B	B	B	B	B	B	B	B	B	C	C	C	C	C	B	B	B	B	B

Raising Factor

The length-frequency samples (Table 1) were raised to total catch per haul by the factor:

$$R_i = W_i/w_i \qquad ...2)$$

where i = no. of haul (station no.)

W_i = total catch of goat fish in haul i
w_i = calculated weight of sample from haul i based on length-frequencies and Eq. (1).

The raised length-frequencies were then added within depth zones pooling over all three areas.

Biomass Estimation

The biomass estimation was based on the swept area method. This method assumes that the mean catch in weight per unit effort or per unit area is proportional to the biomass per unit area (Gulland 1969; Pauly 1984).

The swept area was calculated by

$$a = v*t*h*X_2 \qquad ... 3)$$

where

v = velocity of the trawl over the ground when trawling (3 nm/hour)
t = time spent trawling (1 hour)
h = length of the head rope (34.6 m)
X_2= wing spread relative to length of head rope [Pauly (1984) suggested X_2 = 0.5 for bottom trawlers]

The biomass in stratum j, B_j, was then estimated by

$$B_j = \frac{\overline{CPUEW_j}}{a} * \frac{A_j}{X_1} \qquad ...4)$$

where

$\overline{CPUEW_j}$ = mean catch in weight per haul in stratum j (kg)
A_j = area for stratum no. j.
X_1 = fraction of the biomass in the effective path swept (i.e., the retention coefficient put to 0.5)

In total, the entire inshore area was stratified into three depth zones for better estimation of the biomass. The sea areas between 0 and 20 m, >20 and 40 m and >40 m depths were calculated using a planimeter.

The standard error on $\overline{CPUEWj}$ is obtained directly from SD ($CPUEW_{ji}$), the standard deviation of the CPUEW's in all the trawl hauls, n_j, in stratum j, i.e.

$$SE\ (\overline{CPUEWj}) = SD\ (CPUEW_{ji})/\sqrt{n_j} \qquad ...5)$$

where

$$\overline{CPUEW_j} = \sum_{i=1}^{n_j} CPUEW_{ji}/n_j \qquad ...6)$$

Since B_j is proportional to $\overline{CPUEW_j}$, the same proportionality will hold for the standard deviations, i.e., from Eq. (4),

$$SD\ (B_j) = \frac{A_j}{a} * \frac{1}{X_1} * SE\ (CPUEW_j) \qquad ...7)$$

The estimate of the total biomass for the entire area,

$$B = \sum_{j=1}^{3} B_j \qquad ...8)$$

is associated with a variance of

$$Var\ (B) = \sum_{j=1}^{3} Var\ (B_j) = \sum_{j=1}^{3} [SD(B_j)]^2 \qquad ...9)$$

and the standard deviation of the total biomass estimate becomes

$$SD(B) = \sqrt{\sum_{j=1}^{3} [SD(B_j)]^2} \qquad ...10)$$

Repairing for Mesh Selection

The fraction of fish in the trawl that actually is retained by the meshes may approximately be computed from the logistic model:

$$S(L) = 1/(1 + \exp\ (-S_m(L-L_{50}))) \qquad ...11)$$

where S(L), the selection ogive, gives the fraction of fish in length group L that is retained by the meshes of size m = 4 cm. S_m is a steepness parameter. The higher the value of S_m, the more the selection curve (11) will approach knife-edge selection at L_{50}, the 50% retention length.

A covered cod-end experiment carried out in the Samar Sea gave the following results (Silvestre et al. 1986) for *U. sulphureus,*

$S_4 = 1.180\ cm^{-1}$
$S_4*L_{50} = 11.044$

That is, an L_{50} of 11.044/1.180 or 9.36 cm and a selection factor of

$sf = L_{50}/m = 9.36/4 = 2.3.$

The frequencies raised by Eq (2) to total catch in numbers by length group represent only 100*S(L) % of the fish which have entered the trawl. Dividing the frequency in length class L by 100*S(L) brings the number down to the 1% level and multiplying by 100 raises the level to

100%. This raising procedure by length class therefore amounts to multiplying by the following raising factor

$$R_S(L) = 1/S(L) = 1 + \exp(11.044\text{-}1.18 * L) \qquad \ldots 12)$$

where L denotes the midpoints of each length class.

Methods for Estimation of Growth and Mortality

The ELEFAN I program and catch curve analysis were applied to the combined monthly length frequencies after pooling by area and depth zone. In a second and more refined approach, the monthly length frequencies were constructed by taking into account that a) the small fish dominate in shallow water (Zone I) and b) bigger fish dominate in deeper water. The raised length frequencies were therefore first pooled only by area to give frequencies by month for each depth zone during the three years. Next, these monthly frequencies were corrected for mesh selection by dividing by selection ogives at length class midpoints. Then the frequencies were normalized to a catch of one tonne and weighted by the fraction of estimated biomass per zone before adding by depth zone and pooling by month to produce the second data set input.

Results

Biomass Estimation

The swept area is computed as

$$a = (3 \text{ knots}) \times (1852 \text{ m/nm}) \times (1 \text{ hour}) \times (34.6 \text{ m}) \times 0.5$$

$$= 96119 \text{ m}^2$$

$CPUEW_i$, the catches in weight of *U. sulphureus* per haul are given in Table 1 except for hauls with zero catch. Mean CPUEW for all hauls in each year by depth zones, $\overline{CPUEW}$, are given in Table 2 together with the estimated biomasses per zone in each year. The standard errors on the $\overline{CPUEW}$, Eq. (5), are the standard deviations of the individual CPUEW's divided by the square root of n, the total number of hauls in each zone. The mean body-weight, $\overline{w}$, in the total catch from n hauls is also given in Table 2.

Table 2. Mean catch per trawl haul of *U. sulphureus*, $\overline{CPUEW}$, and standard error (SE) and derived biomass estimates by depth zone and year before and after correcting for mesh selection.

Year	Depth zone (m)	Area A (km²)	No. of hauls[1] n0	n1	n	Not corrected $\overline{w}$ (g)	$\overline{CPUEW}$ (kg)	SE (kg)	Biomass (t)	SD (t)	Corrected $\overline{w}$ (g)	$\overline{CPUEW}$ (kg)	Biomass (t)
1977	0 – 20	9,520	35	20	55	10	3.413	1.078	676	214	4	19.34	3,831
	21 – 40	13,940	20	43	63	17	15.614	2.823	4,529	819	11	25.18	7,304
	> – 41	23,460	10	10	20	23	15.250	4.951	7,444	2,417	16	19.28	9,410
	Total		65	73	138				12,650	2,560			20,545
1978	0 – 20	9,520	15	3	18	7	0.507	0.300	100	59	4	4.57	906
	21 – 40	13,940	22	28	50	14	7.715	2.302	2,238	668	5	23.60	6,845
	> – 41	23,460	3	6	9	24	6.822	4.859	3,330	2,372	23	7.40	3,613
	Total		40	37	77				5,668	2,465			11,364
1979	0 – 20	9,520	67	10	77	9	0.484	0.172	96	34	5	2.71	537
	21 – 46	13,940	87	36	120	20	2.636	0.560	765	162	11	3.59	1,042
	> – 41	23,460	18	11	29	25	5.531	1.595	2,700	779	18	6.04	2,949
	Total		169	57	226				3,561	796			4,528

[1]Total number of hauls by depth zone, n = n0 + n1, includes n0, the number of hauls with zero catch.

In order to correct the biomass estimates for mesh selection, all frequencies were first pooled by month within each depth stratum. These annual frequencies were then normalized to the uncorrected $\overline{CPUEW}$ (Table 2) by dividing by the total number of hauls (n). Eq. (12) was then used to raise each class frequency to the corrected numbers of fish by length group. The $\overline{CPUEW}$'s corrected for mesh selection were then obtained by computing the weight of these raised frequencies using the length-weight relationship. This type of weight calculation was done by computing the mean weight of the fish in each length class, multiplying by numbers and adding up. The new $\overline{CPUEW}$'s and corresponding zone biomass estimates are also given in Table 2.

Growth

First uncorrected data were used, i.e., monthly frequencies obtained by pooling depth zones and combining all years. Fig. 2 depicts the restructured frequencies and a growth curve for the following set of parameters estimated by the ELEFAN method,

$$\left.\begin{aligned} L_\infty &= 18.8 \text{ cm} \\ K &= 0.71 \text{ year}^{-1} \end{aligned}\right\} \quad \text{(uncorrected)}$$

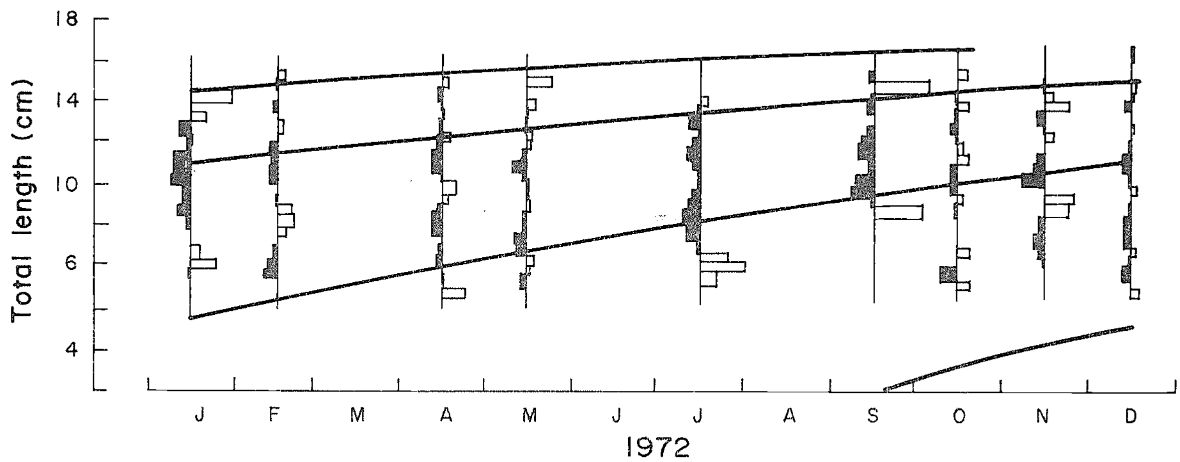

Fig. 2. Restructured monthly length-frequencies of *U. sulphureus*, as obtained (1) after pooling of depth zones and (2) combining years. The growth parameters obtained by ELEFAN I are L_∞ = 18.8 cm and K = 0.71 year^{-1}.

Frequencies corrected for mesh selection and for bias due to depth effects on the length composition are given in Table 4. This data set was constructed based on frequencies by depth zone per month corrected for mesh selection. Such corrected monthly "zone frequencies" were then weighted by factors of the following type (Table 3),

$$\frac{1}{CW_{ji}} * \frac{B_{yj}}{B_y}$$

before pooling by depth zones took place. Here CW_{ji} denotes the total catch in tonnes of *U. sulphureus* from all hauls in depth zone j in month i. The first factor therefore normalizes the frequencies to represent the length composition of a catch of one tonne. The second factor, B_{yj}/B_y, gives the fraction of biomass in zone j in year y obtained from the corrected biomass estimates in Table 2. The new results obtained by ELEFAN I are shown in Fig. 3,

$$\left.\begin{aligned} L_\infty &= 19.9 \text{ cm} \\ K &= 0.875 \text{ year}^{-1} \end{aligned}\right\} \quad \text{(corrected)}$$

Table 3. Depth zone weighting factor for corrected monthly length-frequency data by depth zone per year for *U. sulphureus.*

Time	Mean weight $\bar{w}_j$ (g) I	II	III	Total weight CW_{ji} (kg) I	II	III	$b_{yj} = B_{yj} / B_y$ I	II	III	Weighting factor (b_{yj}/CW_{ji} x 1,000 tonnes^{-1}) I	II	III
Apr/77	5.5	6.4	15.7	64.3	20.6	16.9	0.1865	0.3555	0.4580	2.9	17.26	27.1
Jul/77	8.47	7.1	17.8	110.3	507.6	34.3	0.1865	0.3555	0.4580	1.69	0.70	13.35
Sep/77	–	14.5	19.0	–	74.6	153.9	–	0.4370	0.5630	–	5.86	3.66
Oct/77	6.3	17.1	–	142.6	102.1	–	0.3441	0.6559	–	2.41	6.42	–
Nov/77	3.9	13.4	–	25.3	134.7	–	0.3441	0.6559	–	13.6	4.87	–
Dec/77	3.4	17.0	14.6	723.5	753	165.4	0.1865	0.3555	0.4580	0.26	0.472	2.77
Jan/78	–	20.2	23.5	–	209.1	62.6	–	0.6545	0.3455	–	3.13	5.52
May/78	3.7	4.1	–	82.4	956.6	–	0.1169	0.8831	–	1.42	0.923	–
Oct/78	–	19.9	–	–	4.53	–	–	1.0000	–	–	270.75	–
Nov/78	–	21.2	20.2	–	9.9	3.5	–	0.6545	0.3455	–	66.11	98.71
Jan/79	–	11.5	18.0	–	105	25.8	–	0.2611	0.7389	–	2.49	28.7
Feb/79	25.1	11.6	20.9	10.2	242.1	90.4	0.1186	0.2301	0.6513	11.63	0.95	7.20
Apr/79	–	4.0	10.4		26.2	2.5	–	0.2611	0.7389	–	9.97	295.6
May/79	4.5	–	9.6	195	–	20.3	0.1540	–	0.8460	0.79	–	41.7
Sep/79	–	21.5	24.5	–	22.4	48.8	–	0.2611	0.7389	–	11.65	15.14
Oct/79	19.2	17.1	–	3.7	54	–	0.3401	0.6599	–	91.92	12.22	–

Table 4. Monthly length frequencies of *U. sulphureus* obtained by correcting for mesh selection, by pooling weighted monthly frequencies by depth zones and by combining years.

Mid-length (cm)	Jan	Feb	Apr	May	Jul	Sep	Oct	Nov	Dec
4.75									2,699
5.25		2,884	5,001	52,692			6,912		11,557
5.75		2,487	34,308	103,739	1,177		23,132		20,857
6.25	841	5,454	45,313	36,240	659		4,322	41,615	13,411
6.75	413	1,579	42,465	29,877	3,981		1,222	34,367	3,895
7.25	998	638	40,986	44,221	11,177		0	18,840	9,883
7.75	1,510	616	15,708	40,622	18,604		0	6,692	5,649
8.25	2,431	285	13,196	18,896	17,831		4,295	2,448	5,114
8.75	3,467	405	8,071	12,275	14,791	4,569	8,605	708	3,294
9.25	7,904	506	4,952	3,213	7,059	10,739	12,237	1,953	1,548
9.75	9,173	1,694	1,754	1,885	5,598	18,758	33,291	11,773	933
10.25	14,616	3,045	3,368	1,920	2,045	17,146	38,234	20,622	3,302
10.75	25,695	7,840	6,775	3,020	2,751	9,223	24,215	15,423	5,383
11.25	16,673	9,390	9,085	6,537	3,200	9,640	8,704	12,284	6,639
11.75	16,186	6,015	7,870	6,199	4,163	10,416	7,645	3,178	4,441
12.25	4,844	6,244	5,816	2,639	1,965	8,039	8,143	6,657	3,776
12.75	3,316	2,873	2,527	2,585	747	5,256	6,508	3,309	1,905
13.25	1,628	1,533	4,173	1,444	1,609	2,886	6,865	3,251	1,569
13.75	658	831	1,288	1,245	35	1,820	1,899	1,027	1,191
14.25	312	623	534	300	233	1,216	2,190	577	443
14.75	24	438	506	118		588	795	611	128
15.25		271	157	46		889	111		183
15.75		22				419			53
16.25		0				0			30
16.75		22				403			7
Sum	110,710	55,696	253,855	369,710	97,625	102,106	199,325	185,336	107,891

Mortality

Uncorrected data produce an estimate of total mortality, Z, of about 4.8 year^{-1} (Fig. 4). After correction (Table 3), the estimate of Z increases to 6.7 year^{-1} (Fig. 5). Note that the first points on the catch curve, which represent fish not yet fully recruited to the fishery and/or mesh selection, on Fig. 5 have moved up toward the line compared to Fig. 4, because the catch in numbers (in particular of the small fish) has been corrected for mesh selection (by independent selection data). Natural mortality was estimated from the formula of Pauly (1980) which resulted in M ≈ 1.8 year^{-1}.

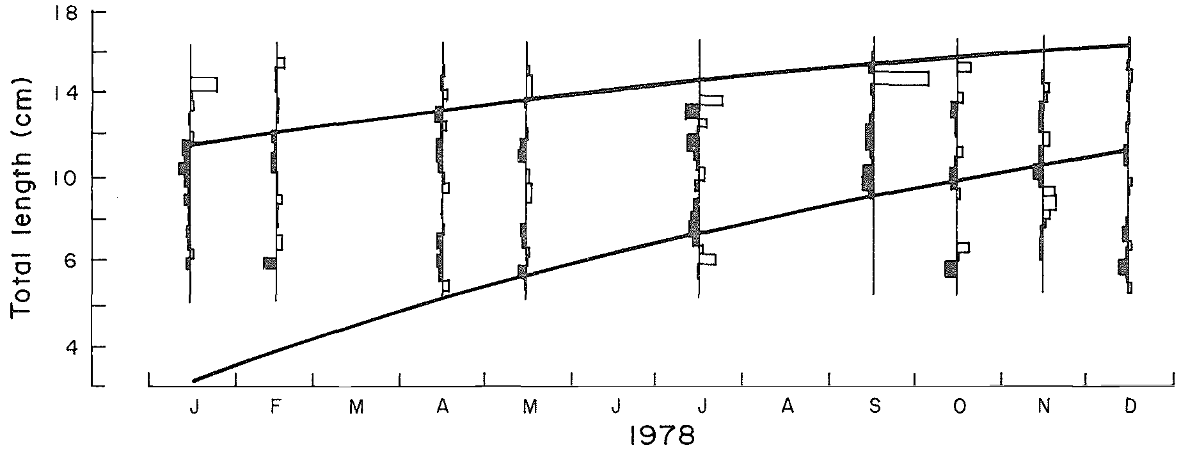

Fig. 3. Restructured monthly length frequencies of *U. sulphureus*, as obtained (1) after pooling of depth zones, (2) continuing years and (3) correcting for mesh selection. The growth parameters obtained by ELEFAN I are L_∞ = 19.9 cm and K = 0.875 $year^{-1}$; note changes with regard to the uncorrected data in Fig. 2.

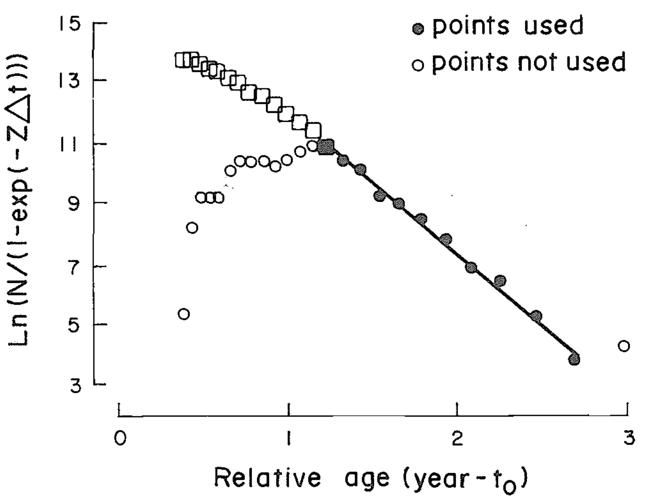

Fig. 4. Length-converted catch curve of *U. sulphureus* based on length-frequency data not corrected for mesh selection (L_∞ = 18.8 cm, K = 0.71 and Z = 4.76 $year^{-1}$).

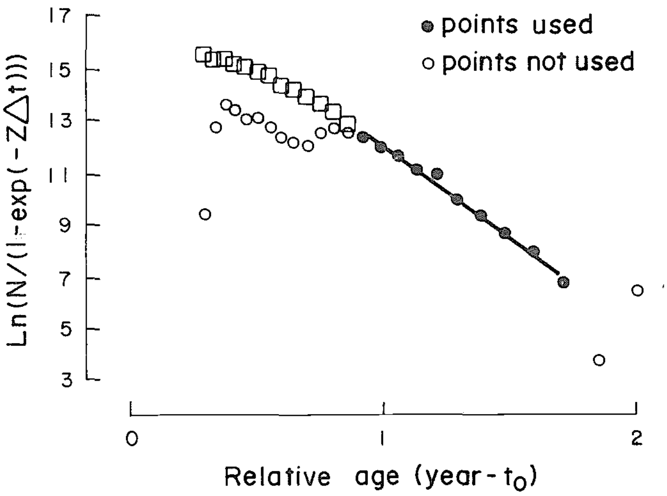

Fig. 5. Length-converted catch curve of *U. sulphureus* based on length-frequency data corrected for mesh selection (L_∞ = 19.9 cm, K = 0.875 and Z = 6.72 $year^{-1}$).

Discussion

The trawl surveys carried out in 1977-1979 by the Indonesian-German Demersal Fisheries Project provides CPUE data of *U. sulphureus* for 16 out of 36 months. The total number of hauls per month and also the number of hauls with catch of *U. sulphureus* vary greatly from one month to the next. For these reasons, it was not considered a sound procedure to attempt to estimate the biomass on, say, a monthly basis. However, a plot of log (CPUE) on months (not included here) showed a clear decreasing trend over 1977-1979. Unfortunately, due to too much "noise" in the data it was not possible to estimate Z as the slope of the "downs" on this plot. It was therefore decided to estimate the biomass on an annual basis as a compromise between having a reasonably large number of hauls (i.e., large period of time) on the one hand and, on the other hand, using only a relative short time-basis during which the biomass could be considered reasonable constant. The biomass estimation in this work should therefore only be considered as a rough estimate of some sort of average annual biomass. Even in a steady-state situtation, the true biomass of *U. sulphureus* in the Java Sea would be expected to vary, say, by a factor of two within a year.

The post stratification by depth zones seems to be of importance. The mean weight of the fish is about three times greater in the catch from depth zone III than in the catch from depth zone I (Table 2). As an example, we may consider the biomass estimate of 3,561 tonnes in 1979 (before correcting for mesh selection). Without stratification, the $\overline{CPUEW}$ would become (Table 2).

$$\overline{CPUEW} = (0.484*77+2.636*120+5.531*29)/226$$
$$= 2.274 \text{ kg}$$

and the corresponding biomass for the entire inshore area of 47,000 km^2 would become

$$B = (\overline{CPUEW}/a)\ A/X_1$$
$$= (2.274/96119)\ 47000*10^6/0.5 \text{ kg}$$
$$= 2220 \text{ tonnes}$$

or about 40% less than the estimate based on stratification. This is because the mean catch of the 29 hauls in zone III is 5.5 kg or more than double the mean catch of the 120 hauls in zone II. Zone III which represents about half the entire area contributes 2,700 t alone to the total biomass. Without stratification everything is averaged out and the mean catch of the hauls is reduced to 2.3 kg.

The procedure of post stratification is obviously more correct than considering the whole area as one homogeneous unit in the present case. However, it should be emphasized again that the biomass results in Table 2 are based on very few hauls spread out over large areas and long periods of time. In particular the estimates for zone III are to be considered uncertain. In 1978 only 9 hauls (out of 77) were made in zone III and *U. sulphureus* was only caught in 6 hauls. Based on the variability in the catches of these 9 hauls, a standard deviation of about 2,400 t was estimated for a biomass of about 3,300 t in zone III. Thus, the coefficient of variation on this biomass estimate is 2,400/3,300 or 73%. In other words, a 95% confidence interval for the biomass in zone III is approximately 3,300 ± 2 * 2,400 or from 0 to about 8,000 t. There is clearly a need for many more trawl hauls in a short period of time for estimating the biomass in such a large area.

The small number of hauls also represents the major reason for not trying to stratify by subareas (A, B and C in Fig. 1).

Another equally important problem is the big mesh size of 40 mm. According to Eq. (12), this means for example that 5 cm fish are underrepresented in the catch by a factor of 172. For 10 cm fish the factor is about 1.5, i.e., the number of 10 cm fish will be raised by 50%. For 15 cm fish the increase is reduced to 0.1%. The length range in the samples is from about 5 to 15 cm with most fish around 10 cm. This means that more or less the entire length composition of *U. sulphureus* caught by 40 mm meshes will be affected by the correction. With respect to the biomass estimation, the correction for mesh selection in particular increases the biomass estimate of small fish in the shallow water. The biomass in zone I actually increases by more than a factor of five when the large number of small fish escaping through the meshes are included in the estimation. The mean weight in catch is at the same time being reduced by about 50% to 4-5 g due to the huge number of small fish not accounted for before correcting for mesh selection. It follows from Eq. (1) that a fish of 4.5 g is about 7 cm long. The raised length frequencies in Table 4 of such small fish are clearly rather imprecise because they are based on few fish caught (Table 1). However, it appears from Table 1 that a mode of about 6 cm can be recognized in the catches. If a reliable estimate of the number at this mean length of 6 cm is to be obtained the mesh size should probably be in the order of 1.5 cm. This mesh size was derived from the requirement

$$L_{50} = sf*m = 2.3*m = 6-\sqrt{6} \text{ cm}$$

or

$$m = (6-\sqrt{6})/2.3 \approx 1.5 \text{ cm}$$

That is, the mesh size is chosen so that the 50% retention length approximately equals the mean length minus one standard deviation of the smallest group of fish recruited to the gear. For lack of an estimate of the standard deviation, the rule of thumb of putting it equal to the square root of the mean has been applied.

The corrected data in Table 2 indicate a severe situation of growth overfishing. The number of small fish in zone I is reduced by 75% from 1977 to 1978 and by 50% from 78 to 79. The total biomass is approximately reduced by 50% each year. Part of this decline could be due to "migration" of the bigger fish to the offshore areas not covered by the present survey in 1977-1979. Badrudin's (1978) estimate of 58,000 t of *U. sulphureus* in 1976 in an offshore area of 289,000 km^2 indicates that inshore and offshore areas must be surveyed at the same time to produce reliable estimates and interpretations of changes in stock abundance.

The procedure of correcting the frequencies also affects the estimation of growth and mortality parameters. Weighing by depth zone alone in general could move modes one length class (frequency data not shown here). This is because the frequencies by depth zone are raised separately by different raising factors before adding. The modes or peaks of the frequencies therefore will change somewhat compared to the starting point. After correcting for mesh selection, the growth curve fits to the restructured frequencies, Fig. 3, has not improved compared to Fig. 2. Different sources of bias (as discussed previously) in the raw data will clearly also be magnified in the raising process of correcting for mesh selection. This is particularly true for the small fish. The fact that a large portion of the bigger fish from the stock is not covered by the present survey is not believed to introduce serious bias in the estimate of K and L_∞. Disregarding the problems of mesh selection, length frequencies representative for the stock over a sufficient length range should be available to produce reliable estimates of the growth parameters. The final estimates obtained here are (Table 5)

$$L_\infty = 19.9 \text{ cm and } K = 0.875 \text{ year}^{-1} \qquad ...13)$$

giving $\phi' = \log_{10} 0.875 + 2*\log_{10} 19.9 = 2.54$. The eight other pairs of growth parameters in Table 5 (obtained from the literature) give a mean ϕ' of 2.575 ± 0.148 (standard error), i.e., the present value of 2.54 is well within a 95% confidence interval of ϕ' based on literature data. The results obtained here are therefore not in disagreement with other growth studies of *U. sulphureus*.

Table 5. Available estimates of growth parameters for *U. sulphureus* (Mullidae) in the Philippines (# 1-5) and Indonesia (# 6-9).

#	Area	L_∞ (TL; cm)	K ($year^{-1}$)		ϕ' ($\log K + 2 \log L_\infty$)	Source
1	San Miguel Bay	15.3	1.05		2.39	Ingles and Pauly (1984)
2	Samar Sea	19.5	1.20		2.66	Ingles and Pauly (1984)
3	Samar Sea	19.5	1.30		2.69	Corpuz et al. (1985)
4	Burias Pass	23.5	1.30		2.86	Corpuz et al. (1985)
5	Ragay Gulf	17.0	1.32		2.58	Corpuz et al. (1985)
6	North Java Coast	15.8	1.74		2.64	Beck and Sudrajat (1978)
7	North Java Coast	17.5	0.90		2.44	Dwiponggo et al. (1986)
8	North Java Coast	16.5	0.78		2.34	Dwiponggo et al. (1986)
–	–	–	–	mean	2.575	
9	This study	19.9	0.875		2.54	This study

The mortality of Z = 6.7 $year^{-1}$ (Fig. 5) may be an overestimate because of possible "migration" of bigger fish to the offshore area. The estimate is obtained in catch curve analysis based on the combined frequencies of the monthly frequencies in Table 3 and the final set of growth parameters in Eq. (13). The underlying assumption of the catch curve analysis are a) steady-state conditions and b) that the frequencies represent the average annual length composition of the stock. Problems with the tails of the frequency distribution due to mesh selection and possible "migration" have already been discussed. By steady-state conditions is meant that recruitment, growth and mortality have remained approximately constant in a period of at least two years. This period of time is based on the following argument. Almost all fish sampled are less than 17 cm and it takes approximately

$$-\frac{1}{0.875}\ln\left(1-\frac{17}{19.9}\right) = 2.2 \text{ years}$$

for the fish ($K = 0.875$ year^{-1}, $L_\infty = 19.9$ cm, $t_0 = 0$ year) to grow to length 17 cm. Under steady-state conditions, the length composition of the stock at any time will be equal to the total length composition obtained from following one cohort through its life span or, at least during 2 years. There is no reason to believe that the growth parameters should have changed in the period 1977-1979. However, the biomass estimation does indicate that the number of recruits decreased during the period. A decreasing stock may also be explained by a constant fishing effort on a stock that has not yet reached steady state or by an increasing fishing mortality assuming constant natural mortality and recruitment. This indicates that the assumptions of catch curve analysis and similar methods (Beverton and Holt's Z - equation, Wetherall method, cumulative catch curve, etc.) are not fulfilled in the present case. A simulation study of the present case would be useful to gain insight in the robustness of the catch curve analysis when the underlying assumptions are not fulfilled. However, above all, information on the fishery in the same period of time would be of importance in the interpretation of the results from the present analysis.

The estimate of a fishing mortality of

$$F = 6.7 - 1.8 = 4.9 \text{ year}^{-1}$$

or an exploitation rate of $E = F/Z = 0.7$ (Fig. 5) in this study should only be taken as an indication of growth overfishing in the period 1977-1979. The obvious method to use for the estimation of total mortality is the Bhattacharya analysis applied to monthly frequencies. Linking normally distributed groups into individual cohorts and then estimating Z from the exponential decay of cohort size with time can be done without assuming constant recruitment and mortalities. However, results from the Bhattacharya analysis are not presented here because it turned out to be very difficult to identify the normally distributed groups.

Instead, the catch curve analysis was applied on all frequencies combined. It is important to note that the estimate of Z/K in this analysis depends on the way the frequencies are pooled. The estimate $Z/K = 6.71$ ($L_\infty = 18.76$ cm) in Fig. 4 is based on all frequencies pooled. The estimate $Z/K = 7.68$ ($L_\infty = 19.9$ cm) in Fig. 5 is based on frequencies weighted by the biomass in each zone and normalized to one unit of biomass in each year before combining months. In the first approach without raising, the combined frequency (and therefore the Z/K estimate) will depend on the distribution of the number of hauls over zones and time. We may say that the number of hauls indirectly represents raising factors in the first approach without direct raising. This is clearly unfortunate and the only reason for including the result is that all the various types of bias introduced per month may have a tendency to cancel out in the combined frequencies. In the other approach, the L_∞ used is 6% greater than before (Fig. 4) which in itself explains part of the difference between the two results (e.g., apart from length to age transforming, a 6% increase in L_∞ produces approximately a 12% increase in L_∞^2 = constant/K). The estimate $Z/K = 7.68$ is considered more reliable because the frequencies are raised to total biomass per zone before combining zones. This is done by the zone raising factor B_{yj}/CW_{ji}. The result is monthly frequencies raised to account for total stock. Since the present data do not allow for a biomass estimation on a monthly basis, the biomass in zone j was considered constant in all months, of year y, i.e., the B_{yj}'s obtained from Table 2. The final step of combining months over the three years presented difficulties because of the decreasing biomass. Therefore the monthly frequencies were normalized by dividing by B_y in order to get compatible frequencies before pooling and applying catch curve analysis to extract information on Z.

Conclusion

The growth parameters $L_\infty = 19.9$ cm and $K = 0.875$ year^{-1} for *U. sulphureus* have been obtained by the ELEFAN I program using trawl survey CPUE data from 1977 to 1979. Unfortunately, the mesh size was 40 mm or almost three times too big. Furthermore the offshore area was not surveyed in 1977-1979. All of this gives rise to bias and noise in the data and it was not possible to use the Bhattacharya method in a sensible way to identify cohorts and estimate mortality.

The biomass estimation indicates a drastic decrease in recruitment and in overall stock biomass during 1977-1979 or immediately before the trawl ban in 1980. However, reliable stock assessments require a considerable number of trawl hauls per depth zone including the offshore area in each month of the survey. The present data and all other data from the entire Indonesian-German Project need to be analyzed in detail to assess the state of the various stocks before trawl banning and to be able to design carefully an eventual demersal trawl survey in the future. It will also be very important to utilize all available information on the commercial fishing before trawl banning. This is needed not only for drawing correct conclusions as regard any changes in fishing effort and other factors influencing fishing mortality but also for providing an additional source of data for stock assessment purposes.

Acknowledgements

The author wishes to thank Ms. Mina L. Soriano and Mr. Felimon C. Gayanilo, Jr. for adapting their computer programs to my specific needs.

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Estimation of Growth Parameters and Mortality Rates for *Drepane africana* in Senegalese Waters

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Abstract

Length frequencies and other data for the most important commercial species including the sickle fish *Drepane africana* were collected from bottom trawler landings in Dakar for several years. However, no specific study has been published before on *Drepane africana* except for the identification of its spawning season (June to September). In the present study, length-frequency data corrected for selection have been used for the period 1977-1980 to estimate the parameters of a seasonally oscillating growth curve and mortality rates. The basic principles of seasonalized growth are described.

Mean lengths at age given by the growth equation appear to be in fair agreement with the mean lengths at age obtained from the Bhattacharya analysis.

Introduction

Along the West African coast, the geographical distribution of *Drepane africana* spreads from Cape Verde to Angola (Fig. 1). Belonging to the mixed sciaenid community (Fig. 2) defined by Longhurst (1969), this species shows local concentrations on some trawlable areas of the coastal continental shelves. The maximum observed total body length is around 45 cm. Sickle fish are mainly caught by trawls and have commercial importance for many countries. From 1977 to 1983 the mean annual landings in Dakar were 515 t (Table 1).

Until now, no specific study has been published on the biology of *D. africana*. Domain (1980), in the context of a general study of the demersal community of the Senegambian and Mauritanian continental shelves, noted that it spawns from June to September at depths between 10 and 20 m on sandy-muddy bottoms. Its main food is composed of bottom invertebrates (Cadenat 1954).

In this paper, the growth parameters and mortality rates are estimated using raised length-frequency data collected by staff of the Oceanographic Research Center of Dakar-Thiaroye (CRODT, Senegal) from commercial bottom trawler landings since 1973.

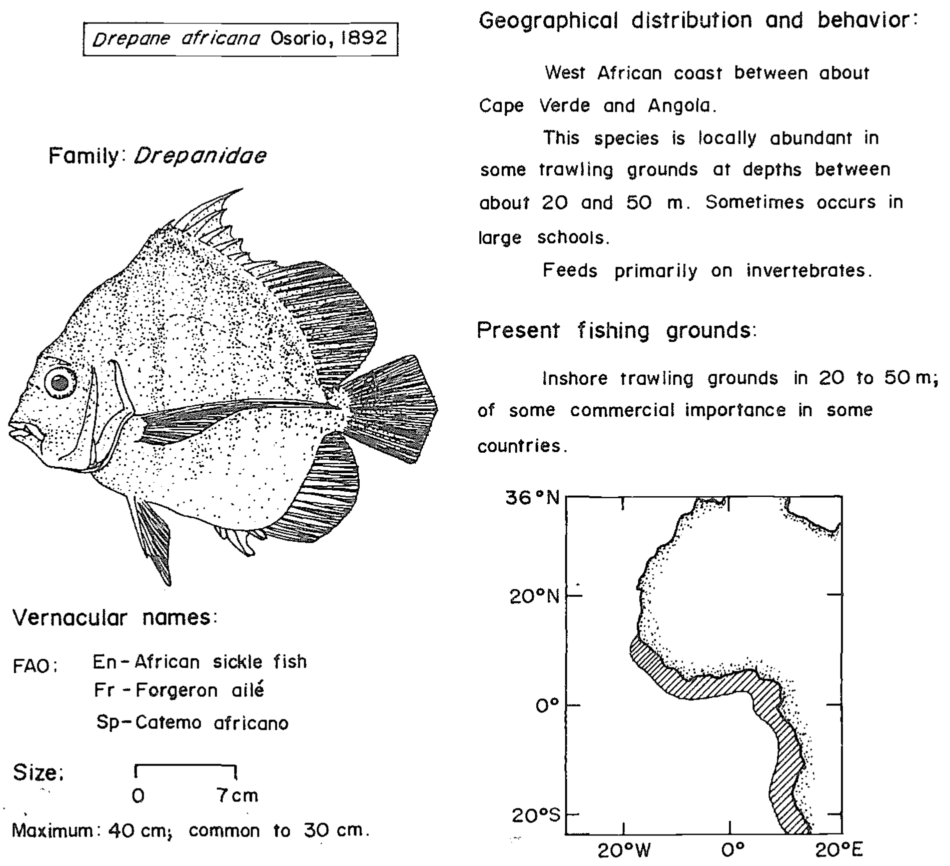


Fig. 1. Selected basic information on *Drepane africana* (adapted from Allen 1981).

Materials

The materials used consist of length-frequency data from the bottom trawl landings in Dakar, the only landing place for industrial fishing boats in Senegal.

For each commercial species, a sample is taken and in this case, all fish were measured to the cm below by technicians trained in taxonomy and sampling methods. A form was filled out with data on the name of the species, weight of the sample, date, name of the boat and fishing area (Fig. 3). Other information is obtained from two different sources: a) from the questionnaire completed by the captain of the fishing boat and b) from the landing card of the boat at the company where the fish was sold from which the catch by species in weight and the time period of each trip can easily be obtained.

The length-frequency raising procedure was done at the CRODT using both the catch data and the corresponding length-frequency data for one year. The raised distribution can be listed in three ways for each species: i) per month for each fishing sector or all sectors; ii) per quarter for each sector or all sectors; and iii) per year for each sector or all sectors.

The frequency distribution for all sectors represents the whole fishing area of Senegal.

For the estimate of growth parameters and mortality rates, we used quarterly based distributions for all sectors from 1977 to 1980. The reason for this choice is that in these four years the highest number of fish was measured. The length frequencies of average quarters are presented in Table 2 and the corresponding histograms in Fig. 4.

The analysis of the available data has been done in the North Sea Centre (Hirtshals, Denmark) using three computers (VAX 11/750, Apple IIc and HP 87XM).

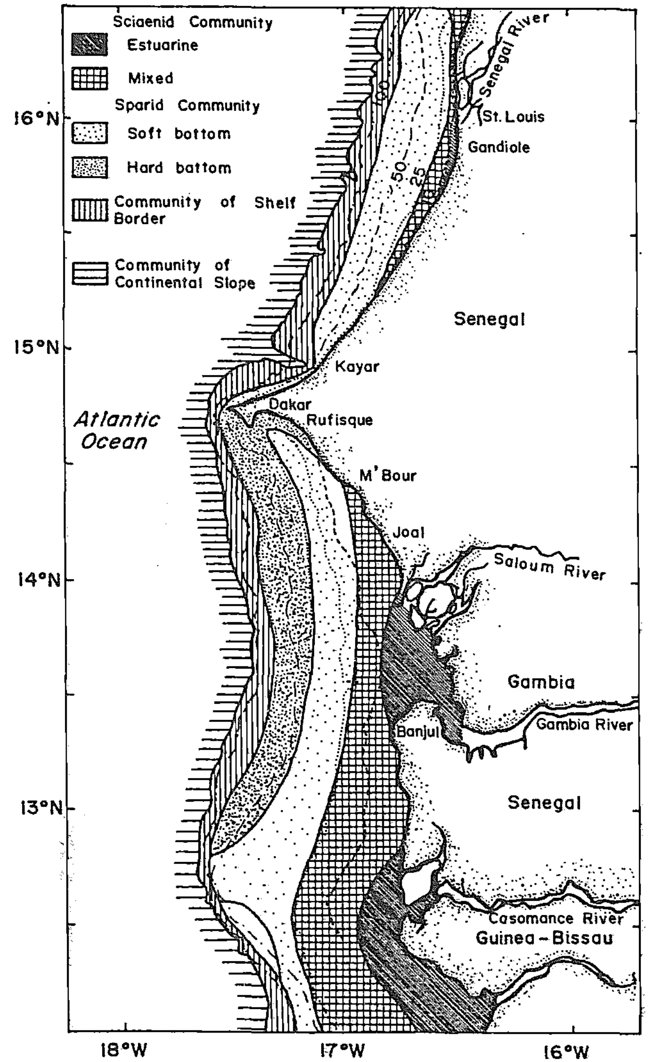


Fig. 2. Distribution of demersal assemblages on the Senegambian continental shelf (from Domain 1980).

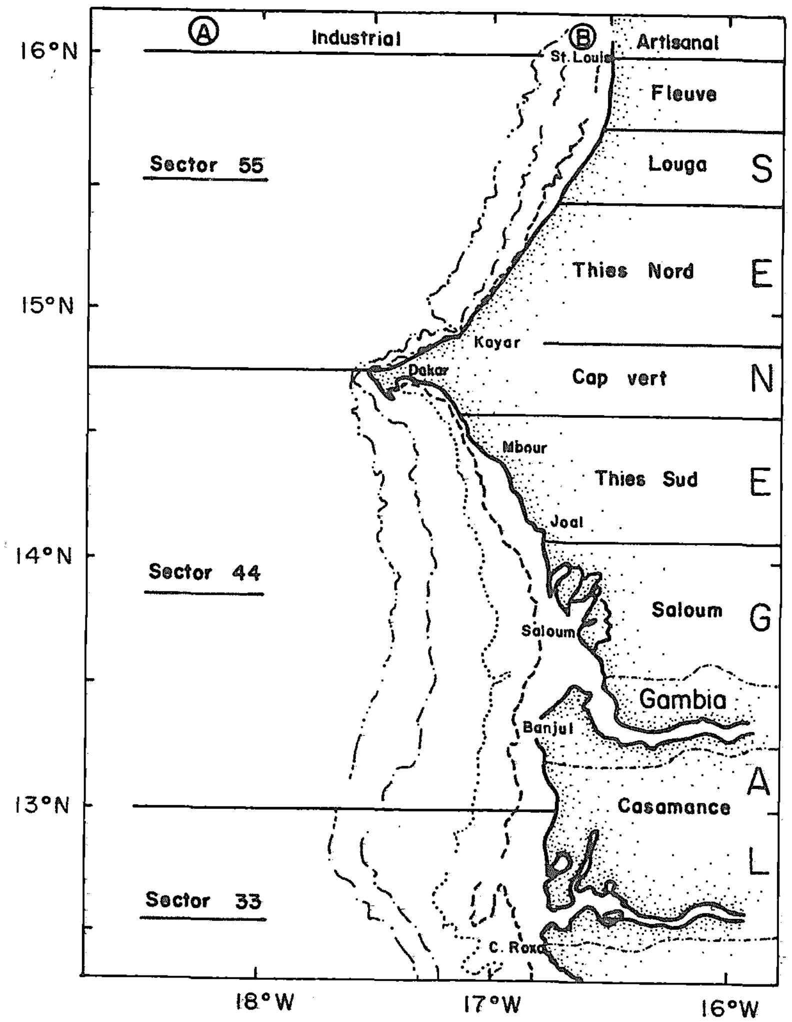


Fig. 3. Statistical fishing sectors in Senegal. A = industrial, B = artisanal fisheries.

Table 1. Total landings (tons) and landings of *Drepane africana* (tons and %) of bottom trawlers, Dakar, 1971-1983.

Year	Total t	Drepane t	Drepane %
1971	5,346	4	0.1
1972	8,788	103	1.2
1973	12,731	352	2.8
1974	15,745	178	1.1
1975	16,204	81	0.5
1976	20,557	329	1.6
1977	33,002	398	1.2
1978	35,583	332	0.9
1979	40,603	507	1.2
1980	43,104	472	1.1
1981	49,065	856	1.7
1982	46,212	428	0.9
1983	47,369	615	1.3

Means 1977-1980: total 38,073; *Drepane* 427 t (1.1%)
Means 1977-1983: total 42,134; *Drepane* 515 t (1.2%)
Sources: Doc. CRODT and CECAF/TECH/86/69

Table 2. Length frequencies of *Drepane africana* raised to landings by quarter averaged over four years (1977-1980), used for this study.

Length class (cm)	Quarter / month / day	1 / 2 / 15	2 / 5 / 15	3 / 8 / 15	4 / 11 / 15	Total
9–				1,000		1,000
10–		824				824
11–				2,002	246	2,248
12–		2,012	479	1,547	91	4,129
13–		17,542	3,661	4,053	3,528	28,784
14–		46,853	8,848	29,305	9,718	94,724
15–		48,951	31,332	108,734	18,082	207,099
16–		72,887	51,872	232,867	60,605	418,231
17–		125,790	112,279	261,737	99,112	598,919
18–		188,606	210,177	182,300	115,101	696,184
19–		217,684	347,011	123,491	112,163	800,349
20–		153,070	320,455	95,393	74,910	643,828
21–		115,206	175,796	92,143	51,589	434,734
22–		85,616	125,274	91,551	29,721	332,162
23–		66,379	98,886	89,173	21,042	275,480
24–		39,896	94,764	84,592	21,448	240,700
25–		24,259	79,851	80,426	15,686	200,222
26–		24,721	60,284	64,122	17,485	166,612
27–		18,885	42,430	41,402	10,812	113,529
28–		10,475	34,958	32,392	7,729	85,554
29–		9,968	29,727	23,716	9,556	72,967
30–		1,732	37,591	18,415	11,163	68,901
31–		7,382	32,299	18,175	5,713	63,569
32–		3,862	26,642	10,602	6,189	47,295
33–		1,173	23,215	8,007	7,040	39,435
34–		1,270	12,661	6,523	2,425	22,879
35–		212	10,745	6,033	3,218	20,208
36–		231	8,396	2,642	480	11,749
37–			6,687	1,260	390	8,337
38–			2,854	97	139	3,090
39–			2,793			2,793
40–			3,680	323		4,003
41–			523			523
42–			84			84
43–			523			523
Total		1,285,486	1,996,777	1,714,023	715,381	5,711,667

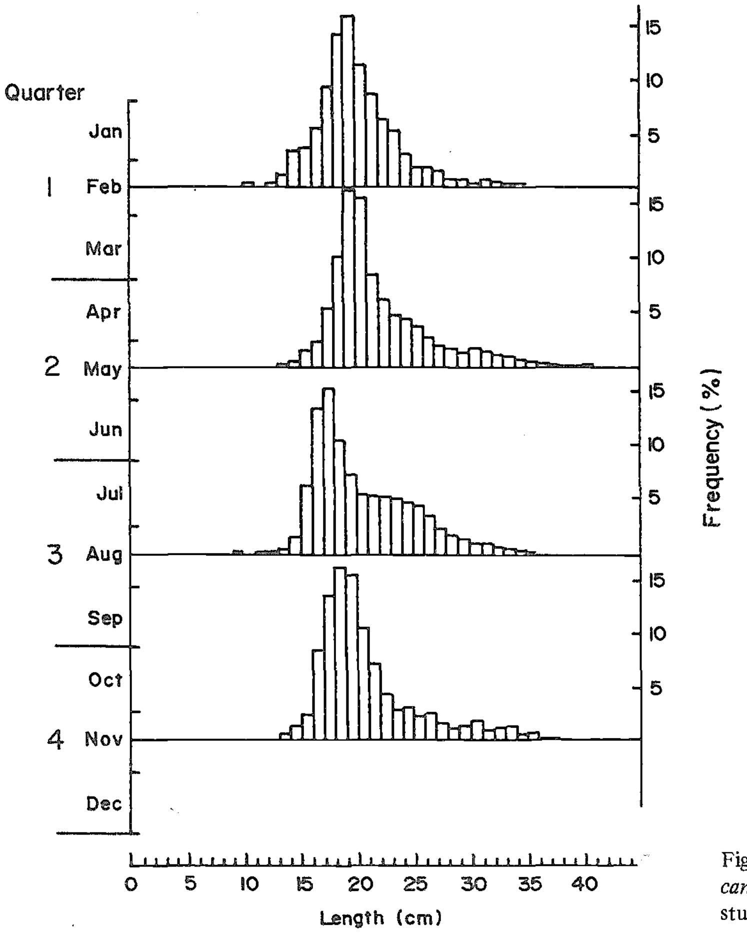


Fig. 4. Histograms of length frequencies of *Drepane africana* for averaged quarters, 1977-1980, as used for this study (see also Table 2).

Methods

Estimation of Growth

The ELEFAN I program (Pauly and David 1981; P. Sparre, pers. comm. to Sims 1985, with correction in Pauly 1985; Thiam 1986) was used to estimate the growth parameters of *D. africana* in Senegalese waters. The results obtained were compared with those obtained by using the method of Bhattacharya (1967).

This method was chosen to avoid the element of subjectivity that inevitably is involved when growth curves are drawn by eye. The ELEFAN I method consists of three main parts:

First, the length frequencies are restructured in order to facilitate the identification of "peaks" and "troughs" in the frequency polygons of each sample.

Secondly, the computer is made to perform a high number of alternative runs modifying growth parameters and switching starting points (a point through which the curve is forced to pass). The likelihood that the maximum value of ESP/ASP will be found is then higher than when a fixed starting point is used.

Thirdly, the results (ratio of ESP/ASP) from different runs are compared and the best set of growth parameters can be selected.

For the estimation of growth parameters, a first rough estimation was done using the observed data and the assumption that the growth of this species follows a nonseasonalized, i.e., standard von Bertalanffy equation. The parameters WP and C are assumed equal to zero. Since the observed distributions are taken from commercial landings, we know that the frequencies of the smaller length gorups are not representative because of selection and discard effects. Therefore, the second step will be to correct the original frequencies of the smallest length group using the probability of capture given by the length-converted catch curve method. A second estimation of the growth parameters under the same assumptions as in the first estimation will be done using the data corrected for selection. One may expect an increase in the value of K (Pauly 1986).

The third step was the investigation of seasonal growth using the corrected data set. The final step was to compare the age-length table obtained from the seasonalized von Bertalanffy equation and the mean lengths of the different cohorts for each quarter obtained, by hand, using the Bhattacharya method.

Basic Principles of Seasonalized Growth in Length

We may write the differential form of the von Bertalanffy equation as follows:

$$\frac{dL(A)}{dA} = K(A)\ [L_\infty - L_{(A)}] \qquad \dots (1)$$

where L(A) is the mean body-length of the fish in the age group (cohort) at relative age A, i.e., the age of the cohort relative to the start of some arbitrary reference year. Thus, A = O is by definition the 1st January. L_∞ is in this model the mean length of infinitely old fish.

If the curvature parameter K(A) is constant then an integration of Eq. (1) yields the ordinary von Bertalanffy growth equation, i.e.,

$$L(A) = L_\infty \{1 - \exp[-\overline{K}(A-T_o)]\};\ K(A) = \overline{K} \qquad \dots (2)$$

where T_o, the initial condition parameter for the cohort is defined by

$$A - T_o = t - t_o \qquad \dots (3)$$

where the lefthand side refers to relative ages and the right hand side to the (unknown) absolute ages.

In order to investigate the effect of seasonal growth we put

$$K(A) = \overline{K}\,[1 + C * \cos(2\pi(A - t_s))] \qquad \dots (4)$$

This cosines term produces seasonal oscillations of the growth rate, Eq. (1). The curvature parameter K varies between $\overline{K}(1 - C)$ and $\overline{K}(1 + C)$.

Thus, the parameter C determines the amplitude of the periodic oscillations relative to the mean annual value of K. C takes a value between 0 and 1. If C = O we obtain the growth equation (2) without seasonality (Fig. 5).

The higher the value of C, the more pronounced are the seasonal oscillations. If C = 1, then the growth rate becomes zero at the so called winter point denoted by WP or t_w.

$$WP = t_w = t_s \pm 0.5 \qquad \dots (5)$$

For most species of the Northern hemisphere, the value of t_w is close to 0.1 year which corresponds to the beginning of February, i.e., in the cold season. At the summer point, $t_s = t_w \pm 0.5$, the maximum growth rate is achieved.

Mean length at age with the seasonalized K(A) from Eq. (4) is obtained by an integration of Eq. (1). Omitting minor problems with T_o, we obtain the usual seasonalized von Bertalanffy equation (Pitcher and MacDonald 1973; Cloern and Nichols. 1978; Pauly and Gaschütz 1979).

$$L(A) = L_\infty \{1 - \exp[-\overline{K}(A-T_o) - (CK/2\pi)\sin(2\pi(A - t_s))]\} \qquad \dots (6)$$

which represents a von Bertalanffy equation with a sines term in the exponent (Fig. 6).

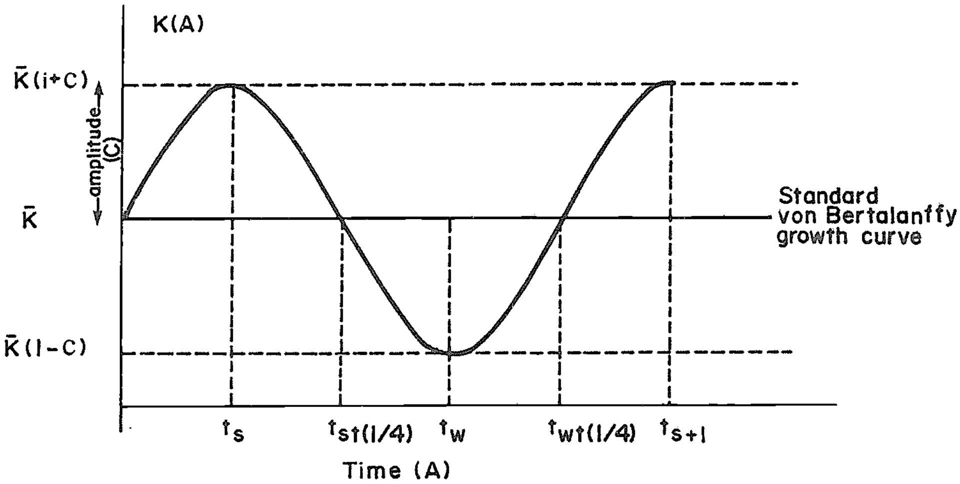


Fig. 5. Schematic representation of seasonal deviations from a standard von Bertalanffy growth curve with definitions of C, t_s and t_w.

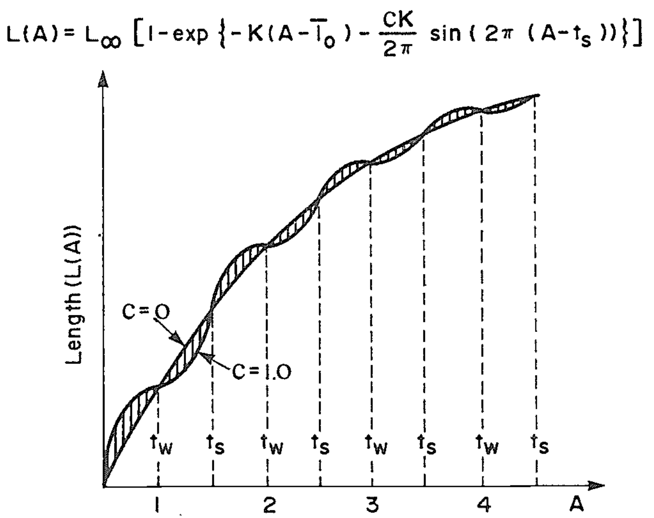


Fig. 6. Schematic representation of the effect of C > O on a growth curve. Note positions of maximum positive deviation (at $t = t_s$) and maximum negative deviation (at $t = t_w$).

The slope of this oscillating growth curve gives the rate of increase in length as may be calculated directly from Eq. (1) inserting K(A) from Eq. (4) and L(A) from Eq. (6). The amplitude of the oscillations decreases as the length of the fish approaches L_∞.

Estimation of Mortality

Using the seasonalized von Bertalanffy growth parameters, the estimation of mortality rates will be done by the length-converted catch curve method which is a routine of the ELEFAN II program presented by Saeger and Gayanilo (1986) and Brey and Pauly (1986). A first estimation of Z is obtained from the equation $\ln(N/\Delta\text{-}) = a + bt$. The final correction of this value of $Z = -b$ for nonlinear growth of fish is made by the following equation:

$$\ln(N/(1 - e^{-Z_i \Delta t}) = a - Z_{i+1} t \qquad (7)$$

Results

Estimation of Growth Parameters

Using observed data without seasonality

The different values of the ratio R = (ESP/ASP) x 1,000 are shown in Table 3. The optimum value is 515 and is obtained for L_∞ = 51.4 cm and K = 0.150/year (Fig. 7a).

All positive frequencies were used as starting points with all combinations of L_∞ and K. The total number of positive frequencies of the observed length distributions is 58. The matrix of Table 3 presents 70 values of L_∞ and 20 values of K. So, the total number of curves drawn by the computer before selecting the best R is equal to 58 * 70 * 20 = 81,200 curves. Such a high number options cannot be evaluated without a fast computer.

Table 3. Matrix of the ratio (ESP/ASP) x 1,000 for the first investigations on the nonconverted data without seasonality.

c (amplitude) : 0.0000
d : 1.0000

TABLE OF (ESP/ASP)A1000

K

Asymptotic length (L_∞ ,cm)

L8/K	0.090	0.095	0.100	0.105	0.110	0.115	0.120	0.125	0.130	0.135	0.140	0.145	0.150	0.155	0.160	0.165	0.170	0.175	0.180	0.185
48.00	-86.	2.	87.	65.	10.	219.	113.	222.	115.	92.	131.	266.	240.	92.	129.	145.	175.	277.	318.	253.
48.10	-10.	4.	-20.	96.	50.	219.	83.	222.	92.	132.	197.	309.	231.	110.	110.	156.	236.	277.	326.	287.
48.20	-159.	-18.	-58.	6.	106.	297.	72.	232.	60.	56.	201.	309.	280.	118.	80.	125.	208.	309.	290.	279.
48.30	-150.	-89.	-37.	-45.	111.	326.	91.	232.	101.	150.	252.	309.	225.	110.	120.	194.	251.	305.	290.	336.
48.40	-142.	5.	-29.	-40.	102.	172.	161.	166.	175.	135.	252.	328.	82.	100.	173.	194.	291.	279.	283.	299.
48.50	-23.	72.	30.	-67.	210.	103.	236.	190.	79.	145.	255.	270.	141.	132.	173.	193.	307.	279.	336.	454.
48.60	-48.	-5.	50.	26.	242.	102.	251.	199.	79.	167.	237.	292.	127.	122.	167.	224.	323.	335.	317.	478.
48.70	-30.	-1.	51.	26.	329.	42.	251.	199.	90.	167.	250.	240.	113.	122.	167.	263.	277.	371.	361.	434.
48.80	-41.	71.	39.	-24.	290.	60.	306.	201.	100.	179.	272.	236.	110.	131.	208.	263.	277.	326.	344.	351.
48.90	-4.	77.	39.	-29.	296.	95.	222.	176.	129.	179.	269.	136.	110.	140.	194.	324.	203.	435.	378.	342.
49.00	26.	57.	59.	65.	269.	176.	107.	146.	146.	255.	301.	154.	113.	101.	212.	351.	279.	361.	379.	342.
49.10	6.	122.	66.	65.	272.	176.	199.	146.	221.	255.	239.	130.	117.	221.	194.	291.	334.	313.	379.	342.
49.20	66.	1.	66.	104.	153.	179.	189.	135.	231.	255.	254.	232.	122.	92.	295.	291.	349.	385.	379.	341.
49.30	67.	59.	10.	137.	153.	247.	179.	111.	148.	255.	211.	150.	122.	154.	295.	330.	409.	305.	319.	257.
49.40	-7.	45.	-32.	148.	130.	205.	282.	126.	177.	258.	294.	168.	122.	177.	280.	402.	435.	411.	351.	199.
49.50	-38.	13.	-32.	213.	99.	205.	202.	94.	179.	258.	143.	152.	174.	212.	390.	386.	435.	411.	349.	212.
49.60	-34.	18.	-32.	302.	65.	189.	244.	96.	179.	292.	229.	141.	148.	177.	362.	415.	295.	379.	182.	212.
49.70	-3.	54.	43.	335.	122.	181.	189.	95.	187.	302.	208.	136.	104.	247.	362.	353.	299.	379.	191.	212.
49.80	43.	51.	64.	316.	141.	237.	172.	136.	229.	283.	232.	165.	115.	295.	342.	354.	329.	453.	191.	201.
49.90	43.	114.	77.	246.	128.	251.	178.	151.	267.	286.	232.	184.	149.	379.	397.	386.	305.	275.	191.	201.
50.00	157.	162.	56.	246.	176.	274.	178.	242.	255.	191.	158.	185.	154.	295.	449.	420.	345.	215.	212.	286.
50.10	106.	141.	90.	216.	201.	276.	118.	242.	306.	163.	158.	105.	177.	295.	441.	444.	411.	181.	199.	319.
50.20	146.	87.	90.	186.	275.	264.	111.	231.	325.	218.	180.	173.	177.	270.	423.	331.	358.	181.	199.	319.
50.30	128.	49.	181.	186.	136.	296.	79.	161.	261.	229.	167.	173.	182.	337.	334.	331.	379.	181.	236.	298.
50.40	65.	28.	136.	186.	228.	267.	114.	213.	279.	211.	176.	104.	251.	393.	362.	345.	275.	191.	286.	339.
50.50	78.	17.	144.	133.	301.	253.	92.	171.	279.	265.	174.	132.	290.	425.	388.	345.	164.	171.	319.	296.
50.60	74.	1.	108.	120.	301.	253.	122.	185.	279.	232.	253.	165.	335.	398.	444.	385.	126.	325.	319.	343.
50.70	112.	33.	107.	155.	263.	101.	160.	257.	246.	232.	224.	165.	369.	418.	444.	325.	164.	286.	418.	343.
50.80	193.	43.	202.	124.	335.	109.	160.	209.	225.	182.	201.	178.	369.	499.	444.	287.	181.	286.	398.	343.
50.90	175.	70.	204.	141.	340.	200.	150.	300.	172.	256.	201.	105.	369.	447.	331.	179.	173.	206.	377.	275.
51.00	224.	72.	312.	120.	340.	187.	185.	354.	226.	256.	184.	220.	413.	450.	275.	179.	184.	299.	330.	339.
51.10	207.	99.	235.	104.	276.	131.	109.	331.	260.	253.	106.	220.	464.	300.	354.	163.	230.	420.	312.	283.
51.20	222.	53.	290.	155.	296.	171.	109.	279.	260.	292.	101.	324.	399.	300.	345.	237.	265.	420.	311.	178.
51.30	139.	63.	106.	302.	276.	170.	192.	107.	260.	227.	165.	324.	419.	300.	104.	136.	265.	397.	322.	229.
51.40	116.	102.	106.	302.	267.	170.	175.	246.	266.	227.	154.	269.	515.	444.	225.	216.	206.	377.	312.	229.
51.50	60.	139.	106.	302.	267.	163.	190.	246.	266.	163.	239.	469.	400.	444.	133.	230.	344.	397.	273.	182.
51.60	52.	111.	154.	301.	267.	130.	315.	246.	266.	199.	239.	453.	460.	219.	190.	230.	420.	287.	273.	243.
51.70	-12.	194.	151.	324.	217.	131.	270.	216.	241.	212.	239.	346.	422.	275.	201.	263.	420.	268.	177.	207.
51.80	-8.	203.	149.	324.	244.	149.	351.	244.	245.	203.	277.	346.	309.	237.	201.	254.	420.	286.	194.	207.
51.90	-23.	201.	145.	359.	244.	196.	351.	325.	253.	166.	235.	430.	445.	250.	237.	376.	418.	261.	203.	174.
52.00	51.	163.	145.	359.	125.	228.	351.	325.	230.	195.	235.	420.	445.	248.	215.	325.	374.	239.	259.	174.
52.10	37.	149.	144.	359.	148.	205.	221.	325.	250.	171.	308.	419.	387.	248.	270.	325.	327.	207.	203.	178.
52.20	60.	215.	146.	348.	158.	241.	280.	325.	250.	239.	315.	419.	284.	248.	270.	399.	327.	207.	182.	190.
52.30	108.	204.	184.	351.	163.	211.	246.	260.	248.	239.	300.	400.	194.	248.	269.	418.	261.	207.	174.	190.
52.40	116.	132.	254.	279.	184.	245.	246.	334.	229.	228.	445.	405.	215.	207.	277.	397.	261.	211.	174.	182.
52.50	69.	132.	254.	353.	250.	249.	246.	291.	164.	196.	445.	461.	255.	212.	350.	374.	261.	211.	174.	193.
52.60	60.	132.	302.	318.	258.	292.	238.	291.	154.	216.	445.	389.	326.	224.	335.	374.	226.	229.	174.	206.
52.70	60.	150.	324.	318.	235.	278.	286.	245.	155.	228.	458.	285.	266.	220.	325.	327.	218.	179.	174.	173.
52.80	97.	88.	324.	274.	154.	291.	259.	245.	194.	220.	460.	245.	248.	272.	344.	327.	218.	179.	186.	173.
52.90	124.	145.	324.	274.	201.	191.	259.	254.	214.	272.	460.	227.	254.	270.	373.	261.	218.	179.	190.	106.
53.00	129.	74.	337.	140.	213.	179.	305.	250.	162.	293.	349.	284.	275.	360.	393.	254.	211.	174.	190.	159.
53.10	96.	83.	393.	117.	213.	245.	360.	166.	173.	310.	405.	294.	281.	349.	374.	245.	211.	174.	187.	159.
53.20	97.	142.	359.	124.	205.	200.	400.	144.	178.	310.	400.	255.	262.	331.	374.	245.	166.	174.	204.	159.
53.30	137.	184.	433.	155.	153.	200.	400.	148.	174.	309.	389.	336.	305.	329.	327.	219.	172.	174.	206.	161.
53.40	173.	236.	381.	116.	179.	246.	400.	140.	228.	391.	353.	326.	321.	344.	327.	218.	179.	186.	321.	147.
53.50	92.	164.	413.	172.	249.	321.	307.	120.	104.	443.	301.	326.	341.	321.	327.	210.	179.	186.	161.	126.
53.60	206.	167.	413.	197.	166.	300.	307.	155.	214.	443.	245.	326.	340.	373.	263.	159.	179.	186.	107.	126.
53.70	149.	254.	330.	193.	222.	301.	305.	155.	220.	503.	274.	326.	330.	369.	254.	175.	170.	200.	87.	133.
53.80	132.	270.	250.	200.	159.	290.	256.	159.	259.	360.	315.	363.	326.	369.	307.	201.	170.	192.	161.	133.
53.90	136.	270.	177.	199.	159.	416.	245.	100.	321.	360.	294.	363.	331.	369.	239.	172.	174.	284.	161.	133.
54.00	105.	276.	177.	106.	179.	336.	146.	171.	321.	350.	294.	200.	327.	323.	239.	143.	106.	144.	147.	120.
54.10	131.	276.	177.	173.	179.	336.	213.	140.	321.	353.	274.	275.	327.	327.	239.	179.	106.	129.	147.	128.
54.20	119.	324.	135.	102.	188.	360.	143.	176.	242.	297.	273.	350.	327.	327.	239.	179.	301.	161.	147.	128.
54.30	44.	411.	139.	107.	254.	360.	94.	155.	242.	353.	273.	314.	353.	327.	190.	179.	141.	161.	147.	245.
54.40	65.	411.	126.	111.	254.	337.	136.	194.	443.	310.	357.	330.	325.	307.	198.	179.	145.	161.	126.	245.
54.50	91.	444.	134.	79.	271.	332.	155.	213.	443.	340.	308.	318.	369.	299.	167.	170.	137.	161.	126.	153.
54.60	119.	380.	130.	184.	287.	307.	152.	215.	288.	323.	407.	326.	369.	239.	179.	170.	131.	147.	120.	153.
54.70	128.	380.	130.	156.	320.	330.	164.	255.	208.	323.	331.	339.	369.	239.	130.	298.	144.	155.	129.	153.
54.80	129.	275.	159.	160.	374.	339.	164.	236.	344.	317.	295.	326.	323.	239.	143.	290.	115.	155.	151.	126.
54.90	201.	275.	216.	160.	374.	305.	174.	241.	287.	316.	295.	327.	323.	239.	193.	141.	144.	147.	172.	131.

highest ESP/ASP-value in this table : 515.
obtained for K = 0.150 and L8 = 51.400

highest ESP/ASP-value in this run 515.

Correction of observed data for selection

The probability of capture of the length groups that are not fully recruited is obtained from a preliminary length-converted catch curve. It is assumed that the probability is equal to one for the fully recruited length groups. The projection of a not fully recruited point on the regression line of the catch curve gives the probability of capture of the corresponding length group. The correction of original frequencies has been done through an option of the ELEFAN package of Brey and Pauly (1986). It may be noted that probabilities of capture lower than 0.01 have been set to 0.01.

Reestimation of growth parameters

Under the same assumptions used in the first estimation but using the data corrected for selection, the new estimates become L_∞ = 50.7 cm and K = 0.156/year (Table 4). As expected, the value of K has increased, indicating that the value of this parameter from uncorrected commercial landings leads to an underestimate.

Table 4. Results of the growth parameter investigations.

L_∞ (cm)	K ($year^{-1}$)	WP (year)	C	ESP/ASP	Number of curves	Remarks
51.4	0.150	0	0	0.515	81,200 (=70*20*58)	no correction for selection and no seasonality
50.6	0.156	0	0	0.456	43,200 (=40*20*54)	correction for selection but no seasonality
54.3	0.134	0.26	0.575	0.564	around 6 million	correction for selection and with seasonality

Seasonal growth

The basic data are the corrected distributions. The value of WP (the winter point constant) varies between 0.1 and 0.6 with steps of 0.05. The value of C (amplitude) varies (for each value of WP) from 0.1 to 1.0.

The best fit obtained (with ESP/ASP = 0.564) corresponds to WP = 0.25 year, C = 0.5, L_∞ = 53.4 cm and K = 0.140/year.

Changing the step fo WP and C, a fit has been obtained for WP = 0.26 year, C = 0.575, L_∞ = 54.3 cm and K = 0.134/year. The value of R is 564. The total number of curves drawn for the estimation of the seasonal growth parameters is around 6 million! (Table 4).

With these estimates for *D. africana* the seasonalized von Bertalanffy equation (6) takes the form

$$L(A) = 54.3 \{1 - \exp [-0.134(A-T_O) - 0.01226 \sin (2\pi(A - 0.76))]\} \qquad (8)$$

where

$$t_S = WP - 0.5 = 0.76 \text{ year}$$

The growth curve is drawn on the restructured frequencies of observed data (Fig. 7a) and on restructured frequencies of data corrected for selection (Fig. 7b). The seasonalized growth curve and the nonseasonalized curve are superimposed on the same graph (Fig. 7c).

The lengths at different ages obtained from the growth equation (Table 5) and the mean length of cohorts calculated by the Bhattacharya method (by hand) are given in Table 6, and some examples are presented in Figures 8-11.

Estimation of Mortality Rates

Using the Pauly's empirical formula (Pauly 1982), a value is obtained for the natural mortality M of 0.35/year, for an average temperature of 20°C. The basic data for the estimation of Z are observed length distributions representative for a whole year. The graphical representation of the catch curve is given in Fig. 12. The estimate of Z is 1.08/year and the fishing mortality F is therefore 1.08 - 0.35 = 0.73/year. The exploitation rate becomes E = F/Z = 0.68.

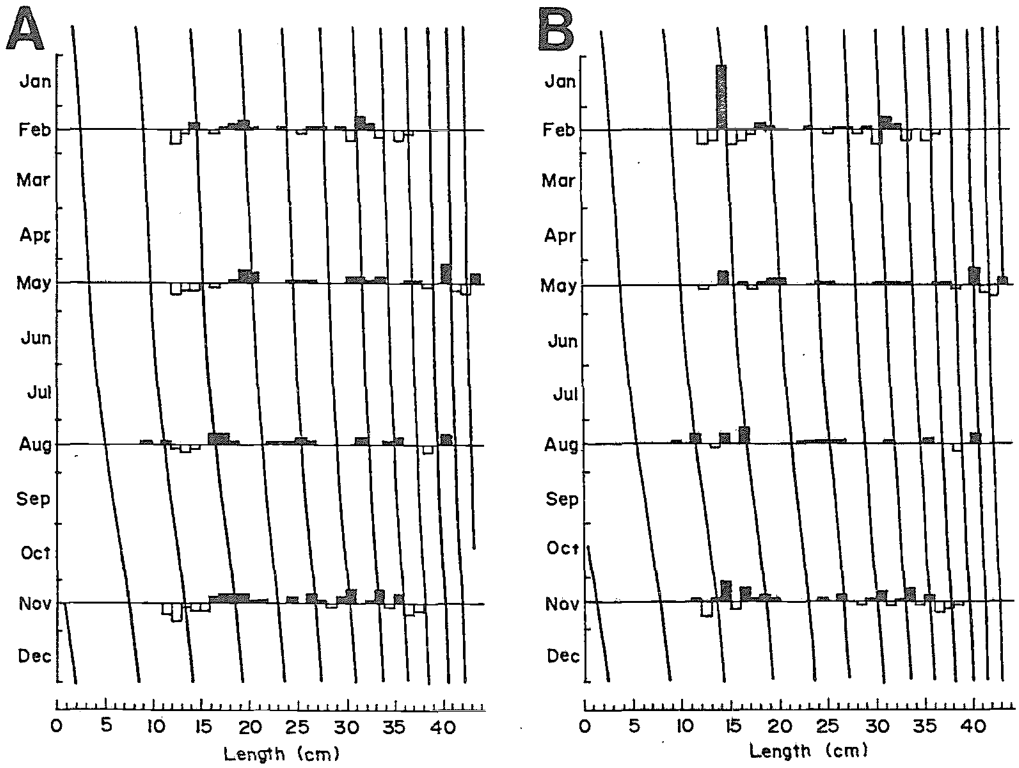
The probability of capture of not fully recruited length groups has been plotted on the resultant curve (Fig. 12) which gives a value of 19.2 cm for L_c, corresponding to fish between 3 and 4 years old.

Table 5. Age-length key using growth equation L_t = 54.3 (1-exp(-0.134 t)).

t (year)	L_t (cm)	t (year)	L_t (cm)
1	6.81	7	33.05
2	12.77	8	35.71
3	17.97	9	38.04
4	22.53	10	40.08
5	26.51	11	41.86
6	30.00	12	43.42

Table 6. Midlengths (in cm) of the normal distributions obtained from the Bhattacharya analysis by hand.

	1st quarter	2nd quarter	3rd quarter	4th quarter
1977	14.9	16.0	17.6	17.7
	17.7	19.4	22.6	19.7
	21.7	22.5	25.8	25.6
	25.7	25.4	29.1	29.8
		28.6	33.4	33.4
		31.4		
		35.9		
1978	18.6	18.9	17.1	19.8
	22.2	23.7	21.3	26.8
	27.2	29.3	25.7	
	31.8	32.9	31.8	
	33.4			
1979	14.9	15.2	17.2	19.4
	19.4	20.2	25.6	23.9
		22.2	31.7	26.7
			35.0	30.2
1980	15.2			
	19.6			
	23.7			
	27.1			
	31.5			



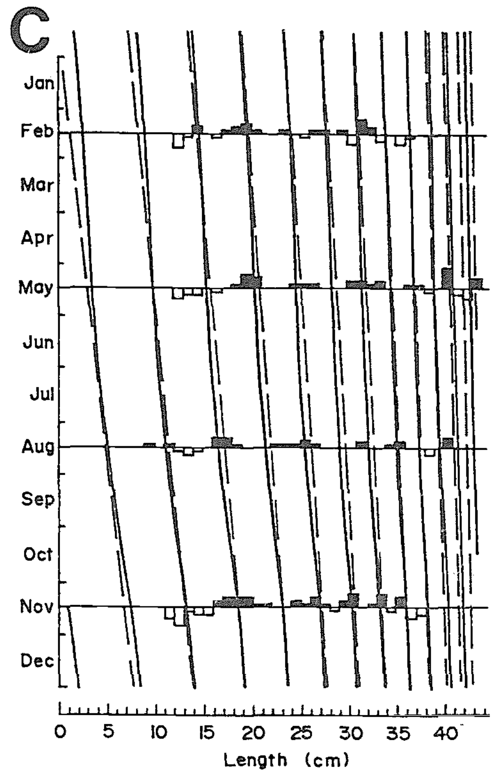
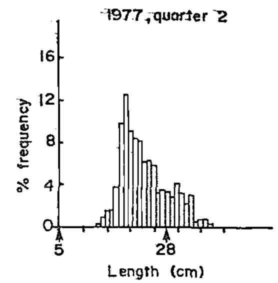


Fig. 7. Restructured length-frequency data for *Drepane africana* from Senegal, 1977-1980. a) seasonalized growth curve, data not corrected for selection; b) seasonalized growth curve, data corrected for selection; c) seasonalized (solid lines) and non-seasonalized (broken lines) growth curve, superimposed on restructured length-frequency data corrected for selection.

Mean length (cm)	Correlation coefficient	Standard deviation
16.0	-0.975	1.206
19.4	-0.960	0.957
22.5	-0.968	1.220
25.4	-0.968	0.889
28.6	-0.907	1.000
31.4	-0.888	1.010
35.9	-0.988	1.293



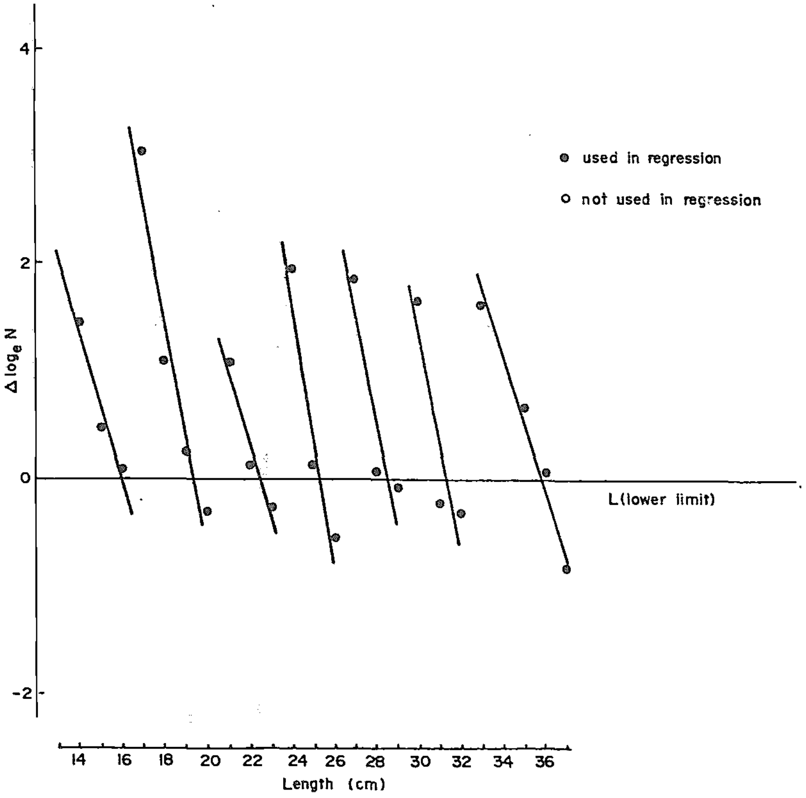
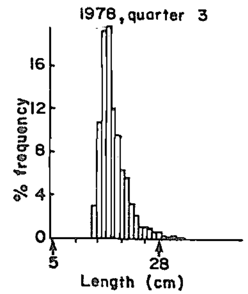


Fig. 8. Separation of the composite length-frequency distribution of *Drepane africana* from Senegal, second quarter of 1977, into normally distributed components (cohorts) using the Bhattacharya method.

Mean length (cm)	Correlation coefficient	Standard deviation
17.1	-0.998	1.313
21.3	-0.990	0.975
25.7	-0.991	1.562
31.8	-0.981	1.112



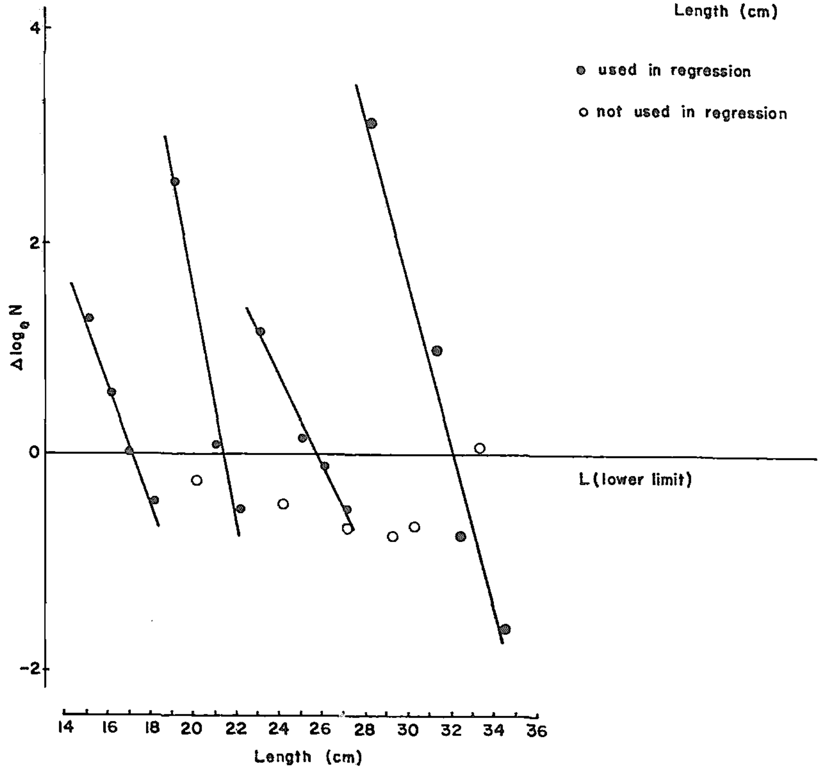
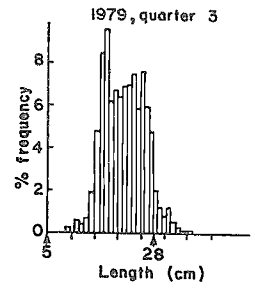


Fig. 9. Separation of the composite length-frequency distribution of *Drepane africana* from Senegal, third quarter of 1978, into normally distributed components (cohorts) using the Bhattacharya method.

Mean length (cm)	Correlation coefficient	Standard deviation
17.2	-0.993	1.504
25.6	-0.985	1.657
31.7	-0.972	1.155
35.0	-0.990	1.261



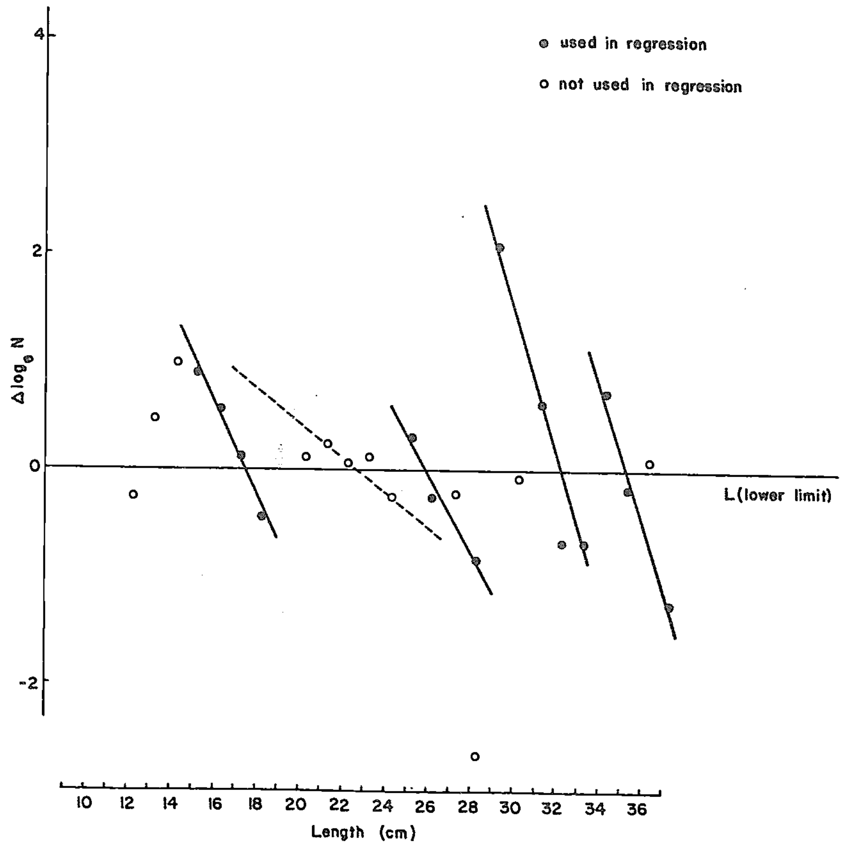
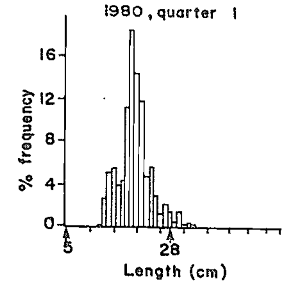


Fig. 10. Separation of the composite length-frequency distribution of *Drepane africana* from Senegal, third quarter of 1979, into normally distributed components (cohorts) using the Bhattacharya method.

Mean length (cm)	Correlation coefficient	Standard deviation
15.2	-0.996	1.421
19.6	-1.000	1.133
23.7	-0.914	1.144
27.1	-0.944	0.781
31.5	-0.997	1.011



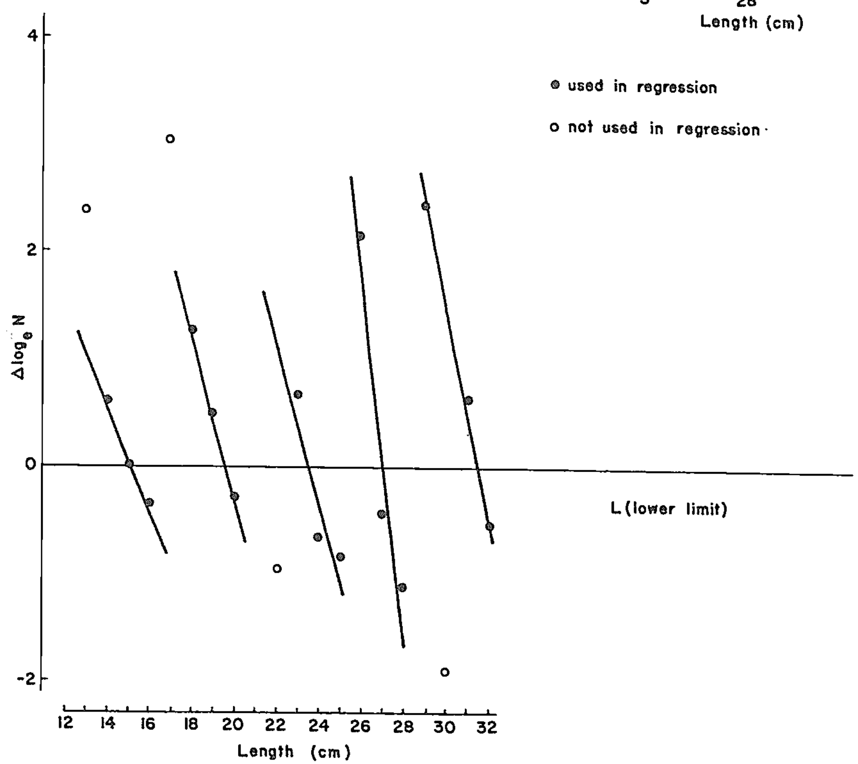


Fig. 11. Separation of the composite length-frequency distribution of *Drepane africana* from Senegal, third quarter of 1980, into normally distributed components (cohorts) using the Bhattacharya method.

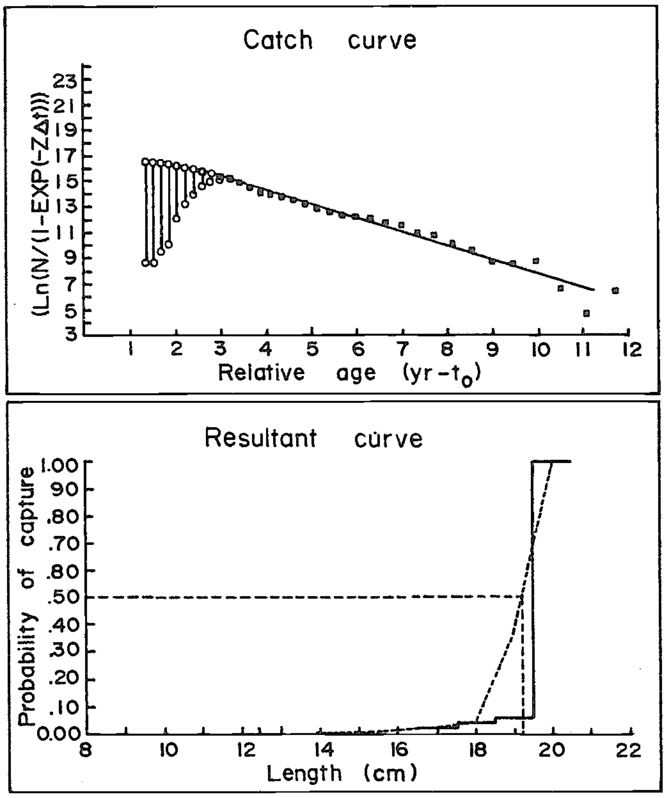


Fig. 12. Length-converted catch curve *(above)* for *Drepane africana* and estimated probabilities of capture *(below)*. The parameter estimates are Z = 1.08 y^{-1} and L_c = 19.2 cm.

Discussion and Conclusion

In order to obtain a best estimate of the growth parameters, the observed (commercial) length distributions have been corrected by using the probability of capture of the not fully recruited length groups. The estimates obtained are the first for this species in Senegalese waters. The lowest value growth rates occur in March-April (WP = 0.26 year) which is the end of the cold season. It may be noted that the middle of the cold season is indicated by WP = 0.1. The relative amplitude of the growth rate oscillation is equal to C = 0.575. No exact birthday can be given. The spawning season is located between June and September (Domain 1980). A better knowledge of the biology of this species would permit a more precise estimate of the growth equation.

It may also be noted that the preference we have for the seasonalized growth parameters is due to the fact that the ratio ESP/ASP has increased by about 25% compared to the nonseasonalized growth curve. Both curves seem to pass through the same peaks for the younger classes. Separate information (data) on seasonal changes in environmental parameters is needed in order to obtain more reliable conclusions in this kind of investigation. Furthermore, the information contained in the present data set on the dynamics of cohorts has not yet been investigated. This study should be considered as the very first step of gaining insight into the basic parameters governing growth and mortality of *Drepane africana*.

The available catch and effort data will also become more useful after this first estimation of the growth parameters and mortality rates.

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Estimation of Biomass, Growth and Mortality Parameters of *Dentex* spp. (Sparidae) in Sierra Leonean Waters

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Abstract

This paper analyzes a bottom trawl survey in March/April 1986 covering the shelf off Sierra Leone. The survey was conducted between 6°40'N and 9°N in the 20 and 100 m depth contour. Further length-frequency data for three species of *Dentex angolensis*, *D. canariensis* and *D. congoensis* (Sparidae) are presented from eight surveys in the same area conducted between 1976 and 1986.

A combined biomass estimate of 5,800 t for the three species was obtained. This estimate is composed of: *Dentex angolensis* 1,700 t (29%); *Dentex canariensis* 200 t (4%) and *Dentex congoensis* approximately 3,900 t (67%).

Growth parameters were obtained for *D. angolensis* and *D. congoensis* from length-frequency data covering 1976-1986. The values of L_∞ determined for *D. angolensis* ranged from 33.8 to 42.6 cm with a range of K values of 0.22 to 0.44/year. The figures for *D. congoensis* were 23.3 to 34.0 cm for L_∞ and 0.41 to 1.59 for K.

The limitations in the methods used are discussed and recommendations are made for further work to be done in this area.

Introduction

The Sierra Leonean fishery has two sectors: the industrial vessels with a range of sophisticated fishing gears and the artisanal or canoe fishery with gears varying from simple hooks and lines to more complicated nets. There is interaction between these two sectors as the smaller trawlers sometimes fish near the coast while the larger canoes venture further offshore.

The species here examined are *Dentex angolensis*, *D. canariensis* and *D. congoensis* (Sparidae), which form an important part of the Sierra Leonean fishery, as they are high value food fish for the local market as well as for export. Although the *Dentex* species are not the most abundant group (comprising only about 1.2 % in the trawl survey catches mentioned below), their high value makes them a target for both the artisanal fishermen, who capture them with hook and line and for the industrial vessels fishing with bottom trawls. However the interaction may not be very strong as the survey results indicate that these species are almost totally absent in the shallower waters.

So far the *Dentex* species in the area have not been the specific object of scientific investigations. The only biological and stock information has been obtained from broad based demersal trawl surveys, of which a review is given in CECAF (1985).

This paper estimates the biomass of *Dentex* species from the 1986 trawl survey catch data and also, where possible, the growth parameters from the length-frequency data obtained during the surveys between 1976 and 1986.

Materials

Biomass Estimation

The data used for the biomass estimation were obtained from a joint Soviet-Sierra Leonean bottom trawl survey by the research vessel (stern trawler) *R/V. Bakhchisaray* in March/April 1986. The gear used was a "Hake-4M" bottom trawl with a headrope of 75 m and a cod-end stretched mesh size of 11 mm.

The cruise covered the whole area between the 20 and 100 m depth contours. The trawl stations are indicated in Fig.1. The duration of each haul was 30 min. and the trawling speed 4 knots. A total of 59 valid hauls were made. The total catches of all species encountered were recorded and length-frequency measurements were made on representative samples. Catches of the three *Dentex* species are presented in Table 1, listing only the hauls with a catch of at least one species with an allocation of depth strata and north-south strata.

Growth Parameters

The material used for the estimation of the growth parameters consists of the length-frequency data obtained during eight surveys made between 1976 and 1986.

A summary of the length-frequency data from these surveys is given for *D. angolensis* in Tables 2 and 3 and for *D. congoensis* in Table 4.

D.angolensis were only caught in two of the eight surveys (Table 3) in the 20-50 m zone while *D. congoensis* did not occur at all in this depth zone.

Table 1. Catches in kg of the three *Dentex* species in the March/April 1986 survey by R/V BAKHCHISARAY in Sierra Leonean Waters. The total number of hauls is 59, those hauls not shown had zero catch for all three *Dentex* species.

Haul no	Depth stratum	North-South stratum	*D. angolensis* kg	*D. canariensis* kg	*D. congoensis* kg
7	I	A	1	20	0
11	II	A	0	0	1
30	II	B	45	0	0
31	II	A	5	0	4
34	II	B	15	17	11
39	II	B	0	0	135
40	II	B	12	0	2
41	II	B	13	0	0
47	I	B	14	0	0
55	I	B	18	0	0
56	II	B	142	0	243
60	II	B	0	0	529
62	II	B	0	0	22
63	I	B	1	0	0
64	II	B	70	0	0
65	II	B	55	0	0

*The total number of hauls per stratum were:
Depth strata I 34, II 25
N/S strata A 29, B 30

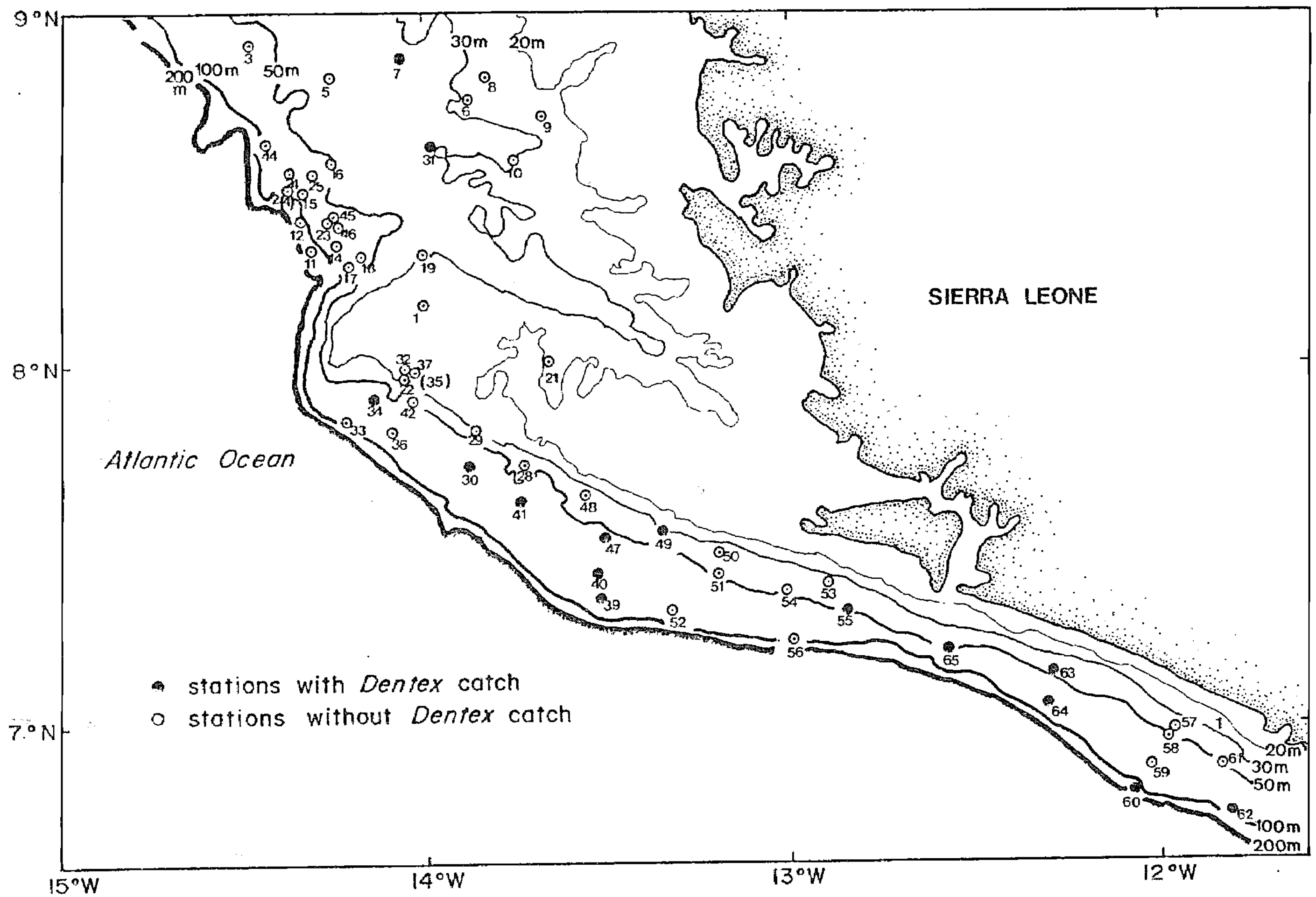


Fig. 1. Sampling stations in March 1986 survey of Sierra Leone.

Table 2. Length frequency data for *Dentex angolensis* in 51-100 m depth zone from 1976 to 1986 surveys.*

Class length (cm)	December 1976	June 1977	February 1982	June 1984	February 1985	July 1985	March 1986
7-	0	3	0	0	0	0	0
8-	0	11	0	0	0	0	0
9-	1	24	0	0	0	1	2
10-	2	23	0	0	0	1	5
11-	25	2	0	0	0	0	0
12-	35	5	0	1	15	1	2
13-	31	31	18	2	35	3	13
14-	47	135	54	4	27	9	24
15-	61	126	90	4	69	26	69
16-	81	37	126	5	70	33	53
17-	137	24	161	9	96	52	48
18-	309	42	270	15	104	81	70
19-	345	56	342	12	100	87	84
20-	361	39	306	16	56	134	131
21-	362	29	234	15	55	124	120
22-	237	8	143	10	25	90	70
23-	149	0	36	4	13	81	33
24-	51	0	18	1	12	79	13
25-	33	0	18	2	14	27	0
26-	15	0	0	1	1	8	0
27-	17	0	0	1	0	1	0
28-	13	0	0	1	0	0	0
29-	1	0	0	1	0	0	0
30-	2	0	0	1	0	0	0

*data for the same months in different years were pooled for ELEFAN I-based analyses of growth (see Fig. 2).

Methods

Biomass

The biomass of *D. angolensis*, *D. congoensis*, and *D. canariensis* has been estimated using the "swept area method". This method assumes that the mean catch in weight per unit effort or per unit area is an index of the stock abundance (Gulland 1969; Pauly 1984).

The area swept by the trawl is

$$a = D * W \text{ nmile}^2 \qquad (1)$$

where D is the distance covered by the trawl during a haul, while W is the width of the path swept by the trawl. Pauly (1980) calculates the width from

$$W = h * X_2 \text{ nmile} \qquad (1a)$$

where h is the length of the headrope of the trawl while X_2 is a factor to correct for the arc formed by the headrope during operation. Pauly (1980) has suggested $X_2 = 0.5$ for bottom trawls.

Table 3. Length frequency data for *Dentex angolensis* in the 20-50 m depth zone from 1985-1986 surveys.

Class length (cm)	Number of fish February 1985	March 1986
7-	0	1
8-	0	4
9-	0	24
10-	0	13
11-	0	0
12-	0	1
13-	0	2
14-	0	7
15-	1	22
16-	1	19
17-	2	33
18-	4	19
19-	4	15
20-	5	22
21-	0	13
22-	3	9
23-	1	4
24-	0	2
25-	0	2

[a]*Dentex angolensis* was not found in surveys prior to 1985 and not in July 1985 in this depth zone.

D, the distance covered by the trawl was obtained from

$$D = V * t \qquad (2)$$

where V is the speed over ground when trawling and t the duration of the haul.

The proportion of fish retained in the net X_1 has been proposed to be 0.5 (Isarankura 1971; Saeger et al. 1976), and the biomass per unit area b, was obtained from the equation

$$b = (\overline{C}w/a)/X_1 \text{ kg/nmile}^2 \qquad (3)$$

where $\overline{C}w$ is the mean catch in weight per haul.

The total biomass B was calculated using

$$B = \frac{(\overline{C}w/a)}{X_1} \times A \qquad (4)$$

where A represents the area of the sea represented by the survey.

This area A was stratified into two depth zones (strata I and II) for better estimation of the biomass. The sea areas 20-50 m (I) and 51- 100 m (II) deep were calculated using the orthographic method.

To see if the above stratification could be improved, the distribution of the *Dentex* species in the survey area was reexamined. As the *Dentex* occurrences were more or less concentrated towards the south, the area was also stratified into a northern zone (stratum A, north of 8ºN) and a southern zone (stratum B, south of 8ºN). The orthographic method was again used to determine the areas of these two strata.

A third estimate of the biomass was made using equation (4) directly on the whole area in the 20-100 m depth contours, without stratification.

The variance of the biomass estimates was estimated as follows.The biomass B is obtained from

$$B = \frac{A}{X_1} * \overline{Ca} .$$

and the variance of B is therefore

$$\mathrm{Var}\ B = \mathrm{Var}\left(\frac{A}{X_1} * \overline{Ca}\right)$$

$$= \left(\frac{A}{X_1}\right)^2_{12} * \mathrm{Var}\,(\overline{Ca})$$

$$= \left(\frac{A}{X_1}\right)^2 * \frac{1}{n}\ \mathrm{Var}\,(Ca_i) \qquad (5a)$$

but

$$Ca_i = \frac{Cw_{(i)}}{a}$$

$$\therefore \mathrm{Var}\ Ca_{(i)} = \mathrm{Var}\left(\frac{Cw_{(i)}}{a}\right) = \frac{1}{a^2}\ \mathrm{Var}\ Cw_i$$

Substituting this for Var Ca_i in equation (5a) gives

$$\mathrm{Var}\ B = \left(\frac{A}{X_1}\right)^2 * \frac{1}{n} * \frac{1}{a^2} * \mathrm{Var}\ Cw_i \qquad (5b)$$

The standard deviation (square root of the variance) was expressed in tonnes and also as a percentage of the biomass estimate.

Table 4. Length frequency data for *Dentex congoensis* in 51-100 m depth zone from 1976 to 1986 surveys.*

Length class (cm)	Number of fish December 1976	June 1977	February 1978	February 1982	June 1984	February 1985	July 1985	March 1986
5-	0	1	0	0	0	0	0	0
6-	0	16	0	0	0	0	0	0
7-	0	82	0	0	0	0	0	0
8-	0	59	0	0	0	0	0	0
9-	0	15	0	0	0	0	0	1
10-	32	36	7	0	5	3	2	6
11-	70	103	31	20	29	6	8	8
12-	89	114	52	73	69	12	16	35
13-	145	102	100	102	160	28	24	38
14-	170	107	171	92	276	61	75	80
15-	203	105	206	120	323	103	110	91
16-	216	86	333	170	394	121	118	107
17-	233	86	385	163	282	120	133	97
18-	225	46	334	108	164	108	112	75
19-	126	19	193	67	76	84	49	62
20-	72	7	98	33	29	48	20	14
21-	32	0	43	7	5	27	1	9
22-	0	0	4	1	4	10	0	1
23-	0	0	1	0	0	3	0	0

*Data for the same month of different years were pooled for ELEFAN I-based analyses of growth (see Fig. 3)

Growth and Mortality Parameters

The K and L_∞ parameters of the von Bertalanffy growth equation were obtained using the ELEFAN I program (Brey and Pauly 1986; Thiam, this vol.).

The Wetherall method (Wetherall 1986, Julien-Flüs, this vol.) was used to estimate L_∞ and Z/K. Z is the total mortality. A length-converted catch curve analysis was carried out using the ELEFAN II program (Brey and Pauly 1986). This provides an estimate of Z. The cumulative catch curve technique of Jones and van Zalinge (1981) was also used to estimate Z/K. Where Z/K was obtained the K estimate from ELEFAN I was applied to provide an estimate of Z.

Calculations and Results

The calculations are illustrated below with examples.

Biomass Estimates

The swept area $a = V * t * h * X_2$ per haul

In this case V = 4 knots, t = 0.5 hour, h = 75 m = 75/1,852 nautical miles, $X_2 = 0.5$,
$a = 4 * 0.5 * 75/1852 * 0.5 = 0.0405$ nmile^2.

Depth stratification	North-South stratification
Area of stratum I = 4100 $nmile^2$	Area of stratum A = 3500 $nmile^2$
Area of stratum II = 2100 $nmile^2$	Area of stratum B = 2700 $nmile^2$

Mean catch per haul for *D. angolensis* in stratum I

$\overline{C}w = 1.0$ kg and $X_1 = 0.5$

Mean catch per unit area Cw/a = 1.0/0.0405 kg/$nmile^2$

Biomass $B = (\overline{C}w/a)/X_1 * A$

$= (1.0/0.0405)/0.5 * 4100$ kg = 202.5 t

The mean catch per haul calculated for the three species is given in Table 5 and the biomass estimated are summarized in Table 6.

Variance and Standard Deviation Calculation

The following example is for *D. canariensis* in Stratum I (Table 5). From equation (5b) and Table 5 we obtain

$\text{Var B} = (4100/0.5)^2 * 1/34 * 1/0.0405^2 * 3.43^2 = 1.4 * 10^{10}$

$\text{S.D.} = \sqrt{1.4 * 10^{10}}$ kg = 118.3 t.

Table 5. No of hauls (n), mean catch per haul ($\overline{cpue}$), standard deviation and coefficient of variation of catch per haul of *Dentex angolensis, D. congoensis* and *D.canariensis* from survey in March/April 1986 with R/V BAKHCHISARAY. The data are given by strata.

			D. angolensis	*D. canariensis*	*D. congoensis*
Stratum	n		34	34	34
I	$\overline{cpue}$	(kg)	1.00	0.59	0.00
20-50 m	Standard dev.	(kg)	3.85	3.43	0.00
	Coeff. of var.	(%)*	385	583	-
Stratum	n		25	25	25
II	$\overline{cpue}$	(kg)	14.28	0.68	37.88
51-100 m	Standard dev.	(kg)	32.64	3.40	115.81
	Coeff. of var.	(%)	229	500	306
Stratumn	n		29	29	29
A	$\overline{cpue}$(kg)	(kg)	0.27	0.69	0.17
9°N-8°N	Standard dev.	(kg)	0.94	3.71	0.76
	Coeff. of var.	(%)	454	539	440
Stratum	n		30	30	30
B	$\overline{cpue}$	(kg)	12.83	0.57	31.4
8°N-6°40'N	Standard dev.	(kg)	30.08	3.10	106.4
	Coeff. of var	(%)	234	548	339
Total	n		59	59	59
Area	$\overline{cpue}$	(kg)	6.63	0.63	16.05
	Standard dev.	(kg)	22.21	3.39	76.85
	Coeff. of var.	(%)	335	540	479

*Coefficient of variation = $\overline{cpue}$/standard deviation * 100

Table 6. Biomass estimates and their standard deviations of the three *Dentex* species in March/April 1986. Estimates are given by strata.

Stratum[a]	Area nmi²		*D.angolensis*	*D.canariensis*	*D.congoensis*	Total *Dentex*
I	4100	biomass (t)	203	119	0	322
		standard dev. (t)	134	119	-	
		S.D. in % of biomass (%)	66	100	-	
II	2100	biomass (t)	1481	71	3928	5480
		standard dev. (t)	677	70	1790	
		S.D. in % of biomass (%)	46	99	46	
I + II	6200	biomass (t)	1684	193	3928	5802
		standard dev. (t)	690	141	1807	
		S.D. in % of biomass (%)	41	73	46	
A	3500	biomass (t)	36	119	29	155
		standard dev. (t)	30	119	24	
		S.D. in % of biomass (%)	84	100	82	
B	2700	biomass (t)	1710	76	4187	5996
		standard dev. (t)	731	76	2590	
		S.D. in % of biomass (%)	43	100	62	
A + E	6200	biomass (t)	1746	195	4216	6151
		standard dev. (t)	733	140	2572	
		S.D. in % of biomass (%)	42	72	61	
none	6200	biomass (t)	2030	193	4914	7137
		standard dev. (t)	885	136	3063	
		S.D. in % of biomass (%)	44	70	62	

[a]Stratum I 20-50 m, Stratum II 51-100 m
Stratum A 9°-8°N, Stratum B 8°-6°40'N

Growth and Mortality Parameters

The estimated growth and mortality parameters are given in Table 7 for each method applied. The restructured data and fitted growth curves are given in Figs. 2 and 3.

The Wetherall plots are given in Figs. 4 and 5 while the Jones and van Zalinge plots are presented in Figs. 6 and 7.

Catch curves are given in Figs. 8 and 9. The L_c obtained is 18.0 cm for *D. congoensis* and 20.2 cm for *D. angolensis*. These lengths correspond to two-year old fish for both *D. angolensis* and *D. congoensis*.

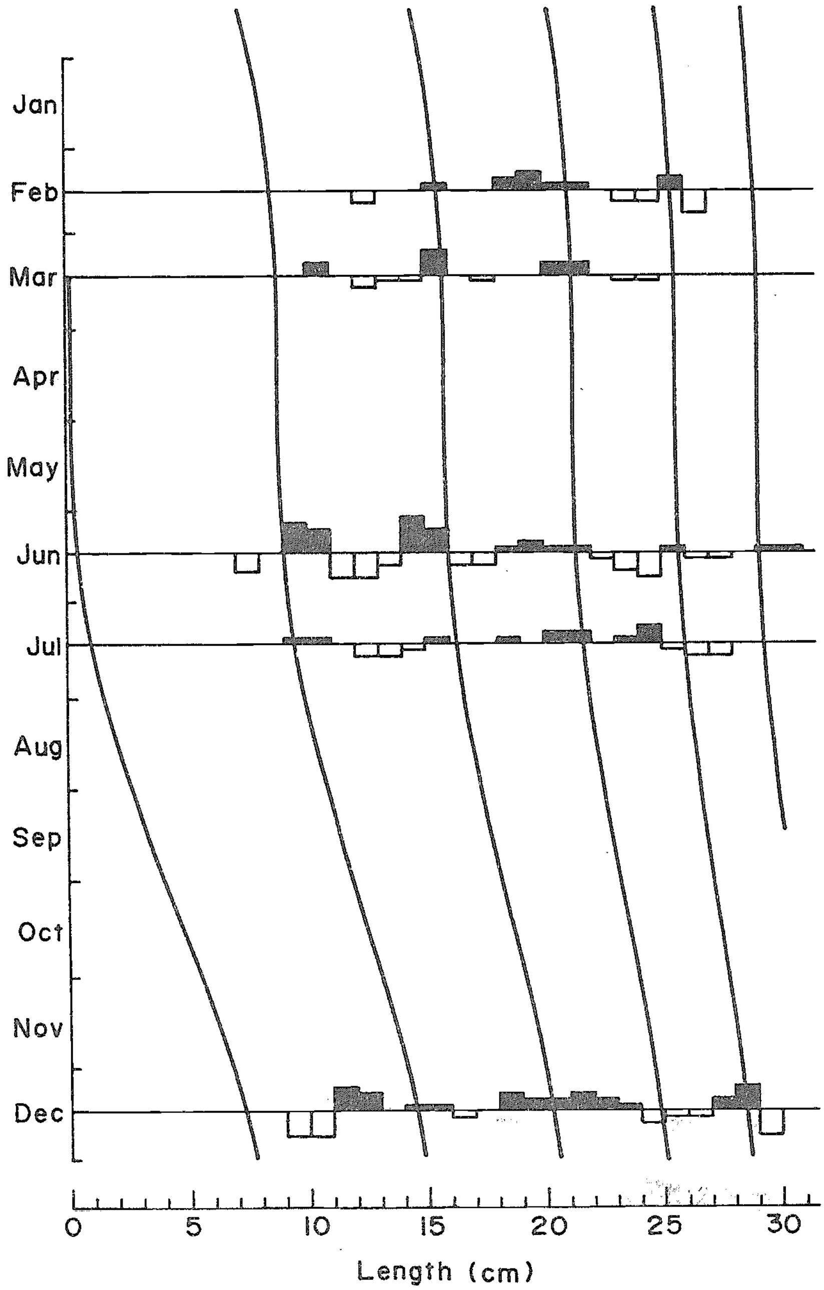
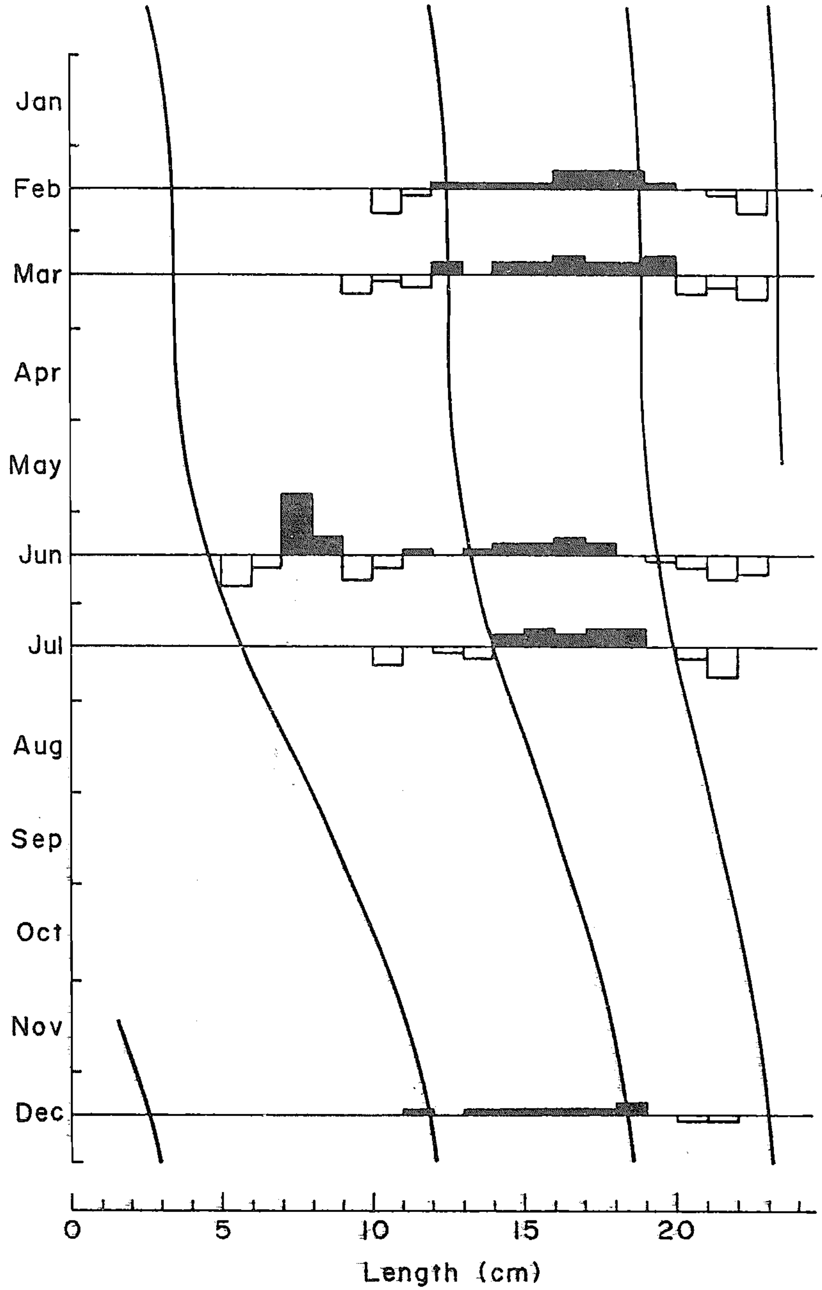


Fig. 2. Restructured length compositions and estimated growth curve for *Dentex angolensis* (1977-1986 from ELEFAN I, for parameters, see Table 7).

Table 7. Estimated growth and mortality parameters for the sparids *Dentex angolensis* and *D. congoensis* off Sierra Leone.[a]

Species	Method	Figure	L_∞ (cm)	K (per year)	Z/K	Z (per year)
D. angolensis	ELEFAN I & II	2 & 8	42.6[c]	0.23[c]	12.30	2.83
	Wetherall	4	33.8	-	6.35	-
	Jones-Zalinge[d]	6	(42.6)	(0.22)	12.20	2.68
	Beverton-Holt[e]	-	(42.6)	(0.23)	12.00	2.76
D. congoensis	ELEFAN I & II	3 & 9	34.0[c]	0.35[c]	16.70	5.84
	Wetherall	5	23.4	-	3.11	-
	Jones-Zalinge[d]	7	(34.0)	(0.41)	10.10	5.13
	Beverton-Holt[e]	-	(34.0)	(0.35)	11.80	4.13
	Ageing + Ford-Walford Plot	-	30.0[f]	0.16[f]	-	-

[a]all analyses, except Yasuda's, based on length-frequency data in Tables 2 & 4, respectively.
[b]parameters in brackets were not estimated using a given method; rather, they represent set values used to estimate remaining parameters on a given line.
[c]estimated along with C = 1 and WP = 0.3 *(D. angolensis)* and C = 1 and WP = 0.2 *(D. congoensis)*.
[d]using preliminary estimates of L_∞ and K.
[e]using cutoff length (L') of 21 and 18 cm, respectively.
[f]questionable values from Yasuda (1950, as cited in Pauly 1978).



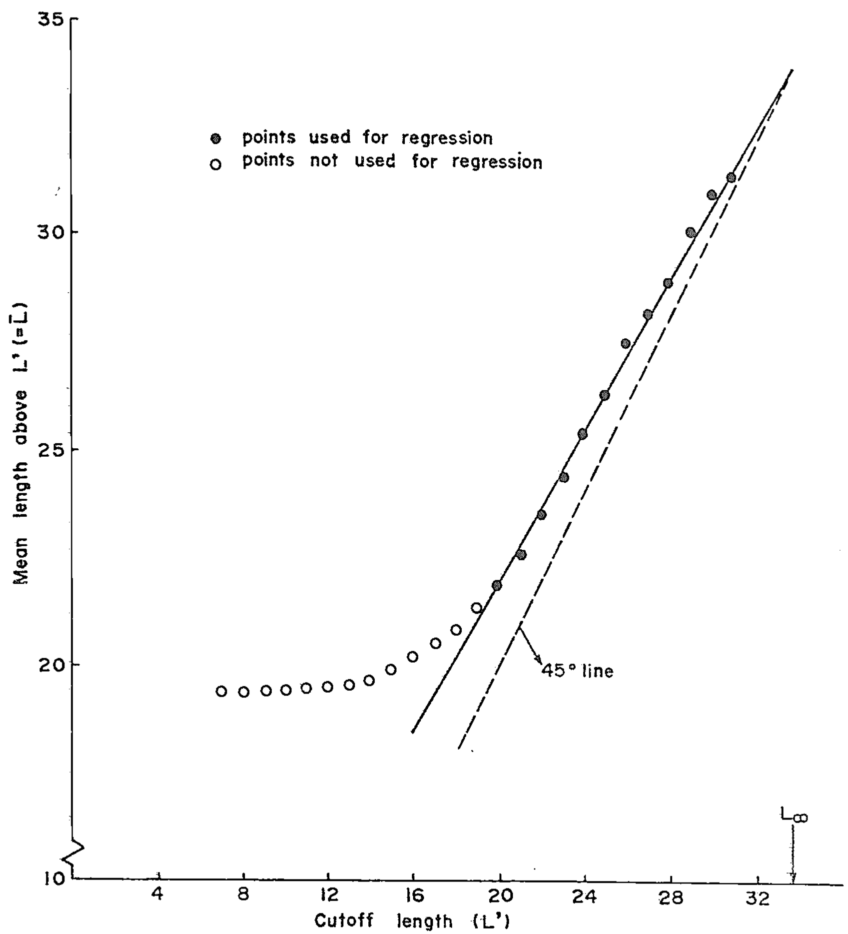


Fig. 4. Wetherall plot for *Dentex angolensis*.

Fig. 3. Restructured length compositions and estimated growth curve for *Dentex congoensis* (1977-1986 from ELEFAN I, for parameters, see Table 7).

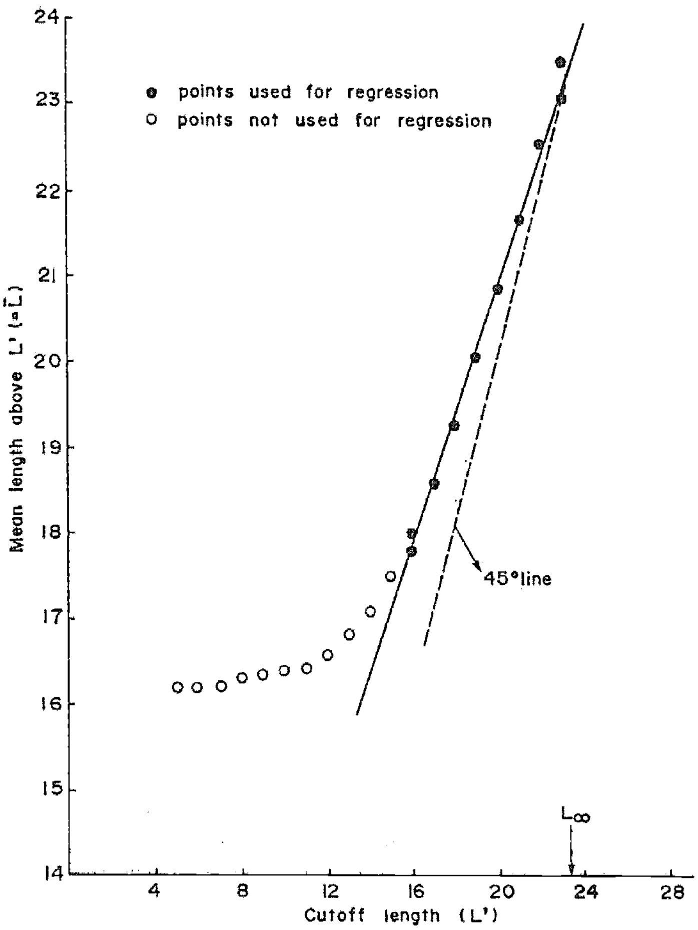


Fig. 5. Wetherall plot for *Dentex congoensis*.

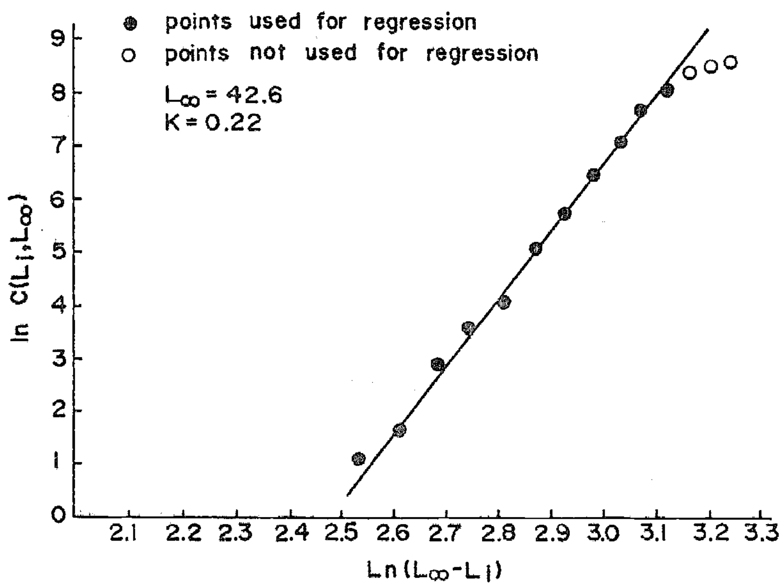


Fig. 6. Jones and van Zalinge (1981) plot for *Dentex angolensis*.

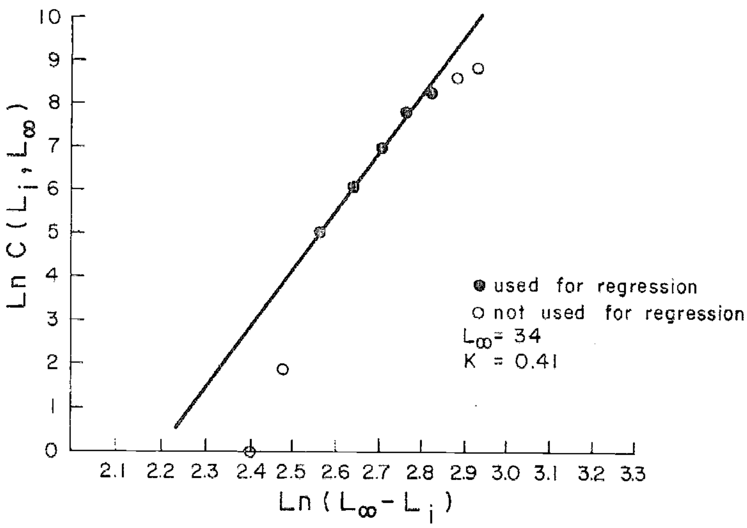
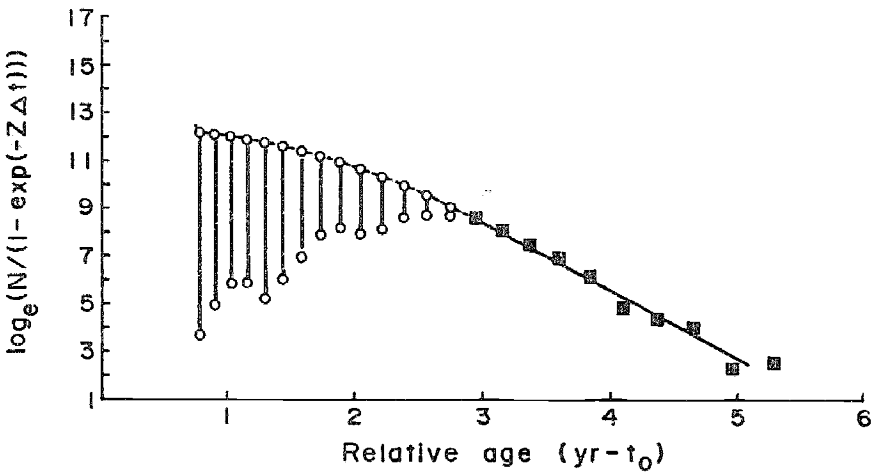


Fig. 7. Jones and van Zalinge (1981) plot for *Dentex congoensis*.



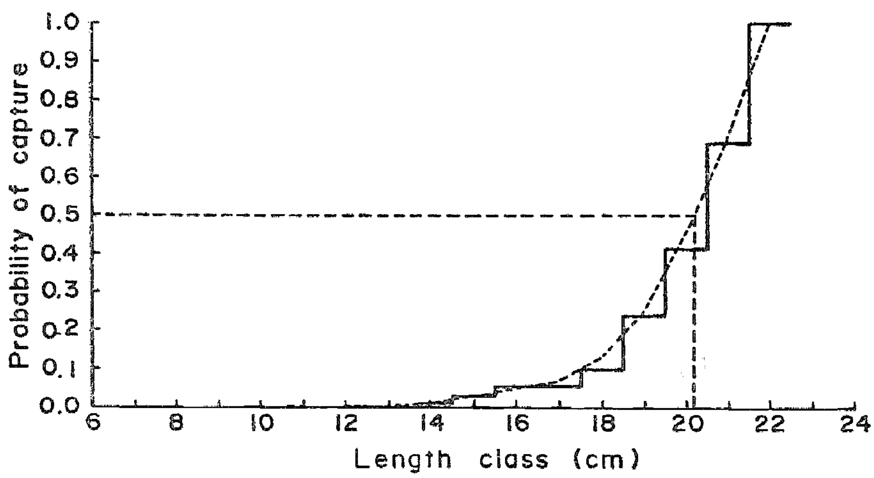


Fig. 8. Catch and resultant curves for *Dentex angolensis* 1977-1986. From ELEFAN II based on length composition data shown in Fig. 2 (see also Table 7).

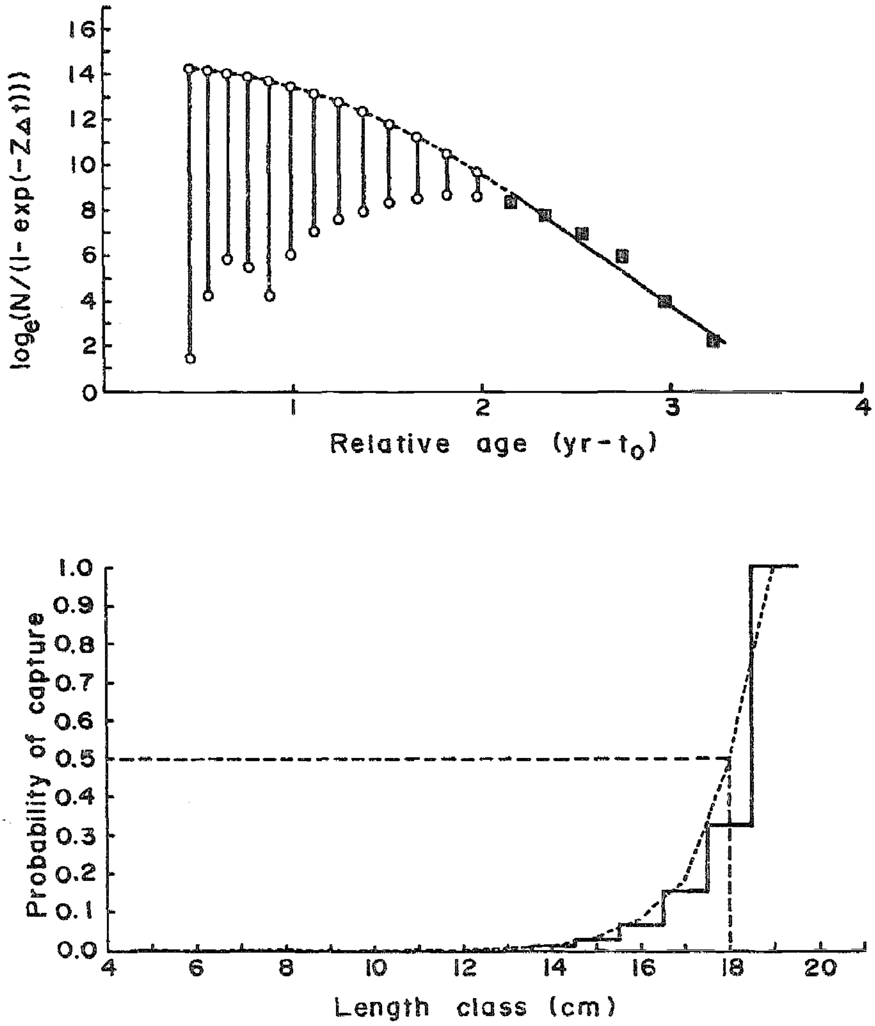


Fig. 9. Catch and resultant curves for *Dentex congoensis* 1977-1986. From ELEFAN II based on length composition data shown in Fig. 3 (see also Table 7).

Discussion

Biomass Estimates

The assumptions in the swept area method are several and most of them are difficult to test. It has been assumed that the bridles of the net had no herding effect. In practice however, the bridles effectively increase the swept area and neglecting this effect should result in an upward bias of the estimate. Another assumption is that the wing spread does not vary between hauls. The wing spread is dependent on hauling speed, warp length, weather conditions and current. The hauling speed and warp length were fixed and the weather conditions at the time were fairly stable. The start position of each haul was recorded but the end position was not. In the absence of this, D was obtained from the speed (v) and the duration of the haul (t). Current may have affected the distance covered.

The area surveyed was stratified into two depth zones. This stratification should give a better estimate of the biomass as data available indicate that the distribution of the *Dentex* species follows a depth pattern (CECAF 1985).

D. canariensis had very few occurrences (only 20 kg in the 20-50 m zone and 17 kg in the 51-100 m zone occurring in 2 out of 59 hauls in the March 1986 survey) (Table 1). *D. congoensis* did not occur in the 20-50 m zone at all in these cruises but was regularly found in all cruises in the 51-100 m zone. There was a marked absence of *D. angolensis* from the 20-50 m zone in five out of the seven cruises. Even in the two cruises in which it occurred in this zone, it was found quite close to the 51-100 m boundary (in 47-50 m). Further as these two occurrences were in February and March (Table 1), it is possible that the fish are present in the shallow waters only at a certain time of the year. The numerous zero catches may also have resulted from the type of bottom trawled as these species may be confined to a certain type of bottom. This would have to be investigated for a proper biomass estimate to be made.

The first stratification into two depth zones indeed gave a better biomass estimate for *D. angolensis,* as indicated by a lower standard deviation of 690 t compared with a standard deviation of 885 t without stratification. The better estimate is 1,684 t, or say 1,700 t.

For *D. canariensis* the biomass estimates were the same with and without stratification 193 t, with standard deviations of 138 t with stratification and 135 t without.

For *D. congoensis* the estimates were 3,928 and 4,914 t with and without stratification, respectively, while the standard deviations were 1,807 t with and 2,572 t without stratification.

The second stratification into a northern zone (Stratum A) and a southern zone (Stratum B) produced estimates which tallied closely with the depth stratification estimates (Table 6).

ATLANTNIRO (1979) has estimated the biomass of the three *Dentex* species based on five surveys in 1976-1979. These estimates are presented below together with those obtained in this study for 1986.

Year	*D. angolensis* Biomass	S.D	*D. canariensis* Biomass	S.D	*D. congoensis* Biomass	S.D
1976-79	2200	N/A	200	N/A	4900	N/A
1986 (stratified)	1700	700	190	140	3900	1800
1986 (not stratified)	2000	900	190	140	4900	3100

Taking the standard error on the 1986 estimates into account, the 1986 estimates do not differ from the 1976-1979 estimates for any of the three species.

The bulk of the *Dentex* species (97%) is found in the southern zone. This would suggest that further surveys could be confined to this region. However, the objective of this survey is to estimate a wide range of species occurring both in the southern and in the northern zones and the survey strategy cannot be based upon the *Dentex* species making up only 1.2% of the total catches.

There is a need for improvement of these estimates. A start could be to increase the quantity of statistical data collected by more frequent and regular surveys. Also as the migratory patterns, if any, are not clear, as much investigation as possible should be done into this and other biological aspects of the species which would help to give more precise biomass estimates.

Growth and Mortality Parameters

Although *D. angolensis* and *D. congoensis* have similar biological characters (CECAF 1985), their growth parameters have however been found to be different. Results from the ELEFAN I, Wetherall, Jones and van Zalinge methods, and their combination suggest a higher L_∞ value for *D. angolensis* (Table 7). The L_∞ and K values for this species could not be compared with other values due to the lack of references at the time this paper was written[a].

Growth parameters obtained for *D. congoensis* are not similar to those based on Yasuda (1950) (in Pauly 1978, see Table 7). The L_∞ value obtained from ELEFAN is only about 6%

[a]Editors' note: Since this was written, we have come across a mimeographed report containing information on the growth of *Dentex angolensis* and *D. canariensis* (see Boukatine et al. 1985). This, and other information on length-frequency distribution and stock sizes off Mauritania contained in said report should be used in future comparative studies.

greater than that of Yasuda (1950). The K value is however considerably higher. The high K estimated in this paper could be attributed to the high seasonal growth in Sierra Leonean waters (Longhurst 1963).

High mortality values were obtained, especially for *D. congoensis*. This may have resulted from the samples being taken from heavily fished areas. (Hence, most adult fish not being represented in the samples). The rate of exploitation for both species is greater than 0.7/year, suggesting overexploitation (Pauly 1984).

The high mortality observed could also be caused by migration of the adults. This proposition is without any firm foundation as the stock structure in these water is unknown.

Future work would consider using other models to estimate growth parameters of *D. angolensis* and *D. congoensis*. With the availability of more detailed biological data and knowledge of migratory patterns a better estimation of the growth and mortality parameters could be achieved.

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Estimation of Biomass and Biological Parameters of *Pentaprion longimanus* (Gerreidae) off the North Coast of Java, Indonesia

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Abstract

Biomass of *Pentaprion longimanus* in the inshore area (0-50 m) of southern Java Sea was estimated on an annual basis before the trawl ban. The data used were the trawl surveys carried out by the Indonesian-German Demersal Fisheries Project in 1977-1979.

The biomass estimation was based on the swept area method post stratifying in depth zones. Estimated biomass in 1979 was less than half the biomass in 1977.

Preliminary estimates of growth mortality parameters were obtained by the ELEFAN method and catch curve analyses using pooled length-frequency data from the 1977-1979 surveys.

The survey was carried out with a 4 cm mesh size severely affecting all length frequencies of this small species. A mesh size of 16 mm or less would be needed to produce reliable estimates of biomass, growth and mortality.

Introduction

The Java Sea has been considered to be one of the most productive areas for demersal fishes. The trawling industries developed rapidly to an effort level reaching 600-1,000 units of trawlers (Losse and Dwiponggo 1977). The increasing fishing intensity by trawlers caused socioeconomic tension in this area as well as concern for overfishing. In order to solve these problems a total ban on trawling was introduced in 1980 (Sardjono 1980).

It is of great importance that the effect of a total ban on trawling is evaluated, primarily of course, to provide biological advice concerning future management strategies for this area. In addition to this objective, an analysis of the effects of the trawling ban will give important scientific knowledge concerning possible management measures also in other areas.

As part of this more general study, this paper deals with an assessment of one species, *Pentaprion longimanus*, in the period 1977-1979 in order to provide a first basis for a comparison with future assessment of the stock after the trawling ban in 1980.

P. longimanus is one of the most common species found in the coastal area especially in the shallow waters down to depths of 30 m (Fischer and Whitehead 1974).

Sadhotomo et al. (1983) estimated growth parameters of *P. longimanus* in the Java Sea and its general population dynamics are given by Beck and Sudradjat (1978) and Dwiponggo et al. (1987).

The present paper estimates biomass for the period 1977-1979 and provides estimates of growth and mortality parameters of *P. longimanus*. Length-frequency data are used for calculation of growth and mortality parameters, whereas catch per unit effort data are utilized to estimate the biomass. The data are collected from research vessel surveys in 1977-1979.

Materials and Methods

Fishing Gear and Basic Data

Length-frequency data and catch per unit effort data were collected by the *R/V Mutiara IV* in the north coast of Java from 1977 to 1979. The standard survey fishing gear and rig was "Thailand trawl" with a headrope length of 34.6 m, a ground rope length of 42.2 m and a cod-end of 40 mm stretched mesh. The standard vessel speed through the water was 3.0 knots and the vertical net opening was estimated at 2.0 m at 3.0 knots vessel speed (Losse and Dwiponggo 1977).

The fishes were generally identified from the FAO Species Identification Sheets (FAO 1974). Length-frequency measurements were made measuring total length (L, upper lobe) to the half centimeter below.

The basic data from the survey, i.e., length-frequency samples and total catch are given in Table 1. All data are taken from Dwiponggo and Badrudin (1978, 1979, 1980).

Raising Factor

In order to obtain data representative of the population in the sea, the raw data were raised to the total catch of one hour trawling. First, the weight of each length class was obtained by using the length-weight relationship (Dwiponggo and Badrudin 1978, 1979, 1980).

$$W = 0.012\, L^3$$

Next the frequencies were raised by the factors (Table 1).

$$RF_j = \frac{W_j}{w_j}$$

where W_j is the total catch of *P. longimanus* in haul j and w_j the calculated sample weight.

Biomass Estimation

The biomass of *P. longimanus* off the north coast of Java was estimated by using the swept area method (Sparre 1985). The survey area was stratified according to area and depth zones. Details of the biomass estimation are given by Budihardjo (this vol.). Fig. 1 shows the stations.

Estimation of Growth and Mortality

Length-frequency samples of *P. longimanus* were available for 15 months in the period 1977-1979. In the majority of the month a length-frequency sample was obtained for each of the three areas and each of the three depth zones. Within each year and month the length frequencies of the total trawl catches were pooled for all areas. Although the biomass appeared unevenly distributed over the depth zones, it was also decided to pool depth zones for this preliminary analysis. Furthermore, since several months in the three-year period were not sampled, it was decided to pool the three years' data on a monthly basis.

Table 1. Length frequency of *Pentaprion longimanus* based on one hour trawl survey by *R/V Mutiara II* in north coast of Java, 1977-1979.

Mid-length (cm)	Apr 1977			Jul 1977	Aug 1977				Sep 1977					Dec 1977																						
	23	23	23	26	27	27	27	27	8	9	9	11	11	2	3	3	3	3	4	4	16	17	17	17	18	18	19	19	19	19	20	20	20	21	21	21
3.75																					1															
4.25																	1	2			8		1													
4.75															1	4	8	7	2		7	1	1							1						1
5.25		1							3						0	22	14	7	8		2	1	1							4						1
5.75									13						2	14	9	6	8	2	2	1	4			1		1		4		1	1			5
6.25		3						1	20						5	12	8	6	24	8	5	2	8		4	8		2	4	6	1	1	2		2	22
6.75		8			1	1		2	3				1		10	12	10	11	11	8	8	4	5	2	3	7	1		6	12	2	1	8		1	19
7.25		35		2	2	8		3	1		1		1		10	22	23	26	9	10	9	1	1		1	5	3	1	1	1	7	3	5			9
7.75	1	39	1	7	9	20	4	4		1	1				37	27	30	36	25	16	15	4	5	1	6	10	2	1	14	3	3	5	2		1	7
8.25		31	1	14	21	17	4	5		3	6		4		12	14	20	21	25	13	9	2	11		4	18	2	5	17	13	5	2			1	17
8.75	3	10	1	21	35	13	3	3	1	6	5	3	2		5	3	3	12	2	3	3	5	7	1	3	13		1	5	24	16	7	3	1		16
9.25	1	3	1	25	27	13	10	5	1	14	16	5	3	2	1	1		1	3	5	2	3	2	1	8		7	13	6	7	29	7	3	1	2	3
9.75	20	2	11	3	4	4	16	13	1	36	26	13	3	3						9	3	2	4	4	25		24	37	24	1	26	14	25	17	13	4
10.25	49	14	61				20	22	3	20	34	35	25	8				1	1	22	4	11	5	10	39		29	41	24	5	1	15	17	18	24	4
10.75	54	18	48				10	22	2	9	21	23	16	26						15	2	12	2	20	12		26	31	5		2	46	12	21	27	
11.25	22	19	25			1	7	7		1	6	26	9	40						10	1	3	1	7	10		6	6			1	22	18	9	18	
11.75	7	9	9					1		2		9	9	17						7		1	1	4	2		3	3		3		5	7	5	13	
12.25	4	3	1								1	3	5	3						5		1			1		1	1				6	1	1	9	
12.75	1	1											1							2															1	
13.25																				2																
Sample nj	162	196	159	72	99	77	74	88	48	92	117	117	79	99	83	131	126	136	118	137	81	54	59	50	86	62	104	143	106	84	93	135	164	73	112	108
Sample wj (kg)	2.33	1.80	2.28	0.58	0.79	0.56	0.87	1.05	0.21	1.06	1.41	1.70	1.14	1.63	0.44	0.54	0.55	0.68	0.55	1.48	0.43	0.57	0.41	0.70	1.36	0.36	1.32	1.77	0.98	0.58	0.85	1.83	1.27	6.03	1.68	0.60
Catch Wj (kg)	6.1	2.0	7.4	9.8	14.5	21.0	4.8	31.5	0.3	4.9	34.9	30.0	10.5	17.4	2.4	3.0	4.2	2.1	2.4	8.6	1.5	12.5	7.9	20.6	67.5	10.2	7.60	81.0	10.8	2.6	22.8	42.0	21.5	50.8	49.5	5.8
Raising Wj/wj	2.62	1.11	3.24	16.8	18.4	37.7	5.49	30.1	1.45	4.64	24.8	41.2	9.21	10.7	5.44	5.61	7.65	3.11	4.34	5.80	3.49	21.9	19.1	29.4	49.8	28.6	97.5	34.4	11.0	4.47	26.9	23.0	17.0	49.5	29.4	9.70
Depth zone	II	III	III	I	II	II	II	II	II	II	III	II	II	III	I	II	II	II	I	II	II	II	II	III	III	II	III	I	I	II	I	II	II	II	II	I
Area	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	B	B	B	B	B	B	A	A	A	A	A	A	A	A	A	A

Table 1. Continued

Midlength (cm)	Jan 1978					May 1978																										
	10	10	13	14	14	19	19	19	19	19	20	20	20	20	20	21	21	22	23	23	23	23	24	24	24	24	25	25	21	21	22	22
3.75												1	1		1													1				
4.25												2	2		3											1						
4.75												2	8		4					1		2					1	2	1	1		
5.25	1						1	4	5			3	8		7		1		2		1								1			
5.75	6	1						2	3	1	1	7	3	3	1	5	3		2	3	1	3					5	7	2	1	5	
6.25	20					2	1	5	6	3	1	8	4	4	8	9	10	2	8	7	9	13	1	2	3	1	7	10	5	4	6	3
6.75	23		6			6	18	9	12	7	7	36	5	6	13	35	33	9	21	21	29	34	9	5	6	10	14	36	22	18	35	15
7.25	19	1	6		1	31	28	28	26	19	12	28	27	25	31	45	40	20	27	21	38	41	12	14	12	18	17	32	29	26	24	17
7.75	17	5	12		5	37	48	22	42	69	4	24	30	41	31	18	13	7	16	14	13	12	7	10	7	13	11	22	17	11	20	2
8.25	9	2	8		10	16	19	6	16	46	1	6	15	10	12	2	5	2	5	13	6	6	4	2	3	1	4	10	5	7	5	3
8.75	22	3	4		18	7	5	2	2	19	3	2	4	3	1	4	2	3	7	1	4	1		2		1	3	5	4	3	3	2
9.25	27	2	9		11					3	2	2			1	1	1	1	3	3						1	1	2	1	2		1
9.75	12	10	10	6	5						8							1		1	1		1	3	1	5	1		10	7		1
10.25	29	24	31	16	10						3						2		2	4	2	1		2	5	17			8	2		
10.75	46	36	33	10	29						2						1	1	1		3	2	1	3	2	17			6			
11.25	51	19	106	11	21						4						1			1				3	5	9			1	3	1	
11.75	17	7	7	16	19						4								2				1	2	2	5			1	1		
12.25				1	4																			1	2	3			1			
12.75																								1								
13.25																																
Sample nj	299	110	232	60	133	99	120	78	112	167	52	121	107	98	113	119	112	48	96	90	107	115	36	50	48	102	64	127	114	86	99	44
Sample wj (kg)	3.23	1.51	3.24	0.95	1.78	0.54	0.64	0.37	0.56	1.01	0.64	0.52	0.49	0.52	0.51	0.53	0.53	0.27	0.52	0.49	0.54	0.52	0.20	0.42	0.42	0.07	0.30	0.58	0.77	0.53	0.46	0.21
Catch Wj (kg)	8.5	6.0	20.6	13.7	19.5	6.12	6.0	3.5	14.4	5.7	23.76	6.66	4.0	12.8	18.36	9.8	7.8	1.5	2.98	6.3	5.15	1.04	0.35	1.2	0.9	1.09	0.6	1.2	4.2	1.8	0.4	0.21
Raising Wj/wj	2.63	3.97	6.36	14.5	10.9	11.3	9.43	9.53	25.9	5.69	51.4	12.8	18.4	24.8	36.1	18.5	14.6	5.60	5.73	13.0	9.56	2.10	1.73	2.89	2.15	1.02	2.03	2.08	5.46	3.41	0.88	0.95
Depth zone	III	II	II	III	II	I	I	I	I	I	II	I	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II
Area	B	B	A	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B

Table 1. Continued

Midlength	May 1978				Jun 1978		Oct 1978				Nov 1978							
(cm)	22	23	25	25	25	25	31	31	31	31	1	2	3	3	3	4	4	4
3.75																		
4.25	6					1												
4.75	23				1	2												
5.25		1	1	3		1								1	1			
5.75	8	4	3	4	1	9												
6.25	6	30	16	15	23	20						1		1				
6.75	8	65	34	33	61	23							1					
7.25	32	39	32	45	89	49		2				1	1	1				
7.75	9	15	13	20	42	41		8	8	1			1	1			1	
8.25	6	7	3	9	10	10	1	6	9	3		6	10	8	3	3	3	
8.75		2	3	3	3	6	1	8	14		2	7	24	29	8		1	1
9.25		1	1	1	1	1	2	13	17		10	5	16	17		4	13	8
9.75	1		1	4			20	20	32	9	15		14	21		6	20	28
10.25			3	1			17	18	25	20	36		6	14			16	26
10.75				4			18	8	12	34	24		10	9		5	9	10
11.25							8	4	4	29	7		6	8		2	6	10
11.75				2			2	5	5	8	4		1					4
12.25			1	1			2			1								
12.75									1									
13.25																		
Sample nj	99	164	111	145	231	163	71	92	127	105	98	20	90	110	12	20	69	87
Sample wj (kg)	0.35	0.67	0.53	0.77	1.04	0.75	0.97	1.02	1.43	1.57	1.30	0.15	0.93	1.15	0.09	0.23	0.82	1.13
Catch Wj (kg)	1.6	3.0	7.1	11.0	0.70	3.1	1.8	1.9	3.1	4.2	1.3	0.3	1.0	1.3	4.0	0.3	1.8	2.6
Raising Wj/wj	4.58	4.45	13.5	14.3	0.17	4.14	1.87	1.86	2.17	2.68	1.00	1.98	1.07	1.13	46.3	1.28	2.19	2.3
Depth zone	II	II	II	II	II	II	II	II	II	II	III	I	II	II	II	II	II	II
Area	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B

Table 1. Continued

Mid-length (cm)	Jan 1979 12	13	13	13	13	14	15	15	16	16	18	18
3.75												
4.25												
4.75												
5.25												
5.75						1	1		1	1		
6.25		1					4		1			3
6.75			1			4	4		0		3	3
7.25		3				2	7	1	3	5	2	4
7.75		5			1	8	12	3	1	2	4	2
8.25	2	4			1	2	28	3	1	4	6	7
8.75	1	3				4	16	1	4	11	1	5
9.25		3	2	3	1	1	6	2	5	8	8	7
9.75		18	7	2	5		1	2	6	1	19	9
10.25	6	39	49	41	15		1	12	13		19	5
10.75	5	39	48	42	20		2	13	11		19	7
11.25	9	14	22	22	18		1	3	3		10	1
11.75	2	2	5	3	3			4			4	
12.25				1	2		1	2				
12.75												
13.25												
13.75												
Sample nj	25	131	134	114	66	22	84	46	49	32	96	53
Sample wj (kg)	0.32	1.69	1.92	1.66	0.98	0.13	0.60	0.61	0.56	0.24	1.18	0.49
Catch Wj (kg)	0.4	6.8	9.8	15.2	7.8	0.7	6.8	0.9	1.41	0.9	0.9	0.4
Raising Wj/wj	1.26	4.03	5.09	9.13	7.96	5.55	1.34	1.47	2.49	3.77	0.76	0.82
Depth zone	II	II	II	III	III	II	II	II	II	II	II	II
Area	B	B	B	B	A	A	A	A	A	A	A	A

Mid-length (cm)	Feb 1979 19	19	19	22	23	24	Apr 1979 26	27	27	27	27	28
3.75			2									
4.25			26									
4.75			44			2		1				
5.25			24						1			
5.75			2			1		3	2			
6.25						1	3	8			2	2
6.75						6	11	19	7		11	11
7.25				3		12	25	48	13	3	14	14
7.75				5	1	19	23	34	9	2	6	6
8.25				13	2	17	4	12	3		2	2
8.75				6	1	2		1	3		1	1
9.25	8			15	2							
9.75	18	4		18	2				1	11	2	2
10.25	47	10	2	8	2				4	17	5	5
10.75	32	4		3					8	35	3	3
11.25	12	78			4				6	18		
11.75	4	2			5					4		
12.25		1		1	3							
12.75					6							
13.25					6							
13.75					3							
Sample nj	121	99	100	72	88	60	66	126	57	90	46	46
Sample wj (kg)	1.64	1.63	0.12	0.69	0.77	0.32	0.32	0.60	0.47	1.28	0.30	0.30
Catch Wj (kg)	28.4	5.4	0.3	3.0	1.8	1.0	1.7	0.8	2.1	1.3	4.1	0.3
Raising Wj/wj	17.3	3.32	2.54	4.34	2.33	3.11	5.32	1.33	4.46	8.86	13.8	1.01
Depth zone	III	II	II	III	II	II	I	II	II	III	III	III
Area	B	B	B	C	C	C	B	B	B	B	B	B

Mid-length (cm)	May 1979 18	18	21	21	22	23	23	Sep 1979 05	07	Oct 1979 13	14	14
3.75												
4.25												
4.75												
5.25				1		1						
5.75				3		1					1	
6.25	1		2	7		8					2	1
6.75	2		2	15	1	19	1				3	
7.25	2	1	6	16	3	21	7				1	7
7.75			19	13	6	39	12	1			8	5
8.25	1	2	22	27	7	30	13	6			1	1
8.75	4	2	19	34	24	6	9	4	14			
9.25	15	7	4	17	25	2	2	8	24	5		3
9.75	13	11		2	14			7	17	8		17
10.25	2	2	1					10	10	11		32
10.75	3							24	8	21		20
11.25	1							22	5	11		3
11.75	3							13	1			
12.25								2				
12.75	1											
13.25												
13.75												
Sample nj	118	25	75	135	80	127	44	97	79	56	16	89
Sample wj (kg)	0.52	0.25	0.50	0.87	0.69	0.68	0.28	1.39	0.88	0.78	0.10	1.05
Catch Wj (kg)	0.4	0.4	7.0	2.7	3.0	1.5	1.0	18.8	5.5	4.1	0.3	6.3
Raising Wj/wj	0.77	1.01	14.0	3.1	4.38	2.20	3.55	13.5	6.23	5.26	3.98	8.0
Depth zone	II	II	II	I	I	II	I	III	III	III	I	II
Area	B	B	B	B	B	B	B	C	C	B	B	B

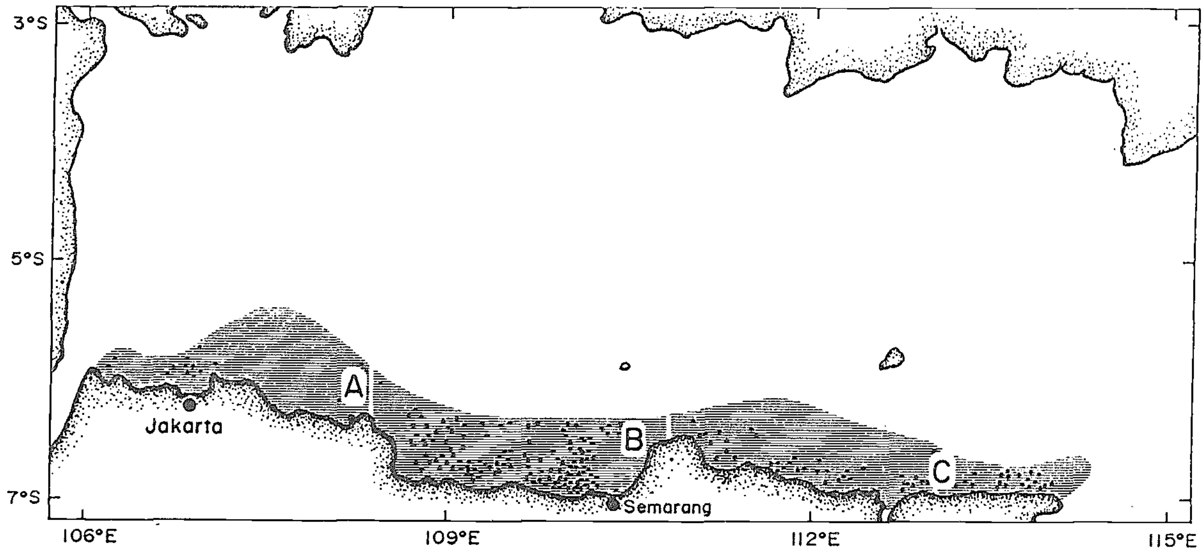

Fig. 1. Fishing (trawl) stations of R/V MUTIARA IV, north coast of Java, 1977-1979.

The final data set which was used to estimate growth and mortality is shown in Table 2. The growth parameters L_∞ and K were estimated using the ELEFAN I program. Natural mortality, M, was obtained from Pauly (1980):

$$\text{Log}_{10}M = -0.0066 - 0.0279 \log_{10}L_\infty + 0.65431 \log_{10}K + 0.4634 \log_{10}T \qquad (2)$$

where T was set equal to the average annual temperature of the Java Sea.

Using the above estimate of L_∞ and K, a length-converted catch curve was constructed applying the pooled data set over all months. From the analysis of the length-converted catch curve an estimate of Z was obtained. Together with the assumed value of M this estimate of Z was used to obtain fishing mortality F and exploitation rate E = F/Z.

Table 2. Monthly length frequencies of *P. longimanus* pooling over areas, depth zones and years.

Midlength (cm)	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.25		5									
3.75		66		30							3
4.25		112		89	4						61
4.75		67	1	186	9						198
5.25	1	5	3	310	4			2		46	354
5.75	16	3	6	356	38			9		0	493
6.25	34	3	30	1,167	98		30	15		3	1,457
6.75	68	19	144	3,804	136		116	7		1	1,543
7.25	84	50	266	7,106	262	34	429	18	4	4	1,438
7.75	153	83	188	7,351	198	118	1,062	21	35	4	2.375
8.25	150	114	64	3,129	48	235	1,200	140	41	175	2,444
8.75	203	35	30	1,280	27	353	1,241	183	47	435	1,926
9.25	193	208	8	283	5	421	1,193	436	65	108	2,644
9.75	248	407	151	350		50	703	664	168	170	6,374
10.25	844	889	514	291			771	1,033	173	153	7,484
10.75	981	579	529	186			716	823	166	94	6,595
11.25	905	476	265	123			287	553	109	61	3,201
11.75	325	87	80	109			30	217	45	14	1.389
12.25	44	15	12	22				76	6		645
12.75		14	2	2				5	2		41
13.25		14									12
13.75		7									
14.25		2									
Sum	4,250	3,260	2,293	26,174	830	1,211	7,778	4,202	861	1,269	40,675

Results

Biomass Estimation

Table 3 gives the result of the swept area method applied to annual data and post stratifying in three depth zones. The total estimated biomass of *P. longimanus* decreased from 4,092 t in 1977 to 3,140 t and 1,797 in 1978 and 1979, respectively. The coefficient of variation of these biomass estimates if about 30%.

It appears from Table 3 that the biomass increases according to depth. On an average for the three years, 7% of the biomass is found in the zone of 0-20 m depth, 23% in the depth zone from 21 to 40 m while 70% of the total biomass in the area is found in the zone of depths of more than 40 m.

Table 3. Mean catch per trawl haul of *P. longimanus*, $\overline{\text{CPUEW}}$, its standard error (SE) and derived estimates of biomass (B), standard deviation (SD) and coefficient of variation by depth zone at north coast of Java, 1977-1979.

Year	Depth zone (m)	Area A (km²)	No of hauls no	nl	n[1]	$\overline{\text{CPUEW}}$ (kg/hr)	SE (kg/hr)	B (tonnes)	SD (tonnes)	SD/B x 100 (%)
1977	0-20	9,520	51	4	55	0.371	0.212	73	42	57
	21-40	13,940	40	23	63	5.922	1.654	1,173	328	28
	⩾ 41	23,460	11	9	20	14.365	5.156	2,846	1,021	36
	total	46,920	102	36	138			4,092	1,073	26
1978	0-20	9,520	11	7	18	2.712	1.080	537	214	40
	21-40	13,940	11	39	50	3.794	0.804	1,100	233	21
	⩾ 41	23,460	5	4	9	3.078	1.642	1,503	802	53
	total	46,920	27	50	77			3,140	862	27
1979	0-20	9,520	72	5	77	0.113	0.057	22	11	51
	21-40	13,940	98	22	120	0.419	0.134	122	39	32
	⩾ 41	23,460	20	9	29	3.386	1.275	1,653	622	38
	total	46,920	190	36	226			1,797	623	35

[1]Total number of hauls include no, the number of hauls with zero catch of *P. longimanus*.

Growth and Mortality

Using the input data from Table 2 we applied the ELEFAN I program to estimate the parameters of a von Bertalanffy growth curve. The restructured data and the best fitted growth curve are shown in Fig. 2. The corresponding estimates of the growth parameters are $L_\infty = 15.75$ cm and $K = 0.945$ year^{-1}.

The plot of the length-converted catch curve is shown in Fig. 3 together with the fitted regression line. The regression line was fitted to all the points in the length interval from 10.5 to 14.5 cm. Inserting the growth parameters and an environmental temperature of 28°C in Pauly's (1980) empirical formula (2) gives $M = 2.0$ year^{-1}.

The estimate of total mortality is $Z = 8.3$ year^{-1} giving a fishing mortality of $F = 6.2$ year^{-1} and an exploitation ratio of $E = 0.76$.

The smooth curve of selection obtained by the ELEFAN I program applying logistic transformation (output not shown here) resulted in a steepness parameter of $r(m) = 1.516$ and a 50% retention length of $L_{50} = 10.10$ cm, i.e., a smooth curve of the following form

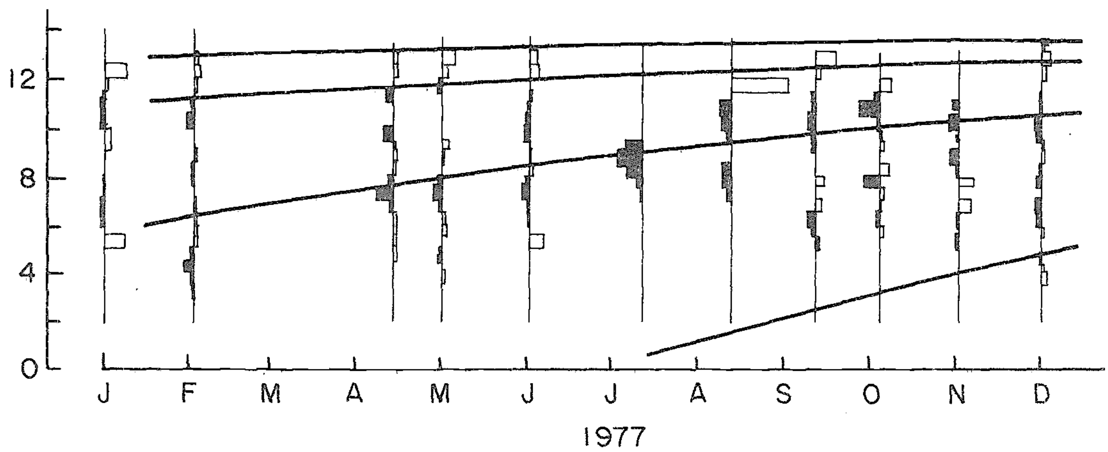

Fig. 2. Restructured length frequency data of *P. longimanus*, north coast of Java, 1977-1979.

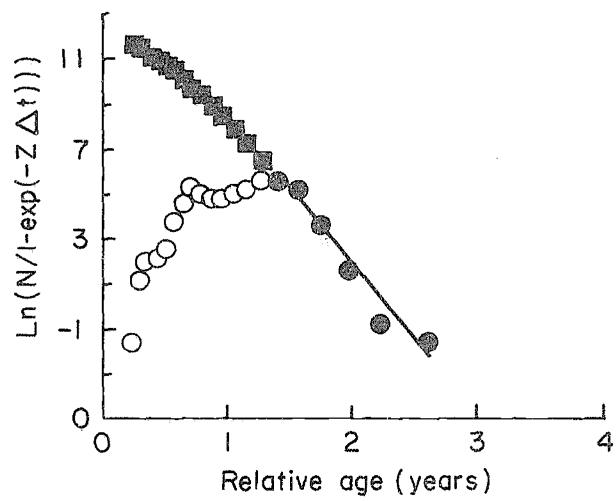

Fig. 3. Catch curve analysis of *P. longimanus*, north coast of Java, 1977-1979.

$$P(L) = 1/(1 + \exp(-1.516\,(L - 10.10))) \quad (3)$$

where P(L) is interpreted as the fraction of fish in length group L that is retained by the trawl of mesh size, m = 4 cm.

It was attempted to use this selection curve to correct the length-frequency data for mesh selection. The corrections are rather severe (connected with low probabilities, P(L)'s) for a large number of length groups and growth curves cannot be identified from the corrected data set.

The above estimates of $L_\infty = 15.75$ cm and $K = 0.945$ year^{-1} are therefore considered the final estimates from this analysis.

The recruitment pattern obtained by the ELEFAN I program is shown in Fig. 4. One annual recruitment pulse is identified.

Discussion

This paper deals with an assessment of *P. longimanus* representing the category of small fish species. Such a single-species assessment of a "trash fish" component may be considered equally important as individual assessments of the more important food fish in providing the basis for developing management strategies of the total multispecies system. These problems are of particular interest for the Indonesian waters due to the total ban on trawling that was introduced in 1980.

In the Java Sea, the comprehensive Indonesian-German trawl surveys (review in Simpson 1982) should provide an excellent basis for assessing the demersal resources prior to trawl banning. However, these surveys were unfortunately carried out with a 4 cm mesh size in the cod-end or more than double the mesh size that was used in the commercial fisheries in the late 1970s.

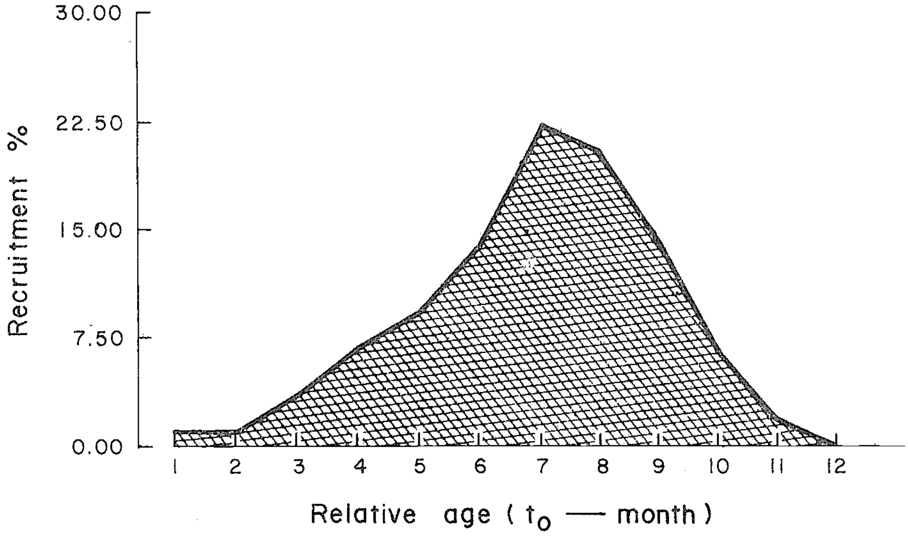

Fig. 4. Recruitment pattern of *P. longimanus*, north coast of Java, 1977-1979.

A 4 cm mesh size produces a high 50% retention length. The estimate of L_{50} from the catch curve analysis is 10.1 cm. However, the resultant curve expressed by Eq. (3) may express incomplete recruitment as well as selection. It is therefore worthwhile to obtain another estimate of L_{50} from an independent source. From measurements obtained from the FAO Species Identification Sheets a standard length/body-depth ratio of 2.2 is found for *P. longimanus*. According to the empirical relation between the selection factor (S.F.) and standard length/maximum body-depth in Pauly (1984, Fig. 3.2) we then obtain S.F. = 2.4 or

L_{50} = S.F. x mesh size = 2.4 x 4 = 9.6 cm

The good agreement between the two estimates supports the catch curve analysis, also with respect to the estimate of mortality.

The calculated selection ogives show that the major part of all length frequencies are subjected to severe selection. The biomass values obtained in this study must therefore be grossly underestimated.

The estimates of the growth parameters obtained in this study seem to be in reasonable agreement with the results given by Sadhotomo et al. (1983) (Table 4). Usually, L_∞ is not affected by selection because it is mainly the length groups of the smaller fish that are underrepresented. However, in the present case where almost the whole range of the length frequencies is underrepresented it is reasonable to assume that not only K but also L_∞ is underestimated.

These problems reflect the fact that the 4 cm mesh size is not a proper mesh size for biomass estimation of *Pentaprion longimanus* and other "small" species. A mesh size around 16 mm would be appropriate for doing research vessel surveys for this species.

Table 4. Estimates of growth and mortality parameters of *P. longimanus* from various sources.

	L_∞ (cm)	K (year^{-1})	ϕ'^{a}	F (year^{-1})	M (year^{-1})	
Philippines						
Carigara Bay	14.50	0.69	2.16	2.79	1.67	Corpuz et al. (1985)
Samar Sea	17.00	1.22	2.55	7.64	2.32	Corpuz et al. (1985)
Burias Pass	15.75	1.00	2.39	6.56	2.07	Corpuz et al. (1985)
Samar Sea	17.25	1.03	2.47	8.00	2.08	Corpuz et al. (1985)
Indonesia, Java Sea[b]						
Area B + C	13.70	1.12	2.32	–	–	Sadhotomo et al. (1983)
B + C	13.50	1.10	2.30	–	–	Sadhotomo et al. (1983)
B + C	14.20	1.80	2.56	–	–	Sadhotomo et al. (1983)
B	13.35	1.77	2.50	–	–	Sadhotomo et al. (1983)
B + C	15.75	0.80	2.30	–	–	Sadhotomo et al. (1983)
Java Sea						
A + B + C	15.75	0.95	2.37	6.20	2.03	Present study

[a] $\phi' = \log_{10} K + 2 \log_{10} L_\infty$ (Pauly and Munro 1984).
[b] See Fig. 1 for locations of areas A, B and C.

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Seasonal Growth, Mortality and Recruitment Pattern of *Sardinella maderensis* off Senegal

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Abstract

This study deals with the biology of *Sardinella maderensis* a pelagic whose adults migrate over long distances. It is caught in Senegalese waters by artisanal gears and by commercial purse seiners. The material used here consists of length-frequency data for the years 1980 to 1982 collected at M'Bour and Joal, Senegal, and raised to the catch of the artisanal fishery. The growth parameter values that were estimated imply that the growth in length of *Sardinella maderensis* slows down substantially during the cold season. A high apparent total mortality ($Z = 3.9\ y^{-1}$) was estimated, probably due to the fact that adults migrate out of the sampling area and hence are underrepresented in the samples. The recruitment pattern suggests that annual recruitment to the stock occurs in the form of two cohorts of unequal strength.

Introduction

In tropical areas, the interpretation of growth marks in hard tissues is often problematic. For this reason, the analysis of length-frequency data represents the most useful method to estimate growth parameters and mortality rates in tropical fish. It can be considered as complementary to those obtained by age-based methods, or used as a first approximation.

From the available programs, we chose ELEFAN I and II which allow for the estimation of growth, mortality and recruitment patterns for incorporation in various models used to evaluate the dynamics of a stock.

The present paper is based on length-frequency data of *Sardinella maderensis* caught by the artisanal fisheries off M'Bour and Joal (south of Dakar, Senegal, see Fig. 1). Growth parameters were estimated taking seasonal fluctuation into consideration. Mortality rates and recruitment patterns, both previously unstudied, were also estimated for this stock.

Biology of Sardinella maderensis

Previous studies (Boely et al. 1979) have shown that there are two main nurseries for this species off northwest Africa, namely off Mauritania and south of Cap Vert peninsula, Senegal (Fig. 1). Juveniles and young mature fish live there. The latter exhibit short-term local migrations which result in differences in availability to the fishery. The adults, on the other hand, undergo major migrations over the entire area but due to their small numbers we consider the two nurseries to be independent.

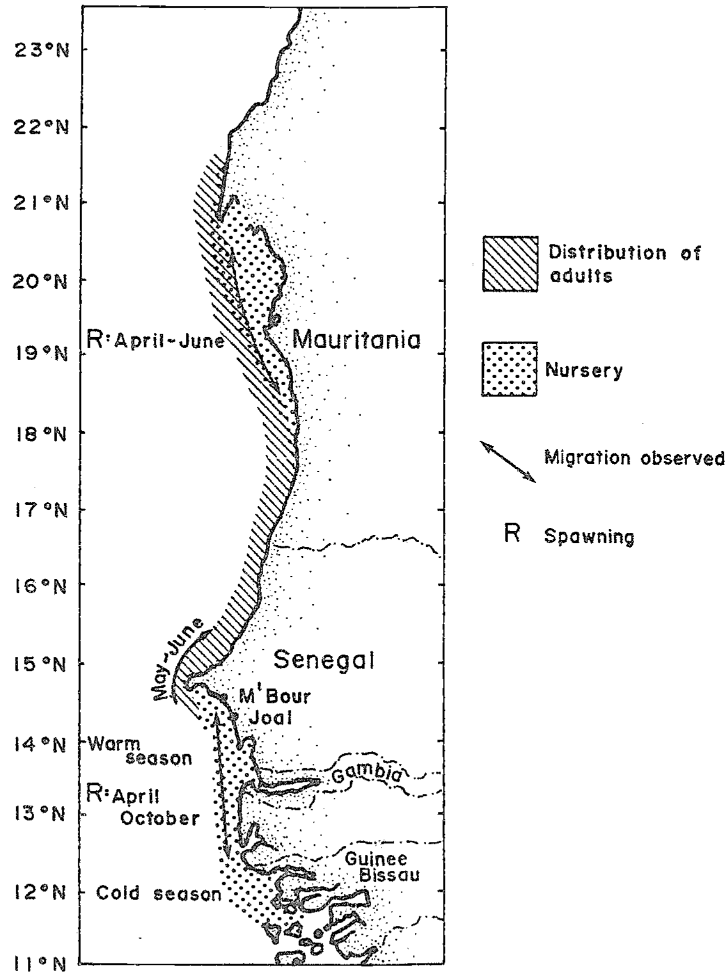

Fig. 1. Migration spawning and nursery areas, and sampling sites for *Sardinella maderensis* from Senegal/Mauritania.

It should be noted that the adults of *S. maderensis* were absent from the catches until 1977, with the exception of 1974. Recorded landings of this species show an increasing trend, which can be associated with decline in the yield of *S. aurita*.

Generally, reproduction takes place from April to November, with the period of peak spawning varying from year to year. Larvae are found throughout the year with a maximum abundance from June to September.

Copepods constitute the main diet of adult *S. maderensis*. The only publication on growth of this species from Senegalese waters was by Postel (1955).

The main fishing ground is south of Cap Vert peninsula. There are both artisanal and commercial fisheries for this species. The artisanal fishery operates with canoes and the main gear is a small meshed ring net, locally called "filet a sardinelle". *S. maderensis* comprises 90% of the catch made with this gear. This fishery also uses small purse seines.

The national industrial fishery is characterized by very old boats (25 m LOA) using traditional purse seines. Foreign boats can be licensed to fish within the territorial waters of Senegal.

Materials

Monthly length-frequency data raised to the total catches from the artisanal fishery were used in this study (Lopez and Sow 1980, 1981; Lopez et al., in press). The data cover the period between 1980 and 1982. The series from the industrial fishery is incomplete and for this reason was not included.

The canoes were sampled at the landing sites (mainly at M'Bour and Joal) by enumerators. Information on catch, effort and fishing area was collected and length measurements (fork length) were taken.

The data from the different landing sites were then pooled as the canoes operate in the same area. Data from the "filet a sardinelle" and the purse seine were also pooled. Previous studies have shown that there is no significant difference in size distribution of the catches from the two gears. In order to raise the sample to the total catch, the size frequencies are first expressed in percentage. The following length-weight relationship was estimated for the southern coast in Senegal (Fréon et al. 1978):

$$W = 0.01034\, L^{3.142}$$

The relationship linking fork length (cm) to body weight (g) was then used to calculate the sample weight in order to obtain the raising factor. For the present study two data sets have been used:

- monthly length-frequency data for the period January 1981 to December 1982 (Table 1) for the estimation of growth parameters (using ELEFAN I) and recruitment pattern (using ELEFAN II)
- frequency data for the years 1980 to 1982 (see Table 2), regrouped in four samples representative of an "average year" used for the estimation of mortality (using ELEFAN II).

The analysis of these data has been done in the North Sea Centre (Hirtshals, Denmark) using two computers: a VAX 11/750 and an HP 87XM.

Table 1. Length frequencies of *Sardinella maderensis* raised to monthly catch for 1981 and 1982.

Length (cm)	Year Month	1981 1	1982 1	1981 2	1982 2	1981 3
9		0	0	0	0	0
10		0	0	0	0	80,730
11		0	0	30,666	0	626,580
12		0	0	199,333	0	998,423
13		0	0	372,117	0	939,311
14		6,200	0	435,963	0	914,845
15		18,600	20,628	294,654	0	884,678
16		69,901	62,840	411,499	0	1,189,420
17		410,191	515,783	493,695	282,885	1,980,439
18		997,671	2,346,148	1,122,679	2,360,152	2,760,775
19		1,077,074	3,683,996	2,478,932	3,163,323	2,696,216
20		1,064,768	2,466,512	2,123,748	2,543,918	1,982,323
21		949,146	1,609,404	1,738,349	1,502,982	1,431,547
22		474,830	574,819	1,088,840	835,498	716,883
23		202,310	199,907	415,055	401,297	476,804
24		74,062	77,056	79,377	115,490	227,341
25		10,899	34,654	66,629	0	115,812
26		7,266	7,011	6,863	64,079	14,476
27		0	3,505	2,745	0	0
28		0	3,505	0	0	0
29		0	0	0	0	0
Total		5,362,918	11,605,768	11,361,144	11,269,624	18,036,603

Table 1. Continued

Length (cm)	Year Month	1982 3	1981 4	1982 4	1981 5	1982 5
9		0	0	0	0	0
10		3,683	0	0	0	0
11		40,516	148,093	0	101,439	0
12		93,999	398,403	0	275,971	21,386
13		193,749	981,441	21,360	567,501	86,682
14		193,917	1,326,731	212,059	1,357,010	286,825
15		89,899	1,064,912	103,021	1,531,586	510,523
16		64,283	1,058,646	206,360	2,133,775	482,737
17		1,041,062	1,683,791	346,798	2,067,863	965,581
18		3,162,099	2,070,322	1,917,225	1,844,782	3,134,588
19		4,554,696	2,108,877	5,392,420	1,333,534	5,141,202
20		3,292,900	1,279,299	4,464,030	1,298,438	4,128,207
21		1,475,842	510,197	4,475,403	1,001,092	1,944,697
22		478,067	323,241	2,205,588	397,486	990,251
23		290,949	150,746	1,311,489	75,168	369,081
24		110,287	53,597	442,441	27,496	264,907
25		15,338	18,796	225,480	6,250	120,528
26		13,377	657	240,049	6,250	12,176
27		8,357	0	55,633	0	4,483
28		3,797	0	0	0	0
29		158	0	0	0	0
Total		15,126,975	13,177,749	21,619,356	14,025,641	18,463,854

Length (cm)	Year Month	1981 6	1982 6	1981 7	1982 7	1981 8
9		0	41,738	0	0	0
10		0	0	0	6,184	3,660
11		17,900	306,752	0	0	7,320
12		0	132,580	0	18,552	0
13		49,450	444,125	165,887	70,017	7,320
14		111,633	310,327	624,133	108,032	113,617
15		275,916	511,676	778,217	271,050	627,120
16		1,149,011	1,581,065	1,554,315	978,531	861,533
17		1,424,595	1,328,204	986,930	2,156,828	1,073,527
18		1,240,848	2,166,872	1,580,309	2,134,404	1,245,786
19		1,613,391	3,859,489	2,657,086	2,623,406	2,870,836
20		2,027,344	4,433,286	3,180,292	2,686,600	1,745,494
21		1,551,335	3,335,799	2,111,480	1,396,863	1,011,212
22		648,175	783,563	444,736	258,919	579,249
23		108,486	82,040	152,839	41,976	241,527
24		42,116	23,586	102,163	9,962	14,207
25		31,919	0	102,163	0	14,207
26		0	0	0	0	0
27		0	0	0	0	0
28		0	0	0	0	0
29		0	0	0	0	0
Total		10,292,119	19,341,102	14,440,550	12,761,324	10,416,615

Table 1. Continued

Length (cm)	Year / Month	1982 / 8	1981 / 9	1982 / 9	1981 / 10	1982 / 10
9		0	0	0	0	0
10		0	0	0	0	13,781
11		0	7,560	0	0	87,284
12		0	7,560	10,277	0	186,690
13		0	11,340	33,166	4,804	289,429
14		39,033	15,120	176,110	4,804	586,384
15		185,350	0	341,944	34,162	377,610
16		358,764	86,554	473,525	605,873	265,091
17		534,097	633,856	577,161	1,645,771	615,091
18		1,361,891	2,795,507	1,545,265	1,720,546	1,265,153
19		2,038,388	4,362,146	3,036,689	2,436,974	2,749,395
20		3,095,873	3,693,816	2,208,118	2,789,361	3,139,164
21		2,882,448	1,934,869	1,344,919	2,290,659	2,280,574
22		1,784,207	724,697	841,850	975,692	955,024
23		1,045,284	105,769	624,489	316,077	399,514
24		709,881	2,424	336,338	50,967	115,351
25		283,314	0	220,394	0	17,412
26		125,917	0	43,686	0	6,381
27		0	2,424	17,269	0	0
28		31,479	0	0	0	0
29		0	0	0	0	0
Total		14,475,926	14,383,642	11,831,200	12,875,690	13,349,328

Length (cm)	Year / Month	1981 / 11	1982 / 11	1981 / 12	1982 / 12	1981/82 / Total
9		0	29,495	0	293,662	364,895
10		0	124,795	0	1,265,477	1,498,310
11		0	281,305	0	3,570,853	5,226,268
12		13,761	756,742	0	4,528,239	7,641,916
13		24,735	1,411,896	1,899	4,577,342	10,253,571
14		85,800	1,659,013	1,266	2,856,968	11,425,790
15		68,074	1,544,298	3,166	1,214,090	10,751,174
16		413,970	1,084,727	145,180	638,329	15,875,929
17		1,703,279	1,457,656	1,248,742	688,752	25,862,577
18		1,712,033	2,583,140	2,472,999	908,743	46,449,937
19		1,126,276	4,267,961	2,248,248	1,423,236	68,943,791
20		661,547	3,556,365	1,469,037	1,478,494	60,808,934
21		435,886	1,696,286	867,394	1,227,892	41,006,275
22		237,325	411,018	326,784	1,155,567	18,212,309
23		144,368	145,382	76,211	791,293	8,168,061
24		93,731	37,932	40,839	317,646	3,369,197
25		0	7,653	3,413	74,007	1,368,868
26		0	0	0	0	548,188
27		0	0	0	0	94,416
28		0	0	0	0	38,781
29		0	0	0	0	158
Total		6,720,785	21,055,664	8,905,178	27,010,590	337,909,345

Table 2. Total length frequencies of *Sardinella maderensis* by quarter for three years combined (1980-1982).

Length (cm)	Quarters / Month / Day	1 / 2 / 15	2 / 5 / 15	3 / 8 / 15	4 / 11 / 15	Total
9		0	41,738	0	323,157	364,895
10		84,413	156,519	9,544	1,445,203	1,695,679
11		697,762	574,184	14,880	4,062,892	5,349,718
12		1,291,755	828,340	36,389	6,440,582	8,597.066
13		1,505,177	2,150,559	287,730	6,959,427	10,902,893
14		1,557,825	3,604,585	1,076,045	5,469,098	11,707,553
15		1,325,668	4,019,246	2,208,020	3,313,325	10,866,259
16		1,879,612	6,660,734	1,882,849	3,462,274	13,885,469
17		5,355,134	8,068,608	6,313,921	8,645,172	28,381,835
18		14,213,601	13,516,679	12,185,936	14,138,635	54,054,851
19		19,651,374	21,095,947	21,257,653	19,974,674	81,979,648
20		15,708,071	19,522,856	21,132,747	18,079,034	74,442,708
21		10,215,742	11,182,284	14,025,813	10,951,520	46,375,359
22		6,004,372	7,128,047	5,843,944	4,279,289	23,255,652
23		3,353,112	2,923,138	2,498,764	2,002,372	10,777,386
24		1,314,252	1,157,902	1,263,220	735,768	4,471,142
25		381,723	493,618	651,418	106,914	1,633,673
26		154,478	288,778	181,651	6,381	631,288
27		17,929	84,184	23,893	0	126,006
28		10,133	7,050	31,479	0	48,662
29		158	2,022	0	0	2,180
Total		84,722,291	103,507,018	90,924,896	110,395,717	389,549,922

Methods of Data Analysis

Growth and Seasonal Oscillations

The ELEFAN I program (Electronic LEngth Frequency ANalysis of Pauly and David 1981) was used for the estimate of the growth parameters. The version used was written in Fortran 77 by Sparre (pers. comm. to Sims 1984), modified as suggested by Pauly (1985) and Thiam (1986).

As explained in detail in Pauly and David (1981) and Ingles and Pauly (1984), the growth parameters L_∞ and K of the von Bertalanffy growth equation in length are estimated by the ELEFAN I program through an objective method, based on the following assumptions:

- the length-frequency samples used represent the population,
- fish of a given age have the same length, such that any difference in length can be attributed to a difference in age,
- growth is similar from year to year.

The program transforms the original length-frequency data into restructured length frequencies (see Table 3). The criterion for optimizing the fit of the growth curve is the ratio (R) between the "explained sum of peaks" (ESP) and the "available sum of peaks" (ASP), i.e., the number of positive points (peaks) through which the curves pass relative to the total number of positive points available in the set of length-frequency data.

In Senegalese waters where research is being done on the relationship between upwelling and recruitment for pelagic fish, it will be interesting to investigate the existence of seasonal growth. So, a seasonally oscillating version of the von Bertalanffy growth equation was used which has the form:

$$L(A) = L_\infty [1 - [\exp -K(A - T_0) - C\, K/(2\pi) \sin (2\pi (A - t_s))]]$$

Table 3. Example of restructured length frequencies showing resultant troughs (–) and peaks (ASP).

Sample November 1981 + 1982 (see Table 1)

No.	Midlength (cm)	Original frequency	Running average	Restructured frequency	
1	9.5	29,495	87,119.00	−0.57089	
2	10.5	124,795	241,219.60	−0.34557	
3	11.5	281,305	528,545.80	−0.32658	
4	12.5	770,503	871,609.40	0.11899	
5	13.5	1,436,631	1,169,124.80	0.54937	
6	14.5	1,744,813	1,412,603.20	0.56329	used for ASP
7	15.5	1,612,372	1,890,689.60	0.07975	
8	16.5	1,498,697	2,462,398.00	−0.22911	
9	17.5	3,160,935	3,192,282.80	0.25316	
10	18.5	4,295,173	3,713,390.80	0.46456	
11	19.5	5,394,237	3,840,085.80	0.77848	used for ASP
12	20.5	4,217,912	3,337,567.40	0.60000	used for ASP
13	21.5	2,132,172	2,536,482.80	0.06456	
14	22.5	648,343	1,483,968.00	−0.44684	
15	23.5	289,750	641,916.20	−0.42911	
16	24.5	131,663	215,481.80	−0.22658	
17	25.5	7,653	85,813.20	−0.88734	
18	26.5	0	0	0	

Average running average = 0.790

where L(A) is the length at relative age A, L_∞ is the mean length the fish would reach if they were to grow infinitely old, and T_0 is the relative age at length zero. Note that the relative age A refers to the age relative to say the start of some arbitrary reference year. The parameters t_s and C control seasonal growth oscillations in a period of one year; t_s is the start of a sinusoidal growth oscillation and C is a parameter expressing the amplitude of the seasonal growth oscillations. The winter point (WP) is defined as: $WP = t_s + 0.5$.

In order to compare different estimates of growth parameters we use the empirical equation of Pauly and Munro (1984):

$$\phi' = \text{Log}_{10}K - 2\log_{10}L_\infty$$

Mortality

The ELEFAN II program was used for estimation of total mortality through a length-converted catch curve (Pauly 1984). An initial value of Z is obtained from the equation:

$$\ln (N/\Delta t) = a + bt$$

where N is the number of fully recruited and vulnerable animals of a given age t, -b = Z, the total mortality, and Δt, the time needed to grow through a length class. The final correction of this value of Z for nonlinear growth of fish is made by the following equation:

$$\ln (N/(1 - e^{-Z_i \Delta t}) = A - Z_{i+1}\, t$$

This method assumes that recruitment is constant from year to year. For pelagic fish where it seems that the recruitment varies with upwelling intensity, this method may result in bias.

However, applying the method to an "average year" will result in smoothing out differences in recruitment.

Natural mortality was estimated using Pauly's empirical equation (Pauly 1980) for a mean surface water temperature of T = 20°C:

$$\log_{10}M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10}K + 0.4632 \log_{10}T$$

Natural mortality is assumed to remain constant for all cohorts considered.

Subtracting the estimate of M from the estimate of Z gives an estimate of the fishing mortality:

$$F = Z - M$$

The probabilities of capture by length classes ("resultant curve") and the length, L_c, at which the probability of capture is 0.5 were obtained through analysis of the left, ascending side of the length-converted catch curve (Pauly 1984).

Recruitment Pattern

A recruitment pattern was computed and the NORMSEP program used to separate the pattern into normally distributed recruitment pulses (Saeger and Gayanilo 1986). A recruitment pattern is a graph whose peaks and troughs reflect the seasonality of recruitment to the stock in question. If a set of length-frequency data and a corresponding set of growth parameter values are available, the recruitment pattern is calculated by projecting each length-frequency sample backward onto the time axis. ELEFAN II uses a more complex computation procedure correcting for the fact that fish growth is not linear:

- each length class (of each sample) is divided into 10 intervals of equal size;
- the value added to the recruitment pattern memory is $N_i/10$ divided by the time required to grow through the length interval in question;
- the lowest monthly recruitment value is subtracted from all 12 values resulting in at least one zero value corresponding to the month of lowest recruitment;
- finally, the resulting distribution is converted into relative frequency.

Note that the division of number by Δt, the time required to grow through the length interval, ensures a correct representation of the frequencies on the time scale. In the time representation, the area of each rectangle in the transformed histogram represents a number (Δt being the baseline and $N/\Delta t$ the height of the rectangle in question). The time interval Δt will increase with the size of the fish because it takes a longer time for a big fish than for a small fish to achieve the same length increment, ΔL. In the simple case of von Bertalanffy growth without seasonality, Δt may be obtained from the difference equation

$$\frac{\Delta L}{\Delta t} = K (L_\infty - L); \text{ when } \Delta t \text{ is small}$$

or

A $$\frac{1}{\Delta t} = \frac{K}{\Delta L} (L_\infty - L)$$

This shows that the factor $1/\Delta t$ plotted against length gives a straight line with slope $-K/\Delta L$.

Results

Estimation of Growth Parameters

Growth parameters without seasonality

The optimum value of ESP/ASP = 0.233 was obtained for L_∞ = 39.5 cm and K = 0.450/year (WP = 0 and C = 0).

The corresponding growth equation reads

$$L(A) = 39.5\left[1 - \exp\left[-0.45\,(A - T_O)\right]\right]$$

Growth parameters with seasonality

Fig. 2 depicts a set of restructured length-frequency samples with the best seasonal growth curve estimated from the 1981-1982 data set. Fig. 3 shows the best fit (solid curve). The secondary curve (dotted) illustrates the existence of a second cohort.

With regard to seasonal growth oscillations two alternatives have been considered:

- slow growth during the cold season (WP = 0.1)
- slow growth during the warm season (WP = 0.6).

An extremely large number of growth curves were fitted (the total number of curves drawn was about 400,000); the best fit (see Fig. 2) to the data (with ESP/ASP = 0.549) was obtained with L_∞ = 37.5 cm, K = 0.3/year, WP = 0.1 year and C = 0.6 (Table 4).

For *Sardinella maderensis* the equation becomes:

$$L(A) = 37.5\left[1 - \exp\left[-0.3\,(A - T_O) + 0.30 \times 0.6/(2\pi)\sin(2\pi\,(A - 0.1)\right]\right]$$

Table 5 gives the estimated values of L_∞ and K of different authors as well as the corresponding values of ϕ', based on the empirical equation of Pauly and Munro (1984).

Estimation of Mortality Rates and Recruitment Pattern

Estimation of mortality rates

Fig. 4a shows the graphical representation of the catch curve. A value of Z = 3.9/year was obtained. Table 6 summarizes the catch curve statistics.

Fig. 4b shows the graphical representation of the resultant curve. This curve gives the mean length at first capture, L_c, which is the length corresponding to a cumulative probability of capture of 0.5 (50%). A value of L_c = 19.9 cm was obtained.

For natural mortality a value of M = 0.5/year was obtained from Pauly's empirical equation and fishing mortality becomes F = 3.9 - 0.5 = 3.4/year.

Hence the exploitation rate E = F/Z = 3.40/3.90 = 0.87.

Recruitment pattern

Investigations on recruitment pattern have been carried out for the years 1981 (Fig. 5) and 1982 (Fig. 6). Each of the two recruitment curves shows two clear modes possibly corresponding to two cohorts, one less pronounced and probably representing fish hatched at the end of the cold season. The second mode may represent fish hatched at the end of the warm season.

Intuitively one would expect the length frequencies of the small and young fish to contain more reliable information on recruitment pattern than those of old and large fish. The division by Δt of the frequencies used for constructing recruitment pattern partly accounts for this; however,

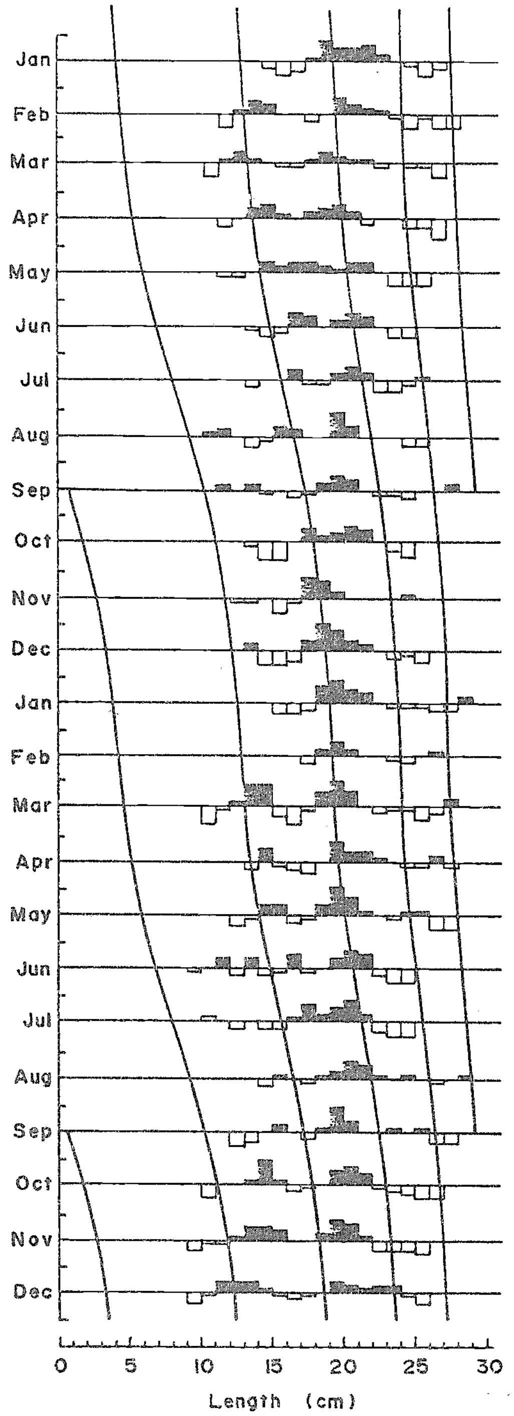

Fig. 2. Seasonal growth curve of *Sardinella maderensis* (1981-1982) in Senegal.

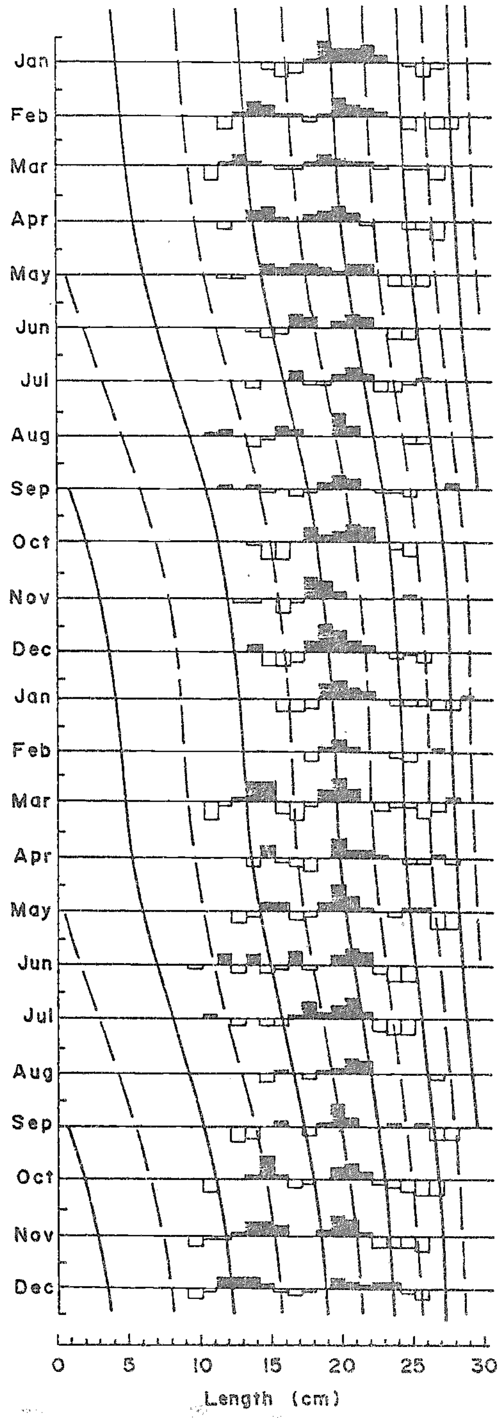

Fig. 3. Seasonal growth curves of *Sardinella maderensis* (1981-1982) in Senegal. Solid = best fit; dotted = forced with starting point.

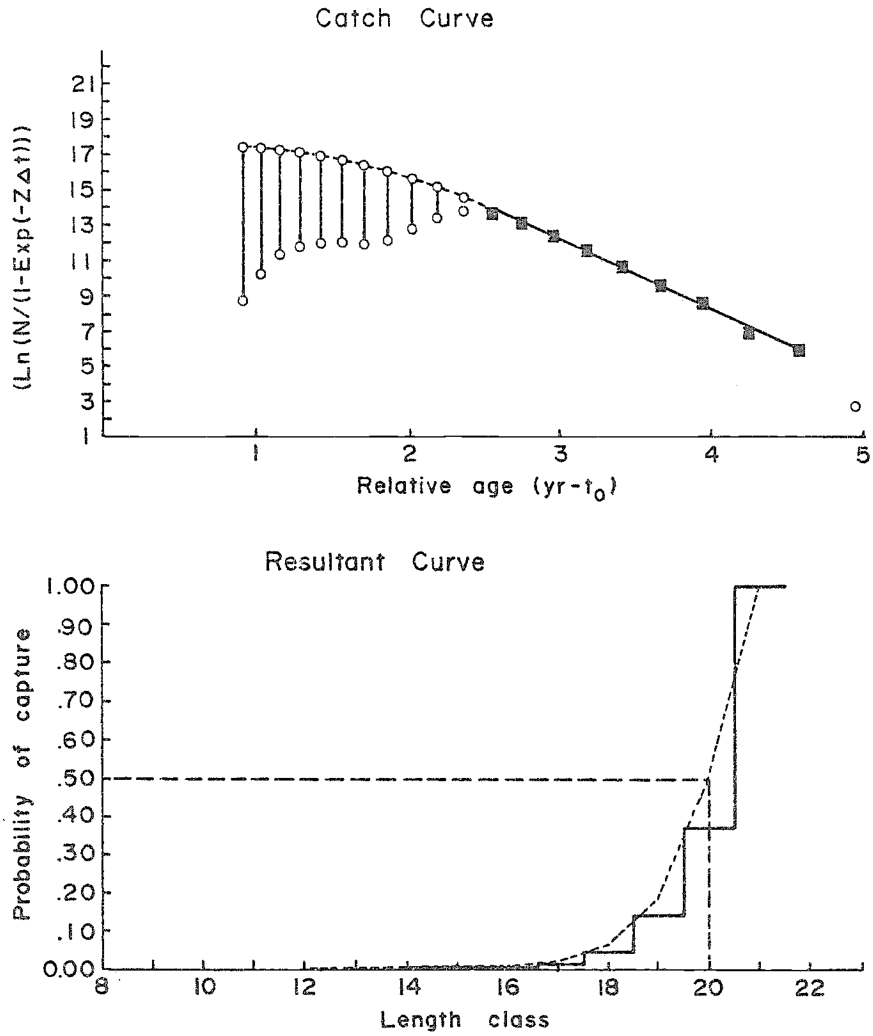

Fig. 4. a) Catch curve and b) resultant curve for *Sardinella maderensis*, 1980-1982 in Senegal. L_∞ = 37.5, K = 0.3, WP = 0.1, C = 0.6, t_0 = 0, M = 0.5, F = 3.426, E = 0.872, L_c = 19.985, T = 20°C.

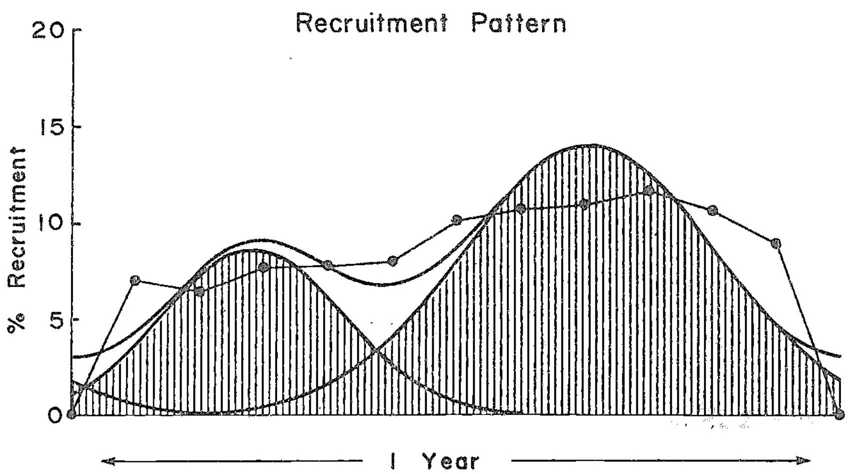

Fig. 5. Recruitment pattern for *Sardinella maderensis* in 1981 in Senegal. L_∞ = 37.5, K = 0.3, WP = 0.1, C = 0.6, t_0 = 0.

Table 4. Results of the estimation of seasonal growth parameters.

	Winter point WP = .1 (fraction of year)						Winter point WP = .6 (fraction of year)					
C	0.5	0.6	0.7	0.8	0.9	1.0	0.5	0.6	0.7	0.8	0.9	1.0
ESP/ASP	0.240	0.549	0.260	0.238	0.241	0.245	0.223	0.213	0.225	0.203	0.193	0.183
K ($year^{-1}$)	0.31	0.30	0.32	0.32	0.30	0.30	0.30	0.31	0.30	0.30	0.30	0.40
L_∞ (cm)	37.0	37.5	33.5	34.5	37.5	35.0	34.0	33.0	34.5	34.0	36.0	38.5

Table 5. Estimates of growth parameters for *Sardinella maderensis* with their corresponding ϕ' values.

Stock	L_∞ (cm)	K ($year^{-1}$)	ϕ' [a]	Source
Senegal	35.0	0.61	2.88	Postel (1955)
Congo	39.6	0.28	2.64	Rossignol (1955)
Congo	24.9	1.00	2.79	Gheno and LeGuen (1968)
Senegal	39.5	0.45	2.85	without seasonality (this paper)
Senegal	37.5	0.30	2.63	with seasonality (this paper)

[a] $\phi' = \log_{10} K + 2 \log_{10} L_\infty$

Table 6. Results of the catch curve analysis. *Sardinella maderensis*, Senegal 1980-1982.

Catch curve statistics

(PT 12 to 20):

a = 24.948	b = −3.877	r^2 = .996	Z = 3.877
a = 23.921	b = −3.928	r^2 = .996	Z = 3.928
a = 23.903	b = −3.926	r^2 = .996	Z = 3.926

Point	Midlength (cm)	Midlength	N	Ordinate[a]
1	10	.91479	1848.78476	8.74528
2	11	1.03385	8591.36323	10.25121
3	12	1.15732	27104.99483	11.36895
4	13	1.28554	43558.07717	11.81113
5	14	1.41889	55240.82922	12.01550
6	15	1.55780	59317.73666	12.05237
7	16	1.70275	55055.21861	11.94229
8	17	1.85429	70352.41212	12.15070
9	18	2.01305	143800.00795	12.82751
10	19	2.17975	273875.45603	13.43222
11	20	2.35523	415359.82554	13.80763
12	21	2.54047	377173.00527	13.66848
13	22	2.73660	234966.37877	13.15076
14	23	2.94500	117827.58030	2.41418
15	24	3.16731	54604.93278	1.59671
16	25	3.40550	22653.58301	0.66637
17	26	3.66204	8277.20232	9.60671
18	27	3.93998	3198.49719	8.60062
19	28	4.24322	638.42468	6.93139
20	29	4.57683	246.55192	5.91959
21	30	4.94758	11.04523	2.75119

L_∞	= 37.5	Cutoff length (L′, cm)	= 20
K	= 0.3	Mean length ($\bar{L}$, cm)	= 21.5
C	= 0.6	Z from mean length	= 3.28
WP	= 0.1	Natural mortality (M)	= 0.59
Z from		Fishing mortality (F)	= 3.34
catch curve	= 3.9	Exploitation rate (E)	= 0.85

[a]Ordinate: ln (N/(1 − EXP (−ZΔt))).

an explicit weighting factor which takes this into account is not incorporated in the recruitment pattern routine of ELEFAN II. As a step in this direction, the recruitment pattern computation was repeated for 1982 omitting all fish of length 19 cm and above. The resultant recruitment pattern is shown in Fig. 7. Comparing this with Fig. 6, we see that the effect of excluding the larger fish from the recruitment computation is a more pronounced peak at the end of the arbitrary year. This example indicates that the present ELEFAN II method of computing the recruitment pattern will be sensitive to the choice of a weighting factor. It is therefore important that such a factor is estimated based on rational modelling. It seems obvious to apply cohort analysis principles and in this way also utilize the growth curve which has been obtained (Fig. 2) as the best relationship to describe the peaks.

Such cohort principles have been included in the ELEFAN III program (Pauly 1987). Alternatively, the recruitment pattern could be obtained by backtransforming normal distributed components resulting from, say a Bhattacharya analysis.

It should be noted that the monthly values of the recruitment pattern, which are based on relative ages, pertain only to an arbitrary year. Precise estimates of absolute ages are needed for recruitment patterns to indicate the time of spawning.

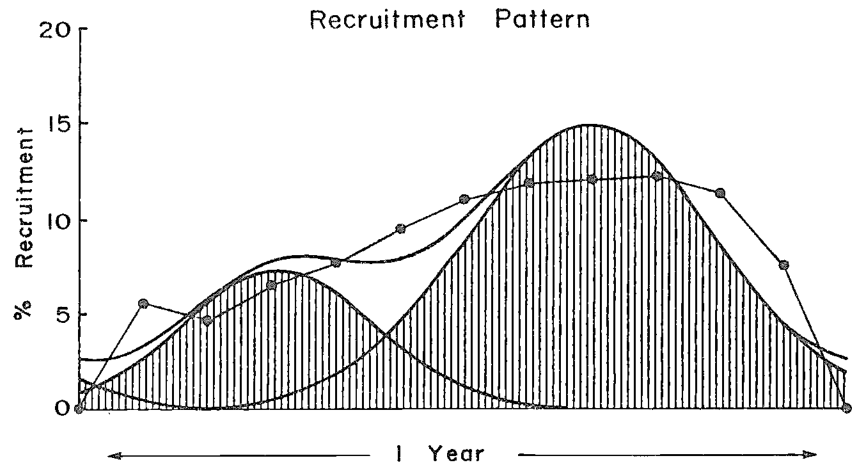

Fig. 6. Recruitment pattern for *Sardinella maderensis* in 1982 in Senegal. L_∞ = 37.5, K = 0.3, WP = 0.1, C = 0.6, t_0 = 0.

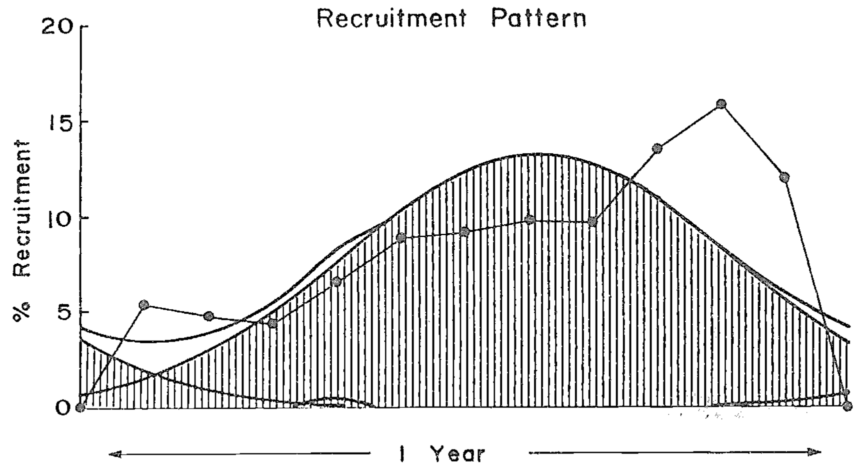

Fig. 7. Recruitment pattern for *Sardinella maderensis* in 1982 in Senegal obtained exactly as in Fig. 6 but only based on 9-18.9 cm fish. L_∞ = 37.5, K = 0.3, WP = 0.1, C = 0.6, t_0 = 0.

Discusssion and Conclusions

The growth of *S. maderensis* in Senegal has been studied by Postel (1955), while growth parameters were estimated by Rossignol (1955), Gheno and Le Guen (1968) for the population of Congo.

The ϕ' value obtained with the estimated growth parameters without seasonality compares well with the ϕ' obtained by Postel (1955) in Senegalese waters (see Table 5). Introducing seasonality led to an improvement of the ESP/ASP ratio by more than 135% which indicates the importance of seasonality on growth. In stating this, it should also be mentioned that the effect of seasonal migration of the adults on growth and, hence on peaks in the restructured length frequencies has not been investigated.

The estimated value of L_∞ and K compare well with results of other authors, notably with those obtained by Rossignol (1955) (see Table 5). Seasonal growth has never been studied for this species with upwelling affecting the life cycle. Our results imply that the growth of *S. maderensis* slows down by approximately 60% with respect to the average growth during the cold season. We note that this species displays seasonal growth oscillations, as occur in temperate species although the amplitude of these oscillations is not as pronounced as those in temperate species. However, one must also emphasize that the growth oscillations of body weight should be studied separately.

High total mortalities were estimated through catch curve analysis and from the mean length. This high value appears to be upwardly biased. This overestimation may be due to the fact that adults migrate out of the sampling area and hence are underrepresented in catch samples. This interpretation is supported by the fact that the bulk of the catches consists of fish of 18 to 22 cm.

However, a related problem is that the samples are collected in an area of very active fishing (south of Cap Vert, Fréon et al. 1979) directed towards young fish and this can produce an overestimation of the proportion of young fish in the population.

Finally, these considerations and the fact that the method used assumes that all size groups should be recruited with the same abundance imply that the estimated Z value will refer to apparent and not to "real" mortality.

Due to considerations of the migration patterns of this species future work should cover the entire distributional range in order to improve on mortality estimates.

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Growth Parameters and Mortality Rates of Nile Perch (*Lates niloticus*) Estimated from Length-Frequency Data in the Nyanza Gulf (Lake Victoria)

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Abstract

Estimates of growth parameters were made for Nile perch (*Lates niloticus*) from the Nyanza Gulf of Lake Victoria with length-frequency data from 1978-1984 trawl surveys. The original frequency distributions were separated into normal distributions using the Bhattacharya method. Modal progression analysis was applied to determine the growth parameters. Values of L_∞ = 205 cm and K = 0.19/year were obtained.

Total mortality was estimated from trawl survey data using the length-converted catch curve analysis. The total mortality was found to vary between the years considered. The average total mortality coefficient for the period 1978-1984 was estimated at Z = 1.6 .

Fishing mortality (F) was estimated for *Lates niloticus* from length-frequency data obtained from the 1981-1985 commercial gill net and shore seine fisheries. Jones' length-converted cohort analysis was used to estimate the average at F = 0.85 (for length range 72-176 cm) for a natural mortality of M = 0.34/year.

Introduction

The fishery of Lake Victoria had been supported for many years by the indigenous species *Oreochromis esculentus* and *O. variabilis*. The former is believed to be extinct from the lake as a result of predation by the Nile perch *(Lates niloticus)*, a hypothesis yet to be ascertained.

Instability in the fishery of *O. esculentus* had been noted from as early as 1909 (Graham 1929) when recommendations were made for the elimination of small mesh nets out of the fishery. The proposals were in favor of gill nets with mesh sizes above 12.5 cm and shore seines. Currently, over half of the shore seine catches are composed of juveniles of *O. niloticus* and *L. niloticus*, whereas the target species in this fishery is *Rastrineobola argenteus*. The minimum mesh of gill nets was adjusted to 10 cm in 1956 when it was observed that the catch number of fish per net had decreased from 40 (in 1909) to 2 (in 1954). Since the reduction in the minimum mesh size there had been a decline in the catches (Lowe-McConnell 1975).

Heavy rainfall in the region around Lake Victoria in 1961 and the subsequent years led to a massive rise in the lake level reaching its peak in 1964 (Welcomme 1969, 1970) leading to an initially favorable environment for spawning and survival of the juveniles of *O. esculentus* which resulted in a continuous rise of catches. Later, the massive rise in the lake level affected the habitats for *O. esculentus* and this might have been the main factor behind the slackening level in the catches over the subsequent years.

(Odero 1979). Hamblyn (1962) reported *L. niloticus* caught in fishermen's nets in 1960 around Jinja. These were introduced from Lake Albert in 1959 (A. Achieng, pers. comm.).

The proposal for *L. niloticus* introduction was first hatched by Graham (1929) to make use of *Haplochromis* spp., then referred to as trash fish in the fishery. Arguments for and against the introduction have come up. Worthington (1932) and Beverton (1959) supported the argument (Anderson 1961). Anderson (1961) also supported the introduction of *L. niloticus* asserting that the Lake Victoria fishery would be improved by the suitable predatory fish.

L. niloticus was noted in commercial catches in Kenyan waters in 1969 (Kongere 1979), though its first appearance was in 1965 (Gee 1969). Table 1 shows the variation of stock densities for various species between 1969 and 1983 (Muller and Benda 1981; KMFRI 1984). *L. niloticus* appears to have increased tremendously over a short period of time.

Table 1. Catch per area for the dominant species in bottom trawl catches from 1969 to 1983 (in kg per ha).

Species	1969-1970 (19 hauls)	1975 (69 hauls)	1977 (167 hauls)	1982-1983 (54 hauls)
Bagrus docmac	11.7	12.5	1.8	0.9
Claraias mossambicus	3.3	2.6	0.7	0.9
Haplochromis spp.	35.8	32.7	28.7	–
Labeo victorianus	0.1	0.1	0.1	0.1
Lates niloticus	0	0.8	2.8	29
Protopterus aethiopicus	3.7	10.7	0.3	–
Schilbe mystus	0.03	0.20	0.01	0
Synodontis spp.	2.10	0.20	0.50	0.04
Oreochromis variabilis	0.03	0.11	0.3	–
Oreochromis niloticus	0.01	0.20	0.70	1.40

(–) not recorded.
(0) catch densities less than 0.01 kg/ha.
Sources: (Muller and Benda 1981; K.M.F.R.I., 1984).

Okedi (1971) noted that the distribution of *L. niloticus* was confined to depths less than 25 m and remarked that good catches were made at the entrance to the Nyanza Gulf (Fig. 1). Kudhongania and Cordone (1974) estimated the standing stock of *Lates* and concluded that the commercial contribution to the ichthyofauna was insignificant. Ogari (1984) noted that the distribution of *L. niloticus* in the Nyanza Gulf was ubiquitous.

The present paper discusses the growth rate, mortality rate and the stock size of *L. niloticus* in the Nyanza Gulf of Lake Victoria.

The Biology of the Nile Perch (Lates niloticus)

Eggs and the larval stages of *Lates niloticus* are pelagic; hatching occurred within 20 hours of spawning in Lake Chad (Hopson 1972). Spawning took place in sheltered sites and migration took place in the course of development unaided by the water currents. In the juvenile stage, they occupied the shallow waters of the lake.

Ogari (1984) noted that postlarvae measuring 1.2 cm TL occur in littoral weeds dominated by *Ceratophyllum* and appear to be restricted to the shallow inshore areas. In the Nyanza Gulf, there was a tendency of sizes of fish increasing with increase in depth (Ogari 1984). The diet in the Nyanza Gulf consisted of fish (Table 2), insects and crustacea (mainly *Cladocera, Chironomids* and *Carodina nilotica*). The type of prey taken depends on the predator size, the prey availability and the abundance in a given habitat. Up to 70 cm TL crustacea formed the main prey for *L. niloticus*, while fish were the main prey for the larger sizes.

The size at 50% maturity was observed at 74 cm TL for males and 102 cm TL for females (Fig. 2) from the maturity ogives. The number of eggs observed ranged from 3,000,000 to

15,000,000 per fish. Up to 80 cm TL, males dominate in the sex ratio, while above 80 cm TL, females dominate (Ogari 1984).

The length/weight relationship (Fig. 3) was calculated as:

$$W = 0.0078\ L^{3.12}$$

with W in g and L in cm (TL)

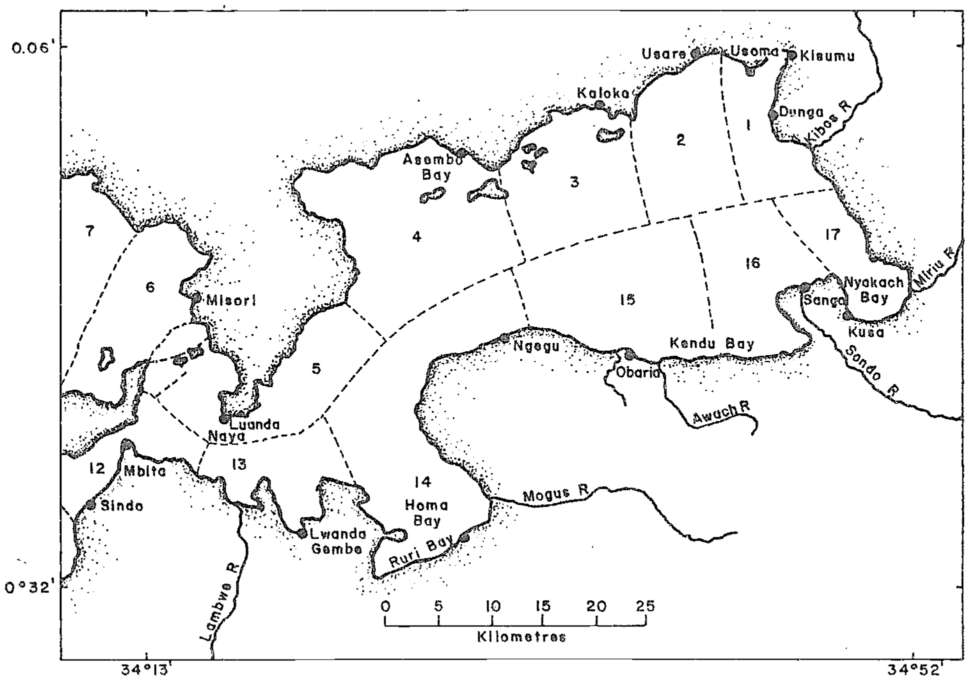

Fig. 1. Map of Nyanza Gulf, Lake Victoria showing landing beaches and geographical stratification for trawl survey sampling.

Table 2. Frequency of occurrence of various fish prey in the stomach of *Lates niloticus* in the Nyanza Gulf of Lake Victoria.

	Stomachs with fish (number)	% of stomachs with fish	% of all full stomachs
Lates niloticus	898	43.1	18.8
Rastrineobola argenteus	756	36.3	15.8
Oreochromis niloticus	153	7.3	3.2
Protopterus aethiopicus	2	0.1	0.04
Haplochromis spp.	232	11.1	4.2
Alestes spp.	16	0.8	0.3
M. frenatus	11	0.5	0.2
Synodontis spp.	14	0.7	0.3
Labeo victorianus	2	0.1	0.04
Mormyrus spp.	1	0.05	0.02
Total number of stomachs containing fish as food	2,085		
Total number of fish with various food items	4,785		

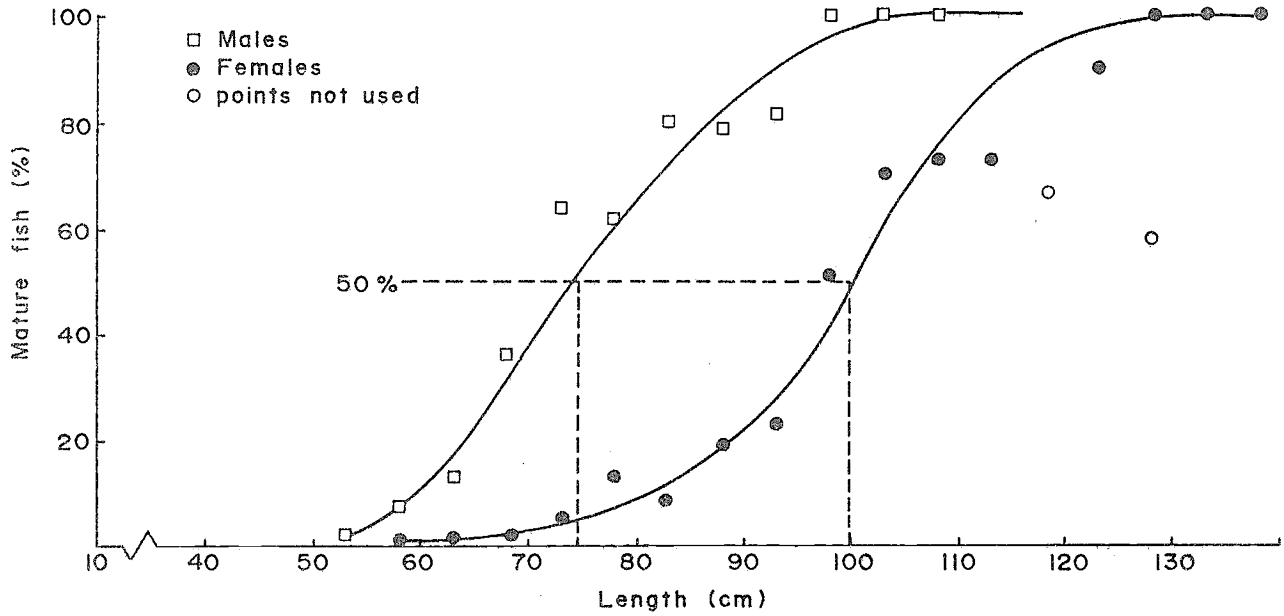

Fig. 2. Maturity ogives for male and female *Lates niloticus*.

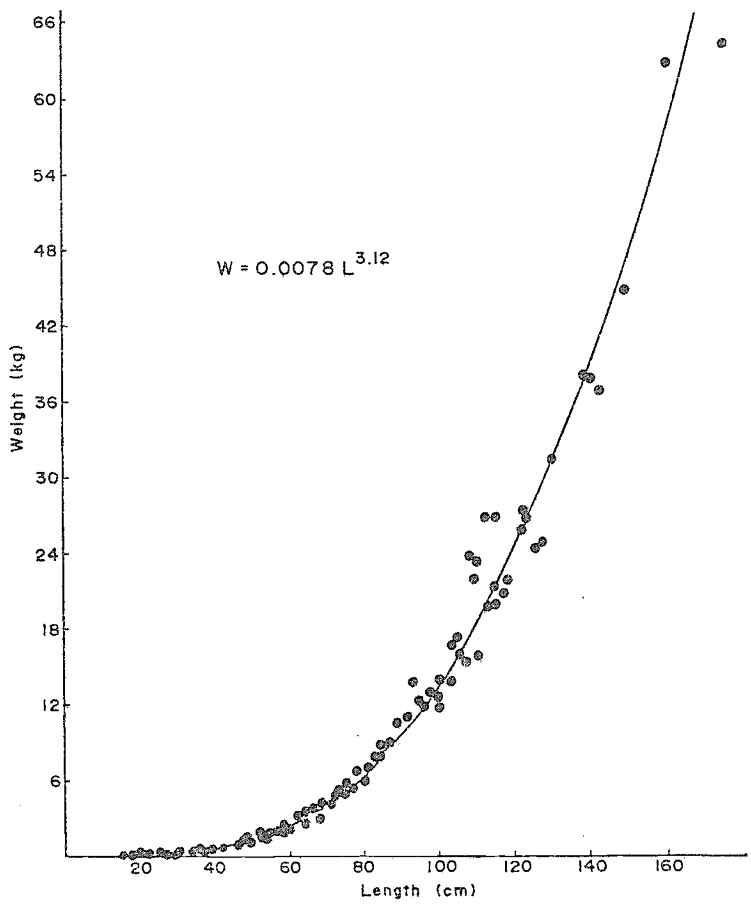

Fig. 3. Length-weight relationship for *Lates niloticus*.

Trawl Survey and Data

Data presented were collected from research surveys conducted within the Nyanza Gulf between October 1978 and May 1984. A map of Nyanza Gulf, which was subdivided into 17 strata by geographical location for sampling purposes is shown in Fig. 1.

The gear used in the sampling was a Granton trawl net with a headrope of 13.3 m and groundrope of length 19.6 m towed by an 85 horsepower fiberglass boat. The cod-end mesh size was 60 mm which was at times lined inside with a mosquito net of 10 mm for purposes of sampling young fish. The trawling speed was maintained at 3.0 knots with each haul lasting 30 min. Trawling was limited to depths greater than 2 m. Fish samples from hauls of bottom trawls were sorted and identified by species. Total catch was weighed by species and samples were taken for length and weight measurements. The total length of the fish was measured to the nearest millimeter. Weight of fish less than 30 cm TL was measured to the nearest 10 g, while fish greater than 30 cm TL but less than 80 cm were weighed to the nearest 100 g and those larger than 80 cm TL to the nearest 500 g. For each haul, the position and the direction of towing were noted together with the total catch. Length-frequency distributions are shown in Fig. 4 and Table 3.

Estimation of Growth Parameters

The various cohorts were separated by applying the method of Bhattacharya (1967) which splits a composite distribution into separate normal distributions. The frequency distribution is transformed into a straight line by taking logarithms of individual frequencies at length (length groups) and then differences are calculated from the logarithms. The differences are then plotted against the lower limit of the length groups. From the left side of the graph (Fig. 5a) the cohorts are removed and the leftover frequencies are plotted after finding their differences (Fig. 5b)

The plots are given in Fig. 5a to 5c. Then growth curves are fitted to the observed modal lengths (Fig. 6) and finally a Gulland and Holt plot is made based on the modes of the identified cohorts (Fig. 7). The result of this analyses on the trawl data are $L_\infty = 205$ cm and K = 0.19/year. The Bhattacharya method and Gulland and Holt plot are fully described by Sparre (1985). The calculations were carried out on an Apple IIc microcomputer using programs developed by Sparre (1987).

Estimation of Total Mortality from Survey Data

Frequencies at length groups were summed up for approximately two-year periods (1978-1979, 1980-1981, 1982-1984) and a seven-year period (1978-1984) (Table 3 and Fig. 8).

The length-converted catch curve analysis (as described in Sparre 1985) based on data in Table 3 was used to determine total mortality. Fish of total length 20 cm and longer were used in the regression analysis.

The analysis was performed using the summed frequencies for the four periods mentioned, and the growth parameters, $L_\infty = 205$ cm and K = 0.19/year.

The results obtained

$$Z_{78,79} = 2.2 \pm 0.2$$

$$Z_{80,81} = 1.4 \pm 0.1$$

$$Z_{82,84} = 1.3 \pm 0.3$$

$$Z_{78,84} = 1.6 \pm 0.1$$

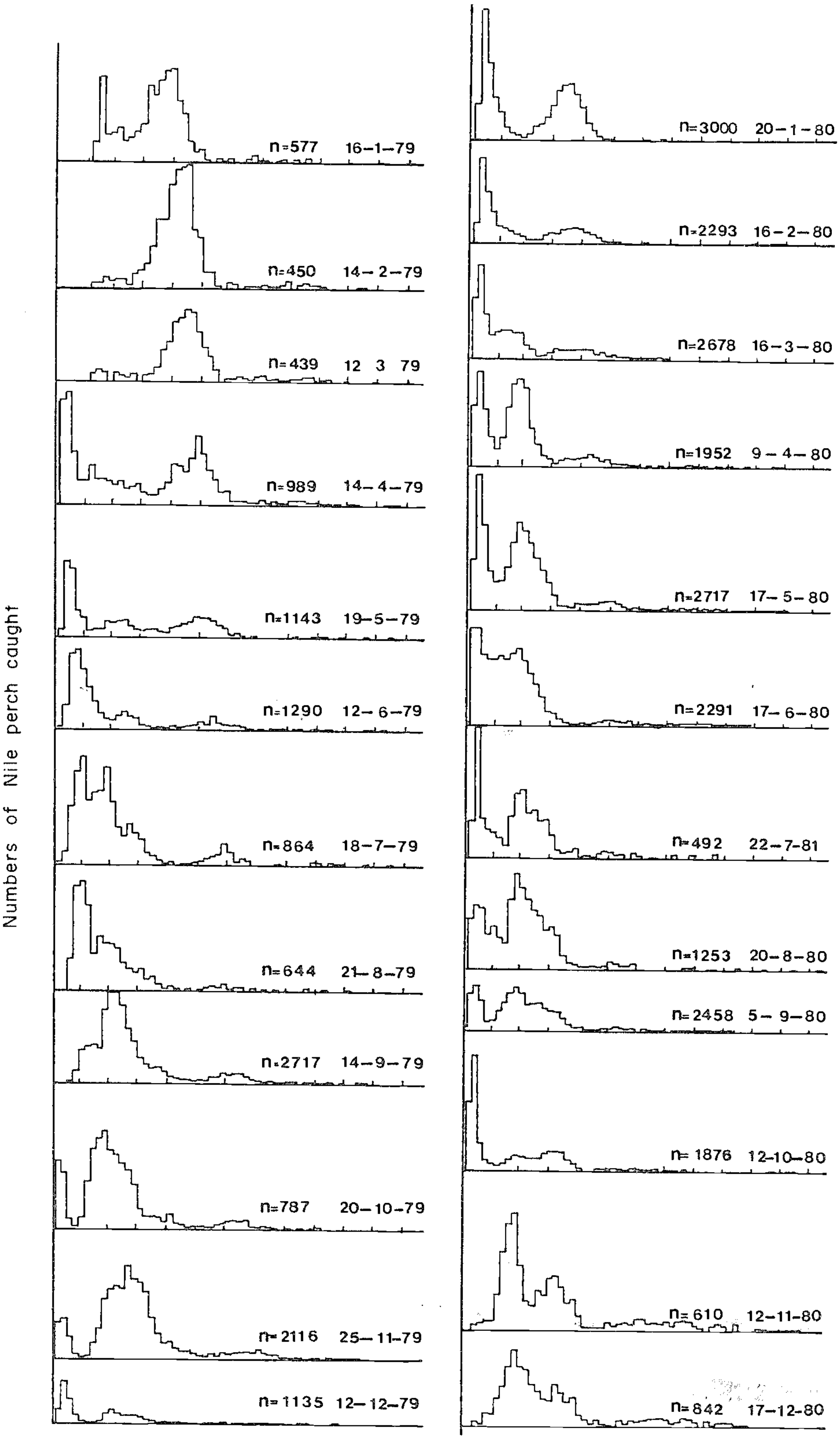

Fig. 4a. Length-frequency distributions of *Lates niloticus* from trawl surveys, 1979-1980, in Lake Victoria.

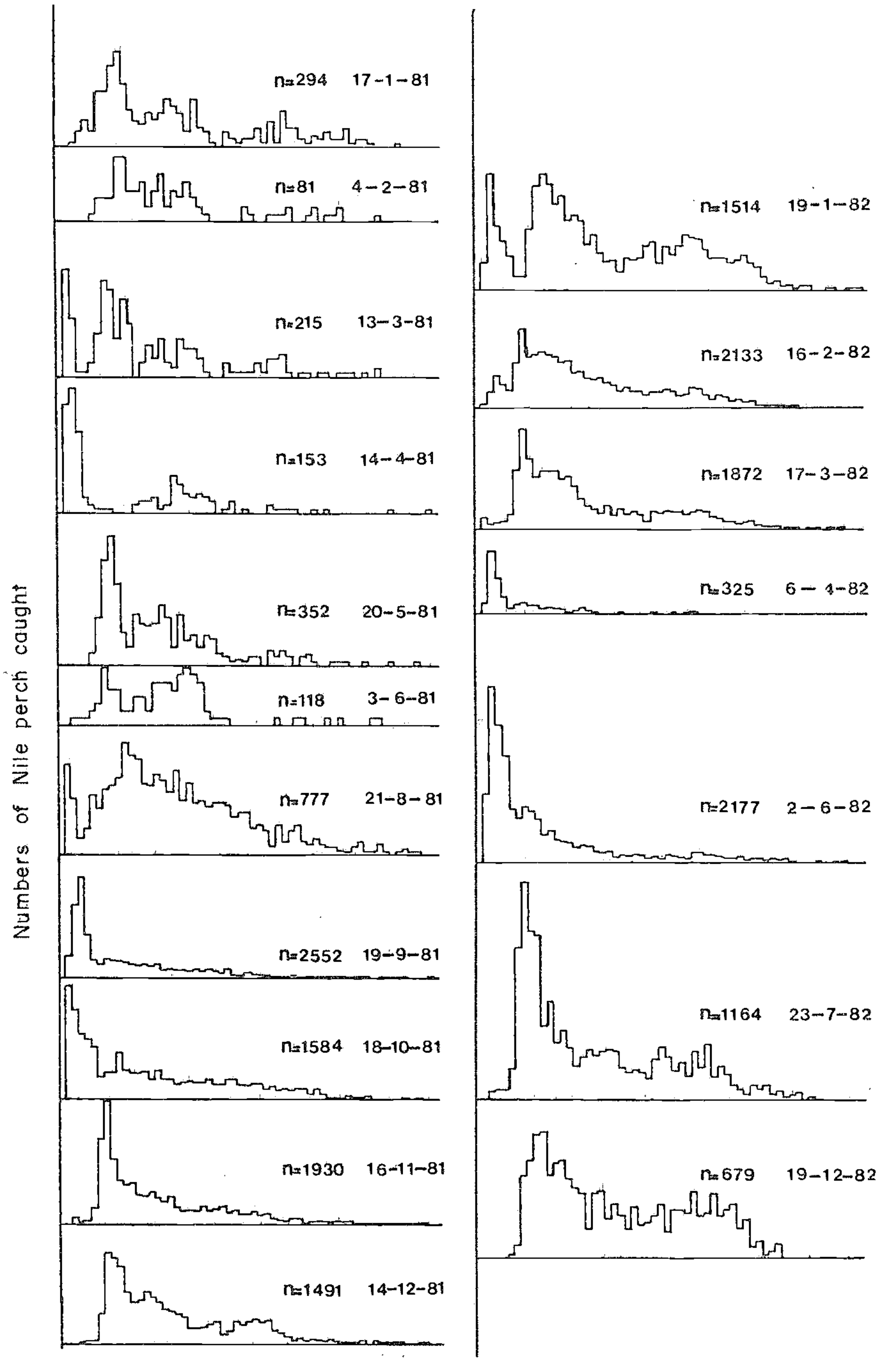

Fig. 4b. Length-frequency distributions of *Lates niloticus* from trawl surveys, 1981-1982, in Lake Victoria.

Table 3a. Length-frequency samples of *Lates niloticus* from research trawl surveys, 1978-1984 in Nyanza Gulf.

Length	1978		1979						Total
(in cm)	10	12	2	3	5	8	10	12	1978-1979[a]
0				106	20	3	72	169	370
4				165	600	93	75	534	1,467
8				44	476	365	176	82	1,143
12	12	11	68	74	213	260	393	45	1,076
16	38	49	43	52	120	244	616	275	1,437
20	68	179	42	50	132	167	803	469	1,910
24	111	357	42	36	144	105	589	472	1,856
28	129	548	92	35	73	86	301	444	1,708
32	93	501	148	33	43	45	142	287	1,292
36	25	241	201	87	32	12	114	107	819
40	22	86	189	171	55	8	60	74	665
44	13	19	111	185	84	3	31	42	488
48	25	11	43	183	130	7	26	22	447
52	11	13	13	86	141	20	35	18	337
56	4	7	8	27	82	37	78	33	276
60	5	1	3	11	36	19	82	32	199
64	7	7	12	7	16	13	76	37	175
68	1	8	7	12	7	2	26	42	105
72	3	9	4	7	5	1	16	27	72
76	1	4	9	4	3	2	5	16	44
80	3	5	6	12	4		8	5	43
84	1	3	10	12	2	3	4	3	38
88		1	4	4	6	5	7	3	30
92		1		2	2		4		9
96									
Total	572	2,071	1,055	1,405	2,426	1,500	3,739	3,238	16,006

[a]Input of the length-converted catch curve analysis,

Table 3b, Continued.

	1980						1981						
Length	2	3	6	8	9	12	1	3	5	8	10	11	Total
(in cm)	2	28	5	5	23	4	26	29	27	21	4	29	1980-1981[a]
0	278	489	384	90	477			38		33	295	1	2,085
4	1,649	1,143	1,028	275	942	16	5	89	2	26	1,064	28	6,267
8	565	381	500	137	174	40	12	30	9	31	471	60	2,410
12	252	521	525	96	301	147	36	13	62	41	215	631	2,840
16	126	705	802	286	528	291	59	11	80	53	289	488	3,718
20	120	414	695	271	430	186	39	12	21	77	222	326	2,813
24	231	112	423	202	359	124	22	10	39	61	204	275	2,062
28	459	118	180	148	361	114	22	21	36	52	194	265	1,970
32	610	130	42	71	260	144	30	13	48	50	137	215	1,750
36	501	132	31	26	119	97	27	17	35	51	119	151	1,306
40	238	159	43	11	41	32	22	12	33	45	121	110	867
44	78	102	55	13	25	16	14	11	24	37	127	128	630
48	29	71	75	25	38	12	2	5	15	38	101	125	536
52	14	38	45	18	61	16	6	8	5	32	123	111	477
56	10	14	24	17	47	19	5	9	3	32	84	101	365
60	22	10	17	6	29	29	8	6	6	21	83	118	355
64	21	18	12	6	26	25	9	6	5	12	55	91	286
68	20	8	12	4	8	27	13	7	8	16	42	45	210
72	18	1	23	7	23	18	12	4	3	21	50	36	226
76	13	15	18	12	20	31	4	1	7	9	39	20	189
80	7	12	21	5	12	11	7	3	1	10	31	22	142
84	2	5	19	7	16	9	8	2		6	9	20	104
88	4	3	9		16	14	9		1	2	15	14	87
92	3	2	3	4	6	10	3				10	9	58
96	1	1	1	1	2	2	2				4		15
Total	5,271	4,614	4,987	1,738	4,321	1,430	376	328	444	765	4,104	3,390	31,768

[a]Input of the length-converted catch curve analysis.

Table 3c. Continued.

	1982				1983				1984		
Length	2	3	6	12	2	8	10	12	2	Total	Total
(in cm)	2	27	27	19	3	15	18	15	1	1982-1984[a]	1978-1984[a]
0	25	40	142							207	2,662
4	222	168	649							1,039	8,773
8	141	73	347	1						562	4,115
12	290	317	408	30	13	9	39	19	9	1,134	5,050
16	335	242	373	70	54	49	97	55	57	1,332	6,487
20	381	203	210	6	99	86	54	67	88	1,254	5,977
24	333	188	154	61	58	61	17	60	82	1,014	4,932
28	275	175	115	47	33	35	4	34	60	778	4,456
32	219	106	116	29	29	28	1	18	31	577	3,619
36	185	66	89	41	2	40		4	14	461	2,586
40	139	68	82	29	14	25		4	15	376	1,908
44	117	64	58	22	9	30	1	13	10	324	1,442
48	112	54	58	26	4	16		11	9	290	1,273
52	126	47	52	24	9	26	1	7	9	301	1,115
56	122	58	73	25	5	14		11	20	328	969
60	124	63	55	30	5	20	2	5	28	332	886
64	155	57	63	35	9	28	4	3	12	366	827
68	138	54	82	26	7	23	4	10	17	361	807
72	86	41	55	33	10	18	2	5	13	263	561
76	75	26	47	32	3	12	2	6	6	209	442
80	74	22	36	22	8	14	2	4	1	183	368
84	50	21	20	8		15	1	3	3	121	263
88	18	10	20	6		2	1	1	3	61	178
92	12	6	14	6		6		2	4	50	117
96	6	3	4			6			3	33	37
									3	3	3
Total	3,759	2,171	3,321	669	390	563	231	341	497	11,942	59,853

[a]Input of the length-converted catch curve analysis.

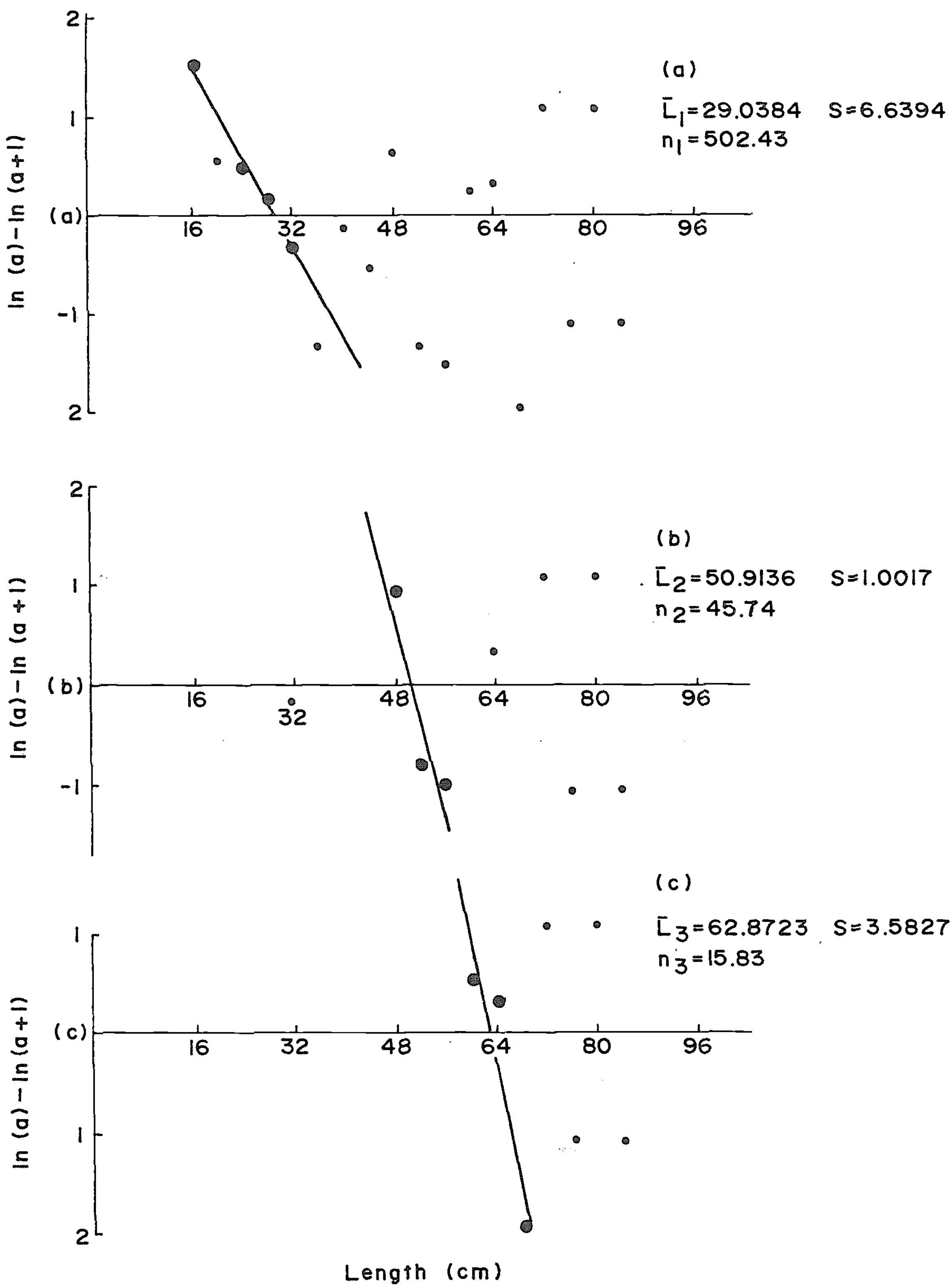

Fig. 5. Example of a Bhattacharya plot of *Lates niloticus* for sample no. 1 of trawl survey data.

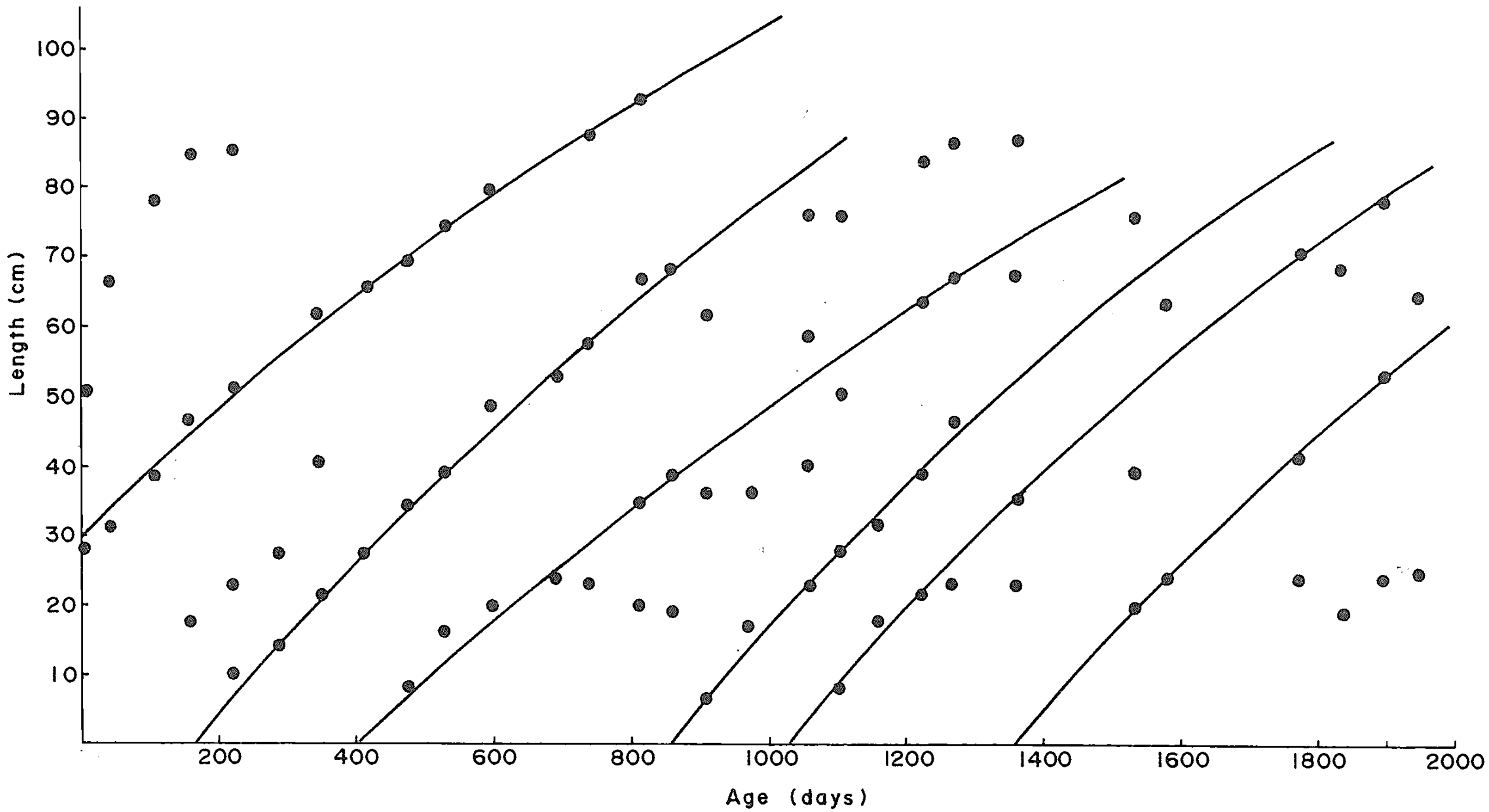

Fig. 6. Fitted growth curves to observed modal lengths from Bhattacharya analysis of *Lates niloticus*.

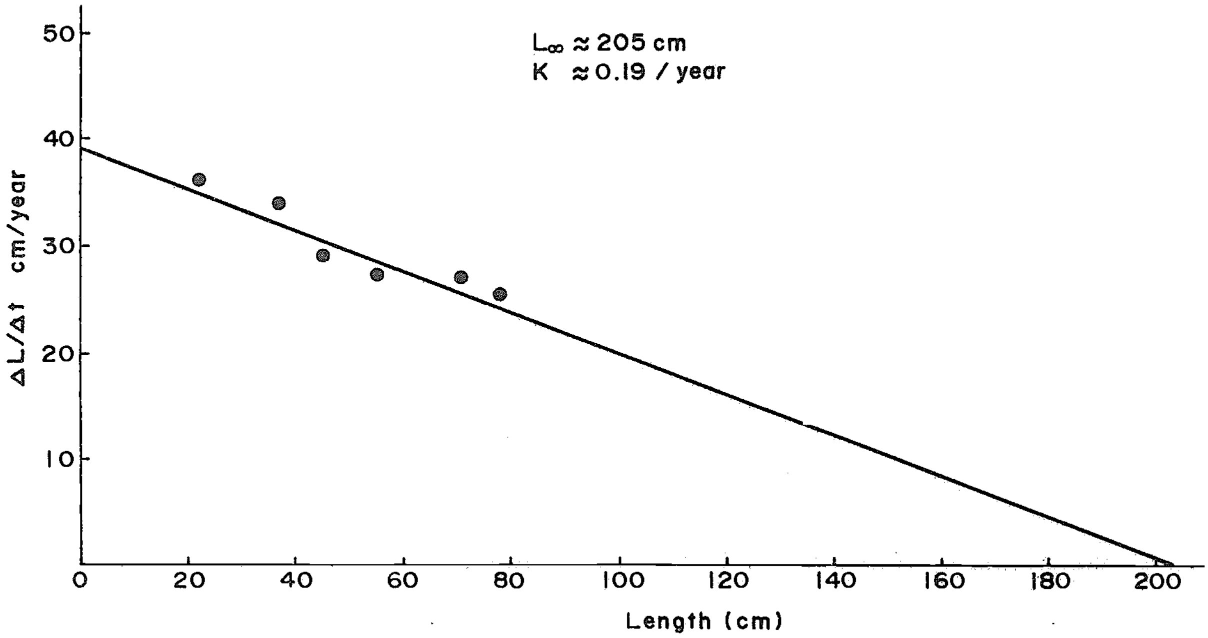

Fig. 7. Gulland and Holt plot with data from Bhattacharya analysis of *Lates niloticus*.

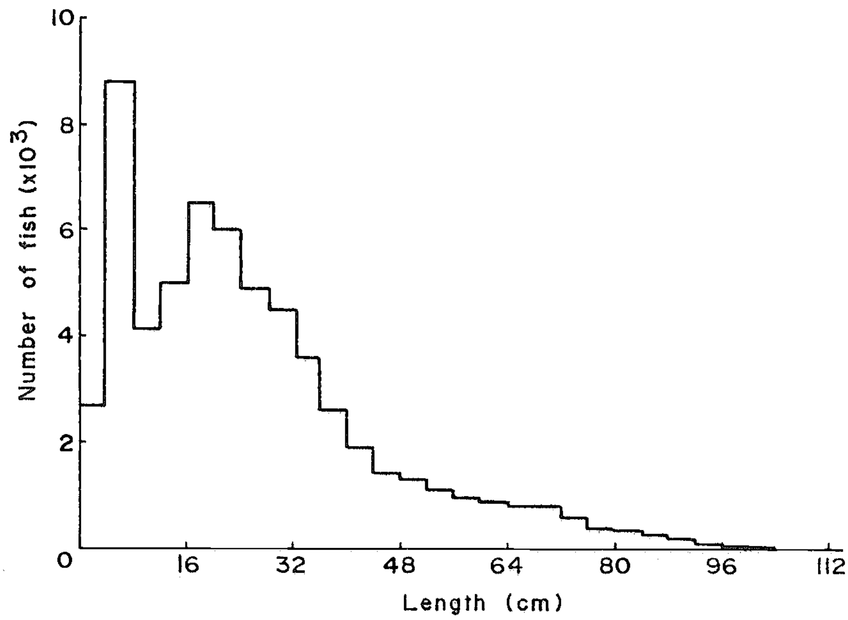

Fig. 8. Length-frequency distribution of *Lates niloticus* for pooled trawl survey data, 1979-1984.

Catch Statistics of Commercial Gill Net Fishery

Fishery and Data

The fishery of the Nyanza Gulf of Lake Victoria is operated by gill nets of mesh sizes ranging from 10 to 33 cm, shore seines, hand lines and long lines. The shore seine nets are of meshes ranging from mosquito nets to 7.5 cm for catching smaller species of fish like

Rastrineobola argenteus, *Haplochromis* spp. and, additionally, juveniles of *Oreochromis niloticus* and *Lates niloticus*.

The fishery is both at subsistence and commercial levels. Vessels used are canoes between 4.5 and 6.0 m long occasionally powered by outboard engines and wind, but mostly rowed by oars to and from the fishing grounds. Artisanal fishery practised at the river mouths (especially R. Yala, R. Nzoia and R. Nyando) catches very few fish and as a result is not included in the catch assessment survey. Since 1981, KMFRI has sampled from 14 beaches, which have over time been increased to 21 beaches in 1986 at various points along the Kenyan shore of Lake Victoria, most of which are shown in Fig. 1.

Enumerators are posted at each of the beaches to record the total length and weight of all species of fish caught. Besides, the number of crew, the types and numbers of nets used, the location of fishing and socioeconomic factors are also recorded. The procedures of taking measurements are the same as in the trawl surveys discussed above.

Length-Frequency of Total Catches from 21 Landing Places for L. niloticus

Table 4 gives the catch in numbers by months from 1981 to 1985 sampled from four beaches out of the 21 covered in the catch assessment survey (see also Fig. 9). Using the length-

Table 4. Length-frequency samples from commercial fishery for *Lates niloticus*, 1981-1985, Lake Victoria.

Length (cm)	Year / Month	1981											1982					
		1	2	3	4	5	6	8	9	10	11	12	1	2	9	10	11	12
8		0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
12		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
16		0	2	7	0	1	1	0	1	3	0	0	1	0	0	0	0	0
20		0	2	6	0	7	5	9	0	10	10	0	16	0	0	0	0	0
24		0	6	20	2	8	13	18	7	8	20	1	14	1	2	0	0	1
28		0	3	67	1	46	34	28	27	16	80	15	21	8	4	1	0	1
32		5	9	63	25	88	151	46	87	27	311	17	79	25	2	3	0	3
36		3	9	79	20	86	131	32	95	18	299	31	105	58	4	5	0	9
40		4	3	39	9	53	56	14	66	7	74	52	46	45	8	17	1	29
44		3	3	29	7	39	18	12	95	12	79	42	23	54	7	24	3	38
48		9	4	34	12	29	12	13	107	6	64	37	20	79	0	45	0	74
52		3	9	14	6	34	11	16	87	6	87	40	15	94	0	61	3	87
56		14	4	17	1	40	17	12	91	2	80	30	12	88	1	44	0	86
60		14	9	12	2	36	10	20	44	1	76	16	28	77	0	19	8	47
64		19	23	11	3	44	11	19	15	2	47	6	29	55	0	9	10	28
68		17	26	7	2	29	23	23	18	1	33	0	22	46	0	8	8	27
72		14	19	1	3	20	15	35	11	5	37	0	25	42	1	6	25	48
76		11	21	5	4	26	13	40	14	5	29	0	23	33	2	5	19	72
80		13	9	3	3	23	17	42	7	6	23	0	26	42	2	6	17	58
84		10	27	5	4	30	18	36	11	7	25	0	20	36	4	1	33	33
88		14	22	4	4	12	12	17	17	14	14	0	16	38	6	3	29	28
92		25	22	4	2	12	15	29	11	8	10	0	20	27	7	0	52	34
96		9	18	17	2	10	2	14	11	11	12	0	16	47	8	2	60	31
100		4	6	0	2	7	11	24	9	9	15	0	7	50	23	0	42	23
104		1	7	1	2	3	7	8	5	10	3	0	3	53	15	0	58	42
108		3	5	0	3	6	5	14	3	5	2	0	9	53	6	0	50	25
112		2	3	2	0	3	4	9	2	8	1	0	3	43	2	0	31	27
116		1	0	2	0	0	3	17	2	7	1	0	2	26	2	0	27	13
120		1	0	0	0	0	1	6	0	5	1	0	1	25	0	0	30	11
124		0	3	0	0	1	0	2	0	1	1	0	0	23	0	0	16	21
128		0	0	0	0	1	0	1	0	3	0	0	1	12	0	0	6	16
132		0	0	0	0	0	0	2	0	0	0	0	0	15	1	0	2	5
136		0	0	2	0	0	1	0	0	0	0	0	0	4	0	0	1	1
140		0	0	0	0	1	0	1	0	0	0	0	1	9	0	0	1	2
144		0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	1	1
148		0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	1	0
152		0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0
156		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
164		0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Total		199	274	453	129	695	617	559	843	225	1,437	287	605	1,218	107	259	535	915

weight relationship from Fig. 3, the length frequencies were raised to total catch for the beaches covered by the scheme, using the catch data presented in Table 5 and

$$N(L_i) = n(L_i) \times \text{(total catch in weight)/(weight of sample)}.$$

The frequencies were summed up by length groups and averaged per year and the results were used as input data to the length-cohort analysis in order to determine the fishing mortality and stock size. It should be noted that the cohort analysis discussed below is actually a relative length cohort analysis since it is based on data for the 21 landing places only, and not on the total landings from Kenyan waters.

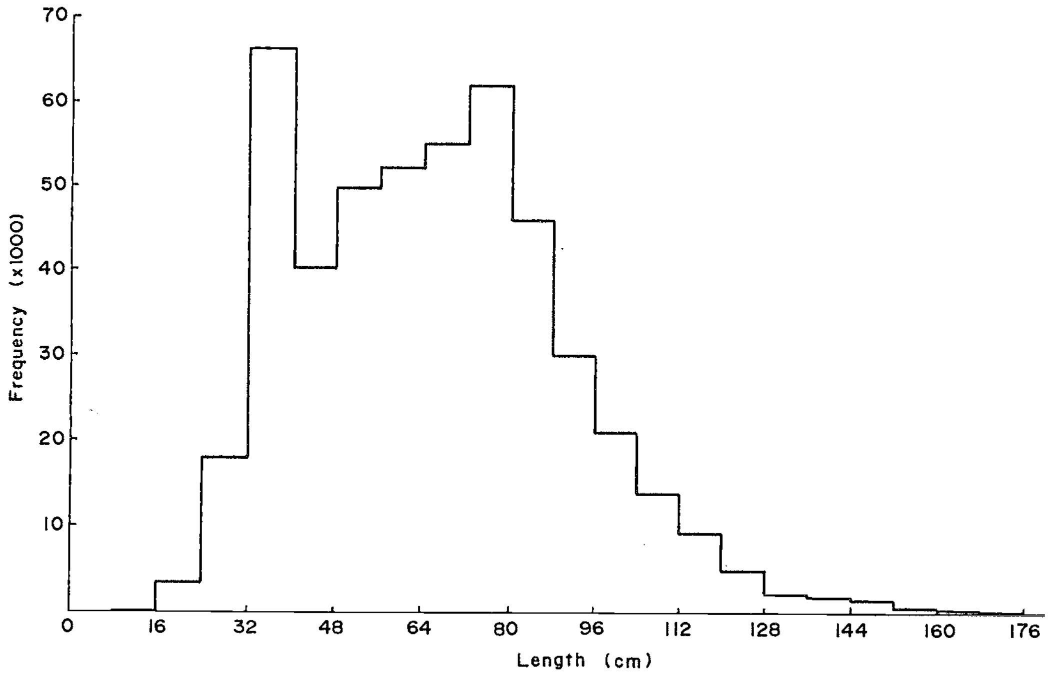

Fig. 9. Mean frequency distributions at length group of *Lates niloticus* from commercial gill net fisheries, 1981-1982.

Table 5. Catch of *Lates niloticus* by month from the catch assessment survey from 1981-1985 (in kg).

Month / Year	1981	1982	1983	1984	1985
January	62,387	218,316	266,429	284,638	291,001
February	85,472	214,379	229,310	179,638	204,514
March	171,528	250,667	214,482	176,465	249,597
April	181,036	218,747	86,244	182,815	302,873
May	228,827	266,970	279,445	47,057	319,196
June	159,112	216,236	94,816	36,438	278,250
July	154,310	224,355	174,342	203,060	270,183
August	139,664	253,256	209,031	225,592	284,795
September	199,821	279,869	324,106	228,245	276,315
October	189,017	281,369	269,917	220,918	260,926
November	147,829	254,268	219,600	201,684	183,990
December	126,685	229,271	219,600	201,684	183,990
Total	1,845,688	2,907,703	2,586,453	2,127,941	3,137,467

"Relative" Length Cohort Analysis

Fishing mortalities and stock numbers accounting for 21 landing places were estimated using Jones' length cohort analysis (Jones 1984).

The natural mortality coefficient was derived using the empirical formula given by Pauly (1980). The temperature adapted was 26°C which is the average water temperature in the Nyanza Gulf. The calculated value of natural mortality was M = 0.34/year. Because the data cover only a fraction of the total fishery, they were insufficient for estimating the total stock size. This is the reason for emphasis on the word "relative". Results are given in Table 6 and Fig. 10. Table 6 gives an estimate of the fraction of the stock which accounted for the catch of the 21 beaches covered by the sampling scheme, viz. 12, 735 tonnes.

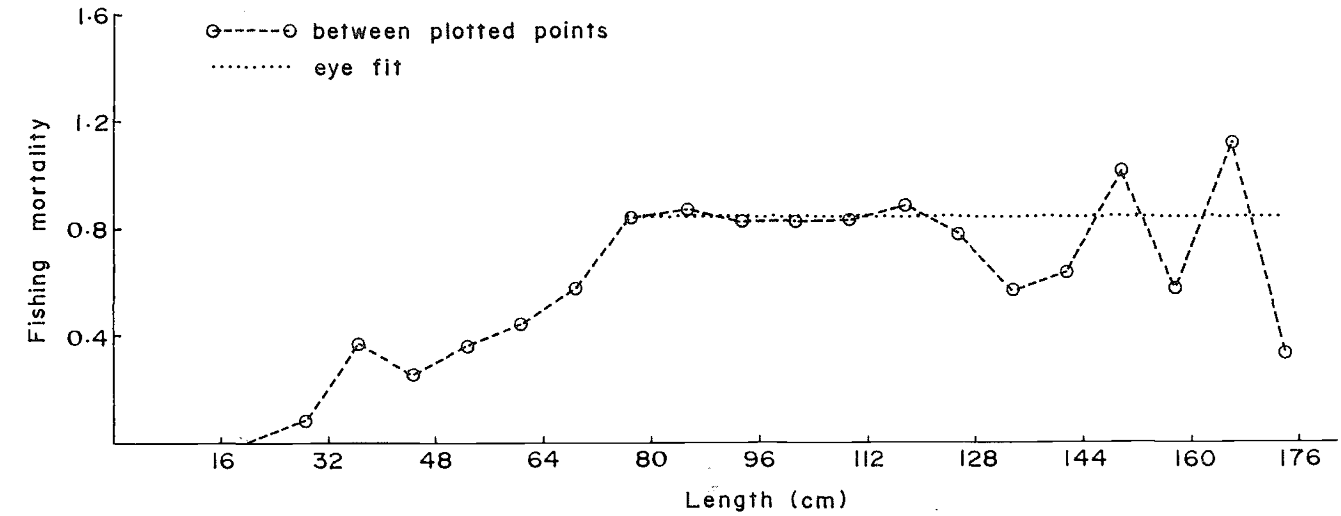

Fig. 10. Fishing mortalities of *Lates niloticus* for combined data 1981-1985 from Jones' length cohort analysis for M = 0.34 per year.

Table 6. Results from Jones' length-converted cohort analysis for *Lates niloticus*, with M = 0.34.

Length (cm)	C	N	F/Z	F	Z	N * W
8	31.4	983,235.8	0.000	0.000	0.34	17,848.1
16	3,362.4	912,903.4	0.047	0.017	0.36	81,569.3
24	17,804.4	841,679.7	0.216	0.094	0.43	214,866.4
32	66,289.2	759,175.4	0.529	0.383	0.72	424,516.4
40	40,027.4	633,964.3	0.434	0.261	0.60	663,018.6
48	49,636.0	541,729.9	0.518	0.366	0.71	954,117.3
56	51,999.0	445,963.0	0.569	0.448	0.79	1,227,493.7
64	54,864.0	354,533.0	0.629	0.576	0.92	1,442,025.8
72	61,943.6	267,276.3	0.715	0.851	1.19	1,538,110.0
80	45,465.8	180,594.3	0.722	0.881	1.22	1,420,181.8
88	29,839.4	117,583.1	0.710	0.834	1.17	1,228,150.2
96	20,615.4	75,579.0	0.708	0.825	1.17	1,239,975.8
104	13,601.6	47,105.9	0.712	0.841	1.18	811,420.5
112	9,019.8	28,005.5	0.722	0.885	1.22	602,893.8
120	4,837.4	15,519.5	0.697	0.781	1.12	411,378.8
128	2,198.2	8,575.5	0.624	0.565	0.90	276,273.1
136	1,573.2	5,054.3	0.653	0.640	0.98	195,645.1
144	1,305.4	2,645.1	0.750	1.023	1.36	121,771.9
152	319.4	905.7	0.631	0.58	0.92	49,138.5
160	256.2	400.1	0.769	1.13	1.47	25,372.9
168	33.4	66.8	0.500	0.34	0.68	4,914.9
	Total number	6,222,495.6			Total weight	12,734,682.9 g

Discussion and Conclusion

Bhattacharya analysis was successfully used in separating out cohorts of *Lates niloticus* into progressing modal lengths for calculating the growth parameters L_∞ = 205 cm and K = 0.19/year.

Acere (1985) obtained K = 0.09/year and L_∞ = 251 cm for *L. niloticus* in the northern waters of Lake Victoria (Uganda waters) using a probability paper method. Hopson (1972) gave K = 0.272/year, L_∞ = 93.07 cm and t_0 = 0.046, using data obtained from scale readings for the first five years of *L. niloticus* from Lake Chad. Hopson's data were used to re-estimate the growth parameters using all ages. The newly derived estimates were K = 0.09/year, L_∞ = 181 cm and t_0 = -0.85. Calculating ϕ' [Pauly and Munro (1984) described by Lablache and Carrara, this vol.], the results in the present paper are very different from the other two earlier results (Table 7). Okemwa (1984) reported fish of 2 m length caught in a beach seine at Luanda Kotieno weighing nearly 200 kg.

The stock biomass estimated from Jones' length cohort analysis (12,735 t) agrees with an earlier estimate of 13,500 t from the swept area method (KMFRI 1984) for the Nyanza Gulf. This finding might indicate that the 21 landing places covered by the present sampling scheme contribute the major part of the Nyanza Gulf fishery. Thus, the figures in Table 6 may not underestimate the total stock size to a great extent.

The total mortality estimates from the catch curve analysis (Z = 1.6 ± 0.1) and Jones' length-converted cohort analysis (Z = 1.2) differ by about 25%. This may be accounted for by the other gears used in the Nile perch fishery whose catches were not included in the analysis.

Table 7. Comparison of growth parameters.

Source	L_∞ (cm)	K ($year^{-1}$)	ϕ'^{a}
Hopson (1972) (young fish only)	93	0.27	3.37
Hopson's data re-calculated (using all ages)	181	0.09	3.47
Acere (1985)	251	0.91	4.76
This study	205	0.19	3.90

[a] $\phi' = \log_{10}K + 2\log_{10}L_\infty$.

Acknowledgements

We are thankful for the support given by the Director and staff of Kenya Marine and Fisheries Research Institute, particularly the technicians who assisted in all possible ways in the collection and organization of the data.

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Sources of Bias in Growth and Mortality Estimation of Migratory Pelagic Fish Stocks, with emphasis on *Decapterus russelli* (Carangidae) in Mozambique

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Abstract

A reassessment of estimates of growth and mortality of the Indian scad, *Decapterus russelli* is made after the available age readings and size-frequency distributions have been evaluated for different sources of bias.

Because of the migratory nature of this species, it has proved difficult to obtain random samples (representing the entire population) based on data collected from the commercial fishery which is restricted to certain fishing grounds.

It was concluded that growth estimates based on properly sampled age data are the best, followed by results obtained by combining length-frequency data and age data. Those based on length frequency alone gave the most biased results.

Catch curve estimates of total mortality were inacceptably high and therefore an alternative method, the "matched samples method", is proposed for the estimation of total mortality from length-frequency data.

Introduction

The Indian scad, *Decapterus russelli* (Rüppell 1830) is the most common scad in the Indian Ocean. It is broadly distributed throughout the Western Indian Ocean and also in the Western Pacific from Japan to Australia. It inhabits coastal waters and open banks at depths not exceeding 100 m (Smith-Vaniz 1984).

Investigations on round scads have been conducted mainly in Southeast Asian coastal states and pertinent references may be found in SCSP (1978), Ingles and Pauly (1984) and Widodo (this vol.).

In Mozambique, a research program for the study of scads, *Decapterus russelli, D. macrosoma and Selar crumenophthalmus* and mackerels, *Rastrelliger kanagurta* and *Trachurus trachurus* has been carried out since 1979. These species are caught in a bottom trawl fishery which started in September 1977. The fishery takes place at Sofala Bank and Boa Paz (Fig. 1).

At Sofala Bank the highest catch rates were obtained at depths of 40 to 100 m in the area south of the Zambesi River. From 1980 to 1984 the total catch amounted to 28,000 t of which 21,000 t came from Sofala Bank and 7,000 t from Boa Paz. Nearly 35% of this catch consisted of *D. russelli* which was the dominant species in the catches.

The spawning peaks at Sofala Bank were found at the end of the wet season (February-March) and at the end of the dry season (August-September). The spawning grounds were found in the areas where the fishery takes place (Figs. 1 and 2). First estimates of growth parameters based on age readings and length-frequency distributions suggested that the species have a lifespan of nearly 4 years. Only few fish older than three years occur in the catches. The estimated turnover rate had a value of 3.16. This value seems to be very high and thus can hardly be explained by mortality alone. The fishing mortality was found to be low compared to the combined effect of natural mortality and possible migrations and the conclusion reached was that the fishery may be expanded further without endangering the stock.

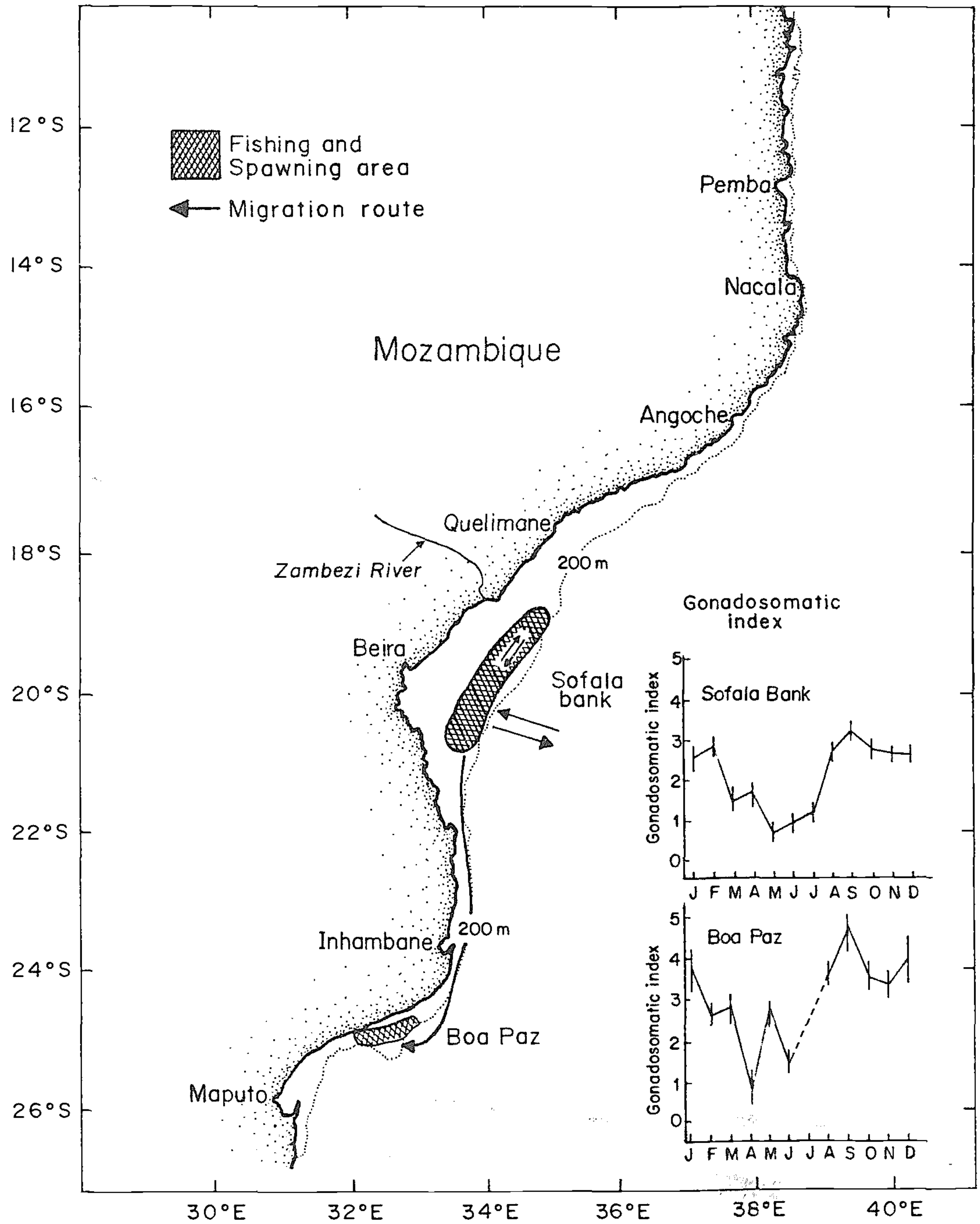


Fig. 1. Fishing and spawning grounds of *Decapterus russelli* off Mozambique, with an indication of possible migration routes and gonadosomatic indexes by area.

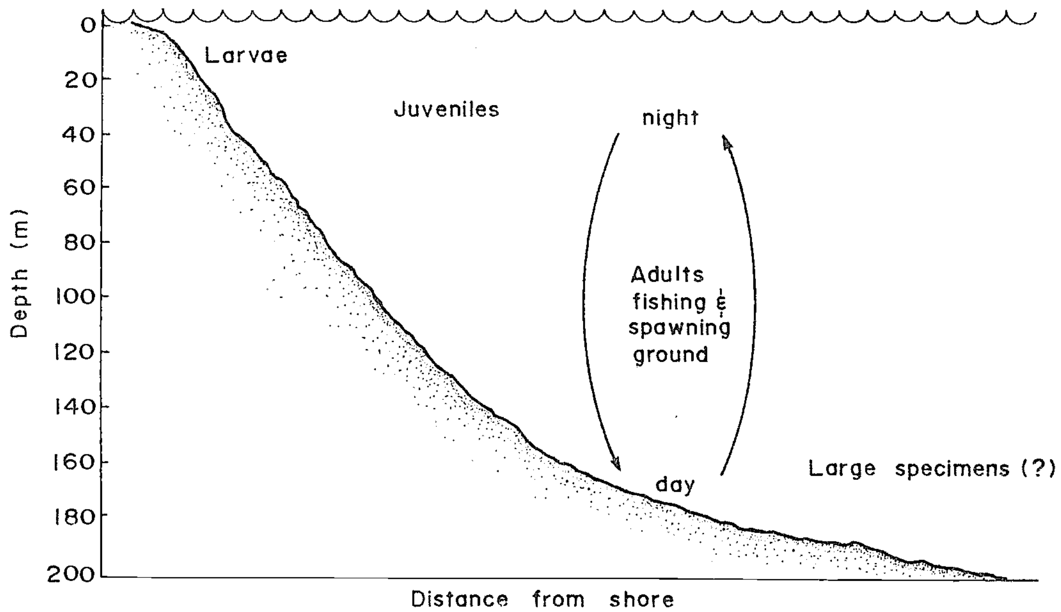


Fig. 2. Selected features of the life history and migration of *Decapterus russelli* off Mozambique (see also Fig. 1 and text).

Due to the behavior and habits of the investigated fish, e.g., their schooling behavior and migrations which may result in differences in a viability or catchability between different age groups of the population, an efficient sampling method representative of the entire population is required. However, samples were mainly collected on board commercial vessels which usually tend to aggregate in the areas where greatest quantities of fish are available.

This paper attempts at presenting the various sources of bias caused mainly by migrations and their effects on growth and mortality estimates.

Materials and Methods

Growth Parameter Estimates from Length and Age Data

Data on age readings and length-frequency distributions used for the preliminary growth estimates in Gjøsaeter and Sousa (1983) and Brinca et al. (1983) were reanalyzed.

Age readings from two sets of data, one from commercial catches (fish of 13.4 to 18.6 cm) and the other from a pelagic trawl survey (fish of 4.2 to 13.0 cm), were combined and the least squares technique used to estimate the growth parameters of the von Bertalanffy growth equation, using a routine provided by P. Sparre (pers. comm.).

A combined set of length-at-age data selected from the age readings and the monthly length-frequency distributions obtained in 1980 from commercial catches (except for the sample collected in September 1980, which was replaced by another collected in September 1982 in a pelagic trawl survey) (see Table 1), was used in conjunction with the ELEFAN version of Brey and Pauly (1986) which allows simultaneous analysis of length-at-age data.

Nine ages were entered (Table 2) and 99 pairs of age i/length i and age i+1/length i+1 were randomly selected by the program from all possible combinations of growth increments. The ELEFAN I program was then used for the identification of the best fitting growth curve to the restructured length-frequency samples combined with the set of length-at-age data, expressed as growth increments. The matrix obtained shows the response of the ESP/ASP ratio to changes in the growth parameters and helps identify the best growth parameter estimates.

The version of ELEFAN I of Saeger and Gayanilo (1986) was used to graph the restructured samples and the growth curve.

Table 1. Length-frequency data on *Decapterus russelli* from Sofala Bank, Mozambique, as used for analysis with the ELEFAN I and ELEFAN II programs of Brey and Pauly (1986) and Saeger and Gayanilo (1986), respectively.[a]

Sample No		1	2	3	4	5	6	7	8	9	10	11
Month		15.01	15.02	15.03	15.04	15.06	15.07	15.08	15.09	15.10	15.11	15.12
Class cm	Midlength											
1	6.75	0	0	0	0	0	0	0	1	0	0	0
2	7.25	0	0	0	0	0	0	0	3	0	0	0
3	7.75	0	0	0	0	0	0	0	10	0	0	0
4	8.25	0	0	0	0	0	0	0	10	0	0	0
5	8.75	0	0	0	0	0	0	0	5	0	0	0
6	9.25	0	0	0	0	0	0	0	1	0	0	0
7	9.75	0	0	0	0	0	0	0	2	0	0	0
8	10.25	0	0	0	0	0	0	0	2	0	0	0
9	10.75	0	0	0	0	0	0	0	3	0	0	0
10	11.25	0	0	0	0	0	0	0	8	0	0	0
11	11.75	0	2	0	2	0	0	0	11	0	0	0
12	12.25	0	1	0	19	5	9	0	19	0	0	0
13	12.75	1	0	0	32	17	34	0	14	0	0	0
14	13.25	0	3	0	66	80	311	1	22	1	0	0
15	13.75	0	18	0	128	115	816	15	30	4	0	1
16	14.25	9	65	7	324	379	1820	54	31	17	1	0
17	14.75	29	252	31	332	717	2343	131	46	29	4	8
18	15.25	80	624	85	543	1606	3354	197	59	38	28	32
19	15.75	129	690	192	500	1690	2624	196	66	27	31	46
20	16.25	324	1099	241	605	1312	2183	206	126	18	40	66
21	16.75	533	2009	264	513	1100	1490	185	129	21	42	61
22	17.25	465	1371	243	480	723	1086	183	100	12	18	33
23	17.75	204	764	118	296	396	643	117	52	11	8	29
24	18.25	79	275	52	193	169	313	56	26	1	3	
25	18.75	32	100	22	111	106	117	26	10	1	0	2
26	19.25	11	36	13	42	52	42	5	5	0	0	1
27	19.75	3	8	0	8	4	17	1	1	0	0	0
28	20.25	2	3	8	0	0	14	3	0	0	0	0
29	20.75	0	1	1	0	0	0	0	1	0	0	1

[a]All data stem from commercial bottom trawl catches made in 1980, except for the September (8th) sample, which originates from a pelagic survey conducted in 1982.

Table 2. Selected[a] length-at-age data of Indian scad (*Decapterus russellii*) from Sofala Bank, Mozambique.

Relative age[b] completed Year(s)	months	days	Length (TL, cm)	number of observations
0	4	18	4,2/4,4/4,5	3
0	7	11	6,7/6,8/6,5	3
0	8	16	8,2/7,5/7,1/7,7/8,3/8,8	6
0	11	10	9,7/10,1/10,8/10,1/10,3/10,1	6
1	2	10	11,9/11,5/11,2/11,3/13,8	5
1	4	17	12,9/15,0/15,2/14,5/15,4/14,4/15,1/15,2	9
1	6	16	16,9/15,9/15,1/15,3/16,1/15,6	6
1	9	13	16,9/17,8/16,5	3
1	11	15	17,7/18,6/18,0/17,2/17,4/17,7	6
				47

[a]These data represent a subset of the daily age data presented in Fig. 7, selected such as to satisfy the requirements of the ELEFAN I routine of Brey and Pauly (1986), which should be consulted for further details.

[b]The age is relative to an arbitrary birth date set on the 1st January. This has no impact on results as long as growth is assumed not to oscillate seasonally.

Estimation of Z Under the Assumption of a Stable Age Distribution and Using the "Matched Samples Method"

Estimates of Z assuming a stable age distribution

The version of ELEFAN II of Saeger and Gayanilo (1986) was used for estimation of mortality using a length-converted catch curve. The samples were weighted by the square root of their original size (after being expressed in percentages) and then added up.

Total mortality was also estimated, using the same accumulated data set and the equation of Beverton and Holt (1956), which is part of ELEFAN II, along with the empirical equation of Pauly (1980) for the estimation of natural mortality (M). The catch curve that was obtained also indicated the number of individuals that would have been caught if the effects of gear selection and incomplete recruitment were not corrected for. By the construction of the resultant curve with the probabilities of capture by length classes, the length at which the probability of capture is 0.5 (Lc) was then obtained.

The "matched samples method"

The "matched samples method" is a method for estimation of the total mortality coefficient, Z.

The estimate of Z is obtained from

$$Z = \frac{1}{dt} \ln \left(\frac{N(t)}{N(t+dt)} \right)$$

where N(t) is the number of survivors from a cohort at age t years and N(t+dt) is the number of survivors from the same cohort the time period dt years later.

The estimates of N(t) and N(t+dt) in numbers caught per unit of effort are obtained from length frequencies using knowledge of the growth curve.

The basic idea is that the migration pattern (more or less) repeats itself from year to year (see example in Fig. 10). Thus, when comparing two samples with a time difference of dt = 1 year they should be comparable (they should "match"). Two samples are considered comparable if they (more or less) show the same structure as far as separation into cohort components is concerned. Further, the mean lengths of corresponding cohorts in the two samples should conform to the growth curve.

The procedure is as follows:

1) Separate the length frequencies into normally distributed components using the Bhattacharya method (see Asila and Ogari, this vol.).

2) Check that mean lengths of corresponding cohorts conform to the growth curve.

3) Check that the cohort structures in the two samples are similar (e.g., the same number of cohorts with approximately the same relative sizes).

4) Calculate Z (using the formula given above and the results of the Bhattacharya analysis).

The method as presented here contains some elements of subjectivity, the degree of which depends on the nature of the data. If the length frequencies show a clear cohort structure, i.e., it is easy to resolve them into normally distributed components in an unambiguous way, the method becomes less subjective.

Separation of Z into Its Components (M and F)

An estimate of M was derived using the empirical equation of Pauly (1980); F could then be estimated from F = Z - M.

Fishing mortality was also estimated directly from

$$F = Y/B$$

where Y is the annual catch in weight; F, the instantaneous fishing mortality rate (on an annual basis); and B, the mean biomass in the course of a year (Sekharan 1974). The value of Y used corresponds to the annual catch of *D. russelli* obtained in 1985 and the biomass estimate was obtained from the swept area method.

Recruitment Patterns

Recruitment patterns were derived and the NORMSEP program used to identify recruitment pulses. Two recruitment pulses were expected to occur per year and separated by about 6 months; the iterations were initiated accordingly (see Saeger and Gayanilo 1986).

As an alternative to the length-based recruitment pattern, the frequency distribution of birthdates of aged fish were also plotted and analyzed.

Effects of Bias Caused by Migrations on Growth and Mortality Estimation

A basic requirement for all traditional fish stock assessment models is the use of random samples of the population. However, gear selectivity and the occurrence of migrations in pelagic fish stocks may strongly affect the representativeness of the samples.

Systematic bias due to schooling behavior and migrations of scads are illustrated in Fig. 3. Such bias occurs because of: (i) diel vertical migrations; (ii) spawning migrations; (iii) "migration" of adults; and (iv) large-scale migrations.

Environmental or population changes may also occur so that a population's growth rate can differ from that of individual fishes.

Diel vertical migrations were found to occur while the scads are on the fishing grounds (Saetre and Silva 1979). During the day they form schools very close to the bottom and disperse at night in the water column. For this reason commercial trawlers operate with bottom trawl nets only during daytime (Fig. 2).

Migration of young fish to the fishing grounds (recruitment) occurs after the fish reach the size at which sexes can be differentiated. At this size (10-11 cm), they start to be caught by commercial bottom trawlers. At about 13 cm they reach first maturity (Brinca et al. 1984). It is likely that the larvae drift away from the spawning ground to a nursery ground, in shallower waters. They are there more secure from predation and the food available enables them to grow, until as young fish they can swim to the spawning grounds (Cushing 1968, chapter 2).

The commercial fishery takes place at Sofala Bank mainly during the spawning seasons when the highest catch rates can be obtained. The concentrations of fish occur at depths from 40 to 100 m and the size of fish usually caught ranges from 11 to 22 cm. Only rarely do fish of larger size occur in the catches (fish up to 27 cm have been caught).

It is possible that older, larger fish migrate away from the fishing grounds. Alternatively, it is possible that their higher swimming speed reduces their vulnerability to the fishing gear (Fig. 2). The word "derecruitment" is used to describe this.

There are indications (Sousa 1983; Brinca et al. 1983; Averin et al. 1983) that migrations of scad may occur between the two main fishing grounds of Sofala Bank and Boa Paz (Fig. 1).

Data from surveys suggest that scad at Sofala Bank tend to concentrate for spawning in the area located south of the Zambesi River, from latitudes 18°50'S to 21°00'S. Migration from latitude 16°00'S southwards was observed at the time spawning approaches. During the spawning season practically the whole stock at Sofala Bank was found to be concentrated on the spawning grounds (Borges et al. 1984). Movements of the commercial fishing fleet from Sofala Bank to Boa Paz generally coincide with the spawning peaks in the southern area, which occurs one to two months later than at Sofala Bank. Also at this time the largest specimens ever recorded in Mozambique appeared in the catches. It is likely that at least a part of the Sofala Bank stock moves southwards to Boa Paz where the growth cycle is probably completed (Fig. 1).

Theoretical Considerations on the Effects of the Use of Biased Samples on Growth and Mortality Estimates

One way of presenting the subject is to consider a hypothetical example of a population of small pelagic fish, assumed to have a lifespan of three years of which the first year represents the unexploited phase, which spawns and recruits twice a year.

Samples for length composition are taken throughout the year. In such case, the expected total population should resemble that represented in Fig. 4, where each of the modes (A to F) can be connected along the time series of length samples. The shifting of modes may give the growth increments of the population. However, if the population is being exploited from its first birthday (Fig. 4b) (modes A and B are missing in the catches) and if some fish have already left the fishery (modes D and F), the interconnection of different modes may lead to misinterpretation of the age groups. Then growth may appear to be negative because of migration of young and large fish, respectively, in and out of the fishing grounds (Fig. 3).

If large specimens arrive when the small ones have not yet been recruited to the fishing grounds (Fig. 5), one can expect an underestimation of the growth rate.

Fig. 6. illustrates a problem often encountered when estimating mortality rates from length frequencies of short-lived migratory species. It shows a (hypothetical) length-frequency sample composed of two cohorts. A third cohort is absent either because it migrated out of the fishing grounds or because it died out. In case of constant recruitment the slope A is related to mortality (the steeper the slope the higher the mortality). Slope B, however, is related to individual differences in growth rates and/or differences in birthdays within the second cohort. Slope B has no relation to mortality rates.

Often, it is difficult to distinguish between these two types of slopes, and if misinterpreted, it creates an overestimate of the mortality rate.

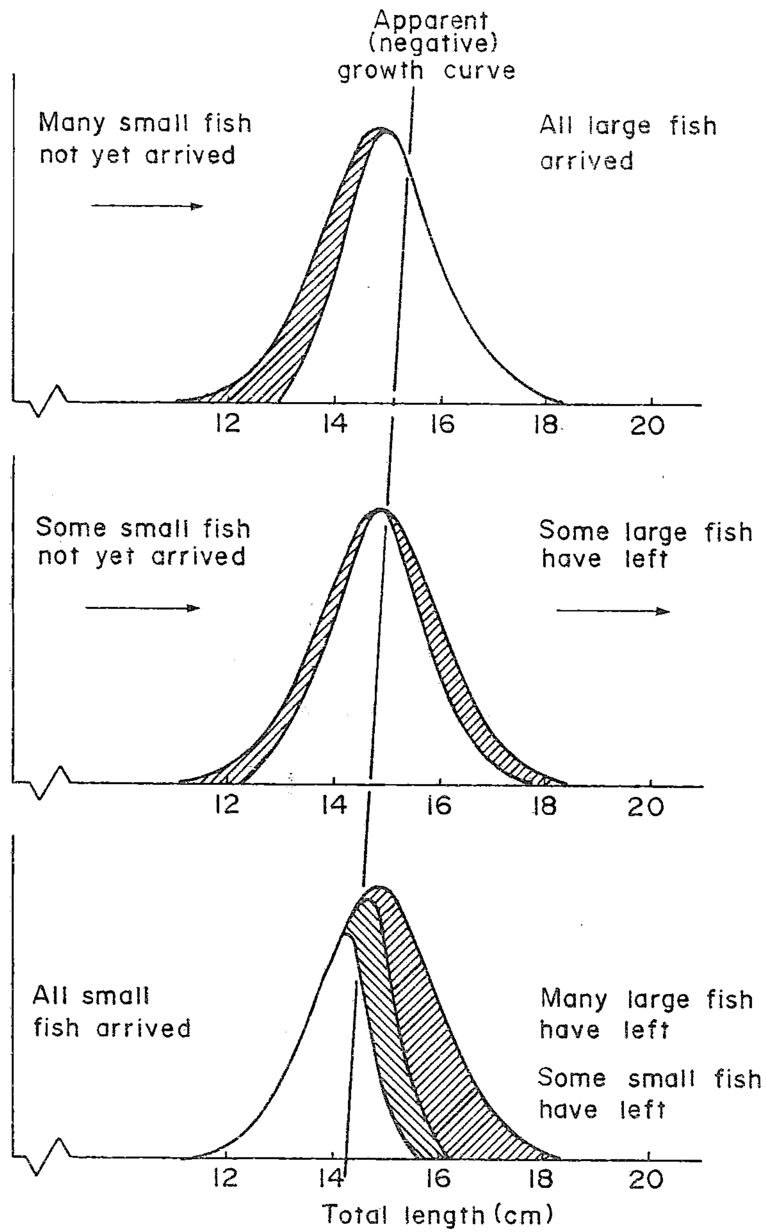


Fig. 3. Schematic representation of reasons why length frequency samples often suggest negative growth. Dashed areas indicate that part of the population that is not sampled.

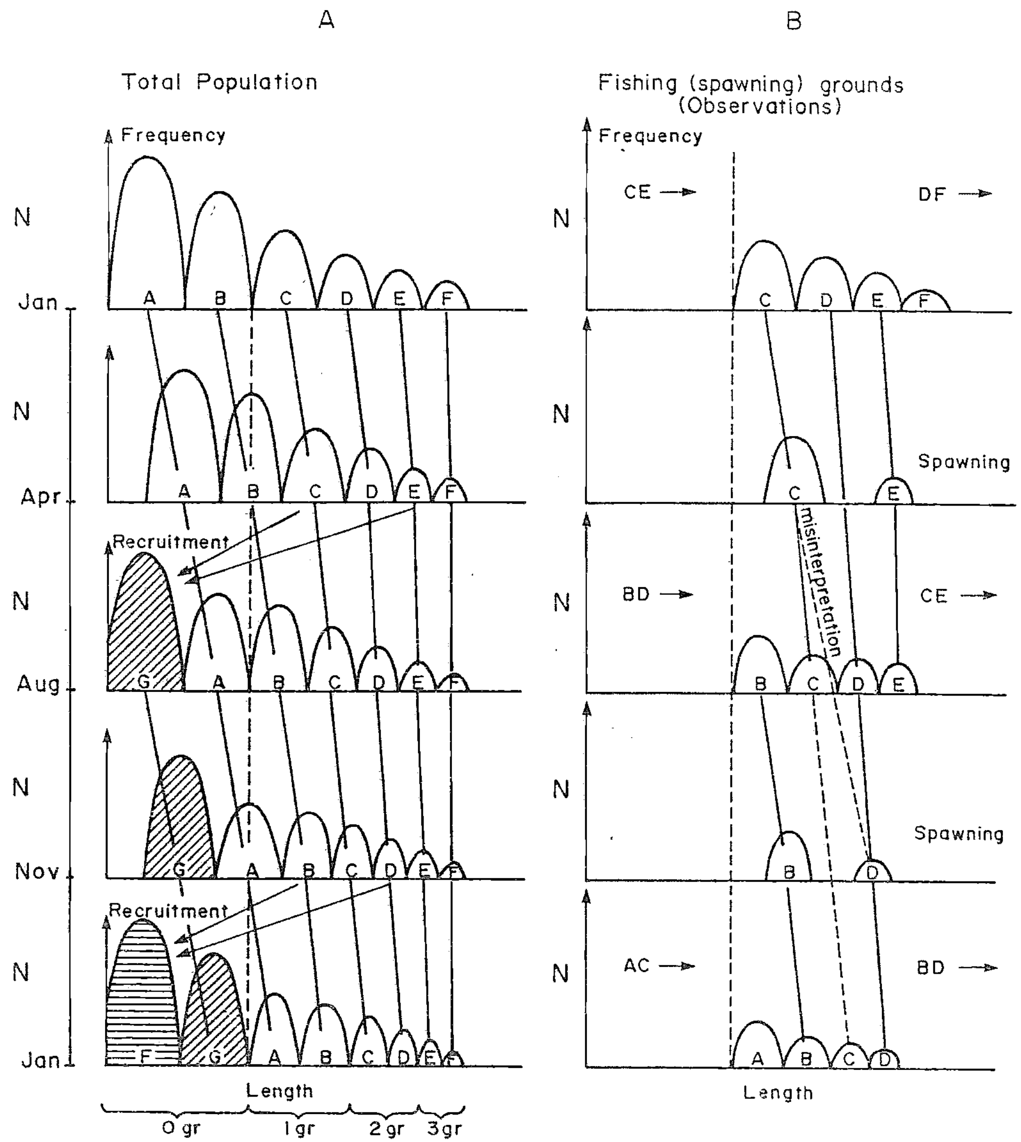


Fig. 4. Selected series of length distributions illustrating the problems in the interpretation of modal progressions. The broken lines pass through the mean length of each sample (N = number of fish).

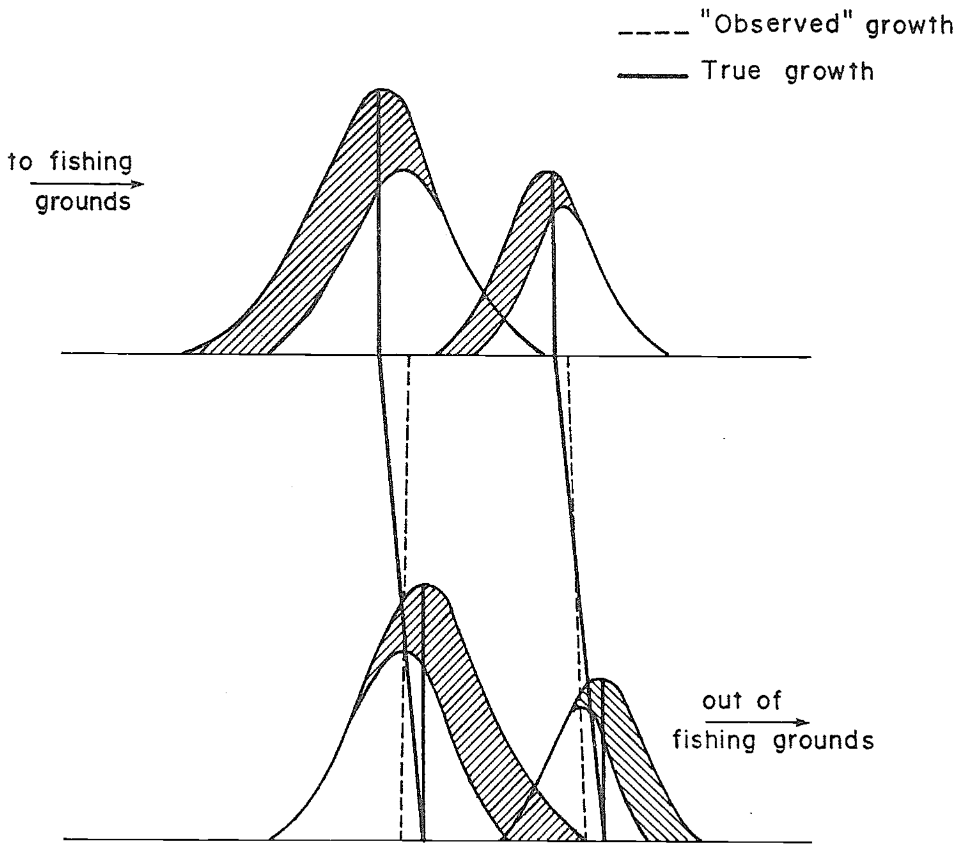


Fig. 5. Schematic presentation of the bias caused by size-dependent migration. Dashed areas indicate parts of the populations that are not sampled (see text).

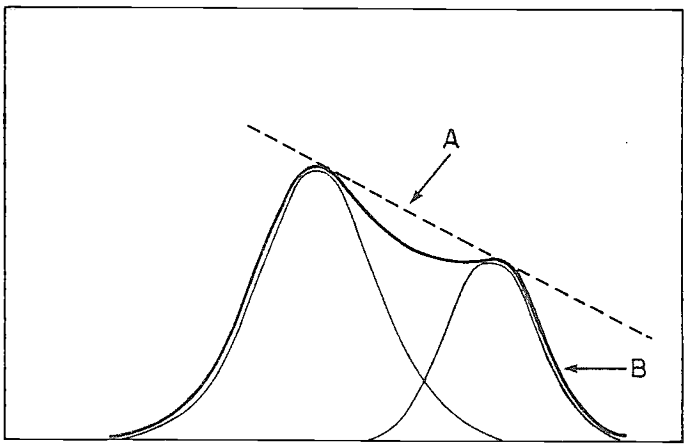


Fig. 6. Schematic presentation of two slopes (A, B) that may be used to obtain an estimate of mortality. Only the first of these two options (A) does reflect mortality. The other (B) reflects mainly difference in growth rate of the fish in a given cohort.

Results

Growth Estimates

Growth estimated from age readings

A total of 118 observations was used for the estimation of growth parameters. The results obtained are presented in Table 3. Fig. 7 shows the data used, the growth curve obtained as well as a plot of its residuals.

Growth parameters estimates from age readings in *D. russelli.*

Parameter	Estimated value	95% Confidence limits lower	upper
L_∞ (TL, cm)	27.9	23.2	32.7
K ($year^{-1}$)	0.562	0.394	0.730
t_0 (year)	0.175	0.112	0.238

Growth estimated from combined length and age data

The combined length and age data from Table 2 were used to run the ELEFAN I program of Brey and Pauly (1986). From the response surface calculation for a given starting point and length (Table 4) the growth parameters selected were $L_\infty = 26.0$ cm and $K = 0.474$. The growth curve is shown in Fig. 8. It can be seen that the curve missed a great number of the available peaks in the restructured samples, which is reflective of values for goodness of fit in Table 4.

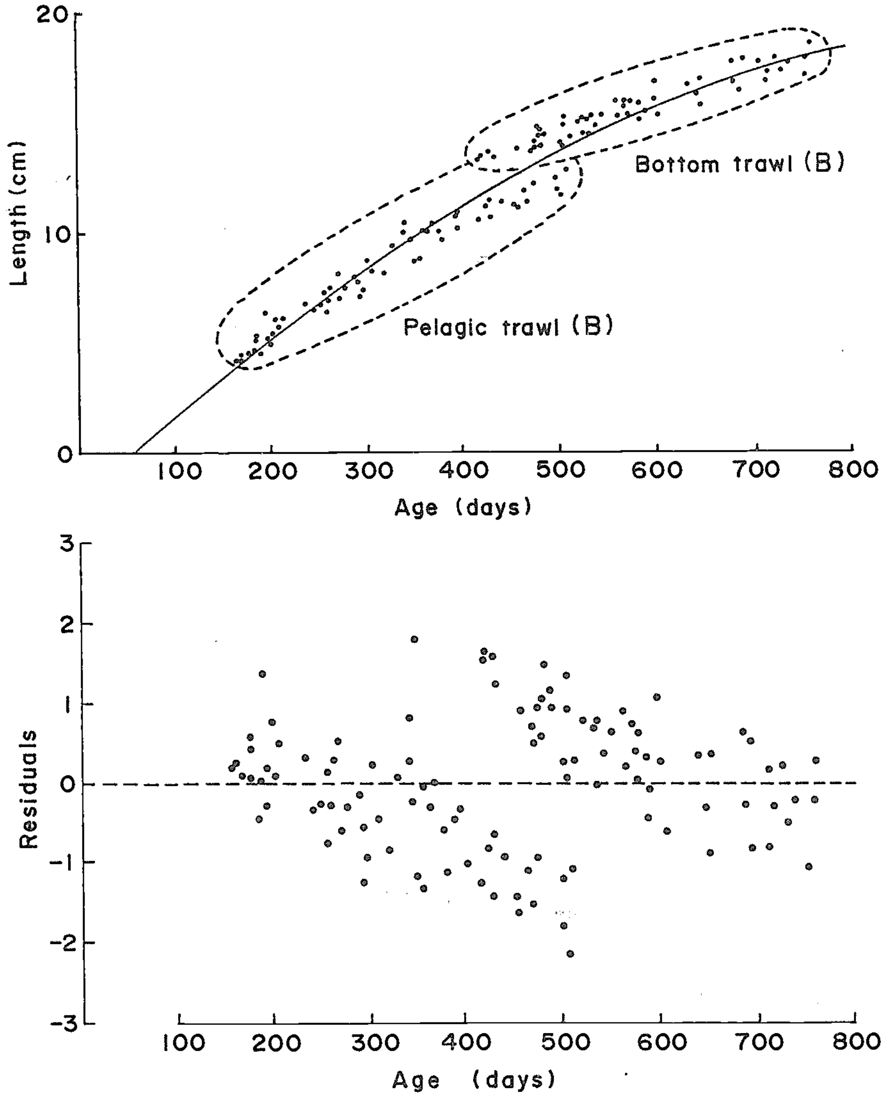
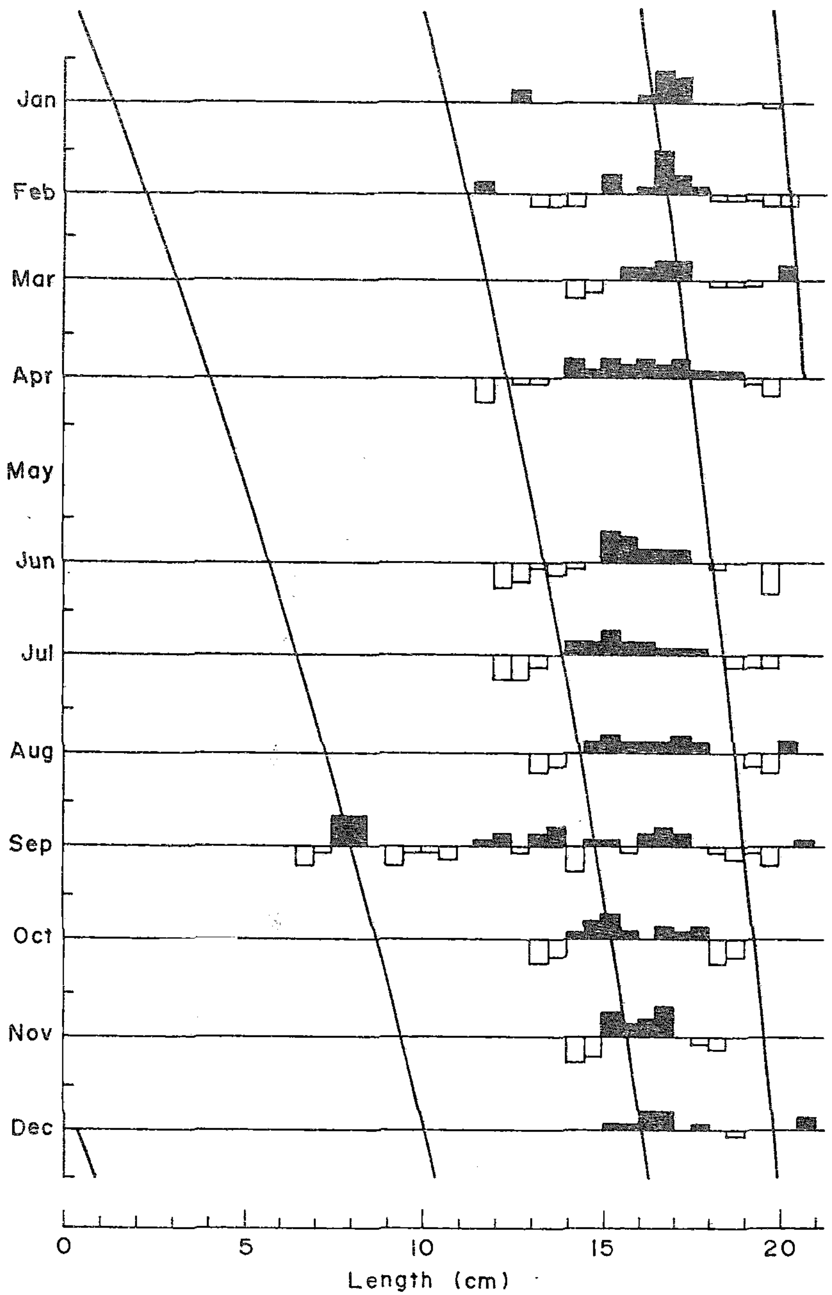


Fig. 7. *Top:* Growth curve of *Decapterus russelli* on Sofala Bank based on daily age readings (N = 118) of fish sampled by the commercial fishery (bottom trawl, 1980) and during a pelagic trawl survey, 1982 (see text). *Bottom:* Residuals of growth curve sharing both sets of data. Note structure of the residuals.



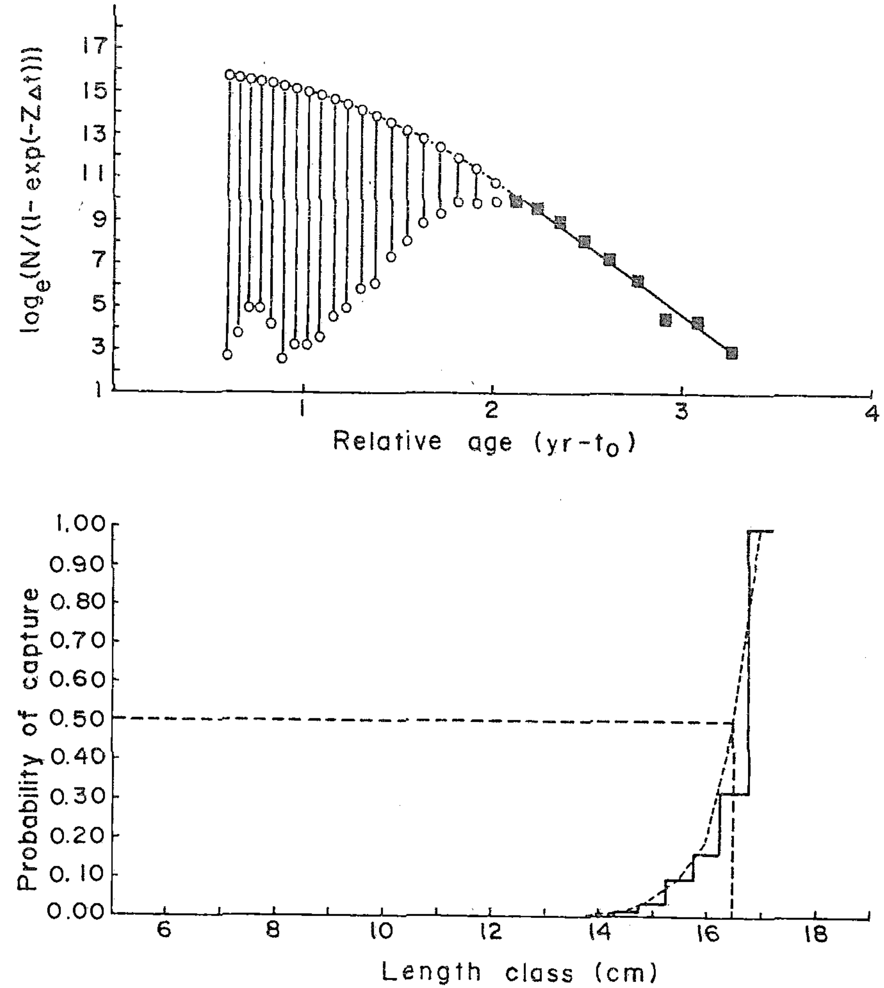


Fig. 9. *Top:* Length converted catch curve of *Decapterus russelli* on Sofala Bank (based on data in Table 1 and growth printers L_∞ = 26 cm, K = 0.474. The estimate of Z = 6.3 is biased upward (see text). *Bottom:* Approximate probability of capture by length of *Decapterus russelli* caught by the commercial fishery on Sofala Bank.

Fig. 8. *Left:* Length-frequency data on *Decapterus russelli* from Sofala Bank (from Table 1), restructured and plotted using the ELEFAN I version of Saeger and Gayanilo (1986) and superimposed with growth curve obtained by simultaneous analysis of length-at-age data using the ELEFAN I routine of Brey and Pauly (1986). The growth parameters are L_∞ = 26.0 cm and K = 0.47 per year. Note rather bad fit of the curve which misses major peaks, particularly in June and July.

Table 3. Growth parameter estimates of Indian scad (*Decapterus russelli*)

Data type and method used	L_∞ cm	K per year	$\varnothing'^{a}$	Remarks[b], source
Length frequencies and ELEFAN I	27.0 30.0 26.0 26.9 33.0	0.80 0.54 0.73 0.69 0.45	2.77 2.69 2.69 2.70 2.69	from Ingles and Pauly (1984) based on Tiews et al. (1971, Magnuson (1970) and unpublished data.
Age readings (commercial bottom trawl 1980)	24.8	0.56	2.54	Gjøsaeter and Sousa (1983) n = 55
Length frequencies (commercial bottom trawl 1979) and ELEFAN I	24.8	0.43	2.42	Gjøsaeter and Sousa (1983)
ibidem, 1980	24.4	0.42	2.40	
ibidem, 1981	26.0	0.46	2.49	
Age readings (pelagic trawl survey, Sept. 1982)	22.0	0.64	2.49	Brinca et al. (1983) n = 62
Age readings (commercial bottom trawl 1980 and pelagic trawl survey Sept. 1982) (Fig. 9)	27.9	0.56	2.64	This paper n = 118
Age readings (Table 2) and length frequency data 1980 (Table 1), analyzed with ELEFAN I (Fig. 10)	26.0	0.47	2.50	This paper n = 47

[a] $\varnothing' = \log_{10} K + 2 \log_{10} L_\infty$ (see Laboache and Carrara, this vol.)
[b] n = number of age readings used

Mortality Estimates

Total mortality estimates based on assumption of stable age distribution

The ELEFAN II program gave estimates of Z from the length-converted catch curve (Fig. 9) and from the Beverton and Holt equation. The growth parameter estimates obtained from ELEFAN I, viz., $L_\infty = 26.0$ cm and K = 0.474/year, were used for these calculations.

The values obtained were:

Z (from catch curve) = 6.30
Z (from mean length) = 5.18

The growth curve obtained from age reading (see above) was used to evaluate the separation into cohorts and the connection of cohorts in a time series of length distributions.

Total mortality based on "matched samples"

The data used are numbers caught per hour trawling at Sofala Bank by commercial trawlers. Each sample, the sum of numbers caught per hour, represents a period of three months, viz., April, May and June 1985 for the first and January, February and March 1986 for the second sample.

Table 4. Response surface generated by the ELEFAN I routine of Brey and Pauly (1986), based on the length frequency data in Table 1 and the age data in Table 2. The goodness of fit which can here reach a maximum of 1000 is generally low, with an optimum region from L_∞ = 25.0 to 27 cm and K = 0.46 to 0.52. (The starting point used for this analysis went through sample 8, eighth length class of Table 1, and seasonal growth was not considered).

K										
.35	93	65	15	-50	-77	-72	-35	-98	-85	-52
.366	32	-21	-80	-50	-72	-38	-73	-39	-30	-9
.381	-78	-69	-63	-56	-88	-53	-48	-8	46	60
.397	-57	-62	-38	-76	-40	-21	38	50	154	194
.412	-90	-18	-62	-43	45	40	112	210	199	199
.428	-57	-77	-16	50	97	169	220	202	225	198
.443	-65	35	84	127	216	211	194	188	182	160
.459	36	100	135	224	202	227	212	162	154	154
.474	107	136	211	229	228	216	155	150	172	153
.49	163	216	219	220	164	151	147	159	147	111
.5	173	219	225	180	157	168	160	166	157	114
.522	236	210	174	162	148	177	158	118	145	130
.544	175	185	143	140	160	144	116	136	144	132
.567	166	152	154	131	110	139	123	152	119	88
.589	147	132	120	132	140	120	140	103	129	158
.611	133	120	125	135	154	120	89	130	160	143
.633	120	117	135	169	104	122	158	148	173	168
.656	126	135	170	89	122	159	165	173	184	141
.678	138	160	122	122	157	161	168	124	129	112
.7	126	122	122	178	160	168	123	124	76	108
L_∞	25	25.33	25.67	26	26.33	26.67	27	27.33	27.67	28

The input data for the "matched samples method" are shown in Table 5 and Fig. 10.

Results of the Bhattacharya analyses, i.e., the resolution into normally distributed components are also given in Table 5 and Fig. 10.

The time difference between the two samples is nine months (or 0.75 years). Using the components indicated in Fig. 10 the estimate of total mortality becomes:

$$Z = \frac{1}{0.75} \ln \frac{N1(\text{May } 1985)}{N2(\text{Feb. } 1986)} = \frac{1}{0.75} \ln \frac{15{,}900}{4{,}300} = 1.7 \text{ year}^{-1}$$

It might have been more appropriate to use two samples with a time difference of one year, bearing in mind the assumption behind the matched samples method. In fact a sample representing February 1985 is available (see Table 5). However, it turned out to be difficult to separate this sample into two components because it forms one single (nearly perfect) normal distribution with a total number of 23,400.

However, assuming the same relative sizes of the components of N1 and N2 in February 1985 as in May 1985 gives:

$$N1(\text{Feb. } 1985) = 23{,}400 \frac{N1(\text{May } 1985)}{N1(\text{May } 1985) + N2(\text{May } 1985)} = 19{,}400$$

which in turn gives:

$$Z = \ln \frac{N1(\text{Feb. } 1985)}{N2(\text{Feb. } 1986)} = 1.5 \text{ year}^{-1}$$

As a compromise, Z was estimated to be 1.6 year^{-1}.

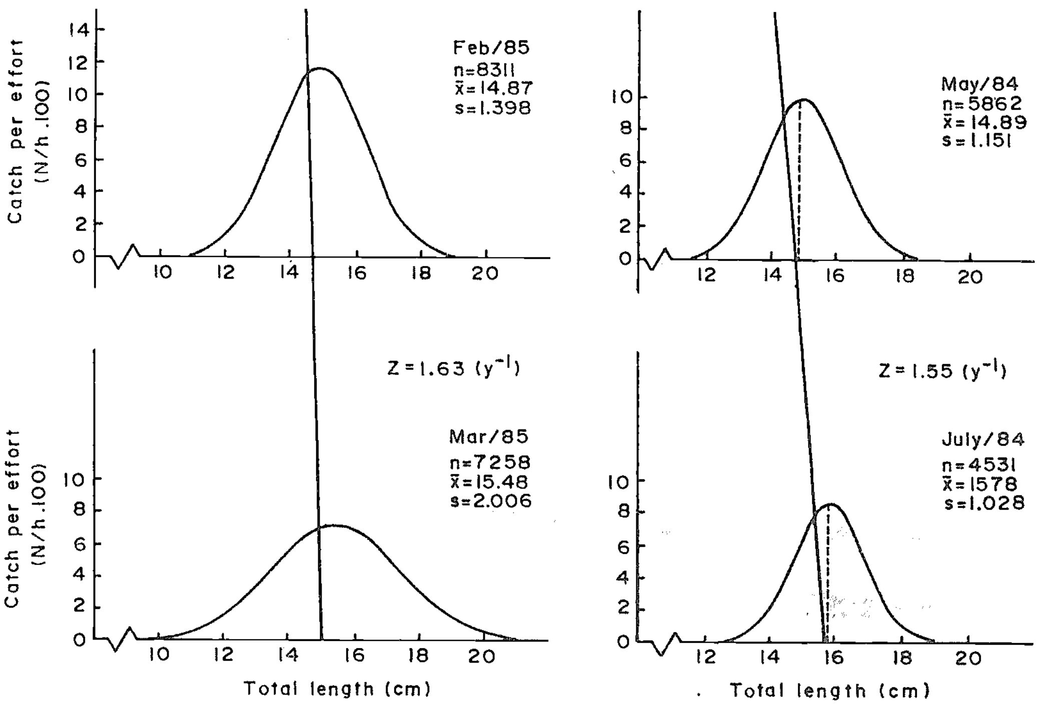


Fig. 10. Application of the matched samples method to *Decapterus russelli* from Sofala Bank (see text).

The growth curve shown in Fig. 10 is based on the parameters, $L_\infty = 26$ cm, K = 0.47/year and $t_o = 0$ years. The table below compares the results of the Bhattacharya analysis and this growth curve:

Sample date	Age	Length from growth curve (cm)	Length from Bhattacharya analysis (cm)
May 1985	1.75	14.6	14.7
Feb. 1986	2.50	17.9	17.3

There is not a perfect agreement but the result is considered acceptable.

Separation of total mortality into fishery and natural mortalities

A value of M = 1.08 was obtained using Pauly's empirical equation, for a water temperature of 25°C; however, a value of M = 1 was used for the backward projection of the catch curve using ELEFAN II, which yielded an estimate of mean length at first capture Lc = 16.5 cm (Fig. 9).

In 1985, the total catch of *D. russelli* was 3,117 t. The biomass estimate based on swept area for 1984 was 24,000 t. The resultant fishing mortality, F, estimated from Sekharan's formula is 3,117/2,400 = 0.13.

By subtracting this value of F = 0.13 from the mean of the two estimates of Z = 1.6, an estimate of M = 1.6 - 0.13 = 1.46 is obtained. This suggests for *D. russelli* a value of M/K = 1.47/0.56 ≈ 2.6, which is realistic (Beverton and Holt 1959; Pauly 1980).

Recruitment Patterns

The results of two approaches regarding recruitment patterns are presented here.

Fig. 12 shows the recruitment pattern that was obtained from ELEFAN II. Two recruitment pulses were considered to occur during the year, one at the beginning of year and the other at the beginning of the second semester.

The age readings on daily rings were used to estimate birthdays of individual fish since the sampling date was known. In Fig.13 the birthdays of fish younger than 18 months were plotted separately. Two main peaks of recruitment can be observed, respectively, in March and October.

Fish older than 18 months represented 26% of the total number sampled, also here two peaks were found, but with a shift of four months with respect to the younger ones. This shift might indicate that there is a fairly large error in the number of rings counted in older fish.

The recruitment peaks based on birthdays from the younger fish agree well with the time at which the smallest fish appear in the catches some 14 months later.

Discussion

Growth parameters estimated by different sets of data, data combinations and methods show that the values obtained are similar. The corresponding values of φ' ranges from 2.40 to 2.64 (Table 3).

Table 5. Estimation of Z, total mortality coefficient by the "matched samples method".

A. Number caught per hour trawling summed over three months, e.g., May represents the period April, May and June.

Length Class (cm)	Feb. 1985	May 1985	Feb. 1986
10-11	128	13	57
11-12	228	63	201
12-13	1013	748	1802
13-14	2903	4307	5118
14-15	5190	4345	5527
15-16	7300	5016	5153
16-17	4858	2905	3173
17-18	1486	1231	1389
18-19	302	430	715
19-20	34	110	249
20-21	0	0	78
21-22	0	0	30
Total	23441	19168	23492

B. Results of Bhattacharya analysis:

N_1 : number in component i, Li mean length

S_1 : standard deviation (compare with Fig. 10)

		Feb. 1985	May 1985	Feb. 1986
first component	N_1	-	15900*	19100
	L_1	-	14.7	14.6
	S_1	-	1.1	1.1
second component	N_2	-	3400	4300*)
	L^2	-	17.1	17.3
	S_2	-	1.1	1.2

Mortality estimate: *

$$Z = \frac{1}{0.75} \ln = \frac{15900}{4300} = 1.7 \text{ year}^{-1}$$

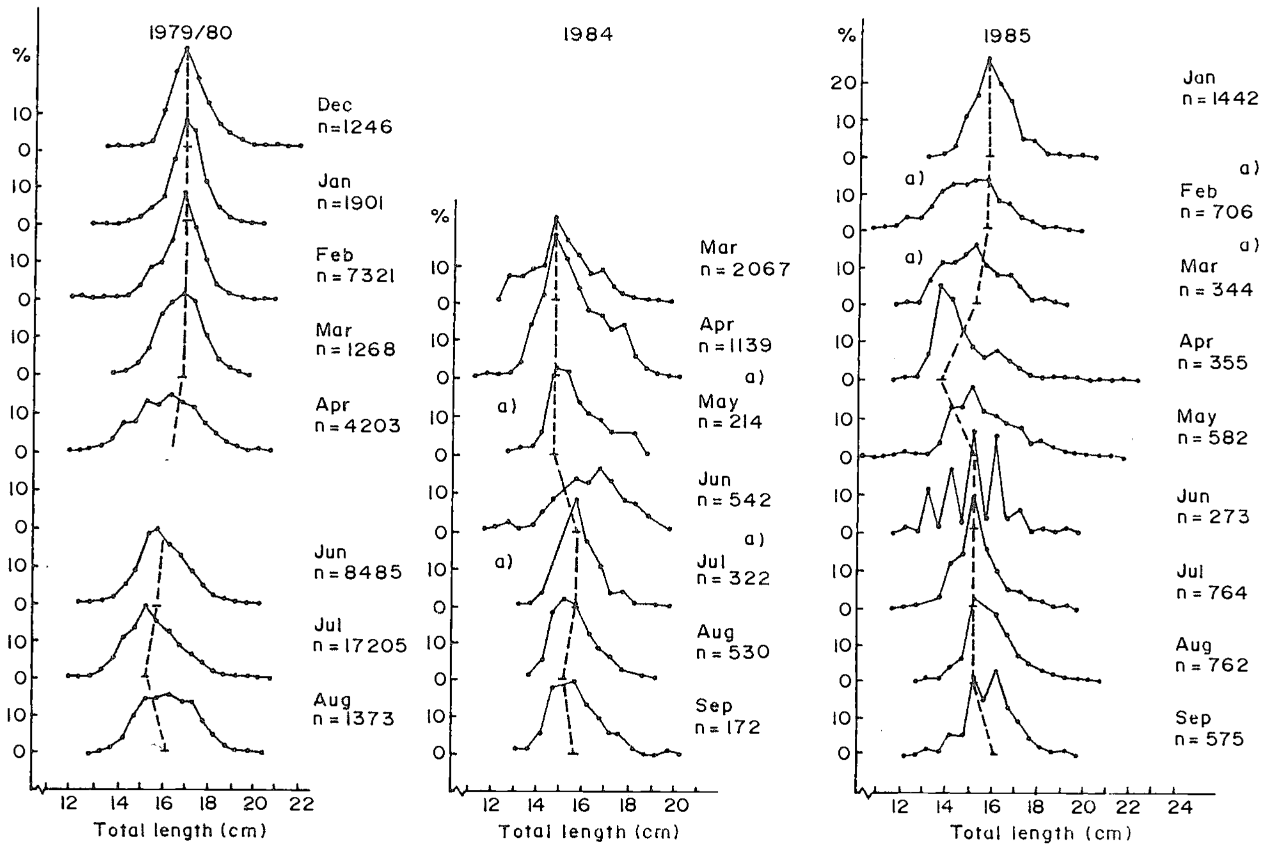


Fig. 11. Selected series of length-frequency samples of commercial catches from Sofala Bank, illustrating the problems in the interpretation of modal progression (n = sample size). The broken lines pass through the mean length of each sample. The samples marked by a) are those used for estimation of Z by the matched samples method.

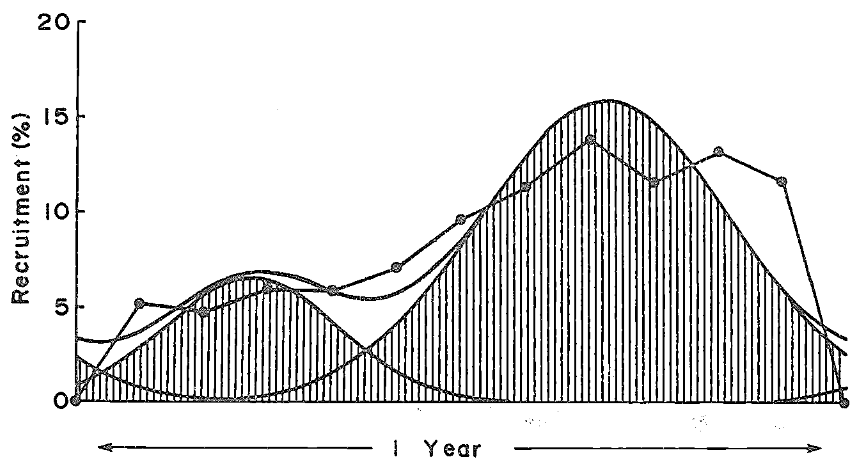


Fig. 12. Recruitment pattern of *Decapterus russelli* on Sofala Bank based on length-frequency data in Table 1, analyzed using ELEFAN II version of Saeger and Gayanilo (1986). Growth parameters used were L_∞ = 26.0 cm and K = 0.474. The shaded area represents two normal distributions separated using the NORMSEP program.

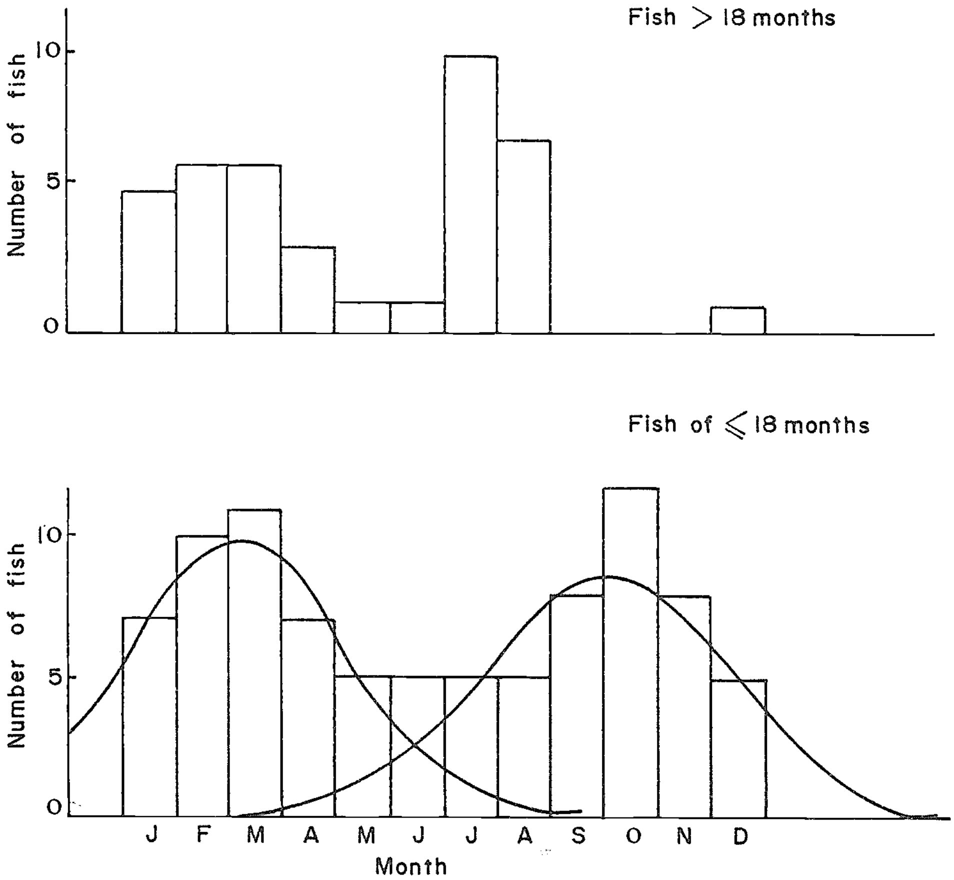


Fig. 13. Birthdate distribution of individual *Decapterus russelli* (see text).

Monthly length-frequency samples collected from commercial vessels were used to estimate growth, with the assumption that they were representative of the entire population. However, no progression in the modes was found when the strong peaks, assumed to represent modal lengths of age classes were combined in a time series of length samples (Fig. 11).

During the period of the first recruitment pulse, which lasts from December to April, no shifting in the mode of the fully recruited single size length group was observed. The same feature appeared during the second recruitment pulse, which lasts from June to August or September. Also negative "growth" can be observed from this figure.

Despite these limitations, ELEFAN I was applied to these data as a first approach to growth estimates (Gjøsaeter and Sousa 1983). The simultaneous analysis of selected length and age readings was also applied. This resulted in parameter estimates lying between the values obtained using length-frequency data alone and those obtained using age readings alone (see ϕ' values in Table 3).

Growth parameters obtained by age readings will also be biased if they are based on data obtained from a part of the stock in which size-dependent derecruitment occurs (A in Fig. 7) or in which fast-growing individual fish are the first to be recruited into a fishery aimed at large specimens (B in Fig. 7). This effect will be relatively strong when individual growth is very variable. As was shown above, these effects can be compensated for by the utilization of a complete data set representing the whole stock (Fig. 7A and B). As might be seen in Table 3 such combination of age readings resulted in the highest growth rates so far obtained in Mozambican waters, with $\phi' = 2.64$, similar to values reported from the Philippines.

It should be noted, however, that the growth parameters in Table 3 include a positive value of t_0, which necessarily implies very low growth rates for fish below 3 cm (see Fig. 7).

Another problem related to otolith readings may also be mentioned. As the fish grow, the number of rings in the otolith increases, becoming thinner and more densely packed at the same time (Gjøsaeter and Sousa 1983). As a result, ages of large individuals will probably be underestimated.

As a whole, this study suggests that age readings, if properly sampled (especially with regard to the very young fish), provide correct estimates. However this method requires a large work input. On the other hand, growth estimates based on length data alone tend to be biased downward. The most cost-effective solution to obtaining reliable growth parameter estimates for practical assessments in Mozambique may thus be some combination of growth and length data as presented above.

The value of Z obtained from the length-converted catch curve was extremely high because the samples must have been biased due to derecruitment (migration and catchability changes in older fish). The total mortality obtained here was even higher than the value of Z = 3.2/year reported by Borges et al. (1984).

The matched samples method provided an average estimate of Z = 1.6, which seems a reasonable value.

As mentioned earlier, the matched samples method contains an element of subjectivity. In the particular case of the Sofala Bank fishery (Table 5 and Fig. 10), the resolution into normally distributed components appears somewhat uncertain.

The estimate of the second component is highly dependent on the estimate of the first component. A minor change of the first component may have a relatively large impact on the estimate of the second component, e.g., changing the first component (N1(Feb. 86) = 19,100) by 5% may create a 25% change in the second component (N2(Feb. 86) = 4,300) which in turn will change the estimate of Z by -ln(.75) = 0.29.

Further, the method as applied here assumes that the sample is a random sample of the entire cohort.

It may well be that the first component is underestimated because of gear selection so that the small fish are underrepresented. This produces an underestimate of N1 which in turn produces an underestimate of Z = ln(N1/N2), if the second component, N1, is not underrepresented in the sample.

Recruitment to and from the fishing ground may play a similar role. The first cohort may be underrepresented because the fish have not yet fully recruited to the fishing ground and the second cohort may be underrepresented because the large fish has migrated to, say, deeper waters.

If more knowledge on migration and gear selection had been available, it would have been possible to adjust the sample so as to turn it into an estimate of a random sample.

Here, a subjective judgment was the only possible solution. The data appear to fit into the normal distributions and the growth curves so at least it can be concluded that data did not show any great violation of the assumptions behind the analysis.

The matched samples method would possibly be useful, after some further refinements, in situations where migrations tend to bias length-frequency samples.

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Population Biology of Russell's Scad *(Decapterus russelli)* in the Java Sea, Indonesia

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Abstract

Fork length-frequency samples of *Decapterus russelli* were collected from commercial purse seiners at the Pekalongan landing site. The samples were raised to account for the total catch in numbers by length groups per month in the Java Sea purse seine fishery from March to December 1986.

The ELEFAN and Bhattacharya methods were used to estimate growth parameters L_∞ and K. Total mortality was estimated by catch curve analysis. The natural mortality was calculated by Pauly's empirical relationship. The estimated rate of exploitation was below the optimum rate of exploitation obtained in yield-per-recruit analysis. The recruitment pattern or the back transformed length frequencies showed a single but broad annual pulse of recruitment.

Introduction

Among the pelagic fish resources of the Java Sea, two species of scads, i.e., Russell's scad *(Decapterus russelli)* and round scad *(D. macrosoma)* are predominant both in terms of catch and economic value. These two species are easily distinguished into *deles (D. macrosoma)* and *layang (D. russelli),* but in terms of statistics and economics they are combined into one category, i.e., scads. In this paper, scads refer to the combined species, while Russell's scad refers to *D. russelli.*

The predominant fishing gear used in the fishery for scads is a purse seine which is operated from vessels ranging from 20 to 50 gross tons. The purse seiners use a traditional fish attracting device, the *rumpon*, a piece of bamboo rope entangled with coconut leaves which is anchored at the fishing ground. Consequently, the fishermen are able to fish directly at the installed *rumpons* instead of spending time searching for fish schools. *Rumpons* are replaced with new ones or moved to other places in accordance with the fish movements.

Basically, there are three major fishing areas for scads in the Java Sea, i.e., Karimun Java Islands and adjacent waters in the western part, Bawean Island and the eastern region, which has been separated into three subareas (Masalembu, Mata Siri and Lari-larian) (Fig. 1).

Actually, the scad fisheries are based in Java with a number of landing places located along the north coast of the island. Pekalongan is the most important; it contributes as much as 47% of the total landings of scads from the Java Sea (Direktorat Jenderal Perikanan 1984, 1985, 1986). From 1975 to 1984 scads formed nearly 11% of the average total annual landings of almost 300,000 t in the Java Sea. While the total yield of scads in 1984 has increased to almost twice the yield of 1974, the number of purse seiners has increased fivefold in the same period.

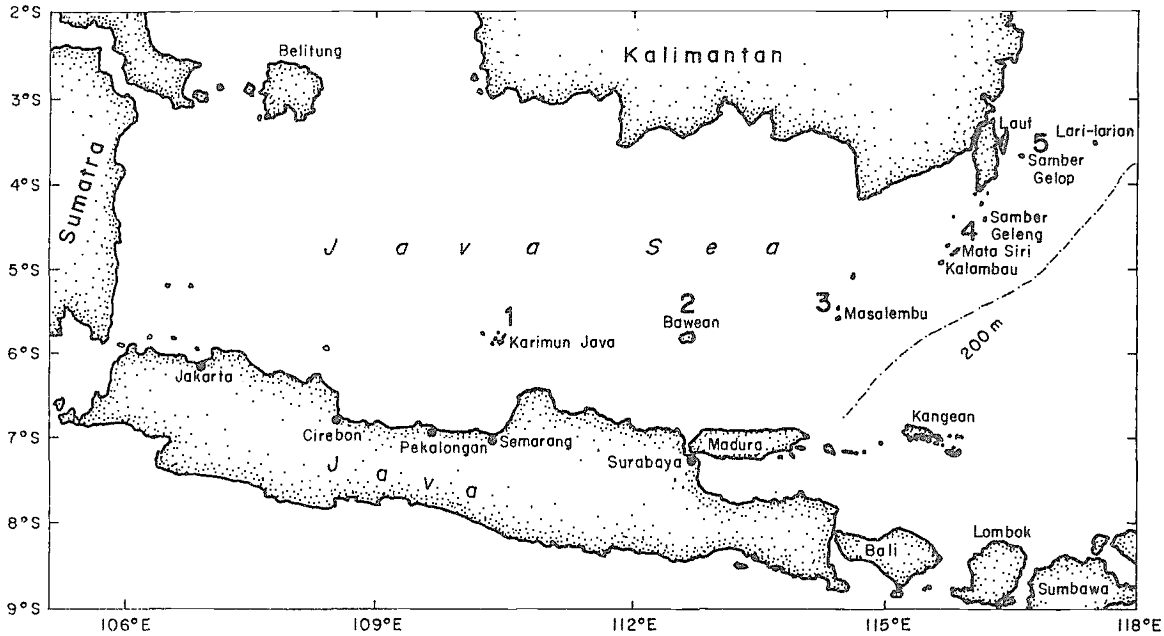

Fig. 1. Fishing grounds of scads in the Java Sea, i.e., 1) Karimun Java; 2) Bawean; 3) Masalembu; 4) Kalambau, Mata Siri and Samber Geleng; 5) Samber Gelop and Lari-larian.

Some aspects of the biology of scads in the Java Sea have been studied. Hardenberg (1938) argued that there exist three stocks of scads in the Java Sea, i.e., an eastern stock originating from the Flores Sea, a northern stock from the South China Sea and a western stock from the Indian Ocean.

Soemarto (1958) pointed out that the distribution of the eastern stock covers an area from the eastern border of the Java Sea to the Karimun Java Islands and that this stock is being fished year-round. Sadhotomo et al. (1983) used the length-distribution data collected from commercial landings at Pekalongan from September 1981 to August 1982 to determine growth, mortality and yield per recruit of Russell's scad. The data used in their analysis were limited to three fishing grounds: Karimun Java, Bawean and Masalembu. They concluded that scad stocks in the Java Sea were exploited extensively and that the optimum exploitation level was exceeded.

Since 1983 the fishing grounds of the eastern scad stocks have been extended towards the Makassar Strait as far as Lari-larian Island. This means that the population parameters as determined by Sadhotomo et al. (1983) were not based on data from the entire stock. The aim of this study is therefore to reassess these population parameters, using length-frequency data collected from the extended fishing grounds. In addition, a stock separation study based on morphometric data of *D. russelli* was performed (see Soriano et al., this vol.).

Materials and Methods

Data collection was concentrated in Pekalongan as the principal landing place for purse seine fisheries in the Java Sea. In addition, it was assumed that data collected from Pekalongan would significantly represent the population of scads in the area concerned. Length frequency, morphometric and biological samples were collected up to three times per week, as far as possible from each of the five fishing grounds.

Data on fishing grounds, number of fishing operations (number of settings), duration of fishing and sailing of a number of vessels were derived from interviews with skippers and fishermen. Data on catch composition per vessel per trip and total landings by month were collected from the Fishing Port Administration at Pekalongan, in the following form (example):

Date	Vessel name	Fishing ground	Duration Fishing	(Days) Sailing	No. of setting	Catch by species (kg)
030886	Sili wangi	Bawean	12	4	14	Scads 3,463 Mackerel 2,325 etc.
	.	.	.	.	.	
.	.	.	.	.	.	
	.	.	.	.	.	

Length-Frequency Data

Length-frequency data, fork length measured to the 0.5 cm below, were obtained from nearly 30,000 fish collected from commercial vessels at Pekalongan from March to December 1986. Each time, a sample of around 40 kg was taken from a vessel before the catch was sorted and landed. The first step was to separate *D. russelli* from other scads *(D. macrosoma)* and other species. The subsample of Russell's scad was then weighed and measured. Afterwards, the samples were grouped by fishing ground.

Only the total length-frequency distribution for all the samples collected in each month in one-cm groups was available for the present study. The raw data of length frequencies for this study are therefore expressed as monthly samples (Table 1).

The weights of these monthly samples from each fishing ground were known and denoted by W_{ij}, (Table 2), i.e., the weight of the samples from fishing ground i (i = 1, 2,..., 5) in month j (j = 1, 2, ..., 10).

The operational aspects data include catch per unit effort, i.e., mean catch of *D. russelli* in weight per one setting operation ($CPUE_{ij}$). Because data on total catch by fishing ground landed in Pekalongan were not available during this study, it was assumed that CPUE for each area could be used as an index of relative abundance of the population in the respective areas (Table 2).

Accordingly, the catch in weight of Russell's scad from fishing ground i in month j, C_{ij}, could be determined as follows:

$$C_{ij} = \frac{CPUE_{ij}}{CPUE_{.j}} \times C_{.j} \qquad \text{... 1)}$$

where $CPUE_{ij}$ is the mean CPUE on fishing ground i in month j and

$$CPUE_{.j} = \sum_{i=1}^{5} CPUE_{ij}$$, the mean CPUE on all five fishing grounds in month j

and $C_{.j}$ denotes total catch in month j from all five fishing grounds.

Finally, the value of the raising factor for fishing ground i in month j, R_{ij}, could be calculated (Table 2).

$$R_{ij} = \frac{C_{ij}}{W_{ij}} \left(\frac{ton}{kg}\right) = \frac{C_{ij}}{W_{ij}}(1{,}000) \qquad \text{...2)}$$

The length frequencies by fishing ground and by month raised to account for total landings of Russell's scad in Pekalongan are pooled by fishing ground in Table 3 to represent total catch in numbers by length groups per month for the entire fishing area.

Table 1. Fork-length frequency samples of *Decapterus russelli* by fishing ground and by month landed in Pekalongan in 1986.

Fishing ground 1 = Karimun Java

Mid-length (cm)	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.75				1	2					
7.75			18	26	48					
8.75			142	94	108					
9.75			154	143	90					
10.75		1	86	322	57					
11.75		23	14	457	102	2	14			
12.75		75	2	671	333	11	183		2	
13.75		58	3	732	595	57	308	15	27	14
14.75		4	7	131	307	32	154	100	76	50
15.75	6	16	47	11	61	27	37	66	68	138
16.75	2	45	135	3	16	31	3	45	34	113
17.75	12	126	155	2	0	15	2	41	7	55
18.75	23	203	122	1	8	3		22		9
19.75	27	221	57	2				1		5
20.75	14	201	22					2		
21.75	13	98	10							
22.75	8	60	4							
23.75		6								
24.75		4								
Sum	105	1,141	978	2,596	1,727	178	701	292	214	384

Fishing ground 2 = Bawean

Mid-length (cm)	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2.75		1						
3.75		4	2					
4.75	40	54	36					
5.75	68	165	120					
6.75	80	135	53					
7.75	57	89	29				4	
8.75	20	43	13	2			36	
9.75	2	25	5	3		15	87	
10.75	0	15	6	11	5	97	22	1
11.75	0	5	4	9	17	56	9	12
12.75	0	0		3	13	209	46	37
13.75	3	0		0	2	261	132	75
14.75	32	1		22	0	80	87	30
15.75	59	36		51	0	18	30	1
16.75	44	74		52	0	53	9	8
17.75	18	56		22	11	47	8	24
18.75	23	28		2	40	30	25	17
19.75	17	19		0	37	45	42	26
20.75	15	9		1	14	29	20	27
21.75	4	1			1	11	5	5
22.75						2	2	1
23.75							1	
Sum	482	760	268	178	140	953	565	264

Table 1. Continued

Fishing ground 3 = Masalembu

Mid-length (cm)	Mar	Apr	May		Jul	Aug	Sep	Oct		Dec
3.75	14		1							
4.75	60		11							
5.75	27		61							
6.75	6		52							
7.75	5		35							
8.75	2		43							
9.75	1		32		4					
10.75	0		14		27		1			
11.75	0		1		30	1	4	1		
12.75	0		0		13	17	24	4		
13.75	13	27	0		3	74	131	40		
14.75	73	200	0		16	96	175	48		38
15.75	80	283	0		67	15	44	11		43
16.75	83	239	3		62		5	1		33
17.75	61	133	9		13			8		30
18.75	51	52	22		11			22		14
19.75	40	32	24		14			46		9
20.75	23	3	6		5			99		6
21.75	4	4	4					37		4
22.75	4							29		1
23.75	1							16		
24.75								4		
Sum	548	973	318		265	203	384	366		182

Fishing ground 4 = Mata Siri

Mid-length (cm)	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.75			2							
4.75			5							
5.75			39							
6.75			95							
7.75			85	1						
8.75			52	3						
9.75			56	31	2	4				
10.75			19	87	1	32				
11.75	4		22	22	8	37		1		4
12.75	16	6	4	7	4	48	1	13	2	60
13.75	116	57	7	3	2	25	9	74	11	77
14.75	222	247	78	14	3	6	48	157	33	52
15.75	209	394	152	38	107	23	71	241	59	55
16.75	103	287	139	93	476	184	29	151	8	49
17.75	40	266	127	140	549	394	16	18	0	11
18.75	9	158	98	153	319	416	72	19	0	10
19.75	4	58	70	102	94	244	52	32	1	2
20.75	2	26	40	78	28	118	17	15		
21.75		27	25	38	15	58	5	6		
22.75		13	5	5	1	0	5	5		
23.75		5		4	1	5	1			
24.75				1						
Sum	725	1,544	1,115	820	1,610	1,594	326	732	115	320

Table 1. Continued

Fishing ground 5 = Lari-larian

Mid-length (cm)	Jul	Aug	Sep	Oct
11.75		4		2
12.75		5		9
13.75		3	12	16
14.75	4		52	34
15.75	104		30	26
16.75	335		6	7
17.75	326		7	
18.75	112		28	
19.75	35		13	
20.75	10		8	
21.75	1			
22.75	0			
23.75	1			
Sum	928	12	156	94

Morphometric Data

The following 11 morphometric characters were measured in 350 fish: total length, fork length, the length of head, snout, first and second dorsal fin bases, anal fin base, pectoral fin, maximum height, eye diameter and the height of the largest scute (Fig. 2).

Biological Data

Separate samples were collected for analysis in the laboratory specifing length (total or fork or both), weight, sex and maturity (scale of I to VII, Holden and Raitt 1974).

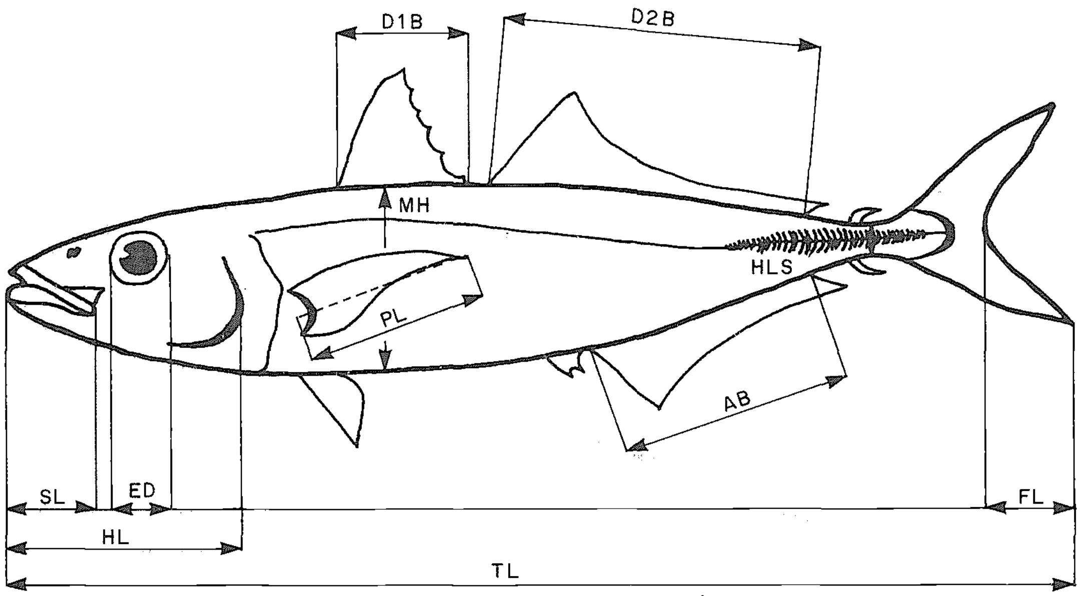

Fig. 2. Morphometric measurements of *Decapterus russelli*. TL = total length; FL = fork length; HL = head length; SL = snout length; PL = pectoralfin length; HLS = largest scute height; ED = eye diameter, MH = maximum height; D1B = first dorsal fin base; D2B = second dorsal fin base; AB = analfin base.

Table 2. Sample weight (W_{ij}), catch (C_{ij}), CPUE, and raising factor (R_{ij}) of *Decapterus russelli* landed in Pekalongan by fishing ground (i) and by month (j) in 1986.

No.	Fishing ground	Catch data	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	Karimun Java	$CPUE_{ij}$ (ton)	0.510	0.344	0.222	0.480	0.912	0.983	0.280	0.510	0.731	0.242
		C_{ij} (ton)[a]	405.1	481.4	244.1	163.5	390.2	538.3	163.0	411.3	1,004.3	451.5
		W_{ij} (kg)	4.318	52.560	30.368	60.894	44.134	7.713	28.570	15.571	11.054	25.269
		R_{ij}/1,000[d]	93.8	9.16	8.04	2.68	8.84	69.8	5.71	26.4	90.0	17.9
2.	Bawean	$CPUE_{ij}$ (ton)	0.344	0.511	0.560	0.440	0.600	0.513	0.840	0.303		
		C_{ij} (ton)	273.2	715.0	615.8	149.9	256.7	280.9	489.0	244.3		
		W_{ij} (kg)	19.657	24.000	2.948	7.630	5.544	52.112	29.514	12.825		
		R_{ij}/1,000	13.9	29.8	208.9	19.6	46.3	5.39	16.6	19.1		
3.	Masalembu	$CPUE_{ij}$ (ton)	0.710	1.224	0.430		0.390	0.823	1.152	1.390		0.795
		C_{ij} (ton)	563.9	1,712.7	472.8		166.9	450.6	670.6	1,120.9		1,483.3
		W_{ij} (kg)	38.90	88.470	11.492		18.598	7.396	14.251	24.239		13.110
		R_{ij}/1,000	14.5	19.4	41.1		8.97	60.9	47.1	46.2		113.1
4.	Mata Siri	$CPUE_{ij}$ (ton)	0.762	0.268	0.236	0.510	1.156	1.187	1.021	1.488	1.249	0.748
		C_{ij} (ton)	605.2	375.0	259.5	173.7	494.6	650.0	594.3	1,199.9	1,715.9	1,395.6
		W_{ij} (kg)	20.03	83.6	47.215	39.503	107.691	78.231	15.523	37.712	5.831	20.262
		R_{ij}/1,000	30.2	4.49	5.50	4.40	4.59	8.31	38.3	31.8	294.3	68.9
5.	Lari-larian	$CPUE_{ij}$ (ton)					2.152	0.616	1.661	1.041		
		C_{ij} (ton)					920.8	337.3	966.8	839.4		
		W_{ij} (kg)					80.049	0.410	13.965	4.296		
		R_{ij}/1,000					11.5	822.7	69.2	195.4		
	Total	$CPUE_{ij}$ (ton)[b]	2.326	2.348	1.448	1.430	5.210	4.122	4.954	4.732	1.980	1.785
		C_{ij} (ton)[c]	1,848	3,286	1,592	487.1	2,229	2,257.1	2,883.6	3,815.8	2,720	3,330.5

[a] $C_{ij} = \frac{CPUE_{ij}}{CPUE_{ij}} \cdot C_{ij}$

[b] $CPUE_{ij} = \sum_{i=1}^{5} CPUE_{ij}$

[c] Modified from fisheries statistics issued by Fisheries Agency in Pekalongan.

[d] $R_{ij} = \frac{C_{ij}}{W_{ij}}$

Table 3. Length-frequency distribution of *Decapterus russelli* raised to total landings in Pekalongan (from all fishing grounds in the Java Sea) by month in 1986 (in 1,000 of fish).

Mid-length (cm)	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2.5		30								
3.5	203	119	463							
4.5	1,426	1,609	7,875							
5.5	1,337	4,917	27,405							
6.5	1,199	4,023	13,584	3	17					
7.5	865	2,652	8,034	75	398		64			
8.5	307	1,281	5,937	305	896		576			
9.5	42	745	3,948	583	825	94	1,392			
10.5	0	456	2,632	1,470	1,145	657	407	20		
11.5	121	360	1,094	1,504	2,080	3,893	441	753		315
12.5	483	714	38	1,900	3,526	7,319	3,090	3,313	766	4,728
13.5	3,733	1,311	62	1,990	5,079	13,445	12,138	9,441	5,703	6,096
14.5	8,208	5,055	471	835	2,881	10,450	17,032	17,896	16,935	9,077
15.5	8,855	8,479	1,191	1,170	3,238	3,205	7,618	16,004	23,446	10,131
16.5	5,113	8,543	1,972	1,415	6,837	3,598	1,867	7,986	5,484	8,838
17.5	3,468	6,598	2,328	1,053	6,514	4,210	1,169	2,486	651	4,829
18.5	3,488	4,412	2,431	729	4,427	3,557	4,806	2,410	0	2,604
19.5	3,470	3,472	1,861	464	2,501	2,092	5,755	1,956	290	1,323
20.5	1,916	2,284	648	370	874	1,042	1,451	4,909		770
21.5	1,333	1,126	385	171	115	499	259	1,727		514
22.5	808	608	59	23	4	8	211	1,306		128
23.5	15	77		18	15	39	52	618		
24.5		37		5				154		
Sum	46,390	58,908	82,416	14,081	41,371	54,111	55,957	72,406	53,275	49,353

Analytical Methods

The length-frequency distributions were analyzed by employing the ELEFAN routine, and the modal progression analysis based on the normal components identified by the Bhattacharya method. A Wetherall (1986) analysis was also carried out to determine the growth parameter L_∞. Total mortality, Z, was estimated from the catch curve and natural mortality, M, was obtained from an empirical relationship (Pauly 1980) based on K, L_∞ and the mean temperature of the environment.

Finally, the estimation of the optimum level of exploitation rate, E, was carried out using the relative yield-per-recruit model of Beverton and Holt (1966) as modified by Pauly and Soriano (1986).

Results

Total Length-Fork Length Relationship

The relationship between total length, L, and fork length, FL, was obtained by linear regression from length measurements of 400 specimens of *D. russelli* collected in this study. The estimated model is

$$L = -0.13 + 1.12\ FL \qquad \ldots 3)$$

where L and FL are measured in cm.

Total Length-Weight Relationship

Total length, L(cm), and weight, W(g), of 269 specimens of *D. russelli* collected in this study were used to estimate the three parameters of the traditional models, i.e.,

$$W = a\,L^b \qquad \text{... 4)}$$

$$W = q\,L^3 \qquad \text{... 5)}$$

where 100 q is the condition factor. The 95% confidence interval for the power b is (2.919, 3.076) and because this interval includes b = 3, the model of isometric growth, Eq. (5), is used. The parameter q is estimated as

$$q = \exp(\bar{y} - 3\bar{x}) = 0.01042 \text{ g/cm}^3$$

where $(\bar{x}, \bar{y})$ is the mean of $(x_i, y_i) = (\ln L_i, \ln W_i)$; i = 1, 2,..., 269

The 95% confidence interval of q is calculated as (0.008, 0.013). The length-weight relationship becomes

$$W = 0.0104\,L^3\ ;\ r = 0.98 \qquad \text{... 6)}$$

and the condition factor is 100 q = 1.

Growth Parameters

Table 4 gives the number of fish and their mean length and standard deviation for each of the groups resulting from the Bhattacharya analysis of the length-frequency data of *D. russelli* by month in Table 3. The mean lengths of these normally distributed groups are plotted *vs.* time in Fig. 3A. Each group is here identified by a number and the plot of standard deviation on mean length in Fig. 4. separates the groups into aggregations which are believed to represent age groups. Group linking according to assumed cohorts is shown in Fig. 3B.

Table 4. Mean length, standard deviation and number of individuals in each normal distribution group obtained from the Bhattacharya analysis of length-frequency data of *Decapterus russelli* by month. The differences between the total catch in number and the explained numbers by the analysis are also shown (all numbers in units of 10^7 fish).

Group specification	No.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean length (cm)	1	6.3	7.6	6.4	13.0	9.5	14.4	15.1	15.6	15.9	16.1
	2	15.5	16.5	8.6	18.0	14.1	18.1	19.1	20.7		20.6
	3	19.7	20.5	18.5		18.3					
Standard deviation (cm)	1	1.2	1.6	0.7	1.7	0.8	1.1	1.0	1.3	0.9	1.8
	2	1.3	1.4	1.4	1.8	1.0	1.4	1.0	1.1		1.4
	3	1.2	1.2	1.7		1.3					
Size in numbers	1	0.5	1.6	5.0	0.8	0.2	3.9	4.5	5.8	5.3	4.7
	2	3.0	3.3	1.7	0.5	1.5	1.3	1.1	1.2		0.2
	3	1.2	0.9	1.3		2.3					
Total explained number	1+2+3	4.7	5.8	8.0	1.3	4.0	5.2	5.6	7.0	5.3	4.9
Total catch in number		4.6	5.9	8.2	1.4	4.1	5.4	5.6	7.2	5.3	4.9
Total catch-explained number		−0.1	0.1	0.2	0.1	0.1	0.2	0.0	0.2	0.0	0.0

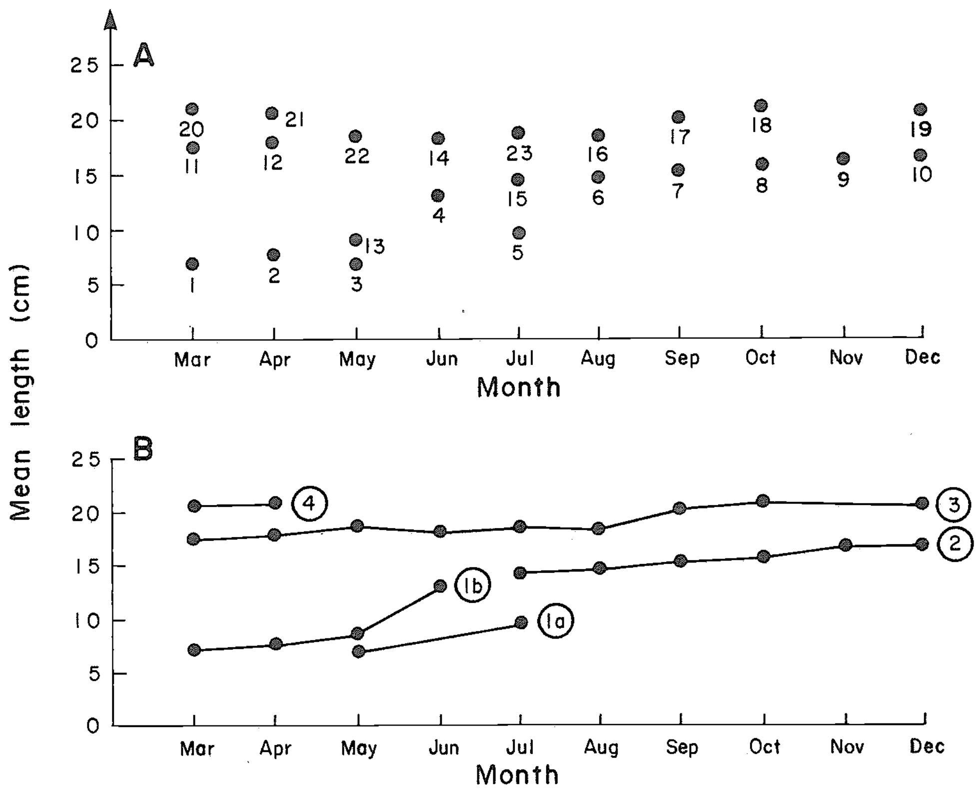

Fig. 3a. Scatter diagram of the mean lengths of the normally distributed components resulting from applying the Bhattacharya method to the monthly length frequency data of *Decapterus russelli* in 1986.
Fig. 3b. Linking the mean lengths of the normal components that are assumed to represent individual cohorts.

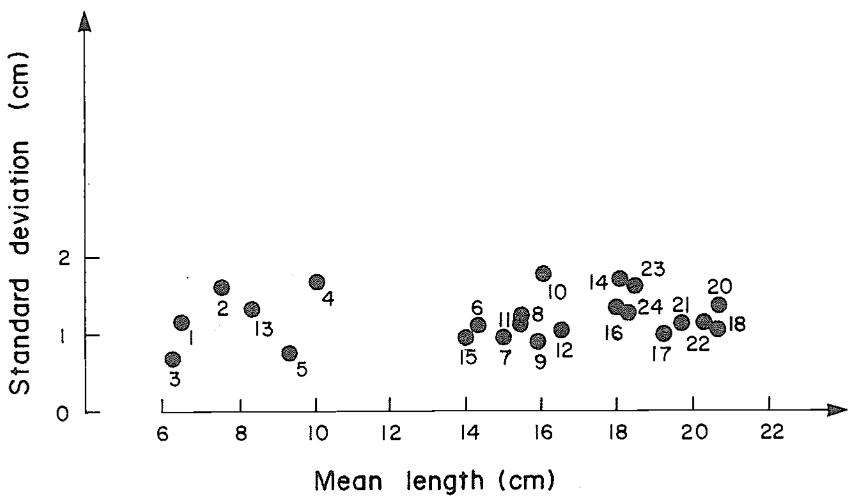

Fig. 4. Scatter diagram of group mean length and standard deviation obtained from the Bhattacharya method applied to the length frequency of *Decapterus russelli* in the Java Sea in 1986.

The estimation of L_∞ and K is carried out by using the Gulland and Holt (1959) method, i.e., regressing L on $\Delta L/\Delta t$ (Table 5). Based on the intercept and the slope of the linear regression, we get estimates of the growth parameters, i.e.,

$$K = -(\text{slope}) = 0.92 \text{ year}^{-1} \qquad ...7)$$

and

FL_∞ = - (intercept/slope) = 28.6 cm

L_∞ can be estimated using equation (3),

L_∞ = -0.13 + 1.12 x 28.6 = 31.9 cm ..8)

Table 5. Input data for the Gulland and Holt plot derived from the results of the Bhattacharya analysis. The four elements refer to the linking.

Elements	1		2		3		4	
Date	$\bar{L}$ (cm)	ΔL/Δt (cm/year)	$\bar{L}$ (cm)	ΔL/Δt (cm/year)	$\bar{L}$ (cm)	ΔL/Δt (cm/year)	$\bar{L}$ (cm)	ΔL/Δt (cm/year)
Mar	7.0	15.6			16.0	1.2	20.1	9.6
Apr	8.1	12.0			17.5	24		
May	10.8	52.8						
Jun	8.0	18.6	13.6	13.2	18.2	3.6		
Jul			14.3	3.6				
Aug			14.8	8.4	18.6	12		
Sep			15.4	6.0	19.9	19.2		
Oct			15.8	3.6				
Nov			16.0	2.4				
Dec								

The Wetherall method (1986) or its modified version (Pauly 1986) gives estimates of FL_∞ and Z/K equal to 25.5 cm and 3.35, respectively. By Eq. (3), we get L_∞ = 28.4 cm.

A value of K can also be obtained by using the relationship

$\phi' = \log_{10} K + 2 \log_{10} L_\infty$ ..9)

where L_∞ and K are the growth parameters, and ϕ' designates the speed of growth (Munro and Pauly 1983; Pauly and Munro 1984). Since the value of ϕ's from a species are approximately normally distributed, the mean ϕ' of available data (Table 6) may be applied to Eq. (9). We get

$2.64 = \log_{10}K + 2 \log_{10} 28.4$ or

$K = 0.54$ year^{-1}

Table 6. Growth parameters and derived ϕ' values of *Decapterus russelli* from Manila Bay and Mozambique.

Location	ϕ'	L_∞	K	Source
Manila Bay	2.77	27.0	0.80	Ingles and Pauly (1984)
Manila Bay	2.69	30.0	0.54	Ingles and Pauly (1984)
Manila Bay	2.70	26.9	0.69	Ingles and Pauly (1984)
Manila Bay	2.69	26.0	0.73	Ingles and Pauly (1984)
Manila Bay	2.69	33.0	0.45	Ingles and Pauly (1984)
Mozambique	2.62	24.8	0.43	Gjøsaeter and Sousa (1983)
Mozambique	2.60	24.4	0.62	Gjøsaeter and Sousa (1983)
Mozambique	2.44	26.0	0.46	Gjøsaeter and Sousa (1983)
Mozambique	2.54	24.8	0.56	Gjøsaeter and Sousa (1983) (otolith reading)

Mean ϕ' = 2.64.

The estimation of the growth parameters using the ELEFAN program (Fig. 5) gives

$FL_\infty = 27.1$ cm

or

$L_\infty = 30.2$ cm

and K = 0.9 year^{-1}

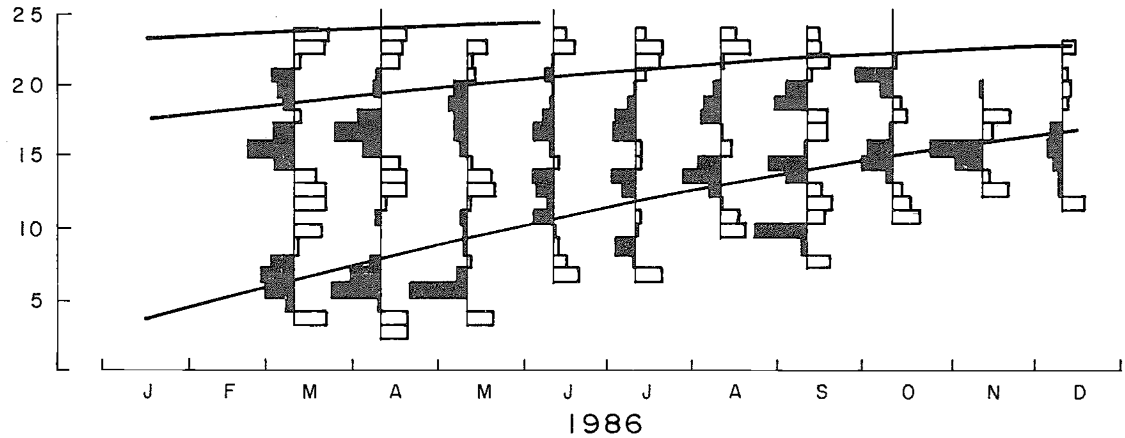

Fig. 5. Estimation of the growth parameters of *Decapterus russelli* by the ELEFAN method.

Mortality Rates

Based on the Wetherall method, total mortality rate, Z, can be calculated from the estimated value of Z/K

$Z/K = 3.35$

$Z = K \times 3.35 = 1.8$ year^{-1} for $K = 0.54$ year^{-1}

The estimation of total mortality rate, Z, using length-converted catch curve (Fig. 6) gave the value of $Z = 4.8$ year^{-1} for $K = 0.93$ year^{-1}.

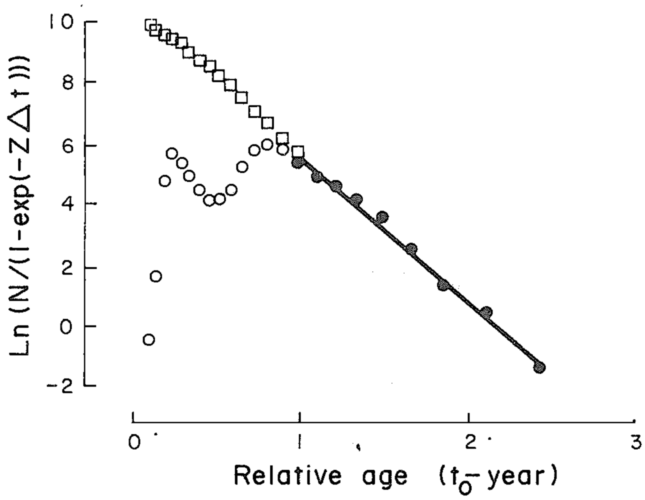

Fig. 6. Catch curve analysis of *Decapterus russelli*. Input $FL_\infty = 27.07$ cm, K = 0.93 year^{-1} and M = 1.782 year^{-1}.

By assuming that the average water temperature in the Java Sea is 29°C, the empirical relationship (Pauly 1980) gives a value of natural mortality, M = 1.8 year^{-1}. Since Z = M + F, then F = 4.8 - 1.8 = 3.0 year^{-1} and the rate of exploitation, E, is equal to 3.0/4.8 = 0.6.

Relative Yield per Recruit

The input data applied in the relative yield-per-recruit analysis are derived from the ELEFAN program, i.e., L_∞ = 30.2 cm,the smallest mid-length = 2.75 cm, the largest mid-length = 24.75 cm, class interval = 1 cm, M/K = 1.9 and the probability of capture of each length group. Based on the analysis of the relative yield per recruit, the estimation of the optimum exploitation rate is 0.6 (Fig. 7).

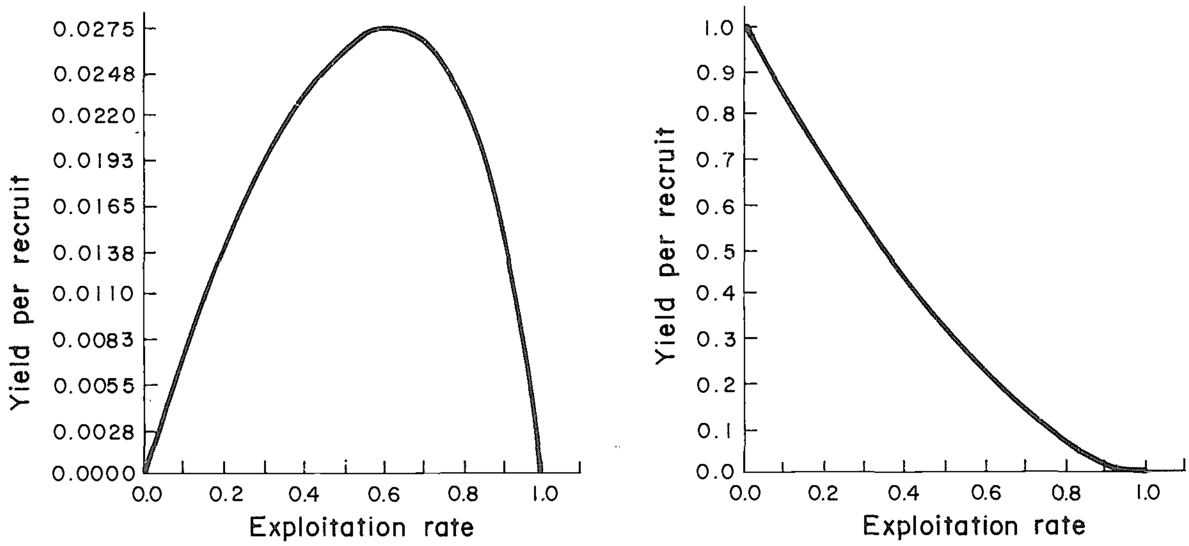

Fig. 7. Relative yield per recruit and relative biomass per recruit of *Decapterus russelli*. Maximum yield per recruit at exploitation rate, E_{max} = 0.6.

Recruitment Pattern

By projecting the length frequency backward, the recruitment pattern of *D. russelli* indicates that there exists one broad annual pulse of recruitment (Fig. 8).

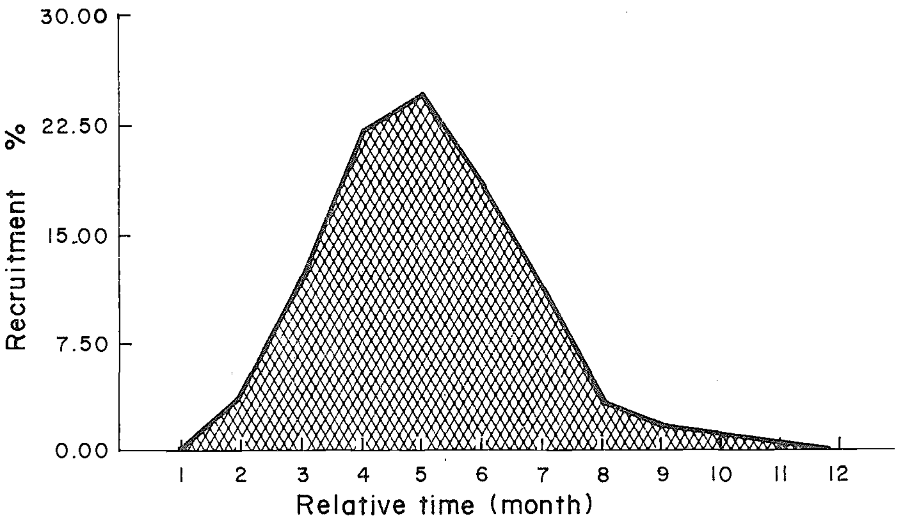

Fig. 8. Recruitment pattern of the *Decapterus russelli*.

Discussion

The estimates of the growth parameters obtained by the various methods are given in Table 7. The fork length of the largest fish found in this study is 26.0 cm or, from Eq. 3, 29.0 cm in total length. The plot in Fig. 4 of standard deviations on mean length of the normally distributed components indicates that the standard deviation in the length range of a cohort remains more or less the same as it grows older (and longer). For this reason, we expect the total length of very old fish to vary around a mean, L_∞, with a standard deviation of about 1.35 cm in fork length (i.e., mean of 9 points in last aggregation (highest mean length in Fig. 4), or with a standard deviation of about 1.35 x 1.12 = 1.5 cm in total length. The largest fish found, 29 cm, represents the upper tail of such an old fish distribution, say, mean plus one or two standard deviations. Then we expect the mean L_∞ to be around 26-27.5 cm. This is not really in agreement with the results in Table 7. However, the Gulland and Holt plot (Fig. 9) used in the Bhattacharya estimation procedure does not look very much like a straight line. In fact, of the 16 points plotted from Table 6, one outlying point corresponding to link 1b in Fig. 3B has a great impact on the estimated regression line. Still the point should not be excluded. The situation merely reflects the problems of identifying individual cohorts in those months where new recruits are continuously entering the fishery. Link 1a tends to draw the line down and link 1b to raise the line. The growth curve fitted by ELEFAN I also represents a rather poor fit to the peaks in the restructured data (Fig. 5). For this reason the result from the Wetherall method, L_∞ = 28 cm is adopted as the final estimate.

Table 7. Estimation of the growth parameters of *D. russelli* by various methods.

Method	L_∞ (cm)	K ($year^{-1}$)	ϕ'[a]
Wetherall	28.4	–	–
Bhattacharya	31.9	0.92	2.97
ELEFAN I	30.2	0.9	2.91

[a] $\phi' = \text{Log}_{10} K + 2 \text{Log}_{10} L_\infty$

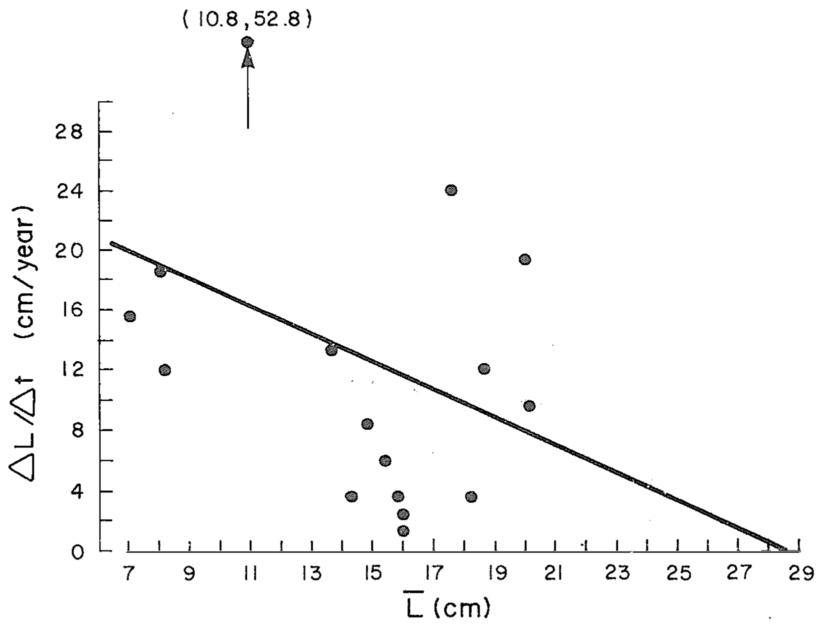

Fig. 9. Gulland and Holt plot of *D. russelli*.

$K = 0.9$ year^{-1} is used as the final estimate obtained from the data in this study. The von Bertalanffy growth curve of *D. russelli* based on these estimates is

$$L(t) = 28\ (1-e^{-0.9\ t})$$

where L(t) is total length in cm at age t in years ($t_o = 0$). It is around this curve of mean growth that we have normal distributions for individual fish length and since the standard deviation remains almost constant, the coefficient of variation (i.e., standard deviation/mean length) apparently decreases as a cohort of *D. russelli* grows older.

The estimate of total mortality is somewhat higher from catch curve analysis ($Z/K = 5.16$) than from the Wetherall method ($Z/K = 3.35$). The Z estimate will be based on the mean result, i.e.,

$$Z = K \times 4.3 = 0.9 \times 4.3 = 3.9 \text{ year}^{-1}$$

which gives a fishing mortality of

$$F = Z - M = 3.9 - 1.8 = 2.1 \text{ year}^{-1}$$

and an exploitation rate of

$$E = 2.1/3.9 = 0.54.$$

Both the Wetherall method and the catch curve analysis are based on an assumption of steady state-conditions, i.e., recruitment to the fisheries and growth and mortality by length groups remains the same over two to three years. Also, it is assumed that the underlying length frequencies for the analyses do represent the mean length composition of the total annual catch (in order to smoothen out variations due to contributions from the individual cohorts). However, in this study, only data for 10 months were available. Furthermore, it also appears from Tables 1 and 3 that certain length groups sometimes are not sampled or caught in the purse seine fishery. It may be due to the characteristics of the purse seine operated with *rumpon*, that only fish of specific length are captured, or it might be connected to migration.

Future sampling techniques should be improved, and not only be based on commercial landings but also on exploratory surveys as well as tagging experiments. The results of the discriminant analysis of morphometrics of *D. russelli* from the central Java Sea and Makassar Strait (Lari-larian) (Soriano et al., this vol.) indicate that data from the latter areas should be treated as coming from a different stock.

Acknowledgments

The author wishes to thank Mr. M. Rofig, Mr. M. Baehagi, Mr. S. Suwasono and Mr. Usulludin, students of the Faculty of Fisheries, University of Pekalongan, for their assistance in collecting the data used in this study.

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Estimation of Growth and Mortality of Round Scad *(Decapterus macrosoma)* in the Java Sea, Indonesia

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Abstract

Length-frequency data on *Decapterus macrosoma* (Carangidae) have been collected from the commercial purse seine fishery at the Pekalongan landing site, Central Java, Indonesia. Frequencies were raised in three steps to represent total catch from the Java Sea.

The growth parameters K and L_∞ were estimated using the ELEFAN I program and the Bhattacharya method, the latter subsequently combined with modal progression analysis. The growth parameters are compared with values from *D. macrosoma* obtained elsewhere.

The seasonality of recruitment of *D. macrosoma* into the Java Sea stock, and its implications for sampling are briefly discussed.

Introduction

The round scad (*Decapterus macrosoma,* Carangidae) is one of the most economically important pelagic fishes in the Java Sea. It is caught in large quantities in the eastern part of Java Sea by purse seiners. During 1981 to 1985, the catch of scads (*Decapterus* spp.) by purse seine in the Java Sea ranged from about 8,000 to 68,000 tonnes (t). The annual catch actually decreased from 15,000 to 8,000 t from 1979 to 1981 (Table 1), but then increased again due to an extension of the fishing grounds and increasing boat sizes.

Table 1. Annual landings of the *Decapterus* spp. category in tonnes by fishing port from the purse seine fishery in the Java Sea.

Fishing port	1979	1980	1981	1982	1983	1984	1985
Tegal	2,615	1,670	1,237	3,030	7,698	4,359	5,187
Pekalongan	6,060	5,483	4,669	8,878	20,349	30,298	40,873
Batang	5,167	2,426	1,673	1,785	2,053	3,041	6,393
Juana	–	–	–	–	–	4,466	9,901
Rembang	999	946	611	1,719	4,441	4,917	5,548
Total	14,841	10,525	8,190	15,412	34,541	47,081	67,902

Source: Annual Statistics from fishing port.

Only few studies of scads populations in the Java Sea appear to have been carried out. Hardenberg's (1938) pioneer study on scad populations indicated the existence of a West, an East and a North stock in the Java Sea. Sadhotomo et al. (1985), Widodo (this vol.) and Soriano et al. (this vol.) comment on some related aspects of the biology on the scad populations in the Java Sea. The present study deals with round scad only. First estimates of growth for *D. macrosoma* in Java Sea were given by Sadhotomo et al. (1985); estimates of the parameters of growth for round scad have been obtained in the Philippines (Ingles and Pauly 1984), Thailand and Sumatra, Indonesia (Anon. 1985).

The aim of this study is to reestimate growth parameters based on recent data and to obtain estimates of mortality and related parameters in order to provide a first basis for rational fishing management.

Materials and Methods

Characteristics of the Fisheries

The activity of the fishery is centered in the province of Central Java. There are five landing places with Pekalongan as the most important one with more than 50% of the annual landings of scads (Table 1). In 1985, the fleet consisted of 438 wooden boats, 1 to 6 years old, of length 19-28 m, power 120-160 hp, GT 19-28 t and crews of 30-35 men. The gear used is a purse seine with mesh size of about 2 cm and fishing takes place using coconut raft *(rumpon)* as fish attraction devices. The duration of a trip is from 10-25 days. The purse seiners operate in two fishing areas comprising five fishing grounds. This study deals only with area 1 which comprises three fishing grounds (Karimun Java, Bawean and Masalembu). Area 2 is in the Makassar Strait, (see Fig. 1 and Widodo, this vol.). Number of trips is the only measure of effort by month that is available for this study.

Sorting of Catch and Sampling Method

In the harbor, the multispecies catch from one fishing trip is sorted on the boat into species and/or commercial categories, i.e., scads, sardines, mackerels, etc. (Fig. 2). The scad category (*D. macrosoma* and *D. russelli*) usually constitutes the major part of the total catch. It is landed in baskets, each of which contains approximately 40 kg. Since the range in Ws_j, the catch of scads per trip (j), is from a few hundred kg to more than 30 t, the number of scad-baskets landed per trip varies from very few to several hundreds. The degree to which the sorting of the scad-catch into baskets actually represents different size categories of scad varies from one trip to another.

Sampling of a trip was done by collecting scads from several baskets into one sample. The weight of the sample of scads from trip j is denoted by ws_j in Fig. 2. The sample was then sorted into *D. macrosoma* and *D. russelli*. The fork length of the nm_j specimens of *D. macrosoma* were measured to the nearest 0.5 cm below.

Samples were collected at the landing site (Pekalongan) from 6 to 16 trips per month from March 1985 to June 1986. All trips sampled represent fishing at three fishing grounds (Area 1). In total, 154 trips were sampled and 10,917 fish were measured.

Raising Samples to Total Catch in Number by Length Group

The starting point for the raising procedure is the number of *D. macrosoma* by fork length group for each trip sampled, i.e., in case of length group No. i for trip j, nm_j (i), see Fig. 2 and Table 2. The total number of *D. macrosoma* measured in each sample j, nm_j, is given at the bottom of Table 2. The aim is to raise these frequencies by appropriate factors in order to represent the monthly catch in number by length group of *D. macrosoma* in the multispecies fishery by the total fleet, purse seiners in the Java Sea. This raising procedure is carried out in three steps as described below.

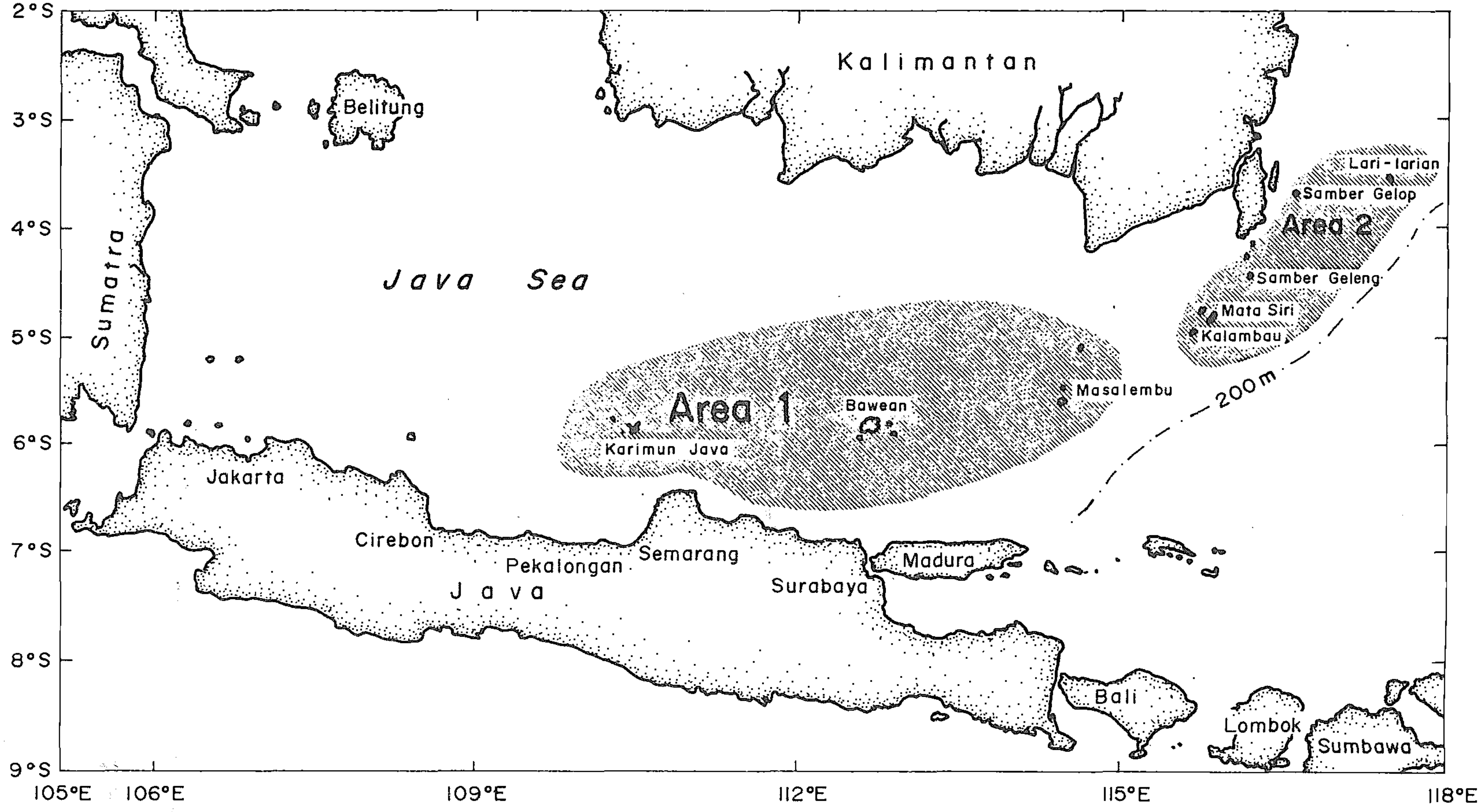

Fig. 1. Fishing grounds for scads in the Java Sea, i.e., Area 1 (Karimun Java, Bawean and Masalembu) and Area 2 (Kalambau, Mata Siri, Samber Geleng, Samber Gelop and Lari-larian).

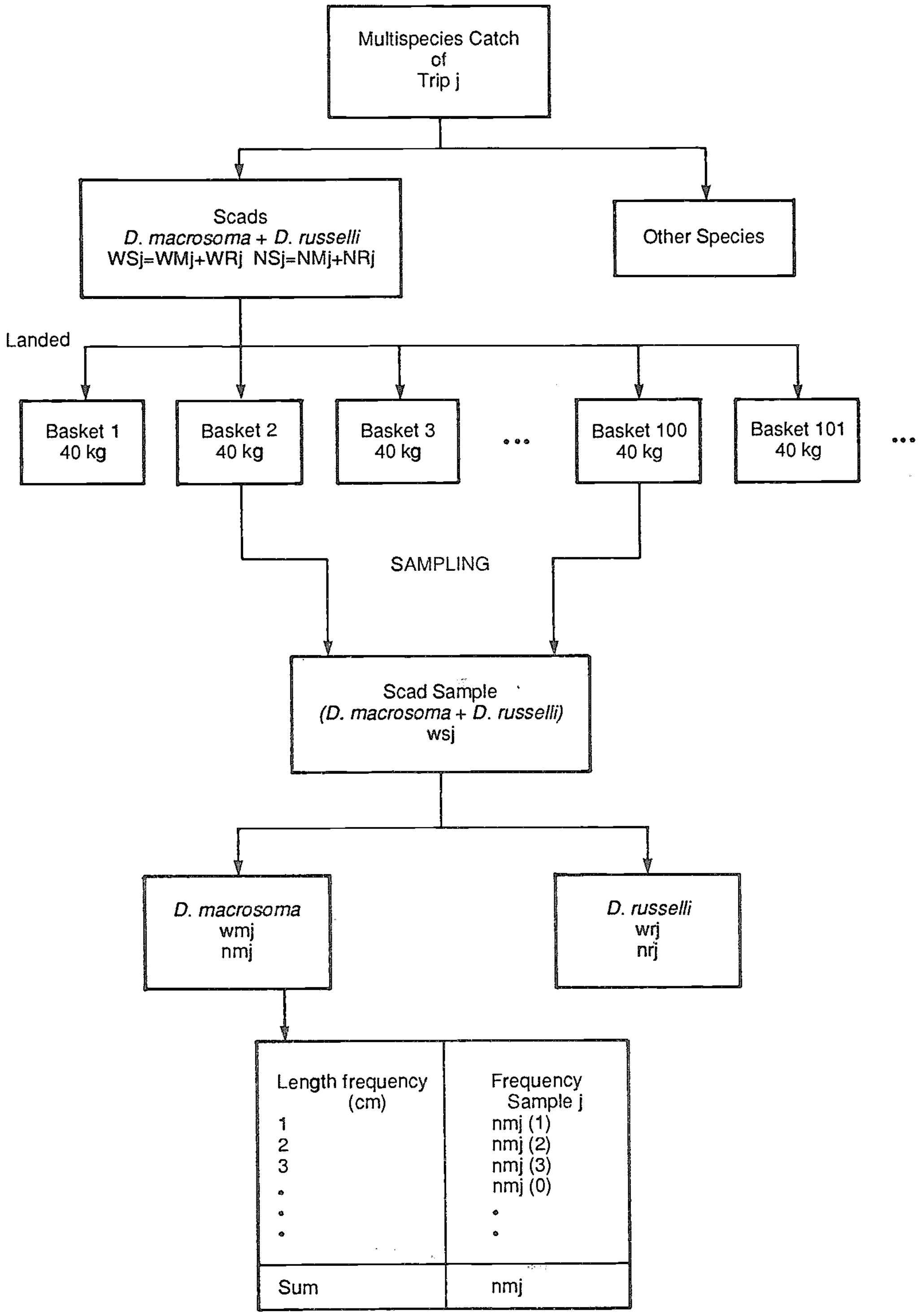

Fig. 2. Sampling scheme for scads *Decapterus macrosoma* and *D. russelli* caught in the Java Sea. The W's refer to weight and N's to numbers.

Table 2. Fork length frequency raw data in 1/2 cm intervals (i.e., the $nm_{j(i)}$'s) for *Decapterus macrosoma* in the Java Sea, sampled at the major landing place (Pekalongan) from individual fishing trips (j) in the period March 1985 to June 1986.

Mid-length	1985 Mar[1]									1985 Apr								1985 May						1985 Jun								
(cm)	8	15	15	17	20	23	24	25	27	3	3	4	10	13	17	20	28	9	16	17	20	22	25	2	8	10	11	17	17	20	24	24
8.75																																
9.25																																
9.75																																
10.25																																
10.75																															1	
11.25																														1	2	
11.75																															4	
12.25																														10	5	
12.75																														12	8	
13.25										1																	2			14	10	
13.75	1									1	2																3			13	5	1
14.25	2			1						2	3	1												1			10			3	3	6
14.75	3			2	1					3	4	1		3	1					1				1			11				1	9
15.25	9	1		3	2					5	5	4		6							4	1		4			6					8
15.75	20	5		4	6					6	13	17		12	3	3		1	1	1	7	2		7	1		10					12
16.25	21	9		11	11		1			5	10	14	1	12	15	4		2	3		8	18		9	3		3					5
16.75	16	20	2	6	6	1	3	2	3	4	3	12	7	8	15	7	1	10	4	3	17	19		7	6		2	2				1
17.25	9	13	3	3	3	8	5	10	9		3	3	13	2	8	8	3	13	7	9	4	17	4	7	12	1		5	1			
17.75	6	5	7	2		11	2	14	10				8	1	2	3	4	13	6	12	4	14	5	3	13	1			2			
18.25	12	2	9			6	2	7	11				11		1	3	6	4	2	19	3	2	7	1	11	9	1	7	3			
18.75	14	1	4			3	1	4	8				3			5	5		1	9		3	8	1	2	9	11	3				
19.25	18		3				1	1	4				1			2		1		1			4			13		6	12			
19.75	13		5			1			2				1			3	2			1		2	2		1	10		2	6			
20.25	7		2													2						3	1			2			2			
20.75	2		1					1								1	1					2				2		1	1			
21.25	1		1														1					1							1			
21.75																																
22.25																																
Sum	154	56	37	32	29	30	15	39	47	27	43	52	45	44	45	41	23	44	24	56	47	84	31	41	39	47	48	34	31	53	39	42

[1]The 15th was used throughout as mean sampling date for every month. Exact sampling dates are where available (a * replaces the day of the month when this information is unavailable).

Table 2. Continued

Mid-length	1985 Jul									1985 Aug										1985 Sep													
(cm)	4	4	8	15	18	21	27	29	30	5	19	29	*	*	*	*	*	*	*	3	3	9	10	11	17	18	20	23	23	28	28	30	30
8.75																				4													
9.25																				7							2						
9.75																				15							5						
10.25											2									13							6	1					
10.75											4									6							4	3	3				
11.25				1							3										1						2	10	3				
11.75				2							2	1								1	5			9			1	8	8				3
12.25				8			3			1	4										6			15				8	17	3			12
12.75				13			2			3	6	3									6			16				4	9	6			8
13.25				11	4		4			7	9	6		1							4			4	1			2	5	7	1		12
13.75				12	6		10			10	3	10		4							5			2					1	6	1		12
14.25				14	10		11			8	2	9		8							2	2		2						7	3		9
14.75				13	11		8			3	1	18		5							1	10		1	3					6	6		8
15.25				16	9		6			2		16		2	6	1						11	2		5	1				1	8	3	6
15.75	4		1	5	11		2			5		9	1	1							1	8	4		10	6				1	6	12	3
16.25	4		4	6	8		1			2		3	4		4		1					4	7	2	6	12					3	16	4
16.75	7		10	4	2	2	1		4				3	1	13	1	2				1	2	8	2	2	14					2	9	3
17.25	10		12	4	6	6			9			1	5		15	2	1	2					5	3	1	4					5	6	3
17.75	9	1	10	2	3	10			10			1	2		11	4	4	3					7	5		2					4	2	1
18.25	6	5	7		10	9		1	13				5	1	6	3	7	2	1				5	4								1	
18.75	8	13	7		7	8		5	10				11		6	8	12	6	2				3	2									
19.25	5	13	3		3	4		5	8				13		8	5	16	4	5				2	2									
19.75	2	14	1		2	3		11	2				9		5	9	9	6	11				1	1									
20.25	1	4				2		8	1				5		2	8	11	4	9				1										
20.75		2				1		4					2		1	7	5	1	5														
21.25		1				1							1			4		2	1														
21.75								1								3																	
22.25																2																	
Sum	57	53	55	111	92	46	48	35	57	41	36	77	61	23	77	57	68	30	34	46	32	37	45	70	28	39	20	36	46	37	39	49	84

Table 2. Continued

Mid-length (cm)	1985 Oct																1985 Nov															
	12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8.75																																
9.25																																
9.75																																
10.25	2																															
10.75	1		1																													
11.25	2	2	2		2																	1				3						
11.75	3	3	8		3					2												1				3						
12.25	6	4	3		6					5												2	1			2						
12.75	8	12	5	1	5	1			2	13			1	1					1		1	4	2			4	1			1		
13.25	19	8	9	3	11	3			4	9		1	7	2				2	1		5	8	4			5	3	2	1	3		2
13.75	15	11	6	5	10	7		7	10	18	5	2	22	7				1	4		5	21	16			6	13	4	6	14		
14.25	5	5	5	7	7	19	3	20	25	14	17	8	55	8	7		3	4	9		14	24	16			9	17	10	10	29	1	4
14.75	2	1	4	9	2	18	10	16	15	10	13	3	35	6	8		11	9	8	2	12	14	21			7	20	12	12	16	5	14
15.25				5		16	11	11	14	3	25	2	30	6	18		19	10	18	3	12	7	19		2	10	15	9	15	4	8	21
15.75		3	2	3	1	4	9	7	4	1	12	1	12	2	19		12	5	8	6	10	2	6		4	7	22	9	10	2	34	28
16.25		1			6		7		3		4		5	3	8	9	7	2	6	5	5	1	6		6	3	14	4	6	1	16	13
16.75				1	2	6	1						1	3	4	12	3	1		4	1		2		3	2	9	4	2		4	8
17.25				1	1	2									2	21	1			2					4	3	2	1	1			1
17.75					1										3	13								1		1	1					
18.25															1	10								2								
18.75																6								3								
19.25																6								6								
19.75																3								4								
20.25																2								2								
20.75																								1								
21.25																								1								
21.75																																
22.25																																
Sum	63	50	45	35	57	76	41	61	77	75	76	17	168	38	70	82	56	34	55	22	65	85	93	20	19	65	117	55	63	70	68	91

Table 2. Continued

Mid-length (cm)	1985 Dec 5	*	*	*	*	*	*	*	*	*	28
8.75											
9.25											
9.75											
10.25											
10.75											
11.25											
11.75											
12.25											5
12.75								1			10
13.25			1	3				3			13
13.75		4	2	8				9			29
14.25		6	4	16				12		2	39
14.75	1	20	9	15		8	4	23		14	36
15.25	11	17	11	15		14	9	18		15	17
15.75	15	22	12	19		33	21	13		28	25
16.25	10	10	6	18	2	27	18	3	3	34	8
16.75	15	4	7	18	7	26	16	1	17	18	
17.25	10	3	2	14	9	13	5		32	7	
17.75	6		1	5	5	18	3		28	2	2
18.25				4	1	12	9		17	3	3
18.75						7	5		23	1	
19.25						3	3		13		
19.75							2		9		
20.25							1		3		
20.75									1		
21.25											
21.75											
22.25											
Sum	68	86	55	135	24	161	96	83	146	124	187

Mid-length (cm)	1986 Jan 6	6	8	13	18	20	27	30
8.75								
9.25								
9.75								
10.25								
10.75								
11.25								
11.75								
12.25								
12.75								
13.25								
13.75		6						
14.25		11					7	6
14.75		18	3	4	5		22	19
15.25	5	14	12	11	10	2	27	17
15.75	17	25	33	22	33	15	42	44
16.25	23	22	26	38	65	28	23	45
16.75	25	21	20	26	54	31	22	28
17.25	16	11	15	24	43	31	8	19
17.75	15	5	5	14	19	23	6	7
18.25	11		6	2	17	18		6
18.75	6			–	14	2		7
19.25	4			1	10			2
19.75				2	14			
20.25				5	4			
20.75				–	9			
21.25				2				
21.75				6				
22.25				2				
Sum	122	133	120	158	297	150	157	200

Mid-length (cm)	1986 Feb 1	5	7	8	12	14	15	20	20	20	26	28
8.75												
9.25												
9.75												
10.25												
10.75												
11.25												
11.75												
12.25												
12.75												
13.25												
13.75											8	
14.25											11	
14.75			2		1		9	7			22	
15.25	3	6	16		4	17	12	15			26	7
15.75	4	18	23	2	16	27	45	32			11	22
16.25	9	23	25	5	19	34	20	46		12	7	21
16.75	9	21	28	12	14	29	9	41		19	1	19
17.25	13	13	9	15	7	20	1	21		16		12
17.75	4	10	9	5	4	12		27		4		5
18.25	3	8		2	–	6		12		4		1
18.75	1	6			3			12		2		3
19.25	1	4						10				3
19.75		3							7			–
20.25		2							24			2
20.75									22			1
21.25									24			
21.75									12			
22.25									2			
Sum	47	114	112	41	98	145	116	223	91	57	86	96

Table 2. Continued

Mid-length (cm)	1986 Mar										1986 Apr						1986 May						1986 Jun					
	3	5	7	10	15	18	19	21	30	30	1	5	10	21	25	27	2	3	12	20	27	*	4	15	24	26	27	30
8.75																												
9.25																												
9.75																									2			
10.25																									10			
10.75																									12	3		
11.25																									9	4		
11.75																									8	15		
12.25																									16	20		
12.75				2					7											1					13	24		
13.25				7					15											5			3		8	18		
13.75				11	6		1		32											8	1		5	2	2	6		
14.25	3		2	12	21	1	8		23	1	1							6		17	3		9	6	1	2		
14.75	9	5	14	11	28	12	10		12	–	2							12	1	10	4	2	3	6		1		
15.25	20	7	12	14	32	16	12	3	12	12	4	2				2	2	12	2	5	7	4	1	5		1		
15.75	21	26	12	7	17	30	10	16	8	16	9	5			2	7	4	13	2	2	10	5	4	7			1	
16.25	16	28	4	6	5	29	8	28	6	21	18	12	2	6	5	3	4	5	3	2	8	6	1	7			4	5
16.75	9	25	9	2		12	6	30	7	6	26	18	6	10	10	9	7	2	1	3	7	5	3	2			8	10
17.25	6	8	5	3		2	2	4		2	17	16	4	12	17	12	4	1	4	10	3	5	2	1			10	17
17.75	12	9				2	7	1		3	8	7	9	10	6	18	12	1	12	11	2	8	2	3			4	16
18.25	14	2				1	16			–	5	2	5	8	10	6	9		10	16	1	4	5	5			2	12
18.75	18					2	23			1		1	2	9	8	2	3		15	14	1	2	6	5			1	8
19.25	13					1	23			–			2	5	2		2		8	8		2	5	2			1	2
19.75	7						10			-				2	1		1		2	2		1	3	1			1	1
20.25	2						4			1				1					1	1			2					
20.75																							1					
21.25																												
21.75																												
22.25																												
Sum	150	110	58	75	109	107	140	82	122	63	90	63	30	58	61	59	48	52	59	118	47	44	53	52	81	94	32	71

Raising to Catch of Each Trip Sampled

The length frequencies of *D. macrosoma* in the sample of scads (weight ws_j) of trip j should be raised to the total by the following raising factors (c.f. Fig. 2).

$$RF1_j = WS_j/ws_j \quad \text{... 1)}$$

However, the sample weights, the ws_j's were not available for this study. Only, estimates of 100 pm, the percentage of *D. macrosoma* by weight in the samples of scads of trip j were available, i.e.,

$$pm_j = wm_j/ws_j \quad \text{... 2)}$$

where $ws_j = wm_j + wr_j$ is the total weight of the sample of scads from trip j. The weight of the sample of *D. macrosoma*, wm_j, was calculated from the frequencies based on the fork-total length relationship (Suwaso 1986),

$$L = -0.22014 + 1.1034FL \quad \text{... 3)}$$

and from the total length-weight relationship (Suwaso 1986)

$$W = 0.009\, L^{3.01} \quad \text{... 4)}$$

The lengths are here measured in cm and weights in g. The mean weight of the nm_j (i) fish in length class i, with mean fork length $LF_{(i)}$ (i.e., the midlength of the class as given in Table 2) was estimated as the weight-at-mean length using Eqs. (3) and (4), i.e., the sample weight of *D. macrosoma* from trip j, wm_j was obtained as follows:

$$wm_j = {}_i\, nm_j(i)0.009(-0.22014 + 1.1034\, FL_{(i)})\ 3.01\ (g) \quad \text{... 5)}$$

where $FL_{(i)}$ is the fork midlength and nm_j (i) represents the numbers in Table 2. The total landing of *D. macrosoma* of each trip is estimated by assuming that pm_j, the fraction of *D. macrosoma* in the scad sample also applies to the total catch of scads, i.e.,

$$WM_j = pm_j * WS_j \quad \text{... 6)}$$

which gives the calculated landing of *D. macrosoma* of trip j.

The first raising factor for each of the 154 trips sampled could then be computed by dividing the catch in weight by the sample weight, i.e.,

$$RF1_j = WM_j/wm_j \quad \text{... 7)}$$

Each of the 154 length-frequency samples in Table 2 was then multiplied by the corresponding RF1, given in Table 3, in order to raise to total catch of *D. macrosoma* of each trip sampled, i.e.,

$$NM_j(i) = RF1_j(i) \quad \text{... 8)}$$

is the number of *D. macrosoma* in length class i caught in trip j.

Table 3. Raising factor. RF1 by month and by trip sampled and raising factor RF2 and RF3 by month for raising length-frequency samples of *D. macrosoma* into the total catch.

Sample trips (RF1)	1985 Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun
1	603	570	4,217	2.650	433	913	3.470	3,450	1,163	1,230	250	342	567	2,681	204	676
2	1,790	2.170	1.380	631	456	2.185	887	361	422	390	1,890	524	128	1.337	411	228
3	643	1.940	364	530	605	120	1.271	813	1.690	1,270	1.430	228	750	595	282	93
4	1.180	2.230	677	268	906	2.120	276	120	1,340	1,580	1,310	602	705	4.430	661	632
5	600	3.160	360	1.680	1,980	423	596	1,120	2.870	130	236	301	214	193	882	359
6	310	1.840	589	552	706	61	8.730	3,840	3,690	1,420	1,070	1,030	690	335	470	2.180
7	4.450	190		217	156	96	1,890	2.270	3,210	1,340	379	906	881			
8	517	157		756	554	670	4.530	347	82	635	73	336	1.147			
9	426			341	634	1,330	876	4,070	365	278		173	4.100			
10						337	2.910	7,600	2.468	451		2.845	1.420			
11							1.000	704	1.910	690		845				
12							423	1,950	1.320			938				
13							269	3,110	5.950							
14							768	457	3,250							
15								596	5,220							
16								818	3,160							
RF2 0	21.22	15.40	15.30	8.78	34.60	17.20	19.60	15.30	16.10	20.70	11.60	9.50	24.10	25.10	17.50	15.5
RF3 2	1.65	1.69	1.51	1.52	1.72	2.05	2.59	2.75	2.62	2.03	1.82	1.94	1.65	1.69	1.51	1.5
nm[1]	439	320	286	37	554	504	608	1,031	978	1,352	1.187	1,224	1,016	1,016	298	383

[1]Total number of *D. macrosoma* sampled by month.

Raising to Monthly Catch from Trips to Area 1 Landings in Pekalongan

Raising to monthly catch of sampled trips was then done by adding the raised frequencies within months. As an example, consider the number of *D. macrosoma* with fork length between 17.50 and 18.0 cm from trips sampled in March 1985. From Table 2 and 3, we obtain, using Eq. (8)

$$6 * 603 + 5 * 1790 + 2 * 643 + 2 * 600 +$$
$$14 * 310 + 10 * 4450 + 11 * 517 + 7 * 426 \quad 72600$$

Thus, about 72,600 *D. macrosoma* with fork length from 17.5 to 18.0 cm have been caught in the 9 trips to fishing Area 1 sampled in the month of March 1985. Area 1 comprises three fishing grounds; Karimun Java, Bawean and Masalembu. The total number of trips to these fishing grounds and landing in Pekalongan in March 1985 was 191 (Table 4). Continuing the example, we assume that a mean catch of 72600/9 8070 *D. macrosoma* in the length class considered is representative for the mean catch of all trips, that is,

$$8070 \text{ x } 191 \approx 1{,}540{,}000$$

Table 4. Number of trips of purse seiners landing in Pekalongan by month.

Fishing ground	1985 Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Jun
Karimun Java	93	44	40	29	115	67	101	70	107	102	33	37	45	49	64	72
Bawean	29	16	7	38	66	84	94	39	29	19	14	30	76	17	7	2
Masalembu	69	63	45	12	130	21	79	136	122	107	46	47	120	85	34	9
Area 1	191	123	92	79	311	172	274	245	258	228	93	114	241	151	105	93

fish of length 17.5-18.0 cm were landed from Area 1 in Pekalongan in March 1985. This defines a monthly raising factor, RF2 (Table 3) as

$$RF2 = \frac{\text{No. of trips to Area 1 by months landed in Pekalongan}}{\text{No. of sampled trips to Area 1 by month landed in Pekalongan}} \quad \text{... 9)}$$

Raising to Catch from Area 1 Per Month by Total Fleet

In March 1985, the catch from a total fo 572 trips were landed in the five fishing ports (Table 1). The catch from 345 of these trips were landed in Pekalongan of which the fraction 191/345 or 55.4% had been fished in Area 1. Assuming that the same percentage of the catch landed in the other fishing ports originated from Area 1, the total number of trips to Area 1 in March 1985 could be obtained as

$$572 \times 191/345 = 572/345 \times 191 = 1.65 \times 191$$

Raising to the catch of the 191 trips to Area 1 has already been accounted for by the monthly raising factor RF2. The second monthly raising factor, therefore, becomes RF3 = 1.65 for March 1985 (see Fig. 3). Thus, the number of *D. macrosoma* of length 17.5-19.0 cm is raised to 1,540,000 x 1.65 ≈ 2,541,000 in order to account for the catch from Area 1 in March 1985. The raising factor RF3 (given in Table 3) is obtained from:

$$RF3 = \frac{\text{Total no. of trips by month}}{\text{No. of trips by month landed in Pekalongan}} \quad \text{... 10)}$$

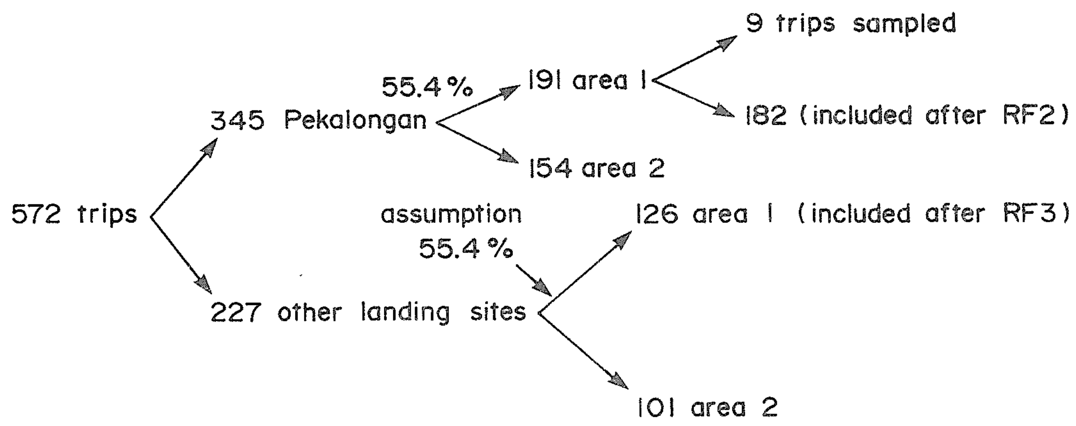

Fig. 3. Example to illustrate the computation of factor RF3, used for raising samples to total catch of *Decapterus macrosoma* in the Java Sea, March 1985.

The underlying assumptions of this final raising are (a) that the mean catch from the sampled trips in Pekalongan is representative for all the trips to Area 1 in the month considered and (b) that the fraction of the fleet operating in Area 1 does not depend on landing site. (The number of trips by landing site for 1986 was not available for this study. The calculation of RF3 for the months of 1986 was instead based on the trip numbers from 1985 in Table 5).

The final raised numbers by fork-length groups pooled on a quarterly basis are given in Table 6.

Table 5. Number of fishing trips by month and landing site of purse seiners.

Landing site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tegal	90	64	58	56	46	47	77	104	118	136	104	73
Pekalongan	315	298	345	320	336	258	369	385	320	316	314	338
Batang	60	55	70	66	66	45	83	101	139	166	139	111
Juana	69	100	63	71	38	27	94	165	168	154	165	125
Rembang	39	49	34	28	21	14	13	34	83	96	100	39
Total	573	566	570	541	507	391	636	789	828	868	822	686

Table 6. Calculated fork-length frequencies in total catch of *D. macrosoma* by quarter (from March 1985 to May 1986).

Mid-length (cm)	Quarter 1	2	3	4	5
8.75			179		
9.25			414		
9.75			925		
10.25		154	1,361		
10.75		316	960		
11.25		385	1,959		
11.75		452	4,441		
12.25		1,554	5,175	144	
12.75		2,599	11,472	317	38
13.25	147	2,942	24,767	711	107
13.75	281	2,792	37,934	2,149	266
14.25	563	3,463	57,922	3,476	440
14.75	1,117	3,223	49,543	6,508	790
15.25	1,979	3,192	43,317	8,301	1,447
15.75	4,528	1,817	34,365	13,917	2,435
16.25	6,083	1,717	19,586	12,718	5,289
16.75	7,450	1,838	100,541	11,712	7,102
17.25	6,612	2,740	4,872	7,617	6,034
17.75	5,030	2,460	4,182	4,590	4,051
18.25	3,847	2,703	2,220	2,817	3,020
18.75	2,188	2,876	1,375	1,354	2,478
19.25	1,278	2,396	963	791	1,518
19.75	802	2,415	631	393	712
20.25	326	1,259	379	380	343
20.75	185	612	99	145	54
21.25	91	204	3	132	12
21.75		39		206	
22.25		4		62	
Sum[1]	42,507	44,152	409,585	78,440	36,136
Bhattacharya[2]	42,310	41,939	319,580	78,056	35,998
Difference[3]	197	2,213	5	84	137

[1]Total catch in numbers of fish by quarter.
[2]Total number of fish explained by identified normal distributions.
[3]Number of fish not accounted by the normal distributions.

Method of Estimation of Growth Parameters and Mortality

Bhattacharya method and ELEFAN I program

The frequency distributions of numbers of fish by length group obtained from catch samples are usually polymodal. In the ELEFAN I program, modes or peaks are identified in an automatic restructuring process, where peaks are assumed to represent individual cohorts and the best fit of a von Bertalanffy growth curve is obtained iteratively (Pauly and David 1981). The method of Bhattacharya (1967) assumes, on the other hand, that each component is normally distributed. The estimation of such a component is based on linear regression, since differences between the logarithm of numbers in consecutive length groups transform a normal distribution into a straight line. The identification of the number of normal components in a frequency data set is more or less a subjective one and so is the choice of links when connecting the components of successive frequency samples in an attempt to identify cohorts. The final step is the standard Gulland and Holt plot which also applies to fork-length, i.e.,

$$\Delta FL_i/\Delta t_i \ = \ KFL_\infty - K\overline{FL}_i \qquad \text{... 11)}$$

where $y = \Delta FL/\Delta t$ represents the growth rate of the cohort at size $x = \overline{FL}$. K and FL_∞ are then obtained by linear regression ($K = -b$ and $Fl_\infty = -a/b$) (Gulland and Holt 1959).

Catch curve and cohort analysis

To estimate mortalities, the length frequencies of catch numbers by months are added to represent the total annual catch in the individual cohorts so the slope of a catch curve should represent total mortality. In cohort analysis, on the other hand, stock numbers and fishing mortalities are calculated, by length group, such as to match the catch numbers. Both analyses require that the stock of *D. macrosoma* is in a steady-state i.e., that mortalities and growth parameters and recruitment have been more or less constant in the early to mid-1980s.

The catch at length data in Table 6 were corrected for incomplete selection and recruitment based on the catch curve in Fig. 7 using the method of Pauly (1984, 1986b).

Wetherall's method and Pauly and Munro's empirical index

The method of Wetherall (1986) for estimation of K and FL_{oo} (as modified by Pauly 1986a) was used to compare the results of the different methods for growth estimation. The final estimates of (K and L_∞) in this study add a new pair of observations to estimate the mean value of Pauly and Munro's (1984) empirical index ϕ' for *D. macrosoma*. This index is defined by

$$\phi' = \log_{10}K + 2\log_{10}L_\infty \qquad \text{... 12)}$$

where ϕ is approximately normally distributed for different stocks of the same species. If n pairs of growth parameter estimates, $(K_i, L_{\infty i})$, i = 1,2,..., n are available for *D. macrosoma* then the best estimate of ϕ' becomes

$$\phi' = \frac{1}{n} \sum_{i=1}^{n} \phi_i' = \frac{1}{n} \sum_{i=1}^{n} (\log_{10} K_i + \log_{10} L_\infty) \qquad \text{... 13)}$$

and it follows from Eq. (12) that

$$\text{Log}10K = \phi' - 2L_\infty 10 L_\infty \qquad \text{... 14)}$$

Recruitment Patterns

The seasonal pattern of recruitment of *D. macrosoma* into the fishery was examined by means of a "recruitment pattern", as derived by the ELEFAN II program (see Samb, this vol. for a detailed description of this method).

Results

Growth

The input data for the estimation of the growth parameters of *D. macrosoma* are the length frequencies of total catch by month (see Table 2), or after pooling over periods of 3 months starting with March 1985 length frequencies by quarter (Table 6).

The results obtained using the ELEFAN I program are $FL_\infty = 24.2$ cm and $K = 0.9$ year^{-1} based on the monthly frequencies and $FL_\infty = 24.0$ cm and $K = 1.15$ year^{-1} based on the quarterly frequencies (Fig. 4).

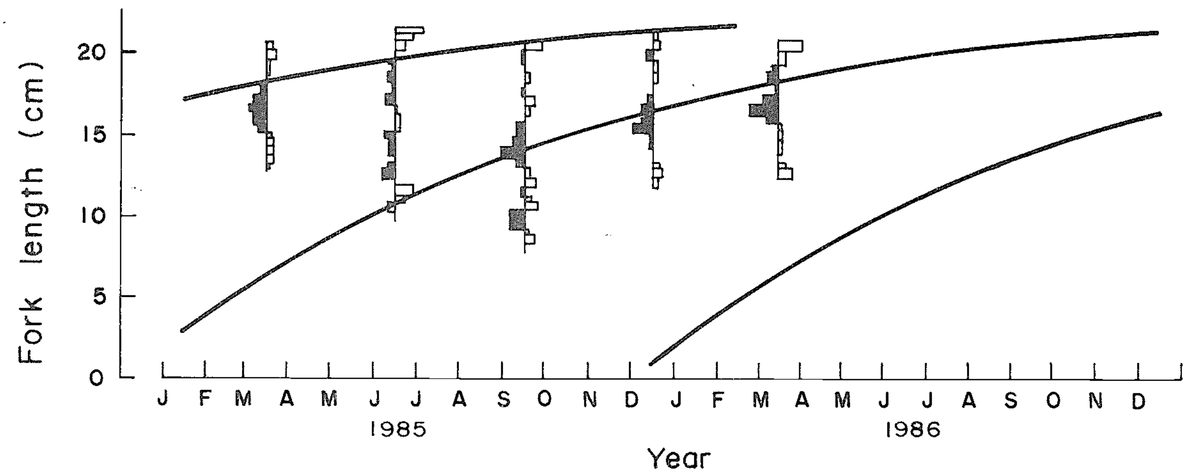

Fig. 4. Restructured fork length-frequency data by quarter, 1985-1986 of *Decapterus macrosoma* as, with superimposed growth curve estimated by ELEFAN I, with parameters $L_\infty = 24$ and $K = 1.15$ year^{-1}.

The Bhattacharya analysis could be performed based on the frequencies by quarter only. Table 7 gives the characteristics of the groups identified. The total numbers of fish included in the groups that were identified in this analysis are compared to calculated catch in numbers at the bottom of Table 6. The mean lengths of the groups are plotted in Fig. 5 and the links used for the Gulland and Holt plot are shown on Table 8 and Fig. 6). (Table 11, Fig. 5). The estimated regression line (see Table 8) gives:

$K = 1.31$ year^{-1}
$FL_\infty = 20.6$ cm or $L_\infty = 22.5$ cm

where L_∞ is estimated from the fork to total length relationship given as equation (3).

The modified Wetherall plot, applied to the pooled frequencies for one year (March 1985 to February 1986) gives (Fig. 7):

$FL_\infty = 24.2$ cm or $L_\infty = 26.5$ cm
and $Z/K = 5.21$

Table 7. Mean length, standard deviation and number of fish for each of the normally distributed groups identified through the Bhattacharya analysis.

Sample data in quarters	Mean length (cm)			
	I	II	III	IV
1 (Mar-May)	17.107	19.548	–	–
2 (Jun-Aug)	11.893	14.454	17.992	19.992
3 (Sep-Nov)	10.493	14.753	16.108	20.165
4 (Dec-Feb)	16.425	20.425	–	–
5 (Mar-May)	15.276	17.186	19.49	–
Sample data in quarters	**Standard deviation (cm)**			
	I	II	III	IV
1 (Mar-May)	0.97743	0.64988	–	–
2 (Jun-Aug)	0.94657	1.29316	0.74535	0.71569
3 (Sep-Nov)	0.65909	1.05276	0.95718	0.4006
4 (Dec-Feb)	1.2219	0.43101	–	–
5 (Mar-May)	0.96648	0.83269	0.70085	–
Sample data in quarters	**Cohort size ('000)**			
	I	II	III	IV
1 (Mar-May)	38,226	4,084	–	–
2 (Jun-Aug)	2,061	21,931	13,356	4,591
3 (Sep-Nov)	4,348	6,246,435	61,012	7,785
4 (Dec-Feb)	77,127	929	–	–
5 (Mar-May)	2,934	27,711	5,353	–

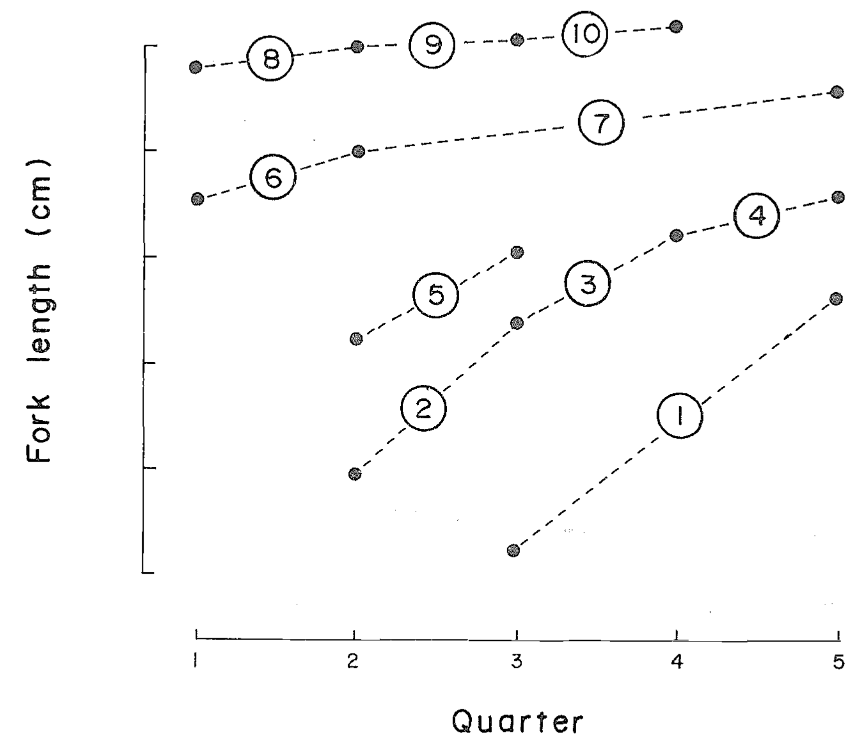

Fig. 5. Mean length of normally distributed components of length-frequency data of *Decapterus macrosoma* (1985-1986). Numbers identify increments used to estimate growth parameters (see also Fig. 6).

Table 8. Input data for Gulland and Holt plot, with statistics of regression analysis (data derived from Fig. 5 and Table 7).

Link no.	L (t_1) (cm)	L (t_2) (cm)	ΔL (cm)	Δt (year)	ΔL/Δt (cm/year)	(L (t_1) + L (t_2))/2 (cm)
1	10.493	15.276	4.783	0.50	9.57	12.89
2	11.893	14.753	2.86	0.25	11.44	13.33
3	14.753	16.425	1.672	0.25	6.69	15.59
4	16.425	17.186	0.761	0.25	3.04	16.81
5	14.454	16.108	1.654	0.25	6.62	15.28
6	17.107	17.992	0.885	0.25	3.54	17.55
7	17.992	19.49	1.498	0.75	2.00	18.74
8	19.548	19.992	0.444	0.25	1.78	19.98
9	19.992	20.165	0.173	0.25	0.69	20.08
10	20.165	20.525	0.26	0.25	1.04	20.30

$Y = 26.99 - 1.31X$; ($r = -0.96$, $n = 10$)
b (slope) = –.131; a (intercept) = 26.99

$Sb^2 = 1/(n-2) \cdot (SY/SX)^2 - b^2) = 0.0176$; $Sb = 0.1326$

$t\,(n-2) = 2.31$
95% confidence limits for b = (–1.62, –1.00)

$Sa^2 = Sb^2\,((n-1)/n) \cdot Sx^2 + \bar{X}^2) = 5.23$; $Sa = 2.29$

95% confidence limits for a = (21.70, 32.28)

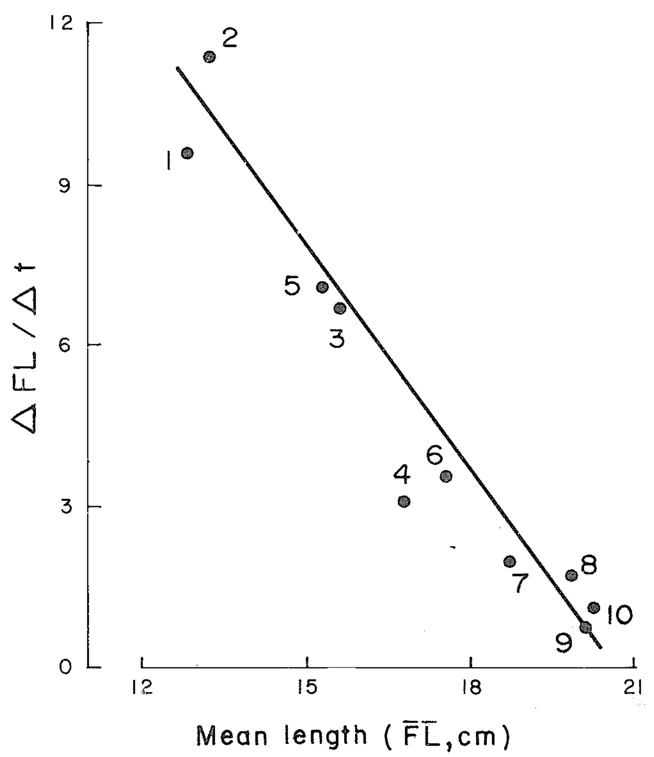

Fig. 6. Gulland and Holt plot for *Decapterus macrosoma* (Java Sea) based on growth increments in Fig. 5, with "mean lengths" (abscissa) expressed as the average of the length at the start and at the end of a growth increment (see text).

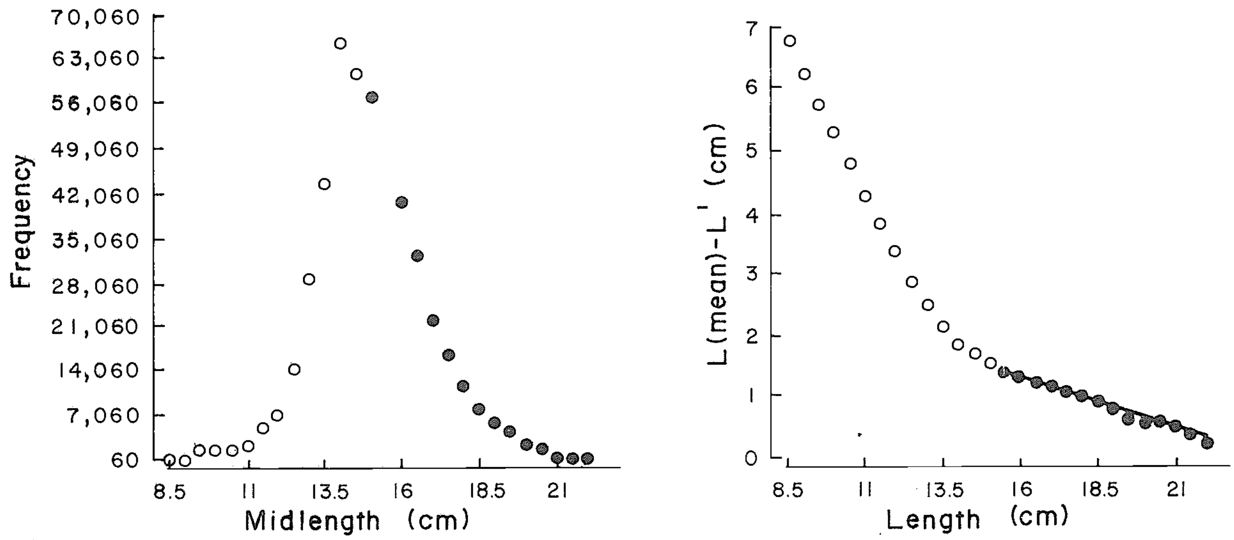

Fig. 7. Modified Wetherall plot (left) and plot of cumulated frequencies (right, used to identify classes to use in Wetherall plot) of *Decapterus macrosoma* from the Java Sea. The plot leads to L_∞ = 26.5 cm and Z/K = 5.21.

Mortality

In exploited populations, abundance declines as a result of death due to fishing and to natural causes. Total mortality rate (Z) can be expressed as being equal to F + M, where F and M are fishing mortality and natural mortality, respectively. F should be proportional to the level of fishing effort and catch per unit effort should be proportional to abundance*. Fig. 8 shows the length-converted catch curve for *D. macrosoma* in the Java Sea, while Fig. 9 shows the results of the length-cohort analysis. Table 9 gives effort in number of trips by quarter. Cohort sizes (Table 7) divided by effort (Table 9) gives cohort size in CPUE (Table 10). Assuming cohorts such as in Fig. 9, Table 11 gives calculated estimates of Z.

Estimates Based on Corrected Frequencies

The frequencies by quarter (Table 6), corrected for mesh selection, and analyzed by ELEFAN I gave:

L_∞ = 24.02 cm. and
K = 1.950 $year^{-1}$

The Bhattacharya method, based on the corrected figures leads to the mean lengths in Table 12. These values, analyzed using a Gulland and Holt plot, lead to

L_∞ = 20.4 cm
K = 0.950 $year^{-1}$

The recruitment pattern for *D. macrosoma* in the Java Sea is given as in Fig. 10.

* These assumptions are often not met in pelagic fishes such as scad (Editors' note)

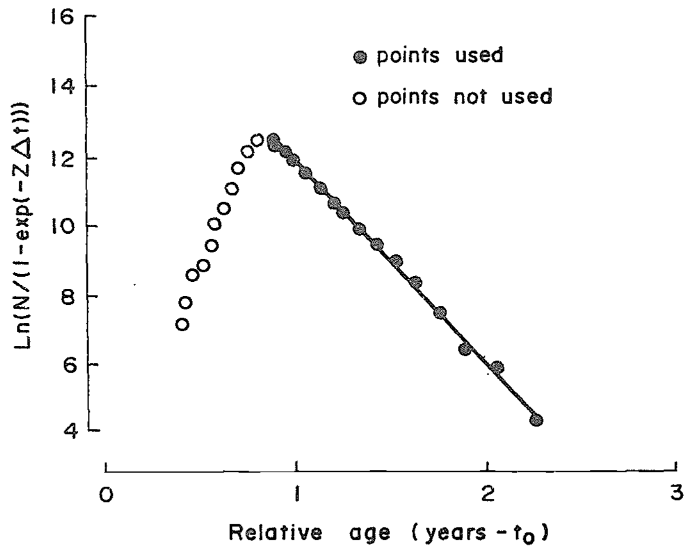

Fig. 8. Length-converted catch curve for *Decapterus macrosoma* (Java Sea), based on FL_{∞} = 24 cm and K = 7.15 $year^{-1}$.

Table 9. Total number of trips to Area 1 by month and by quarter.

		Trips		
Month/quarter	Pekalongan	Other fishing ports	Total by month	Total by quarter
Mar '85	191	126	317	
Apr '85/1	123	85	208	664
May '85	79	47	139	
Jun '85	172	69	148	
Jul '85/2	245	214	525	1,007
Aug '85	228	162	334	
Sep '85	114	457	731	
Oct '85/3	245	442	687	2,082
Nov '85	258	406	664	
Dec '85	228	104	332	
Jan '86/4	93	77	170	750
Feb '86	114	134	248	
Mar '86	241	159	400	
Apr '86/5	15	111	262	818
May '86	105	51	156	
Jun '86	93	69	162	

Table 10. Cohort or group size obtained from the Bhattacharya analysis and normalized to CPUE.

	CPUE ('000) Cohort			
Quarterly	I	II	III	IV
1 (Mar-May)	57.6	6.2	–	–
2 (Jun-Aug)	2.0	21.8	13.3	4.6
3 (Sep-Nov)	2.1	118.4	29.3	3.7
4 (Dec-Feb)	102.8	1.2	–	–
5 (Mar-May)	3.6	33.9	6.5	–

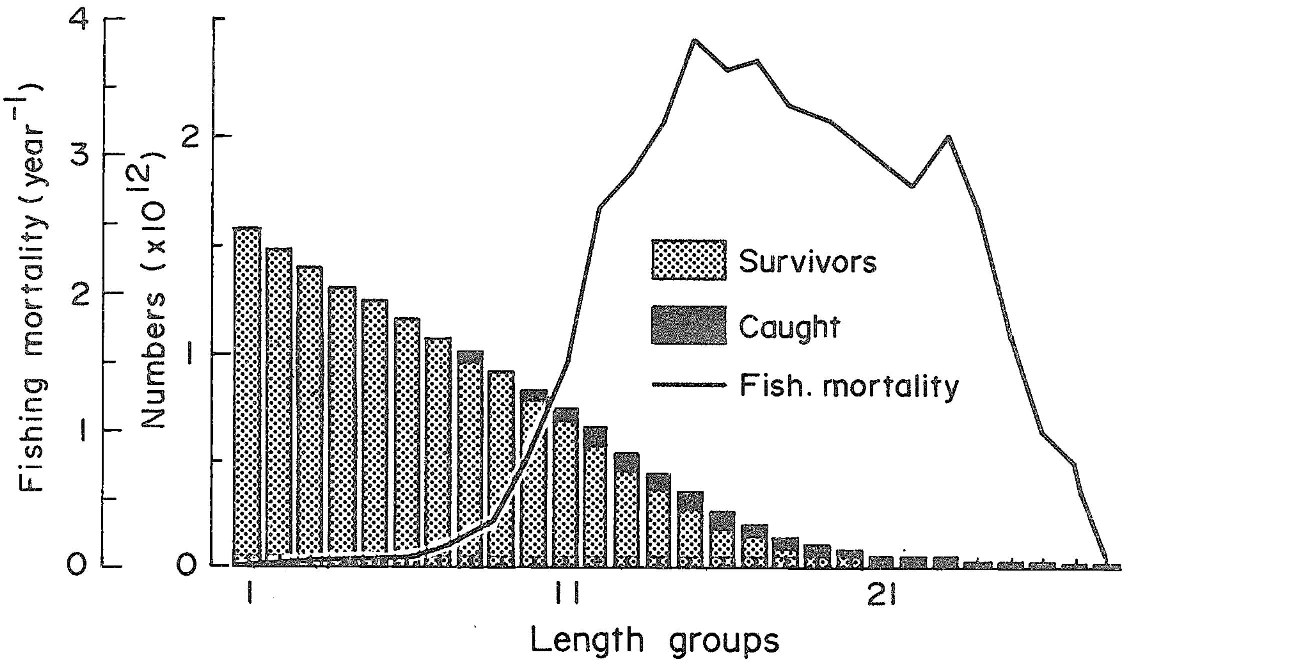

Fig. 9. Result of length-cohort analysis in *Decapterus macrosoma* (Java Sea). Inputs were: FL_{∞} = 24 cm, K = 1.15, M = 2.025 and $F_{ter.}$ = 0.1.

Table 11. Estimation of total mortality based on modal progression analysis (see Fig. 5 and Table 10).

No.	$N(t_1)$	$N(t_2)$	Δt	Z^a
1	2.1	3.6	0.50	1.08
2	2.0	118.4	0.25	16.32
3	118.4	102.8	0.25	0.57
4	102.8	33.9	0.25	4.44
5	21.8	29.3	0.25	1.18
6	57.6	13.3	0.25	5.86
7	13.3	6.5	0.75	0.95
8	6.2	4.6	0.25	1.19
9	4.6	3.7	0.25	0.87
10	3.7	1.2	0.25	4.50

[a] $Z = -\ln(N(t_2)/N(t_1))/\Delta t$.

Table 12. Mean lengths and group sizes of *Decapterus macrosoma* in the Java Sea, as obtained by Bhattacharya analysis, after correcting for mesh selection.

	CPUE ('000) for group number			
Quarter	I	II	III	IV
3	9.4	13.3	15.5	19.2
4	15.5	20.1	–	–
3	1,048	431	74	2
4	136	2	–	–

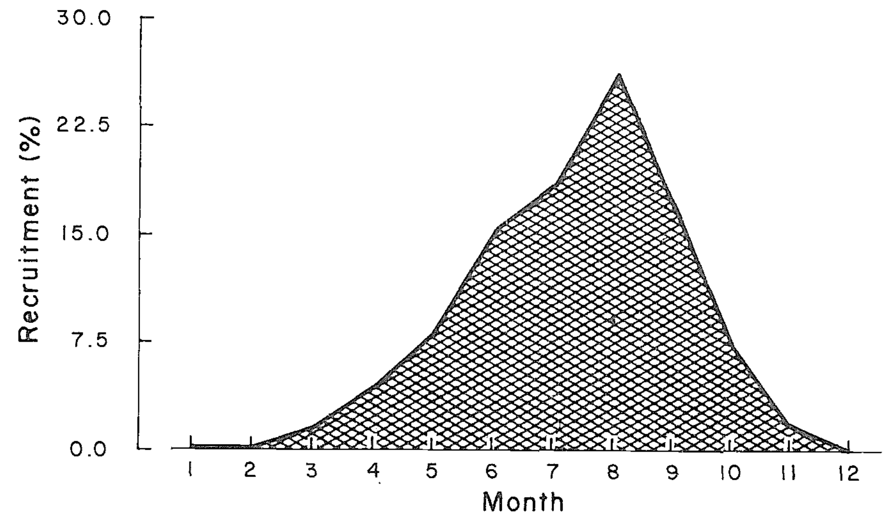

Fig. 10. Recruitment pattern for *Decapterus macrosoma* in the Java Sea, suggesting a single and protected annual spawning/recruitment peak.

Discussion

Growth parameters and mortality rates in this study were based on length-frequency data after raising to catch and effort (trips). The accuracy of parameter estimates depend on the sampling methods and the statistical data (catch-effort).

Length frequencies from the auction place had almost the same structure, compared with samples from the fish holds of the various vessels, when the vessel operated on only one fishing ground.

The values of L_∞ obtained from ELEFAN I are slightly larger than the values of L_∞ obtained through the Gulland and Holt plot and conversely for the K values (Table 13). The different results between ELEFAN I and the Gulland and Holt plot are caused by the different basic assumptions of these two approaches.

Table 13. Some growth parameter values of *Decapterus macrosoma* and derived values of $\phi' = \log_{10}K + 2\log_{10}L_\infty$.

Location	L_∞ (cm)	K (year^{-1})	ϕ'	Source/remarks
Manila Bay	31.5	0.65	2.81	Ingles and Pauly (1984)
Manila Bay	31.5	0.71	2.85	Ingles and Pauly (1984)
Palawan	27.0	0.90	2.82	Ingles and Pauly (1984)
Palawan	26.8	0.71	2.71	Ingles and Pauly (1984)
Palawan	26.5	1.00	2.85	Ingles and Pauly (1984)
Palawan	27.8	0.83	2.81	Ingles and Pauly (1984)
Palawan	33.0	0.50	2.74	Ingles and Pauly (1984)
Palawan	27.5	1.25	2.38	Ingles and Pauly (1984)
Palawan	25.0	1.20	2.88	Ingles and Pauly (1984)
Palawan	25.5	0.85	2.74	Ingles and Pauly (1984)
Palawan	25.5	0.80	2.72	Ingles and Pauly (1984)
Palawan	33.0	0.65	2.85	Ingles and Pauly (1984)
Palawan	30.0	0.74	2.82	Ingles and Pauly (1984)
Thailand	23.2	1.00	2.73	Anon. (1985)
Sumatra	27.7	1.20	2.96	Anon. (1985)
Sumatra	27.5	0.90	2.77	Anon. (1985)
Sumatra	24.0	1.00	2.76	Anon. (1985)
Java Sea	25.6	1.05	2.84	Sadhotomo et al. (1985)
Mean of values in the literature	–	–	2.78	This study (see also below)
Wetherall method	26.5	[0.86]	2.78	K derived from L_∞ and ϕ'
ELEFAN I	26.5	0.90	2.80	Monthly data
ELEFAN I	26.3	1.15	2.90	Quarterly data
Bhatta. + G&H Plot	22.4	1.31	2.82	Quarterly data

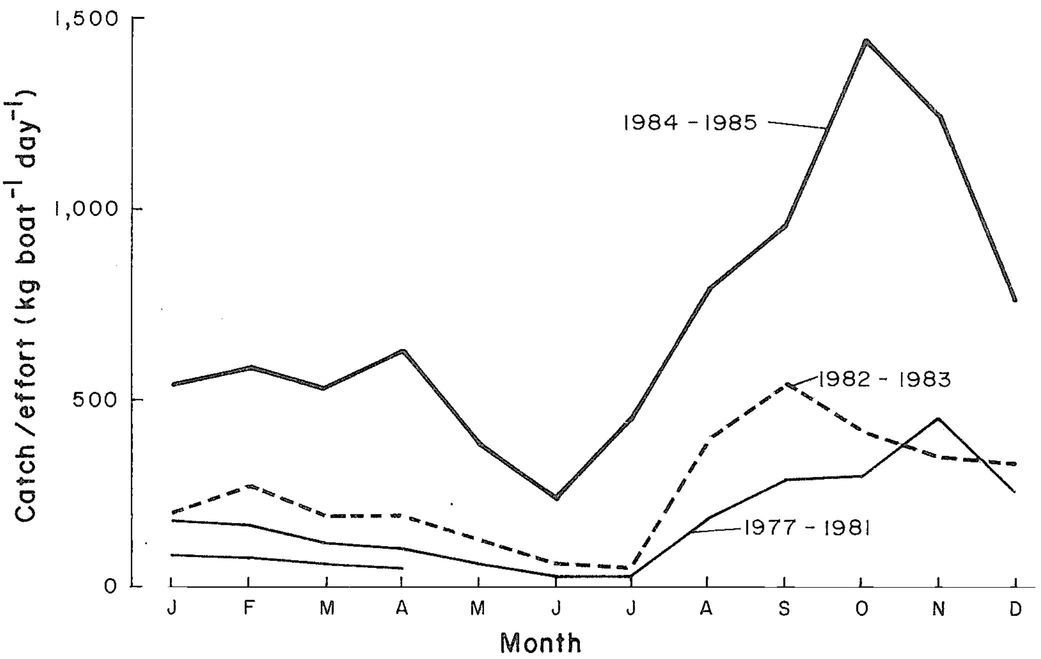

Fig. 11. Seasonal and interyear changes in the relative abundance of *Decapterus macrosoma* in the Java Sea, 1977-1985. Based on data pertaining to purse seiners landing in Pekalongan.

The mortality estimates obtained showed variation of Z values between cohorts (Table 11). This may be due to seasonal changes of recruitment which also could be shown to have a great impact on abundance in the fishing grounds (Fig. 11).

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Growth, Mortality, Recruitment and Exploitation Rate of *Selar boops* in Davao Gulf, Philippines

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Abstract

Length-frequency data of *Selar boops* in Davao Gulf, Philippines, for 1984 and 1985, were analyzed using the computer-based ELEFAN methods. The estimated growth parameters are $L_\infty = 28.96$ cm and $K = 1.9$ year^{-1}. Analysis of the length-converted catch curve gave very high estimates of Z and F and consequently the exploitation rate, E, was estimated to be high.

Catch curve analysis based on length-frequency samples from ring nets indicates that the largest specimens migrate out of the main fishing area of this gear. If this is the case, Z (and F) are overestimated. Although the results suggest that *S. boops* are overexploited, the results might not be conclusive.

Introduction

Davao Gulf, located in the southeastern part of Mindanao, Philippines (Fig. 1), is endowed with rich marine life. It is the fishing area for the three Davao provinces including Davao City.

*Selar boops** is an oblong, moderately compressed fish belonging to the Carangidae and commonly called big-eye scad. It is found in the warmest coastal waters and feeds on invertebrates and fishes. The maximum recorded size is 25 cm and the most common size is 20 cm (Fischer and Whitehead 1974).

The Regional Resources Assessment Project undertaken by the Ministry of Agriculture and Food (MAF), Region XI, estimates that in 1984, *S. boops* comprised 7% of the total marine fishery production of Davao Gulf (Bureau of Fisheries and Aquatic Resources 1984). It was etimated that 1,541 t of *S. boops* were caught in Davao Gulf of which 674 t were caught by ring nets in association with 'payaos', fish attracting devices made of bamboo poles and suspended in the water by weights. The remainder of the catch is taken by gill nets, bag nets and hook and line fishing.

This study is limited to *S. boops* caught by ring nets in Davao Gulf, and has the following objectives:

a. to provide a description of the population of *S. boops* in Davao Gulf based on the catch and effort data collected in two handling centers in Davao City where 80% of the total number of ring netters fishing in the Gulf land their catch;
b. to estimate growth parameters, recruitment pattern and mortality rates of *S. boops* and furthermore to consider the exploitation rate and yield per recruit.

*Editor's Note added on proofs: There is some uncertainty about the identification of the species discussed in this paper which may be *Selar crumenophthalmus*.

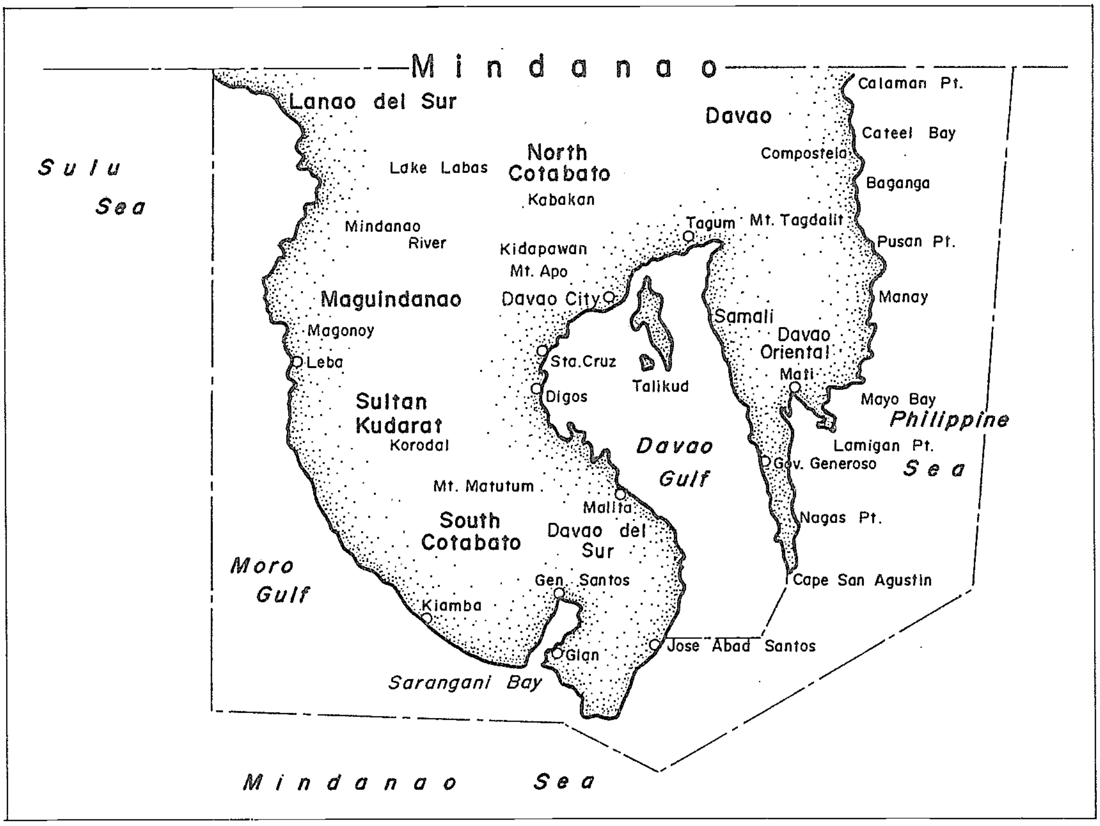

Fig. 1. Davao Gulf and surroundings, Southern Philippines.

Materials and Methods

Sampling Methodology

Sampling was carried out by fishery biologists of the MAF, Region XI, Davao City, in two major landing centers in Davao City, Daliao and Talomo. Landings in Daliao are from vessels fishing in the outer part of the Gulf, whereas those in Talomo are from the inner part of the Gulf.

The sampling programs were identical in the two landing centers. Sampling was carried out every three days regardless of Saturdays, Sundays and holidays. Catch, effort and length-frequency data of *S. boops* were gathered seven to times a month for each landing center.

Length-frequency samples were taken from more than 50% of the total landings. Fish were measured in cm using a fish measuring board. Since sampling is carried out several times a month, the monthly assigned date is the average of the sampling dates.

The length-frequency data were raised to the total catch. Total catch was obtained from all the recorded landings during sampling days and these were raised to monthly catch using the ratio of the total number of days in a month to number of sampling days conducted in a month. For mixed species landings, samples were taken, sorted into species, weighed and length frequencies of *S. boops* taken. The recorded weight of *S. boops* was then raised to the weight of mixed species boxes and then raised to the total mixed species landings for the day. The basic data used here for 1984 and 1985 may be found in Tables 1 and 2, respectively.

Table 1. Length frequency, catch and effort data of *Selar boops* in Davao Gulf for 1984.

Mid-length (cm)	J	F	M	A	M	J	J	A	S	O	N	D	Total
5.5						1							1
6.5						1							1
7.5						2							2
8.5					1	5		2					8
9.5						5		2	1	4			12
10.5			1		3	5		4		6		2	21
11.5	1		1		1	2		7	2	4		5	23
12.5	1	3	3		3	18		8	2	1		5	42
13.5	7	1	5		22	12		16	12	8		10	93
14.5	17	2	2		31	15		17	17	9	5	15	130
15.5	18	10	16		32	45		15	40	20	13	7	216
16.5	20	11	11		17	28		18	39	21	40	8	213
17.5	11	30	29		22	58		41	64	22	25	6	308
18.5	33	31	27		15	90		40	38	20	21	10	325
19.5	61	25	40		22	64		22	19	13	45	15	326
20.5	16	22	63		4	6		35	22	7	23	11	211
21.5	7	11	61		20	1		10	8	5	10	4	135
22.5	2	9	13		19	1			2	3	3		52
23.5	1	1	2		2	2					1	1	10
24.5					1						3		4
25.5											1		1
26.5											4		4
27.5													
28.5													
Sum	195	156	272		215	361		237	266	143	196	99	2,140
Total catch (kg)	30,346	26,110	23,775		13,731	18,218		21,651	28,818	18,222	17,425	31,811	230,107
Total no. of F/B landed	186	104	131		287	208		230	197	149	75	176	1,743
No. of net sets	227	183	197		438	311		311	300	223	150	269	1,790

Table 2. Length frequency, catch and effort data of *Selar boops* in Davao Gulf for 1985.

Mid-length (cm)	J	F	M	A	M	J	J	A	S	O	N	D	Total
7.5			3	2	2		1						8
8.5	1		6	1	9		3	4			2	2	28
9.5		1	4	5	15	1	5	21	1			1	54
10.5	1	3		3	4	11	12	17	3	3		4	61
11.5		1	2	2	6	7	11	12	8	2	1	7	59
12.5		6	5	15	14	22	11	7	21	4		19	124
13.5	3	5	8	23	33	27	22	37	21	6	4	39	228
14.5	3	5	18	38	71	15	24	37	5	18	8	49	291
15.5	21	11	31	66	77	26	28	18	6	26	5	32	347
16.5	39	11	41	69	48	33	70	40	6	46	6	3	439
17.5	34	18	44	62	14	65	88	62	21	53	21	17	499
18.5	28	31	44	39	34	34	69	77	38	42	50	30	516
19.5	18	46	68	72	26	42	131	94	25	51	71	24	668
20.5	6	68	104	49	26	25	71	120	33	27	64	70	663
21.5	13	47	129	97	28	21	26	56	45	17	64	42	585
22.5	12	20	39	32	43	23	23	10	22	23	35	10	292
23.5	2	9	7	9	15	10	20	6	2	16	18	2	116
24.5				2	2	1	1	1	1	3			11
25.5							1	1		4			6
26.5								1		4			5
27.5							1						1
Sum	181	282	553	586	467	363	618	621	258	345	349	378	5,000
Total catch (kg)	22,312	43,506	49,949	38,000	14,026	30,614	60,836	66,018	31,487	27,248	59,034	37,027	480,057
Total no. of FIB	128	202	218	214	194	208	201	240	226	199	247	216	2,493
No. of net sets	225	306	358	373	318	337	344	430	398	358	419	363	4,229

Estimation of Growth Parameters

Length-frequency samples of *S. boops* in this study could be raised to the total catch using the length-weight relationship determined for *S. boops* caught in the Java Sea (Martosubroto and Pauly 1976).

Initial values of L_∞ and Z/K were estimated using the Wetherall (1986) method and subsequently by the ELEFAN I program (Pauly and David 1981).

The values of K and L_∞ obtained through ELEFAN I were used to calculate the length-converted catch curve (Ricker 1975; Pauly 1985). This allows an estimate of the total mortality (Z) to be derived. Estimates of natural mortality, M, can be derived from the empirical equation given by Pauly (1980) using the estimated value of L_∞ and K, together with the environmental temperature. Knowing M and Z, the fishing mortality (F), as well as the exploitation rate (E = F/Z) could be obtained.

Recruitment patterns were obtained by projecting the length-frequency data on the time axis using the estimated values of the growth parameters and the ELEFAN II program.

Results

Growth

With the Wetherall method applied to the length-frequency data grouped in 2 cm class intervals, the estimates were L_∞ = 31.08 cm and Z/K = 6.41 (Fig. 2), while 1 cm class interval estimates gave L_∞ = 27.04 cm and Z/K = 4.17 (Fig. 3). L_∞ = 27.04 cm was used since the value is nearer to the highest length in the samples and a straight line can be fitted to a larger number of points.

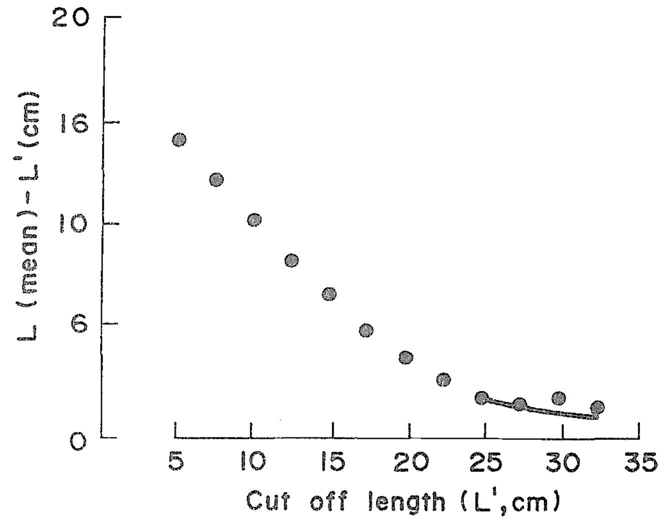

Fig. 2. Modified Wetherall Plot for *Selar boops* caught in the Davao Gulf, Philippines (data grouped in 2 cm class intervals).

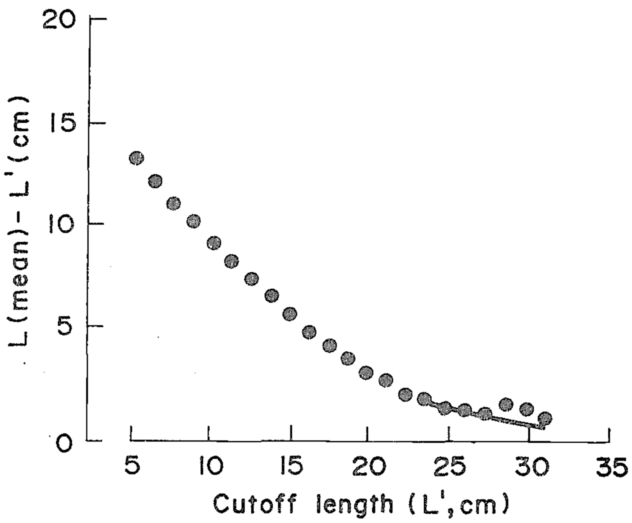

Fig. 3. Modified Wetherall Plot for *Selar boops* caught in the Davao Gulf, Philippines (data grouped in 1 cm class intervals).

The parameters L_∞ and K of the von Bertalanffy Growth Function were then estimated using the ELEFAN I program, considering only the adjusted 2 cm class intervals. The restructured data are given in Fig. 4. The response surface calculated for values of L_∞ ranging from 25 to 30 cm and for K ranging from 0.5 to 2/year offers three possible choices for plateaus of high peak values corresponding to the different sets of growth parameters, viz., (a) L_∞ = 25.0 cm, K = 0.95 $year^{-1}$, (b) L_∞ = 25 cm, K = 2 $year^{-1}$ and (c) L_∞ = 28.5 cm, K = 2 $year^{-1}$. Choosing the first two combinations seems inappropriate because, from the length-frequency distribution of *S. boops* in Davao Gulf (Fig. 4), 2% of the total samples are larger than 25 cm, while the largest fish in the sample is 26.5 cm. Moreover, the Wetherall method suggests estimates of $L_\infty = 27.04$ cm. We chose the $L_\infty = 28.5$ cm and K = 2 $year^{-1}$ as "seed" input and performed a search for optimum combination resulting in final estimates of $L_\infty = 28.96$ cm and K = 1.9 $year^{-1}$. The growth curve corresponding to these parameters is shown in Fig. 4 together with the restructured data.

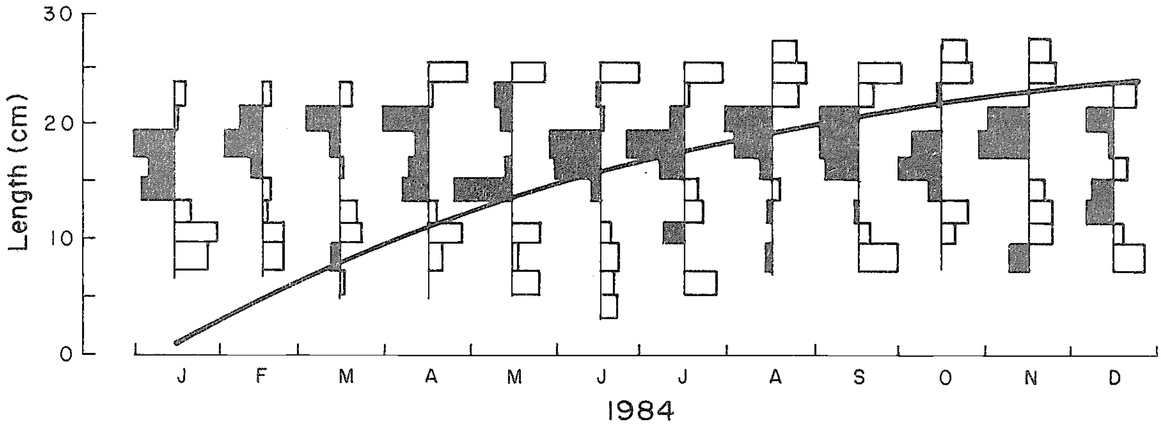

Fig. 4. Restructured length-frequency data for *Selar boops* caught in Davao Gulf (not corrected for selection effects), with superimposed growth curve estimated by ELEFAN I ($L_\infty = 28.96$ cm, K = 1.9).

A correction of sampled length-frequency data for the resultant selection due to gear selection and gradual recruitment to the fishery area, as discussed in Pauly (1986), was applied. However, the length-frequency data tend to shift downwards, becoming more irregular, thus making it more difficult to fit a growth curve. Since correcting the data did not result in improved values of L_∞ and K, the uncorrected data were used for the estimates of mortalities.

Mortalities

Using the $L_\infty = 28.96$ cm and K = 1.9 $year^{-1}$ obtained through ELEFAN I and M = 2.75 from Pauly's (1980) empirical relationship, the estimated value of Z obtained from the catch curve (Fig. 5) is Z = 10.1, which results in F = 7.35 and E = 0.73. Although the curve indicates a high total mortality, this can only be attributed to few length groups of large fish (from 18.5 cm) in the catch curve.

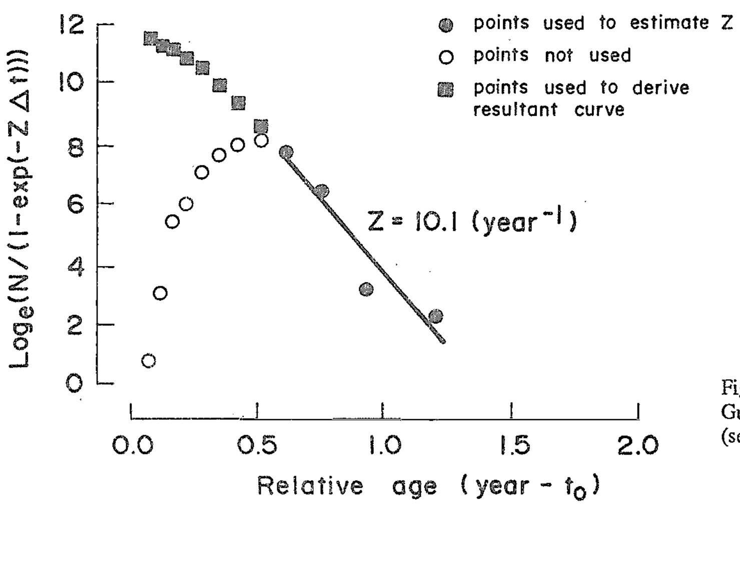

Fig. 5. Length-converted catch curve of *Selar boops* in Davao Gulf, Philippines. Note high value of (apparent) total mortality (see text).

Table 3. Combined length frequency, catch and effort data (1984 and 1985) of *S. boops* in Davao Gulf.

Mid-length (cm)	Month J	F	M	A	M	J	J	A	S	O	N	D	Total
5.5						1							1
6.5						1							1
7.5			3	2	2	2	1						10
8.5	1		6	1	10	5	3	6			2	2	36
9.5		1	4	5	15	6	5	23	2	4		1	66
10.5	1	3	1	3	7	16	12	21	3	9		6	82
11.5	1	1	3	2	7	9	11	19	10	6	1	12	82
12.5	1	9	6	15	17	40	11	15	23	5		24	166
13.5	10	6	13	23	55	39	22	53	33	14	4	49	321
14.5	20	7	20	38	103	30	24	54	22	27	13	64	421
15.5	39	21	47	66	109	71	28	33	46	46	18	39	563
16.5	59	22	52	69	65	61	70	58	45	67	46	38	652
17.5	45	48	73	62	36	123	88	103	85	75	46	23	807
18.5	61	62	71	39	49	124	69	117	76	62	71	40	841
19.5	79	71	108	72	48	106	131	116	44	64	116	39	994
20.5	22	90	167	49	30	31	71	155	55	34	89	81	874
21.5	20	58	190	97	48	22	26	66	53	22	74	46	722
22.5	14	29	52	32	62	24	23	10	24	26	38	10	344
23.5	3	10	9	9	17	12	20	6	2	16	19	3	126
24.5				2	3	1	1	1	1	3	3		15
25.5							1	1		4	1		7
26.5								1		4	4		9
	376	438	825	586	682	724	617	858	524	488	545	477	7,140
Total catch (kgs)	52,658	69,616	73,724	38,000	27,757	48,832	60,836	87,669	60,305	45,470	76,459	68,838	675,964
Total no. of FIB	314	306	349	214	481	402	201	470	423	348	322	392	4,236
Total no. of net sets	452	489	555	373	756	648	344	741	698	581	569	632	6,838

*– represents 1 year data only.

Table 4. Response surface for *S. boops* in Davao Gulf.

RESPONSE SURFACE (Rn values x 1,000)

Filename	:	SB1A
Species name	:	*Selar boops*
Other labels	:	pooled 12 months
Lengths	:	5-29 CENTIMETER

K/L_∞	25.00		26.00		27.00		28.00		29.00		30.00
0.500	107	52	38	27	12	13	25	18	20	30	28
0.650	85	52	34	38	44	43	52	60	56	71	114
0.800	128	170	127	77	62	68	61	70	69	92	75
0.950	214	124	80	78	67	65	83	101	78	59	64
1.100	165	132	164	144	85	91	83	71	68	73	76
1.250	184	167	148	109	83	90	68	62	61	89	103
1.400	181	134	108	105	78	68	60	76	89	91	112
1.550	170	151	129	86	87	65	83	85	107	125	202
1.700	197	154	129	95	84	95	100	135	174	205	245
1.850	206	171	118	104	103	124	169	194	245	253	229
2.000	215	159	135	119	140	169	194	253	229	208	170

for:
C = 0
WP = 0
Starting point
sample no. = 5
length = 14.5

Resultant Curve and Recruitment Pattern

The resultant curve (Fig. 6A) fitted with logistic transformation (Fig. 6B) estimates L_c = 18.0 cm, which is a very high value. The recruitment pattern of *S. boops* in Davao Gulf (not shown) suggests three recruitment pulses. Whether this is due to the specific feature of the available sample or the breeding habit of the fish cannot be assessed.

Yield per Recruit

Using the values of L_∞ = 28.96 cm, K = 1.9 year^{-1} and L_c = 18.0 cm, the relative yield-per-recruit (Y/R) model of Beverton and Holt (1966) as modified by Pauly and Soriano (1986) estimates E_{max} = 0.6 (Fig. 7).

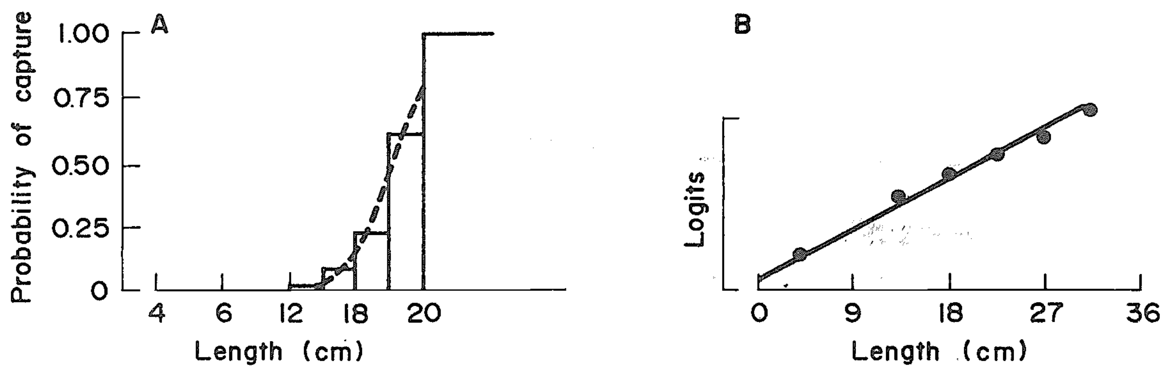

Fig. 6. A *Selar boops*, Davao Gulf, Philippines: Probability of capture resulting from catch curve in Fig. 5 ("resultant curve"); B linearization of logistic curve fitted to date in (A).

Discussion

Although no literature on previous studies on the biology of *S. boops* was available to the author, the values of K and L_∞ obtained in this study seem reasonable when compared to those of other *Selar* species. The value of ϕ' obtained for *S. boops* is 3.21, while for *S. crumenophthalmus* a ϕ' = 3.07 can be computed from growth parameters in Ingles and Pauly (1984).

It was difficult to extract the growth curve from the length-frequency distributions because the catches at length are very similarly distributed between months.

The high value of Z obtained from the catch curve does not necessarily confirm the assumption that the area is overexploited, because, as seen in Fig. 5, the line pertains to only a few large length classes. The large value of Z strongly suggests that the fish migrate out of the main fishing area. In other words, the ring net fishery concentrates on a limited size range of the population. This assumption supports the previous doubt on the high value of L_c which seems unreasonable.

Using the nomogram of Pauly (1984, Fig. 3.2) expressing the selection factor (S.F.) as a function of the depth ratio of the fish multiplied by the mesh size, a value of the selection factor, S.F. = 2.4 was obtained. If the selection curve derived from the catch curve should be generated by a trawl type selection, then this would correspond to a trawl mesh size = L_c/SF = 18/2.4 = 75 mm. The actual fishery uses ring nets of 30 mm mesh size, and it is obvious that this contradicts the calculated selection curve. It is therefore concluded that the catch curve and the fitted line do not reflect the actual mortalities in the stock.

Similar problems in using length-converted catch curves to estimate mortality in a fishery from which only purse seine samples are available have been encountered also in other areas (Boonraksa, this vol.).

The data presented in this paper represent 44% of the total estimated production of *S. boops* in Davao Gulf caught by ring nets. The 56% unsampled landings represent the catch of bag nets, gill nets and hook and line. The validity of the results presented here concerning mortality rates may indeed be questionable. The assumption that the data used in this paper represent the *S. boops* fishery is not realistic since the other unsampled gears might have caught an entirely different length-frequency distribution. It is therefore recommended that sampling for length-frequency data be expanded to cover other gears in order to determine whether the estimated growth parameters obtained in this study represent the whole *S. boops* fishery of Davao Gulf.

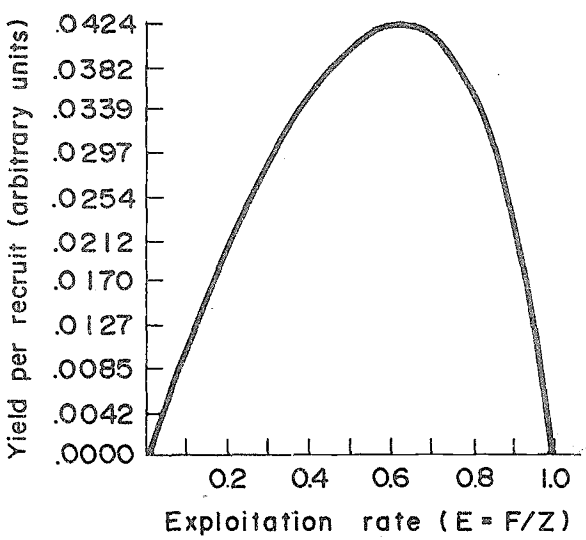

Fig. 7. Relative yield per recruit of *Selar boops* as a function of Exploitation rate in Davao Gulf, Philippines.

Acknowledgements

The author extends her thanks to MAF Regional Director Juan Y. Solomon and Asst. Regional Director Dennis B. Araullo and all the staff of MAF, Region XI, Davao City, for all the support they have extended in the conduct of this study.

She appreciates the efforts of all the biologists who have assisted in the gathering and compilation of the data used in this study. Furthermore, thanks go to the fishing boat operators and fishermen of Daliao and Talomo, Davao City, for the cooperation they have extended.

She also acknowledges the support of the Bureau of Fisheries and Aquatic Resources Research Division, Manila, in the implementation of this project.

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Growth, Mortality and Maximum Sustainable Yield of the Indo-Pacific Mackerel *(Rastrelliger brachysoma)* Off the Southwest Coast of Thailand

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Abstract

Monthly length-frequency data sampled during 1984-1986 were used to estimate growth parameters K and L_∞ using both the ELEFAN I program and modal progression analysis (Bhattacharya method and Gulland Holt plot). The same data were raised to the total catch and then pooled to estimated mortality and probability of capture using catch curve analysis. Yield per recruit and biomass per recruit were obtained through the Beverton and Holt model.

Total catch of *R. brachysoma* from the Statistics Section, Department of Fisheries, Thailand, during 1979-1985 and catch per unit of effort data collected by the staff of Phuket Marine Fisheries Station were used to establish surplus production models. The Schaefer and Fox models were used to estimate the maximum sustainable yield and the optimum fishing effort.

Introduction

The Indo-Pacific mackerel *(Rastrelliger brachysoma)* plays a vital role in the pelagic fisheries in the southwest coast of Thailand. It contributed about 40% of the total pelagic catch in this area in 1979-1985. Indo-Pacific mackerel is mainly exploited by purse seines, this gear accounting for approximately 90% of the total landings of *R. brachysoma*. The purse seine fishery in Thailand has been developing since World War II. The first purse seiners used modifications of the Chinese purse seine. After 1982, light attraction was commonly used. The common mesh size used in purse seines in this area is approximately 2.5 cm, while length and depth of the seine are within 400-1,000 m and 40-100 m, respectively. The intensive areas for purse seines are within 30 km from the coastline when the depth of seawater is within 15-80 m. The disposal of the catch depends on the size of the fish, large fish are sold fresh in the market and small ones are processed into fish meal.

An assessment of *R. brachysoma* in this area has been undertaken as part of the more general study of mackerel in the Bay of Bengal Programme (BOBP) during 1982-1985. The BOBP analyses cover the Malacca Strait.

Based on evidence from tagging experiments in this area, earlier analyses subdivided the *R. brachysoma* stocks of the Andaman Sea into three areas (Fig. 1.) Recent analysis of morphometric data suggests that Areas II and III could be considered as one unit stock. Since the recaptures from the tagging experiment were obtained largely within a few weeks after the releases, the author has greater confidence in the results of the morphometric analysis than in the tagging experiment.

In this paper catch data and length-frequency data from 1984 to 1986 were used to estimate growth parameters, mortalities and exploitation rate for the combined Areas II and III.

Detailed analyses of spawning areas and spawning period of *R. brachysoma* in the Andaman Sea are given by Pimoljinda (1977) and Sutthakorn (1986). *R. brachysoma* has been studied in the Philippines by Ingles and Pauly (1984) who give estimates of growth parameters and mortalities for the stock in Manila Bay, Samar Sea and Carigara Bay.

Materials and Methods

Length-frequency data on *R. brachysoma* were obtained by random sampling from the purse seiners. Sampling was carried out by the Phuket Marine Fisheries Station on a monthly basis during 1984-1986 at five important landing places along the coast of the study area. The map (Fig. 1) shows the area covered off the coast of five provinces of the west coast of Thailand, namely, Phuket, Phang-nga, Krabi, Trang and Satun. The number of samples taken varied with the season of the fishery, but most often 5 to 25 samples were obtained each month in each landing place. The specimens were measured to the 1 cm below. The weight of samples was calculated for each month using the length-weight relationship equation: $W = 0.01296L^{3.2104}$ (Pimoljinda 1978), where W is weight g and L is body length in cm. The data are given in Table 1.

Catch per unit of effort (CPUE) information was obtained from each sampled vessel measured as the total catch per fishing day. This information was collected in each port by the Phuket Marine Fisheries Station for the years 1979-1985. The data are shown in Table 2.

Monthly total catch of market-size Indo-Pacific mackerel landed by purse seine and other gear during 1979-1985 was obtained from the Fisheries Statistics Unit, Department of Fisheries, Thailand, based on landing place surveys. It is important to note that for some areas landing of Indo-Pacific mackerel, which are processed into fish meal are not included in the total catch data. The data are given in Table 2.

The length distribution of the total catch was obtained by means of a raising factor (R.F.) for each month in 1984 and 1985

$$\text{R.F.} = \text{Total monthly catch / Sample weight}$$

Estimation of von Bertalanffy Growth Parameters

The parameters L_∞ and K were estimated by means of basically two methods. Estimates of L_∞ and Z/K were obtained using the method of Wetherall (1986, as modified by Pauly 1986). Next, the ELEFAN I method (Pauly and David 1981, Pauly 1982) was used to estimate L_∞ and K. A preliminary set of estimates was obtained using the observed length-frequency data. Using these values for L_∞ and K in the length-converted catch curve (Ricker 1975; Sparre 1985) allowed for estimation of total mortality Z. Assuming that the mortality at age 0 is M and that total mortality increases stepwise to Z at length of full exploitation, then the actual population size (by length group) can be calculated. Comparing these with the numbers caught allows the selection curve to be estimated (Pauly 1984).

The length-frequency data corrected for selection were then used for a final estimation of L_∞ and K using the ELEFAN I program.

The Bhattacharya method was used to deconvolute the monthly length-frequency data for 1984-1986 to obtain the mean length, standard deviation and number of fish in each cohort (Sparre 1985). The mean lengths of the identified cohorts were joined and a Gulland and Holt plot was used to estimate the growth parameters K and L_∞.

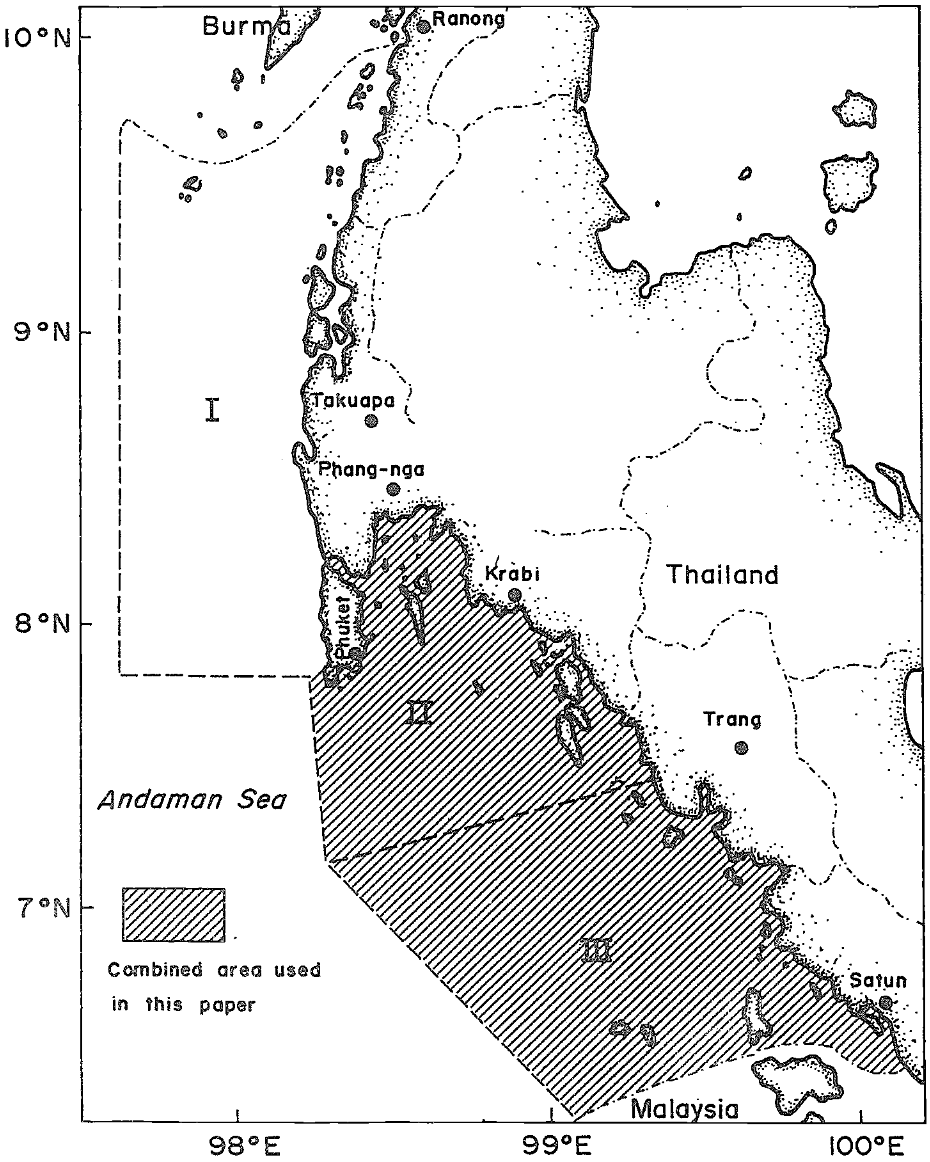


Fig. 1. Area subdivisions used by the Bay of Bengal Programme for the study of *R. brachysoma* in the west coast of Thailand.

Total mortality, Z, was obtained using the length-converted catch curve. The method was applied to the actual length-frequency data for the total catch for 1984-1985. Natural mortality was estimated from the empirical relationship (Pauly 1980).

$$\text{Log}_{10}\, M = 0.0066 - 0.279\, \log_{10}(L_\infty) + 0.6545\, \log_{10}(K) + 0.4634\, \log_{10}(T)$$

where T is the temperature of the environment in ^{o}C.

The recruitment pattern was estimated by the method given by Pauly (1982). Yield per recruit and biomass per recruit, as defined by Beverton and Holt, were also estimated. The Y/R model and Beverton and Holt B/R model (Beverton and Holt 1964; Pauly and Soriano 1986) are briefly discussed further below.

The estimated values of L_∞ and K obtained by the analyses above were inserted in these models.

Maximum sustainable yield was predicted, using the Schaefer and Fox models, as given in Sparre (1985) with a purse seine unit for standard gear. Data from 1979 to 1985 were applied.

Table 1. Length-frequency data and calculated sample weights of *R. brachysoma* in the southern west coast of Thailand, 1984-1986.

A: 1984

Month	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Sampling Date/Mid-length	25	26	30	27	15	26	12	24	22	26	12	15
6.5												
7.5	3				8							1
8.5	3	23		3	31			30				4
9.5	163	110		114	33		6	252				18
10.5	412	45	3	307	99	2	6	313				55
11.5	278	3	26	55	154	29	34	80	4		1	28
12.5	91	11	106	16	174	279	436	16	42	47	7	85
13.5	51	451	105	192	459	1091	1239	418	639	338	75	192
14.5	223	771	385	504	667	251	358	1530	1130	1063	750	650
15.5	193	131	372	725	1005	46	224	560	449	233	527	670
16.5	33	46	31	518	211	38	46	72	30	16	58	118
17.5	3	3	5	154	26	7	2	11	1		5	8
18.5	5			7	4		1					2
19.5	17											4
20.5	39											12
21.5	2											2
22.5												1
No. sampling	1616	1594	1033	2592	2851	1743	2352	3282	2295	1697	1423	1850
Calculated on the wt. samples (g)	80006	98878	73934	195194	199184	99567	137983	202418	157613	116243	108627	137456

Table 1. Length-frequency data and calculated sample weights of *R. brachysoma* in the southern west coast of Thailand, 1984-1986.

B: 1985

Month	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Sampling Date/Mid-length	26	18	15	19	18	11	17	17	16	26	11	11
6.5												
7.5	4	1	2		14							
8.5	31	0	4	13	60							14
9.5	46	10	8	49	26	2						16
10.5	12	66	12	88	36	27						1
11.5	0	214	100	150	129	31	4	3	3		1	60
12.5	3	422	779	176	248	164	332	111	59	47	1	117
13.5	30	541	509	452	584	297	1367	692	808	338	45	274
14.5	48	551	792	1005	712	291	426	1140	1704	1063	632	390
15.5	13	387	767	436	1528	185	257	580	800	233	794	773
16.5	3	100	147	58	328	25	56	88	49	16	99	317
17.5		16	8	6	28		2	3	1		7	16
18.5					3		1					
19.5												
20.5												
21.5												
22.5												
No. sampling	190	2308	3128	2433	3696	1022	2445	2617	3424	1697	1579	1978
Calculated on the wt. samples (g)	8095	141066	202976	154879	268806	63954	147933	181797	239699	116243	126046	151578

Table 1. Length-frequency data and calculated sample weights of *R. brachysoma* in the southern west coast of Thailand, 1984-1986.

C: 1986

Month	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Sampling Date/Mid-length	12	7	15	11	13	6	7	20	28	26	13	17
6.5				2								
7.5			12	23	2							
8.5	10	2	82	122	2			15				2
9.5	159	1	88	69	40		12	126				11
10.5	119	0	4	28	162	1	11	156				2
11.5	181	28	13	34	179	88	64	41	5			2
12.5	248	194	246	62	100	711	541	63	25	47	14	0
13.5	245	251	143	287	294	440	1110	555	470	338	105	0
14.5	685	465	183	690	623	172	289	1335	556	1063	868	34
15.5	1052	591	191	470	482	204	191	570	98	233	261	320
16.5	236	189	60	74	94	58	36	80	11	16	18	193
17.5	8	13	2	1	24	13	3	7			2	26
18.5			1		5	6						1
19.5												
20.5												
21.5												
22.5												
No. sampling	2943	1734	1025	1862	2007	1693	2257	2948	1165	1697	1268	591
Calculated on the wt. samples (g)	200002	127847	57595	119561	129631	96057	127907	192057	75399	116243	91281	53965

Table 2. Catch, effort and catch per unit of effort (Purse seine as standard gear) of *R. brachysoma* in the southern west coast of Thailand, 1979-1985.

Y E A R	1979	1980	1981	1982	1983	1984	1985
Total catch (tons)	6995	11747	13623	7919	9685	15317	19497
Total effort (days)	8022	10179	13761	8139	9430	23420	29496
CPUE (tons/day)	0.872	1.154	0.990	0.973	1.027	0.654	0.661

Source: Total catch from the landing place survey, Department of Fisheries, Thailand. CPUE from the sampling survey conducted by Phuket Marine Fisheries Station, Phuket, Thailand.

Results

Length-frequency data from 1984 to 1985 were raised to the total catch in each month. The Wetherall plot based on these input data is shown in Fig. 2. The points on a Wetherall plot are expected to follow a straight line for length classes which are fully exploited. For lower length classes points are supposed to gradually approach the line from above. As shown in Fig. 2, it proved to be difficult to select points for a straight line. The regression line was fitted to the points L' = 18 cm to the last point L' = 22 cm (dark point). The result shows a high correlation coefficient (r) of about -0.947, and the value of L_∞ close to L_{max}. Values of L' lower than 18 cm cannot be used to fit a regression line, since this gives a poor fit, with a high L_∞ far from L_{max}. The results from Fig. 2 show values of L_∞ and Z/K of 22.1 and 1.05, respectively.

The ELEFAN I program was used to estimate the value of K and L_∞ using the pooled length-frequency data for 1984-1986. As a first step, curve fitting by eye was used to find a good starting point. Next the response surface was inspected to find the best values of L_∞ and K. The best estimates K and L_∞ are 1.15 and 22.2 cm, respectively. The growth curve is shown in Fig. 3 together with the restructured sample.

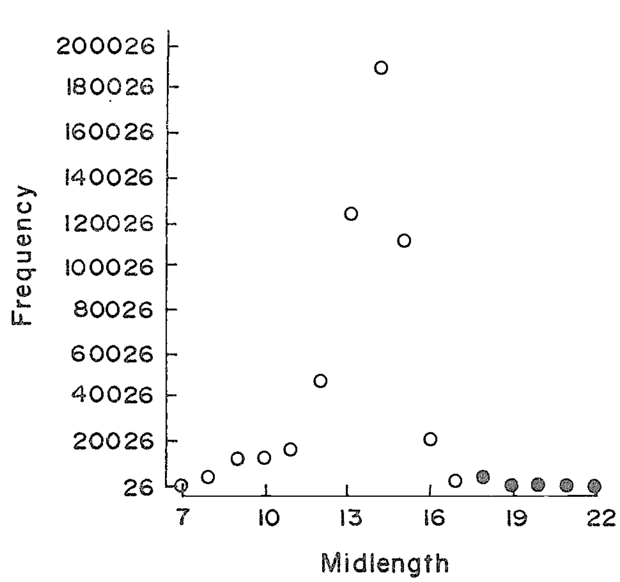
Catch curve analysis was used to estimate total mortality, Z. The catch curve is shown in Fig. 4. A regression line was fitted to points immediately to the right of the highest point of the catch curve excluding, however, the last two points corresponding to very high "ages". Whether or not these two last points are included for the estimation of Z affects Z dramatically. The natural mortality obtained from the formula was M = 2.13. Z was 11.27, F = 9.4 and E = (F/Z) = 0.811.

The resultant selection curve was derived from the backward extension of the catch curve. Logistic transformation of the selection curve was used to smooth the probability of selection as shown in Fig. 5. The smoothed curve has a length at first capture, L_c = 15.9 cm. The smoothed probability capture was used to correct for selectivity.

The ELEFAN I program was then used to estimate the values of K and L_∞. The restructured data with the superimposed growth curve is shown in Fig. 6. The growth curve corresponds to the estimated value of K = 1.15, L_∞ = 22.3.

The mean lengths of all components identified by the Bhattacharya method are shown in Table 6 and Fig. 13. The Gulland and Holt plot was used to estimate L_∞ and K considering the length increments in mean length of the connected points.

The mean lengths and the basic data for the Gulland and Holt plot are shown in Table 7. The results show K = 2.83 and L_∞ = 17.8 cm using a least squares regression on all points. The value of L_∞ is obviously too low, since L_{max} = 22.5 cm. The Wetherall method gives a value of L_∞ = 22.0 and it was decided to force the regression line through (22.0, 0). The slope of the regression line corresponds to an estimate of K = 1.53/year.



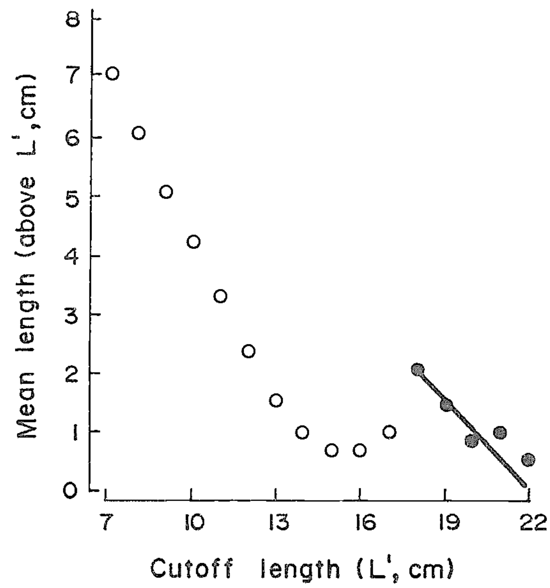


Fig. 2. The Wetherall method for estimated L_∞ and K from length-frequency data of *R. brachysoma* in the southern west coast of Thailand, 1984-1985.

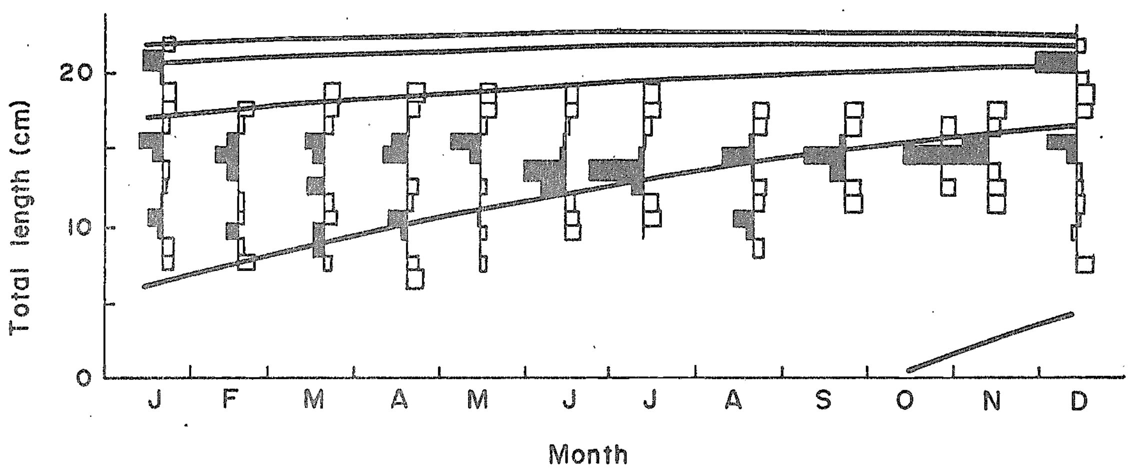


Fig. 3. Restructured length-frequency data and growth curve of *R. brachysoma* in the southern west coast of Thailand, 1984-1986.

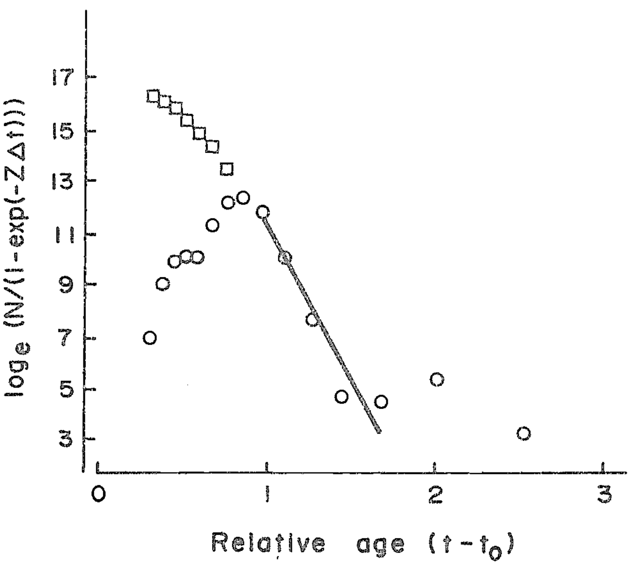


Fig. 4. Catch curve of *R. brachysoma* in the southern west coast of Thailand, 1984-1985 (K and L_∞ from 1984-1985).

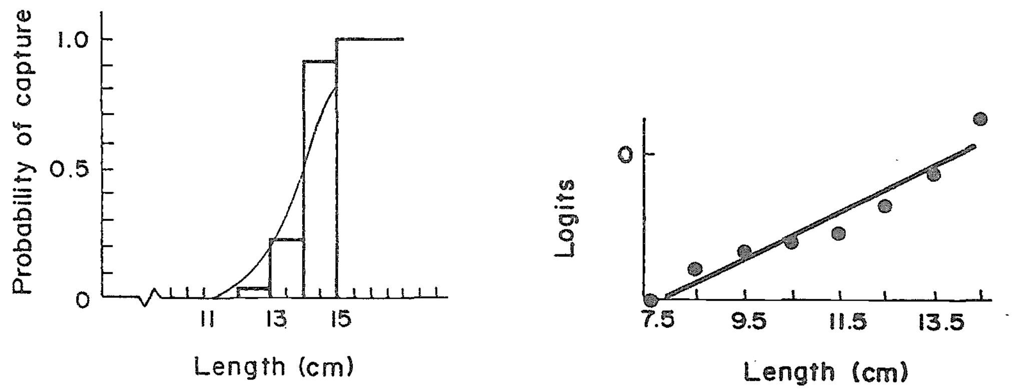


Fig. 5. The resultant curve, smoothed selection curve and length at first capture of *R. brachysoma* in the southern west coast of Thailand, 1984-1985.

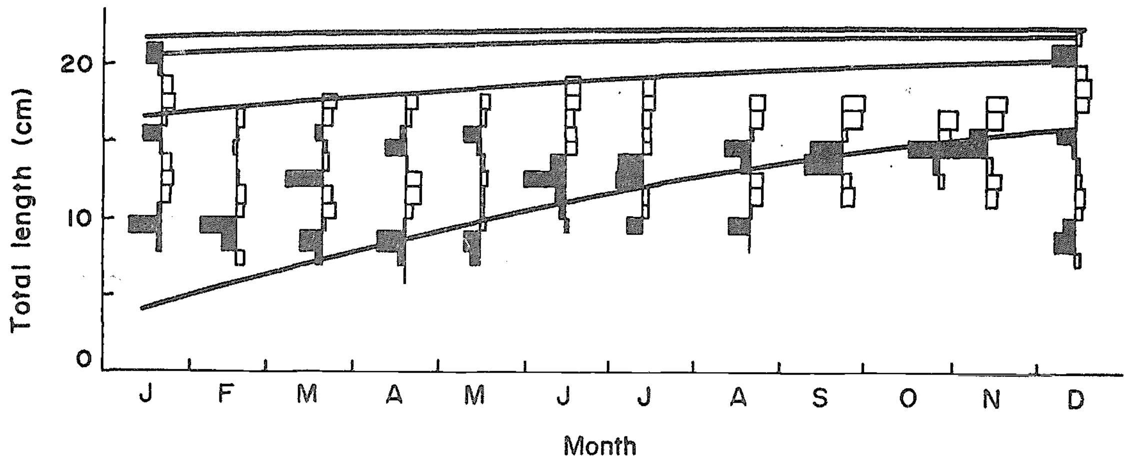


Fig. 6. Restructured length-frequency data and growth curve of *R. brachysoma* in the southern west coast of Thailand, 1984-1985 (data corrected for selection).

The estimates of mortalities, exploitation rate, probability of capture, yield per recruit and biomass per recruit all depend on the values of L_∞ and K. New estimates are therefore obtained inserting K and L_∞ as estimated from the corrected length-frequency data.

The catch curve analyses as shown in Fig. 7 give the following estimates: Z = 11.51, M = 2.13, F = 9.38 and E = 0.815.

The resultant curve derived from catch curve using all points that fit the logistic transformation is shown in Table 3 and Fig. 8. The length at first capture L_c = 14.0.

A recruitment pattern is obtained by projecting a set of length frequencies backward onto a one year time axis. The recruitment pattern suggests two recruitment pulses per year (Fig. 9).

Yield per recruit and biomass per recruit as a function of exploitation rate are shown in Table 4 and Fig. 10. The Y/R and B/R were calculated taking into account that knife-edge selection cannot be applied in this case. The estimated probabilities of capture were used following the method of Pauly and Soriano (1986). Relative yield and biomass per recruit were converted to weight units using:

$$Y/R = (Y'/R) \,.\, W_1 \,.\, \exp^{-(M(t_2 - t_0))}, \text{ and}$$
$$B/R = (B'/R) \,.\, W_1 \,.\, \exp^{-(M(t_2 - t_0))},$$

respectively.

The exploitation rate giving maximum yield per recruit was E_{max} = 0.646.

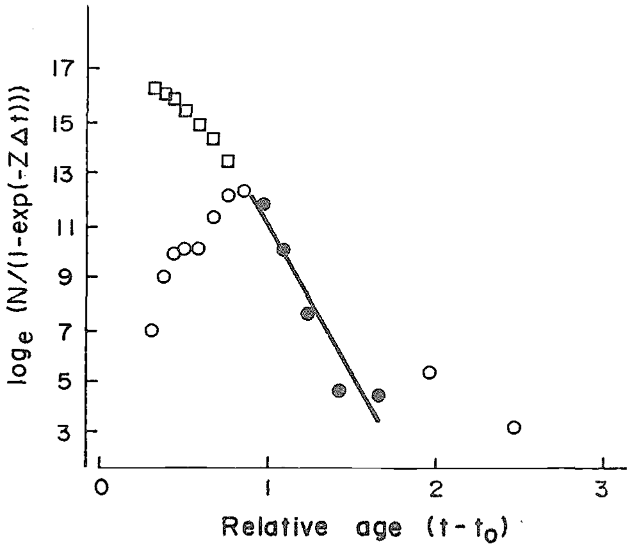


Fig. 7. Catch curve for *R. brachysoma* in the southern west coast of Thailand, 1984-1985 (K and L_∞ from 1984-1986) (data corrected for selection).

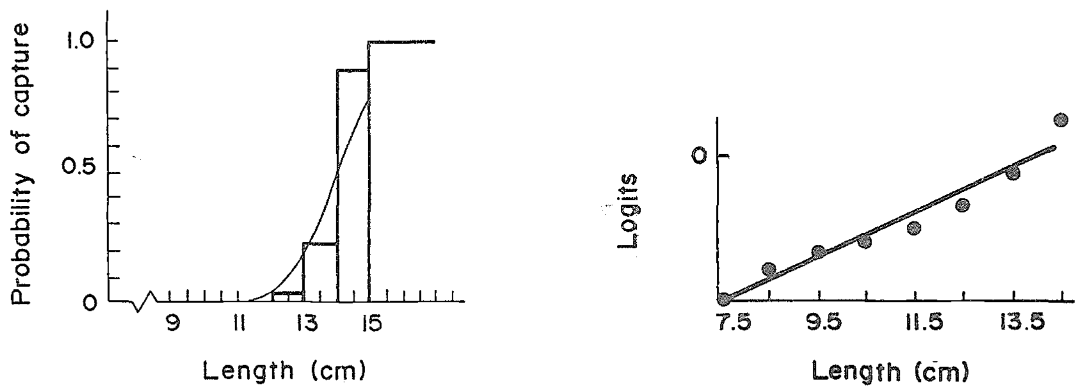


Fig. 8. The resultant curve, smoothing curve of selection and length at first capture of *R. brachysoma* in the southern west coast of Thailand, 1984-1985 (K and L_∞ from 1984-1986) (data corrected for selection).

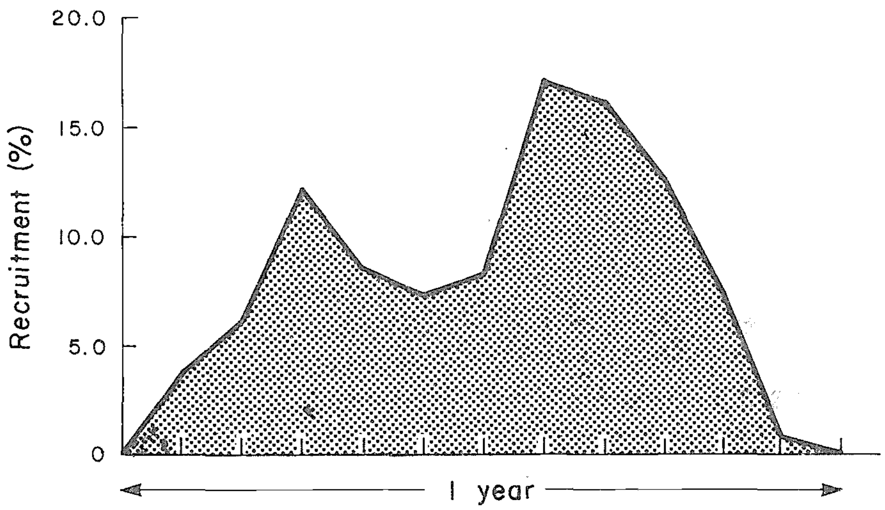


Fig. 9. Recruitment pattern of *R. brachysoma* in the southern west coast of Thailand, 1984-1985 (K, L_∞ corrected 1984-1986).

Table 3. Probability of capture of *R. brachysoma* in the southern west coast of Thailand, 1984-1985.

Midlength	Probability of Capture
7.500	0.0001
8.500	0.0004
9.500	0.0019
10.500	0.0084
11.500	0.0368
12.500	0.1471
13.500	0.4379
14.500	0.7786
15.500	1.0000
16.500	1.0000
17.500	1.0000
18.500	1.0000
19.500	1.0000
20.500	1.0000
21.500	1.0000

Table 4. Yield per recruit and biomass per recruit at different exploitation rates of *R. brachysoma* at the southern west coast of Thailand, 1984-1986 (Probability of capture = 1).

E	Y'/R	B'/R	E	Y'/R	B'/R
0.05	.0044323	.926163	0.55	.0331437	.296272
0.10	.0086299	.854007	0.60	.0339381	.246714
0.15	.0125800	.783616	0.65	.0341887	.200224
0.20	.0162683	.715079	0.70	.0338088	.157041
0.25	.0196791	.648494	0.75	.0326736	.117463
0.30	.0227950	.583963	0.80	.0305952	.081904
0.35	.0255963	.521595	0.85	.0272750	.050977
0.40	.0280606	.461509	0.90	.0222131	.025675
0.45	.0301618	.403832	0.95	.0144396	.007657
0.50	.0318689	.348702	1.00	.0000042	.000000

E for maximum Y'/R	0.6449
E for slope 1/10 of origin	0.6142
E for biomass 1/2 of unexploited stock	0.3677

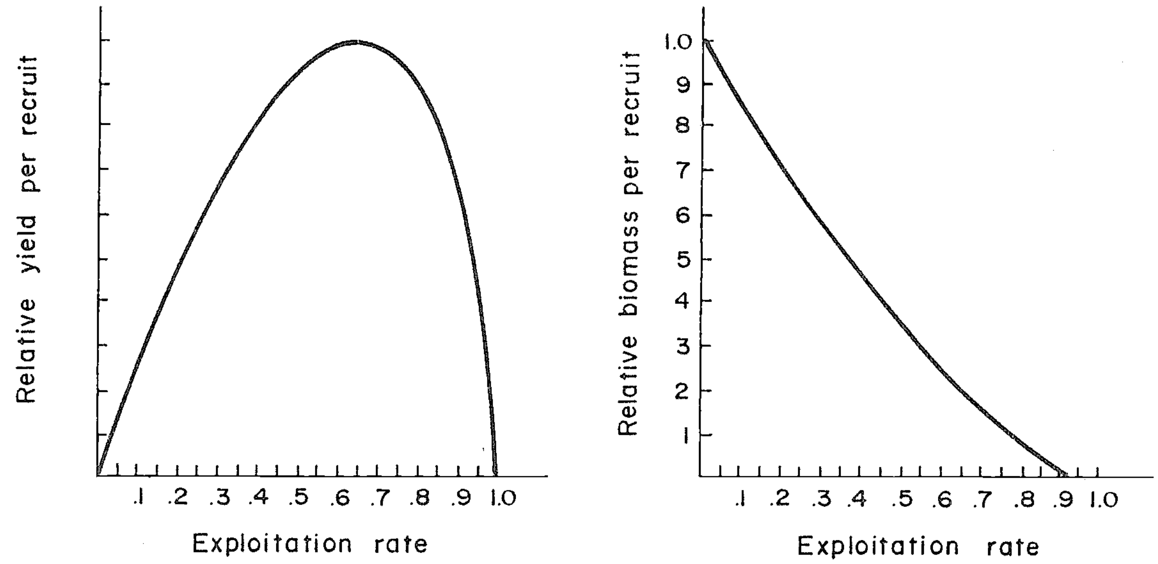


Fig. 10. Yield per Recruit and Biomass per recruit of *R. brachysoma* in the southern west coast of Thailand, 1984-1985 (K, L_∞ corrected 1984-1985).

Estimation of Maximum Sustainable Yield

Total catch of *R. brachysoma* from all gears in this area was available from 1979 to 1985. The CPUE from purse seiners was available for the same period. The CPUE is, in each year, calculated as the total catch of the sampled vessels divided by the total number of fishing days for the sampled vessels. A division of the total catch (all gears) with the CPUE of purse seiners allows one to determine the total effort (measured in number of purse seiner fishing days). The result is shown in Table 2. Applying the Schaefer and Fox models gives the results shown in Fig. 11. The equations and results are as follows:

Schaefer $c/f = 1.1714 + (-.00001824)f$
Fox $c/f = 1.2264836\, e^{0.000022178f}$,

where c is catch in t and f is effort in days.

	MSY (t)	Fishing effort (days)	r	r^2
Schaefer	18,807	32,111	-.82	.68
Fox	20,344	45,090	-.85	.73

The fitted regression lines for the Schaefer and the Fox models are given in Fig. 12.

Discussion

The analyses of the length-converted catch curve based on data from the purse seine fishery proved to be difficult. As seen in Fig. 4, it was not possible to fit a straight line to all points above a length class corresponding to full recruitment to the fishery. This indicates that the mortality is not constant for fish above a given length. The problem is often encountered when analyzing catch curves from a purse seine fishery on pelagic fish (see Dy-Ali, this vol.).

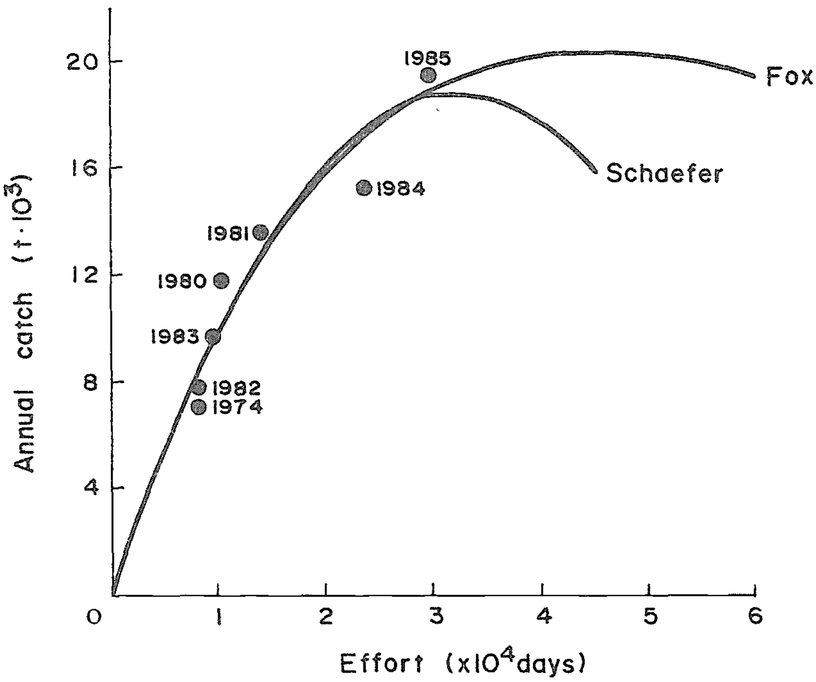


Fig. 11. Relationship between catch and total effort (purse seine unit) *R. brachysoma* in the southern west coast of Thailand, 1979-1985.

It was, however, decided to fit a straight line to that part of the catch curve which seemed reasonably linear and the extended line was used to calculate the selection curve.

The estimation of L_∞ and K, based on the length-frequency data set corrected for selectivity using ELEFAN I gave K = 1.15 and L_∞ = 22.3. The growth curve corresponding to the maximum value on the response surface does not however follow identified peaks for the smaller size groups. A comparison with the result from the Wetherall method confirmed that a value of L_∞ around 22 cm seems reasonable.

It is however more difficult to find support for K = 1.15 in the literature. Other estimates of L_∞ and K are summarized in Table 5, showing a rather wide range of K values for *R. brachysoma*.

Studies on the Gulf of Thailand in 1970 suggest K values of around 3.0, whereas more recent studies especially on the west coast of Thailand point to a K value between 1.3 and 1.6. Inspection of the restructured length frequencies (Fig. 6) show that a steeper growth curve, corresponding to a higher K, can be traced through marked peaks.

The modal progression analysis was carried out to resolve this problem.

Two cohorts per year were identified and linkage of modes (Fig. 13) resulted in the Gulland and Holt plot in Fig. 14. The plot contains virtually no information on L_∞ since growth increments for relatively large individuals could not be determined.

It was decided to use the estimate of L_∞ = 22.0 cm from the Wetherall method and subsequently to force the regression line in the Gulland and Holt plot through 22.0 cm.

The derived value of K = 1.42 is considered to be reliable, this value also being in agreement with the more recent estimate of K in this area.

The identification of two cohorts per year and the estimates of the recruitment pattern by the ELEFAN method (Fig. 9) are in good agreement and it was concluded that *R. brachysoma* showed two distinct recruitment pulses per year.

The calculated relative yield per recruit and estimated exploitation rate E (Fig. 10) suggest that E is beyond the exploitation rate corresponding to maximum yield. Fishing mortality should be drastically reduced from 9.4 to about 4 in order to achieve maximum yield. This result is grossly contradicted by the surplus production models (Fig. 12). The Schaefer model indicates that the present effort level is slightly below the level which gives maximum sustainable yield, whereas the Fox model suggests that fishing effort could be increased with 50% to achieve maximum sustainable yield.

As explained above, the estimates of fishing mortality derived from the catch curve are highly unreliable, and there is reason to believe that the surplus production models give the most realistic picture of the exploitation rate in the fishery. The latter models however, depend on a few years of observation only and the result should not be the basis for an effort increase until it has been confirmed by information from additional years.

Table 5. Estimated values of parameters and the ø' of *R. brachysoma* in different areas of the region.

Location	L_{∞}	K	ø'	References
Gulf of Thailand	20.0	3.53	3.18	Sucondharman et al. 1970
Gulf of Thailand	19.6	4.14	3.20	Sucondharman et al. 1970
Gulf of Thailand	20.9	4.20	3.26	Somjaiwong and Chullasorn 1974
Gulf of Thailand	18.2	1.56	2.71	Somjaiwong and Chullasorn 1974
Gulf of Thialand	23.0	3.60	3.28	Kurogane 1974
Gulf of Thailand	20.9	3.58	3.17	Hongskul 1972
West Borneo	22.9	2.28	3.08	Sudjastani 1973
Manila Bay	34.0	1.10	3.10	Ingles and Pauly 1984
Samar Sea	25.0	1.60	3.00	Ingles and Pauly 1984
Samar Sea	24.5	1.28	2.89	Corpuz et al. 1985
Samar Sea	25.0	1.30	2.91	Corpuz et al. 1985
Samar Sea	25.5	1.45	2.97	Corpuz et al. 1985
Malaysia	23.5	1.5	2.92	Anon 1985
West coast of Thailand	26.5	1.3	2.95	Anon 1985
West coast of Thailand	22.4	2.0	3.00	Anon 1985
West coast of Thailand	24.5	1.4	2.92	Anon 1985
Southern west coast of Thailand (II)	25.1	1.25	2.90	Boonraksa 1986
Southern west coast of Thailand (II)	25.4	1.33	2.93	Boonraksa 1986
Southern west coast of Thailand (II & III)	27.75	1.15	2.95	This study

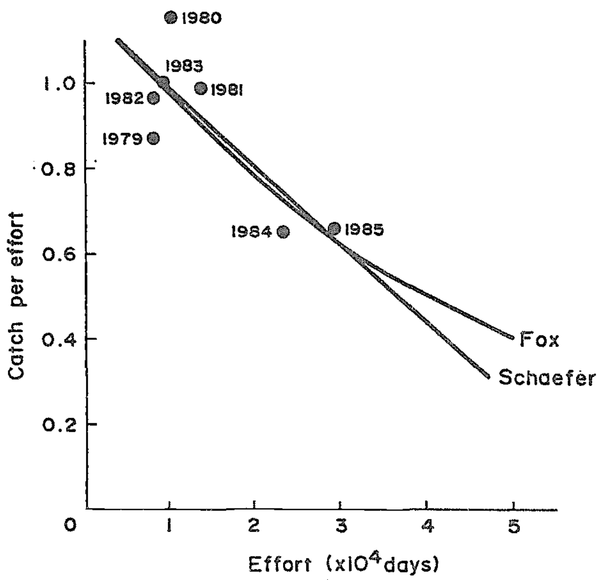


Fig. 12. Relationship between catch per unit of effort and total effort (purse seine unit) of *R. brachysoma* in the southern west coast of Thailand, 1979-1985.

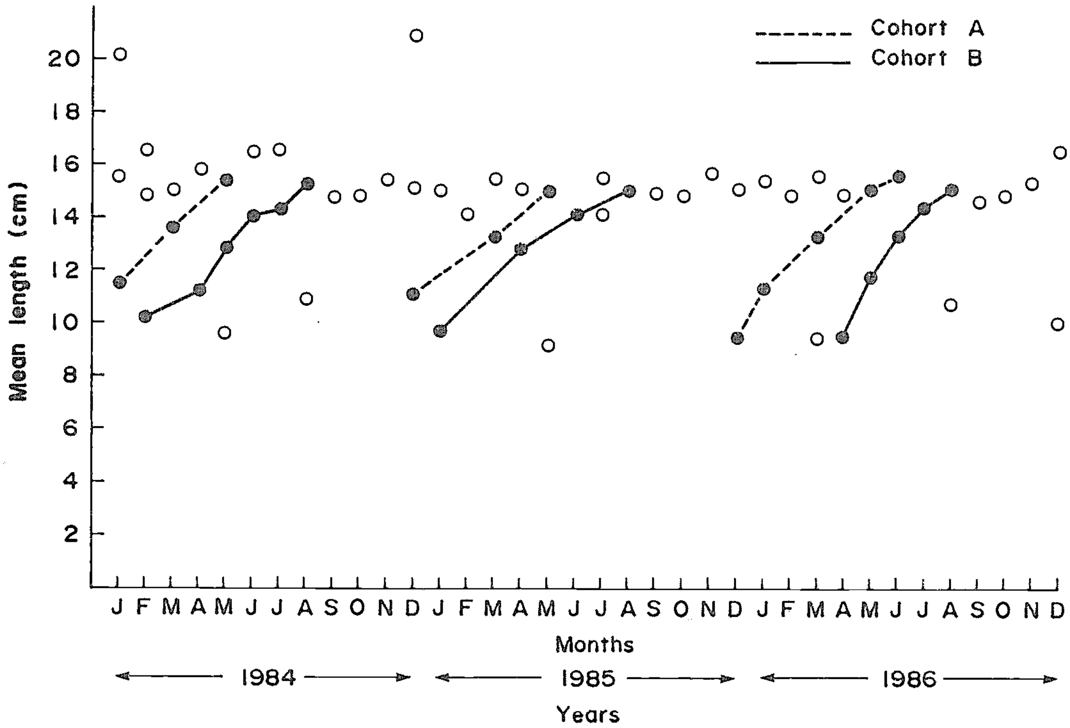


Fig. 13. Mean length of *R. brachysoma* in the southern west coast of Thailand, 1984-1985 from Bhattacharya method.

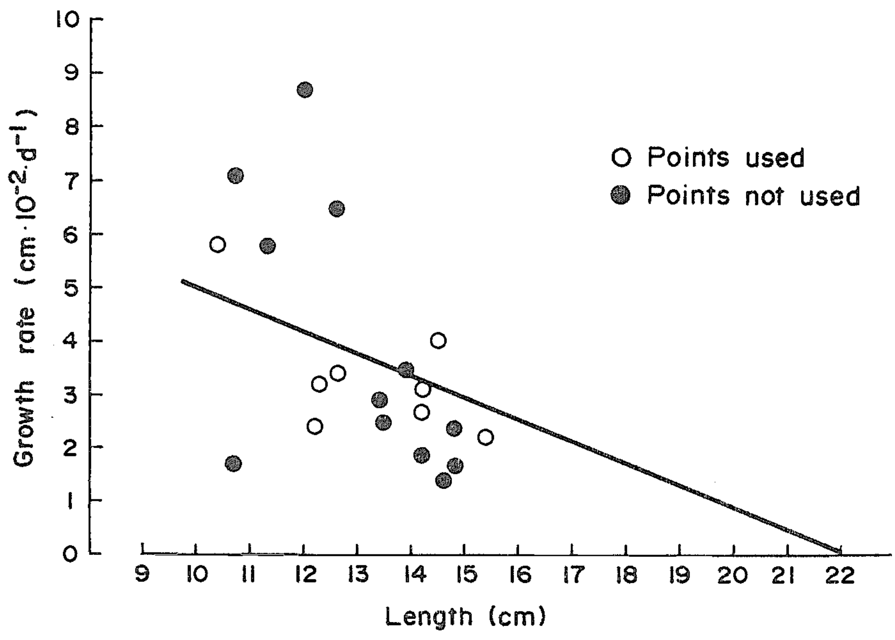


Fig. 14. Gulland and Holt's plot, *R. brachysoma* in the southern west coast of Thailand, 1984-1986. The equation, with the X intercept forced at $L_\infty = 22$ cm is $\Delta L/\Delta t = 0.0922 - 0.004192$ L (with t = 1 day), corresponding to $K = 0.04192 \cdot 365 = 1.53$ y^{-1}.

Acknowledgements

The author would like to thank Mr. Udom Bhatia, Chief of Phuket Marine Fisheries Station and the staff for their assistance in the collection of the data which form the basis of this paper.

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Growth and Mortality Estimation of Indian Mackerel *(Rastrelliger kanagurta)* in the Malacca Strait, Indonesia

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Abstract

Growth and mortality of Indian mackerel (*Rastrelliger kanagurta* Scombridae) were studied using the length-frequency data from Banda Aceh during the period of 1984-1986. The data were collected from the purse seine catches in Malacca Strait, Indonesia.

The estimation of growth parameters was carried out using the length-frequency analysis, i.e., the ELEFAN program and the Wetherall method. Using Pauly's empirical equation to estimate M, fishing mortality and the exploitation rate were derived.

Introduction

The Malacca Strait is one of the most important fishing grounds of Indonesia, yielding an average annual catch of 270,000 tonnes during the period of 1980-1984, or about 18% of the total catch of Indonesia. A map of the area including the provincial borders and main landing places is presented in Fig. 1. The purse seine is the most common gear for pelagic fishery in this area with an average total catch of 23,400 t/year from 1976 to 1984.

The purse seine catches consist of a mixture of species, of which Indian mackerel *(Rastrelliger kanagurta)* is among the most important. However the biology of the species in this area, including the estimation of growth parameters and mortality rates is still not well documented. In the most recent years an international study of this and adjacent areas, i.e., Andaman Sea, west coast of Malaysia, Java Sea has been initiated. The study on Indian mackerel was part of the Bay of Bengal Programme (BOBP), which organized two workshops, in Colombo, Sri Lanka, on October 1985 and in Phuket, Thailand, on August 1986. At these workshops, preliminary studies of growth parameters were undertaken using length-frequency data for the period May 1984 to December 1985. At the last workshop it was suggested to continue improving the results by incorporating more data as they become available.

This paper attempts to improve the previous assessment by inclusion of length-frequency data from January to September 1986. In addition, landings and fishing effort data for the Indonesian side of the Malacca Strait will be used.

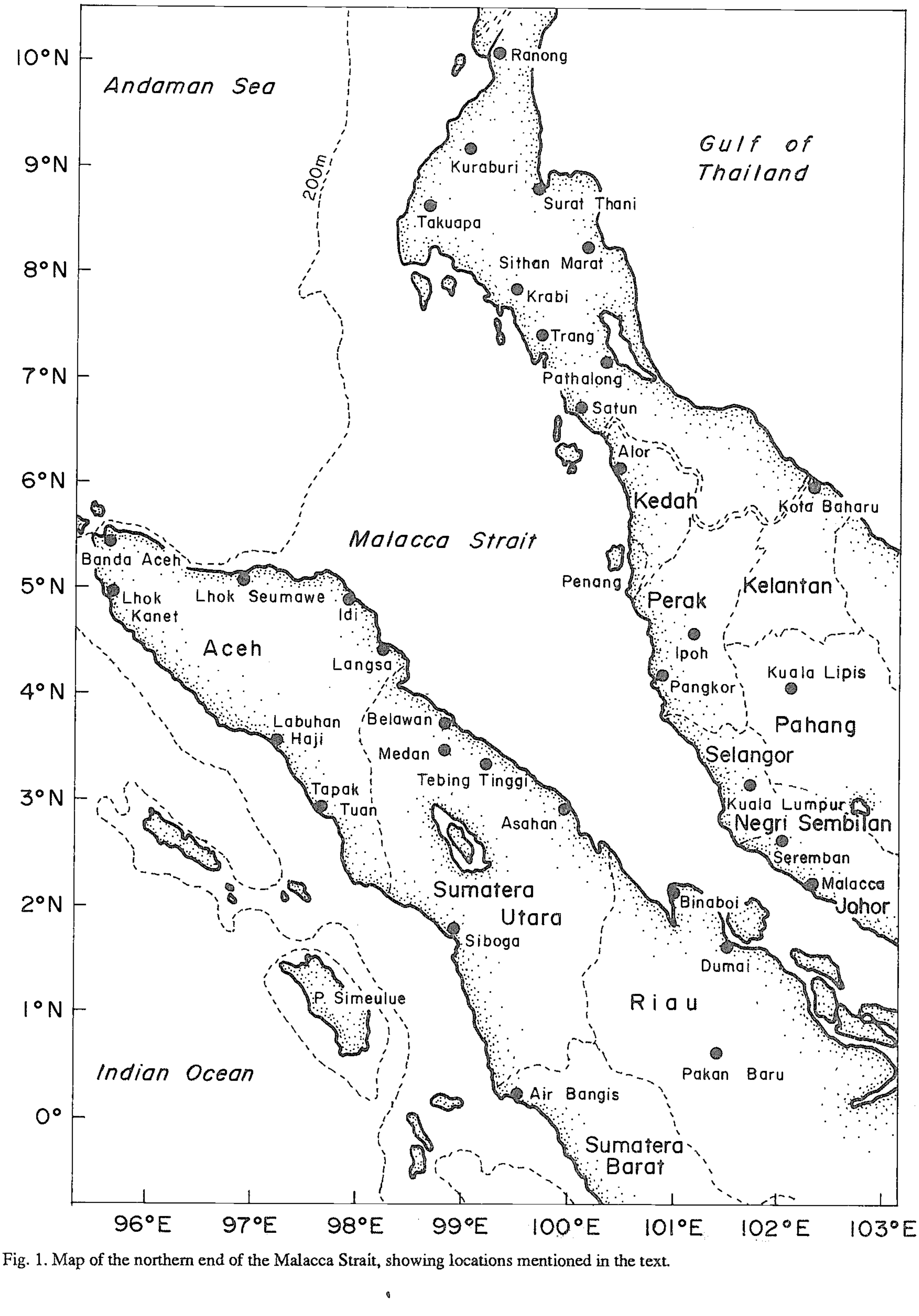

Fig. 1. Map of the northern end of the Malacca Strait, showing locations mentioned in the text.

Materials and Methods

Landing Data

Total annual catch of Indian mackerel from 1979 to 1985 were obtained from the Statistics Division of the Directorate General of Fisheries (DGF) in Jakarta by province and hence separately for the northern and southern Malacca Strait. The landings of *Rastrelliger* are recorded at genus level, which means that the monthly landing data of *R. kanagurta* are mixed with those of other *Rastrelliger* spp. Such data were collected in Banda Aceh, the northern area and Asahan in the southern area, by the respective Fishing Port Administrations for 1984-1986.

Fishing Effort Data

The number of landings per day by purse seiners was recorded by those Fishing Port Administrations over the same period (1984-1986).

In addition, the number of purse seiners registered in the Provincial Fishery officers of North Sumatera (in Medan) and Aceh (in Banda Aceh) were available, for each year from 1979 to 1985. Table 1 shows the available data on catch and effort by month for Banda Aceh and Asahan from 1984 to 1986.

Table 1. Total catch (kg) and effort (no. of purse seiner landings) of *Rastrelliger kanagurta* in Banda Aceh and Asahan, 1984-1985, Malacca Strait, Indonesia.

Year/Month		Banda Aceh Total catch (kg)	Banda Aceh Purse seiner landings (no.)	Asahan Total catch (kg)	Asahan Purse seiner landings (no.)
1984	May	na	na	436,886	1,105
	Jun	na	na	913,453	2,636
	Jul	na	na	na	na
	Aug	na	na	na	na
	Sep	na	na	na	na
	Oct	1,185	112	na	na
	Nov	2,270	297	388,235	1,144
	Dec	3,655	231	249,497	788
1985	Jan	1,100	429	263,561	825
	Feb	1,040	384	271,490	698
	Mar	14,875	297	196,061	678
	Apr	18,025	226	391,867	1,023
	May	3,590	136	348,200	828
	Jun	850	51	514,080	991
	Jul	2,645	193	937,651	1,334
	Aug	6,035	na	1,005,162	1,367
	Sep	na	na	na	na
	Oct	4,080	408	na	na
	Nov	5,145	374	274,334	1,011
	Dec	2,675	330	249,497	763
1986	Jan	241	277	na	na
	Feb	na	na	na	na
	Mar	5,907	231	na	na
	Apr	2,390	121	na	na
	May	na	na	na	na
	Jun	na	na	na	na
	Jul	na	na	na	na
	Aug	8,595	339	na	na
	Sep	9,905	271	na	na
	Oct	na	na	na	na

Length-Frequency Data

Length-frequency data were collected by the staff of the Provincial Fishery Offices of Aceh and North Sumatera, respectively, in Banda Aceh and Asahan from May 1984 to September 1986. The number of samples taken varied from one to four each month and the sample size varied from 2 to 10 kg. The samples were taken on board the vessel before discharge at the fishery auction. The length measurements refer to the total length measured to the half cm below. The available length-frequency data were pooled within each month. Table 2 shows the available pooled length-frequency data by month from Banda Aceh. Table 3 shows similar length-frequency data for Asahan.

Table 2. Length-frequency samples, catch and effort of *Rastrelliger kanagurta* landed by purse seine in Banda Aceh, 1984-1985, Malacca Strait, Indonesia.

	1984								1985											1986						
Mid-length (cm)	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Jan	Mar	Apr	Jun	Jul	Aug	Sept
9.5																					2					
10.5											1						6		2	9	17	9			2	2
11.5											15						2	8	9	10	11	15			1	
12.5											34						16	13	16	9	25	28			5	19
13.5			12								13			6			45	28	18	12	29	36			2	2
14.5		16	46	7			2				8			6		12	49	23	17	8	29	32			7	6
15.5	3	39	62	52	61	60	50			9	12			6	2	40	12	43	10	5	32	30	4	5	26	12
16.5	18	40	53	127	87	74	91	23		10	20			3	14	110	3	21	23	11	29	38	8	43	24	19
17.5	25	50	1	111	88	81	99	56	14	31	10	9		4	2	109		41	20	4	34	31	32	80	44	24
18.5	26	46		71	33	60	103	104	11	30	1	132		6	10	69		24	16		34	28	50	63	61	6
19.5	21	48		19	1	29	73	88	20	30		87		1	6	37	2	29	12		14	17	50	37	69	7
20.5	19	36					33	18	26	13	10	5	1		8	2	17	22	16	3			33	18	23	6
21.5	2	5							22		12		11	1	6		16		9	7			87	5	19	
22.5									7	26	13			3	2								9		4	
23.5									6	27			5						4						3	
24.5									5				3		3				9							
25.5									2				1		1											
26.5									2				1		1				3							

Table 3. Length-frequency samples, catch and effort of *Rastrelliger kanagurta* landed by purse seine in Asahan, 1984-1986, Malacca Strait, Indonesia.

	1984				1985										1986				
Midlength (cm)	May	Jun	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Feb	Jul	Aug	Sept	Oct
9.5																			
10.5																			
11.5	3	2			8														
12.5	7	1												4		1			
13.5	34	11	1					3					135	1	2	3	10		
14.5	4	7	1		14			11	1		6		100	13	4	12	12	9	2
15.5	2	4	3	6				11	5		14		242	21	11	5	3	27	1
16.5		1	6	17	8		4	4	7		16	1	312	28	13			7	6
17.5			8	39	26	6	12	11	2		13	9	172	28	22		19	24	10
18.5	2	3	18	28	28	10	9	13		5	39	43		25	6		6	23	22
19.5	4	4	15	2	10	5	18	21	1	11	73	107		87	5			4	29
20.5	3	13	4	3	8	4	5	7	2		32	61		57	22				3
21.5	5	4			2	5	2				12	7		5	21				
22.5	1				4	7					19	23			8				
23.5	4	4				6					3	12			6				
24.5	4	8																	
25.5		1				4													
26.5																			

Morphometric Data

Morphometric data were available from May to September 1986 for a sample of approximately 200 fishes from each area. The measurements were taken by the staff of the Provincial Fishery Office. The data used are: total length (TL); fork length (FL); standard length (SL); first dorsal length (S_1D); second dorsal length (S_2D); head length (HL); pectoral length (PL); body length (BL); body depth (BD); weight (W, in gram); and eye diameter (OD).

The above length measurements were made in mm, their position is shown in Fig. 2.

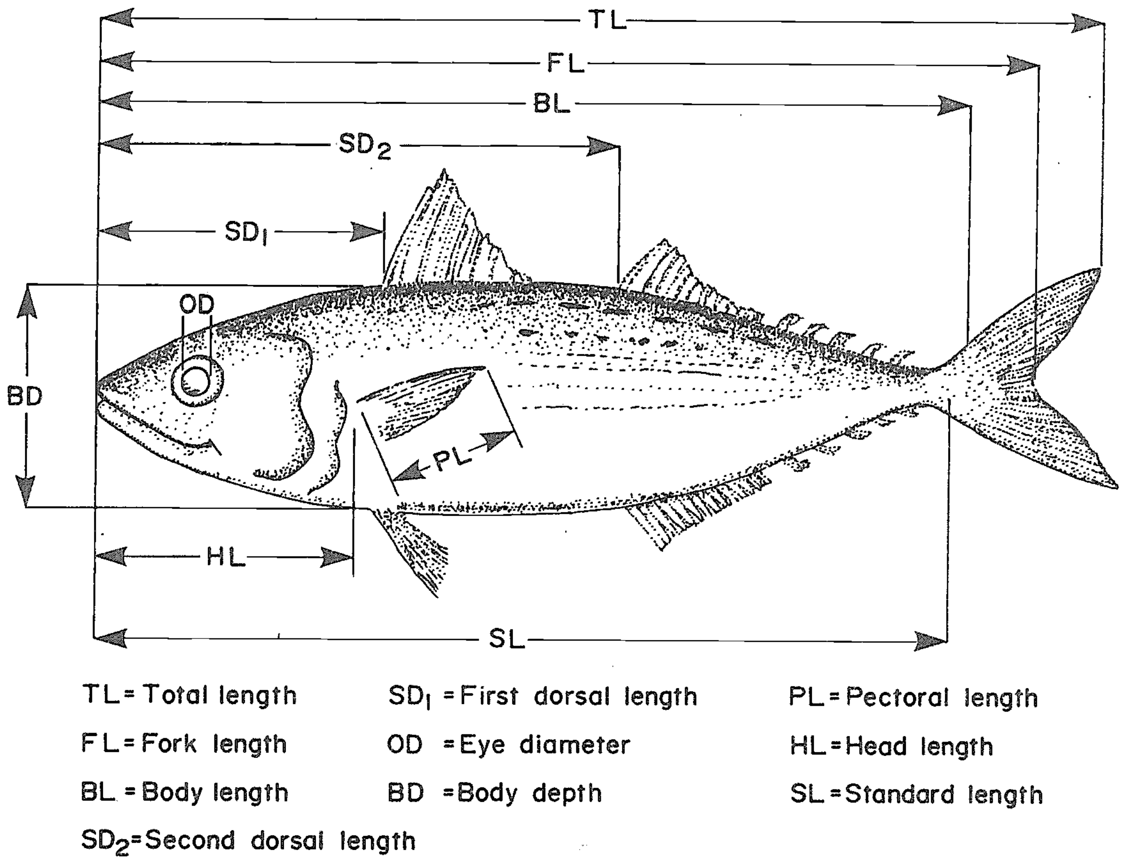

Fig. 2. The morphometric measurement of *Rastrelliger kanagurta*.

Estimates of von Bertalanffy Growth Parameters

The von Bertalanffy growth parameters L_∞ and Z/K, where Z is the total mortality, were estimated using the method described by Wetherall (1986), as modified by Pauly (1986a).

The monthly length-frequency data were raised to the monthly total catch in 1985. Data from Banda Aceh and Asahan were first analyzed separately. The weight of samples was estimated using the length-weight relationship derived from a sample of 60 specimens. The growth parameters L_∞ and K were estimated using the ELEFAN I program with modifications as described in Pauly (1986a). This program also includes adjustments for selection as described in Pauly (1986b).

Estimates of Mortality

To estimate natural mortality, M from the growth parameters L_∞ (in cm) and K, and mean temperature T (28°C) the following equation from Pauly (1980) was used:

$$\log_{10}M = -0.0066 - 0.279 \log_{10}L_\infty + 0.6453 \log_{10}K + 0.4634 \log_{10}T$$

Total mortality was estimated using a length-converted catch curve (Pauly 1983). From estimates of F and M, the exploitation rate was estimated. Relative yield per recruit was obtained from the estimated growth parameter and probabilities of capture by length (Pauly and Soriano 1986). The above calculations were carried out using the "Compleat ELEFAN" program package for IBM-PC and compatible microcomputers recently developed at ICLARM.

Morphometric Analysis

The method used for the analysis of the morphometric measurements and the results of these analyses are given in Soriano et al. (this vol.).

Results

Length-Weight Relationships

The length-weight relationship of *R. kanagurta* was determined using the equation:

$$W = a L^b$$

where W is weight of an individual fish in g; and L is total length of an individual fish in mm. A total of 60 fishes ranging in length from 143 mm to 204 mm were employed for this purpose.

The observed values of lengths and weights of individual fish in the fresh state were transformed into logarithmic values.

The regression line was estimated as follows:

$$\log W = -5.840 + 3.377 \log L$$

The back transformed power function then becomes $W = 0.000001445\ L^{3.377}$ The observed values of length and weight to which the equation was fitted together with the back-transformed power function is given in Fig. 3. This equation was used to calculate the weight of the samples of length-frequency data. To obtain the total catch in numbers, the weight of the samples was raised to the total catch.

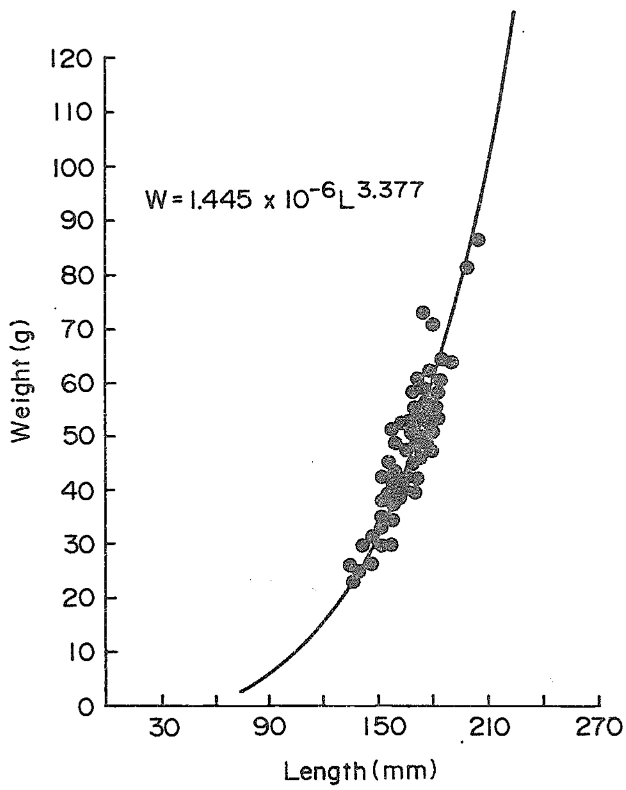

Fig. 3. Length-weight relationship of *Rastrelliger kanagurta*.

Simultaneous Estimation of L∞ and Z/K

The Wetherall method (1986) as modified by Pauly (1986a) was used to estimate the L_∞ and Z/K. The total catch at length from Banda Aceh were added for all months of 1985.

The Wetherall plot is shown in Fig. 4. Based on this plot it was decided that the points from 18 cm and above show a good linear relationship and that points of lengths below 18 cm smoothly approach the extended line. The corresponding estimates of L_∞ and Z/K are 30.8 cm and 5.74, respectively.

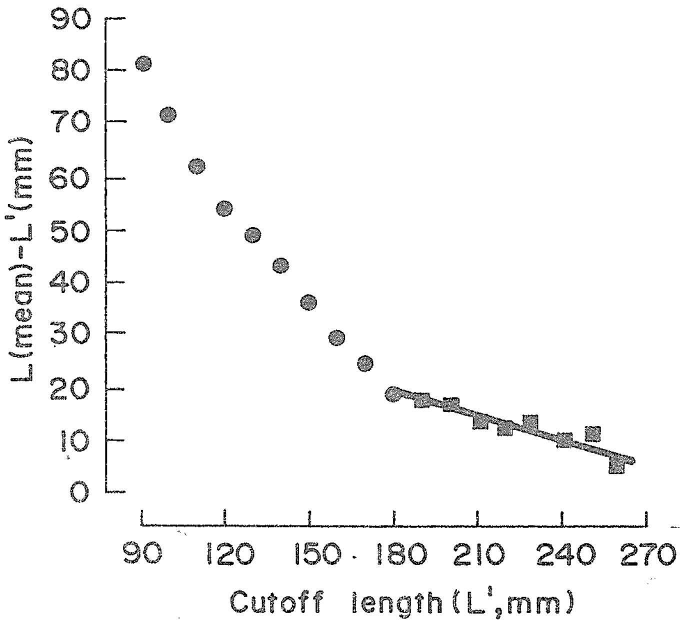

Fig. 4. Growth parameter estimation by the modified Wetherall method for *R. kanagurta* during 1985 in Banda Aceh.

Estimation of L∞, K and Z

An additional estimate of the L_∞ and an estimate of K were obtained using the ELEFAN I program based on the length-frequency data from Banda Aceh from May 1984 to September 1986 (Table 2).

Fig. 5 shows the restructured data together with the best fitting growth curve. The corresponding estimates are $L_\infty = 28.2$ cm and $K = 0.80$.

Since the catch data were obtained by a selective gear an attempt was made to correct for selection in order to avoid a bias on the estimates, especially of K, using the method of Pauly (1986b).

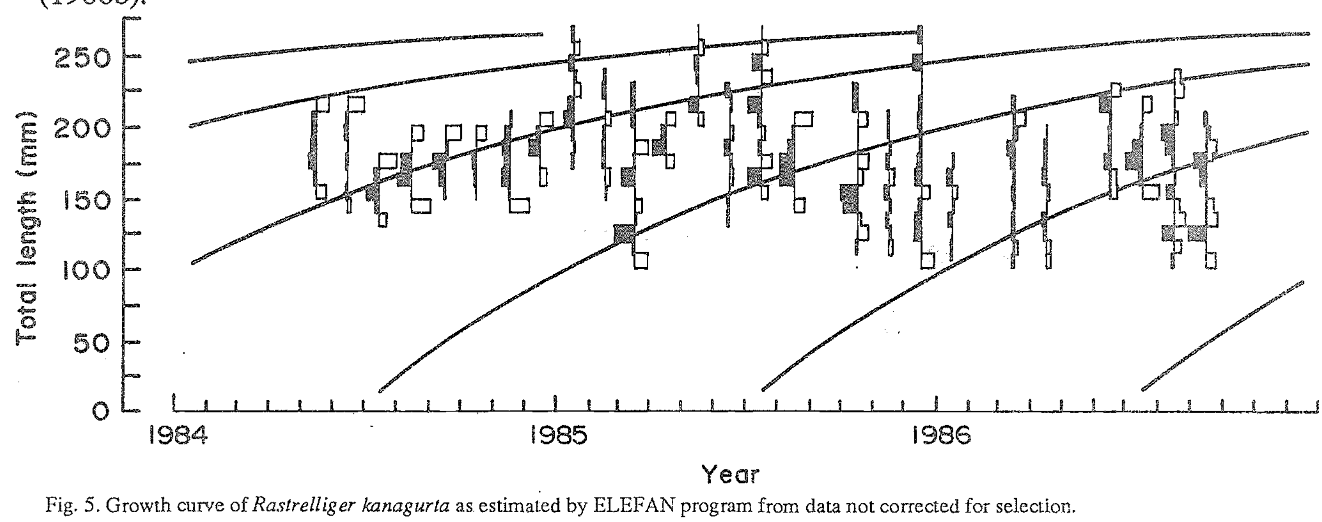

Fig. 5. Growth curve of *Rastrelliger kanagurta* as estimated by ELEFAN program from data not corrected for selection.

The length-converted catch curve was based on the same data set as the one used for the Wetherall method. The catch curve was constructed by applying the preliminary estimates from the ELEFAN I program, i.e., $L_\infty = 28.7$ cm and $K = 0.80$.

Assuming that from a given length class and upwards the fish are recruited and subject to constant mortality one can fit a straight line to the points from that given length. Fig. 6 shows the fitted straight line pertaining to length class 19.5 to 25.5 cm.

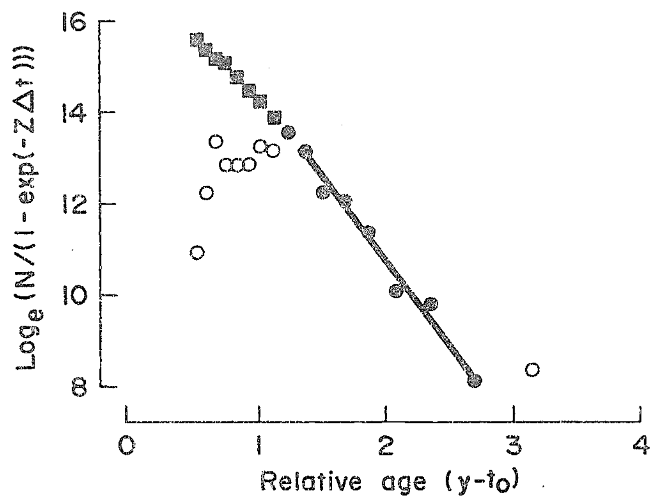

Fig. 6. Length-converted catch curve for *R. kanagurta* (1985) based on the growth parameters estimated from data not corrected for selection and the growth parameters $L_\infty = 28.7$ cm and $K = 0.8$.

The extension of the straight line backwards is constructed in accordance with the following assumptions. Total mortality at age 0 (zero) consists of natural mortality (M) only, and it increases stepwise to F + M = Z, at length when the fish is fully recruited. This length class corresponds to 19.5 cm.

The growth parameters $L_\infty = 28.7$ and $K = 0.80$ from the preliminary estimates and the mean environmental temperature (T) of 28°C is inserted in the equation for M and M = 1.56 was obtained (Pauly 1980).

Fig. 7 shows the resulting selection curve which is derived from the ratios between the actual number caught by length class and the estimated number in the population using the backward extension of the line. The probabilities of capture were smoothed using the moving average technique and this curve was used to correct the length-frequency data. The corrected length-frequency data from Banda Aceh, from May 1984 to September 1986, were then reanalyzed using the ELEFAN I program. Fig. 8 shows the restructured data and the best fitting growth curve. The new estimates of growth parameter of *R. kanagurta* are $L_\infty = 28.7$ cm and $K = 0.775$ (per year), i.e., virtually the same as before.

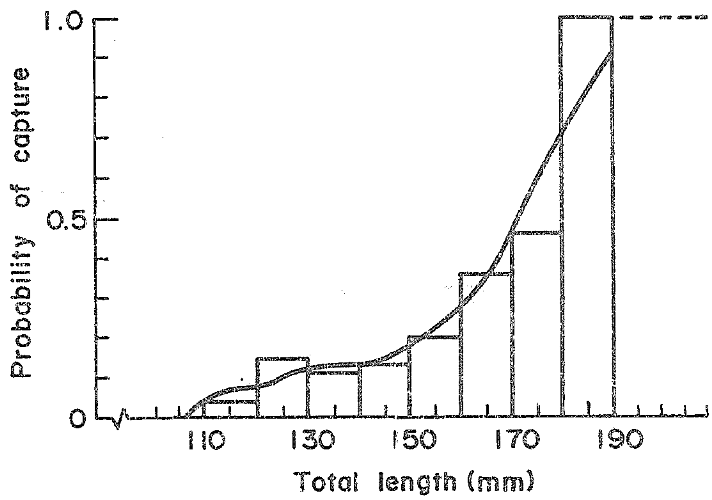

Fig. 7. Selection pattern (resultant curve) obtained, via running means, by applying growth parameter estimates derived from L/F data not corrected for selection.

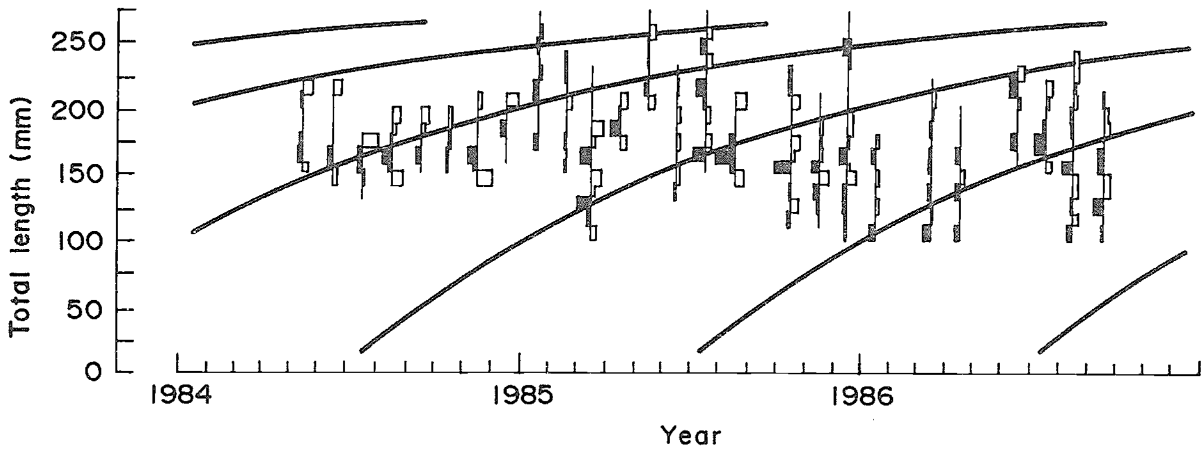

Fig. 8. Growth of *R. kanagurta* as estimated by the ELEFAN I program from length-frequency data corrected for selection.

Mortality Estimation

In order to estimate the total mortality rate of *R. kanagurta*, the catch at length data from Banda Aceh in 1985 were used as a basis for a length-converted catch curve analysis. The natural mortality (M = 1.53) was obtained from the same equation as used above, now inserting the final estimates of growth parameters of L_∞ = 28.7 cm, K = 0.775 and temperature T = 28°C.

Fig. 9 shows the catch curve of *R. kanagurta*. The points in length classes between 19.5 and 25.5 cm were used to fit a straight line. The derived estimate of Z = 3.89, hence F = 3.89 - 1.53 = 2.26.

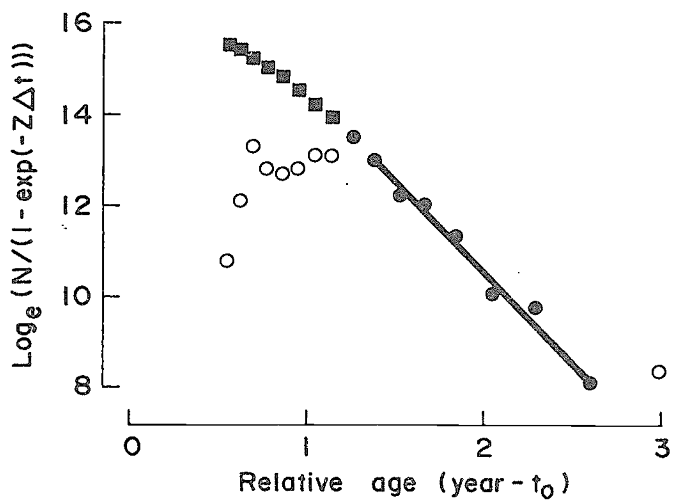

Fig. 9. Length-converted catch curve for *R. kanagurta* off Banda Aceh, applying growth parameter estimates from data corrected for selection.

Using a smoothing method as described above the new catch curve analysis was used to estimate the final selection curve.

Fig. 10 shows the resultant curve, where moving averages have been used to smooth the curve.

In addition to the above analyses, the recruitment pattern was derived of *R. kanagurta* in Banda Aceh (Malacca Strait). As Fig. 11 shows, recruitment occurs in two pulses of near equal strength.

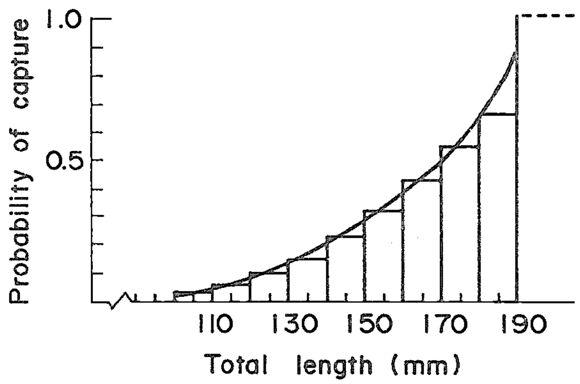

Fig. 10. Selection curve (resultant curve) applying growth parameter from data corrected for selection.

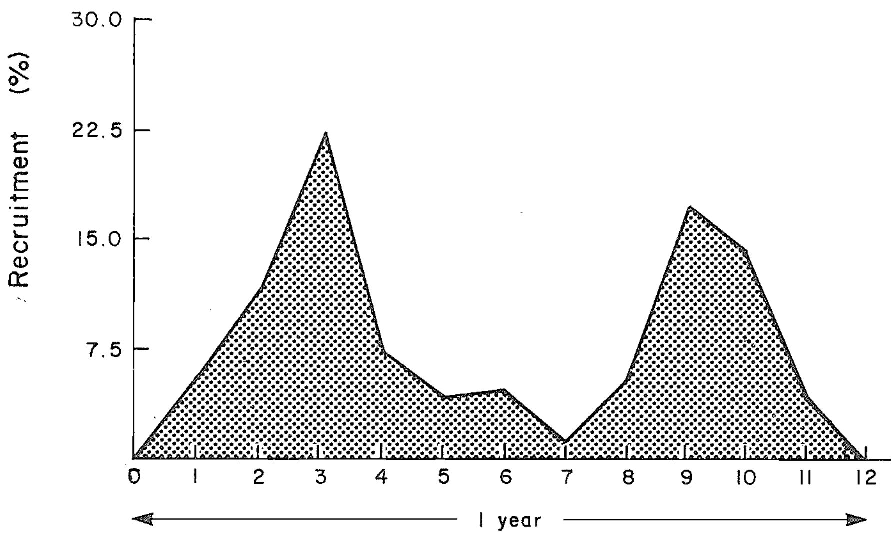

Fig. 11. Recruitment pattern for *R. kanagurta* caught with purse seiners in Banda Aceh, Malacca Strait of Indonesia; 1985.

The Yield per Recruit and Biomass per Recruit

The yield per recruit and biomass per recruit were determined as a function of the exploration rate assuming L_c/L_∞ and M/K are 0.59 and 1.98, respectively. Fig. 12 shows that the present exploration rate (E = 0.61) exceeds the optimum exploration rate (E_{max} = 0.56).

A similar analysis of length-frequency data from Asahan for May 1984 to October 1986 was carried out as the one performed with length-frequency data from Banda Aceh. Fig. 13 shows the restructured data from which no clear growth curves could be identified by eye. The growth curve fitted by ELEFAN I proved to be rather flat (i.e., had a low K value) and this was not acceptable for *R. kanagurta*. This data set was therefore not analyzed any further.

Discussion

The power function for weight-length relationship estimated in this paper seems to be in good agreement with other findings, i.e., Luther (1973), Sudjastani (1973) and Bay of Bengal Programme (1985) (see Table 4). Further, the curve fits the point reasonably well (Fig. 3). The equation obtained from the present study is therefore expected to give reliable weights for the

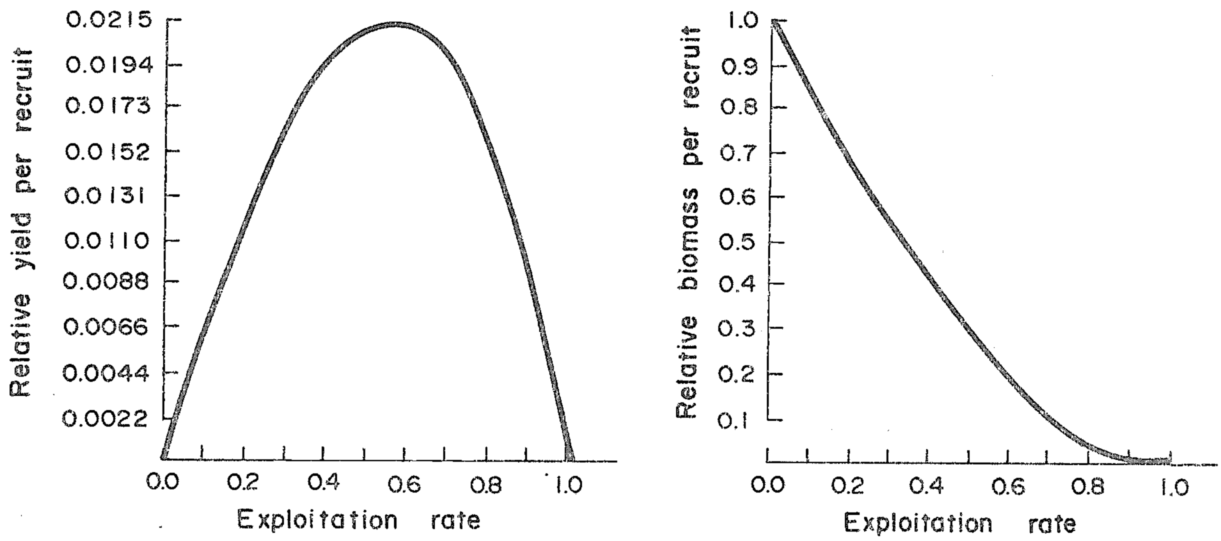

Fig. 12. Relative yield per recruit and biomass per recruit as a function of exploitation rate (E = F/Z) in *R. kanagurta* from Banda Aceh.

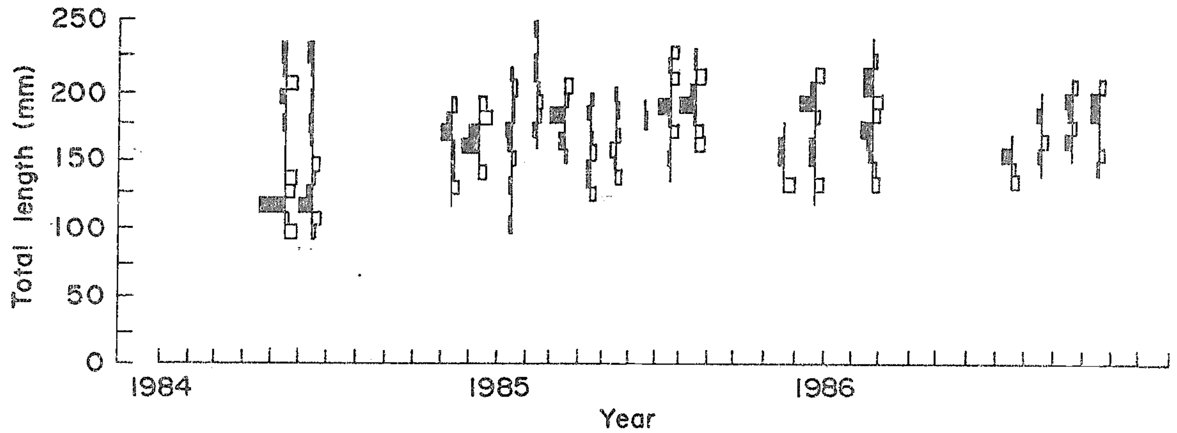

Fig. 13. Length-frequency data for *R. kanagurta* from Asahan (1984-1986), as restructured by ELEFAN I. This data set was deemed useless for growth analysis.

Table 4. Length-weight relationships of *R. kanagurta* in the Malacca Strait and adjacent areas.

Authors	Area	a	b
Luther (1973)	Andaman Island	2.16 x 10^{-6}	3.33
Sudjastani (1973)	Java Sea	3.88 x 10^{-6}	3.19
Anon. (1985)	West Coast Malaysia	3.60 x 10^{-6}	3.22
	Malaysia	6.70 x 10^{-6}	3.09
This study	Banda Aceh Malacca Strait	1.44 x 10^{-6}	3.38

length-frequency samples. The actual weights of the sample were available in the basic data. For some months, however, there was a clear discrepancy between the recorded weights and the calculated weights of the sample. Thus it was decided to use the calculated weights.

Growth parameters from studies in other areas are summarized in Table 5. The estimates of K and L_∞ obtained from studies in Indian waters cover a very wide range of values. The results show K values between 0.6 and 5.2, and L_∞ between 21.8 and 42.0 cm. Estimates from areas adjacent to the Malacca Strait, i.e., Samar Sea, Andaman Islands, west coast of Malaysia and the Java Sea show values of K between 0.6 and 1.9 and L_∞ between 25.7 and 29.5. The values obtained in this study of $L_\infty = 28.7$ and $K = 0.78$ are well within the range of values in this area. The mean ϕ' value of L_∞ and K for studies in this area is 2.93, and this agrees with a value of 2.81 for this study. The estimates of the von Bertalanffy growth parameters seem reliable.

Table 5. Summary table of estimates of L_∞, K and ϕ' values *R. kanagurta* (adapted from Dalzell and Ganaden 1987)

Location	L_∞	K	L_{max}	ϕ'	Reference
India Cochin	21.8	5.16	22.0	3.39	George and Banerji (1964)
India Calicut	23.3	3.12	22.0	3.23	George and Banerji (1964)
India Karwar	22.4	4.32	22.0	3.20	George and Banerji (1964)
Java Sea	23.9	2.76	23.5	3.20	Sudjastani (1973)
India	23.9	4.92	22.0	3.45	Banerji (1973)
Egypt (Red Sea)	42.0	0.288	-	2.71	Rafail (1972)
India	31.3	0.64	29.0	2.80	Sekharan et al. (1969)
India	31.6	0.60	29.0	2.78	Seshappa (1958)
Mozambique	27.8	0.753	25.0	2.76	Sousa and Gislason (1985)
India	39.0	0.74	33.5	3.05	Luther (1973)
India	26.6	0.83	26.2	2.77	Udupa and Bhat (1984)
India	30.5	0.8	29.0	2.87	Seshappa (1958)
Samar Sea	27.5	1.30	25.0	2.99	Corpuz et al. (1985)
Samar Sea	28.0	1.31	26.0	3.01	Corpuz et al. (1985)
Palawan	28.0	1.55	25.0	3.08	Ingles and Pauly (1984)
W. Thailand	26.0	1.90	23.0	3.11	Bay of Bengal Programme (1985)
W. Thailand	26.3	1.50	21.0	3.02	Bay of Bengal Programme (1985)
W. Thailand	25.0	1.60	21.0	3.00	Bay of Bengal Programme (1985)
Malaysia	27.0	0.70	-	2.71	Bay of Bengal Programme (1985)
Sumatra	29.5	0.60	26.0	2.72	Bay of Bengal Programme (1985)
Sumatra	26.5	0.80	26.0	2.75	Bay of Bengal Programme (1985)
Indonesia	25.7	1.625	-	-	Sadhotomo and Atmadja (1985)
Malacca Strait	28.7	0.78	26.5	2.81	This study

The analysis of growth and mortality of *R. kanagurta* presented here is based on data from the fishery in Banda Aceh. The purse seine fishery in this area is directed towards small tuna and *R. kanagurta* cannot be considered a target species for this fishery. In respect to the analysis in this paper this matter can be an advantage because the fishery is likely to catch "random samples" of the stock of *R. kanagurta*. The data from the fishery are therefore expected to mirror the average stock composition.

In contrast, the purse seine fishery from Asahan is directed towards *R. kanagurta*. The fishing area extends northwards from Asahan but the vessels are only capable of fishing in water depths below 200 m (see Fig. 1). Although the exact spawning location is unknown, it is expected that this area is a transition area mainly populated by "medium-sized" individuals. The length-frequency samples from Asahan support this idea, since the monthly samples are homogeneous in respect to size and no apparent growth curve can easily be identified. For this reason we did not utilize the length-frequency data from Asahan to estimate growth and mortality.

In this context, the results of the discriminant analysis of morphometrics of *R. kanagurta* from Banda Aceh and Asahan are very interesting (see Soriano et al., this vol.).

The analysis shows that there is a difference between the two sampling sites and that there are likely to be two separate stocks of which the one fished near Banda Aceh is found off the shelf, while the one near Asahan is found in much shallower waters.

The above suggestions are, however, by no means conclusive and sampling in both places should certainly be continued.

The total mortality, Z, was estimated to 3.9 year^{-1} from the length-converted catch curve. The Wetherall method gives Z/K = 5.74 which corresponds to Z = 4.5 accepting the K value of 0.78. This is probably also due to the nature of the fishery where *R. kanagurta* is considered a bycatch in the fishery (Banda Aceh).

The recruitment pattern estimated here suggests two recruitment pulses per year. This is in agreement with Pachansalani (1962) who studied annual variation in catches.

The yield-per-recruit analysis shows that the present exploitation rate is beyond E_{max}. For resource management purposes, it is suggested that the exploitation rate should reduced below the optimum exploitation rate.

Acknowledgements

The author wishes to thank Mr. Isman and Mr. Muchtar Kosoemasumantri and the staff of the Fisheries Offices in Asahan and Banda Aceh, respectively, for their assistance in collecting the data for this study.

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A Study of Growth Parameters and Mortality Rates of *Scomberomorus brasiliensis* from the Coastal Areas of Trinidad, West Indies

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Abstract

Beach seine catches (1971-1972) were re-analyzed using length-frequency methods. The resulting mean lengths at age were similar to those obtained earlier from otolith readings by M.G. Sturm.

Comparison of gill net and beach seine size frequencies from 1971 to 1973 gave a selection curve similar to the normal curve shape found by earlier authors. Comparison of gill net frequencies for 1971-1973 and 1981-1985 suggested that the gill nets in present use are less selective.

A bimodal gill net selectivity curve, caused by entanglement of larger fish was also tried, but led to almost the same mortality estimates as uncorrected data.

Mortality estimates from beach seine and gill net length data from 1971-1973 were higher than those based on otolith readings.

Mortality estimates from the 1981-1985 samples using age frequencies obtained from an age-length key and length frequencies were similar, but higher than those from earlier studies.

Introduction

Scomberomorus brasiliensis (Collette et al. 1978) is the Spanish mackerel distributed in the southern Caribbean and along the Atlantic coasts of Central and South America from Belize to Rio Grande do Sul, Brazil. This species was previously confused with *S. maculatus* which ranges further north in the Gulf of Mexico and along the Atlantic coast of the United States. The ranges of these two scombrids show no apparent overlap (Collette and Russo 1984). Whiteleather and Brown (1945) report that *S. brasiliensis* is the most abundant neritic pelagic fish in Trinidad where it is commonly known as "carite". Unpublished data from the Ministry of Agriculture, Lands and Food Production (MALFP) indicate that carite constitutes the largest proportion by weight of the landed catches recorded at 18 major coastal sites around Trinidad. One thousand metric tonnes of carite, valued at seven million TT dollars, constituted 28% by weight and 31% by value of the total landed catches recorded for 1983. Due to the commercial importance of this species, the biology and status of the fishery in Trinidad has already been investigated (Sturm 1974, 1978). Apart from these studies, several Brazilian authors have investigated various biological aspects of this species. These papers are listed in an annotated bibliography of the western Atlantic *Scombridae* (Manooch et al. 1978).

In Trinidad, carite are caught with five different gear types, namely, "filette" (gill) nets, trolling, "a-la-vive", beach seines and Italian seines (ranked in descending order of importance). Filette nets and Italian seines are used all year-round. However, due to the large crew required for Italian seining, this fishing method is becoming less popular. The other three methods, trolling, beach seines and "a-la-vive", are seasonal. Trolling and "a-la-vive" are used mainly between March and September, whilst the use of beach seines peaks during June, July and August. The five gears used for catching carite for commercial purposes are not selective for carite only. Carite amounts to 50-60% of the catch with filette nets, trolling and "a-la-vive" lines, 16% of the catch with beach seines and 5% of Italian seine catches (1983 data from MALFP). The presence of carite appears to be seasonal with a period of abundance from May to October which seems to coincide with the suggestion that carite moves to areas of low salinity to spawn (Sturm 1974, 1978).

Sturm (1974, 1978) carried out studies on the biology of *S. brasiliensis* off Trinidad, in which estimates of growth parameters and mortality rates were obtained using traditional methods of analysis such as otolith readings. The present investigation has been designed to investigate:

(a) whether length-frequency methods of parameter estimation when applied to data from 1971-1973 give similar results.

(b) whether growth and mortality parameters have changed since 1973.

Materials

Two main data sets have been used in this paper:

(a) Length frequencies of samples caught with beach seines in August 1971 and June to August 1972 and with gill nets in 1971 to 1973 (from Sturm 1974).

(b) Length frequencies collected at the major fish market in Port-of-Spain. These were taken on a monthly basis from May 1981 to December 1985 and were fork lengths measured to the centimeter above. Frozen samples were not measured. It was sometimes difficult to obtain permission to put the fish onto a measuring board. As a result, from August 1983, a measuring tape was introduced, which gave a slightly longer measure due to the inclusion of the curvature of the fish. To correct for this, simultaneous measurements of both board and tape were taken to the millimeter, and a correction factor calculated and applied. Where possible, length frequencies were collected by gear type.

In addition to these two data sets, length frequencies collected during mackerel tagging exercises have been included.

An age-length conversion table (Sturm 1974) based on otolith readings of samples from beach seine exercises in 1971 and 1972 was applied.

Methods of Data Analysis

(a) Length-frequencies collected from beach seines were analyzed using the Bhattacharya method, as described by Asila and Ogari (this vol.). The separation index was calculated according to Hasselblad (1986) as

$$S.I. = \frac{L_a - L_b}{(sa + sb)/2}$$

where L_a and L_b are successive mean values and sa and sb the corresponding standard deviations. Growth parameters (L_∞, K) were calculated using Gulland and Holt plots of annual length increments against length, and whose slope and x-intercept are equal to $(1-e^{-K})$ and L_∞, respectively (Gulland and Holt 1959; Gulland 1983).

(b) The parameter $\phi' = \log_{10} K + 2 \log_{10} L_\infty$ (Pauly and Munro 1984) was calculated for values of L_∞ (cm) and K/year extracted from the literature and the results compared with the ϕ' value resulting from L_∞ and K values estimated in this paper.

(c) Length-frequency data were collected from August 1983 using a measuring tape. Ordinary regression analysis of a series of simultaneous board (y) and tape (x) measurements was done, but the intercept with the ordinate axis was not significantly different from zero. Correction was therefore based on $y = bx$ where $b = dxy/dx^2$ using the method outlined in Sparre (1985a, 1985b). The correction factor b thus obtained was 0.9684.

(d) Gill net and beach seine length frequencies collected in 1972 (Sturm 1974) were analyzed for gill net selectivity. Fractions retained in each length group were calculated and converted into percentages which were plotted against the mid-lengths.

Cumulated percentages were transformed to a linear relationship in the form of probits (y), which were plotted against the upper limit of each length group (x). Linear regression analysis provided estimates of the mode of the selection curve L_m and the standard deviations as follows:

L_m = length when probit value is 5

s = (length when probit value is 6) - L_m.

Using the estimated values of L_m and s, the normal distribution with these characteristics was calculated by insertion of successive lengths into the equation describing the probabilities of a normal distribution.

$$P = \frac{1}{S\sqrt{2\pi}} * e^{-\left(\frac{(x-\bar{x})^2}{2s^2}\right)}$$

$$\% = \frac{100 * \Delta L}{s\sqrt{2\pi}} * e^{-\left(\frac{(L-L_m)^2}{2s^2}\right)} \qquad ...1)$$

where ΔL is the class interval.

The gill net selection factor (k) was calculated as

$k = L_m/m$

where m is the mesh size (stretched).

A similar analysis of the fractions retained by hooks was also done.

(e) There was a change in mesh size since the early years of sampling from 11.45 cm stretched mesh in 1971-1973, to 10 cm in 1981-1985. This was accounted for by calculating a new $L_m = k * 10$ cm, assuming that the standard deviations remained constant.

Frequencies at length were raised by applying the factor

$$e^{\left(\frac{(L-L_m)^2}{2s^2}\right)}$$

to values greater than L_m. Attempts were not made to repair the recruitment part of the catch curve.

(f) Corrected market length frequencies for the period May 1981 to December 1985 were converted to age using the age-length key derived from otolith readings (Sturm 1974). This calculation was based on the assumption that there have been no major changes in growth and mortality.

(g) Age frequencies for 1981 to 1985 were converted to percentages and the mean percentage by age distribution for the whole time period obtained. Linear regression analysis (of points above full recruitment) of natural log of % frequencies (y) against age (x) was used for estimation of total mortality (Z) as the slope. Similar analysis was done using beach seine and gill net data from Sturm (1978).

Length-converted catch curve analysis (Pauly 1984) was also done on combined length frequencies for 1981-1985, combined beach seine data from 1971 and 1972 and combined gill net data from 1971 to 1973.

(h) Length frequencies for 1981-1985 were analyzed using the method outlined by Wetherall (1986). This method is based on the linear regression.

$$\bar{L} = a + b L'$$

where L' is the lower limit of each length class and L the mean size of fish ≥ L'. The equation is a rearrangement of

$$\frac{Z}{K} = \frac{L_\infty - \bar{L}}{\bar{L} - L'}$$ (Beverton and Holt 1956)

$\bar{L}$ is obtained from a cumulative computation of

(class mid-lengths * frequencies)/(sum of frequencies)

beginning at the largest length class represented in the sample, as shown in the example below:

L'	Mid-length (L)	n	Σn	L*n cumul.	$\bar{L}$
6	6.5	10	20	145.0	7.25
7	7.5	6	10	80.0	8.00
8	8.5	3	4	35.0	8.75
9	9.5	1	1	9.5	9.5

Generally, plots of $\bar{L}$ (y) and L' (x) are linear with a curved section representing fish not fully recruited (see Fig. 6a). The point of full recruitment is chosen from the graph and linear regression of (L', $\bar{L}$) from this point upward is used for estimation of

$$L_\infty = a/(1 - b)$$

$$Z/K = b/(1 - b)$$

The intercept of L' = $\bar{L}$ with $\bar{L}$ = a + bL' is equal to L_∞. The value of b may be close to one. A high number of significant digits must therefore be carried to ensure accuracy. According to Wetherall (1986) each point of(L', $\bar{L}$) should be weighted by its respective sample size (Σn). This was not done in this paper because it gives the highest weight to the first observation of full recruitment, the choice of which is not entirely objective.

Results and Discussion

Three main analytical steps covered in this investigation are:

(a) to verify estimates of age-readings and the resultant growth parameters;

(b) to account for problems due to gill net selection and the effects that adoption of uncorrected length data from 1981 to 1985 would have on growth and mortality estimates; and

(c) to estimate growth and mortality rates from previous and recent samples using age-frequency distributions and age-independent methods.

Verification of Age-Readings through Estimates of Growth Parameters

The combined beach seine length frequencies from August 1971 and June, July and August 1972 are shown in Table 1 and comprise a total of 1,044 fish.

Table 1. *S. brasiliensis* – combined beach seine length frequencies (Sturm 1974).

Length ranges (cm)	Numbers (n)	Length ranges (cm)	Numbers (n)
14.1 – 16.0	1	46.1 – 48.0	55
16.1 – 18.0	1	48.1 – 50.0	56
18.1 – 20.0	1	50.1 – 52.0	40
20.1 – 22.0	6	52.1 – 54.0	54
22.1 – 24.0	11	54.1 – 56.0	74
24.1 – 26.0	12	56.1 – 58.0	37
26.1 – 28.0	15	58.1 – 60.0	20
28.1 – 30.0	26	60.1 – 62.0	24
30.1 – 32.0	26	62.1 – 64.0	17
32.1 – 34.0	43	64.1 – 66.0	18
34.1 – 36.0	72	66.1 – 68.0	12
36.1 – 38.0	97	68.1 – 70.0	7
38.1 – 40.0	124	70.1 – 72.0	1
40.1 – 42.0	95	72.1 – 74.0	2
42.1 – 44.0	50	74.1 – 76.0	1
44.1 – 46.0	45	76.1 – 78.0	1

Using the method of Bhattacharya (1967), five cohorts were separated from the data set. Mean lengths, standard deviations(s), numbers in each cohort (n) and S.I. or separation index (>2 is a reasonable result) are shown in Table 2. Regression analysis of the first three length

Table 2. Bhattacharya analysis of length frequencies shown in Table 1.

Cohort number	Mean length (cm)	s	n	S.I.
1	28.55	3.735	109	
2	38.60	3.277	495	2.867
3	48.54	2.911	196	3.212
4	55.35	2.541	167	2.497
5	63.22	3.076	73	2.800

increments against mean length gave values for L_∞ and K of 93.8 cm and 0.18/year, respectively. The last length increment was omitted from the regression as it was based on the mean length of cohort 5, which is probably an overestimation due to the inclusion of some older fish (Fig. 1)

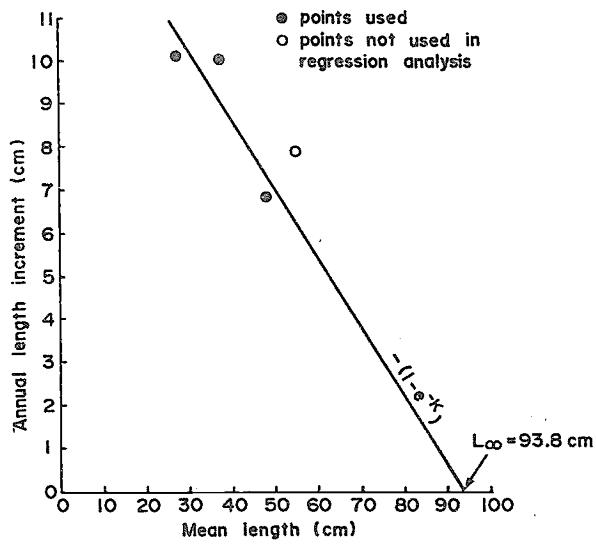

Fig. 1. Gulland and Holt plot of Bhattacharya results for *Scomberomorus brasiliensis*, beach seines, 1971-1972.

Mean lengths at age from Bhattacharya analyses show similarity to the growth curve described by Sturm (1974, 1978). This is shown in Fig. 2, where the mean length of the first age-group identified, is assumed to be age group 1.

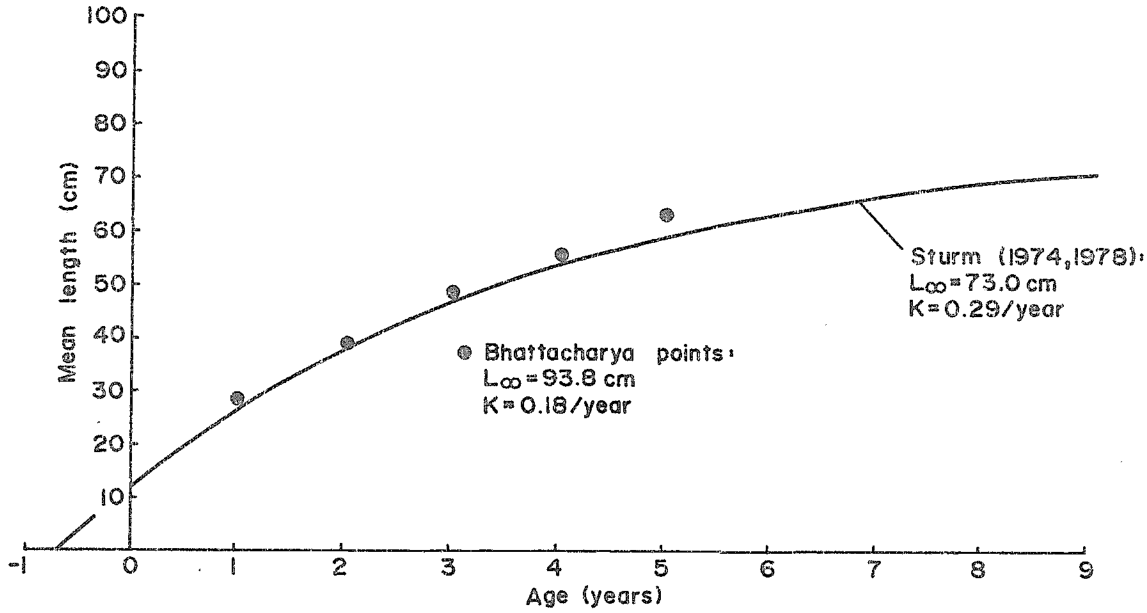

Fig. 2. Growth of *Scomberomorus brasiliensis* as estimated from otolith readings by Sturm and from length-frequency data (Bhattacharya analysis).

Random samples of a given species show some variance between pairs of estimated values of L_∞ and K. Since these growth parameters are functions of one another, it is possible to describe a common parameter which facilitates comparison of several different results. The parameter ϕ' (described in the section on Methods of Data Analysis (b)) seems to have this property. Using this method, growth parameters from previous studies and this investigation have been transformed into ϕ' values for comparison (Table 3).

The results show that all the calculated ϕ' values compare favorably, confirming the otolith readings of Sturm (1974).

Due to the verification of otolith readings, it is sensible to apply the age-length key of Sturm (1974) to the length frequencies collected from May 1981 to December 1985, on the assumption that growth and mortality have not changed significantly.

Table 3. Von Bertalanffy growth curve parameters and ϕ' for *Scomberomorus brasiliensis* and other *Scomberomorus* spp.[a]

Species	Study area	Sex	L_∞ (cm)	K/year	ϕ'	Source
S. brasiliensis	Brazil	Male	83.0	0.20	3.14	Nomura 1967
		Female	94.4	0.20	3.25	
S. maculatus	Florida	Male	61.2	0.373	3.15	Klima 1959
		Female	76.7	0.356	3.32	
S. brasiliensis	Trinidad	Male	71.0	0.26	3.12	Sturm 1978
		Female	83.0	0.23	3.20	
	Mean values	Both	78.22	0.27	3.22	All authors
S. brasiliensis	Trinidad	Both	93.81	0.1765	3.19	This investigation

[a] ϕ' values according to Pauly and Munro (1984) on $\log_{10}$ basis. See also Cheunpan (this vol.).

Gill Net Selectivity

Gill nets are recognized as being selective at both ends of the length range of a species. Data samples from 1981 to 1985 seem to exclude beach seine catches, as smaller fish found in catches in 1971-1972 of beach seines, are absent. In addition, all recent samples were collected at the main fish market on the west coast (Fig. 3) and it seems that most of the fish arriving here were caught with gill nets and hooks. The possible selectivities of gill nets and hooks have to be considered.

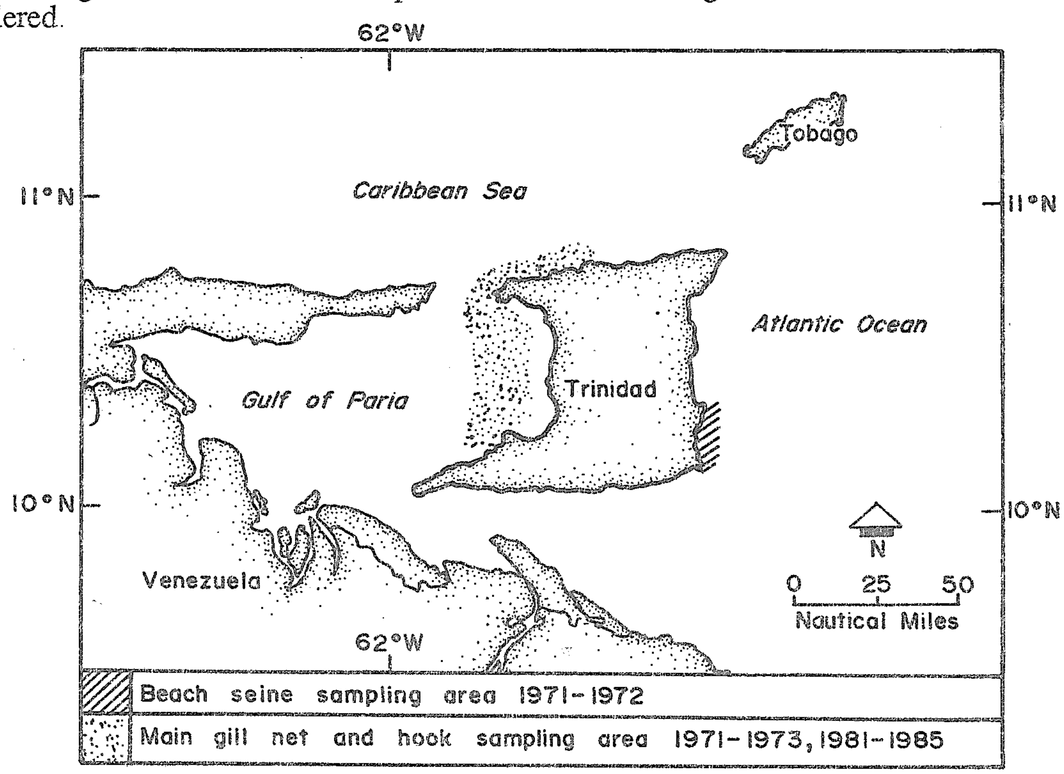

Fig. 3. Map of Trinidad showing sampling areas.

Therefore, beach seine and gill net frequencies from 1971 to 1973 have been treated as described in Methods of Data Analysis (d) (Table 4).

Table 4. Treatment of beach seine (B) and gill net (G) frequencies.

Lower limit	Upper limit X_1	Midpoint X_2	G	B	G/B	Percentages Y_2	Cumulative %	Probits Y_1
14.1	19.0	16.5		3				
19.1	24.0	21.5		17				
24.1	29.0	26.5		25				
29.1	34.0	31.5		61				
34.1	39.0	36.5	1	102	0.0098	0.4022	0.4022	2.348
39.1	44.0	41.5	25	76	0.3289	13.4972	13.8994	3.915
44.1	49.0	46.5	75	106	0.7075	29.0340	42.9334	4.821
49.1	54.0	51.5	109	104	1.0481	43.0113	85.9447	6.078
54.1	59.0	56.5	32	118	0.2712	11.1294	97.0741	6.892
59.1	64.0	61.5	2	50	0.0400	1.6415	98.7156	7.230
64.1	69.0	66.5	1	32	0.0313	1.2845	100.0001	
69.1	74.0	71.5		6				
74.1	79.0	76.5		2				
Totals			245	702	2.4368	100.0001		

Plots of X_2, Y_2 and X_1, Y_1 (see Table 4) are shown in Fig. 4. Regression analysis of X_1, Y_1, gives values for L_m and s of 50.42 and 5.06 cm, respectively. The calculated normal distribution with these characteristics is also shown.

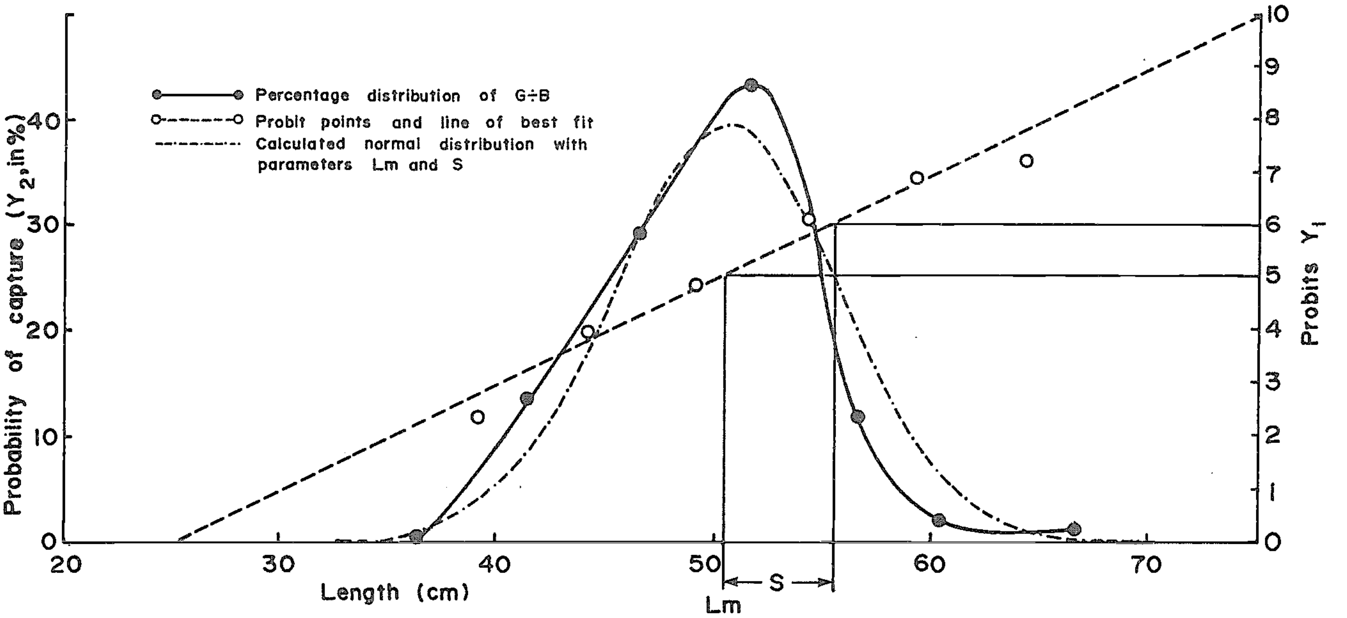

Fig. 4. Selection curves of *Scomberomorus brasiliensis*. Plots of (X_1, Y_1) and (X_2, Y_2) (see Table 5) and estimated normal distribution with a mean of L_m = 50.42 cm and a standard deviation of s = 5.06 cm.

Sturm (1974, 1978) used gill nets with stretched mesh sizes ranging from 10.8 to 12.1 cm. Using L_m = 50.42 cm, selection factors for these mesh sizes were calculated, using the equation in Methods of Data Analysis (d).

Assuming a mean mesh size of 11.45 cm, the estimate of a selection factor was 4.40 (see Methods of Data Analysis (d)). This result resembles those of Trent et al. (1983) who found a mean selection factor for *Scomberomorus maculatus* of 4.9 and a mean value of s of 6.6 cm with s = 5.0 for a mesh of 9.5 cm. The correction was applied to the recent data set. The commercial mesh size has decreased to 10 cm, which has a modal length of 44.0 cm (based on k = 4.4) and the same standard deviation of 5.1 cm (Fig. 5).

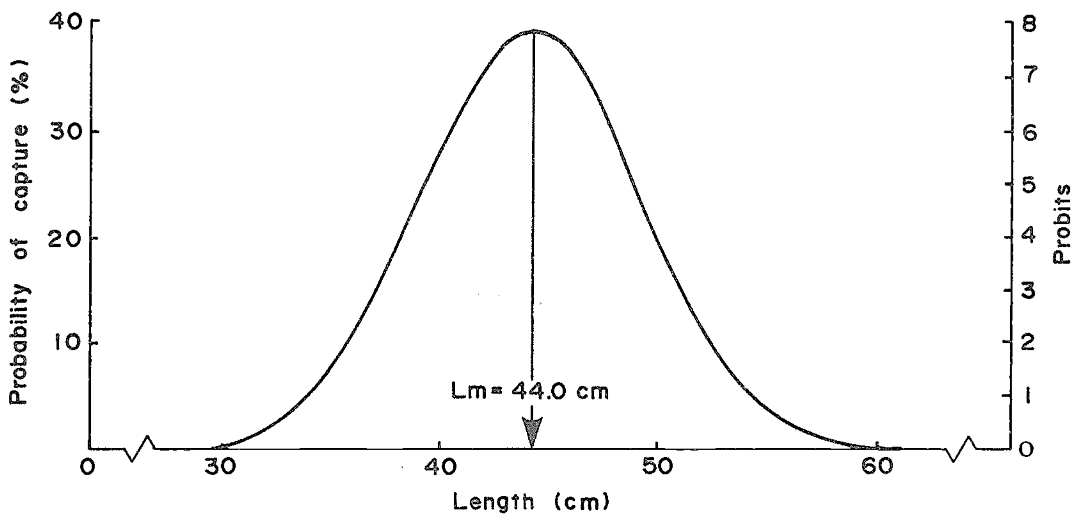

Fig. 5. Calculated normal selection of *Scomberomorus brasiliensis* mesh. L_m = 44.0 cm, s = 5.06 cm.

Gill net length frequencies (1985) above L_m = 44.0 cm were raised as described in Methods of Data Analysis (e). This correction gave reasonable results for only two or three length classes above L_m and unbelievably high frequencies in the larger groups (Table 5). This indicates that although data sets from 1971 to 1973 followed the findings of Trent et al. (1983), the recent samples did not.

Table 5. Gill net correction factors, original and corrected frequencies (for lengths above L_∞ = 44.0 cm) for 1985.

Length ranges (cm)	Midlengths (cm)	Correction factor	Original frequencies	Corrected frequencies
43.1 – 45.0	44.0	1	191	191
45.1 – 47.0	46.0	1.08	201	217
47.1 – 49.0	48.0	1.37	274	375
49.1 – 51.0	50.0	2.02	247	499
51.1 – 53.0	52.0	3.49	253	883
53.1 – 55.0	54.0	7.05	191	1,347
55.1 – 57.0	56.0	16.64	129	2,147
57.1 – 59.0	58.0	45.95	84	3,860
59.1 – 61.0	60.0	148.31	47	6,971
61.1 – 63.0	62.0	559.61	22	12,311
63.1 – 65.0	64.0	2,468.59	13	32,092
65.1 – 67.0	66.0	12,731	19	241,889
67.1 – 69.0	68.0	76,758	9	690,825
69.1 – 71.0	70.0	541,051	8	4,328,407
71.1 – 73.0	72.0	4,458,607	6	$27 * 10^6$
73.1 – 75.0	74.0	42,954,562	2	$85 * 10^6$
75.1 – 77.0	76.0	483,802,777	1	$480 * 10^6$
77.1 – 79.0	78.0	6,370,542,053	3	$600 * 10^6$

Hooks seem to be less selective than gill nets (see Table 6). A few hook samples are included (and inseparable) in the 1981-1985 data. Their influence upon the results was assumed negligible.

Table 6. Length frequencies of *Scomberomorus brasiliensis* caught by hook and line (H) and gill net (G), Trinidad, September-October 1985.

Length ranges (cm)	H N	G N
28.1 – 31.0	2	
31.1 – 34.0	2	2
34.1 – 37.0	10	8
37.1 – 40.0	46	59
40.1 – 43.0	30	99
43.1 – 46.0	28	67
46.1 – 49.0	34	72
49.1 – 52.0	72	90
52.1 – 55.0	71	56
55.1 – 58.0	40	33
58.1 – 61.0	19	12
61.1 – 64.0	8	6
64.1 – 67.0	6	1
67.1 – 70.0	1	
70.1 – 73.0		
73.1 – 76.0	1	
76.1 – 79.0	1	

Examination of gill net frequencies from the two study periods (Table 7) indicate that modern nets are less selective at both ends of the length range.

Table 7. Length frequencies of *Scomberomorus brasiliensis* caught by gill net, Trinidad, 1971-1973 and 1981-1985.

Length ranges (cm)	1971-1973 N	1981-1985 N
25.1 – 28.0		5
28.1 – 31.0		7
31.1 – 34.0		19
34.1 – 37.0		67
37.1 – 40.0	5	282
40.1 – 43.0	29	577
43.1 – 46.0	79	855
46.1 – 49.0	133	1,219
49.1 – 52.0	131	1,236
52.1 – 55.0	112	884
55.1 – 58.0	49	529
58.1 – 61.0	24	248
61.1 – 64.0	10	141
64.1 – 67.0	3	93
67.1 – 70.0	2	45
70.1 – 73.0		24
73.1 – 76.0		9
76.1 – 79.0		15
79.1 – 82.0		4

Fonteles-Filho and Alcantara-Filho (1977) did selectivity studies on *Scomberomorus brasiliensis* in Brazil and found a bimodal selectivity curve, which was accounted for by entanglement of larger fish.

Riedel (1963) described this effect as the hanging coefficient (i.e., bagginess of net) on the basis of his findings for tilapia of an increase in entanglement when the hanging coefficient was increased from 1.1 to 1.3. This factor was also supported by Hamley (1975).

The combined data (1981-1985) was corrected on the basis of this bimodal selection suggested by the Brazilian paper (Table 8). Using the Wetherall method described in the

Table 8. Original (N_1) and corrected (N_2) length frequencies from gill nets (1981-1985) with L computations.

L'	Midlength (cm)	N_1	$\bar{L}_1$	N_2	$\bar{L}_2$
25.0	26.5	5	49.6	5	46.97
28.0	29.5	7	49.6	7	46.97
31.0	32.5	19	49.6	19	46.97
34.0	35.5	67	49.7	67	46.98
37.0	38.5	282	49.8	282	47.01
40.0	41.5	577	50.4	577	47.10
43.0	44.5	855	51.3	15,817	47.22
46.0	47.5	1,219	52.6	5,638	51.03
49.0	50.5	1,236	54.6	2,541	54.57
52.0	53.5	884	57.1	1,258	57.93
55.0	56.5	529	60.0	663	60.97
58.0	59.5	248	63.2	353	63.52
61.0	62.5	141	66.0	337	65.26
64.0	65.5	93	68.7	328	67.22
67.0	68.5	45	71.7	88	71.02
70.0	71.5	24	74.4	28	74.66
73.0	74.5	9	77.0	9	77.32
76.0	77.5	15	78.1	17	78.39
79.0	80.5	4	80.5	7	80.5

Methods section (h), plots of (L', $\bar{L}$) for both N_1 and N_2 (Table 8) were obtained, and are shown in Fig. 6. The estimates were $L_\infty = 100.2$ cm, $K = 0.15$/year, $Z = 1.2$ for N_1 and $L_\infty = 98.2$ cm, $K = 0.16$/year, $Z = 1.2$ for N_2. The separation of K and Z was based on a ϕ' value of 3.22 (Table 3).

This is a remarkably small difference. A decrease of Z after correction was to be expected. It seems that the adoption of a very broad, bimodal selection curve like the Brazilian one amounts to almost the same as an assumption of full entanglement of the larger fish.

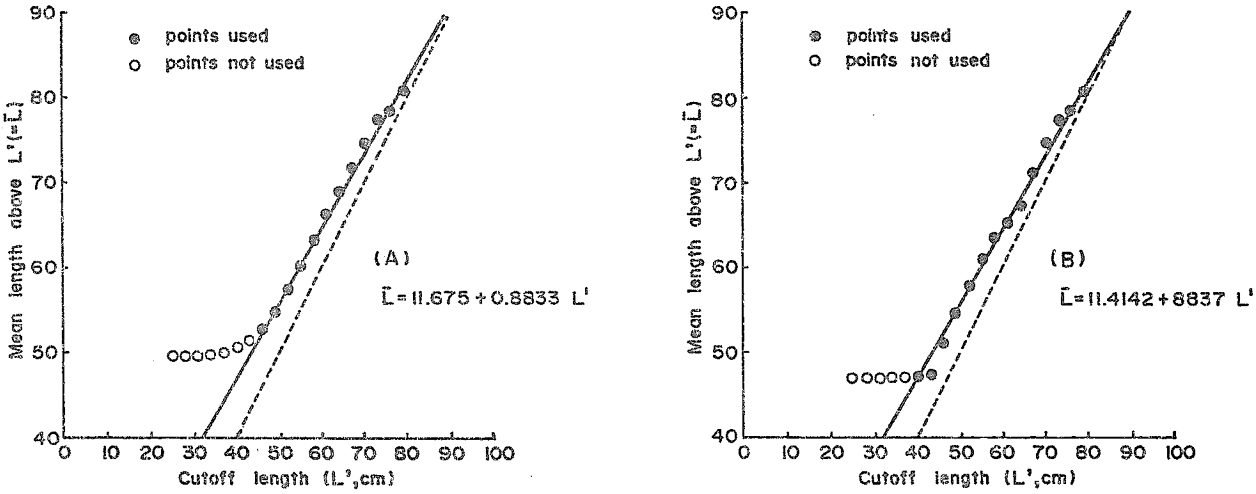

Fig. 6. Wetherall plots for (A) original frequencies of *Scomberomorus brasiliensis* from 1981 to 1985 and (B) frequencies raised following the bimodal selection curve for gill nets.

Estimation of Growth and Mortality

Using the age-length key (Table 9), yearly length frequencies (1981-1985) shown in Table 10, were converted to age. These yearly age frequencies were raised to percentage to standardize for changes in sampling intensity.

Table 9. Age-length conversion key (Sturm 1974) based on otolith readings. In percentages per length group.

Length group (cm)	Age group									
	0	I	II	III	IV	V	VI	VII	VIII	IX
14.1 – 16.0	100									
16.1 – 19.0		100								
19.1 – 22.0		100								
22.1 – 25.0		100								
25.1 – 28.0		96	4							
28.1 – 31.0		55	45							
31.1 – 34.0		5	95							
34.1 – 37.0			91	9						
37.1 – 40.0			73	27						
40.1 – 43.0			33	65	2					
43.1 – 46.0			15	77	8					
46.1 – 49.0			5	65	29	1				
49.1 – 52.0			1	47	50	2				
52.1 – 55.0				38	51	11				
55.1 – 58.0				10	62	21	7			
58.1 – 61.0				3	50	25	22			
61.1 – 64.0					19	44	31	6		
64.1 – 67.0						66	17	17		
67.1 – 70.0							75	25		
70.1 – 73.0								33	33	33
> 73.0									50	50

Table 10. Yearly length frequencies for 1981-1985.

Length range (cm)	1981 N	1982 N	1983 N	1984 N	1985 N
25.1 – 28.0		1		4	
28.1 – 31.0			1	4	2
31.1 – 34.0				8	11
34.1 – 37.0	1	3	5	17	41
37.1 – 40.0	5	20	16	52	189
40.1 – 43.0	39	100	46	89	303
43.1 – 46.0	169	163	94	128	301
46.1 – 49.0	238	196	223	154	408
49.1 – 52.0	229	239	193	150	425
52.1 – 55.0	153	202	124	126	279
55.1 – 58.0	76	143	64	88	158
58.1 – 61.0	34	64	30	55	65
61.1 – 64.0	15	42	19	41	24
64.1 – 67.0	9	7	5	37	25
67.1 – 70.0	2	9	2	21	11
70.1 – 73.0	1	4		12	7
> 73.0	1	2	1	19	5

The mean percentages at age per year were calculated for the whole sampling period 1981-1985 along with the total numbers at age. These frequencies are presented in Table 11 along with the age frequencies from beach seines and gill nets which were obtained from otolith readings (Sturm 1974).

Table 11. Age frequencies in numbers (N) and percentages (%).

	Gill nets + hooks 1981-1985		Beach seines 1971-1972		Gill nets 1971-1973	
Age	N	%	N	%	N	%
I	10	0.2	46	5.2		
II	679	9.6	286	32.4	21	4.5
III	2,886	45.9	266	30.2	231	49.0
IV	1,984	32.6	181	20.5	176	37.4
V	432	7.2	61	6.9	30	6.4
VI	185	3.2	31	3.5	11	2.3
VII	41	0.7	9	1.0	2	0.4
VIII	23	0.4	2	0.2		
IX	19	0.6				

Catch curve plots as described in the Methods section (g) are shown in Fig. 7. Total mortality rates are $Z = 1.0$ for beach seines and $Z = 1.4$ for the simultaneous gill net samples. This is as expected because the old type gill nets were found to be selective and should overestimate Z. The value of $Z = 1.2$ for recent data reflects the lower selectivity of the modern gill nets but still may be a slight overestimate because of remaining selectivity.

The previous estimation of mortality for 1981-1985 assumes constant growth and mortality because the old age-length key was applied. To avoid the assumption of constant mortality, a length-converted catch curve analysis was done on data for 1971-1973 and 1981-1985 using Sturm's estimates of growth parameters. Plots of (x,y) (Table 12) are shown in Fig. 8 and results in mortality estimates of 0.61 (beach seine 1971-1972), 1.3 (gill nets 1971-1973) and 0.90 (all gears 1981-1985, no correction for selection).

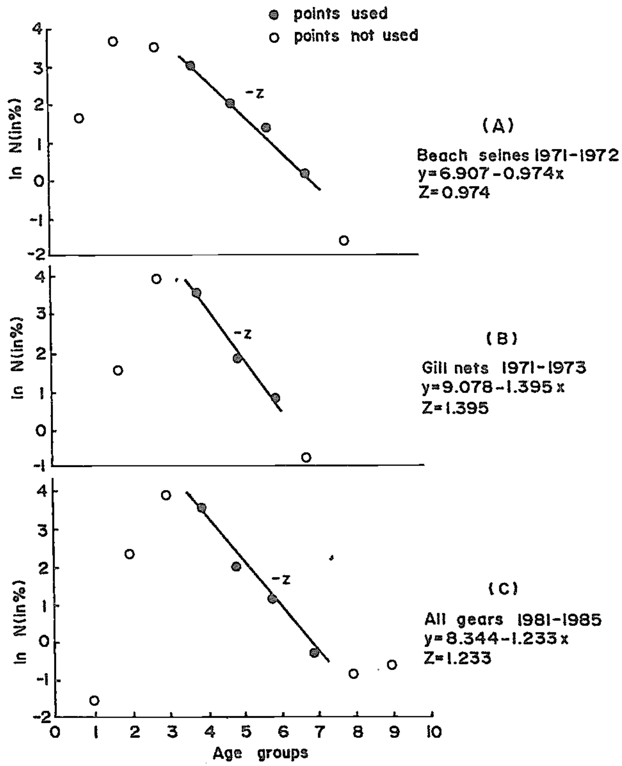

Fig. 7. Plots of ln % at age of *Scomberomorus brasiliensis* for beach seines (B) and gill nets (G) in 1971-1973 and for all gear (mostly gill nets) in 1981-1985. Open dots were omitted from regression analyses.

Table 12. Length-converted catch curve analysis with

$$x = t\,\frac{(L_1 + L_2)}{2} \quad \text{and } y = \ln \frac{C}{\Delta t} \quad \text{for } L_\infty = 73.0 \text{ cm and } K = 0.29/\text{year}.$$

Length range (cm)	x	Beach seine (1971-1972) freq.	y	Gill net (1971-1973) freq.	y	All gears (1981-1985) freq.	y
13.1 – 16.0	0.77	1	1.77				
16.1 – 19.0	0.95	2	2.41				
19.1 – 22.0	1.14	6	3.45				
22.1 – 25.0	1.34	15	4.31				
25.1 – 28.0	1.56	23	4.67			5	3.14
28.1 – 31.0	1.79	28	5.11			7	3.41
31.1 – 34.0	2.04	57	5.44			19	4.34
34.1 – 37.0	2.30	111	6.03			67	5.52
37.1 – 40.0	2.59	182	6.44	5	2.85	282	6.88
40.1 – 43.0	2.90	119	5.92	29	4.51	577	7.50
43.1 – 46.0	3.25	71	5.31	79	5.41	855	7.80
46.1 – 49.0	3.63	86	5.39	133	5.82	1,219	8.04
49.1 – 52.0	4.07	65	4.98	131	5.68	1,236	7.93
52.1 – 55.0	4.56	84	5.09	112	5.38	884	7.45
55.1 – 58.0	5.14	81	4.89	49	4.39	529	6.77
58.1 – 61.0	5.83	34	3.82	24	3.47	248	5.81
61.1 – 64.0	6.70	27	3.33	10	2.34	141	4.99
64.1 – 67.0	7.87	24	2.87	3	0.79	93	4.23
67.1 – 70.0	9.65	13	1.72	2	–0.15	45	2.96
70.1 – 73.0	13.51	2				24	
73.1 – 76.0		2				9	
76.1 – 79.0		1				15	
79.1 – 82.0						4	

Another estimate of $Z = 1.2$ from the 1981-1985 data was given in the section on Gill Net Selectivity using the Wetherall method. Table 13 and Fig. 9 describe a similar analysis of the 1971-1973 data.

Results of this analysis were: $L_\infty = 75.6$ cm and $Z/K = 2.4$ for beach seines, and $L_\infty = 79.2$ cm and $Z/K = 5.8$ for gill nets. $L_\infty = 100.2$ cm and $Z/K = 7.87$ were calculated from the 1981-1985 data in the Gill Net Selectivity section.

Values for L_∞ are almost the same, while Z/K values are very different. Unfortunately, separation of Z and K can only be based on the parameter $\phi' = 3.22$ (Table 3), which will give K values of 0.29/year (beach seines), 0.26/year (gill nets) and 0.17/year (1981-1985) which are relative to L_∞ estimates. The Z related estimates of 0.70 (beach seines), 1.5 (gill nets) and 1.3 (1981-1985) are similar to those obtained from catch curves (Figs. 8 and 9).

Table 13. Wetherall analysis of previous data set.

Lower limit L' (x)	Midlength Lm	Beach seine (1971-1972) N	ΣN	$\bar{L}$	Gill net (1971-1973) N	ΣN	$\bar{L}$
13.0	14.5	1	1,044	44.2			
16.0	17.5	2	1,043	44.2			
19.0	20.5	6	1,041	44.3			
22.0	23.5	15	1,035	44.4			
25.0	26.5	23	1,020	44.7			
28.0	29.5	38	997	45.1			
31.0	32.5	57	959	45.8			
34.0	35.5	111	902	46.6			
37.0	38.5	182	791	48.1	5	577	50.2
40.0	41.5	119	609	51.0	29	572	50.3
43.0	44.5	71	490	53.3	79	543	50.8
46.0	47.5	86	419	54.8	133	464	51.9
49.0	50.5	65	333	56.7	131	331	53.7
52.0	53.5	84	268	58.3	112	200	55.7
55.0	56.5	81	184	60.4	49	88	58.6
58.0	59.5	34	103	63.5	24	39	61.2
61.0	62.5	27	69	65.5	10	15	63.9
64.0	65.5	24	42	67.4	3	5	66.7
67.0	68.5	13	18	70.0	2	2	68.5
70.0	71.5	2	5	73.9			
73.0	74.5	2	3	75.5			
76.0	77.5	1	1	77.5			

Conclusion

The shape of the growth curve estimated by Sturm (1978) and based on readings of annual rings in otoliths was confirmed for age groups one to four by analysis of length-frequency distributions from the same period. Estimates of L_∞ and K obtained by various methods of length-frequency analysis in some cases indicated a higher growth rate of old fish which are poorly represented in the samples available here.

Mortality estimates are somewhat ambiguous. Beach seine estimates for 1971-1972 (probably the more reliable) range from $Z = 0.7$ to $Z = 1.0$. Recent estimates (1981-1985), perhaps slightly biased upwards by mesh selection, range from $Z = 0.9$ to $Z = 1.2$. The increase in fishing mortality, if any, is therefore moderate.

There are indications that gill net catches from 1971 to 1973 are heavily biased by mesh selection of the normal curve type found by Trent et al. (1983) for a similar species. Gill nets in use in 1981-1985 seem notably less selective in the upper ranges of fish size, if selective at all.

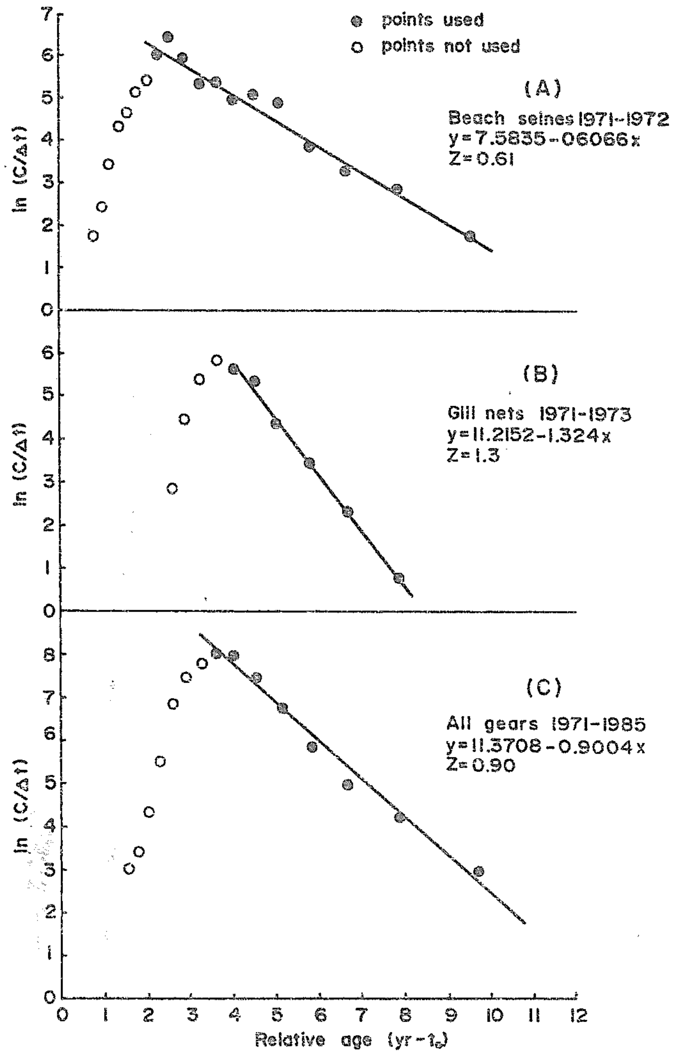

Fig. 8. Length-converted catch curves of *Scomberomorus brasiliensis* for (A) beach seines 1971-1972, (B) gill nets 1971-1973 and (C) all gears, 1981-1985.

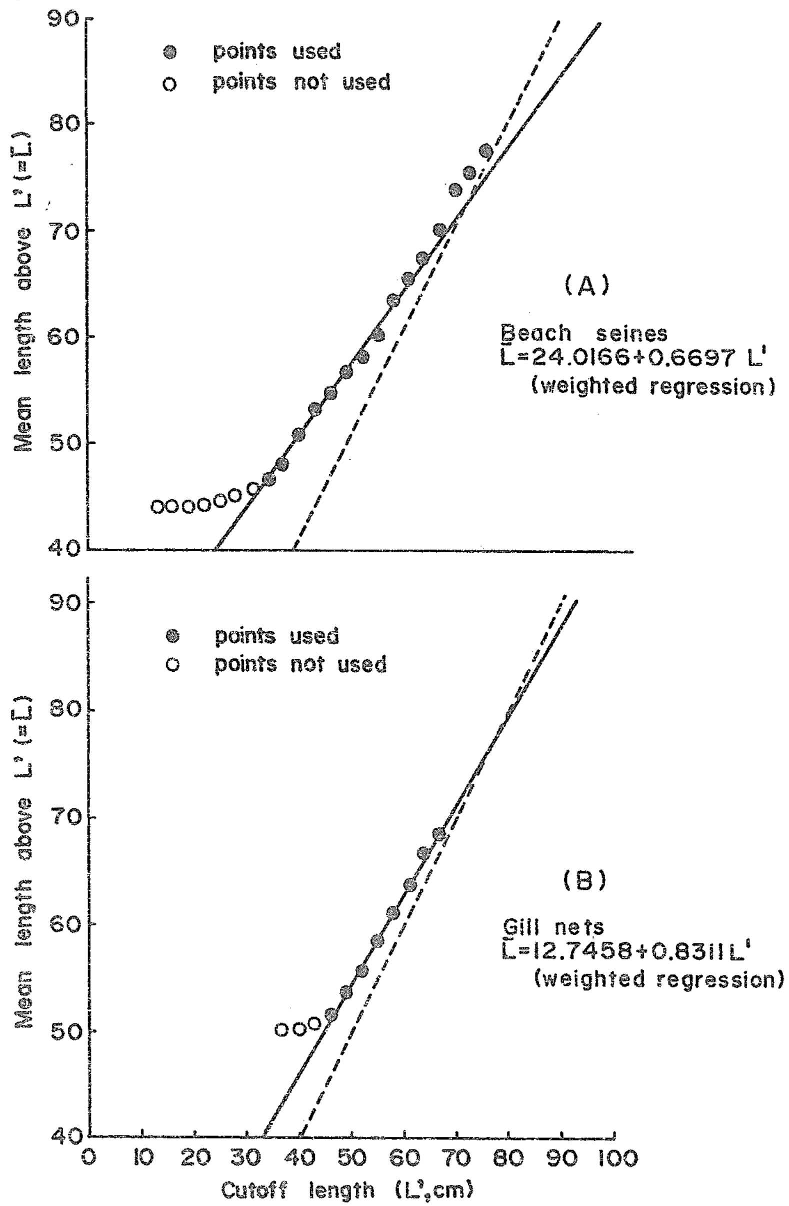

Fig. 9. Wetherall plots for *Scomberomorus brasiliensis*. (A) beach seine data, 1971-1972 and (B) gill net data, 1971 to 1973.

Acknowledgements

The author thanks the Institute of Marine Affairs, Dr. Sturm and Ms. Maingot for their assistance.

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An Assessment of King Mackerel (*Scomberomorus commerson*) in the Inner Gulf of Thailand

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Abstract

The growth parameters (L_∞ and K) and mortality of *Scomberomorus commerson* are estimated based on length-frequency data from trawl and drift gill net fisheries in the inner part of the Gulf of Thailand during 1974-1977. L_∞ is around 110 cm, while K was found to be 0.1 per year which is probably an underestimate. Cohort analysis and yield-per-recruit analysis based on these estimates are presented to evaluate the state of stock. F-at-length is found varying with length suggesting that *S. commerson* can escape the trawl fishery when they reach about 35 cm.

Introduction

Three species of king mackerel are found in the inner part of the Gulf of Thailand: *Scomberomorus commerson, S. guttatus* and *S. lineolatus*. The most abundant among them in Thailand, known as "Pla in See Bang", is the narrow-barred Spanish mackerel (*S. commerson*, Lacépède, 1801). It occurs from shallow water to depths over 40 m and is more abundant around the islands. *S. commerson* is mainly caught with pair trawls and drift gill nets. The pair trawls with a cod-end of 16 mm mesh size, are used in coastal waters. The drift gill net fisheries use nets of 2 to 8 km long and 20 m deep with a mesh size of 10 cm. This fishery extends into the deeper parts at depths over 20 m. *S. commerson* is also caught by other gears, but these catches are of minor significance. Both the pair trawl fishery and the drift gill net fishery are multispecies fisheries, which are not directed specifically to king mackerel.

King mackerels are economically important as most of the production is exported to Malaysia, Singapore and Hongkong; therefore information on population dynamics and biology of these species is required for management purposes.

Length-weight relationships of *S. commerson* are given by Chullasorn et al. (1974). Ingles and Pauly (1984) estimated growth parameters of *S. commerson* taken from Philippine trawl fisheries. Other information on *Scomberomorus* is mainly restricted to the Caribbean (Julien-Flüs, this vol.; Trent et al. 1983; Johnson et al. 1983) and southern India (Devaraj 1983).

The present study utilizes data from gill net and pair trawl fisheries in the Gulf of Thailand for 1974-1977 to determine growth parameters and mortalities. Based on these data an assessment of the stock of *S. commerson* in the inner Gulf of Thailand is presented.

Materials and Methods

Monthly field surveys were made in landing locations along the west coast of the Gulf of Thailand from Petchaburi to Surat Thani province (Fig. 1). The four largest landing places were

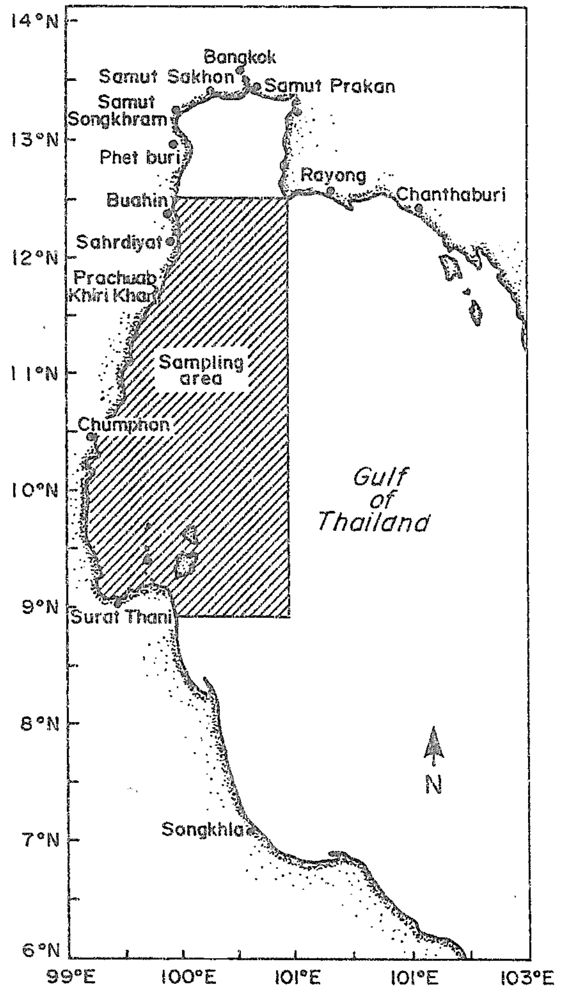

Fig. 1. Map showing the location of *S. commerson* sampling sites.

visited on each trip. Sampling was done during eight days each month at a sampling intensity on these days of three out of each ten landings. The lengths of *S. commerson* were punched on cards from which later length frequencies grouped by 2 cm classes were obtained. In 1976 both the gill net and the pair trawl fisheries were sampled, while in 1974, 1975 and 1977 only the drift gill net fishery was investigated. Table 1 shows the available length compositions by month and type of fishery, but aggregated over the landing places. Monthly total catches by fishery for 1974-1977 were calculated based on catch/boat/day-absent-from-port, Such data were recorded during the sampling. Interviews with fishermen gave an estimate of the number of boat-days which had been realized at each landing place. This was raised to total monthly landings (Supongpan and Sommai, pers. comm.). These monthly catches are given in Table 2.

An estimate of the asymptotic length, i.e., L_∞ in the von Bertalanffy growth function (VBGF) was obtained from the modified Wetherall method (Pauly 1986). This analysis was applied to the raised average 1975-1976 length frequencies from the gill net fishery only (ranging from 60 to 100 cm). An alternative estimate of L_∞ was obtained based on deconvoluted length compositions from the gill net fishery, corrected for selectivity, into normal components using the Bhattacharya method.

K in the VBGF is obtained from the trawl data. The rationale behind this approach is that the trawlers exploit the size range 15-60 cm, while gill netters exploit the range 40-100 cm. Therefore gill net length frequencies can be used to obtain an estimate of L_∞ , while the trawl data provide an estimate of K.

Stock sizes and fishing mortalities were estimated using Jones' length cohort analysis (Jones 1981).

Table 1a. Length compositions of king mackerel (*Scomberomorus commerson*) in the inner part of the Gulf of Thailand, obtained **from drift gill nets (1974-1977).**

MID-LENGTH (cm)	YEAR:1974 MONTH FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	
40					7		3				
42					3		10				
44					4	1	8			2	
46	5				8	7	17	1		6	
48	30	1		1	10	4	19	14	1	24	
50	58	6	1	3	11	7	7	49	3	40	
52	90	14	7	4	11	6	10	86	6	44	
54	131	30	22	7	21	4	9	71	5	33	
56	147	51	55	14	14	4	23	50	14	54	
58	95	65	63	83	10	11	40	48	33	65	
60	85	61	74	142	13	14	81	17	56	51	
62	111	72	66	261	3	46	72	15	49	40	
64	102	66	77	220	7	60	47	10	59	28	
66	113	81	62	102	8	44	26	39	33	17	
68	94	56	52	57	3	21	13	37	22	16	
70	83	42	47	21	2	11	10	44	16	13	
72	63	40	39	16	4	8	13	25	27	10	
74	76	17	36	14	15	8	7	14	22	5	
76	49	12	32	20	7	2	3	9	21	3	
78	28	11	18	12	5	1	4	1	11	1	
80	16	2	9	6	6		7	2	2		
82	14		3	3	7		7	1	1		
84	7		1	2	3		3		1		
86	3				3		3				
88							2				
90							1				
92											
94											
96											
98											
SUM	1400	627	662	988	185	259	445	533	382	452	511

Table 1a (cont.)

MID-LENGTH (cm)	YEAR:1975 MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
40						2	3			2		
42						5	6		3	4		
44						7	14	3	3	14	2	1
46	1	3	1		1	4	22	9	4	35	16	10
48	13	5	1		2	4	44	5	10	53	44	23
50	28	4	2	1	3	7	68	5	11	37	62	46
52	31	5	7	2	2	7	56	5	16	38	64	60
54	22	9	13	3	8	9	21	9	8	32	71	86
56	20	6	28	15	26	6	1	19	9	49	114	76
58	36	13	43	36	111	26	5	27	20	32	137	37
60	31	14	65	35	196	75	22	23	24	17	97	29
62	41	27	74	41	203	62	40	13	18	23	74	51
64	54	48	76	35	146	71	98	15	18	25	84	44
66	44	63	79	25	108	34	95	21	27	17	75	41
68	34	48	95	38	74	19	97	19	25	25	78	38
70	40	76	98	22	72	15	79	15	28	31	38	22
72	35	84	87	27	95	16	79	14	28	28	27	27
74	35	79	91	37	77	12	79	5	19	10	28	17
76	19	67	65	15	57	11	85	11	10	19	9	20
78	11	44	50	10	27	9	58	13	5	11	1	10
80	5	34	28	7	15	11	36	7	11	12		9
82	8	16	23	6	8	8	20	4	2	5		7
84	2	11	9	2	3	10	10	3	1	2		6
86	1	6	4			5	2	1				1
88		3	4			7	2					
90		1	2			8	3					
92			1			4	1					
94						2						
96						1						
98												
SUM	511	666	946	357	1234	457	1046	246	300	521	1021	661

Table 1a (cont.)

MID-LENGTH (cm)	YEAR:1976 MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
40									1			
42	4						1	2	5	3		3
44	10						2	15	8	3		7
46	3				1		13	41	20	12	6	19
48	2			2	4		46	59	40	25	5	49
50	7	1		2	2		73	127	96	47	9	99
52	25	3	1	1	3	2	83	144	69	76	13	134
54	67	20	7	6	3	2	29	180	76	80	33	227
56	169	27	25	21	8	3	51	94	64	46	58	443
58	179	71	128	127	41	7	100	31	89	42	61	422
60	102	47	251	279	186	16	129	15	61	57	44	263
62	86	43	306	471	371	33	271	23	22	67	30	175
64	130	50	233	378	453	60	489	45	22	102	55	146
66	99	28	177	276	318	41	610	54	45	87	57	170
68	73	34	148	124	138	24	546	72	55	54	57	106
70	75	39	91	77	59	18	320	71	42	36	25	57
72	61	27	81	56	37	9	204	49	18	24	16	24
74	60	34	81	52	19	7	139	22	14	19	22	26
75	41	21	38	41	36	6	78	14	4	7	4	32
78	31	9	31	52	20	4	63	11	6	8	10	17
80	18	12	16	31	14	5	56	5	3	3	2	11
82	19	2	14	10	9	5	39	6	1	2	1	6
84	8	2	2	8	3	4	23	1	2	1	2	2
86	5	3	3	1		1	5	1			1	1
88	2	1	1				6	2				
90	3	1	1				3					
92												
94												
96												
98												
SUM	1279	475	1636	2015	1725	247	3376	1084	763	801	511	2439

Table 1a (cont.)

MID-LENGTH (cm)	YEAR:1977 MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
40			1	1			1		
42			2	1	2	1	12		
44			2	3	6	4	15	12	
46	1		2	20	6	3	12	33	4
48	3		2	16	23	7	18	28	13
50	4	3	3	9	41	13	30	14	21
52	41	7	8	8	57	28	69	19	40
54	38	9	21	6	43	29	90	15	26
56	65	14	34	32	12	43	85	38	17
58	167	35	77	108	15	15	56	41	5
60	224	85	167	317	51	21	49	46	21
62	239	114	313	532	100	42	55	72	26
64	201	106	290	678	166	103	131	95	29
66	182	123	208	623	200	141	187	137	26
68	220	104	160	397	155	127	230	181	43
70	178	86	116	253	100	80	184	211	43
72	119	79	81	181	80	57	164	157	43
74	99	62	75	140	63	54	134	146	30
76	72	39	52	115	77	44	127	130	22
78	60	42	62	120	75	74	89	107	22
80	44	21	30	85	66	52	67	89	6
82	29	13	22	52	36	23	55	64	8
84	12	4	10	24	16	18	32	46	3
86	6	6	3	9	4	2	20	29	5
88	7	3	2	2		3	3	16	1
90	1	1		2		2	2	5	1
92		2		2			1	2	
94								2	
96								1	
98								1	
SUM	2012	958	1743	3737	1394	986	1918	1737	455

Table 1b. Length composition of king mackerel (*Scomberomorus commerson*) in the inner part of the Gulf of Thailand, obtained from pair trawls (1976).

MID-LENGTH (cm)	1976 MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
10						1						
12					5	5						
14		1			71	19		44				
16		7			330	37		62				
18		9	8		207	144	11	53	6	6		
20		2	7	8	54	374	43	8	59	57	4	
22		2	50	23	27	155	141	7	117	33	11	
24			73	22	40	53	99	7	148	21	22	
26			30	63	43	224	24	2	127	7	40	
28			12	74	43	294	22	16	92	3	24	
30	5		4	34	33	147	43	54	27	5	15	1
32	1		0	4	45	49.	46	51	5	30	3	2
34	0		1	1	49	32	28	21	11	32	6	11
36	0		1	0	45	32	30	10	20	18	10	25
38	3		10	1	27	29	24	9	44	12	13	21
40	8		4	2	9	24	4	5	62	12	14	22
42	13		6	8	0	8	4	2	46	7	1	13
44	10		1	2	0	9	0	2	14	7	0	17
46	9		7	3	1	2	1	0	5	5	1	1
48	7		15		1		2	1	10	7	1	12
50	4		9				2		14	3		9
52	0		6				1		16	1		4
54	0		1						4			3
56	3								1			6
58	1											2
60												1
SUM	64	21	245	245	1030	1638	525	354	828	266	165	175

Source : Sampling survey data.

Table 2. Monthly landings by gear type of king mackerel (*Scomberomorus commerson*) in the inner part of the Gulf of Thailand, 1974-1977 (in tonnes).

GEAR MO./YEAR	DRIFT GILL NET 1974	1975	1976	1977	TRAWL 1976
JAN	-	246	144	241	102
FEB	48	231	138	201	89
MAR	41	153	120	160	80
APR	46	157	98	158	92
MAY	37	136	132	152	89
JUN	37	126	109	143	91
JUL	34	102	61	129	90
AUG	35	147	91	144	172
SEP	37	168	129	160	132
OCT	42	181	148	-	135
NOV	49	292	142	-	110
DEC	-	297	196	-	119

Source: Sampling survey data.

Results

Estimation of L_∞

Gill nets usually show a bell shaped selection ogive (Hamley 1975). Trent et al. (1983) give a selection ogive for gill nets with a 12.1 cm (5 inch) mesh referring to king mackerel (*S. cavalla*). It is assumed that this selection ogive is also applicable to *S. commerson*. Based on their data a transformation of their selection ogive from 12.1 to 10 cm mesh was done by moving the entire ogive from a top point of 92.5 to 76.4 cm (= 92.5 x 10/12.1), leaving the width of the ogive unchanged. Subsequently the length frequencies from the catches were raised to the stock by correcting for selection from the transformed ogive. The raising factors used are given in Table 3. These raised compositions were then separated into normal distributions with the Bhattacharya method. The mean lengths thus obtained and their assignments are given in Table 4. As could be expected, identification of peaks near L_∞ is not possible, which leads to a somewhat uncertain estimate of L_∞ .

A Ford-Walford plot applied to these data gave L_∞ = 130 cm (Fig. 2). The Wetherall plot for the 1975-1976 average situation for the gill net fishery is shown in Fig. 3. The 1974 data only cover February-November and the 1977 data only 9 months (January-September). These two years were therefore not included in the average length composition. Prior to pooling, the annual length compositions were converted into percentages in order to reduce the influence of effort variability between years.

Table 3. Raising factor for length composition of *Scomberomorus commerson* caught by gill nets in the inner Gulf of Thailand.

MID-LENGTH (cm)	RAISING FACTOR	MID-LENGTH (cm)	RAISING FACTOR
40	0.0002	70	0.7731
42	0.0006	72	0.8856
44	0.0014	74	0.9645
46	0.0030	76	0.9990
48	0.0063	78	0.9840
50	0.0125	80	0.9218
52	0.0237	82	0.8211
54	0.0427	84	0.6956
56	0.0732	86	0.5604
58	0.1191	90	0.4293
60	0.1845	92	0.3128
62	0.2717	94	0.2167
64	0.3805	96	0.1428
66	0.5068	98	0.0894
68	0.6418	100	0.0533

Table 4. Mean lengths by month, identified by splitting length frequencies (corrected for selection of *Scomberomorus commerson* from drift gill net samples into normal components using the Bhattacharya method.

MONTH	$\overline{L}$(m)
JAN	51.25
FEB	54.74
MAR	57.09
APR	58.86
MAY	61.09
JUN	62.62
JUL	65.00
AUG	67.45
SEP	69.43
OCT	70.99
NOV	73.74

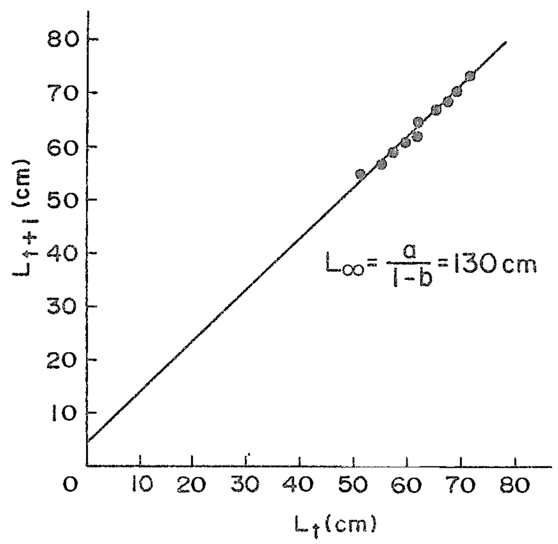

Fig. 2. Ford-Walford plot of mean length corresponding to Bhattacharya method for *Scomberomorus commerson*, Gulf of Thailand.

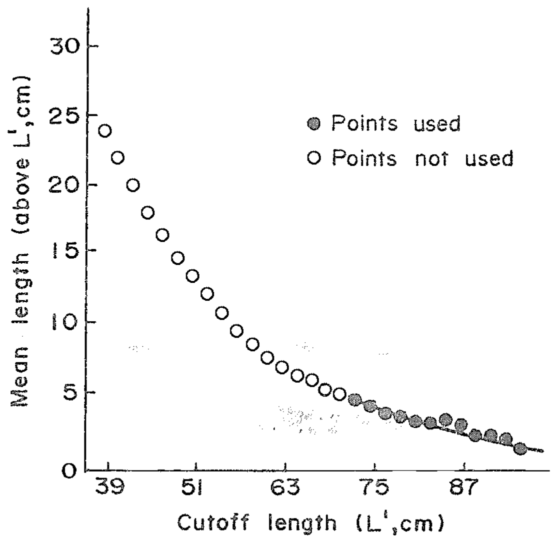

Fig. 3. Wetherall plot for *Scomberomorus commerson* to estimate L_∞.

The selection of points is of course rather arbitrary and L_∞ estimates between 95 and 115 cm can be obtained with reasonable choices of points. The particular set shown on Fig. 3 gives L_∞ = 101 cm. The Z/K value obtained from the Wetherall plot is not reliable, because of the decrease in fishing efficiency with increasing size, for lengths above approximately 76 cm.

The estimate obtained from the Bhattacharya analysis L_∞ = 130 cm is well above that obtained using the Wetherall plot. The length distributions (Table 1) show no fish above 100 cm, but the selection properties of the gill net (see above) are such that fish above 100 cm are fished with low efficiency. The FAO identification sheet for *S. commerson* gives a maximum size of 220 cm (Collette 1984). The problem cannot be resolved at this stage. The subsequent analyses are based on a compromise value of L_∞ = 110 cm.

Estimation of K

The length frequencies obtained from pair trawl landing are probably not influenced by mesh selectivity. Species similar to king mackerel show selection factors between 2.5 and 3 (data from the Marine Fisheries Division Bangkok, Thailand and Meemeskul 1979). The mesh size used in the pair trawl fishery is around 2 cm (Meemeskul, this vol.) but it is variable and interviews with the fishermen have indicated that mesh sizes of 1.6 cm are actually more common. Using the upper range of both values then L_{50} = 3 x 2 cm = 6 cm, which suggests that mesh selection is of no importance, since king mackerel of sizes below 10 cm do not occur, neither in the trash fish (Meemeskul, pers. comm.) nor in the samples used here. The apparent gradual appearance in the catches of the sizes ranging from 10 to 20 cm is assumed to reflect migration into the fishing grounds from nursery areas, where no fishing for pelagics with small meshed gears takes place. The gradual disappearance of the larger sizes of king mackerel from the trawl catches probably reflects an increasing ability to avoid the trawls and/or a migration to offshore waters. All these processes will affect the parameter estimations. Recruitment could well be size dependent and therefore lead to an overestimate of the mean lengths of the various cohorts, while the decreasing ability of the trawl to catch the largest specimens underestimates the mean lengths. The analysis was therefore restricted to the 15-35 cm size range. This range was chosen in an attempt to have an interval where full recruitment has occurred for smaller sizes and the decrease in gear efficiency has not really become a problem.

Results of a Bhattacharya analysis on the monthly length compositions from the trawl data and the assignment of peaks with cohorts are given in Table 5. These points (L) are then transformed by $\ln(1 - L/L_\infty)$ with L_∞ = 110 cm (see above) and plotted against a relative age (Fig. 4). The slope, which is equal to K, was found to be 0.1 $year^{-1}$.

Table 5. Mean lengths by months, identified by splitting length frequencies of *Scomberomorus commerson* from trawl samples (1976) into normal components (Bhattacharya) and applied to a von Bertalanffy plot, with L_∞ = 110 cm.

MONTH: 1976 :	Length (cm)	$-\ln(1-L/L_\infty)$	relative age(mo)	Length (cm)	$-\ln(1-L/L_\infty)$	relative age(mo)
JAN				-	-	9
FEB				(18.3)[b]	(0.1620)[b]	10
MAR				25.7	0.2661	11
APR				28.1	0.2950	12
MAY[a]	17.9	0.1776	1	27.2	0.2841	13
JUN	20.9	0.2107	2	29.3	0.3097	14
JUL	23.7	0.2427	3	31.8	0.3412	15
AUG	-	-	4	32.1	0.3451	16
SEP	25.7	0.2661	5			
OCT	23.1	0.2357	6			
NOV	26.8	0.2792	7			
DEC	-	-	8			

a) Chosen as starting month of relative age in months.

b) Not used in the von Bertalanffy plot.

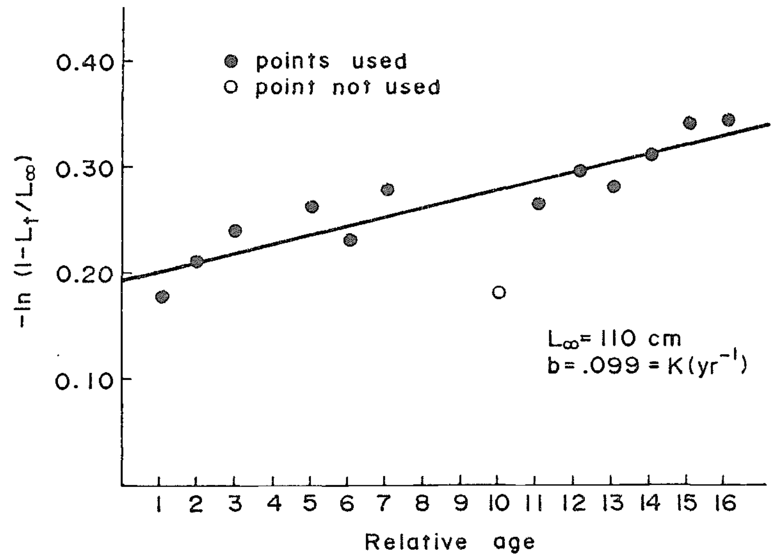

Fig. 4. Von Bertalanffy plot corresponding to Bhattacharya deconvolution of trawl length frequencies 1976 presented in Table 5.

Cohort Analysis

Length-based cohort analysis (Jones 1981) accepts fishing mortality as a function of length; the usual assumptions are: a) constant natural mortality, i.e., M is independent of time and length, b) the growth parameters K and L_∞ are known, c) the variability of length for a given cohort at a given time is small, d) fishing mortality for the largest size groups must be known and e) the data should represent an average situation. Most of these assumptions are shown, in the subsequent paragraphs, not to have been strictly met.

The monthly length compositions were raised to total monthly catch by gear and added to give the total annual length composition for the period 1974-1977.

Natural mortality M is not known. Pauly (1980) presented a formula which links M, K, L_∞ and the ambient temperature of the sea. This formula, with K = 0.1 year, L_∞ = 110 cm and T = 28°C, suggests an M value around 0.27. This value was adopted for the cohort analysis.

The fishing mortality for the largest king mackerel was assumed to be small since the selection ogive (Table 3) indicates that the gill nets are not efficient for sizes much above 90 cm, therefore a terminal F = 0.25 was adopted.

Based on these assumptions a cohort analysis was made. The results are presented in Fig. 4, which shows F as a function of length. The two fisheries give each rise to a peak in the F values, as should be expected.

Yield-per-Recruit Analysis

A yield-per-recruit calculation procedure for cases where fishing mortality varies with length is presented by Supongpan (this vol.). The basis for the calculations presented on Fig. 6 are the input parameters and the resulting F-at-length from the cohort analysis. The length-weight relationship (Chullasorn et al. 1974) is

$$W = 0.01302\, L^{2.884} \quad \text{(W in g; L in cm)}$$

Two yield-per-recruit curves are shown in Fig. 6. The first, labeled A, demonstrates the effects of changing the effort in such a way that the ratio of F's between the gill net and the trawl fishery is maintained. This curve is based on the F-at-length array presented in Fig. 6 and represents the 1974-1977 situation. The second, labelled B, represents the gill net fishery, in the hypothetical situation that the pair trawl fishery were banned. This situation is simulated by setting F = 0 for all lengths below 40 cm.

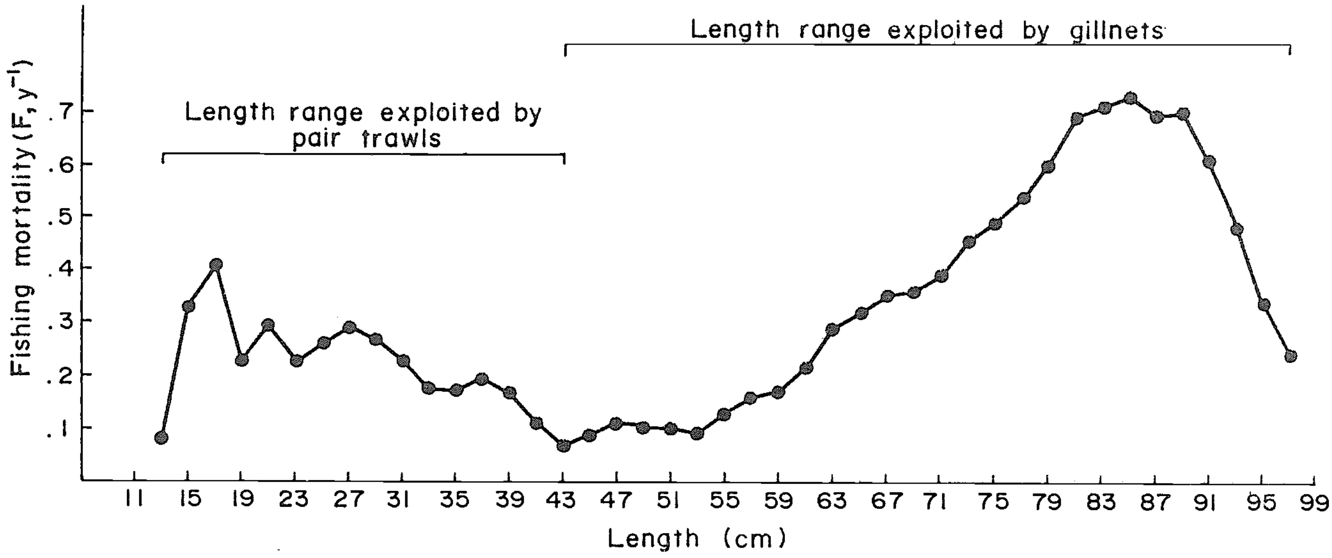

Fig. 5. F at length for *Scomberomorus commerson* from cohort analysis, Gulf of Thailand.

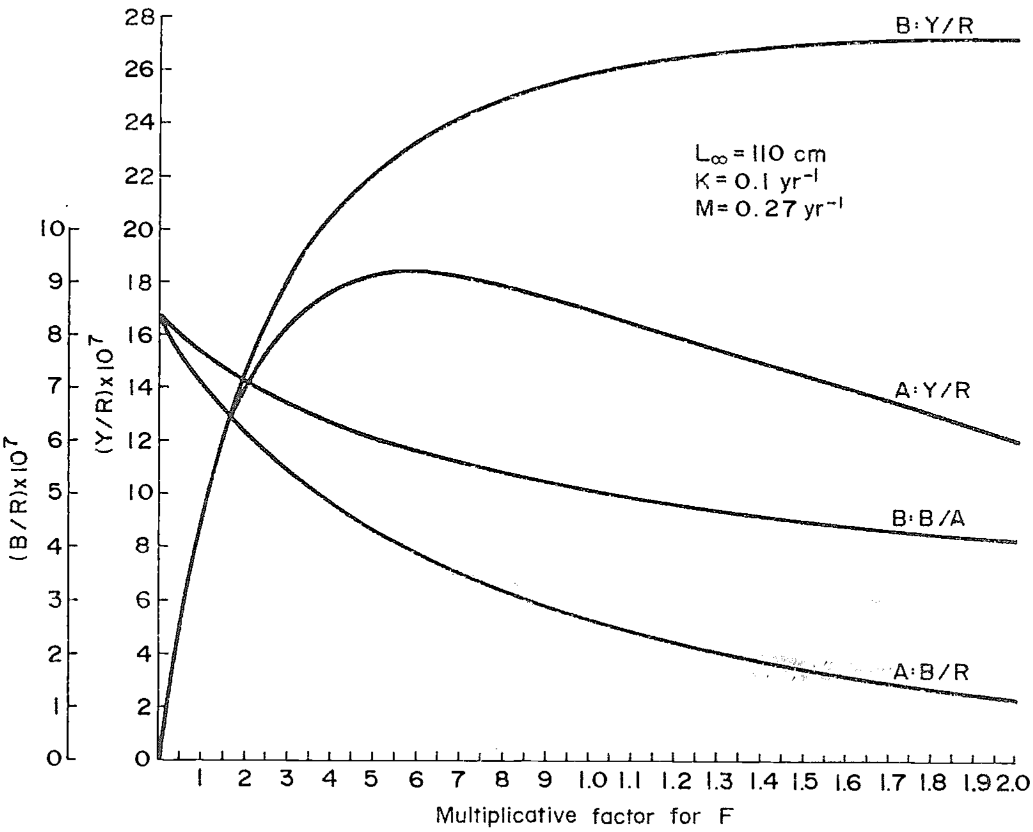

Fig. 6. Beverton and Holt's relative Y/R curves for *Scomberomorus commerson*, Gulf of Thailand, 1974-1976.

Discussion

King mackerels have been studied elsewhere. Table 6 summarizes growth parameters for large *Scomberomorus* species. The L_∞ = 49 cm and the corresponding K = 0.7 year^{-1} from the Philippine waters is out of line with the other estimates and is probably a misinterpretation of data from a fishery where only trawl catch data were available. The L_∞ estimates of 100-130 cm obtained above seems within the range of the other estimates. The most recent FAO identification sheet for *S. commerson* for the western Indian Ocean, however, gives a maximum length of 220 cm (Collette 1984), very much above the maximum observed in this study.

The K value obtained here of 0.1 year^{-1} seems low compared to other estimates. Comparison using $\phi' = 2 \log_{10}L_\infty + \log_{10}K$ (Pauly 1984 and Munro 1984) suggest a value of 0.18 year^{-1}. However, there is no K value available for *S. commerson,* but only analogies to other king mackerels in the Caribbean and Gulf of Mexico, as presented in Table 6 and in Julien-Flüs (this vol.).

The cohort analysis demonstrated the relative importance of the effect of the pair trawl fishery on the gill net fishery. This is brought out clearly by the hypothetical calculation of a yield-per-recruit curve based on the assumption that no pair trawling is taking place (Fig. 6, Curve B). The CPUE in the gill net fishery would then increase and the MSY would be realized for much higher efforts in the gill net fishery than seen today. With the given exploitation pattern (F-at-length as presented in Fig. 5), however, the level of effort around 1976, the period to which the estimated mortalities refers, was close to MSY level.

Table 6. Von Bertalanffy growth curve parameters and Ø' for various *Scomberomorus* species[a].

SPECIES	SEX	STUDY AREA	L_∞ cm	K per year	Ø'	SOURCE
S. commerson	both,	Philippines	49.0	0.70	3.23	Ingles and Pauly (1984)
"	both,	Gulf of Thailand	**110.0**	0.10	**3.08**	This study
S. brasiliensis	both,	Trinidad	93.8	0.18	3.19	Julien-Flüs (this vol.)
"	male,	Brazil	83.0	0.20	3.14	Nomura (1967)[b]
"	female,	"	94.4	0.20	3.25	"
"	male,	Trinidad	71.0	0.26	3.12	Sturm (1978)[b]
"	female,	"	83.0	0.23	3.20	"
S. maculatus	male,	Florida	61.2	0.37	3.15	Klima (1959)[b]
"	female,	"	76.7	0.36	3.32	"
S. cavalla	male,	N.E. Brazil	116.0	0.18	3.38	Johnson et al. (1983)
"	female,	"	137.0	0.15	3.45	"
S. spp.[c]	male,	S.E. USA exclud.	96.5	0.28	3.42	Johnson et al. (1983)
"	female,	Louisiana	106.7	0.29	3.52	"
"	male,	Louisiana	152.9	0.14	3.52	"
"	male,	Florida	90.3	0.35	3.46	"
"	female,	"	124.3	0.21	3.51	"

a) Ø' values according to Pauly and Munro (1984) on $\log_{10}$ basis. See also Julien-Flüs (this vol.) Table 3.

b) Reference in Julien-Flüs (this vol.)

c) Probably *Scomberomorus maculatus* (see Julien-Flüs, this vol.).

Since the mid-1970s, effort in the pair trawl fisheries has increased, both due to an increase in the number of vessels from about 900 to 1,300 boats and to an increase of the average engine power (Thai Fishing Vessel Statistics 1971 to 1983). The gill net effort has also increased from about 150 nets in the mid-1970s to 234 registered in 1983. The efficiency of this gear has, however, not changed or, if anything, rather decreased since small tuna have become more important to the fishermen than before, which has caused some changes in fishing grounds. The yield per recruit which applies to the fishery in the mid-1980s is therefore relatively more influenced by the pair trawl fishing mortality than the F-at-length values presented in Fig. 5. In addition, the overall level of effort has probably increased, thus suggesting growth overfishing of king mackerel today.

Acknowledgements

The author thanks Mr. Vanich Vareekul, Director General of Fisheries and Mr. Boonlert Phasuk, Director of the Marine Fisheries Division for allowing her to attend the FAO/DANIDA Follow-up Training Course on Fish Stock Assessment in the Tropics, and Mr. Sakul Supongpan for supplying the monthly catch data.

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Discriminant Analysis of Morphometrics of Indian Mackerel *(Rastrelliger kanagurta)* in the Malacca Strait and Scad *(Decapterus russelli)* in the Java Sea, Indonesia*

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Abstract

Morphometric measurements of Indian mackerel *(Rastrelliger kanagurta)* and scad *(Decapterus russelli)* in Indonesian waters were analyzed using the linear discriminant method in order to identify existence of homogeneous subpopulations of these fish. *R. kanagurta* was found to form two distinct groupings in the northwestern Malacca Strait, while *D. russelli* groupings changed gradually from the southwestern to the northwestern Java Sea.

Introduction

Morphometric measurements of small pelagic fishes have been collected for several years in Southeast Asia for purposes of stock identification. In this contribution, we analyze measurements on Indian mackerel (*Rastrelliger kanagurta,* Fam.: Scombridae) collected in the frame of a research project under the Bay of Bengal Programme (Tampubolon, this vol.) and on Russell's scad (*Decapterus russelli,* Fam.: Carangidae), collected in the frame of an Indonesian national research activity (Widodo, this vol.).

*ICLARM Contribution No. 438.

Materials and Methods

Study 1. Morphometric measurements of *R. kanagurta* of two sources in Indonesia - Banda Aceh and Asahan, Sumatra (Fig. 1) were obtained during the period of May to September 1986 with 201 and 206 specimens, respectively. The morphometric data are shown in Table 1.

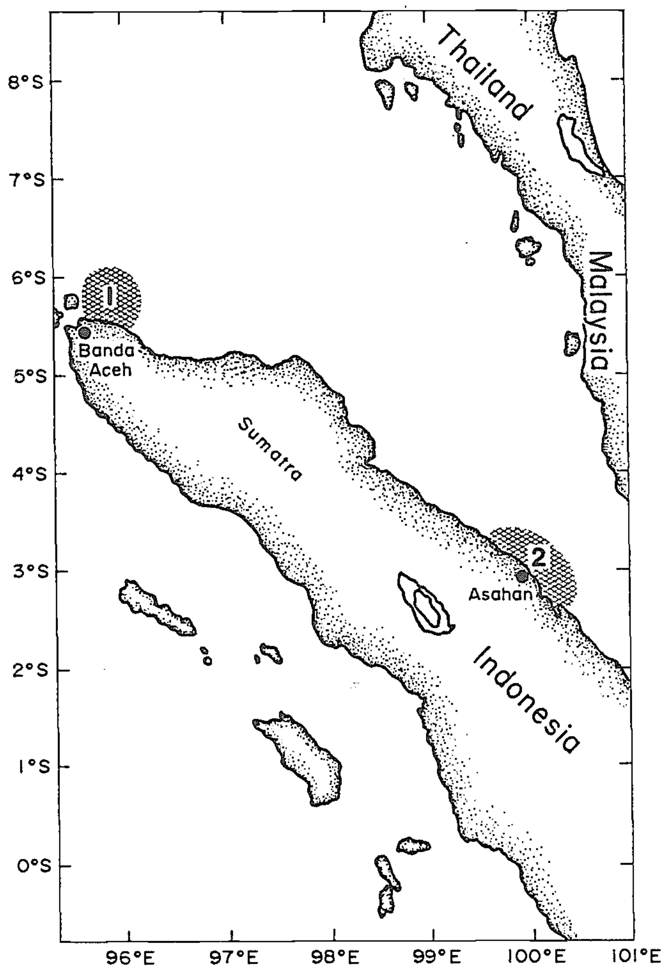

Fig. 1. Northwestern part of Malacca Strait, with sampling sites (1, 2) for *Rastrelliger kanagurta*.

Table 1. Morphometric data analyzed here.[a]

Study 1 *Rastrelliger kanagurta*[a]	Study 2 *Decapterus russelli*[b]
– total length	– total length
– fork length	– fork length
– head length	– head length
– standard length	– eye diameter
– first dorsal	– first dorsal
– second dorsal	– second dorsal
– pectoral length	– pectoral fin
– eye diameter	– anal fin
– body depth	– body depth
– weight in grams	– high scute
– body length	– snout length

[a]See Tampubolon, this vol. for definitions.
[b]See Widodo, this vol. for definitions.

Study 2. Morphometric measurements of 364 specimens of *D. russelli* were collected from five fishing grounds in the Java Sea (Fig. 2) during the period of March to December 1986. The five fishing grounds and the number of samples taken are shown below:

Fishing grounds	Samples
1. Bawean	82
2. Masalembu	75
3. Karimun Java	60
4. Matasiri	97
5. Samber Geleng and Lari-larian	56

For both studies, each measurement was corrected for heterogeneity in length by reexpression as a ratio of total length and by using logarithmic transformation for the analysis. Outliers were excluded from both sets.

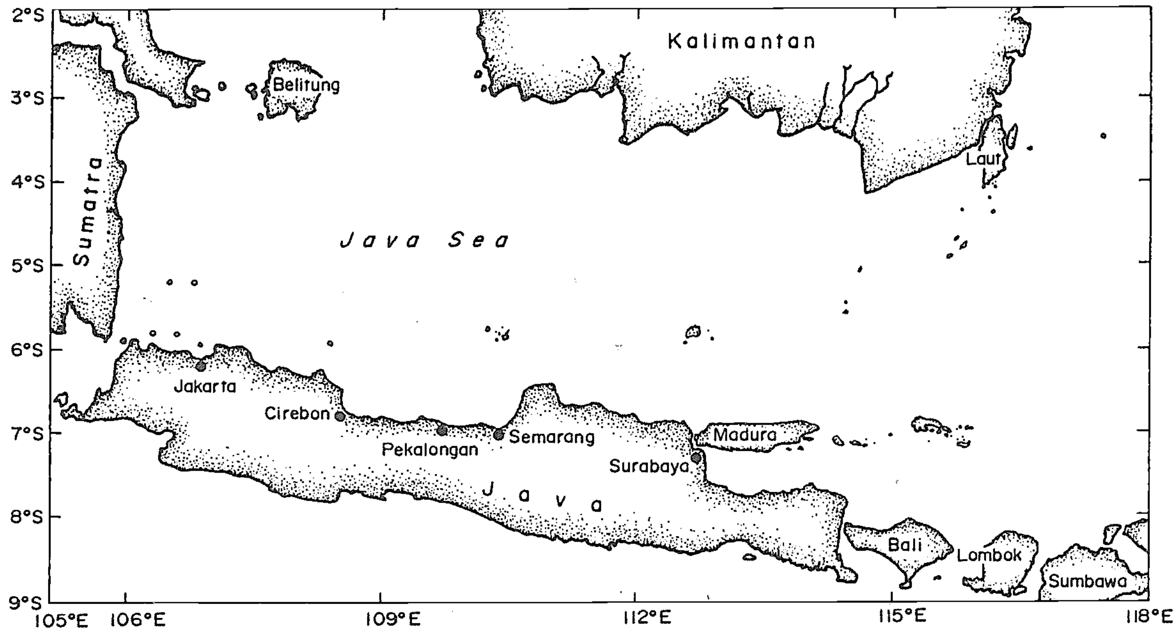

Fig. 2. The Java Sea, with sampling sites (1-5, see text) for *Decapterus russelli.*

Results and Discussion

The DISCRIM procedure of the SAS (Helwig and Council 1979) package for multivariate data was used to derive a model that would optimally classify an observation to one of the groups or populations.

Study 1. Table 2 shows the discriminant classification of the samples from Banda Aceh and Asahan. It is evident from the results that the discriminant function successfully identified morphological differences in fish caught in these two places, separating them with only 15.92% and 17.33% misclassifications, respectively.

Study 2. The five fishing grounds were grouped into two larger areas, A and B, the northeast-deepwater fishing grounds (Mata Siri, Samber Geleng and Lari-larian) and the southwest-shallow water fishing grounds (Karimun Java, Bawean and Masalembu), respectively. The discriminant analysis applied to this study was not able to detect marked morphological differences between the two areas as shown in Table 3, i.e., about 75% of the fish in group B were misclassified.

Table 2. (Study 1) Summary of classification results using Discriminant Analysis.

	Discriminant classification (%)		
	A	B	Total
A	169 (84.08)	32 (15.92)	201 (100)
B	35 (17.33)	167 (82.67)	202 (100)

A = Banda Aceh; B = Asahan.

Table 3. (Study 2) Summary of classification results using Discriminant Analysis.

	Discriminant classification (%)		
	A	B	Total
A	160 (95.81)	7 (4.19)	167 (100)
B	114 (74.51)	39 (25.49)	153 (100)

A = Karimun Java, Bawean, Masalembu.
B = Mata Siri, Samber Geleng, Lari-larian.

Another try of discriminant analysis was made this time using the extreme grounds, Samber Geleng and Lari-larian in one group and Karimun Java on the other. The result is shown on Table 4 with 17.86% misclassification for the former and 1.67% for the latter. Thus the extreme fishing grounds are different. Evidently, the fishing grounds between these places (Bawean, Masalembu and Mata Siri) must contain a mixture of *D. russelli* from the deep water and the shallow end.

This exercise of formulating a discriminant model to classify fish into distinct (sub)populations may be viewed as an exploratory tool for interpreting multivariate data and testing the validity of pooling samples from different areas from Banda Aceh and Asahan can be separated into two distinct groups or populations based on its morphometric data. Study 2, on the other hand, shows that only the two extreme fishing groups (Karimun Java and Samber Geleng and Lari-larian) may be treated as two different groups. The fishing grounds between these two areas (Bawean, Masalembu and Mata Siri) contains mixture of the two groups.

Table 4. (Study 2) Summary of classification results using Discriminant Analysis.

	Discriminant classification (%)		
	A	B	Total
A	59 (98.33)	1 (1.67)	60 (100)
B	10 (17.86)	46 (82.14)	56 (100)

A = Karimun Java.
B = Samber Geleng, Lari-larian.

Ideally, the analysis of morphometric data should not end here. Rather, attempts should be made to relate the available morphometric data to location-specific environmental variables, such as to be able to attribute causes to the observed morphometric differences between subpopulations.

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Aspects of the Lake Victoria Fisheries with Emphasis on *Oreochromis niloticus* and *Alestes sadleri* from the Nyanza Gulf

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Abstract

The biology of the fish stocks and their fishery in Lake Victoria are reviewed. The major fisheries started to decline long before the introduction of the Nile perch *(Lates niloticus)*, therefore it is questionable whether this predatory species is the sole cause of decline in the stocks of tilapia and anadromous fish.

Length-frequency data covering the period July 1985 to April 1986 for *Oreochromis niloticus* and *Alestes sadleri* were obtained from five landing Kenyan beaches in Nyanza Gulf and Port Victoria. Growth parameters were estimated for both species, and an estimate of total mortality was provided for *A. sadleri*.

Fecundity of *A. sadleri* was found to be relatively low. Egg size increases with increasing gonad weight, fork length and total body weight, but the ratio of number of eggs and total body weight does not appear to change. Mean relative fecundity was 350 eggs/g body weight.

Introduction

Lake Victoria, at 1,135 m above sea level, has the second largest area of all lakes in the world, about 70,000 km^2. Its coastline is irregular with a length of 3,440 km. It has a distinctive offshore area with greater light penetration. There are papyrus swamps at the river mouths and along some other parts of the coast.

The lake gets 80 to 90% of its water from direct rainfall of about 1,450 mm/year, though this may be variable due to changing climatic conditions. The rest of the water comes, with a replacement time of about 170 years, from streams dominated by the Kagera river and this inflow is balanced by the outflow through the river Nile. The water has an average conductivity of 960 >mho and pH of 7.8. The lake has different kinds of bottoms: hard (sand rock and gravel), soft (mud, humus or clay) and mixed.

The fishery is dominated by four major groups, namely, *Lates niloticus* (Nile perch), *Rastrineobola argentea, Oreochromis niloticus* and a multispecies complex of cichlids belonging to the genus *Haplochromis*, which contains over 250 species (Bergstrand and Cordone 1971; Kudhongania and Cordone 1974). The stock size of anadromous fishes has declined and the fishery is seasonal with low catches. There has been a continuous decline in catch rates with time. Recently there have been localized mass fish kills in the lake.

This paper presents studies on two species in the Nyanza Gulf waters, namely, *Oreochromis niloticus* and *Alestes sadleri*, and also reviews major biological aspects of the Lake Victoria fisheries.

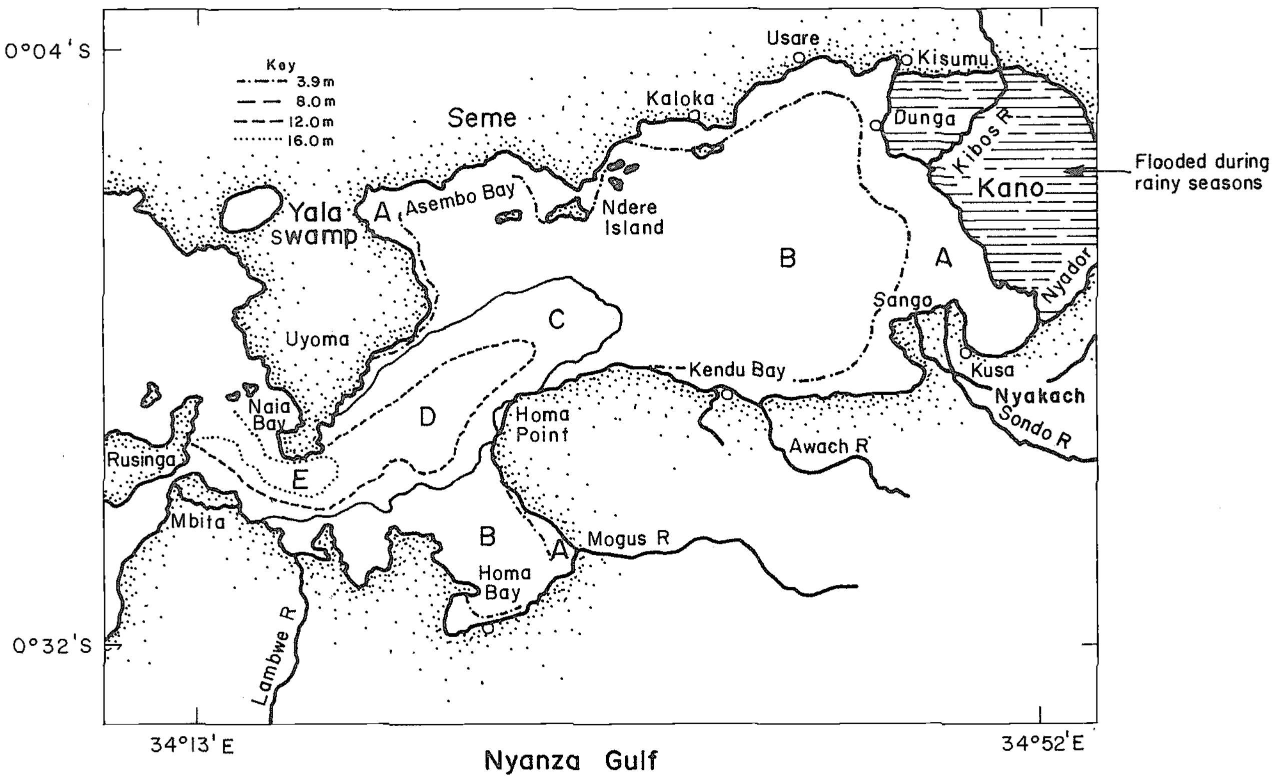

Fig. 1. Map of Nyanza Gulf (Lake Victoria) showing depth contours (from FAO, 1984).

Table 1. Contribution of *Oreochromis niloticus*, *Haplochromis* spp. *Rastrineobola argentea* and *Lates niloticus* to the total catch of Nyanza Gulf in % of total landed weight.

Year	*O. niloticus*	*Haplochromis* spp.	*R. argentea*	*L. niloticus*
1976	2.3	34.1	30.3	0.5
1977	2.4	32.4	34.7	1.1
1978	1.1	27.8	36.5	4.5
1979	3.1	21.6	30.5	14.0
1980	4.4	13.5	35.1	16.0
1981	4.8	2.1	20.4	59.7
1982	4.2	4.2	17.1	54.4
1983	3.3	0.8	21.3	67.7

Fishery Biology of Victoria Lake

Development of the Fishery

The total reported catches from Lake Victoria from 1968 to 1984 are shown on Fig. 2. Catch rates have shown a constant decline and marked changes in the species composition of the catches have been observed as well (Table 2). Explanations for the causes of the decline include:

a) increased use of larger mesh size nets which only take large *L. niloticus* leaving the smaller species, b) predation of other species by *L. niloticus*, c) competition for food and habitat, d) local overfishing resulting from high demand of particular fish species and e) fluctuations of the environmental factors. The latter is thought to be the agent of the recent mass fish kills in various parts of Lake Victoria. The species which lost appreciable amounts of biomass were *L. niloticus* and *O. niloticus*. The effects of pollution from urban, industrial and agricultural wastes on the riverine and lacustrine fisheries have not been assessed. There are some scientific data to support an overfishing hypothesis and effects of predation by *L. niloticus*. There is little scientific basis for the other explanations.

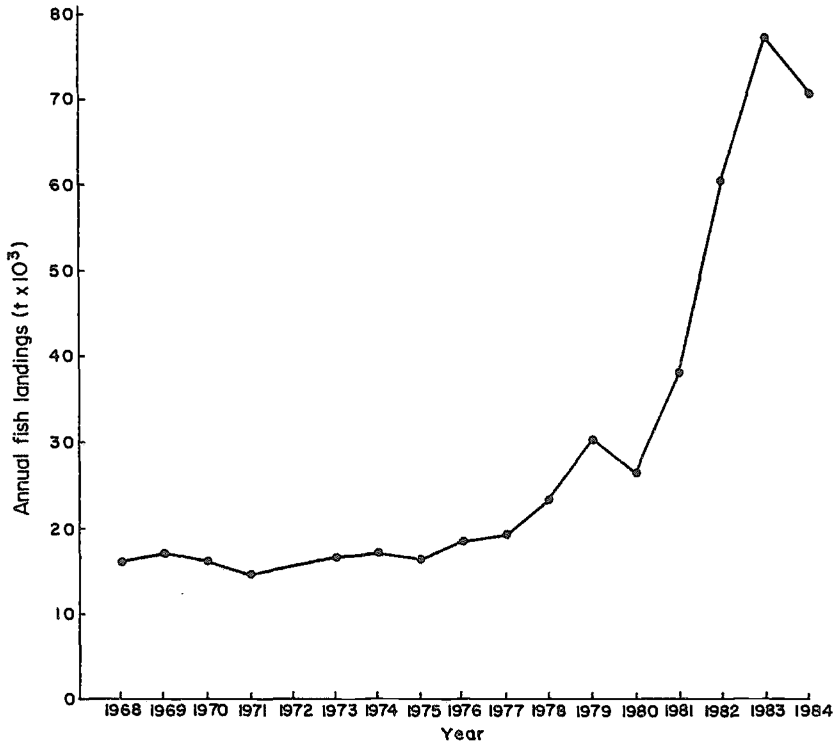

Fig. 2. Total annual fish production of Lake Victoria, 1968-1984 (from FAO, 1984).

Table 2a. Mean catch rates (kg/hr) of *Oreochromis niloticus* and all fish combined in Ugandan waters of Lake Victoria, 1968-1983.[a]

Year	*O. niloticus*	All other species combined
1968-1971	3.36	796.72
1981	13.6	594.94
1982	6.56	363.3
1983	5.03	355.28

[a]from Okaronon et al. (1984)

Table 2b. Mean stock densities (kg/ha) of *O. niloticus*, *Haplochromis* spp., *Lates niloticus* and all the other species combined from bottom trawl surveys in Lake Victoria, 1969-1981.[a]

Year	*O. niloticus*	*Haplochromis* spp.	*L. niloticus*	All others
1969-1970 (19 hauls)	0.013	35.837	-	56.901
1975 (69 hauls)	0.188	32.721	0.827	60.467
1977 (167 hauls)	0.722	28.55	2.804	35.965
1981 (No. of hauls not given)	2.533	—	0.446	42.515

[a] based on data collected by UNDP, EAFFRO, KMFRI and TPRI.

From past records (Table 3), it is clear that the major fisheries of Lake Victoria started to decline long before the introduction of *L. niloticus* in the late 1950s and early 1960s which has been blamed to have destroyed the tilapiine and the anadromous fishery of the Nyanza Gulf and other parts of the lake (Table 3). A decline of the tilapia fishery can easily be noticed before the introduction of *L. niloticus* and therefore it cannot be concluded that *Lates* has been the only cause. *L. niloticus* predates on fish in the lake but to which extent has not been documented. *Haplochromis* species which used to form up to 80% of the catch by weight have shown a decline which may be attributed to predation by *L. niloticus*, since the start of their decline coincided with a rapid expansion of *L. niloticus*.

There are research data to support the thesis that the tilapia and the anadromous fisheries of the lake have declined due to overfishing (Garrod 1961a; Cadwalladr 1965). This also applies to some *Haplochromis* stocks which are habitat restricted (CIFA 1983). Before 1900, fish served mainly for subsistence of the fishermen using rather inefficient traditional gear. The catch rates of the tilapia and the anadromous fishes were high. As more efficient gear such as flax nets, monofilament gill nets (Garrod 1961b) and efficient outboard engine boats were introduced, the rate of exploitation increased. This was enhanced by the improvement of the communication within the lake basin and other parts of the countries bordering the lake, where fish was in high demand. This made markets available and transportation of fish easier. This encouraged more fishermen to join the fishery and the catch rates started to drop as early as 1937 (Table 3) long before the introduction of *L. niloticus* (Ssentongo and Welcomme 1985). Due to lack of price differential between big and small fish, fishermen were encouraged to use smaller meshes and go for the younger stages in order to maximize fish numbers and prices (CIFA 1982). As the catch rates continued to drop, there was an increase in smaller mesh nets with time. Fishing at the river mouths with small mesh gill nets, where ripe females and males congregate on their way to spawn in the riverine environment during the rainy season, has been very intense and this has led to recruitment overfishing of the anadromous fishes such as *Alestes* sp., *Mormydiae, Labeo victorianus* and *Barbus altianalis* (Cadwalladr 1965; Katunzi 1985). These species are now occasionally caught with small mesh gill nets and are no longer a basis for major fisheries. The use of small mesh gill nets is banned in Kenyan waters. The riverine anadromous fishes are threatened by overfishing, modification of riverine regimes by irrigation and pollution. The complex multispecies fishing was further made unstable by the introduction of new tilapia species, namely, *Oreochromis leucosticus*, *O. niloticus* and *Tilapia zillii*.

Table 3. Catch rates of tilapias and all other species in Lake Victoria, 1905-1968 (number of fish per net).[a]

Year	Catch per net of tilapia species	Catch per net of all other species
1905	50-100	-
prior to 1921	6	-
1928	6	-
1933	7	-
1937	3.08	-
1939/49	-	2.2
1942	2.5	-
1947	2.12	-
1952	1.9	2.0
1954	1.6	-
1962	1.388	1.56[b]
1965	0.51	0.54
1968	0.35	0.45

[a]Based on Worthington and Worthington (1973) and various EAFFRO and KMFRI reports.
[b]4" gill net

Changes in Dominant Species and Current Trend

The Lake Victoria fishery has seen changes in the dominant species in the catch. According to the estimates by Bergstrand and Cordone (1971) and Condone and Kudhongania (1972), *Haplochromis* spp. used to dominate, but fairly recently *L. niloticus* has become the dominant species (Mainga 1982; Okemwa 1984; Ogari 1985). Mainga (1982) showed that the catch in the Nyanza Gulf comprised 63.6% *L. niloticus*, 20.7% *R. argentea*, 7.4% *O. niloticus* and 1.5% *Clarias mossambicus*. Muller and Benda (1981) found that there was a reduction in the mean stock densities for *Bagrus docmac, C. mossambicus, Haplochromis* spp., *Protopterus aethiopicus, Schilbe mystus* and *Synodontis* spp. The continued decline of the *Haplochromis* spp. threatened earlier hopes of investment into the fishery. Further Marten (1979) observed that *Labeo victorianus, Alestes* sp., *Mormyridae* and *O. esculentus* had drastically declined during the 1970s.

At present the fishery is most intense in Kenyan waters with about half the total number of fishermen operating in Lake Victoria while the Kenyan segment of the coast only constitutes 12% of the total. This fishery is artisanal and operates in the inshore waters at 0-25 m depth. The main species taken are *L. niloticus, R. argentea, O. niloticus* and few anadromous fishes.

One other feature of this fishery is the continued adoption of larger mesh nets to fish the abundant *L. niloticus,* prompted by low catches of traditional species. As a consequence, some of these species mainly *O. niloticus, Labeo victorianus, Barbus altianalis* and the Mormyridae have shown some upward trends in their catches (Okemwa 1981; CIFA 1982). In Kenya the catch of *O. niloticus* rose from 1,000 t in 1976 to 4,500 t in 1982, while *A. sadleri* and some of the small Mormyridae have started to show signs of recovery (pers. obs.).

The major commercial species at present in order of importance are: *L. niloticus, R. argentea* and *O. niloticus*. These three species make up over 96% of the total annual catch. Three other species provide a cheap source of protein for subsistence: *C. mossambicus, P. aethiopicus* and *Barbus* sp.

R. argentea is fished with mosquito seines while the two other species are fished with gill nets and beach seines with meshes of about 11 cm.

Biomass Estimates

The fishery for *R. argentea* is relatively new (Katunzi 1985). The biology of this species is not documented apart from a few very localized studies. Gee and Gilbert (1967) suggested that harvesting could be done with a purse seine of 0.5 cm mesh and 274-451 m long.

Since the last lakewide bottom trawl surveys of UNDP, EAFFRO and TPRI in 1969-1970, 1975 and 1977, respectively, no survey covering the whole lake has been made. However, local trawl surveys were made by the fishery institutes of Kenya, Uganda and Tanzania. The catch rates of the various species have been recorded (Okemwa 1981, 1984; Okaronon et al. 1985; Mbahinzireki 1985). The characteristics of the major exploratory bottom trawl surveys are presented on Table 4. In spite of these surveys there are major gaps in the knowledge of the resources. Results of local surveys are presented by Gee and Gilbert (1967) and Okemwa (1981). Information on the type of gears and cod-end mesh sizes is often lacking. The vessels used could not trawl waters of 0-5 m depth, e.g., most of Nyanza Gulf. Trawling was also not possible on the rocky bottoms of the lake. There is therefore lack of information about the stocks found in these habitats, e.g., *O. niloticus* in the shallow waters and certain *Haplochromis* species in the rocky areas. The same applies to fish in swampy areas in particular *C. mossambicus* and *Protopterus aethiopicus*.

A long time has elapsed since the surveys took place. Another lakewide exploratory trawl survey should be carried out to determine the catch rates and biomass of the different species.

Habitats and Food Preferences of Major Species

The fish of Lake Victoria live in a number of habitats. The species for the adjacent swamps and Kano floodplain are *O. niloticus, C. mossambicus, T. zillii, Haplochromis* sp. (particularly *Pseudo-clanilabrus bicolor*), *Barbus* sp., *Protopterus aethiopicus, Aplacheilichthys pumibus, Ctenopema muriei* and *Notobranchius* sp. The anadromous fishes which migrate to the rivers to spawn and then back to the lake are *A. sadleri, A. jacksoni, Labeo victorianus, Barbus radcliffi,* other *Barbus* spp. particularly small ones, *Synodontis victoriae, S. afrofischeri, Schilbe mystus, Mormyrus kannume,* small Mormyridae and *C. mossambicus*. The fishes which are confined to Lake Victoria and mainly to the pelagic zone are *L. niloticus* and *R. argentea. A. jacksoni* and *A. sadleri* occur in the pelagic zone during the phase when they are in the lake and are found associated with *R. argentea*. The fishes found in the rocky areas are some species of the *Haplochromis* stock, *tilapias* and to some extent *Bagrus docmac*.

Within the lake the fish are distributed in the numerous niches which are available and some species are oligobathic while others are eurybathic. The oligobathic species are *P. aethiopicus* which are found in shallow waters and the adjacent *Papyrus* swamps, *Labeo victorianus, Schilbe mystus, Gnathonemus longibarbis, L. niloticus* and some tilapia species. The eurybathic species are *Bagrus docmac, C. mossambicus* and *Xenoclarias* sp. *Alestes* sp. and *Rastrineobola* sp. tend to occur in muddy water, while *C. mossambicus* are distributed in the whole water column. On the sandy bottoms are found the tilapia and *Haplochromis* spp. On the muddy bottoms are found *Labeo victorianus, P. aethiopicus* and *Clarias mossambicus*. Highest concentrations of fish are usually encountered in the shallowest depth stratum while lowest concentrations occur in the deepest waters at 70-79 m. Welcomme (1964) found that younger specimens of some fish were found in shallow waters while the older stages were found in deep water. Species exhibiting a similar distribution are *Xenoclarias* sp., *Synodontis* sp., *Haplochromis* sp., *O. niloticus, Tilapia zillii* and *O. leucosticus*.

Predatory species are *L. niloticus, Bagrus docmac, C. mossambicus,* some *Haplochromis* species, *P. aethiopicus* and *Alestes* sp. Those which feed on bottom deposits are *Mormyrus kannume, Labeo victorianus,* some *Haplochromis* spp., *O. niloticus, C. mossambicus* and *P. aethiopicus. R. argentea,* younger stages of *L. niloticus* and *Alestes* sp. feed on zooplankton.

Table 4. Characteristics of important bottom trawl surveys carried out in Lake Victoria, 1967-1981.

Year and source	Vessel used and its capacity	Period taken in hours	No. of sampling units of the lake	No. of hauls made	Most commonly used codend (stretched) cm	Other codend mesh size used (stretched)	Distance covered km	Amount of fish caught kg	Catch rate kg	Speed knots
1. Bergstrand and Cordone (1971)	IBIS, 180 HP was 17.1 m long with 2.4 m draught displacement, 74.5 grt	1117	12	841	3.8, 6.8	5.1, 5.7 6.4, 7.6 and 8.3	6209	272,980	244.4	2
2. Kudhongania and Cordone (1974)	IBIS same as above	1463 (calculated)	13	772 effective	1.9, 3.8 and 6.4	5.1, 5.7, 7.6 and 8.3	-	679,007	463.45	3
3. Okemwa 1981	FWANI and OMENA 85 HP		Nyanza Gulf	794	3.8				99.5	2.5
4. Gee and Gilbert 1967	15 m sea plane powered by 2 Perkins S6 diesel engines		Entebbe area						141.5	

Omnivorous are *O. niloticus* and to some extent *Tilapia zillii,* which are largely herbivorous. Those that eat insect larvae such as *Chaoborus* are the small Mormyridae, *Barbus* spp. and *Ctenopoma muriei.*

Growth and Mortality of *Alestes sadleri*

The genus *Alestes* (family Characidae) is restricted to the fresh waters of Africa and is common in waters less than 30 m deep amongst marginal vegetation. This species exhibits vertical diurnal migration. Ripe *A. sadleri* run up rivers, probably to spawn. There is no directed fishery for *A. sadleri* but it is fished as a bycatch in the mosquito seine fishery for *R. argentea,* which is the second most important fishery in Nyanza Gulf. *A. sadleri* stock sizes are at a low level at present but recent observations suggest some recovery in the Nyanza Gulf.

Materials and Methods

Length-frequency data were collected once monthly from five Kenyan landing beaches in Nyanza Gulf, Lake Victoria. Ten samples between July 1985 and April 1986 were obtained and are given in Table 5. Fecundity studies were carried out on *A. sadleri.* Ripe fish were selected from the beaches, sexed and weighed. The gonads were removed from the females, weighed and divided into subsections. Egg counts were made on each subsection and the total number of eggs per female was calculated by multiplying the number of eggs in one subsection by the number of sections of the ovary made. Because of the small mesh mosquito nets used, a correction for mesh selection is not needed.

Table 5. Length frequency distribution of *Alestes sadleri* from Nyanza Gulf, Lake Victoria, 1985-1986.

Midlength (cm)	Jan 86	Feb 86	Mar 86	Apr 86	Jul 85	Aug 85	Sep 85	Oct 85	Nov 85	Dec 85
3.75	1	3	1	1	1					
4.25	3	25	0	14	11	1	6	1	1	
4.75	17	40	2	24	44	20	31	11	9	10
5.25	32	50	12	28	69	116	55	32	18	29
5.75	62	55	15	51	22	150	112	37	10	83
6.25	62	18	27	24	10	148	102	82	57	83
6.75	24	8	37	14	1	65	24	61	65	49
7.25	19	33	91	6	9	6	5	24	35	44
7.75	11	61	96	24	53	7	40	8	24	29
8.25	19	43	12	38	52	36	80	6	43	5
8.75	33	22	17	55	78	50	48	28	38	21
9.25	34	4	25	29	31	48	44	48	26	31
9.75	60	2	61	20	18	21	20	22	7	40
10.25	27	1	80	3	9	7	6	10	7	22
10.75	17	1	60	1	9	3	7	3	5	14
11.25	5	0	27			1	2	3	3	7
11.75	4	0	4			4		3	2	5
12.25			5							2

Total frequency: 4585

All samples were taken during the first week of the month.

The version of the ELEFAN I computer program for HP 87 XM of Saeger and Gayanilo (1986) was used to estimate L_∞ and K. Total mortality, Z, was estimated from a length-converted catch curve using ELEFAN II from the same computer program package.

Results

The restructured length distributions are presented in Fig. 3 together with the fitted growth curve. This curve corresponds to L_∞ = 13.7 cm, K = 0.46/year. The ESP/ASP ratio is rather low and indeed from Fig. 3 it is seen that several peaks are unaccounted for. Ignoring this problem however and accepting the estimated K value, a catch curve analysis was done. The sampling intensity is assumed to be proportional to the catches, the two missing months, May and June, are assumed to be well represented with the average length compositions of the months which have been sampled. Based on these assumptions a length-converted catch curve (Fig. 4) giving a 1.65/year was calculated. Application of Beverton and Holt's (1956) Z/K method suggested a Z value of 1.2/year.

The length compositions obtained from July to November 1985 may be jugded as being fairly well accounted for by by the growth curve fit (Fig. 3). The Bhattacharya (1967) method was applied to those length compositions in order to investigate the total mortality by comparing month by month the abundance in the two main peaks identified (Table 6). The ratio estimated is influenced both by recruitment (there are two different cohorts involved) and by mortality. It would probably be unjustified to assume that the two cohorts have equal strength but even so, the ratio should be constant. This is not observed as the range of the logarithm of this ratio ranges from 0.4 to -1.1.

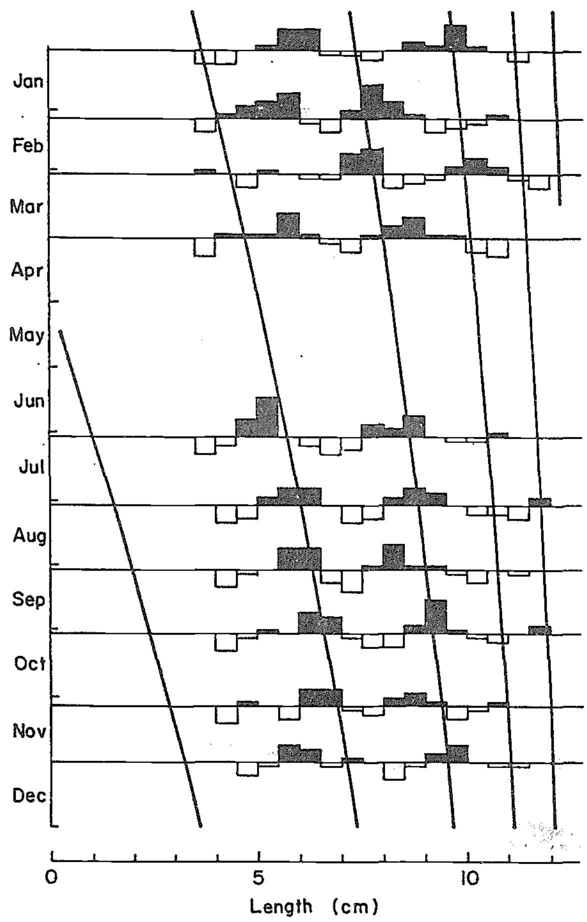

Fig. 3. Restructured length distributions for *Alestes sadleri* from Nyanza Gulf, July 1985-April 1986, with superimposed growth curve (parameters L_∞ = 13.7 cm and K = 0.46) (see also Table 5).

Table 6. Bhattacharya split into normal components for the length composition for *A. sadleri* obtained for the months July-November 1985.

Month	Component 1 Mean length (cm)	Calculated N1	Component 2 Mean length (cm)	Calculated N2	ln N1/N2
July	5.084	154	8.452	218	-0.348
August	5.399	506	8.429	161	+1.145
September	5.702	333	8.308	153	+0.778
October	6.278	252	9.434	118	+0.759
November	5.275	192	8.490	129	+0.398

Fishing mortality on *A. sadleri* is probably low as there is no directed fishery for this species and therefore as a first guess on the natural mortality (M), the total mortality (Z) estimate of 1.65 (see Fig. 4) can probably be used.

The mean fecundity of *A. sadleri* is presented in Table 7 and ranged on average from about 3,800 to about 5,400 eggs. The mean number of eggs and egg size was found to increase with increase in gonad weight, body weight and fork length (Table 7). The number of eggs/g body weight was found to be on average 350.

Discussion

The analysis presented above is only very preliminary. The various approaches to obtaining a total mortality rate gives rather different results.

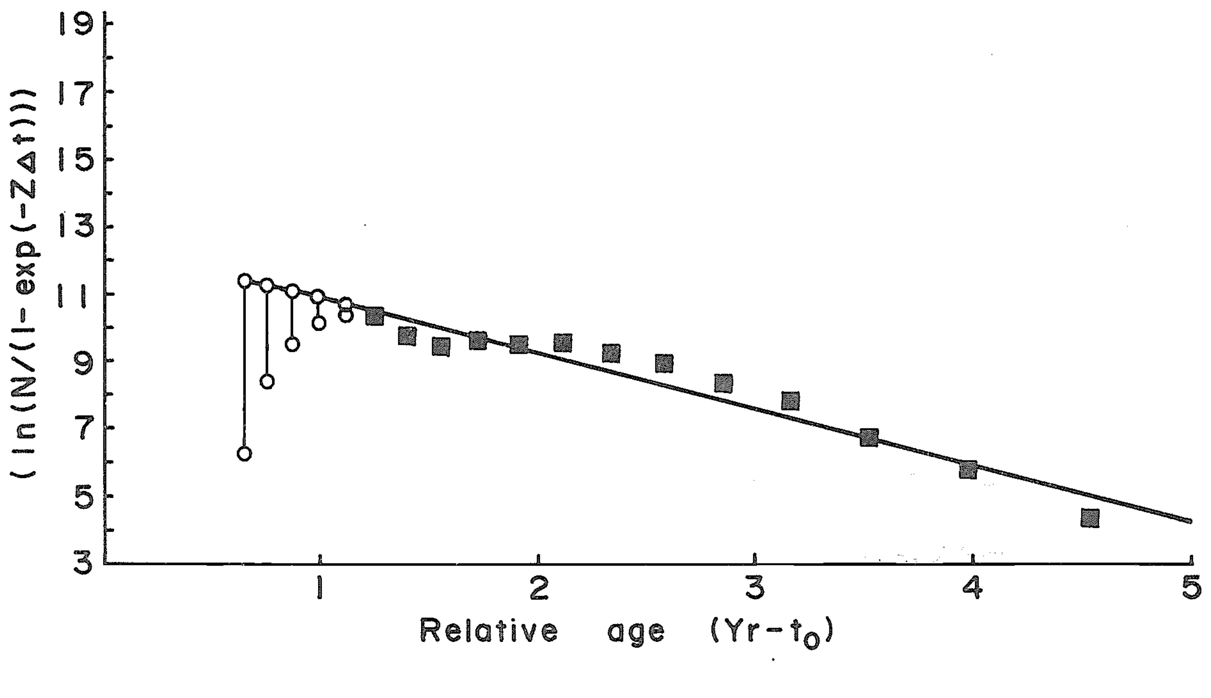

Fig. 4. Length converted catch curve for *Alestes sadleri* from Nyanza Gulf, July 1985-April 1986, based on length frequency data presented in Table 5, with L_∞ = 13.7 cm, K = 0.46. The estimate of Z is 1.65.

Table 7. Fecundity characteristics of *Alestes sadleri* from Nyanza Gulf, Lake Victoria.

Class mid-length (cm)	Mean weight (g)	Mean gonad weight (g)	N	Mean No. of eggs * 10^3	eggs/kg body wt. * 10^6	Mean weight of eggs (mg)
8.75	10.6	1.6	9	3.8	0.358	0.407
9.25	11.6	1.9	11	4.2	0.362	0.439
9.75	13.1	2.3	3	4.3	0.328	0.521
10.25	13.0	2.6	3	5.4	0.415	0.477
10.75	15.1	2.5	2	4.5	0.298	0.560
					Mean = 0.352	

The growth curve shown in Fig. 3 leaves only a few major peaks unaccounted for, and as these pertain to small fish, the retention of which is strongly reduced by selective effects, it can be assumed that Fig. 3 gives a fair representation of growth in the stock of *A. sadleri* investigated here. The catch curve analysis in Fig. 4 is based on the unverified assumption of sampling intensity being proportional to the fishery. The sampling represents only Kenyan waters and as *A. sadleri* occurs widely in Lake Victoria this limitation adds to the uncertainty about the representativeness of the estimated growth and mortality parameters.

A. sadleri is anadromous and spawns during the rainy season. The recruitment of young fish to the fishery could come from the major rainy season which starts in March and ends in July/August. This is in accordance with the growth curve given in Fig. 3. The unexplained peaks may be due to a weaker recruitment from the second short rainy season which occurs late in the year. If this explanation is accepted then the second peak found in the Bhattacharya analysis would include both broods and this would partly account for the July sample. In general indications of the total mortalities in Table 6 would be underestimates.

The fecundity of *A. sadleri* seems to be lower than that of most of other fish in the lake, particularly compared to the predators which feed on it. For example, the fecundity of *A. sadleri* ranges from about 1,000 to 7,500 while that of its predator *L. niloticus* is in the order of millions. This could be the reason why the stocks of *Alestes* declined rapidly after the introduction of *L. niloticus*. The egg size of *A. sadleri* seems to increase with the size of the fish. The ratio of number of eggs per unit body weight remained fairly constant (Table 7).

Growth and Mortality of *Oreochromis niloticus*

Materials and Methods

O. niloticus, a mouthbrooder, belongs to the family Cichlidae. It is the third most important commercial fish in the Nyanza Gulf. In 1984, over 6,000 t of *O. niloticus* were landed. The fishery is carried out year-round with gill nets (about 10 cm mesh size), and beach seines and long lines. Although the legal mesh size is 10 cm, the presence of juveniles of about 2 cm in the catches indicates that illegal mesh sizes are being used. This species is commonly found in shallow inshore waters where it breeds and feeds on zooplankton, phytoplankton and bottom deposits. It grows to a size of 59-62 cm and at this length weighs about 5 to 5.5 kg.

Length-frequency data on *O. niloticus* were collected from five landing beaches for a period of 10 months from July 1985. These are presented in Table 8.

Table 8. Length-frequency distribution for *Oreochromis niloticus* from Nyanza Gulf, Lake Victoria.

Midlength	1985						1986			
(cm)	2/7	4/8	3/9	2/10	6/11	2/12	3/1	4/2	3/3	1/4
2	9	20					9	20	18	33
4	65	55	76				4	13	13	22
6	79	82	132	1		1	17	55	36	11
8	104	62	167	35	23	8	25	68	126	31
10	118	108	140	87	180	10	37	102	102	114
12	149	181	178	90	73	27	70	168	106	159
14	132	158	127	87	70	40	91	122	93	85
16	104	169	108	68	50	73	109	105	90	40
18	68	96	97	50	66	88	129	45	61	21
20	42	43	51	40	48	62	57	28	37	35
22	31	32	30	16	19	59	56	44	19	12
24	42	17	38	28	24	60	45	36	23	27
26	19	20	21	91	59	75	54	73	58	42
28	22	17	20	92	106	69	23	58	47	27
30	18	9	13	34	100	43	58	72	47	35
32	6	9	6	28	64	37	11	29	23	11
34	10	10	5	14	29	18	17	13	6	16
36	12	13	5	9	18	12	9	28	6	14
38	9	27	12	22	12	22	18	30	18	28
40	15	31	15	21	13	5	29	48	34	22
42	14	27	24	22	19	19	27	45	19	16
44	18	26	24	11	11	7	26	30	21	11
46	35	44	23	8	17	14	29	34	18	19
48	36	23	25	13	18	14	22	28	45	26
50	40	30	17	14	17	17	21	38	59	83
52	30	23	20	15	20	18	26	60	60	93
54	18	16	4	20	9	13	14	16	15	29
56	14	7	5	16	5	9	15	5	9	18
58	3	3	1	6	6	5	7	5	2	4
60	0	0	0	2	0	3	4	3	2	0

Results

The length-frequency data show several peaks and an attempt to identify the mean length for each peak and the number of fish in each component out of the total sample was made using the restructuring algorithm of ELEFAN I and the Bhattacharya method. ELEFAN I estimated the parameters of a growth curve under the assumption that the peaks are indeed caused by the interaction of recruitment fluctuation and growth. Fig. 5 shows the restructured samples and the fitted growth curve. Fig. 5 does not appear convincing enough to substantiate the assumption of the abovementioned interactions being the dominating agent in creating the peaks observed in the length compositions.

The number of fish estimated for each component in each sample under the growth assumption should represent cohorts. Although recruitment could be highly variable, it seems unlikely that recruitment should offset mortality over 5-6 cohorts which is the number of peaks identified in each sample (Table 9). Consequently a plot of ln (number of fish) *vs.* the peak

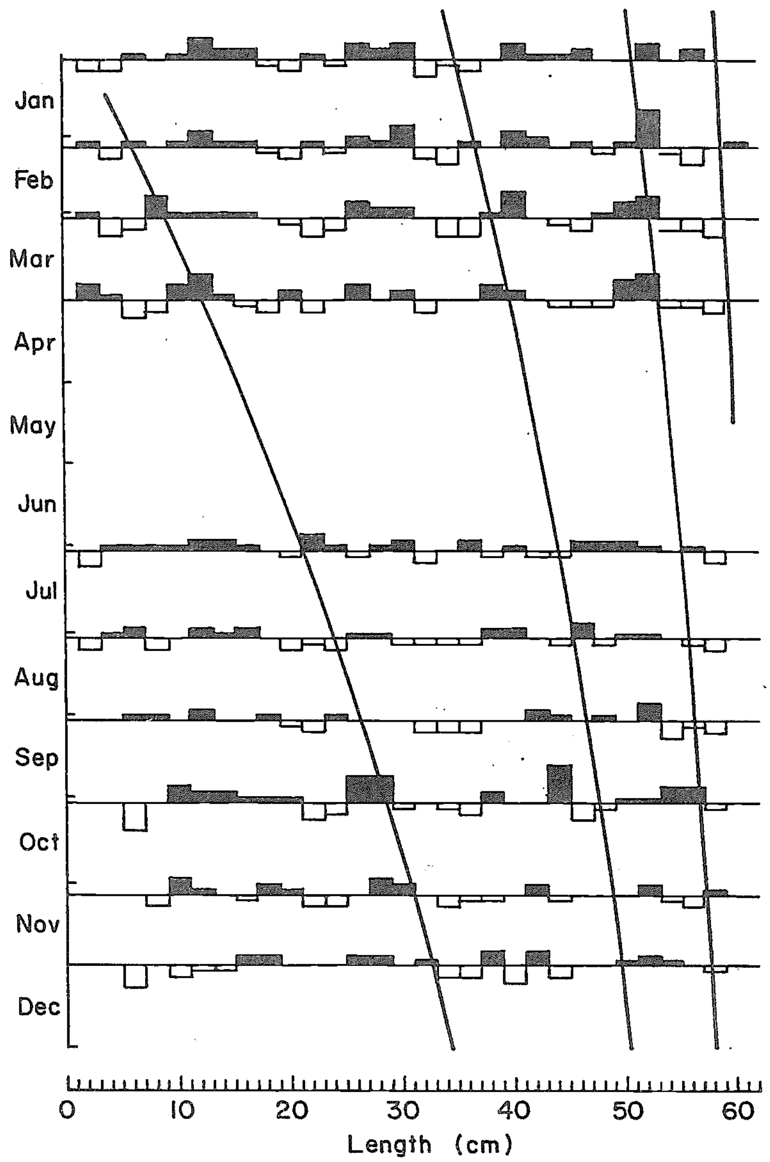

Fig. 5. Restructured length distributions for *Oreochromis niloticus* from Nyanza Gulf, July 1985-April 1986. Based on data presented in Table 8. Note absence of fit, suggesting that peaks do not represent cohorts.

number should show a declining trend even if highly variable. This plot is presented in Fig. 6 and the decline is very modest. Thus, the relative strength of the different peaks does not support the assumption that these peaks are caused by the interaction of variable recruitment and growth.

Discussion

This data set does not contribute to our knowledge of growth of *O. niloticus*. The same species occurs in many African and Asian lakes and Table 10 summarizes growth parameter estimates made by other authors. It might be noted that everywhere, except for Lake Itasy, *O. niloticus* attains a smaller maximum length than in Lake Victoria.

The peaks observed in the length compositions are clearly visible and probably not due to sampling errors. Several fisheries are involved with very different gears and sampling takes place at different landing places. Investigations into the sampling procedures and structure of the fisheries are obviously required. If catch curve analysis is attempted the relative importance of the different fisheries must also be documented.

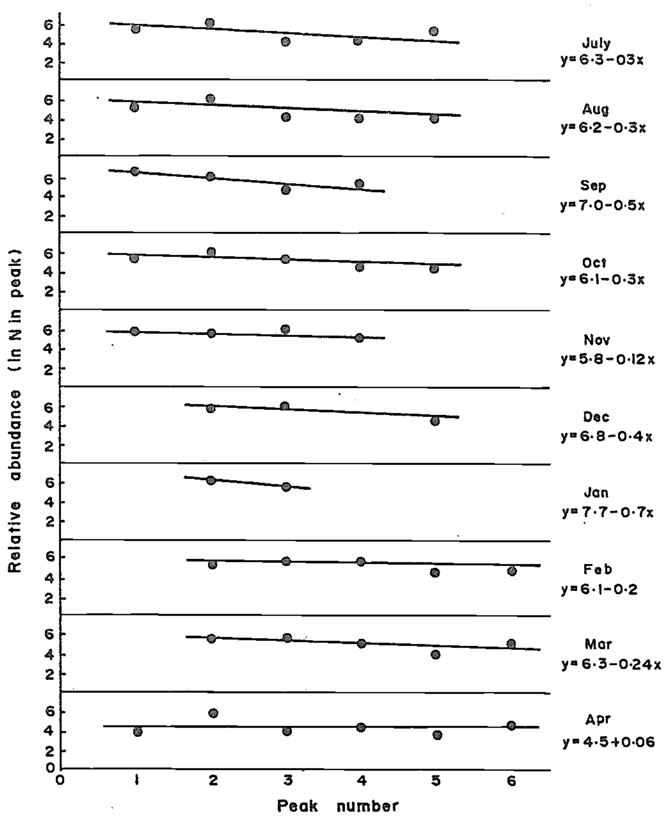

Fig. 6. The peak number identified by Bhattacharya split of the data for *Oreochromis niloticus* presented in Table 8 *vs* the logarithm of the corresponding abundance of the peak (see Table 9).

Table 9. Table showing peak number plotted against the natural logarithm (ln) of the calculated number N from the Bhattacharya analysis for *Oreochromis niloticus* from Nyanza Gulf, Lake Victoria.

Month	Peak No	Calculated N	ln	Month	Peak No	Calculated N	ln
7/1985	1	317	5.8	12/1985			
	2	578	6.4		2	317	5.8
	3	139	4.9		3	357	5.9
	4	73	4.3		5	105	4.7
	5	156	5.0				
				1/1986	2	544	6.3
8/1985	1	232	5.4		3	268	5.6
	2	761	6.6				
	3	81	4.4	2/1986	2	245	5.5
	4	91	4.5		3	352	5.9
	5	95	4.6		4	286	5.7
					5	186	5.2
9/1986	1	685	6.5		6	144	5.0
	2	453	6.1				
	3	103	4.6	3/1986	2	286	5.7
	4	179	5.2		3	396	5.9
					4	211	5.4
10/1985	1	210	5.3		5	83	4.4
	2	386	6.0		6	197	5.3
	3	241	5.5				
	4	103	4.6	4/1986	2	445	6.1
	5	85	4.4		3	61	4.1
					4	111	4.7
11/1985	1	277	5.6		5	54	4.0
	2	214	5.4		6	135	4.9
	3	392	6.0		7	230	5.4
	4	155	5.0				

Table 10. Growth parameters of *Oreochromis niloticus* in African and Asian waters.[a]

Area	Sex	W_{∞}	TL_{∞}	$Year^{-1}$	Ø'	Author
Lake Tiberias		-	35.7	0.501	2.805	Ben Tuvia (1960
		-	33.3	0.538	2.776	- " -
Lake Alaotra		1214	41.8	0.233	2.610	Moreau (1979)
		387	28.5	0.438	2.551	- " -
Lake Mantasoa		851	35.8	0.510	2.815	- " -
- " -		745	34.0	0.503	2.765	- " -
L. Itasy		7059	71.5	0.137	2.845	- " -
- " -		1579	43.4	0.275	2.714	- " -
L. Mariout		1016	36.8	0.594	2.905	El Zarka (1961)
- " -		1635	43.0	0.450	2.920	Payne & Collison (1983)
- " -		780	33.9	0.578	2.822	- " -
L. Manzala		1013	36.8	0.294	2.600	- " -
Moussa Hydrodome		1373	40.8	0.356	2.773	Jensen (1957)
L. Tchad		1985	46.0	0.283	2.777	Blache (1964)
L. Albert		3504	48.8	0.500	3.076	Ssentongo (1971)
L. Kainy		7134	70.4	0.405	3.303	Petr & Kapetsky (1983)
L. Nasser		3984	57.8	0.546	3.261	- " -
- " -		5663	65.1	0.216	2.962	Payne & Collison (1983)

[a]Adapted from Table 1 in Moreau et al. 1986.

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Estimating the Food Consumption per Unit Biomass of a Population of *Epinephelus fuscoguttatus* (Pisces: Serranidae)*

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Abstract

Food consumption per unit biomass (Q/B) was estimated for a natural population of *Epinephelus fuscoguttatus* based on data from cage culture experiments in Guiuan, Eastern Samar, Philippines using recently developed models structured around the analysis of food conversion efficiencies (K_1). Growth parameters used were asymptotic length (L_∞) = 91.7 cm, asymptotic weight (W_∞) = 12,338 g, growth coefficient (K) = 0.19, total mortality (Z) = 0.44 and age at length zero (t_o) = -0.66 all on annual basis. Population estimates of Q/B per year is 4.01 and maintenance ration is 2.9/year or 0.8% of body weight per day. Effects of ration and body weight on K_1 as well as that of Z on trophic efficiency (E_T) and Q/B are discussed.

Introduction

There are two approaches to the assessment of a multispecies fishery. One considers technological interactions based on considerations involving mesh sizes (Ward, this vol., Silvestre and Soriano, this vol. and Meemeskul, this vol.) and the other involves biological interactions. The latter approach generally requires food consumption estimates.

Estimation of food consumption is a basic step in constructing ecosystem models. It is necessary in order to calculate the efficiency of a fish population to convert food into flesh and to find out whether the population age structure is in proper relation to the food resources that are available to it (Mann 1978). In terms of predator-prey relationships and trophic structures, knowing how much a predator species population consumes of a prey species population, one can approximate the production of the consumed species and the fraction of that production which goes in satisfying the food requirements of the next trophic link (Winberg 1971).

There are various methods for estimating food consumption of fishes. Windell (1978) gives full descriptions of five methods using data from field, laboratory and hatchery conditions. He

*ICLARM Contribution No. 439.

mentions (1) bioenergetics, (2) Winberg's equation, (3) nitrogen balance equation, (4) radioisotopes and (5) a method involving the progression of food in fish guts. Another important group of methods of estimation is through the analysis of stomach contents (Jobling 1981, 1986; Medved 1985; Mullen 1986; Persson 1986; Temming 1986).

Because of practical difficulties in implementing some of these methods, Pauly (1986a) proposed a new model which estimates the food consumption per unit biomass (Q/B) of a fish population using information from feeding experiments and growth information, i.e., the parameters L_∞ and K of the von Bertalanffy growth equation. This method was used in this paper to estimate Q/B for a population of *Epinephelus fuscoguttatus* based mainly on data from cage culture experiments in Guiuan, Eastern Samar, Philippines.

Materials and Methods

Results of an aquaculture experiment on the net cage rearing of *Epinephelus fuscoguttatus* (Fam: Serranidae) fed with mixed chopped trash fish in Guiuan, Eastern Samar, Philippines (Pagdilao et al., unpublished data) were used to obtain gross food conversion efficiency (K_1) values for fishes raised in two different experiments (Tables 1 and 2). Gross food conversion efficiency is defined by Ivlev (1939, in Paloheimo and Dickie 1966) as

$$K_1 = \text{growth increment/food ingested} \quad \ldots 1)$$

for any given time period.

Gross conversion efficiency and weight usually have a strong negative correlation and are therefore plotted against each other in a regression analysis. Pauly (1986a) suggests that the data on K_1 can be reduced most appropriately by expressing K_1 as a function of weight in the form

$$K_1 = 1 - (W/W_\infty)^\beta \quad \ldots 2)$$

where W_∞ is the asymptotic weight and β, the slope of a double logarithmic plot of the form

$$-\log_{10}(1-K_1) = \beta \log_{10} W_\infty - \beta \log_{10} W \quad \ldots 3)$$

This relationship predicts a value of W_∞ (x-intercept) when $K_1 = 0$ and a value of $K_1 = 1$ when $W_\infty = 0$. The W_∞ that is defined in this relationship is analogous to that used in the von Bertalanffy growth formula (VBGF) of the form

$$W_t = W_\infty (1 - e^{-K(t-t_0)})^3, \quad \ldots 4)$$

which can be fitted to size-at-age data. The slope obtained in Eq. (3), being compatible with the definitions of W_∞ in Eq. (4) can thus be expressed as

$$\beta = \overline{C} / ((\log_{10} W_\infty \text{ VBGF}) - \overline{\log_{10} W}) \quad \ldots 5)$$

where $\overline{C} = -\overline{\log_{10}(1 - K_1)}$, and where W_∞VBGF is an estimate of asymptotic weight obtained from growth data (see below).

In cases where other factors (besides body weight) affecting K_1 are considered, Eq. (3) is extended to the form

$$C = a - \beta \log_{10} W + (\sum_{i=1}^{n} b_i V_i) \quad \ldots 6)$$

when $C = -\log_{10}(1 - K_1)$ and where V_i, i = 1, ...n are other factors, e.g., ration, feeding frequency, type of food, temperature, etc. related to K_1. With Eq. (6), it is thus possible to

Table 1. Food intake data extracted from results of *E. fuscoguttatus* cage culture experiments in Guiuan, Eastern Samar, Philippines (Pagdilao et al., unpublished data).

Month	Initial no. of fish in cage	Initial biomass in cage (g)	Food consumed (g)
	A	B	C
May	220	2,180	17,980
Jun	208	4,056	13,340
Jul	207	8,032	48,410
Aug	205	18,409	110,330
Sep	203	21,824	100,020
Oct	203	28,773	124,670
Nov	202	32,276	146,180
Dec	179	36,346	–
May	220	4,860	44,650
Jun	218	10,769	32,700
Jul	204	17,707	111,620
Aug	202	27,735	176,330
Sep	137	22,900	102,670
Oct	137	27,827	120,090
Nov	136	35,433	169,080
Dec	127	36,411	–

Table 2. Food conversion efficiency data on *E. fuscoguttatus* computed from feeding data in Table 1.

No.	Mean weight of individual fish (g)[a]	Log_{10} mean wt	Mean biomass in cage (g)[b]	Monthly growth increment per fish (g)[c]	Monthly food ingested per fish (g)[d]	Daily ration in %[e]	K_1	C[f]
Experiment 1								
1	14.70	1.1673	3,118	9.59	81.73	18.53	0.1173	0.054187
2	58.30	1.7657	6,044	19.30	64.13	3.667	0.3010	0.15552
3	64.30	1.8082	13,220	59.00	233.86	12.12	0.2181	0.10685
4	98.65	1.9941	20,116	17.71	538.20	18.19	0.03290	0.014529
5	124.62	2.0956	25,298	34.23	492.71	13.18	0.6948	0.031274
6	150.76	2.1783	30,524	18.04	614.14	13.58	0.02938	0.012951
7	181.42	2.2587	34,311	43.27	723.66	13.30	0.05979	0.026775
Experiment 2								
8	60.44	1.7813	7,814	27.31	202.95	11.19	0.1346	0.062783
9	68.10	1.8331	14,238	37.40	150.00	7.342	0.2493	0.12453
10	112.05	2.0494	22,721	50.50	547.16	16.28	0.09230	0.042058
11	152.23	2.1825	25,318	29.85	827.92	19.11	0.03420	0.015113
12	185.14	2.2675	25.364	35.96	749.42	13.49	0.04798	0.021354
13	231.83	3.3652	31,630	57.42	876.57	12.60	0.06550	0.029421
14	273.62	2.4371	35,922	26.16	1,243.24	15.15	0.02104	0.0092351
means	126.87	2.0846				13.4092		0.50470
s.d.	73.497	0.482832				4.22367		.046248

[a] $W = ((B_i/A_i) + (B_{i+1}))/2$.
[b] $B = (B_i + B_{i+1})/2$.
[c] Growth increment = $(B_{i+1}/A_{i+1}) - (B_i/A_1)$.
[d] Food ingested = C_i/A_i.
[e] % daily ration = ((monthly food ingested/monthly mean weight)/30) x 100.
[f] $C = -\log_{10}(1 - K_1)$.

account for the difference in experimental and natural conditions since it is possible to use values obtained from experiments and to use Eq. (7) to obtain values of β adjusted to field conditions.

To calculate W_∞, Eq. (6) is transformed, given that $K_1 = 0$ at W_∞, to the form

$$\log_{10} W_\infty = (1/\beta)\,(a + \sum_{i=1}^{n} b_i V_i) \qquad \text{...7)}$$

which, however, may still lead to W_∞ values that are very different from those obtained from the field (Pauly 1986a). In order to avoid such discrepancy in W_∞ estimates, it is suggested that an equation analogous to Eq. (5) be used. That is,

$$\beta = (1/\log_{10} W_\infty VBGF)\,(a + \sum_{i=1}^{n} b_i V_i) \qquad \text{...8)}$$

where $W_\infty VBGF$ is that obtained from growth data fitted to the von Bertalanffy equation, as in Eq. (5). For optimum results, Eq. (6) should be a GM (or type II or "functional") regression, rather than an AN (or type I, or predictive) regression. The method outlined in Pauly (1986a) for deriving the parameters of a GM multiple regression was followed (see Appendix I).

Using the β estimated through Eq. (6), food consumption (Q) of a given fish between age t_r and t_{max} can be estimated in terms of the relationship between the rate of food consumption per fish (dq/dt), the growth rate in the field (dw/dt) as the first derivative of the VBGF and K_1 as a function of age ($K_{1(t)}$), i.e. through

$$Q = W_\infty\, 3K \int_{t_r}^{t_{max}} \frac{(1-\exp(-Kr_1))^2 \cdot \exp(Kr_1)}{1-(1-\exp(-Kr_1))^{3\beta}}\, dt \qquad \text{...9)}$$

Finally, one can define food consumption per unit biomass (Q/B) in an age-structured population as

$$\frac{Q}{B} = \frac{3K \displaystyle\int_{t_r}^{t_{max}} \frac{(1-\exp(-Kr_1))^2 \cdot \exp(-(Kr_1+Zr_2))}{1-(1-\exp(-Kr_1))^{3\beta}}\, dt}{(A_1+A_2+A_3+A_4)} \qquad \text{...10)}$$

where Z is the instantaneous mortality between age t_r and t_{max}, where $r_1 = t - t_0$, $r_2 = t - t_r$, $r_3 = t_{max} - t_r$, $r_4 = t_r - t_0$ and where

$$A_1 = \frac{1-e^{-Zr_3}}{Z} \qquad A_2 = \frac{-3e^{-Kr_4}(1-e^{-(Z+K)r_3})}{Z+K} \qquad A_3 = \frac{3e^{-2Kr_4}(1-e^{-(Z+2K)r_3})}{Z+2K}$$

and

$$A_4 = \frac{-e^{-3Kr_4}(1-e^{-(Z+3K)r_3})}{Z+3K}$$

This model also enables the estimation of maintenance ration and trophic efficiency. Maintenance ration is defined as the amount of food used by the fish in order to maintain its body weight. This is usually estimated by feeding the fish with a wide range of rations such that interpolation gives a ration that results in neither weight gain nor loss (Johnson 1966; Jones

1976). As defined by this model, maintenance ration is the Q/B at W_∞ (which is the mean size at which the fish of a given population stop growing and therefore utilizes food only to maintain themselves). Another definition of maintenance ration is defined by the relationship between total mortality (Z) and Q/B wherein maintenance ration is the Q/B that results from the backward extrapolation of the curve to Z = 0, because the population would then be composed only of large old fish. The maintenance ration obtained from these two methods should correspond to each other.

Table 3. Combined length-frequency sample from Guiuan, Eastern Samar, Philippines (Pagdilao et al., unpublished data) and Tigak Islands, Papua New Guinea (Wright and Richards 1985) used to estimate L_∞ with a Wetherall plot.

Length class	Tigak Islands Papua New Guinea 1980-1981	Guiuan Eastern Samar Philippines 1985-1986	Combined data
12 – 15.99		2	2
16 – 19.99		2	2
20 – 23.99	4	9	13
24 – 27.99	16	3	19
28 – 31.99	33	10	43
32 – 35.99	46	8	54
36 – 39.99	57	4	61
40 – 43.99	42	5	47
44 – 47.99	35	7	42
48 – 51.99	25	6	31
52 – 55.99	18	–	18
56 – 59.99	18	–	18
60 – 63.99	18	–	18
64 – 67.99	11	–	11
68 – 71.99	14	1	15
72 – 75.99	4	–	4
76 – 79.99	10	–	10
80 – 83.99	4	–	4
84 – 87.99	4	–	4
Total	359	57	416

Table 4. Length-weight data on *E. fuscoguttatus* caught with three types of gear (fish trap, spear gun and hook and line), Guiuan, Eastern Samar, Philippines in 1985-1986 (Pagdilao et al., unpublished data).

Length class (cm)	Mean length (cm)	Mean weight (g)	Frequency
12 – 15.99	14	37.50	2
16 – 19.99	18	105.00	2
20 – 23.99	22	190.00	9
24 – 27.99	26	353.33	3
28 – 31.99	30	428.50	10
32 – 35.99	34	601.43	7
36 – 39.99	38	953.75	4
40 – 43.99	42	1,060.00	5
44 – 47.99	46	1,521.40	7
48 – 51.99	50	2,089.20	6

Trophic efficiency is here defined as the production of the population per unit of food consumed (Pauly 1986a), production being expressed as a function of Z, or

$$P = Z \cdot B \qquad ...11)$$

(Allen 1971; Pauly and Palomares 1987) and thus,

$$E_T = Z\,(B/Q) \qquad ...12)$$

where E_T is the trophic efficiency.

The growth parameters needed as input for Eq. (10) were obtained as follows:

Asymptotic size: using the data in Table 3 and the method of Wetherall (1986), as modified by Pauly (1986b) to estimate L_∞, with subsequent computation of W_∞ from L_∞ using a length-weight relationship of the form

$$W = a \cdot L^b \qquad ...13)$$

and based on the data in Table 4.

Growth parameter K: using the ϕ' concept of Pauly and Munro (1984) and the growth parameters of *E. fuscoguttatus* in Table 5.

Growth parameter t_o : from the empirical relationship

$$\log_{10}(-t_o) = -0.3922 - 0.275 \log_{10} L_\infty - 1.038 \log_{10} K \qquad ...14)$$

which provides rough estimates of t_o, given L_∞ (in cm) and K/year (Pauly 1979).

Natural mortality (M): from the equation of Pauly (1980)

$$\log_{10} M = -0.2107 - 0.0824 \log_{10} W_\infty + 0.6757 \log_{10} K + 0.4687 \log T \qquad ...15)$$

used here because Q/B shall be estimated for an unexploited, steady-state population (hence Z = M, and F = O).

Table 5. Estimation of the K value in *E. guttatus* with L_∞ = 91.7 cm using the ϕ' concept and based on previously published growth parameter estimates (Munro and Williams 1985).

Stock	TL_∞ (cm)	K (1/yr)	ϕ'
Kavieng, Papua New Guinea	90.5	0.20	3.21
	99.1	0.16	3.20
This study[a]	91.7	0.19	ϕ' = 3.205

[a]L_∞ value based on data in Table 3 (see Fig. 2).

Results

Fig. 1 shows the modified Wetherall plot which led to the estimate of L_∞ = 91.7 cm.

Chan et al. (1984) reports maximum size at 120 cm and a common range of 60 to 70 cm. Since this fish occurs between 20°N and 55°S, it is possible to accept the estimate L_∞ = 91.7 cm in the (warmer) central part of their geographic distribution (see Pauly 1979).

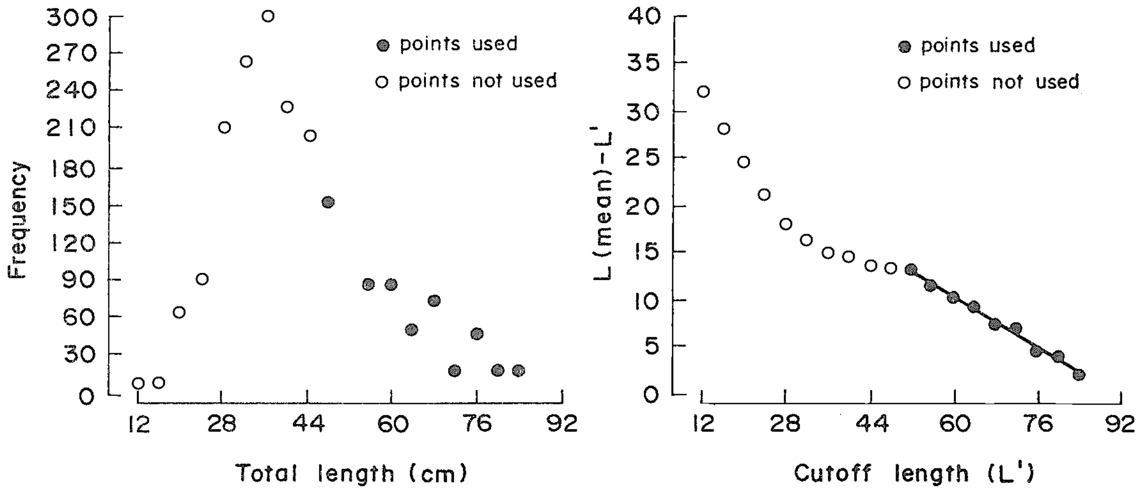

Fig. 1. Modified Wetherall plot for data in Table 3 on *Epinephelus fuscoguttatus*. Results are L_∞ = 91.7 and Z/K = 2.02 (see text).

The length-weight relationship estimated from the data in Table 4 was

$$\log_{10} W = 0.02341 + 2.891 \log_{10} L \quad \text{... 16)}$$

with r = 0.968 and with a condition factor (c.f.) = 1.6. Since the slope of Eq. (16) was not significantly ≠ 3, the c.f. value was used, leading to

$$W = 0.016\, L^3 \quad \text{... 17)}$$

The W_∞ estimate derived from L_∞ = 91.7 cm and Eq. (17) = 12,338 g.

The values of $\bar{\phi}'$ = 3.205 in Table 5 lead to an estimate of K = 0.19 year^{-1}; the estimate of t_o obtained from Eq. (14), K = 0.19 and L_∞ = 91.7 cm is equal to -0.66 years, M, finally was estimated, for a value of T = 28°C as 0.44 year^{-1}.

The (GM) multiple regression derived from the data in Table 2 was

$$C = 0.2838 - 0.05188 \log_{10} W - 0.00933\, R \quad \text{... 18)}$$

with both partial slopes significant ($P < 0.05$).

Solving Eq. (18) for W_∞ using R = 0.7, i.e., for the mean daily ration of the epinephelids in Table 6, gives for Eq. (A4) a value of W_∞ = 910 kg; solving for Eq. (A13) for R = 0.7 gives W_∞ = 221 kg which indicates that the transition from (A4) to (A12) had the expected effect of reducing the W_∞ estimate, albeit not close to the estimate that was obtained by using growth data, which is W_∞ = 12 kg (see above). This latter value of 12 kg is then used to solve for a "first" estimate, of β using

$$\beta = (1/\log_{10} W_\infty \text{ VBGF})\,(a' + b_2 R) \quad \text{... 19)}$$

and setting R = 0.7 yields a value of 0.06778 which is well within the 95% confidence interval of $-b_i$ in Eq. (A8).

The β value obtained from Eq. (19) is then used to estimate an initial value of Q/B from Eq. (10) which corresponds to R = 0.7. This Q/B value is then used in an iterative manner as the next R value used to solve for the next estimate of β. This is done over again until the value of b generates a value of Q/B that is equal to the value of R that was last inputted in Eq. (19). This procedure is used here because the value of ration in nature is not known and also because R is actually a value of Q/B expressed on the basis of an individual fish.

This procedure converged after three iterations, leading, for W_∞ = 12,338, M = 0.44, t_o = 0.66, W_r = 1 and W_{max} = 12,000 g, to an estimate of Q/B = 4.01 per year, or 1.1% per day. The corresponding value of trophic efficiency was E_T = 0.11.

Maintenance ration was estimated using two approaches. One is illustrated in Fig. 2 where it is defined as Q/B at W_∞ as calculated using Eq. (10). The other definition is illustrated in Fig. 3 where it is estimated by graphical extrapolation of the curve to a value of Q/B at Z = 0. In both cases, the maintenance ration should be of the same value. This is here the case, with maintenance ration estimated to be equal to 2.9/year or 0.8%/day (see also Fig. 2).

Fig. 4, on the other hand, illustrates the relationship between Z and E_T. This is an exponential curve, as in Fig. 3. This relationship is briefly discussed below.

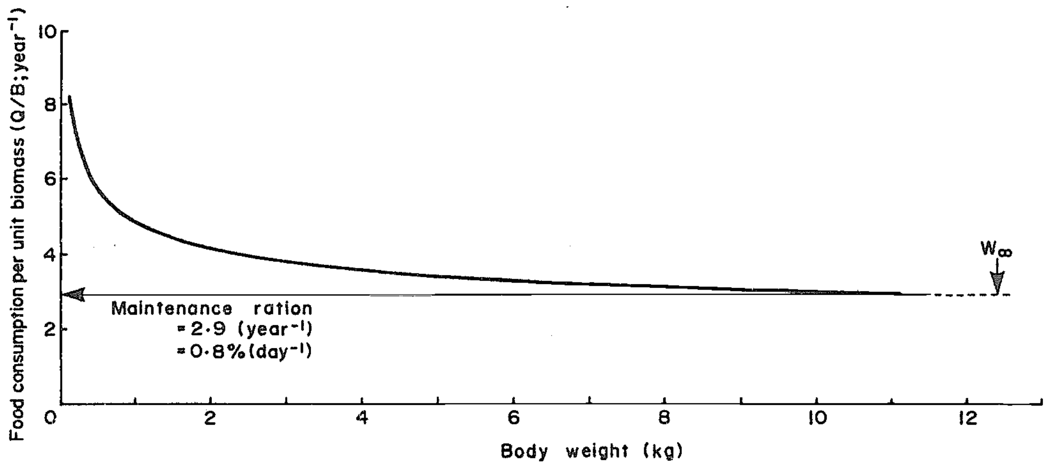

Fig. 2. Relationship between body weight in kg and food consumption per unit biomass for *E. fuscoguttatus.* Note estimate of annual Q/B = maintenance ration at W_∞.

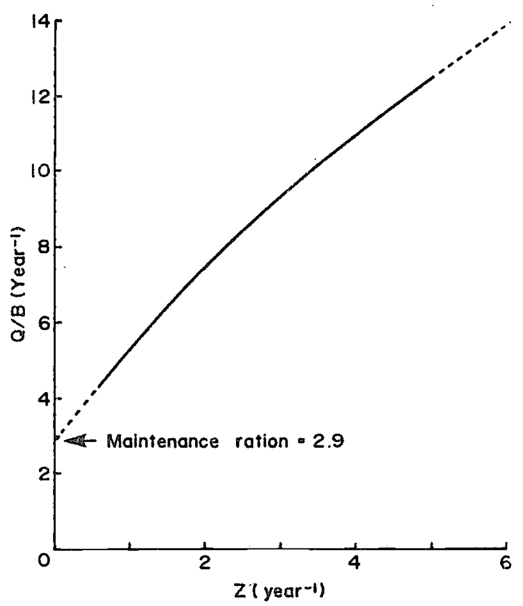

Fig. 3. Relationship between Z and Q/B. Note that the value of Q/B = maintenance ration at Z = 0 which is the same estimate as that shown in Fig. 2. Broken lines beyond Z = 5 indicate probable direction of curve (see Discussion).

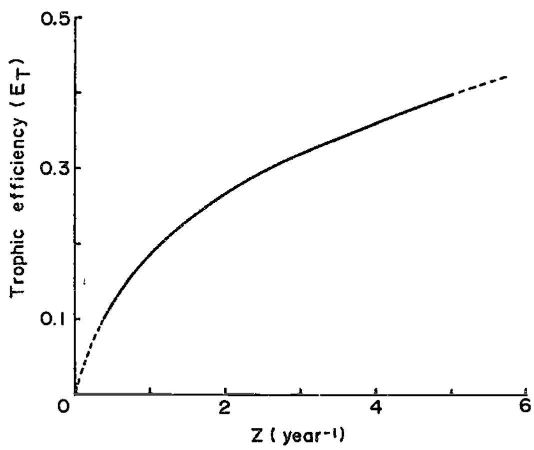

Fig. 4. Relationship between annual total mortality and trophic efficiency (E_T). Broken lines indicate possible direction of curve (see Discussion).

Discussion

Although the value of Q/B estimated here is comparable to other estimates for groupers, it should be noted that the fish used in this experiment were stressed (since they were transported from their natural environment to the fish cages) and overfed (as indicated by the relatively high rations in Table 6) and were therefore consuming more food than would have been normally available to them in the field, which justifies using R as a variable.

Table 6. Estimates of food consumption for other epinephelids (from Pauly and Palomares 1987; see Table 5).

Species	Habitat	°C	Q/B daily	Q/B annual	Remarks
E. tauvina[a]	Indo-Pacific	28	0.64	2.34	mean Q/B (daily) - 0.7 = R
E. guttatus[a]	Caribbean reefs	28	0.76	2.78	
E. fuscoguttatus	Philippines	28	1.10	4.01	this study

[a]From Pauly and Palomares (1987).

It should also be noted that the data in Table 2 gave significant negative correlations between C and mean weights (as in Eq. (3)), and between C, mean weights and daily ration (as in Eq. (6)). That is, as expected, K_1 was found in this data set to decline with body weight. Again as expected, as the fish grew bigger and consumed more food, their food conversion efficiency declined (Paloheimo and Dickie 1966). The relationship between K_1, body weight and biomass per cage was also investigated. As biomass per cage is highly correlated with mean weights, its effect on the whole correlation is high and very significant, but, the partial correlations proved to be of no significance at all.

It can be hypothesized that in a population composed mainly of big fish and wherein Z is very low, trophic efficiency (or the amount of food consumed that is added to the weight of the population), as well as food consumption per unit biomass tends to be low. In situations such as this, the food consumed goes mainly to the maintenance of the weight of the population and not to growth and therefore production per unit of food consumed would be almost nil. On the other hand, when the population is composed of very small fish, the reverse would be true. That is, where Z is high, it is expected that the population would be composed of small fish that would eat less but grow more, and therefore more of the food consumed would be added to the weight of the population. This relationship progresses exponentially as is illustrated in Figs. 3 and 4. This example does not give the whole picture because the software which was used to compute the values of Q/B and E_T was not capable of handling very small nor very big numbers for computation. Thus, the dotted lines for $Z < 0.4$ and $Z > 5$.

One assumption that could be made regarding the relationship illustrated in Fig. 3 is that extrapolating the curve to $Z = 0$ would give a value of Q/B = maintenance ration. Note that in Fig. 2 estimated maintenance ration is equal to 2.9/year which corresponds to the value (graphically) extrapolated in Fig. 3. As in Fig. 4, the dotted lines here indicate the directions that the curve will take if Z is increased steadily. It is possible that the curve, at extremely high values of Z, would level off asymptotically to a value of Q/B which at this point would, however, mean nothing because the population would then be just composed of planktonic larvae whose growth is not explained by the VBGF.

In view of all these and of the assumptions made in this exercise, it can be concluded that the model discussed above has met all the expectations. That is, it can be fitted to a data set obtained from the results of an experiment and give reasonable estimates of food consumption for a natural fish population.

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Appendix I

The multiple AM regression corresponding to Eq. (6) which resulted from the analysis of the data in Table 3 had the form

$$c = a + \beta \log W + b_1 R \qquad \text{... A1)}$$

where R is the daily ration in % of body weight and $C = -\log_{10}(1-K_1)$.

In the following, the steps, adapted from Pauly (1986a), are presented which transforms Eq. (A1) into a GM regression.

Changing the dependent variables, Eq. (A1) is first transformed to

$$\log_{10} W = \alpha_1 + d_1 C + d_2 R \qquad \text{... A2)}$$

and then to

$$R = \alpha_2 + d_3 \log_{10} W + d_4 C \qquad \text{... A3)}$$

Equations (A2) and (A3) can be solved for C, thus obtaining three equations with C as dependent variables. The geometric mean of the slopes (d_i) of these three regressions can then be computed. The three regressions in question were

$$\text{a) } C = 0.2508 - 0.0408 \log_{10} W - 0.008556 R \qquad \text{... A4)}$$

$$\text{b) } C = -\alpha_1/d_1 + 1/d_1 \log_{10} W - d_2/d_3 R \qquad \text{... A5)}$$

and hence

$$C = -(4.04/-11.94) - (1/-11.94) \log_{10} W - (-0.1009/-11.94) R \qquad \text{... A6)}$$

c) $C = \alpha_2/d_4 - d_3/d_4 \log_{10}W + 1/d_4 R$ ... A7)

and hence,

$$C = -(25.43/-89.02)-(-3.612/-89.02)\log_{10}W-(1/-89.02)R \quad \text{... A8)}$$

with multiple regression coefficients (corrected R^2) that are significant ($P < .01$) and equal to 0.774, 0.398 and 0.718, respectively, and all partial correlations significant at the 5% level.

The parameters of the GM regression (a' = intercept; b'_i = slopes) were then calculated with

$$\overline{C} = a' + b'_1\overline{\log_{10}W} + b'_2\overline{R} \quad \text{... A9)}$$

where $\overline{C}$ = mean of all $-\log_{10}(1-K_1)$ values, $\overline{\log_{10}W}$ = mean of all $\log_{10}W$ values, R = mean of all daily ration values (see Table 2) and where

$$b_1 = (b_1 \cdot 1/d_1 \cdot d_3/d_4)^{1/3} = -0.05188 \quad \text{... A10)}$$

$$b_2 = (b_2 \cdot d_2/d_1 \cdot 1/d_4)^{1/3} = -0.00933 \quad \text{... A11)}$$

thus,

$$a' = 0.05047 + (0.05188 \times 2.085) + (0.00933 \times 13.41) \quad \text{... A12)}$$

and thus a' = 0.2838; therefore the original AM equation (A1) has become a GM regression

$$C = 0.2838 - 0.05188 \log_{10}W - 0.00933R \quad \text{... A13)}$$

i.e., Eq. (A9) above.

Contributions to Tropical Fisheries Biology: Papers by the Participants of FAO/DANIDA Follow-up Training Courses. Edited by S. Venema, J. Möller-Christensen and D. Pauly. FAO Fisheries Report 389. Rome, 1988.

An Analysis of Statistical Data from the Jamaican Inshore Fisheries

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Abstract

Since 1968 the total annual fish production from the inshore areas of Jamaica has been about 7,000 t despite a doubling of the fishing effort. From the early 1950s the fishing fleet has undergone a process of mechanization whereby dug-out canoes propelled by oars or sails are being replaced by larger motor-driven fiberglass boats with improved capabilities. So, although the total number of boats increased by only 21% between 1968 and 1981, the effective fishing effort increased by about 100%. Since 1968, the catch per effective canoe (c/f) has declined at an average rate of 133 kg/year, and in 1981 stood at 59% of the 1968 rate. A plot of ln (c/f) against fishing intensity produces a linear curve, which when translated to give a total catch curve shows that maximum yields of 2.2 t/km^2/year are possible from the Jamaican shelf with a fishing intensity of about 1.1 mechanized canoes per km^2. The potential yield from the 4,170 km^2 of shelf and proximal banks is therefore estimated to be about 9,000 t/year. This maximum yield can only be attained if the fishing effort is regulated to ensure an even distribution of about 1.1 mechanized canoes per km^2 of shelf. At present the canoes are very unevenly distributed resulting in too great a fishing intensity in some areas and too little in others. The species composition of the catch has been changing. The high value species (e.g., Lutjanidae) declined from 43% of the total catch in 1968 to 29% in 1981, while low value fish (e.g., Acanthuridae) increased from 30% of the total catch in 1968 to 41% in 1981.

Introduction

This paper examines the changes in fishing effort and intensities that have occurred in the Jamaican inshore fishery and their impact on the exploited fish stocks.

In Jamaica the demand for fish and fish products is very high and far exceeds the available supply. The local marine fishery supplies less than one-half of the total demand. The unemployment rate in Jamaica is very high, approximately 30% of the labor force in 1984. Fishing is one of the few job opportunities for a large segment of the labor force with very little education and capital. At the same time the fishing industry is subsidized by the Government, and access to the fish resources is open (Aiken and Haughton) (in press).

The consequence of this situation is that there is an ever increasing competition for access to, and use of, the limited fish resources. The inshore fishing grounds that have traditionally supported a relatively small number of artisanal fishermen using mainly dug-out canoes propelled by oars are now supporting many more fishermen using larger mechanized fiberglass canoes as well as a large number of sport fishermen using high powered boats.

The Jamaican fishing industry may be divided into two sectors: the inshore fishery and the offshore fishery.

The inshore fishery is by far the most important of the two and takes place on the island shelf and its nine proximal small banks (Figs. 1 and 2). The South Shelf is relatively wide and reaches a maximum width of about 24 km south of the parishes of St. Catherine and Clarendon. The North Shelf is very narrow and its width does not exceed 1.6 km at any point. The island shelf and the nine proximal banks have a total area of 4,170 km^2.

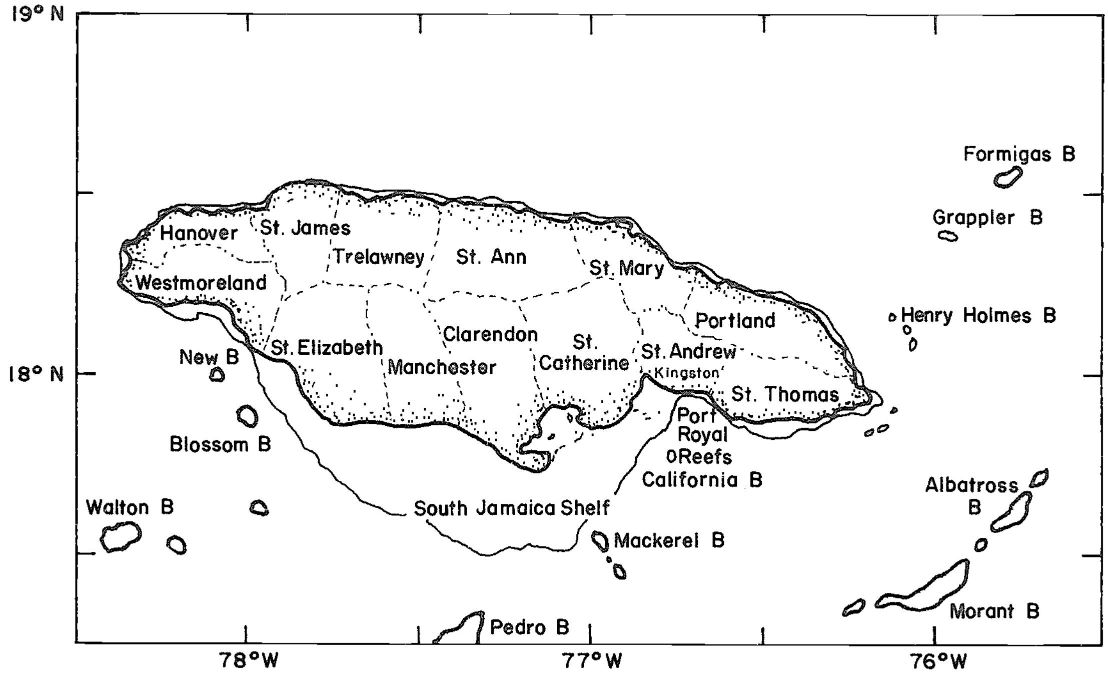

Fig. 1. Map of Jamaica showing extent of shelf areas (less than 200 m) and positions of proximal oceanic banks (from Munro and Thompson 1973).

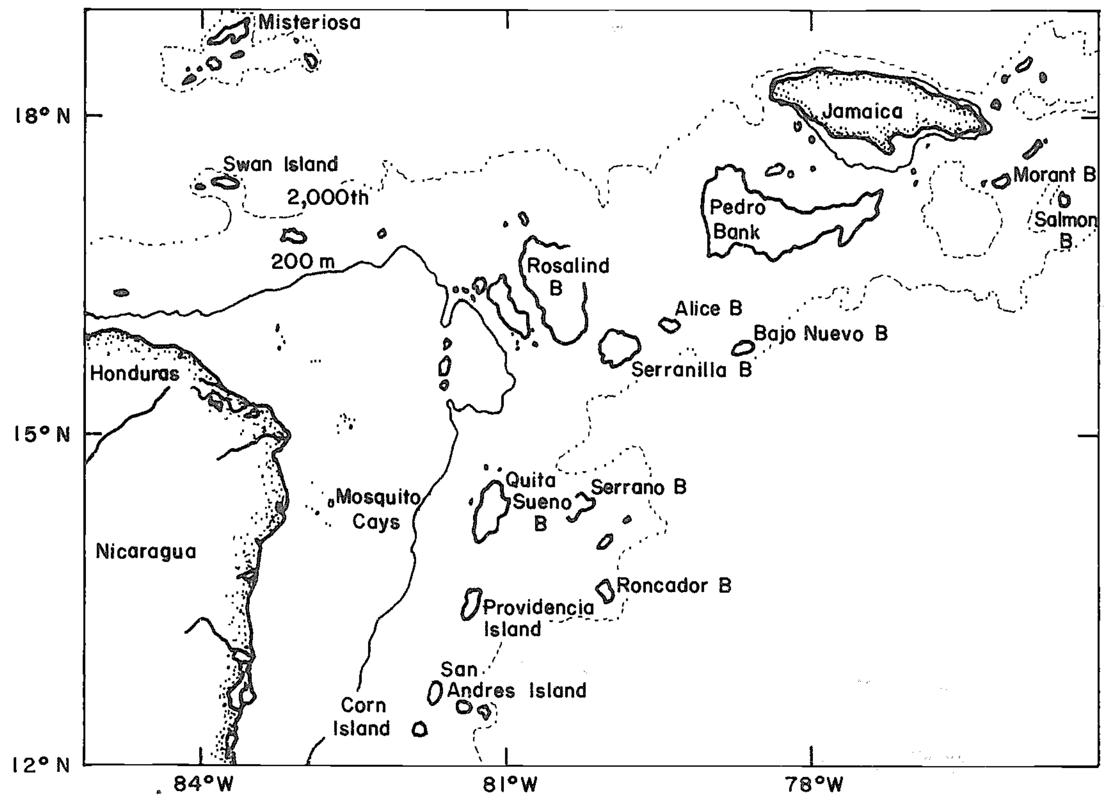

Fig. 2. Map of the west-central Caribbean, showing locations and extent of oceanic banks, and place names mentioned in the text (from Munro and Thompson 1973).

In 1981 an estimated 3,760 canoes operated from the 184 fishing beaches distributed around the island (A. Sahney, Ministry of Agriculture, Kingston, pers. comm.). There are over 16,000 persons registered as marine fishermen in Jamaica. Approximately 12,000 of these are believed to be full-time commercial fishermen; the remaining 4,000 are part-time and sports fishermen (Fisheries Division Files). Approximately 95% of the full-time fishermen operate within the inshore fishery and land about 88% of the catch in Jamaica.

The traditional Antillean "Z" trap made of galvanized wire of 3.2 cm mesh size is by far the most important fishing gear. Traps made of mesh wire of 2.5 cm mesh size are also common. Hand lines, troll lines, snapper reels, spear guns, gill nets and beach seines are also widely used.

The offshore fishery includes fishing operations that are based on offshore cays, as well as deep-sea fishing conducted by vessels operating independently of any land base for extended periods. There is at present a fleet of about 200 mechanized canoes and 550 fishermen based on the Morant and Pedro Cays. They are serviced by 10 carrier boats in the 10 to 26 m range, which ply between the Cays and Kingston, transporting supplies to the fishermen and returning with fish in ice. Under the Jamaica/Colombia fishing agreement of 1984, 28 Jamaican fishermen using nine mechanized canoes, base their fishing operation in Serranilla Cay in the San Andres archipelago (Fig. 2). They are supported by three carrier vessels.

In addition to the cay based operation, there are about five vessels ranging in size from 15 to 30 m operating as independent fishing vessels on either the Pedro, Bajo Nuevo or Serranilla Banks (Fig. 2). These vessels operate with hand lines, snapper reels, Antillean Z traps and lobster traps.

Materials and Methods

The material examined in this paper was taken from sample surveys of the fishing industry undertaken in 1962, 1968, 1973 and 1981 (Chuck 1962; Nembhard 1970; Data Bank and Evaluation Division 1982). Two other sample surveys of the fishing industry are reported to have been done but the results of these were apparently never published. The data contained in the surveys were obtained by enumerators who regularly visited the fishing beaches during the years of the surveys and sampled the catch as the boats arrived at the landing sites.

Because there was no standardized format for the sample surveys, the data collected on fishing effort and fish landings were analyzed, arranged and presented in different forms in the three surveys. For example, the 1968 survey presented the landings by parish, while the other two surveys did not. As a consequence, it was sometimes difficult to extract comparable data required for the analyses.

The reported fish landings for 1962 were extraordinarily high and various statisticians have argued that the sampling techniques employed during this survey resulted in greatly inflated estimates (Munro and Thompson 1973). The estimated landings based on the 1962 survey are therefore not used in this paper. The other surveys do not seem to have suffered such sampling deficiencies.

Reliable scientific data are thus available for three years, 1968, 1973 and 1981. In order to effectively increase the data base the island shelf is divided into North and South and each area is considered separately. This seems reasonable if, following Munro and Thompson (1973), we make the assumption that the ecological regimes and productivity of the North and South shelves and proximal banks are similar and that the only difference between the areas lies in the fishing intensities. The 1973 data could not be separated into North and South shelves because of the arrangement and presentation of the original data.

The best available measure of fishing effort in the Jamaican fishery is the number of canoes in operation. There are essentially two different types of canoes, those propelled by motors (mechanized canoes) and dug-out canoes propelled by oars or sails (unmechanized canoes). In general there are marked differences between these vessels in terms of their characteristics and capabilities. In order to develop a standardized measure of effort, unmechanized canoes are converted to their equivalent as mechanized canoes based on the catch ratio (R) of the "shelf fish" between the two types of boat. The catch ratio (R) is the catch of fish caught on the shelf per mechanized boat divided by the catch per unmechanized boat.

The "effective canoe effort" on the shelf (f) is then calculated from the number of mechanized canoes operating on the shelf (S) plus the number of unmechanized canoes (U), which are all operating on the shelf, divided by the catch ratio (R).

$$f = S + U/R \tag{1}$$

The resulting theoretical effective canoe effort is expressed in units of mechanized canoes and should be a more accurate representation of the true fishing effort, than is the total number of canoes in operation as used by Munro and Thompson (1973).

An important variable that is not taken into account in the computation of the effective fishing effort is the relative importance of the various types of fishing gear that are used. The type of data that would be required to introduce the contribution of the gear type is not available.

From the late sixties (and possibly earlier) it was known that mechanized canoes operating from beaches along the South Shelf travelled to the Pedro Bank up to 110 km from their bases. Munro and Thompson (1973) reported that such operations were quite productive. The results of the 1981 sample survey suggest that the catch per trip for such vessels was ten times higher than the catch per trip for other vessels operating on the South Shelf. The 1981 survey estimated that 22% of the total landings from the inshore fishery were made by such vessels. Unfortunately this survey gives no indication of the number of boats that were involved. The previous surveys were totally silent on this matter. All the fish landed on the South Shelf beaches were assumed to have come from the South Shelf. The mixing of the catch from the Pedro Bank with that from the South Shelf means that the productivity of the South Shelf may have been overestimated.

Finally, in addition to fishing on the shelf, some mechanized canoes fish with troll lines for oceanic pelagic fishes (*Scomberomorus cavalla, Scomberomorus regalis, Acanthocybium solandri, Coryphaena hippurus* and *Euthynnus alletteratus*). In order to obtain the correct number of mechanized canoes operating on the shelf (S), the estimated effort spent fishing for oceanic pelagics was subtracted from the total number of mechanized canoes in operation (Munro and Thompson 1973). The effort spent fishing for oceanic pelagic fishes expressed in number of vessels (C) was obtained by multiplying the total number of mechanized canoes (M) by the fraction of oceanic pelagic fishes in the catch (P). The fraction of oceanic pelagic fishes was obtained by dividing the total catch of oceanic pelagics, by the total catch of mechanized canoes.

The quantity of oceanic pelagic fishes landed is subtracted from the total fish landed to obtain the catch of shelf dwelling species. All the species of major economic importance from the shelf fishery have been included in this paper. The ten most important families grouped according to their value are: quality fish (high value) - Lutjanidae, Serranidae, Carangidae and Mullidae; common fish (medium value) - Pomadasyidae and Scaridae; trash fish (low value) - Balistidae, Acanthuridae, Holocentridae and Chaetodontidae.

The area of the island shelf and proximal banks was measured with the aid of a planimeter, using the 100 fathoms isobath as the limit (Table 9).

Results

Introduction

The results are presented mainly in tabular and graphical form. There are 9 tables and 7 figures which are arranged in sequence to show the calculations made, as well as the results.

Catch and Effort Relationship

Since 1968 the catch per effective canoe has been steadily declining. Fig. 3 is a plot of catch per effective canoe against years showing a steady decline. The actual rate of decline computed by linear regression is 133 kg/canoe/year. Using 1968 as the base year (100%), then the catch per effective canoe had fallen to 82% in 1973 and it had dropped further to 59% in 1981.

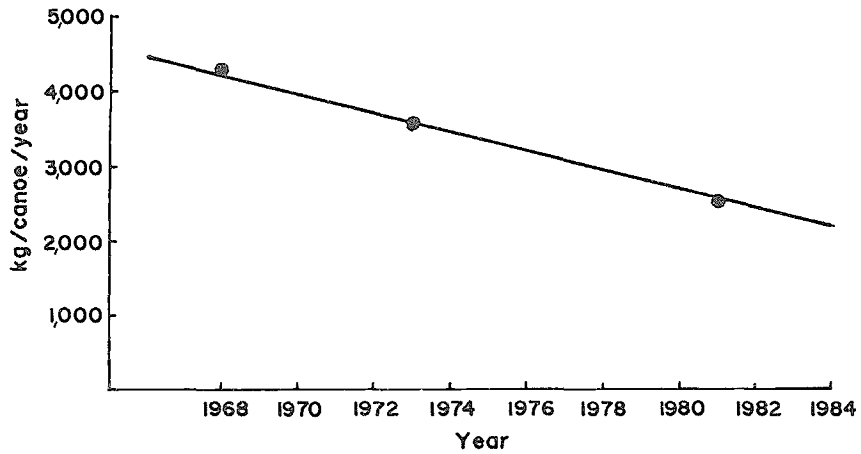

Fig. 3. Jamaica: Catch Per Canoe Against Years

Fig. 4 is a plot of catch per effective canoe against the number of effective canoes (f). It shows that as the number of effective canoes increases the catch per effective canoe decreases. With a 97% increase in fishing effort, the catch per unit of effort declined by 59%.

Catch and Fishing Intensity Relationship

The linear model

Fishing intensity is measured as the number of effective canoes (mechanized) per km^2. Fig. 5 is a plot of the catch per effective canoe (c/f) against fishing intensity (FI). The relationship appears to be linear and produces the following regression line: (r = 0.939):

$$c/f = 4618 - 2190FI$$

Fig. 7. includes a total catch curve constructed by reading points off the regression line in Fig. 5 and converting to t/km^2/year. This linear model suggests that maximum yields from the shelf of 2.4 t/km^2/year are possible with a fishing intensity of between 1.0 and 1.1 mechanized canoes per km^2. The model further suggests that at a fishing intensity of just over 2.1 mechanized canoes per km^2 the exploited fish stocks will be totally annihilated. This does not appear to be realistic and so the model must be rejected.

The logarithmic model

A plot of the natural logarithms of catch per effective canoe (1n c/f) against fishing intensity (FI) is shown in Fig. 6. The relationship is to be linear and produces the following regression line: (r = -0.986):

$$1n\ (c/f) = 8.58494 - 0.89492FI$$

Fig. 7 includes a plot of total catch constructed by reading points off the logarithmic regression line and converting to t/km^2/year. This logarithmic model suggests that maximum yields of around 2.2 t/km^2/year are possible with a fishing intensity of between 1.0 to 1.2 mechanized canoes per km^2 of shelf.

The logarithmic model appears to be more realistic than the linear model. It seems to fit the existing data more closely. Also the decline in catch as fishing intensity increases is much more gradual and is consistent with our knowledge of other tropical fisheries which show great resilience under increasing fishing pressure, e.g, the Gulf of Thailand demersal trawl fishery (Pauly 1984).

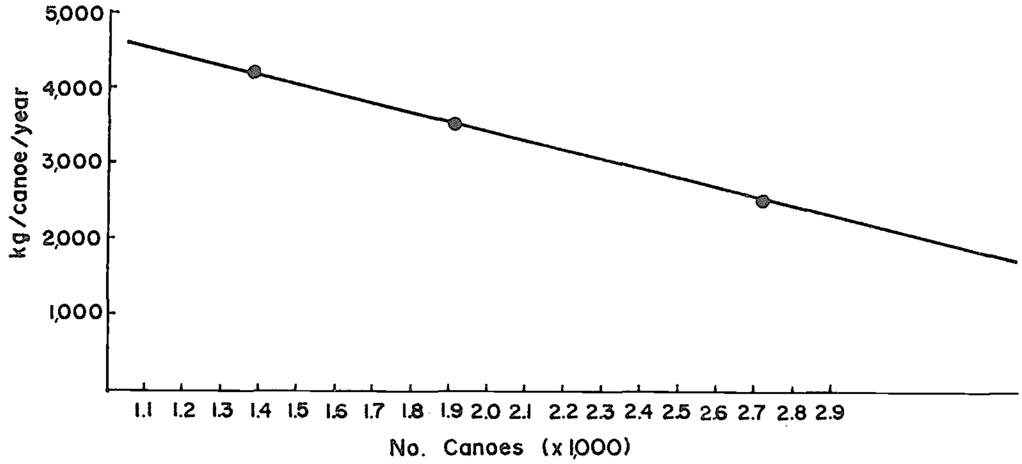

Fig. 4. Catch per effective canoe against number of effective canoes on Jamaican shelf.

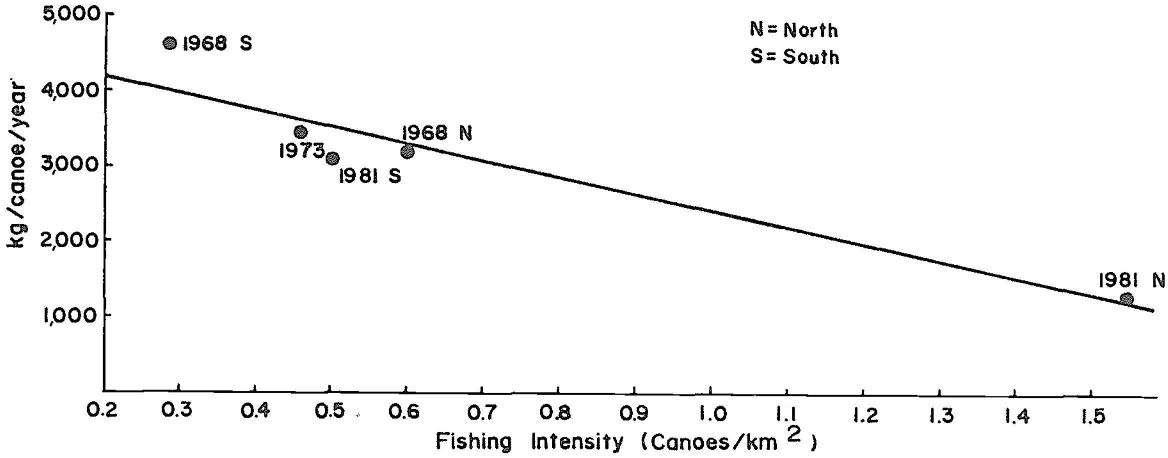

Fig. 5. Catch per effective canoe against fishing intensity (no. of effective canoes) on Jamaican shelf.

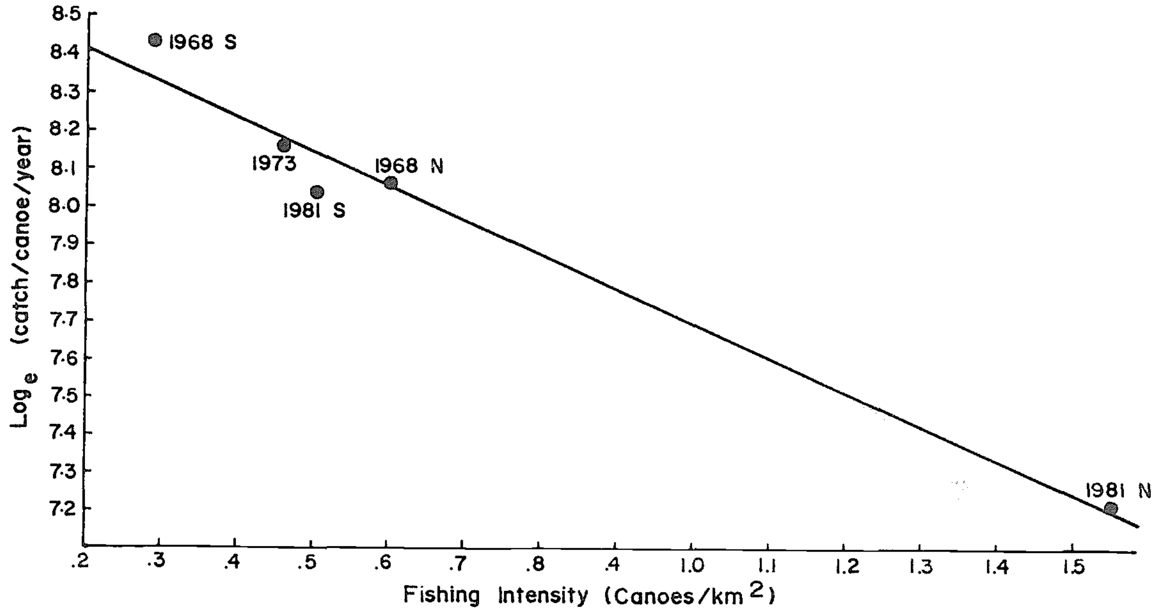

Fig. 6. Natural log of catch per effective canoe against fishing intensity (no. of effective canoes) on Jamaican shelf.

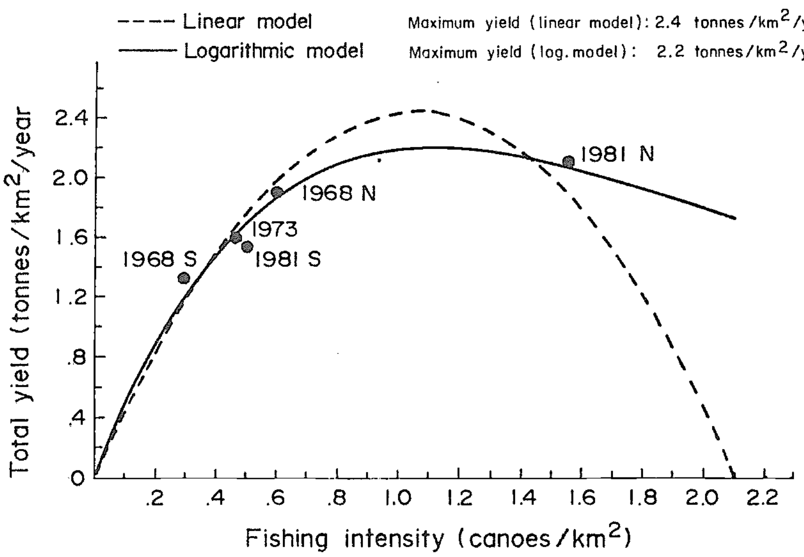

Fig. 7. Surplus yield models of the Jamaican shelf

Table 1. Fish landings from the inshore fishery in Jamaica (tonnes).

Year	North Shelf	South Shelf	Total
1968			
Total catch	1590	4982	6572
Subtotal mech. canoes	826	3586	4413
Oceanic pelagics (mech.)	433	299	732
Shelf fish (mech. canoes)	393	3287	3681
Shelf fish (unmech. canoes)	764	1396	2159
Subtotal shelf fish	1157	4683	5840
1973			
Total catch	477	6756	7233
Subtotal mech. canoes	77	4981	5058
Oceanic pelagics (mech.)	N/A	N/A	622*
Shelf fish (mech. canoes)	N/A	N/A	4436
Shelf fish (unmech. canoes)	400	1775	2175
Subtotal shelf fish	N/A	N/A	6611
1981			
Total catch	1476	5681	7157
Subtotal mech. canoes	1228	3787	5015
Oceanic pelagics (mech.)	194	206	400
Shelf fish (mech. canoes)	1034	3581	4615
Shelf fish (unmech. canoes)	248	1894	2142
Subtotal shelf fish	1282	5475	6757

Source: Government Fishery Statistics Surveys.
*Obtained by multiplying the total catch by mechanized canoes in 1973 by the average fraction of oceanic pelagics in 1968 and 1981
N/A - not available

Table 2. Number of canoes by area and type engaged in the inshore fishery of Jamaica.

	1968	1973	1981
North Shelf mechanized	211	328	503
North Shelf unmechanized	1063	834	1044
South Shelf mechanized	837	1129	1517
South Shelf unmechanized	998	824	696
Subtotal mechanized	1048	1457	2020
Subtotal unmechanized	2061	1658	1740
Total	3109	3115	3760

Source: Government Fishery Statistics Surveys

Table 3. Mechanized canoe effort on Jamaican shelf.

	1968	1973	1981
Total no. of mechanized canoes (M)	1048	1457	2020
Total catch by mech. canoes (C)	4413	5058	5015
Catch of oceanic pelagics (P)	732	622	400
Fraction of oceanic pelagics (p)	0.17	0.12	0.08
Mech. canoes off shelf (O)	178	175	162
Mech. canoes on shelf (S)	870	1282	1858

Notes: p = P/C; O = p * M; S = M - O

Table 4. Catch per canoe type and catch ratios of Jamaican canoes.

	Mechanized (t/year)	Unmechanized (t/year)	Catch ratio (R)
1968	4.23	1.05	4.03
1973	3.46	1.31	2.64
1981	2.48	1.23	2.02

Notes: Catch per mechanized canoe was obtained by dividing the catch of shellfish by mechanized canoes (Table 1) by the number of mechanized canoes on the Jamaican shelf (S in Table 3).

Table 5. Computation of effective canoe effort on Jamaican shelf.

	North	South	Total
1968			
No. mech. canoes (M)	211	837	1048
Fraction oceanic pelagics (p)	0.52	0.08	0.17
No. mech. canoes off shelf (O)	110	67	177
No. mech. canoes on shelf (S)	101	770	871
No. unmech. canoes (U)	1063	998	2061
Catch ratio (R)	4.03	4.03	4.03
Effective canoe effort on shelf (f)	365	1018	1382
where f = S + U/R			
1973			
No. mech. canoes (M)			1457
Fraction oceanic pelagics (p)			0.12
No. mech. canoes off shelf (O)			175
No. mech. canoes on shelf (S)			1282
No. unmech. canoes (U)			1658
Catch ratio (R)			2.64
Effective canoe effort on shelf (f)			1910
1981			
No. mech. canoes (M)	503	1517	2020
Fraction oceanic pelagics (p)	0.16	0.05	0.08
No. mech. canoes off shelf (O)	80	76	162
No. mech. canoes on shelf (S)	423	1441	1858
No. unmech. canoes (U)	1044	696	1740
Catch ratio (R)	2.02	2.02	2.02
Effective canoe effort on shelf (f)	940	1786	2719

Table 6. Catch and effort relations per year from the Jamaican shelf fishery.

	1968	1973	1981
Total shelf landings (t/year)	5840	6611	6757
Effective canoe effort (f)	1382	1910	2719
Catch/effective canoe (kg/canoe/year)	4226	3461	2485
ln (catch/effective canoe)	8.35	8.15	7.82
Area of shelf (km^2)	4170	4170	4170
Fishing intensity (FI) (canoe/km^2)	0.331	0.458	0.652
Yield per area (kg/km^2/year)	1400	1585	1620

Table 7. Catch and effort relations from North and South Jamaican Shelves.

	1968 North Shelf	1968 South Shelf	1973 North & South Shelves	1981 North Shelf	1981 South Shelf
Total landings (kg/year)	1157	4683	6611	1282	5475
Effective canoe effort (f)	365	1018	1908	940	1786
Catch/effective canoe (kg/canoe/year)	3170	4600	3465	1364	3065
ln (catch/canoe)	8.06	8.43	8.15	7.22	8.03
Area of shelf (km^2)	608	3562	4170	608	3562
Fishing intensity (canoe/km^2/year)	0.600	0.286	0.458	1.546	0.501
Yield per area (t/km^2/year)	1.90	1.31	1.59	2.11	1.54

Changes in Species Composition

There have been significant changes in the species composition of the landings from the inshore fishery since 1968. The Government Sample Surveys indicate that the percentage of high value species (quality fish) such as snappers (Lutjanidae) is decreasing while the percentage of low value species and of common fishes such as surgeon fishes (Acanthuridae) and parrot fishes (Scaridae), respectively, in the total catch is increasing.

Table 8 is compiled from the sample surveys and sets out the changes in the catch composition that have taken place between 1968 and 1981.

Discussion

The sample surveys of the fisheries industry suggest that the total catch from the inshore fishery changed very little between 1968 and 1981. This, coupled with the fact that the total number of canoes in operation did not increase dramatically during this period, led many to conclude falsely that the fishery had stabilized and was producing at about the maximum sustainable yield.

An examination of the process of mechanization of the fishing fleet reveals that very significant changes in both fishing effort and fishing patterns were taking place. The mechanized canoes which are replacing the unmechanized canoes are capable of carrying more fishermen, going farther offshore, spending longer periods in the fishing grounds and servicing more fish traps than the unmechanized canoes. As a consequence, they harvest more fish per unit of time.

Although the logarithmic model appears to be more reliable than the linear model (Fig. 7), its predictions must be viewed with caution considering its limited statistical base.

The estimated maximum yield of 2.2 t/km^2/year is substantially lower than the 4.1 t/km^2/year predicted by Munro and Thompson (1973). With a total shelf area of 4,170 km^2 this would give a total potential yield of 17,000 t/year, compared to 9,000 t/year obtained in this paper. Maximum yield from other shelf areas with similar ecological characteristics around the Caribbean may vary from 0.5 to 1.5 t/km^2/year (FAO 1985).

Munro and Thompson's model suffers from three major weaknesses. The first is the exclusion of the parish Trelawney from the analysis because, it did not fit in with the trend of the other parishes. The second is the assumption that mechanized and unmechanized canoes represent equivalent units of fishing effort. The third problem arises from the use of the small

Table 8. Changes in catch composition of the Jamaican canoe fishery.

Year	Quality fish Weight (t)	%	Common fish Weight (t)	%	Low-value fish Weight (t)	%	Lobsters Weight (t)	%
1968	2763	43	1525	23	1994	30	290	4
1973	2192	30	1780	25	2808	39	452	6
1981	2016	29	1960	27	2897	41	233	3

Table 9. Shelf areas (down to 100 fathoms) by main island parish and proximal banks.

Main island Parishes	Shelf area km²	Proximal Banks	Shelf area km²	Subtotal km²
Westmoreland	164	California	11	
St. Elizabeth	633	Morant	158	
Manchester	531	Mackerel	25	South
Clarendon	1,134	Blossom	63	3562
St. Catherine	382	New Bank	38	
St. Andrew	114	Walton	75	
Kingston	37			
St. Thomas	197			
Portland	69	Albatross	113	
St. Mary	59	Formigas	119	
St. Ann	50	Grappler	25	North
Trelawney	44	Henry Holmes	13	608
St. James	48			
Hanover	68			
	3,530	Total shelf + banks	640	4170

area of shelf adjacent to each parish, particularly on the North Shelf, as separate areas. While unmechanized canoes do not travel far from their bases of operation and may confine their operation to the shelf adjacent to their bases the same cannot be said about mechanized canoes. For example, mechanized canoes from Kingston often fish on the St. Thomas Shelf and land their catch in Kingston.

The inshore shelf fishery of Jamaica is at a stage in its development where government intervention is needed to regulate fishing effort (Haughton 1987). Both the linear and logarithmic models presented in Fig. 7 indicate that the fishing intensity on the North Shelf in 1981 was too high while at the same time the fishing intensity on the South Shelf needs to be stabilized at the result in major increases in yield of fish.

Another statistical survey of the Jamaican shelf fishery is due to be conducted during 1987. The results of this survey should significantly improve the model of the fishery presented in this paper. It is hoped too that economic data, notably on fishing cost and gross value of the catch will be collected so that an economic model of the fishery can be constructed, and the loss in resource rent from further increases in fishing effort estimated.

Acknowledgements

The author expresses his sincere appreciation to Mrs. B. Nembhard, Mr. R. Russell and Mr. K. Sahney, who compiled the results of the statistical surveys for 1968, 1973 and 1981 respectively. This paper would not have been possible without their contribution. He also thanks Mr. W. Shaul of the Fisheries Division for his assistance in measuring the areas of the Jamaican shelf.

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Mesh Size Selection in Antillean Arrowhead Fish Traps

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Abstract

The effect of mesh size selection in Antillean arrowhead traps was examined using data collected from 530 trap hauls of arrays of traps of identical dimensions and design constructed of three different mesh sizes. Selection ogives are determined for selected species and species groups. Comparisons are made of the results of this study with those predicted from considerations of mesh size and body depth. Determinations of the relative fishing power of the three mesh sizes are made for each of the selected species or species groups. The results indicate that selection by mesh size does occur and that J.L. Munro's predictions of selection parameters based on mesh size-body depth considerations are valid for selected species, but provide underestimates of retention sizes for others. The fishing power of traps is found to be affected by mesh size with large mesh traps fishing poorly. The species composition of the catch was affected by the mesh size used.

Introduction

The Antillean arrowhead is the dominant design of the fish traps of Bermuda. This design probably has been in use in the Antilles for several centuries (Munro et al. 1971) and is one of several still in use throughout the Caribbean. The design of the fish traps of the region has been described in some detail by Munro et al. (1971).

Fish traps are widely used throughout the Caribbean, the Bahamas and Bermuda to harvest a wide variety of reef finfish and crustaceans. The catch of traps contributes significantly to the landings of the artisanal fisheries of the region. Despite their importance to the livelihood of the fishermen and to the management of the fishery, relatively little is known of the way in which traps work. The important contributions of Munro et al. (1971) and Munro (1974) have identified some of the more important factors affecting fish trap catches. Specifically the effect of baiting, soak time, moon phase, conspecific attraction and escapement of trapped fishes are considered to be important. Munro (1974) developed a model to predict the build up of trap catches over time on the assumption that trap catches will approach an asymptotic level with increased soak time, due to increased escapement of trapped fish. Munro (1974) and Hartsuijker and Nicholson (1981) observed that species composition changes with soak time. The latter workers further demonstrated that the catch of small fish, particularly *Balistes* species decreases with time. This is in contrast with the findings of Stevenson and Stuart-Sharkey (1980) who reported that longer soak times led to an increase in the catch of the smaller, less valuable species.

High and Beardsley (1970) found that traps set in close proximity to reefs perform better in catching reef fishes with restricted home ranges. Hartsuijker and Nicholson (1981) further developed this concept and found that the presence of small groupers in trap catches is indicative of traps being set adjacent to reefs.

Stevenson and Stuart-Sharkey (1980) tested the effect of three different mesh sizes and found that increasing the mesh size led to a significant reduction in the number of fish caught, especially those in the smaller size classes. They also reported changes in the species composition of the catch. Some fish, particularly *Holocentrus* species were more effectively harvested by the larger mesh. They suggested that for management purposes the shift in species harvested would have to be considered in addition to the overall catch rates.

A major gap in the study of the workings of fish traps is the effect that the size of the funnel opening may have on size selection. Fishermen at Bermuda commonly open the funnel wide at the inner end when they are targeting spiny lobsters and close them for finfish. It is apparent that this does change the workings of the gear but, to date, no attempts have been made to quantify the effect. Luckhurst and Ward (in press) studied the effect of funnel type on retention of trapped fish and concluded that the "horseneck" funnel is more effective in preventing escapement and that funnel design will affect the way in which trap catches build up over time.

Hartsuijker (1982) conducted mesh size experiments in Jamaica using two different meshes, nominally 3.8 cm and 5.1 cm and found that the losses of small, shallow bodied fish were sufficiently great to suggest that the adoption of a larger mesh should not be seriously considered.

Although little work has been done on the effect of mesh size in traps, Munro (1983) proposed that the yield of the Jamaican reef fishery could be improved through the use of a larger mesh size. He developed a model for the prediction of the size at recruitment using a function of the maximum aperture of the mesh and the maximum body depth of the fish. Although he did recognize that the minimum size observed in his work was somewhat larger than the predicted minimum retention size this model was much criticized by Hartsuijker and Nicholson (1981) who proposed that the size at recruitment is more likely a function of the ecology and behavior of the species in question. They cited changes in foraging patterns and home ranges with age as probably determining the size at which the fish become susceptible to this gear type. They also suggested that the size at recruitment may be larger than the size predicted by considerations of maximum body depth as fish may be able to squeeze through meshes smaller than predicted.

The present study investigates the effect of using traps of mesh sizes much greater than those in use in Jamaica where Munro, Hartsuijker and their associates did their work. The Jamaican fishery is based on the use of traps of 3.2 cm mesh with some fishermen using 2.4 cm mesh (Haughton, this vol.) which is relatively small in comparison with those in use in Bermuda where this study was conducted. Bermuda has a legal minimum mesh size for traps of 3.8 cm but recently many of the local fishermen have decided to opt for a 5.1 cm mesh as it is less expensive and easier to build traps from (less meshes to cut and less ties to make). The intent of this study is to assess the effect of the use of this larger mesh on size at recruitment and fishing power.

Methodology

Traditional Antillean arrowhead traps of 120 x 120 x 60 cm were constructed of galvanized hexagonal wire mesh and reinforcing rod. The traps were made of three mesh sizes, 3.8, 5.1 and 8.3 cm, measured as the minimum opening between knots. The long axis of the mesh allowed 5.4, 7.0 and 10.4 cm openings, respectively. For the purposes of this study these meshes will be identified by the long axis (Fig. 1).

These traps were fished at several inshore sites during the summers of 1981 through 1983 using straight funnels and at offshore site during 1985 after being fitted with funnels of the "horseneck" (turned down on the inner end) design. The inner end of the funnel formed an entrance of approximately 26 x 15 cm in both designs.

Soak times were varied during the course of inshore trapping whilst they were basically constant (twice weekly) for the duration of the offshore work. Soak time has been found to effect species composition and catch levels of traps (Munro 1974; Hartsuijker and Nicholson 1981). To avoid soak time confounding the effects of mesh size, all traps were hauled on every sampling trip.

The catch was counted and measured to the nearest half cm. During the inshore work both the fork length (total length in groupers and parrot fish) and maximum body depth were recorded. No body depth measurements were taken in the offshore sampling. Lengths were later pooled into 1 cm or 2 cm groups. With 1 cm groupings the range of the "16 cm" class is 15.25-

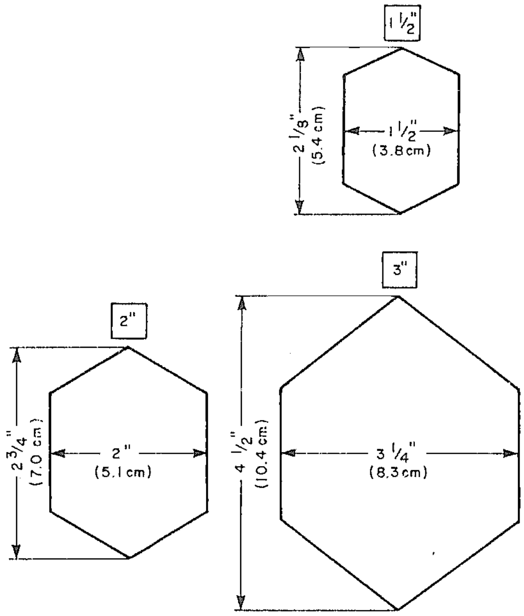

Fig. 1. Principle dimensions of commercially available wire mesh for traps used in Bermuda.

16.25 cm, midpoint 15.75 cm. With 2 cm groupings the range of the "16.5 cm" class is 15.25-17.25 cm, midpoint 16.25 cm. Mean values etc. are corrected accordingly.

Size-frequency data by length and maximum body depth were sorted by mesh size. Determinations of selection ogives were attempted for the dominant species and species groups. The % retained was determined by comparing the catch of fish of a size class in the mesh size under consideration with that of the corresponding catch in the 5.4 cm mesh. Moving averages of 3 were used to smooth out the selection curve. The 5.4 cm mesh was taken to be a standard with the assumption made that selection by this mesh did not occur in the size range in which the selection by larger meshes occurred. A point at full retention was assumed and the frequencies in the study mesh were raised to the level of the standard such that the cumulative frequency of post selection size classes was equal. This was done to remove the effect of differences in the fishing power of the different mesh sizes. Species were pooled in the body depth comparisons. The selection ogive was estimated as a cumulative normal distribution with mean L_c and standard deviation s (Beverton and Holt 1957). The 75% fractile is stated for consistency with authors approximating the selection ogive by a logistic curve (Hoydal et al. 1982). An example of this analysis and the results generated is presented in Table 3 and Fig. 3.

Calculated lengths at 50% retention (L_c) were compared with those predicted by the model of Munro (1983):

$$L_c = dD + v$$

where v and d are constants and D is the maximum aperture of the wire mesh and also the maximum body depth of a fish of length L_c. In the case of determining the predicted L_c for species groups, the constants v and d were averaged.

In all groups excluding *Acanthurus* the sample size for the 10.4 cm mesh was insufficient for the construction of selection ogives. In these cases estimates of the selection parameters were made by extrapolation from the results of the analysis of the 7.0 cm mesh using the relationship $L_c = M \times SF$ where M = mesh size and SF = selection factor. Given the L_c of the previous analysis and the corresponding mesh size, SF can be determined making calculations of L_c possible for other mesh sizes. From this L' (length at full recruitment) may be estimated as for instance:

$$L' = L_c + 2s$$

thus identifying 97.7% retention with full retention.

Relative fishing power was calculated by dividing the cumulative frequency of fish of sizes greater than or equal to a guessed L' in the mesh under examination by the corresponding cumulative frequency of fish in the 5.4 cm mesh.

Results

General

Of the 530 trap hauls included in this study, a total of 3,129 fish and shellfish were examined representing approximately 60 species. This led to fairly small sample sizes for most of the species and this precluded detailed analyses of the size-frequency data of all but the most dominant species or species groups.

The sample size by mesh size varied greatly with the 5.4 cm and 7.0 cm mesh traps catching far more fish than the 10.4 cm mesh (Table 1). No significant differences in the total catch (expressed as the average number of fish per trap haul) were observed between the 5.4 cm and 7.0 cm traps.

Table 1. Effect of mesh size and location fished on the mean catch and mean length.

Mesh size		Mean catch per haul Inshore	Offshore	Total		Mean length (cm) Inshore	Offshore
5.4 cm	H	108	65	173	n	830	567
	n	951	709	1660	L	26.6	28.1
	n/H	8.81	10.91	9.60	S	7.31	8.94
	S	10.33	9.58	10.08			
7.0	H	107	67	175	n	756	809
	n	813	912	1728	L	28.2	28.2
	n/H	7.60	13.61	9.87	S	7.52	5.86
	S	7.30	9.45	8.67			
10.4	H	108	69	177	n	102	65
	n	102	103	205	L	36.7	30.7
	n/H	0.94	1.49	1.15	S	9.52	7.39
	S	1.33	5.48	3.56			

H = number of trap hauls, n = number of fish caught, n/H = mean catch per haul, S = standard deviation, L = mean length (cm).

Both the location fished and the mesh size used were found to affect the species composition of the catch (Table 2). The differences between the species composition of the 5.4 cm and 7.0 cm mesh traps may be a reflection of the small sample size and random variation. However the 10.4 cm mesh clearly samples a much reduced species group. The differences in species taken at the different locations is indicative of the different species assemblages found in these areas and is included here for descriptive purposes only.

The location fished was found to affect the average size of fish caught. The 5.4 cm traps caught smaller fish at inshore sites whilst the 10.4 cm traps caught larger fish inshore than at offshore sites. The 7.0 cm mesh traps caught fish of a similar size regardless of area (Table 1). It is likely that this was a result of: a) the increased abundance of young fish being sampled by the small mesh inshore and b) the absence from offshore samples of several large species that are vulnerable to large mesh traps. Large inshore species that are caught by large mesh traps include the cowfish *Acanthostracion quadricornis,* hogfish *Lachnolaimus maximus* and the parrotfish *Scarus guacamaia*.

Table 2. Species composition by mesh size, ranked by abundance.

5.4 cm mesh Species	%	7.0 cm mesh Species	%	10.4 cm mesh Species	%
Inshore					
Haemulon sciurus	17.7	Haemulon sciurus	20.7	Acanthostracion quadricornis	31.0
Panulirus argus	12.8	Lutjanus griseus	18.2	Calamus calamus	14.6
Diplodus bermudensis	9.6	File fish*	14.6	Balistes capriscus	12.6
Sparisoma aurofrenatum	9.6	Diplodus bermudensis	8.4	Lachnolaimus maximus	8.7
Lutjanus griseus	8.9	Panulirus argus	6.6	Holocanthus isabelita	5.8
File fish*	5.7	Acanthostracion quadricornis	5.7	Rhinosomus triqueter	5.8
Haemulon album	5.2	Haemulon album	2.9	Scarus guacamaia	4.9
Haemulon flavolineatum	3.5	Lutjanus synagris	2.2	File fish*	3.9
Acanthurus bahianus	2.8	Calamus calamus	2.0	Calamus bajonado	2.9
Chaetodon spp.	2.3	Holocanthus isabelita	1.8	Caranx hippos	2.9
Offshore					
Acanthurus spp.	8.8	Acanthurus spp.	19.7	Acanthurus spp.	29.0
Holocentrus spp.	8.4	Acanthurus coeruleus	8.7	Acanthurus coeruleus	27.4
Panulirus argus	8.3	Scarus vetula	7.3	Holocanthus isabelita	14.5
Scarus vetula	8.1	Holocentrus spp.	6.9	Calamus spp.	11.3
Sparisoma viridae	7.8	Sparisoma viridae	6.5	Scarus coeruleus	8.1
Acanthurus coeruleus	7.5	Sparisoma spp.	5.5	Balistes capriscus	4.8
Haemulon flavolineatum	5.0	Pseudoupeneus maculatus	5.4	-	-
Scarus taeniopterus	4.1	Panulirus argus	4.6	-	-
Pseudopeneus maculatus	3.8	Scarus taeniopterus	3.8	-	-
Halichoeres radiatus	2.8	Paranthias furcifer	3.2	-	-

*File fish = *Stephanolepis hispidus, Cantherhirus pullus* and *C. macrocerus*.

If the hypothesis that rigid mesh fishing gear will select fish by body depth is accepted then it makes good sense that the grouping of species is done for purposes of assessing the effect of mesh size on catch. When the entire catch is pooled by body depth the effect of mesh selection is clear (Fig. 2). The minimum sizes retained correspond well to the maximum aperture of the mesh. This is particularly true when all observations of the abberantly-shaped cowfish *Acanthostracion* spp. and trunkfish *Rhinosomus triqueter* are removed. These fish have rigid bodies, triangular in cross section, which may prevent small individuals of a body depth less than the maximum dimension of the mesh from passing through.

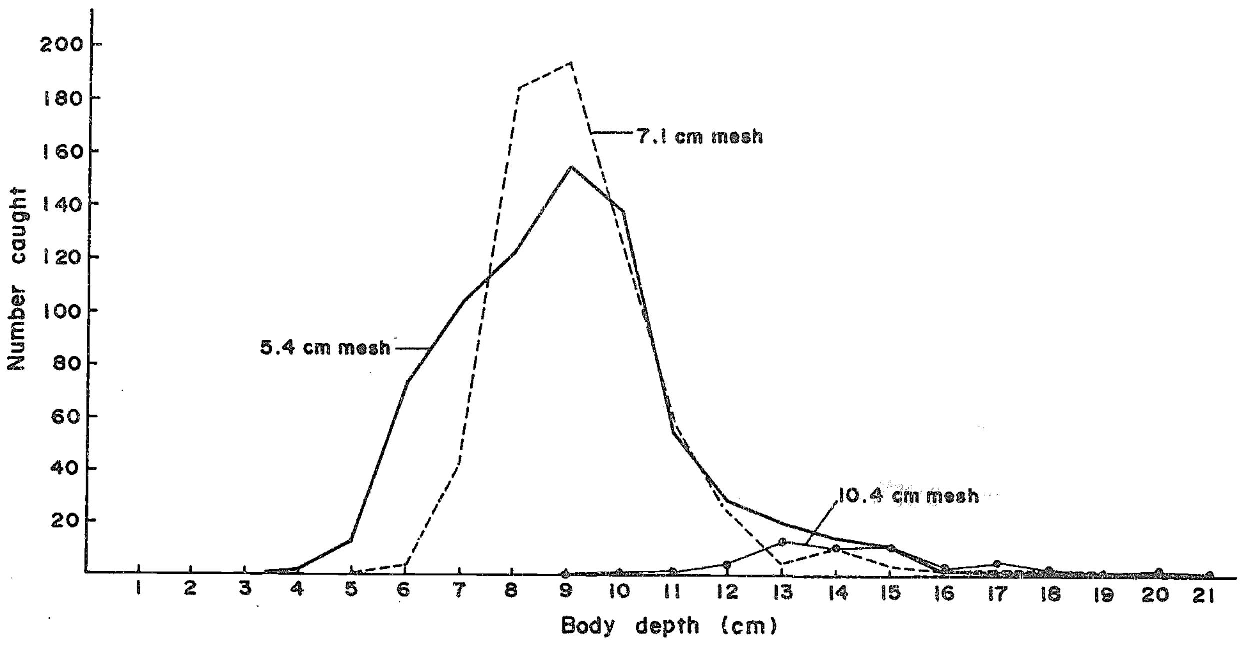

Fig. 2. Size distribution by body depth of catch from traps of 3 mesh sizes in Bermuda.

Selection Ogives

Five species and species groups were identified that had data sets which looked promising for the assessment of selection parameters. Species grouping was done only with species of similar body shape and habits.

Haemulon spp.

This group includes three species presented here ranked in descending order of abundance: *H. sciurus*, *H. flavolineatum* and *H. album*.

Table 3 presents a full example of the way in which the analyses were done using the genus *Haemulon* and Fig. 3 shows the selection curve and corresponding probit diagram. No specimens of this genus were observed in the 10.4 cm mesh traps. The length at "full retention" (L') was guessed to be 27 cm. The probit analysis led to estimates of L_c = 20.7 cm and of the guessed L'

Table 3. The method of retention analysis; *Haemulon* species in 7.0 cm mesh traps. (NB : L' assumed to be 25 cm for calculations of fishing power and raising factors).

	5.4 cm mesh		7.0 cm mesh				
F.L. cm	Freq. n	Moving avg. of three	Freq. n	Moving avg.	Raised avg.	Retained %	Probit
<10	5						
15	1						
16	1 P	1.00					
17	1	1.67					
18	3	3.33	1	0.33	0.29	8.7	3.64
19	6	8.00	0	1.33	1.17	14.6	3.95
20	15	12.00	3	4.33	3.81	31.8	4.53
21	15	16.33	10 P	10.0	8.80	53.9	5.10
22	19	17.67	17	13.67	12.03	68.1	5.47
23	19	16.33	14	15.33	13.49	82.6	5.94
24	11	12.67	15	15.33	13.48	106.5	
25	8	11.00	17	18.67		165.3	
26	14	15.33	24	24.33		154.5	
27	24	20.67	32	27.33			
28	24	24.67	26	28.0			
29	26	25.67	28	27.0			
30	27	23.00	25	25.33		100	
31	16	19.67	23	19.67			
32	16	12.67	10	12.67			
33	6	9.00	5	5.67			
34	5	4.33	2	2.33			
35	2	2.67	0	0.67			
36	1	1.00					
37	0	0.33					
Totals	265		252				
≥ L	169		192				

L_c = 20.73 cm
L_{75} = 22.15 cm
L_{95} = 24.19 cm
$L_{99.9}$ = 27.23 cm
s = 2.105
P = L_c predicted from Munro's model c
The assumed L' corresponds to 97.2% retention
Fishing power of 7.0 cm mesh = 1192/169 = 1.1361

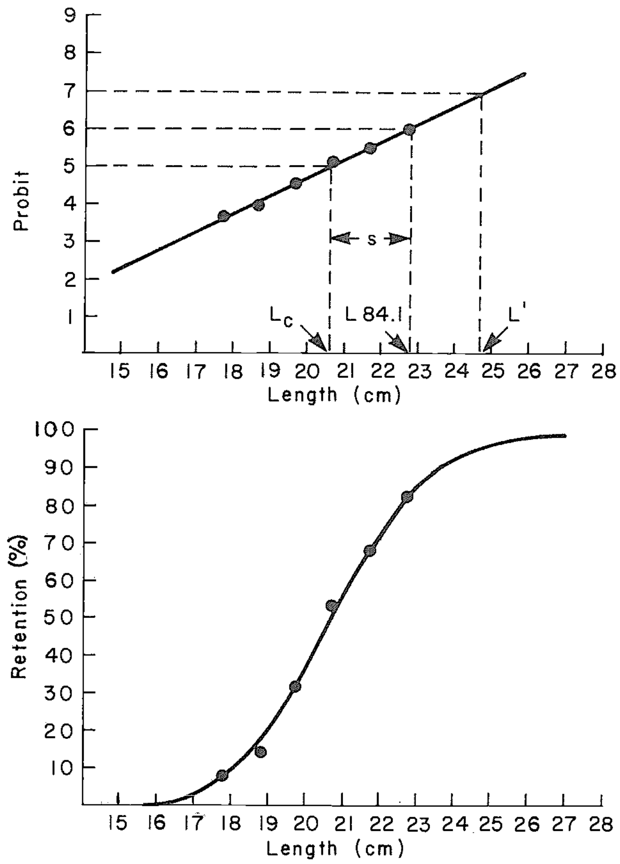

Fig. 3. Mesh size selection by fork length. Selection curves for *Haemulon* spp. in 7.0 cm mesh.

as the 97.2% fractile. The L_{75} (75% fractile) = 22.2 cm. This value for L_c compares well with the predicted value of 21.2 determined using the Munro model. The fishing power of the 7.0 cm mesh was determined to be 1.14, using the 5.4 cm mesh as a standard. The standard deviation of 2.10, which is indicative of the spread of the selection curve, is relatively small in this group. Small values of standard deviation are to be expected in deep bodied species where small increases in length correspond to relatively large increases in body depth and in species that do not actively attempt to escape from the gear. *Haemulon* spp. are not particularly deep bodied fish but after many hours of observing the behavior of these animals in traps, this author feels that they could be classified as "passive".

Haemulon sciurus was the most abundant species observed in the course of this study, the large majority of which were taken inshore. The size distribution reported in Table 4 shows a very close correlation between the calculated and predicted values of L_c, 20.5 cm and 21.6 cm, respectively, for the 7.0 cm mesh. The predicted value for 5.4 cm mesh (17 cm) also corresponds well with the observed frequencies. The $L_{99.9}$ was found to be 27.3 cm and L_{75} = 22.0 cm. The relatively small s value indicates that selection by mesh size is quite pronounced in this species. The observation of the decrease in value when all *Haemulon* spp. are pooled (Table 3) is probably indicative of the effect of increased sample size allowing for better estimations of % retention. The fishing power of 7.0 cm mesh was determined to be 1.02. *H. sciurus* were not caught in the 10.4 cm mesh traps.

Acanthurus spp.

This group was made of the three species occurring at Bermuda. In descending order of abundance, they are *A. bahianus, A. chirurgus* and *A. coeruleus*.

Table 4 shows the distribution of this group amongst the three mesh sizes. As was the case in the work of Munro (1983), the predicted L_c is somewhat smaller than the minimum observed

Table 4. Observed size frequency distribution of selected species and species groups presented by mesh size and including observed and predicted selection parameters.

	Acanthurus spp.			*Haemulon sciurus*				*Lutjanus griseus*				*Scaridae*		
FL (cm)	A 5.4 cm	B 7.0 cm	C 10.4 cm	A 5.4 cm	B 7.0 cm	C 10.4 cm	FL (cm)	A 5.4 cm	B 7.0 cm	C 10.4 cm	FL (cm)	A 5.4 cm	B 7.0 cm	C 10.4 cm
14	1						18.5				20			
15	1			1			20.2	4 P	1		21	4		
16	1	P		1			22.5	8	0		22	2-	1*P	
17	4	1		1 P			24.5	19	0		23	4	1	
18	0	1		2	1		26.5	11	10		24	4	5	
19	5	7*		4	0		28.5	17	50		25	12	4	
20	4	12	P	5	1		30.5	8	14		26	14	9	
21	11	14	1	5	3*		32.5	3	16		27	11	14	
22	18	28	0	7	6 P		34.5	5	10		28	17	22	
23	28	48	3	14	6		36.5	2	7	P	29	14	32	
24	17	30	6*	7	14		38.5	2	3		30	31	39	
25	7	23	2	6	17		40.5	1	1		31	21	27**P	
26	7	24	5	12	19		42.5	1	0		32	22	18	
27	7	21	2	20	27**		44.5	1	1		33	15	18	
28	5	8	8**	17	19		46.5	0	1	1	34	18	10	
29	2	7	4	18	16		48.5	0	1	0	35	12	11	
30	3	2	2	17	20		50.5	0	1	0	36	11	7	
31	4	5	1	11	12	*	52.5	0	0	1	37	13	7	
32	0	1	1	10	6		54.5	0	0		38	12	12	**
33	1			2	2	P	56.5	0	1		39	7	3	
34	2			4	1		58.5	0			40	5	5	
35				1		**	60.5	0			41	10	4	1
36				1			62.5	0			42	4	0	0
37							64.5	1			43	0	0	0
38											44	0	1	0
39											>45	1	4	6
Total	128	232	35	265	252	0		83	144	2		264	254	7
s =		4.51	3.21		2.08								2.77	

Legend:
* = L_c calculated ** = $L_{99.9}$ calculated
P = Predicted L_c s = standard deviation
A, B and C = different mesh sizes.

size; however, the differences are small. Munro's model predicts L_c values of approximately 10 cm for 5.4 cm mesh and 16 cm for 7.0 cm mesh. Very few small fish were caught in either mesh size (i.e., FL < 20 cm, n = 12 (5.4 cm mesh) and n = 9 (7.0 cm mesh)). Construction of selection ogives from such limited data is tenuous as is reflected in the very high value for 7.0 cm mesh. Data from 5.4 cm and 7.0 cm mesh were pooled for comparison with the 10.4 cm mesh as the size range for selection in 10.4 cm mesh is well beyond the size at which selection is likely in these smaller meshes. The L_c for 10.4 cm mesh was calculated to be 24.3 cm, L_{75} = 26.5 cm and L' = 35.0 cm. The relatively high value for these fish may simply be a result of the small sample size in the large mesh. The observation of individuals in the 5.4 cm mesh traps of a size much smaller than the predicted L_c for the two larger mesh sizes suggests that the lack of small fish in the larger mesh traps is not due to size related behavioral changes. Some other factor is influencing the minimum size retained. As the trend of increasing size at first retention increases with mesh size it is clear that mesh selection is occurring, only at a size larger than predicted. This could be due to differences in the observed body depth of fish measured whilst in the defensive posture and that of the same fish when attempting to pass through the mesh or simply because these fish are good at squeezing through the mesh.

Lutjanus griseus

This species, the most abundant predator observed in this study, was rarely found in the offshore catch. Upon close examination of the size distribution of the catch by mesh size, it became clear that the data are insufficient for the construction of a meaningful selection ogive. Table 4 shows that the occurrence of *L. griseus* in 7.0 cm mesh traps builds up rapidly at the 26.5 cm-28.5 cm size range to levels higher than those observed in the 5.4 cm mesh. This occurs at the point slightly larger than Munro's model predicts the 50% retention size to be (predicted L_c = 25.0 cm). The corresponding predicted value for 5.4 cm mesh coincides with the minimum size observed in this gear. The predicted L_c for 10.4 cm mesh is much smaller than the minimum size caught in this mesh. The length/body depth relationship for this species is not reported by Munro (1983) and was determined (by means of linear regression of data collected during this study) to be, in cm:

$$FL = 1.3 + 3.4 \times \text{Body depth}$$

This species displays much higher catch rates in the 7.0 cm mesh with fishing power values of 2.6 being obtained if the length at full recruitment is assumed to be 32.5 cm or 1.7 if no correction for selection is made. Only two specimens were observed in the 10.4 cm mesh traps suggesting a very low fishing power for this mesh.

Scaridae

This group was made up of several species, *Sparisoma aurofrenatum, S. crysopterum, S. viridae, Scarus taeniopterus, S. vetula* and *S. guacamaia* of which *S. aurofrenatum* was the most abundant.

The Scaridae or parrot fish comprise a large proportion of the catch from offshore stations. However certain species, most notably *Scarus guacamaia,* were caught mainly inshore. Both predicted and calculated L_c values are equal to 22 cm for the 7.0 cm mesh traps (Table 4). The predicted L_c for 5.4 cm mesh of 17 cm is smaller than the observed minimum size caught. This also occurred with the 10.4 cm mesh where the predicted value of 31 cm was much smaller than the smallest fish observed in this mesh. The fishing power of 7.0 cm mesh was calculated as 0.74 and the 10.4 cm mesh as 0.18. Interestingly, if no corrections are made for selection, the fishing power of 7.0 cm mesh is increased to 0.96. As was the case with *Lutjanus griseus,* this reflects the fact that this mesh caught more small fish than expected.

All species by body depth

The data from all inshore sampling were combined and, after the removal of those fish with bodies of triangular cross section, the data were used to determine the selection ogive and probit diagram for all species by body depth as was the case with *Lutjanus griseus* (Table 5 and Fig. 4). The assumption is made that if selection is a function of body depth then a selection ogive for all species can be constructed using this measure instead of length. The results of this analysis give a D_C value (depth at 50% retention) of 6.8 cm for 7.0 cm mesh. The difference between this value and the 7.0 cm prediction of the Munro model is considered to be insignificant. The small value observed is expected because a small increase in body depth will result in a substantial increase in retention if selection by mesh size occurs. Using the calculated selection factor (SF = 6.86/7.0 = 0.98) the value of D_C for 10.4 cm mesh is found to be 10.0 cm. The fishing power of 7.0 cm mesh was determined to be 1.2, and that for 10.4 cm mesh to be 0.7.

The selection ogive by body depth (Fig. 4) can be used in conjunction with the length to body depth relationships reported by Munro (1983) to estimate the selection ogive by length for fish which are not prone to "squeezing" (see Discussion). The example of *Haemulon sciurus* 7.0 cm mesh is presented here to illustrate this:

Table 5. Analysis of retention by body depth in 7.0 cm mesh (all species pooled); D' assumed to be 7.5 cm for calculations of fishing power and raising factors.

	5.4 cm mesh		7.0 cm mesh				
Body depth (cm)	Freq n	Moving avg (3)	Freq n	Moving avg (3)	Raised avg	Retained %	Probit
3.5	2	0.67					
4.0	0	1.33					
4.5	2	4.33					
5.0	11	9.67	0	0	0	0	
5.5	16	28.33	0	1.33	1.14	4.0	3.25
6.0	58	39.33	4	3.33	2.86	7.3	3.55
6.5	44	54.0	6	16.0	13.73	25.4	4.34
7.0	60	51.0	38	38.33	32.89	64.5	5.37
7.5	49	44.33	71	74.33			
8.0	74	61.0	114	90.67			
8.5	60	76.67	87	103.0			
9.0	96	71.67	108	84.0			
9.5	59	77.67	57	78.0			
10.0	78	56.67	69	54.0			
10.5	33	44.0	36	42.0		>100	
11.0	21	22.0	21	23.0			
11.5	12	13.67	12	15.33			
12.0	8	11.0	13	9.0			
12.5	13	10.0	2	6.33			
13.0	9	16.0	4	13.0			
≥ 13.5	26	11.67	33	12.33			
Totals	672		675				
> D'	538		627				

D_c = 6.86 cm
D_{75} = 7.33 cm
$D_{99.9}$ = 9.02 cm
s = 0.699
The assumed D' corresponds to 82.0% retention.
Fishing powetr of 7.0 cm mesh = 627/538 = 1.1654

FL = 3.1 * Body depth + 0.3 (Munro 1983):

D_C = 6.86 cm L_C = 3.1 * 6.86 + 0.3 = 21.6 cm (20.5)
D_{75} = 7.33 cm L_{75} = 3.1 * 7.33 + 0.3 = 23.0 cm (22.0)
$D_{99.9}$ = 9.02 cm $L_{99.9}$ = 3.1 * 9.02 + 0.3 = 28.3 cm (27.3)

The values given in parentheses are the calculated values from the selection ogive constructed for this species and are presented for comparison.

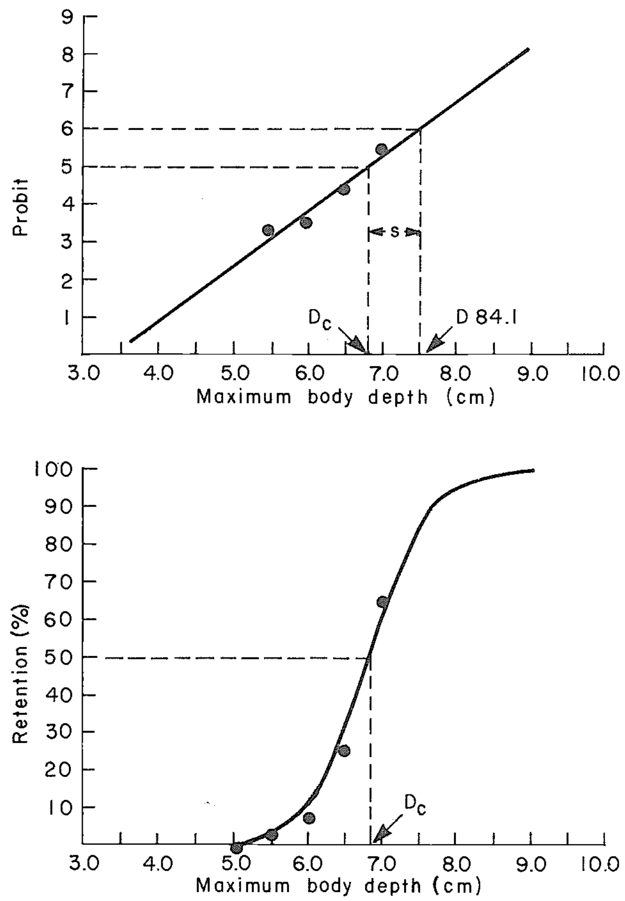

Fig. 4. Mesh size selection by body depth. Selection curves for 7.0 cm mesh.

Discussion

The results of this study show that size selection by mesh size does occur in Antillean arrowhead traps. This is most clearly demonstrated when the size of fish caught is considered as a function of body depth and mesh size. This is consistent with the predictions of Munro (1983). However, it must be appreciated that the predictive value of Munro's model varies with the species under consideration. For instance, although mesh selection was seen in *Acanthurus* spp., the model predicted values of L_C much smaller than the minimum size of fish observed. Hartsuijker and Nicholson (1981) proposed that this phenomenon, which was also observed in Jamaican trap catches, may have been caused by size related behavioral changes, flexibility in body depth or variations in mesh sizes. In this study fish of sizes smaller than the predicted L_C for the larger mesh sizes were caught in the smaller mesh traps. This indicates that the absence of these fish from the catch of the larger mesh traps is not due to size related behavioral changes, but some other factor such as "squeezing". The ability of fish to squeeze through rigid mesh will vary between species depending upon body rigidity and, perhaps ecological association with habitats where squeezing is advantageous.

The differences between observed and expected L_C values reported by Munro (1983) are much greater than those found in this study. Although the causes are unclear, this may be a reflection of the smaller mesh size used in Jamaica leading to an expected L_C small enough for size related behavioral factors to become important in determining vulnerability to traps. Alternatively in Jamaica there may be a higher incidence of a "nuisance fish", one which shows marked aggressive behavior when trapped, than in Bermuda. This could provide an increased incentive for escapement resulting in an increase in squeezing behavior. Luckhurst and Ward (in press) observed highly aggressive behavior by *Balistes capriscus* in traps at Bermuda. In

Jamaican offshore waters Munro (1983) found *B. vetula* to be the dominant species. If this species is similarly aggressive, this increased abundance in *Balistes* spp. in Jamaica may be responsible for the apparent increase in squeezing behavior observed there.

It is not unlikely that the escapement potential of trapped fish decreases with increasing size. Small fish would probably have less difficulty in escaping from the funnel entrance without injury from the terminal "spines" of the wire mesh funnel. This could reduce the proportion of the small fish in the catch as would the effects of squeezing behavior.

Another factor which may have a considerable effect on the escapement of trapped fish is the mesh size of the funnel. It is quite likely that funnels of small mesh provide a more distinct image to fish than those of larger mesh thereby making it easier for trapped fish to find their way out.

Predictions of yields from a trap fishery based on the effects of using different mesh sizes must include considerations of fishing power. Munro (1983) assumed that the fishing power of traps of different mesh sizes would be equal for fish larger than the size where selection would occur. The results of this study show that this is not valid, at least not for very large mesh traps. It is clear that 10.4 cm mesh traps do not fish well. Munro (1974) reports the observation that traps with a complex framework may present a stronger visual outline and therefore be more attractive to fish than those with less complex structures. Luckhurst and Ward (in press) also found that, from a diver's point of view, large mesh traps present a poor visual image. Anecdotal information from Bermudian fishermen suggests that well fouled traps are more effective in catching certain species than new ones. These observations along with the low catch rates for large mesh traps found in this study suggest that the visual impact of a trap may influence the area fished, at least in cases of unbaited traps or after the bait has been exhausted. The lack of retention of small fish may also reduce the fishing power of large mesh traps.

The data suggest that an unexpected increase in fishing power occurs when the mesh size is increased from 5.4 cm to 7.0 cm. This increase is, on the average, very small but for some species it is quite dramatic. The causes of this are unknown and more work needs to be done to clarify the effect of small increases in mesh size on the fishing power of traps.

As was suggested by Stevenson and Stuart-Sharkey (1980) another factor which should be considered when attempting to predict the effect of changes in mesh size on the yield of a trap fishery is the likely change in the species composition of the catch. In this study the increase in mesh size from 7.0 cm to 10.4 cm led to a reduction in the number of species taken as well as a reduction in the number of individuals of many of the species taken.

From the results of this study it appears as though the use of 7.0 cm mesh in the place of 5.4 cm mesh traps by Bermudian fishermen will not result in significant reductions in their catch rates and, due to the savings in material costs and time to construct the gear, may actually lead to more profitable operations. The fact that many of the fishermen are moving to this larger mesh gear is probably the best indicator of the economic sense of this observation.

Acknowledgements

The author would like to express his appreciation for the help and support of the staff of the Bermuda Government, Division of Fisheries without which this study could not have been conducted. He would also like to thank Roger Hollis for his help in the collection of the data from the offshore trapping work.

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A Comparative Study of Fish Mortality Rates in Moderately and Heavily Fished Areas of the Philippines

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Abstract

This paper deals with a comparative study of mortalities and densities of resource between heavily and moderately fished areas of the Philippines.

Apparent total mortalities in a number of demersal and pelagic fish species were found to be higher in areas being exploited by >70 fishermen/km of coastline and lower in moderately fished areas or those exploited by 2-70 fishermen/km.

Estimates of M obtained from plots of apparent total mortality *vs.* fishermen/km led to estimates of natural mortality that were credible in the case of demersal fish and unrealistically high in the case of pelagic fish. The latter effect is attributed to migration of the fish out of the sampling area.

Some implications of these findings for research and management are given.

Introduction

Instantaneous mortality rates are widely used population parameters in fish stock assessment. They tell something about the dynamics of the population when knowledge is available on how much of the total mortality is due to fishing and how much to natural causes (Gulland 1969).

As far as mortalities are concerned, Pauly (1984) indicated tasks for a fishery biologist: a) to estimate total mortality (Z), and b) to split the estimates of total mortality, where appropriate, into separate estimates of natural (M) and fishing mortalities (F). Knowledge of the parameters is important in fishery management, e.g., to determine whether an area is heavily fished or underfished, so that possible management measures can be taken.

There are several methods of estimating mortality rates in fish populations (Beverton and Holt 1957; Paloheimo 1961; Gulland 1969, 1983; Ricker 1975; Pauly 1984). The most straightforward of these is a plot of total mortality against fishing effort (f). Such plot should have an intercept (at $f = 0$) equal to M, and hence allow estimation of values of F through Z-M.

The purpose of this paper is to identify heavily and moderately fished areas in the Philippines based on a comparison of fish mortality rates and fishermen density (fishermen/km of coastline). This contribution also attempts to estimate natural mortality in a number of stocks, using Z and the density of fishermen as a relative index of fishing effort. The values of M thus obtained have been checked against estimates of M obtained through the empirical formula for estimating M presented by Pauly (1980). The basic hypothesis here being that catch curve estimates of Z may overestimate total mortality in some fishes which have a tendency to migrate out of the sampling area.

Materials and Methods

Values of Z, F, M, L_∞ and K of the different fish species from the various fishing grounds in the Philippines were taken from Ingles and Pauly (1984) and Corpuz et al. (1985).

Raw length-frequency data from the files of the Bureau of Fisheries and Aquatic Resources (BFAR) were also used. Most of these data were collected by the Regional Resource Assessment Team from their respective regional areas and a few were taken from the results of Fox (1986) of the USAID-funded Rainfed Resources Development Project.

Estimates of mortality rates (Z, F, M) for the raw data were calculated using the length-converted catch curve method, a built-in routine of the ELEFAN II Program (Pauly et al. 1981).

Due to the availability of these estimates of L_∞ and K, a comparative approach using ϕ' (Pauly and Munro 1984) was made for validation of the published growth parameters (Table 1). For each species, the highest values of L_∞ from the list were taken with the estimated K value derived from the mean ϕ' values to estimate Z, F and M for all raw length-frequency data; this procedure allowed analysis, using length-converted catch curves, of all available length data sets for a given species, using the same pair of L_∞, K values, thus ensuring comparability of Z estimates.

Table 1. Asymptotic length (L_∞ in cm), growth coefficient (K, $year^{-1}$) and computed ϕ' of different species taken from different fishing areas in Philippine waters.

Species	Area	Year	Source	L_∞	K	ϕ'
Nemipterus japonicus	Manila Bay	1978-1979	Ingles and Pauly (1984)	30.0	0.70	2.80
	Carigara Bay	1979	Corpuz et al. (1985)	23.5	0.70	2.59
	Samar Bay	1979	Corpuz et al. (1985)	26.5	0.60	2.62
	Guimaras Strait	1986	BFAR file	29.4	0.81	2.85
	Maqueda Bay	1986	BFAR file	29.4	0.81	2.85
	Leyte Gulf	1984	BFAR file	21.0	0.95	2.62
	Leyte Gulf	1985	BFAR file	30.0	0.583	2.72
						$\bar{\phi}'$ = 2.72
				L_∞ = 30.0, K = 0.583		Std. = 0.11
						C.V. = 3.86%
Nemipterus hexodon	Guimaras Strait	1986	BFAR file	25.5	0.475	2.48
	Maqueda Bay	1986	BFAR file	25.5	0.475	2.48
	Manila Bay	1982	BFAR file	25.5	0.475	2.48
				L_∞ = 25.5, K = 0.473		$\bar{\phi}'$ = 2.48
						Std. = 0
						C.V. = 0%
Saurida tumbil	Manila Bay	1978-1979	Ingles and Pauly (1984)	37.5	1.03	3.16
	Visayan Sea	1976-1977	Ingles and Pauly (1984)	41.0	0.70	3.07
	Samar Sea	1981	Corpuz et al. (1985)	43.0	0.64	3.07
				L_∞ = 43.6, K = 0.68		$\bar{\phi}'$ = 3.10
						Std. = 0.05
						C.V. = 3.10%

Table 1. Continued

Species	Area	Year	Source	L_∞	K	ϕ'
Pentaprion longimanus	Carigara Bay	1979	Corpuz et al. (1985)	14.5	0.69	2.16
	Samar Sea	1979	Corpuz et al. (1985)	17.0	1.22	2.55
	Samar Sea	1981	Corpuz et al. (1985)	15.75	1.00	2.39
	Burias Pass	1981	Corpuz et al. (1985)	17.25	1.03	2.49
	Samar Sea	1979-1980	Ingles and Pauly (1984)	16.5	1.55	2.63
	Java Sea	1978-1979	Dwiponggo et al. (1987)	13.5	1.10	2.30
				L_∞ = 15.25, K = 0.89		$\bar{\phi}'$ = 2.42
						Std. = 0.17
						C.V. = 7.85%
Upeneus sulphureus	Samar Sea	1979-1980	Ingles and Pauly (1984)	19.5	1.20	2.66
	San Miguel Bay	1980-1981	Ingles and Pauly (1984)	15.3	1.05	2.39
	Burias Pass	1981	Corpuz et al. (1985)	23.5	1.30	2.86
	Samar Sea	1981	Corpuz et al. (1985)	19.5	1.30	2.69
	Leyte Gulf	1985	BFAR file	2.35	0.81	2.65
				L_∞ = 23.5, K = 0.89		$\bar{\phi}'$ = 2.65
						Std. = 0.17
						C.V. = 6.35%
Sardinella fimbriata	Manila Bay	1981	BFAR File	17.0	1.20	2.64
	Visayan Sea	1985	BFAR File	21.3	1.03	2.67
	Guimaras Strait	1985	BFAR File	18.9	0.87	2.49
	Leyte Gulf	1984	BFAR File	21.3	0.91	2.62
	Leyte Gulf	1984	BFAR File	20.4	1.02	2.63
	India	1964	Radhakrishnan (1964)	18.4	1.32	2.65
	Manila Bay	1959	Ingles and Pauly (1984)	18.0	0.70	2.36
	Leyte Gulf	1965-1966	Ingles and Pauly (1984)	22.0	1.15	2.75
				L_∞ = 22.0, K = 0.82		ϕ' = 2.60
						Std. = 0.12
						C.V. = 4.65%
Sardinella longiceps	Palawan	1965	Ingles and Pauly (1984)	23.0	1.1	276
	Ragay Gulf	1981	Corpuz et al. (1985)	15.75	1.00	2.39
	Manila Bay	1978-1979	Ingles and Pauly (1984)	21.0	1.10	2.69
	Visayan Sea	1983-1985	BFAR File	27.0	0.90	2.82
	Bali Strait	1979	Dwiponggo et al. (1987)	22.3	0.85	2.63
	Bali Strait	1979	Dwiponggo et al. (1987)	23.2	1.28	2.84
	Visayan Sea	1984	BFAR File	21.5	1.05	2.69
	India		Antony-Raja (1972)	21.0	0.6	2.42
	India (W. Coast)	1973	Banerji (1973)	20.7	0.5	2.33
	India	1960	Nair (1960)	27.0	0.4	2.46
	India (Malabar)	1924	Hornell and Naidu (1924)	20.7	0.5	2.33
	India (Calicut)	1965	Bennet (1973)	21.0	0.6	2.42
	India (Karwar)	1969	Annigeri (1969)	21.0	0.6	2.42
				L_∞ = 27, K = 0.50		$\bar{\phi}'$ = 2.56
						Std. = 0.19
						C.V. = 7.29%
Gazza minuta	Ragay Gulf	1981	Corpuz et al. (1985)	22.5	1.3	2.82
	Palawan	1977-1978	Ingles and Pauly (1984)	17.5	0.97	2.47
	San Miguel Bay	1958	Ingles and Pauly (1984)	14.0	1.10	2.33
				max L_∞ =22.5, K =0.69		$\bar{\phi}'$ = 0.25
						Std. = 0.25
						C.V. = 9.94%

Continued

Table 1. Continued

Species	Area	Year	Source	L_∞	K	ϕ'
Rastrelliger brachysoma	Ragay Gulf	1981	Corpuz et al. (1985)	24.5	1.28	2.89
	Samar Sea	1979	Corpuz et al. (1985)	25.5	1.45	2.97
	Samar Sea	1981	Corpuz et al. (1985)	25.0	1.30	2.91
	Samar Sea	1979-1980	Ingles and Pauly (1984)	25.0	1.60	3.00
	Manila Bay	1958-1959	BFAR File	34.0	0.98	3.05
	Manila Bay	1960	BFAR File	34.0	0.98	3.05
	Visayan Sea	1983	BFAR File	34.0	0.98	3.05
	Visayan Sea	1984	BFAR File	32.5	1.2	3.1
	Visayan Sea	1985	BFAR File	34.0	0.98	3.05
	Samar Sea	1984	BFAR File	29.75	1.3	3.06
	Java Sea	1979	Dwiponggo et al. (1987)	22.9	1.8	2.97
	G. of Thailand	1970	Sucondharman et al. (1970)	20.0	3.53	3.15
	Manila Bay	1978-1979	Ingles and Pauly (1984)	34.0	1.10	3.10
	Leyte Gulf	1985	BFAR File	34.0	0.98	3.05
	Manila Bay	1958	BFAR File	34.0	0.98	3.05
	G. of Thailand	1970	Sucondharman et al. (1970)	19.6	4.14	3.20
	Borneo		Sudjastani (1974)	22.9	2.28	2.94
	G. of Thailand		Hongskul (1982)	20.9	3.38	3.11
	G. of Thailand		Samjaiwong et al. (1972, unpublished MS)	20.9	4.2	3.26
				L_∞ = 34.0, K = 0.98		$\bar{\phi}'$ = 3.05
						Std. = 0.11
						C.V. = 3.77%
Rastrelliger kanagurta	Palawan	1965	Ingles and Pauly (1984)	28.0	1.55	3.58
	Ragay Gulf	1981	Corpuz et al. (1985)	27.5	1.30	2.99
	Illana Bay	1984	BFAR File	39.0	0.72	3.04
	Illana Bay	1983	BFAR File	39.0	0.72	3.04
	Samar Sea	1981	Corpuz et al. (1985)	28.5	1.31	3.03
	Guimaras Strait	1985	BFAR File	27.5	1.65	3.10
	Samar Sea	1984	BFAR File	26.5	1.6	3.05
	Visayan Sea	1984	BFAR File	37.0	0.7	2.98
	Visayan Sea	1983	BFAR File	29.5	1.5	3.12
	Java Sea	1979	Dwiponggo et al. (1987)	25.8	1.63	3.04
	India	1964	George and Banerji (1964)	21.8	5.16	3.39
	India	1964	George and Banerji (1964)	23.3	3.12	3.23
	India	1964	George and Banerji (1964)	22.4	4.32	3.34
	Java Sea	1973	Sudjastani (1974)	23.9	2.76	3.20
	India	1973	Banerji (1973)	23.9	4.92	3.45
	India	1958	Seshappa (1958)	31.3	0.64	2.8
	Mozambique	1979	Sousa and Gislason (1985)	21.5	0.85	2.59
	Mozambique	1980	Sousa and Gislason (1985)	28.5	0.825	2.83
	Mozambique	1981	Sousa and Gislason (1985)	30.5	0.90	2.92
	Mozambique	1981	Sousa and Gislason (1985)	28.5	0.72	2.77
	India	1970-1974	Yohannan (1979)	24.1	2.61	3.18
	India	1980-1981	Udupa and Bhat (1984)	26.6	0.83	2.77
	India	1967-1974	Luther (1973)	39.0	0.74	3.05
				max L_∞ = 39, K = 0.72		$\bar{\phi}'$ = 3.04
						Std. = 0.21
						C.V. = 6.81%
Selaroides leptolepis	Guimaras Strait	1986	BFAR File	23.0	1.22	2.81
	Maqueda Bay	1986	BFAR File	23.0	1.22	2.81
	Manila Bay	1978-1979	Ingles and Pauly (1984)	29.0	0.80	2.83
	Visayan Sea	1976-1977	Ingles and Pauly (1984)	23.0	1.15	2.78
	Ragay Gulf	1981	Corpuz et al. (1985)	26.0	1.32	2.95
	Samar Sea	1981	Corpuz et al. (1985)	19.25	1.10	2.61
	Java Sea	1977	Dwiponggo et al. (1987)	22.0	1.20	2.76
				max L_∞ = 29, K = 0.733		$\bar{\phi}'$ = 2.79
						Std. = 0.10
						C.V. = 3.62%

Continued

Table 1. Continued

Species	Area	Year	Source	L_∞	K	ϕ'
Decapterus macrosoma	Visayan Sea	1985	BFAR File	33.0	0.607	2.82
	Visayan Sea	1984	BFAR File	33.0	0.607	2.82
	Samar Sea	1979	Corpuz et al. (1985)	23.0	1.25	2.82
	Ragay Gulf	1981	Corpuz et al. (1985)	25.5	1.26	2.91
	Manila Bay	1957-1958	Ingles and Pauly (1984)	31.5	0.65	2.81
	Manila Bay	1958	Ingles and Pauly (1984)	31.5	0.71	2.85
	Palawan	1957	Ingles and Pauly (1984)	27.0	0.90	2.82
	Palawan	1957-1958	Ingles and Pauly (1984)	26.8	0.71	2.71
	Palawan	1958	Ingles and Pauly (1984)	26.5	1.00	2.85
	Palawan	1958-1959	Ingles and Pauly (1984)	27.8	0.825	2.80
	Palawan	1959	Ingles and Pauly (1984)	33.0	0.50	2.74
	Palawan	1960	Ingles and Pauly (1984)	27.5	1.25	2.98
	Palawan	1965	Ingles and Pauly (1984)	25.0	1.20	2.88
	Palawan	1965-1966	Ingles and Pauly (1984)	25.5	0.85	2.74
	Palawan	1966	Ingles and Pauly (1984)	25.5	0.80	2.72
	Palawan	1968A	Ingles and Pauly (1984)	33.0	0.65	2.85
	Palawan	1968B	Ingles and Pauly (1984)	30.0	0.74	2.82
	Visayan Sea	1983	BFAR File	33.0	0.607	2.82
	Guimaras Strait	1985	BFAR File	33.0	0.607	2.82
				max L_∞ = 23, K = 0.607		$\bar{\phi}'$ = 2.82
						Std. = 0.07
						C.V. = 2.60%
Leiognathus bindus	Manila Bay	1958	Ingles and Pauly (1984)	10.3	1.25	2.12
	Manila Bay	1959	Ingles and Pauly (1984)	8.2	1.25	1.92
	Manila Bay	1960	Ingles and Pauly (1984)	8.2	1.30	1.94
	Ragay Gulf	1981	Corpuz et al. (1985)	13.6	1.03	2.28
	Burias Pass	1981	Corpuz et al. (1985)	13.5	0.96	2.24
	Samar Pass	1981	Corpuz et al. (1985)	13.75	0.88	2.22
				max L_∞ = 13.75, K = 0.70		$\bar{\phi}'$ = 2.12
						Std. = 0.156
						C.V. = 7.38%

The values of Z of the different fish species were then tabulated together with the fishermen densities in each fishing area (Table 2). A list of municipal fishery population statistics for 1980 was obtained from the National Census and Statistics Office to get population statistics of coastal fishing communities that provide estimates of the density, which can be used as a relative index of fishing pressure. Densities given were calculated for full-time fishermen only. For each fishing area included in this paper, densities were calculated only from identified fish landing sites used by BFAR personnel for collection of catch and effort and length data. For those with unidentified fish landing areas, densities were taken from all coastal fishing communities.

An attempt was made to estimate the natural mortality coefficient from

$$Z = M + qf$$

where

M = intercept of the regression of Z *vs.* fishing effort, expressed as number of fishermen/km
q = the catchability coefficient = slope of the regression line.

For each species for which more than two values of Z were available, estimated values of Z were plotted against the density of fishermen to determine relative impact of fishing in moderately and heavily exploited areas of the Philippines.

The definition of heavily and moderately fished areas here is based on Fox (1986) where:

heavily exploited > 70 fishermen/km

moderately < 2-70 fishermen/km

and where lightly fished areas are those with 0.20 to 2 fishermen/km.

Table 2. Values of Z ($year^{-1}$) of the various fish species and density of fishermen coastline (from Fox 1986) at the Philippine fishing ground where the species are taken.

Species	Fishing ground	Year(s)	Z ($year^{-1}$)	Density (fishermen/km)
Nemipterus japonicus	Guimaras Strait	1986	4.25	15
	Maqueda Bay	1986	6.214	98
	Manila Bay	1978-1979	3.31	104
	Carigara Bay	1979	2.49	22
	Samar Sea	1979	2.09	38
	Leyte Gulf	1984	4.707	16
	Leyte Gulf	1985	3.266	16
Nemipterus hexodon	Guimaras Strait	1986	1.849	15
	Maqueda Bay	1986	4.342	98
	Manila Bay	1982	1.904	104
Saurida tumbil	Manila Bay	1978-1979	4.83	104
	Visayan Sea	1976-1977	2.22	28
	Samar Sea	1981	1.68	38
Pentaprion longimanus	Carigara Bay	1979	4.46	22
	Samar Sea	1979	9.97	38
	Samar Sea	1981	10.80	38
	Burias Pass	1981	8.63	18
	Samar Sea	1979-1980	12.20	38
Upeneus sulphureus	Samar Sea	1979-1980	6.96	38
	San Miguel Bay	1980-1981	3.18	18
	Burias Pass	1981	5.75	18
	Samar Sea	1981	9.70	38
	Leyte Gulf	1985	5.593	16
Sardinella fimbriata	Manila Bay	1981	6.643	104
	Visayan Sea	1985	2.474	28
	Guimaras Strait	1985	3.752	15
	Leyte Gulf	1985	2.684	16
	Leyte Gulf	1984	2.744	16
	Manila Bay	1959	3.38	104
	Palawan		6.56	3
Sardinella longiceps	Ragay Gulf	1981	5.52	9
	Manila Bay	1978-1979	7.37	104
	Visayan Sea	1983-1985	3.155	28
	Palawan	1965	7.26	3
Gazza minuta	Ragay Gulf	1981	3.11	9
	Honda Bay, Palawan	1977-1978	6.62	3
	San Miguel Bay	1980-1981	8.85	18
	Manila Bay	1978-1979	4.27	104

Continued

Table 2. Continued

Species	Fishing ground	Year(s)	Z (year^{-1})	Density (fishermen/km)
Rastrelliger brachysoma	Ragay Gulf	1981	6.10	9
	Samar Sea	1979	9.14	38
	Samar Sea	1981	5.50	38
	Samar Sea	1979-1980	6.93	38
	Manila Bay	1958	9.512	100
	Manila Bay	1958-1959	11.351	104
	Manila Bay	1960	13.187	104
	Manila Bay	1982	10.294	104
	Visayan Sea	1983	3.617	28
	Visayan Sea	1984	7.620	28
	Visayan Sea	1985	5.887	28
	Samar Sea	1984	6.098	38
	Leyte Gulf	1985	8.383	16
Rastrelliger kanagurta	Illana Bay	1984	7.340	42
	Illana Bay	1983	7.348	42
	Samar Sea	1981	5.32	38
	Guimaras Strait	1985	4.586	15
	Samar Sea	1984	7.013	38
	Visayan Sea	1984	4.871	28
	Visayan Sea	1983	5.523	28
	Palawan	1965	8.27	3
	Ragay Gulf	1981	4.56	9
	Visayan Sea	1985	5.523	28
Selaroides leptolepis	Guimaras Strait	1986	7.4	15
	Maqueda Bay	1986	7.6	98
	Manila Bay	1978-1979	2.76	104
	Visayan Sea	1976-1977	8.64	28
	Ragay Gulf	1981	17.08	9
	Samar Sea	1981	6.69	38
Decapterus macrosoma	Visayan Sea	1985	1.90	28
	Visayan Sea	1984	7.64	28
	Samar Sea	1979	3.29	38
	Ragay Gulf	1981	4.50	9
	Manila Bay	1957-1958	3.74	104
	Manila Bay	1958	3.80	104
	Palawan	1957	4.01	3
	Palawan	1957-1958	4.71	3
	Palawan	1958	6.89	3
	Palawan	1958-1959	6.46	3
	Palawan	1960	10.5	3
	Palawan	1965	11.57	3
	Palawan	1965-1966	4.14	3
	Palawan	1966	5.26	3
	Palawan	1968A	3.38	3
	Palawan	1968B	5.79	3
	Visayan Sea	1983	8.981	3
	Guimaras Strait	1985	5.335	3
Leiognathus bindus	Manila Bay	1958	6.70	104
	Manila Bay	1959	4.00	104
	Manila Bay	1960	4.58	104
	Ragay Gulf	1981	6.52	9
	Burias Pass	1981	5.89	18
	Samar Sea	1981	6.23	38

Results

Table 1, based predominantly on Dalzell and Ganaden (1987), shows growth parameters (L_∞ and R) and ϕ' values for the ten fish species included in this paper.

For the species covered, the computed values of ϕ' range from $\phi' = 2$ to $\phi' = 3$ with a coefficient of variation of less than 10% within any given species.

Table 2 lists the mortality rates of the species and their corresponding densities in the thirteen fishing areas. Manila Bay and Maqueda Bay are considered heavily exploited areas based on their density values of 104 and 98 fishermen/km, respectively. Moderately fished areas included in the lists are: Carigara Bay, Samar Sea, Guimaras Strait, Leyte Gulf, Visayan Sea, Burias Pass, San Miguel Bay, Ragay Gulf and Illana Bay. Palawan and Honda Bays are lightly fished areas. Fig. 1 shows the distribution of heavily, moderately and lightly fished areas around the Philippine waters as described by Fox (1986).

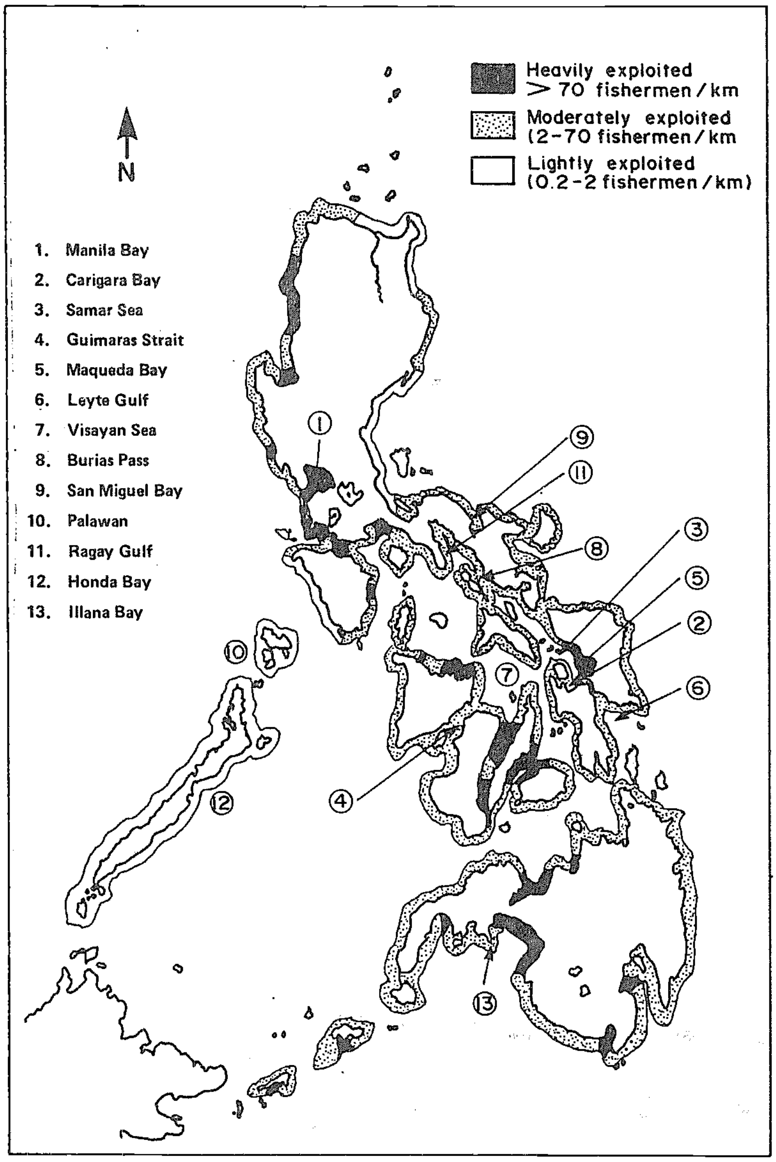

Fig. 1. Map of the Philippines, showing level of exploitation of different fishing grounds (adapted from Fox 1986).

The demersal species included in Table 2 are: *Nemipterus japonicus* , *Nemipterus hexodon, Gazza minuta, Saurida tumbil, Pentaprion longimanus, Upeneus sulphureus* and *Leiognathus bindus*. The pelagic species include *Sardinella fimbriata, Sardinella longiceps, Rastrelliger kanagurta, Rastrelliger brachysoma, Decapterus macrosoma* and *Selaroides leptolepis*.

Figs. 2 to 14 show the relationship of mortality rate (Z) against fishermen density for the individual species. Note that none of the plots was statistically significant; hence this analysis includes plots for further discussion only if the sign of the slope is positive. As might be seen, *Decapterus macrosoma, Selaroides leptolepis* and *Leiognathus bindus* did not have the expected positive correlation between Z and density.

Fig. 15 shows the relationship between the estimated M and the predicted M (using Pauly's equation, T = 28°C) for all species considered. It is shown that the demersal species have a ratio of about 1:1 of the predicted M *vs*. the estimated M values while the pelagic species have estimated values of M which are much higher than the expected values.

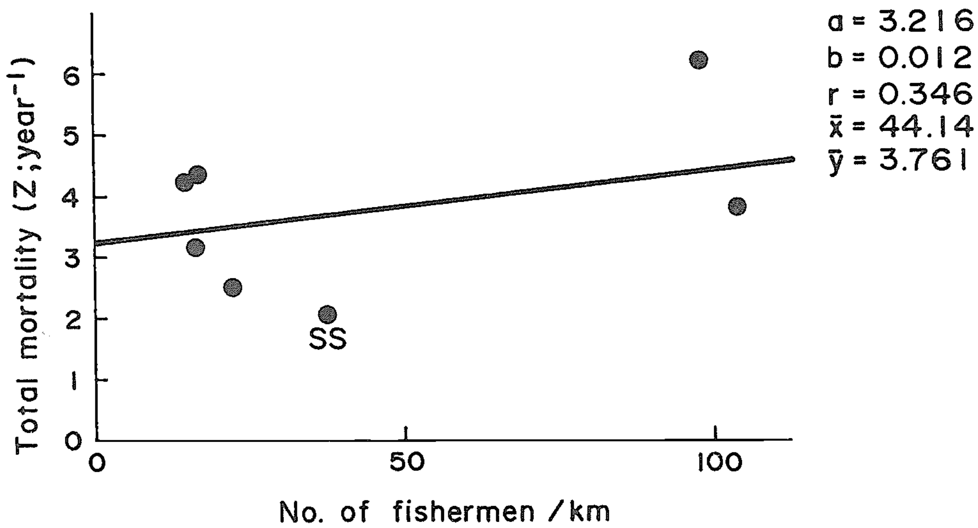

Fig. 2. Relationship between total mortality and fishing intensity in *Nemipterus japonicus*, Philippines.

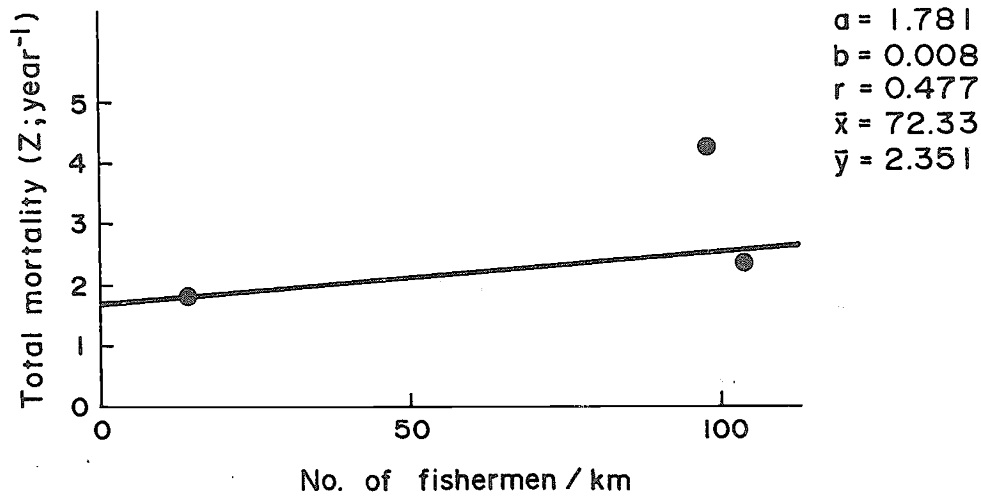

Fig. 3. Relationship between total mortality and fishing intensity in *Nemipterus hexodon*, Philippines.

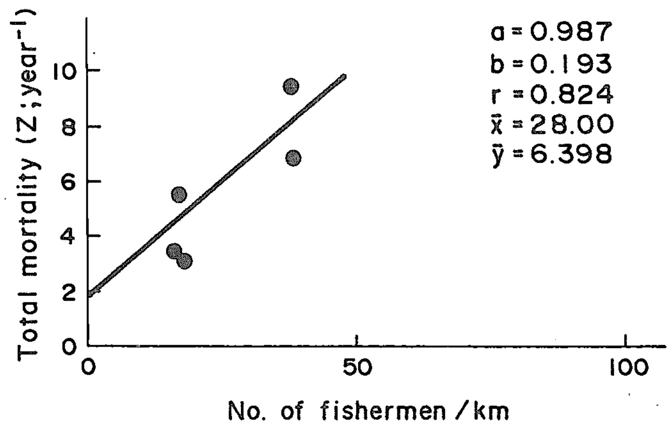

Fig. 4. Relationship between total mortality and fishing intensity in *Upeneus sulphureus*, Philippines.

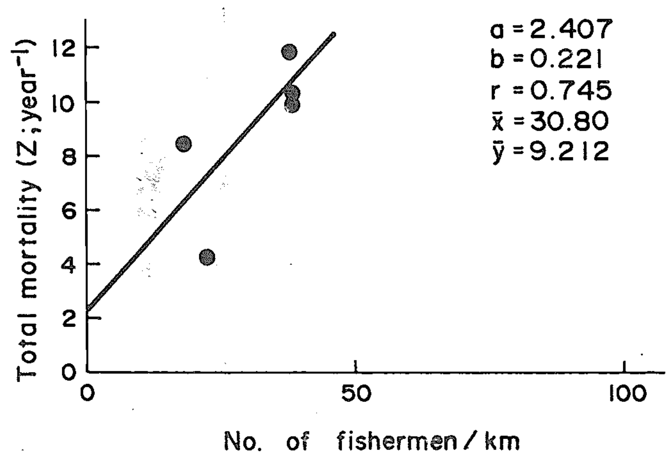

Fig. 5. Relationship between total mortality and fishing intensity in *Pentaprion longimanus*, Philippines.

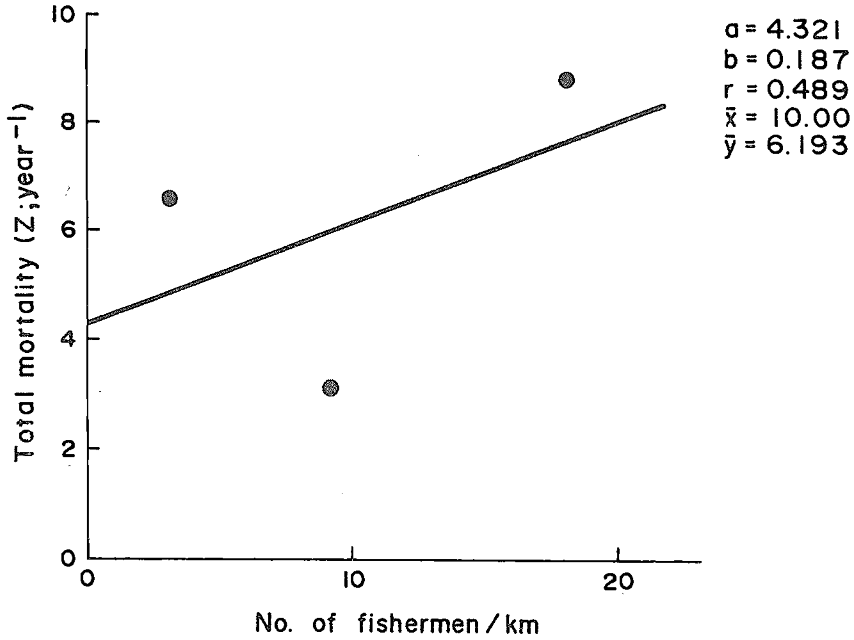

Fig. 6. Relationship between total mortality and fishing intensity in *Gazza minuta*, Philippines.

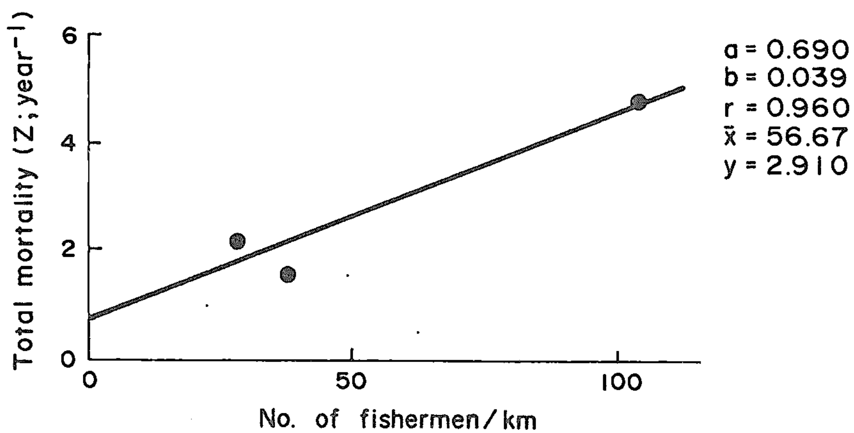

Fig. 7. Relationship between total mortality and fishing intensity in *Saurida tumbil*, Philippines.

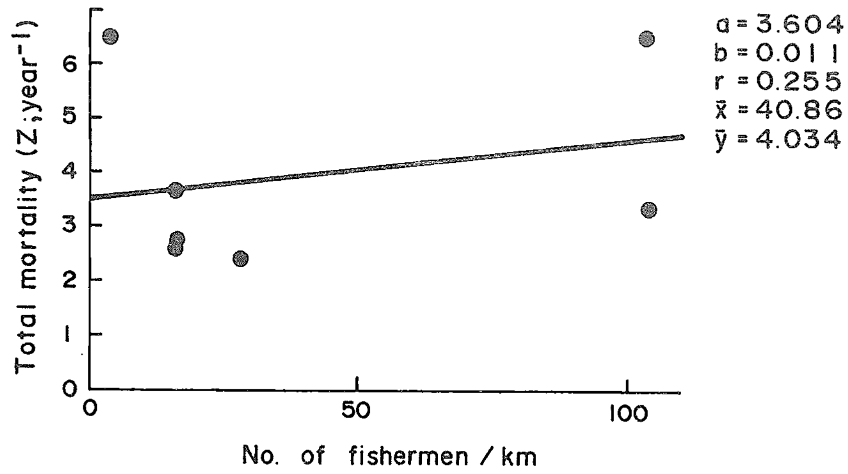

Fig. 8. Relationship between (apparent) total mortality and fishing intensity in *Sardinella fimbriata*, Philippines.

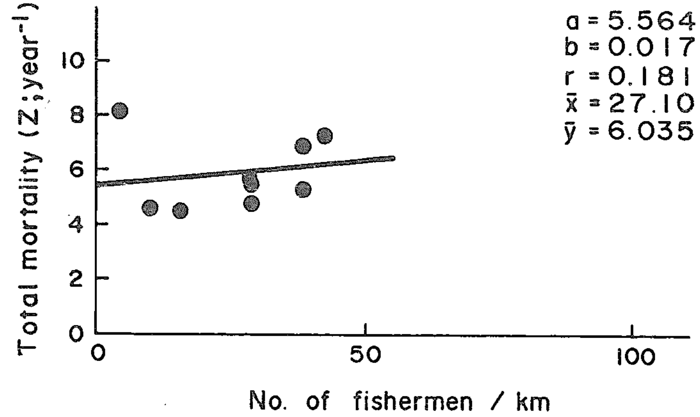

Fig. 10. Relationship between (apparent) total mortality and fishing intensity in *Rastrelliger kanagurta*, Philippines.

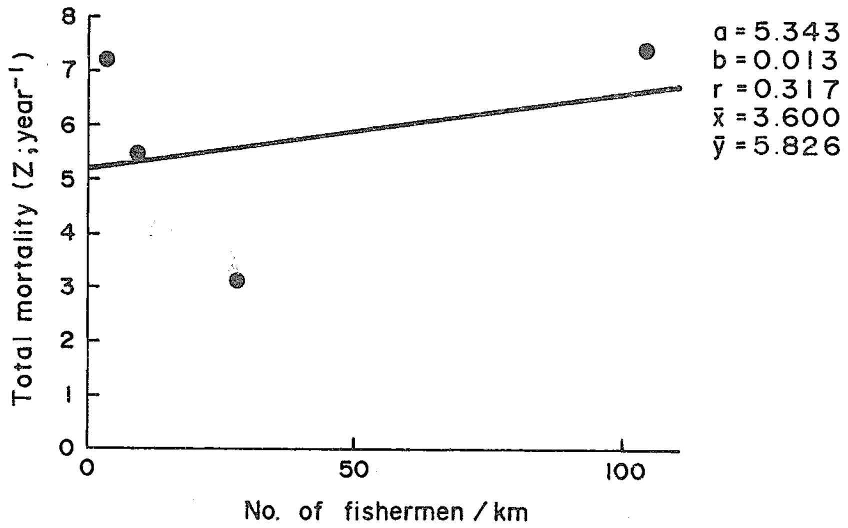

Fig. 9. Relationship between (apparent) total mortality and fishing intensity in *Sardinella longiceps*, Philippines.

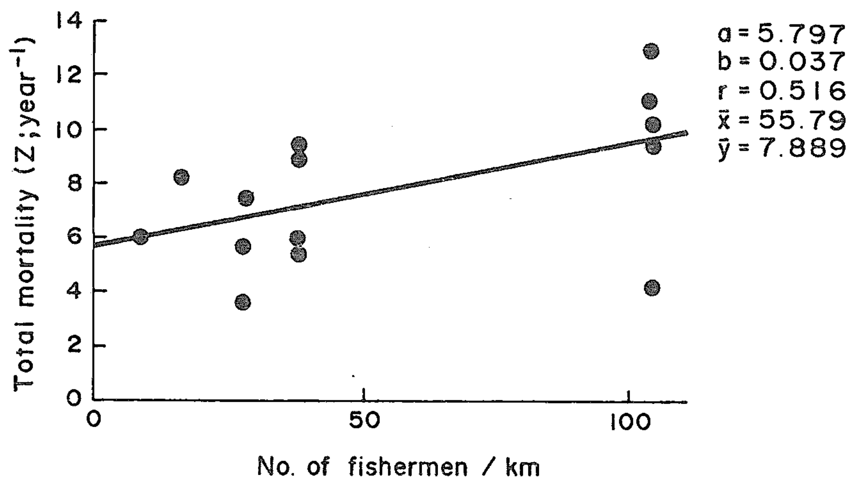

Fig. 11. Relationship between (apparent) total mortality and fishing intensity in *Rastrelliger brachysoma*, Philippines.

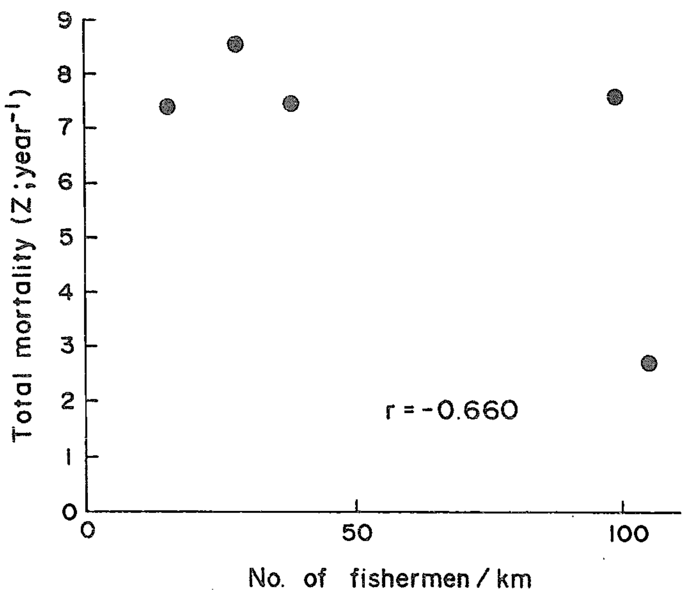

Fig. 12. Apparent total mortality *vs.* fishing intensity in *Selaroides leptolepis*, Philippines.

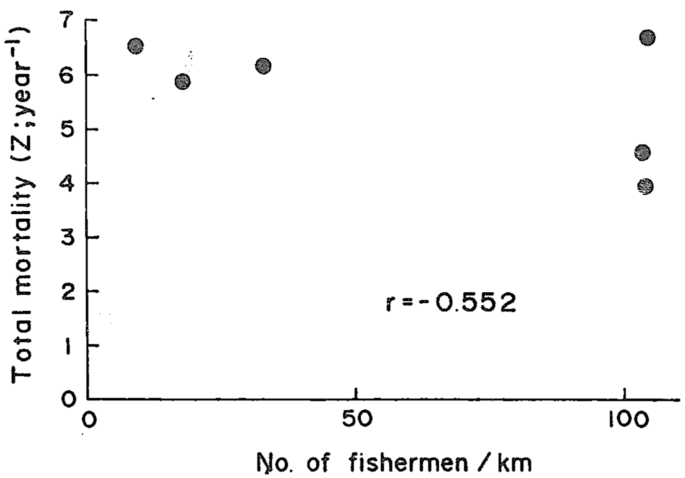

Fig. 13. Apparent total mortality *vs.* fishing intensity in *Leiognathus bindus*, Philippines.

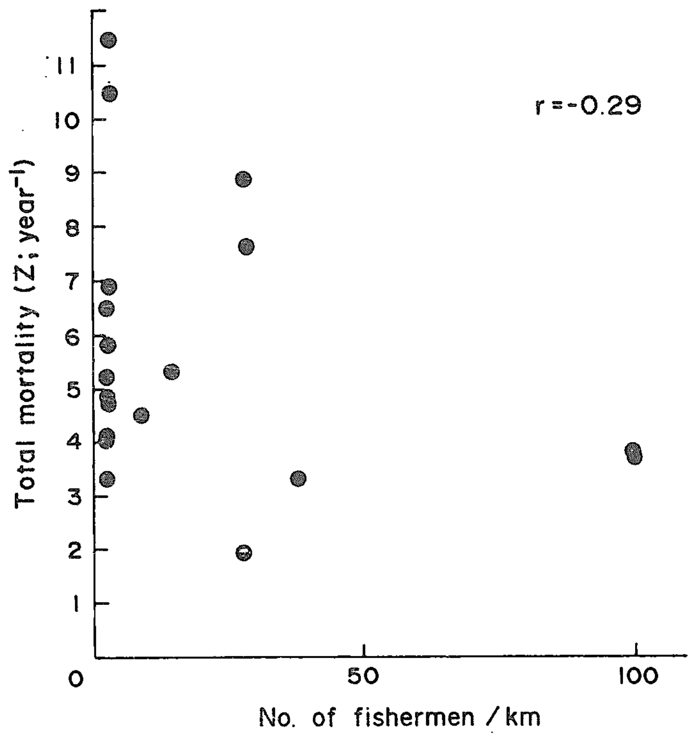

Fig. 14. Apparent total mortality *vs.* fishing intensity in *Decapterus macrosoma*, Philippines.

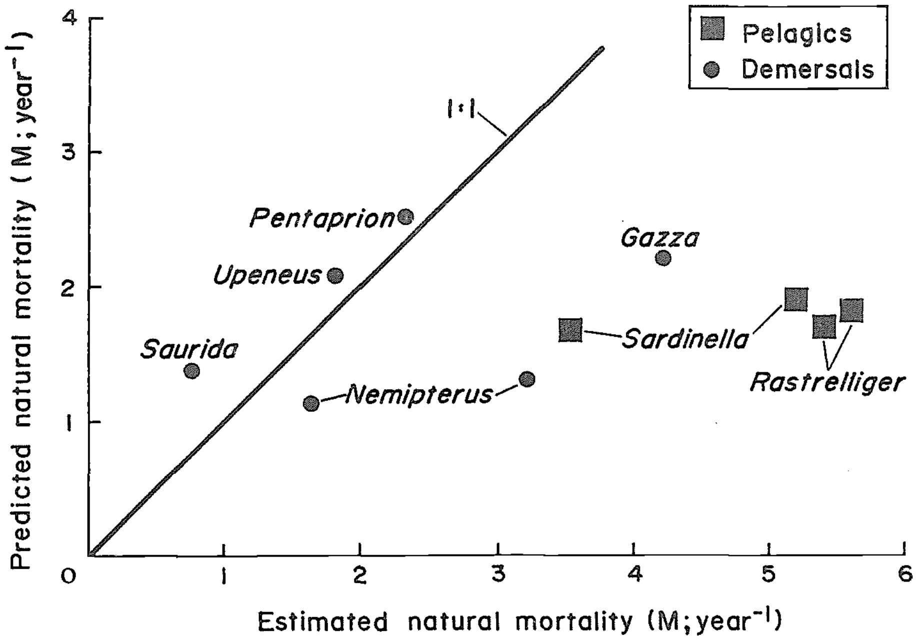

Fig. 15. Relationship between estimated and predicted values of M in Philippine fishes. Note relatively good match for the demersal species (see text).

Discussion

The values of ϕ' obtained by species show that the computed values of ϕ' are normally and narrowly distributed within any given species. Thus, the method of estimating K on the basis of ϕ' values derived from other studies on the same species may not lead to large errors and has proven its usefulness in cases where L_∞ and K cannot be derived due to lack of length-frequency and/or age data.

Compared to the estimates obtained from the equation of Pauly (1980), the approach used here in estimating M independently by regressing Z *vs.* density leads to a very high estimate of apparent M in the pelagic fishes *R. brachysoma, R. kanagurta* and the clupeids. However, the method seems to work with the demersal fishes as shown in *U. sulphureus* , *P. longimanus, G. minuta, S. tumbil, N. japonicus* and *N. hexodon* (Fig. 15).

The overestimated values of M in the pelagics are probably due to their migratory nature and the apparent M values estimated here could in principle be corrected by subtracting emigration from Z (Pinto 1986).

The data presented here confirm the applicability of Pauly's empirical formula to the demersal fishes. Also, the results confirmed that several major fishing grounds around the Philippine waters are biologically overfished as in the case of Manila Bay (Ronquillo et al. 1960; Caces-Borja 1975; Ronquillo 1985; Silvestre et al., in press).

Overall, the approach used here seems reasonable in that the estimated values of Z seem compatible with the densities in the respective areas. There may be some errors here especially in selecting a few landing areas with densities that do not express effort well. A more applicable refinement in using the effort (density) is to include not only a complete enumeration of full-time artisanal fishermen but also to consider the impact of the commercial sector in all coastal areas.

It is worth mentioning here that the results of Fox (1986) showed that fishermen in very high density areas have an average daily catch of about 1 kg/man/day at current landing prices of less than ₱10 (about 0.5 US$) while fishermen from average density areas catch about 9 kg/man/day.

Thus overall, our results confirm that length-frequency data analysis can be used to determine the state of a stock and hence, indirectly, the income of the fishermen involved in the fishery. It is hoped that rapid appraisal methods of this type will be used widely and will indirectly lead to remedial actions likely to increase fishermen's income.

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Effect of Incorporating Sigmoid Selection on Optimum Mesh Size Estimation for the Samar Sea Multispecies Trawl Fishery*

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Abstract

The evaluation of optimum mesh size for multispecies trawl fisheries relies primarily on the aggregation of individual yield-per-recruit response surfaces. The analytic model expression incorporated in these procedures assumes knife-edge selection - an assumption recently demonstrated to generate considerable bias in single-species assessment of short-lived tropical fish species. This present study examines the effect of replacing the usual knife-edge selection assumption with empirically-based sigmoid selection in the evaluation of the optimum mesh size for the Samar Sea multispecies demersal trawl fishery. Relaxation of the knife-edge assumption in favor of sigmoid selection results in the decrease of the optimum mesh size for the mix of 12 trawl-caught species considered in the study. Overall, sigmoid selection leads, however, to more conservative results or measures (e.g., lower optimum exploitation levels and catch rate expectations) than would other have been obtained with knife-edge selection.

Introduction

The analytic or yield-per-recruit (Y/R) model (Beverton and Holt 1957; Ricker 1958) represents one of the traditional approaches to the analysis of yield from exploited fish populations. Adopting the "additions and removals" theory of Baranov (1918), and incorporating the age structure of the population as an important element in determining harvestable yield, the model allows for the evaluation of the optimum levels of exploitation (e.g., fishing effort, f; fishing mortality, F; or exploitation rate, E) and age/size at first capture (t_c/L_c) for a given fish stock. Conventionally applied to single-species populations, the analytic model is commonly used in calculating yield on a per-recruit basis due to uncertainties in the determination of absolute recruitment (Gulland 1979, 1983; Jones 1979).

Several workers have proposed modifications to the original formulation presented by Beverton and Holt (1957) and Ricker (1958) (e.g., Jones 1957; Paulik and Gales 1964; Beverton and Holt 1966; Andersen and Ursin 1977). These works vary from attempts at more simplistic generalizations to complex incorporation of details in efforts at more properly depicting

*ICLARM Contribution No. 440.

biological "reality" as it is in relation to harvestable yield. Of late, Pauly and Soriano (1986) demonstrated that the assumption of knife-edge selection conventionally made in Y/R computations generates considerable bias, especially in the case of short-lived tropical fish species. This is because selection usually covers a good proportion of the lifespan of short-lived species. The bias generated not only affects the magnitude of the Y/R, but more significantly, the location of the optimum in the exploitation level and age/size at capture response surface.

Most fisheries in the Southeast Asian region (for that matter, also other regions in both tropical and temperate areas) are multispecies in nature. Hence, what is generally of interest is the yield from the mix of species rather than that for a single component of the species mix. Several attempts at combining single-species assessments are available in the literature for estimating the best mesh size (proportional to t_c/L_c) and exploitation levels for multispecies stocks (e.g., Sinoda et al. 1979; Sainsbury 1984; Silvestre 1986a; Federizon et al. 1986). Majority of these works rely on the use of the yield-per-recruit model with the usual assumption of knife-edge selection. For instance, Silvestre (1986a) examined the biologically optimum mesh size for the Samar Sea demersal trawl fishery assuming knife-edge selection and equal catchabilities for the 12 species included in his analysis. The present contribution examines the effect of incorporating sigmoid size selection in determining the optimum mesh size for the said fishery.

Materials and Methods

The basic data for this study were collected in the Samar Sea (Fig. 1) during the course of a trawling survey from March 1979 to May 1980 and selection experiments in May 1982 conducted by the University of the Philippines in the Visayas (UPV) College of Fisheries in collaboration with the German Agency for Technical Cooperation (GTZ). Details with respect to the Samar Sea demersal fishery and survey methodology are given in Armada et al. (1983). The catch rate, selection and length-frequency data generated during the survey had been analyzed in previous works for the following: 1) growth parameters (W_∞, L_∞, and K) of the von Bertalanffy equation (Silvestre 1986b); 2) mortality coefficients (Z and M) of the exponential decay model (Silvestre 1986b); 3) size selection parameters (Silvestre et al. 1986) and 4) relative recruitment (Silvestre 1986a). The parameters estimated in the above studies were primarily used for the 12 species included in the analysis below. These 12 species (Table 1) account for about 50% of the total catch of fish and invertebrates taken during the entire course of the Samar Sea trawl survey.

The approach used here to evaluate the optimum mesh size (incorporating size selection) for the Samar Sea demersal trawl fishery follows the procedure described by Silvestre (1986a) with one major modification - the yield-per-recruit equation used was replaced by that presented by Pauly and Soriano (1986). This procedure involves the aggregation of individual Y/R response surfaces of the 12 species included in the analysis. The aggregation procedure involves standardization along the three axes of the Y/R response surface, namely, 1) the fishing effort/mortality/exploitation rate axis; 2) the age/length at first capture axis and 3) the Y/R axis. For purposes of this study, the aggregation was done using the expression:

$$Y'(Ms, F) = \sum_{j=1}^{n} [\; Y'/R\,(Ms, F) \;]_j \cdot R_j \cdot W_{\infty j} \qquad \ldots 1)$$

where Y'(Ms,F) is the value of the aggregate yield index at the lattice points Ms,F of the yield response surface (Ms being the mesh size and F the fishing mortality rate); [Y'/R (Ms,F)]j is the relative Y/R for species j at the lattice points Ms,F; R_j is the relative recruitment index for species j and is a measure of the relative significance of species j to aggregate yield; $W_{\infty}j$ is the asymptotic weight of species j and n the number of species included in the aggregation procedure. The relative yield per recruit at the lattice points Ms,F for each species was calculated using the expression of Pauly and Soriano (1986),

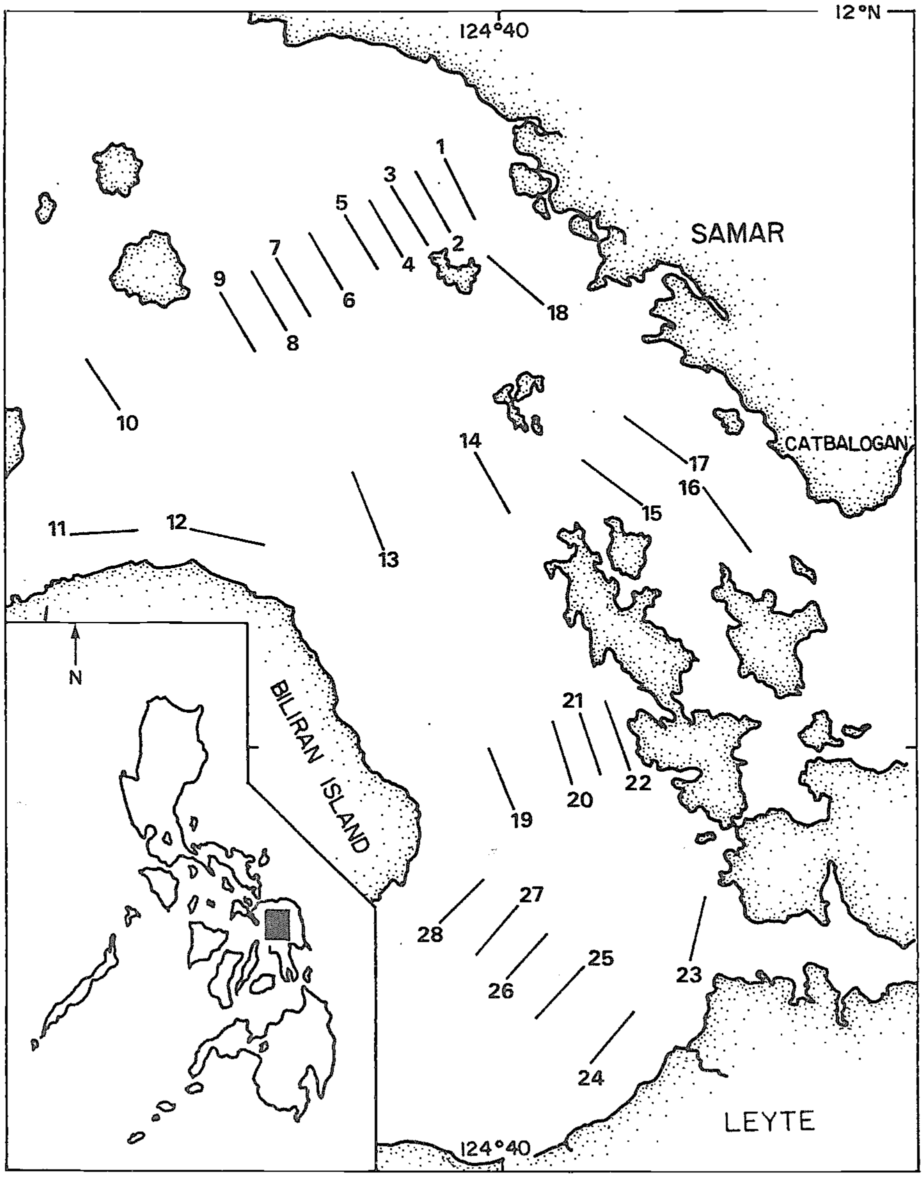


Fig. 1. Fishing tracks utilized during the Samar Sea trawl survey. Parameters stem from data collected in the area from March 1979 to May 1980, as well as in May 1982.

$$Y'/R = \sum_{i=L_{min}}^{L_\infty} P_i \bullet \left[(Y'/R)_i \bullet G_{i-1} - (Y'/R)_{i+1} \bullet G_i\right] \qquad \text{... 2)}$$

in which $(Y'R)_i$ and $(Y'/R)_{1+1}$ refer to relative Y/R as computed from the lower limit of length class i and i+1, respectively; P_i, the probability of capture between L_i and L_{i+1}, and G_i is defined by

$$G_i = \prod_{j=1}^{i} r_j \qquad \text{... 3)}$$

Table 1. Growth, mortality, recruitment and selection parameters utilized for the computation of the optimum multispecies mesh size for the Samar Sea.

Species	W_∞[a] (g)	L_∞[b] (cm)	K[b] ($year^{-1}$)	M[c] ($year^{-1}$)	R'[d]	SF
Leiognathus bindus	44	12.1	0.98	2.21	3,306	1.58[e]
Pentaprion longimanus	72	14.0	0.70	1.69	180	2.08[e]
Saurida undosquamis	323	33.3	0.30	0.77	6	2.40[e]
Upeneus sulphureus	146	18.8	0.55	1.33	148	2.34[e]
Nemipterus nematophorus	295	25.5	0.55	1.05	7	1.99[e]
Leiognathus splendens	63	13.1	0.90	2.02	128	1.68[f]
Leiognathus equulus	380	24.0	0.56	1.26	2	1.59[f]
Priacanthus tayenus	293	29.0	0.65	1.34	4	1.94[f]
Selaroides leptolepis	158	19.9	0.53	1.29	14	2.45[f]
Nemipterus japonicus	340	26.6	0.45	1.08	1	2.26[e]
Upeneus moluccencis	276	24.1	0.65	1.43	14	2.37[f]
Leiognathus leuciscus	39	13.7	0.93	2.12	93	1.70[e]

[a]From Silvestre (1986a) using the length-weight relationship given by Villoso (1981).
[b]From Silvestre (1986b) estimated using ELEFAN I.
[c]From Silvestre (1986b) using the empirical equation of Pauly (1980).
[d]From Silvestre (1986a) using the expression $R' = c/f \cdot Z \cdot e^{Z\,(tr1 - tr2)} \cdot e^{M\,(tr2 - t_0)}$.
[e]From Silvestre et al. (1986) estimated via covered codend selection experiments in the Samar Sea.
[f]Average of selection factor values for the species from other areas in the South China Sea (Jones 1976; Saeger et al. 1976; SEAFDEC 1978; Eiamsa-ard 1979; Meemeskul 1979; Sinoda et al. 1979).

where r_i is a factor expressing the proportion of recruits of length L_i which survive and grow to length L_{i+1}, and is computed (for $0 < E < 1$) from

$$r_i = \frac{(1 - c_i)^{(M/K)\,(E/(1 - E))P_i}}{(1 - c_{i-1})^{(M/K)\,(E/1 - E))P_i}} \qquad \text{... 4)}$$

where $r_{L_{min-1}} = 1$ and $r_{L_\infty} = 0$. The $(Y'/R)_i$ and $(Y'/R)_{i+1}$ in equation 2 is computed using the expression given by Beverton and Holt (1966), i.e.,

$$\frac{Y'}{R} = (1 - c)^{M/K} \bullet \left[1 - \frac{3\,(1 - c)}{1 + \frac{(1 - E)}{M/K}} + \frac{3\,(1 - c)^2}{1 + \frac{2\,(1 - E)}{M/K}} - \frac{(1 - c)^3}{1 + \frac{3\,(1 - E)}{M/K}} \right] \qquad \text{... 5)}$$

where E is the exploitation rate (= F/Z = F/(F+M); F and M, respectively, being the instantaneous rate of fishing and natural mortality), c is the ratio L_c/L_∞ (L_c being the length at first capture and L_∞ the asymptotic length), and K the growth coefficient of the von Bertalanffy equation.

The use of the above equations involves standardization along the three axes of the conventional Y/R response surface, and requires: 1) determination of the relative catchabilities of the mix of species being considered; 2) rescaling of the L_c/c axis to a common entity, in this case mesh size (Ms) and 3) a measure of relative (in the absence of absolute) recruitment. With respect to the first requirement, the catchability coefficients (q's) were taken as equal and constant through the range of F. This is due to the lack of information by which differential fishing pressure could be examined. The assumption holds if trawlers (on the average) catch the species under consideration in equal proportion relative to their respective population sizes.

The second requirement was met by converting c to L_c, and subsequently to Ms using selection factors, S.F. (see Gulland 1969) computed for each species, i.e.

$$c = L_c/L_\infty \quad \text{... 6)}$$

$$Ms = L_c/S.F. \quad \text{... 7)}$$

The S.F. values were obtained either from selection experiments in the Samar Sea (Silvestre et al. 1986) or from the average of S.F. values for the species from other areas in the South China Sea (see selection studies cited in Silvestre 1986a). The probabilities of capture at length (P_i's) for each species included in the analysis at a given mesh size were obtained as follows: (1) the lengths corresponding to 25%, 50% and 75% probability of retention (i.e, L_{25}, L_{50} and L_{75}), at a mesh size of 4.0 cm were obtained for each species (e.g., from Silvestre et al. 1986 and other selection studies cited in Silvestre 1986a); (2) these were plotted in the L_c *vs.* Ms coordinates and projected backward to the origin to obtain linear expressions for L_{25}, L_{50}, and L_{75} as a function of mesh size and (3) the P_i's were then subsequently computed from the logistic that best describes L_{25}, L_{50} and L_{75} at that mesh size. Fig. 2 gives a representation of this procedure for the specific case of *N. nematophorus* where the P_i's are obtained for a mesh size of 3.0 cm (marked B in the figure).

The third requirement was met by using relative recruitment indices. Sainsbury (1984) presents alternative procedures by means of which such indices could be estimated. In this study, the index of relative recruitment was computed from an expression that stems from the formulation of Ricker (1975), Munro (1979) and Munro and Thompson (1973), namely,

$$R' = (c/f) \cdot Z \cdot e^{Z(t_{r1} - t_{r2})} \cdot e^{M(t_{r2} - t_o)} \quad \text{... 8)}$$

where c/f is the mean catch per effort (number/hour) for the species during the Samar Sea trawl survey; t_{r1} the relative age at first capture to the survey gear (Ms = 4.0 cm); t_{r2} the relative age at first capture to the 2.0 cm mesh size common among trawlers in the Samar Sea; and the rest as previously defined. Silvestre (1986a) used this expression to estimate R' for the species included in this analysis.

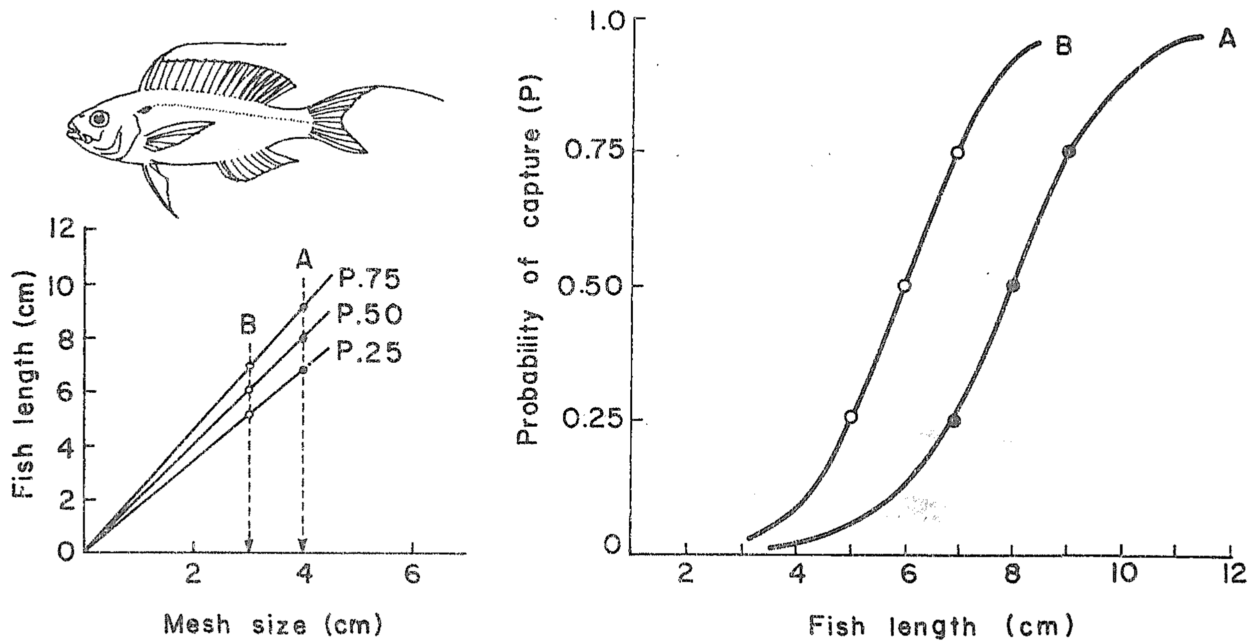


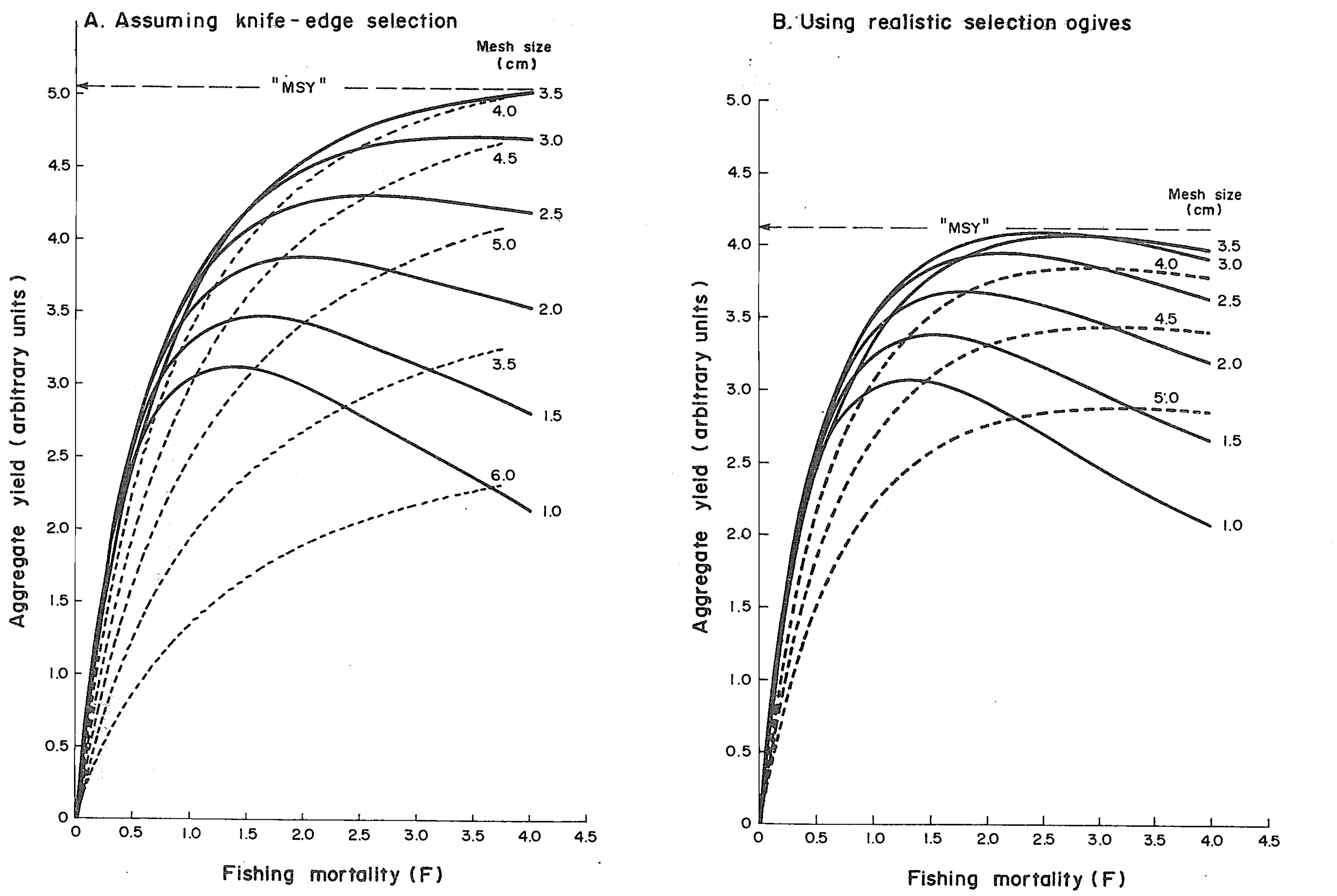
Fig. 2. Representation of the method utilized for estimating probabilities of capture as a function of any mesh size (e.g., mesh size in left panel) based on an empirical selection ogive (A in right panel) and constant slopes (i.e., probabilities) to link fish length and mesh size (left panel). Based on selection data for *Nemipterus nematophorus* from Silvestre et al. (1986).

Results

The parameter values utilized in the calculation of aggregate yield indices for this study are summarized in Table 1. The parameters of the von Bertalanffy equation (W_∞, L_∞ and K) and natural mortality (M) of the exponential decay model are given in columns 2 to 5. It appears that the species herein considered are characterized by relatively high growth rates and natural mortality indicating high turnover rates. The relative recruitment indices computed by Silvestre (1986a) for each of the 12 species are given in column 6. These indicate a trend of higher R' among smaller-sized species (e.g., *L. bindus* with R' = 3306) and vice versa (e.g., *N. japonicus* with R'=1). The S.F. values given in the last column of Table 1 come primarily (i.e., 7 of the 12 estimates listed) from covered cod-end selection experiments conducted in the Samar Sea (Silvestre et al. 1986). The rest were taken from the average of S.F.'s for the species from other areas in the South China Sea (Jones 1976; Saeger et al. 1976; SEAFDEC 1978; Eiamsa-ard 1979; Meemeskul 1979; Sinoda et al. 1979). The S.F. values varied between 1.58 for *L. bindus* and 2.45 for *S. leptolepis*. Note that the lower the value of S.F. for a given species implies a shorter length at first capture (L_c) for the species to a given mesh size of the trawl cod-end.

The length-specific probabilities of capture at 4.0 cm mesh size for each of the 12 species are given in Appendix I. These were utilized in estimating the length-specific probabilities of capture for the species at other mesh sizes as explained in the previous section. The P_i's at Ms = 4.0 cm for seven species *(L. bindus, P. longimanus, S. undosquamis, U. sulphureus, N. nematophorus, N. japonicus* and *L. leuciscus)* were obtained from the Samar Sea selection experiments (Silvestre et al. 1986). The rest were estimated as follows: (1) for *L. splendens* and *L. equulus*, a logistic curve drawn through L_{25}, L_{50} and L_{75} estimated from the S.F. value for the species and the selection range of *L. bindus* was used to estimate P_i's at Ms = 4.0 cm; (2) for *U. moluccencis*, the same procedure as in (1) was followed except that the selection range of *U. sulphureus* was used; and (3) for *P. tayenus* and *S. leptolepis*, the same procedure as in (1) was followed except that the selection ranges used stemmed from the resultant curves for the species given by Corpuz et al. (1985).

The aggregate yield response surface for the mix of 12 species considered in this study are given in Tables 2 and 3 for computations involving knife-edge selection and length-specific probabilities of capture, respectively. These are given through the range of F (0.25 to 3.00 at 0.25 intervals) *vs.* Ms (1.0 to 6.0 cm at 0.25 cm intervals). Values giving maximum Y' at a given F are underlined while those giving maximum Y' at a given Ms are indicated by an asterisk for the range and step values of F and Ms considered. The response surfaces are illustrated graphically in Fig. 3 with mesh sizes ranging from 1.0 cm to the mesh size that gives maximum aggregate yield at very high exploitation levels (F=4.0), at 0.5 cm mesh size increments, indicated by solid lines. Subsequent MS giving lower Y' are indicated by dashed lines. It is clear that the mesh size of 2.0 cm that is used by trawlers in the Samar Sea is inappropriate and counter-productive for the mix of species under consideration, whether the computation involves knife-edge selection or length-specific probabilities of capture. Aside from this, however, the incorporation of length-specific probabilities of capture leads to considerable changes in the results of the analysis - the consequent advice - toward generally more conservative figures. With the incorporation of probabilities of capture, the Y' values at given Ms become more "humped" and the F levels that maximize Y' at a given Ms are lower. The magnitude of the Y' values have also decreased together with the measure of overall "MSY" for the species mix (i.e., from about 5,000 to 4,100 or an 18% decrease). The biologically optimum mesh size for the species mix, however, decreased throughout the range of F values. Fig. 4 illustrates the disparity in optimum mesh size results when selection ogives rather than knife-edge selection is incorporated in the computations. The location in the Ms, F plane of the Y' maximum at fixed F are indicated by the curves A, B and C using knife-edge selection, empirical selection ogives, and doubling the seclection range of the empirically-determined selection ogives, respectively. These curves indicate a decrease in optimum Ms value at fixed F with the incorporation of selection ogives, the disparity with that predicted using the usual knife-edge selection increasing with increasing selection range and F value. Similarly, the location of the Y' maximum of fixed Ms is indicated by the curves A' (knife-edge), B' (empirical ogives), and C'(doubling of selection ranges used in B'). Note that the appropriate F at fixed Ms shifts to lower values; the



Figs. 3a and 3b. Aggregate yield index (Y′) *versus* fishing mortality (F) for the 12 trawl-caught species from the Samar Sea with computations involving (A) knife-edge selection and (B) realistic selection ogives. Mesh size ranges from 1.0 cm to the size that gives maximum Y′ at high exploitation levels (e.g., F about 4.0), at 0.5 mesh size intervals, are indicated by solid lines. Subsequent mesh sizes giving lower Y′ are indicated by dashed lines.

disparity with that predicted assuming knife-edge selection (curve A') increasing with Ms and selection range. Additionally, Fig. 4 together with Tables 2 and 3 illustrate that the global Y' maximum (located at the intersection of curve A with A', B with B', and C with C' marked by darkened circles in the figure) continuously declines in magnitude, and transposed to lower Ms and F combinations, with increasing selection range. Hence, in the case of the 12 species herein considered, the intersection of curves B and B' show that fishing the species mix at Ms beyond 3.2 and F beyond 2.6 is unjustified in maximizing biological yield. More specifically, the use of empirical selection ogives allows better delimitation of the range of Ms and F values within which the fishery should operate.

As an additional illustration of the tremendous changes in system behavior with the incorporation of sigmoid selection, we expanded the range of the Ms and F axis to 10 (although for practical fishery purposes this may be unrealistic). Fig. 5 shows the location of maximum Y' Y' at fixed Ms in the Ms, F plane using knife-edge selection (A') and empirical selection ogives (B'). Note that A' shows a monotonous increase in appropriate F with Ms; while B' shows a limit to F expansion (i.e., F=3.6) with increasing mesh size, and a discontinuity (marked by an arrow in the figure) wherein appropriate F declines due to loss of smaller (i.e., higher S.F. valued) fish/species. Thus, Fig. 5 illustrates that incorporation of sigmoid selection better depicts what we expect in actual exploited populations both conceptually and empirically.

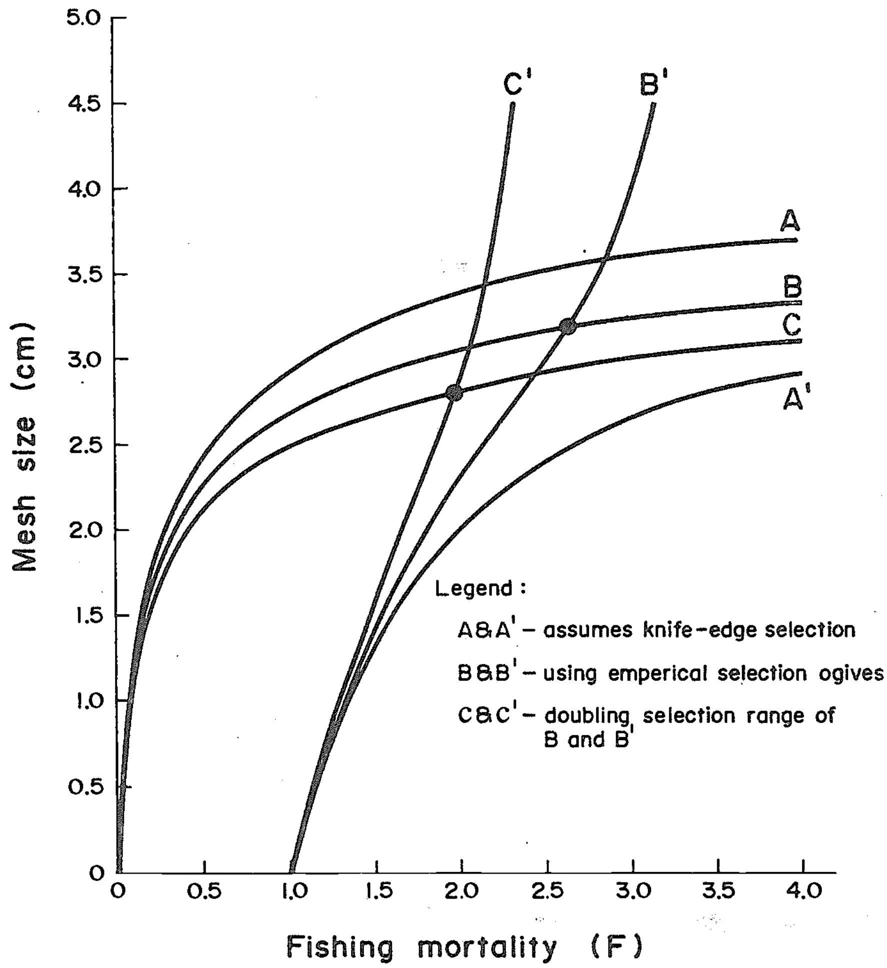


Fig. 4. Eumetric fishing lines for the mix of 12 trawl-caught species from the Samar Sea. The location in the Ms, F plane of the Y' maximum at fixed F is indicated by the curves marked A, B and C. Similarly, location of the Y' maximum at fixed Ms is indicated by the curves A', B' and C'. Note that the disparity in location of optimum Y' values in the Ms, F plane from that predicted by the usual knife-edge assumption increases with increasing selection range and fishing mortality. Additionally, the global Y' maximum (located at the intersection of the curves A and A', B and B', and C and C' marked by darkened circles) continuously decline in magnitude and transposed to lower Ms and F values with increasing selection range.

Table 2. Aggregate yield index Y′ (x 10), response surface for 12 trawl-caught species from the Samar Sea assuming knife-edge selection. (Values underlined: maximum Y′ at given F. Values with asterisk : maximum Y′ at given mesh sizes).

Mesh size (cm)	Fishing mortality (F) 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
6.00	50	86	114	135	153	167	179	189	198	205	212	218
5.75	61	105	138	164	185	202	217	229	239	248	256	263
5.50	72	124	163	193	218	238	254	268	280	291	300	308
5.25	83	143	187	222	250	272	291	306	320	331	341	350
5.00	94	161	211	249	280	304	325	342	356	368	378	388
4.75	104	178	233	275	308	334	355	373	388	400	411	421
4.50	114	194	253	297	332	360	382	400	415	428	438	448
4.25	123	209	271	317	353	381	404	422	437	449	459	468
4.00	131	221	286	334	370	398	420	438	452	464	474	482
3.75	138	232	298	347	383	410	432	449	462	473	482	489
3.50	144	241	308	356	392	418	438	454	466	475	483	488
3.25	150	248	315	362	396	421	440	454	464	472	478	482
3.00	154	253	319	365	397	420	436	448	457	462	467	469
2.75	157	256	321	364	394	414	429	438	444	448	451	452*
2.50	159	257	320	361	388	406	417	424	428	430	430*	429
2.25	160	256	317	356	380	394	403	407	409*	408	406	404
2.00	160	255	313	348	368	380	386	387*	386	384	399	375
1.75	160	253	307	338	356	364	367*	366	362	357	352	345
1.50	160	250	300	328	342	347*	346	343	337	330	323	315
1.25	159	246	293	317	327	329*	326	320	312	303	294	285
1.00	157	241	284	305	312*	311	305	297	287	277	266	256

Table 3. Aggregate yield index, Y′ (x 10), response surface for 12 trawl-caught species from the Samar Sea incorporating sigmoid size selection. (Values underlined: maximum Y′ at given F. Values with asterisk : m maximum Y′ at given mesh sizes).

Mesh size (cm)	Fishing mortality (F) 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
6.00	51	84	107	124	136	144	151	155	159	161	163	164
5.75	60	100	127	147	161	171	179	184	188	191	193	194
5.50	70	116	148	171	188	200	208	215	219	222	224	225
5.25	80	133	170	196	215	228	238	245	250	254	256	257
5.00	90	150	191	220	241	256	268	275	281	284	287	288
4.75	100	166	211	244	267	283	295	304	310	314	316	317
4.50	109	181	231	266	291	308	321	330	336	340	342	343
4.25	118	196	249	286	312	331	344	353	359	363	365	366
4.00	126	209	265	303	331	350	363	372	378	382	384	384
3.75	134	220	278	318	348	365	378	387	393	396	398	398
3.50	140	230	290	330	358	377	389	398	403	405	406*	406
3.25	146	238	299	339	366	384	396	403	408	409	410*	408
3.00	150	244	305	344	371	388	398	404	408	408*	408	406
2.75	154	248	308	347	372	387	396	401	403*	402	400	397
2.50	156	251	310	347	369	383	390	393	394*	392	389	385
2.25	158	252	309	344	364	375	381	382*	380	377	373	368
2.00	159	251	306	338	356	365	368*	367	364	359	353	347
1.75	159	250	302	331	346	352	353*	350	345	338	331	323
1.50	159	247	296	322	334	338*	336	332	325	317	308	299
1.25	158	244	290	313	322	323*	320	313	304	295	285	275
1.00	157	240	282	302	308*	306	300	291	281	270	259	248

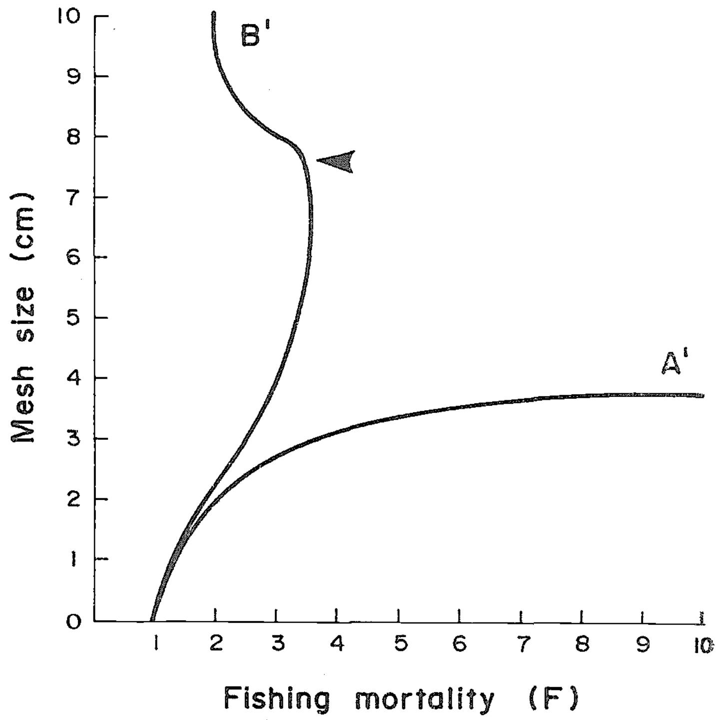


Fig. 5. Location of maximum Y′ and fixed Ms in the Ms, F plane using knife-edge selection (A′) and empirical selection ogives (B′). Note the decline in appropriate F with increasing mesh size past the point indicated by the arrow due to loss of smaller (i.e., higher S.F. valued) fishes/species.

Discussion

The assumption of knife-edge selection has been demonstrated to result in considerable bias in the case of single-species yield-per-recruit analysis (Pauly and Soriano 1986). The bias generated by such assumption, hence, is expected to be far more serious (i.e., compounded) in studies involving combined/aggregate single-species assessments. The present study illustrates the disparity of results generated by optimum mesh size analysis for multispecies trawl fisheries when knife-edge selection is assumed. The optimum mesh size for the Samar Sea demersal trawl fishery has been shown to decrease through the range of F when length-specific probabilities of capture are incorporated in the computations. Overall, however, doing away with the knife-edge assumption leads to more conservative figures/advice (e.g., lower exploitation levels, lower catch rate expectations) than otherwise would have been obtained with such an assumption.

The aggregation/optimization procedure presented above involves solely the maximization of biological yield. A final evaluation of the optimum mesh size for the Samar Sea demersal trawl fisheries would have to incorporate: (1) the rest of the other species being exploited or vulnerable to the trawl gear, (2) de-recruitment in the older fishes and (3) measures of socioeconomic desirability (e.g., prices) of species comprising the catch. The standardizations employed along the three axes of the conventional Y/R response surface need further empirical attention, especially the elaboration of differential fishing pressure exerted on the species mix by the trawl fishery. In addition, the limitations of the conventional analytic approach to tropical multispecies assessment are widely understood. Utilization of the results above must be made in the light of the assumptions and simplifications that the models and methods utilized entail.

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Effects of a Partial Increase of the Mesh Size in the Multispecies and Multifleet Demersal Fisheries in the Gulf of Thailand

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Abstract

A model is presented fitted to simulate short- and long-term effects in a multispecies and multifleet fishery caused by changing the mesh size or fishing effort. Yields are estimated and discussed of four demersal fish groups in the Gulf of Thailand, caught by five fishing fleets after introduction of a 4 cm legal cod-end mesh size for otter and pair trawls, while leaving the mesh sizes of beam trawl and shrimp trawl and push nets unchanged at 2 cm.

Introduction

Marine fisheries play a vital role in fish production in Thailand. The introduction of trawl fishing in 1960 caused an enormous expansion in yield and fishing effort. Today, Thailand ranks among the top ten countries in the world in capture fisheries. However, a decade of fish stock studies has also clearly shown that demersal fish stocks in the Gulf of Thailand have become overfished (Menasveta 1980). These resources are being exploited by active gear (otter, pair, beam and shrimp trawls and push nets) and passive artisanal gear. The mesh size (stretched) in the cod-ends of all types of trawls and push nets is approximately 2.0-2.5 cm. The combined effect of high levels of effort and the small mesh size causes overfishing. Higher yields could be obtained by decreasing effort and/or by using larger mesh sizes. However, this gain would only follow after a transition period of decreased yields. An increase in the mesh size has been considered earlier, e.g., by Sinoda et al. (1979) who estimated the best cod-end mesh size for trawl fisheries in the South China Sea region to be around 4.5 to 5.5 cm. The immediate loss by introducing a 5.0 cm mesh size could be as high as halving the catches presently taken (Meemeskul 1986).

Regulating fisheries, however, involves not only fish stock considerations but socioeconomic factors as well. On these grounds introduction of a 5 cm minimum mesh size has been considered unrealistic and further calculations of the effect of less drastic mesh size increases are therefore required. A proposal to introduce a 4 cm minimum mesh size is presently discussed in Thailand and in this paper the effect of a limited introduction of this particular mesh size is investigated.

Based on covered cod-end experiments Meemeskul (1986) calculated the immediate short-term loss from introducing a 4 cm minimum mesh size to be 23% overall. However, long-term effects have not yet been calculated.

Hitherto the artisanal fisheries have been disregarded in the analyses presented and this is also the case in this paper. The objective of this paper is to demonstrate a method which predicts the yields of each group of fish by type of fishing gear after the introduction of change in the cod-end mesh size. The example used is the effect of introducing a 4 cm legal mesh size for otter and pair trawls (previously 2.5 cm), while leaving those of beam and shrimp trawls and push netters unchanged at 2.5 cm. The calculations are based on single-species fisheries models as described in the theoretical section below.

Theory

General Outline of the Model

The model is constructed so as to facilitate an analysis of interactions between various fishing fleets exploiting the same populations. The model is also aimed at a study of both short-term and long-term effects of either a mesh size change or an effort change in one or sevel fleets.

The model works on the length composition in a stock at some point in time. This length composition is then during a time step modified by

- catch of fish by the various fleets
- death from causes other than fishery
- growth of the survivors
- recruitment to the smallest length class.

The basic structure of the model is depicted in Fig. 1.

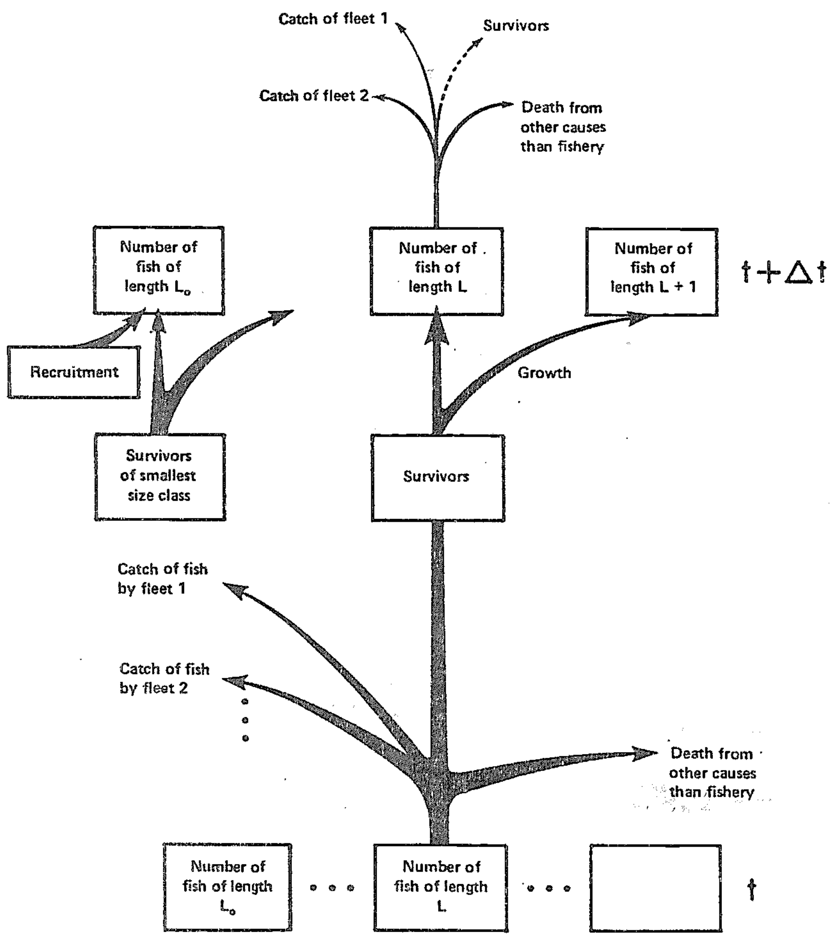

Fig. 1. General outline of simulation model used in this contribution (see text for details).

Mortality

The fishing mortality ($F_{sf}(L)$) which is inflicted upon a stock (s) by fishing fleet (f) depends on the effort (E_f) and the length (L) through the selectivity of the gear P(L). The relationship is

$$F_{sf}(L) = q_s E_f P(L) \qquad \text{... 1)}$$

q_s is a species specific constant, the catchability.

Considering only one species we can drop the subscripts. If the mortality is taken over a very small fraction of time (F+M) $\Delta t<<1$, then the numbers of fish caught $\Delta C_{ft}(L)$ by fleet f in length class (L) between time t and t + Δt can be calculated as:

$$\Delta C_{ft}(L) = N_t(L) F_f(L) \Delta t \qquad \text{... 2)}$$

and those which die from natural mortality number

$$\Delta D_t(L) = N_t(L) M\Delta t \qquad \text{...3)}$$

where $N_t(L)$ is the number of live fish of length class (L) at time t; $\Delta C(L)$ and $\Delta D(L)$ are numbers of deaths due to fishing and natural mortality respectively. M is assumed to be constant independent of the length. Adding equations (2) and (3) will give the total number of fish of length class (L) removed by mortalities.

The selection ogive S(L) depends on the selection factor (sf) which depends on the body shape of the fish, the mesh size (m) and the steepness of the selection ogive (r_m) and can be calculated by

$$S(L) = 1/(1 + e^{-r_m (L - L_{50})}) \qquad \text{... 4)}$$

where L is the midpoint of the length class; L_{50} is the length where 50% of fish are retained in a particular mesh size through

$$L_{50} = \text{selection factor (sf) x mesh size (cm)} \qquad \text{... 5)}$$
$$r_m = \ln 3/(L_{75} - L_{50}) \text{ (see Sparre 1986)}$$

The fishing mortality (F(L)) of each length class can be obtained as in Eq. (1).

Yield Calculation

Yield from the fishery of a certain species by a particular fishing gear (Y_f) can be obtained by converting the numbers of fish caught per length class through a length-weight relationship:

$$Y_{ft}(L) = C_{ft}(L) \cdot aL^b \qquad \text{... 6)}$$

where $C_{ft}(L)$ is the sum of $\Delta C_{ft}(L)$ calculated from Eq. (2) over the time period for which the yield is required.

These yields for the changed mesh size are calculated relative to the yields which would have resulted if no change were made.

Growth

The average growth of a cohort is assumed to be described by the von Bertalanffy growth equation (VBG)

$$L_t = L_\infty (1-e^{-K(t-t_o)}) \quad \text{... 7)}$$

The mortality calculations were done by fixed length groups and the model constructed should maintain this feature. Therefore the growth is simulated by adding a fraction of the fish in a particular size interval to the next larger size interval in each time step. This fraction is calculated such that the average growth increment of the population is as described by VBG.

In a small fraction of time (L_∞ x K x $\Delta t/ci << 1$) we apply the VBG in its differentiated form

$$\Delta L = (L_\infty - L)K\Delta t \quad \text{... 8)}$$

where ΔL is the length increment of a fish of length L during the time interval Δt; L_∞ is the asymptotic length of a particular species; K is the growth parameter of VBG Eq. (7); and ci is the class interval used in the length composition.

The simulation is done by moving a fraction of the stock in length class L one class up and leaving the rest in the original length class. This fraction is

$$\Delta L/ci \quad \text{... 9)}$$

which will on average give the correct growth increment in the population.

Fish do not grow in jumps but this model will simulate differences in growth rate of the same cohort and maintain an average growth according to the VBG Eq. (7).

The calculated mean growth in the population will simulate the corrected average growth in the population, i.e., the length compositions observed will fit with those calculated and the simulation will still function even if this model seems unrealistic. Hence the number of survivors of length class (L) from t to time t + Δt will become:

$$N_{t+\Delta t}(L) = [N_t(L-1) - \Delta C_t(L-1) - \Delta D_t(L-1)][\Delta(L-1)/ci] + [N_t(L) - \Delta C_t(L) - \Delta D_t(L)][1-(\Delta L/_{ci})] \quad \text{... 10)}$$

Recruitment

Recruitment is expressed as a rate, the number of specimens per year which are produced of the smallest length considered in the length composition. This rate R_t varies over the year and the number which is produced between time t and time t + Δt is

$$R_t \Delta t \quad \text{... 11)}$$

The number of fish in the lowest length class (L_o) after a time step Δt is therefore

$$N_t + \Delta t(L_o) + R_t \Delta t \quad \text{... 12)}$$

where $N_{t+} \Delta t(L_o)$ is calculated from Eq. (10) where of course $N_t(L_o\text{-}1) = 0$.

The Simulation Model

The model was implemented in compiled BASIC for an IBM PC and calculates for each time increment Δt the number caught for each fleet and length class for each species (Eq. 2). Similarly fish dying from natural causes are calculated from Eq. (3). These deaths are cumulated over some user specified time period, e.g., 1 month.

The number at the end of the time interval $N_{t+\Delta t}(L)$ is then calculated from Eq. (10) and the lowest length class is adjusted for recruitment (Eq. 12). Recruitment is assumed constant within a month but can vary, as the user specifies, between months. The simulation starts at time = 0 which is taken as the 1st of January in relation to the recruitment pattern.

Selection of Parameters for the Simulations

The demersal fishery in the Gulf of Thailand exploits numerous species and it is obviously neither practical to simulate the effects on all species nor is it necessary. The simulations presented here are aimed at illustrating the effect on typical demersal species occurring in the fishery. Each of these groups represents a proportion of the total catch and this proportion is judged based on the 1983 catch statistics for Thailand.

The basis for this classification should be similar in the parameters which control the model. The necessary parameters are:

L_∞, K	for	growth
M,q_s,E_f,r_m,sf	for	mortality
$R_t(L_o)$ by month	for	recruitment
a , b	for	length/weight relationship

Estimates of these parameters can be obtained from the literature.

Species Groups

The 1983 total catch by otter and pair trawl in the Gulf of Thailand is given in Table 1 by species groups. Since the change of mesh size is only simulated for these gears the species groups which will be affected are those given in Table 1.

Table 1. Catch composition of otter trawls and pair trawls in the Gulf of Thailand, by species groups, 1983 (in tonnes).

Species group	Otter trawls	Pair trawls	Total	% of total
Trash fish	313,820	99,877	413,697	67.8
Cephalopods	47,327	21,401	68,728	11.3
Shrimps	28,662	792	29,454	4.8
Nemipterus spp.	7,574	3,525	11,099	1.8
Priacanthus spp.	5,517	2,702	8,129	1.3
Saurida spp.	5,102	1,604	6,726	1.1
Cynoglossus spp.	2,888	415	3,303	0.5
Sciaenidae	2,860	992	3,852	0.6
Carangidae	2,741	1,685	4,426	0.7
Sphyraena spp.	1,275	618	1,893	0.3
Other fish	42,029	17,390	59,419	9.8
Total	459,795	151,021	610,816	100.0

Source: The Marine Fisheries Statistics. Based on sampling survey in 1983. (Dept. of Fish., Bangkok, Thailand)

Trash fish

Trash fish in commercial trawl fisheries consists of approximately 60% short-lived species with asymptotic lengths of about 10-12 cm. Some larger species but without commercial value are also recorded in this category, but those are of minor importance and are therefore ignored in the simulations. The remaining 40% consists of small (young) specimens of species of commercial value at larger sizes.

Squids and cuttlefish

Squids and cuttlefish are important because of their high value. Selection factors for *Loligo* spp. are given by Liu et al. (1985) (sf = 0.7 - 0.8) with corresponding L_{50} in a 4 cm cod-end of 2.8 cm, respectively. Escapement of squid through trawl meshes is probably not directly related to mantle size, however, because the tentacles rather than the size of the mantle are the active elements in retention. Hence, it is expected that an increase in mesh size will have little effect on the catch of squid and cuttlefish, particularly of those of commercial size. This catch component is therefore not included in the simulations.

Shrimp

Promsaka (1983) gives a selection factor of 1.58 for *Metapenaeopsis* spp. Shrimp caught by otter and pair trawls are of small commercial sizes so a 4 cm mesh could release shrimp in significant amounts. However, the target species of otter and pair trawl are fish and these trawlers operate during daytime as opposed to the proper night shrimp fishery. Shrimp reported in the official statistics from otter and pair trawlers may be overestimated. Trawling with research vessels on the same grounds as the commercial trawlers gave much less shrimp, only 0.9% of the catch compared to 4.8% from Table 1. Also the Thai statistical sampling survey suggests a smaller shrimp catch than indicated by the official statistics.

The relative importance of shrimp in the catches of otter and pair trawlers is uncertain, therefore shrimp has also not been included in this simulation.

Demersal fish

The fish species may be grouped as follows:

1. Short lived small species. Most of the trash fish species belong to this group.
2. Fast growing large fish, e.g., lizard fish (*Saurida* spp.) and barracuda (*Sphyraena* spp.).
3. Fast growing small fish, e.g., big eye (*Priacanthus* spp.) and many carangids.
4. Slow growing small fish, e.g., threadfin breams (*Nemipterus* spp.) and many species classified as "Other fish" in Table 1.
5. Slow-growing large size fish, e.g., groupers (*Epinephelus* spp.), and snappers (Lutjanidae) and similar species. These species have not been included in the simulations although they are of economic importance. The available catch statistics are not detailed enough for an evaluation of their contribution to the catches.

Representative species for the simulations

The simulations are done for species considered representative for the first four demersal fish groups identified above, which are abundant in their group. The following choices were made:

Group 1 - Pony fish *(Leiognathus bindus)*
Group 2 - Lizard fish *(Saurida undosquamis)*
Group 3 - Big eye *(Priacanthus tayenus)*
Group 4 - Threadfin bream (*Nemipterus* spp.)

Table 2 gives growth parameters and length-weight relationships extracted from the literature for these species. The data all refer to the Gulf of Thailand. This set of parameters was actually used in the simulation.

Table 2. Biological and other parameters of selected demersal fishes from the Gulf of Thailand.

	Leiognathus bindus	*Saurida undosquamis*	*Priacanthus tayenus*	*Nemipterus* spp.
L_∞ (cm)	10.3[a]	37.1[d]	26.8[a]	27.0[a]
K (per year)	1.25[a]	1.30[d]	2.15[c]	0.65[a]
Z (per year)	6.7[a]	4.5[d]	9.2[c]	3.4[a]
M (per year)	2.8[a]	1.5[a]	3.0[a]	1.4[a]
F (per year)	3.9	3.0	6.1	2.0
a	$3.E^{-6}$[f]	$3.52E^{-6}$[b]	$2.61E^{-6}$[b]	$7.8E^{-6}$[b]
b	3[f]	3.13[b]	2.89[b]	3.1[b]
s.f.	1.95	3.47	1.86	2.44
r_m (cm^{-1})	0.713	0.336	1.037	0.873
% in total catch 1983	40.6	2.5	3.7	22.1
Maximum length of trash fish component in catch (cm)	10.3	12.0	15.0	6.0
Length at recruitment (cm)[f]	3.5	5.0	5.0	5.0
Recruitment peaks (months)	1,7,8[e]	2,6,12[e]	3,5,10,12[e]	3,5,6[e]

Sources: [a]Ingles and Pauly (1984).
[b]Menasveta (1980).
[c]Boonvanich (MS).
[d]Meemeskul and Boonvanich (1982).
[e]Chullasorn and Martosubroto (1986).
[f]guessed.

Selection Ogives

A covered cod-end experiment was conducted in July 1986 by *R/V Pramong 2*. The meshes were, respectively, 40 cm in the cod-end and 25 cm in the cover. The length compositions for *Leiognathus bindus, Priacanthus tayenus, Saurida undosquamis* and *Nemipterus mesoprion* are presented in Table 3 and plotted in Fig. 2. Selection factors (sf) and steepness (r_m) of the selection ogives are estimated by the model

$$S(L) = 1/(1 + \exp(-r_m(L - sf \times \text{mesh size})))$$; see equations (4) and (5)

These estimates are given in Table 2 and used in the simulations.

Fishing Effort and Catchability

Five fleets are considered in the simulations: otter, pair, beam and shrimp trawlers and push netters. The effort measure used is number of boats in the Gulf of Thailand. The number of registered boats is published annually as Thai fishing vessel statistics (Department of Fisheries, Bangkok, Thailand). The effort by fleet for 1983 is shown in Table 4. However the number of

Table 3. Length frequencies from covered cod-end experiments in the Gulf of Thailand, by *R/V Pramong 2,* July 1986. (Cod-end mesh size 4.0 cm, covernet 2.5 cm).

Mid-length (cm)	*Leiognathus bindus* Number caught		*Saurida undosquamis* Number caught		*Priacanthus tayenus* Number caught		*Nemipterus* spp. Number caught	
	Cod-end	Cover	Cod-end	Cover	Cod-end	Cover	Cod-end	Cover
3.0	1	23	–	–	–	–	–	–
3.5	30	172	–	–	–	–	–	–
4.0	125	418	–	–	–	–	–	–
4.5	201	677	–	–	–	–	0	1
5.0	231	846	0	7	–	–	0	12
5.5	190	724	0	110	–	–	4	54
6.0	125	600	0	323	0	1	12	134
6.5	60	223	5	465	0	6	25	325
7.0	31	141	4	682	2	8	37	372
7.5	21	32	11	466	6	6	74	316
8.0	6	6	15	446	8	8	124	290
8.5	7	2	22	460	12	2	176	335
9.0	3	1	40	410	30	0	254	320
9.5	0	1	39	358	57	1	299	593
10.0	0	0	44	318	88	0	449	790
10.5	0	0	42	210	85	0	437	694
11.0	0	0	45	159	60	0	487	561
11.5	1	0	32	182	44	0	510	437
12.0	–	–	44	125	72	1	518	112
12.5	–	–	48	69	135	0	378	31
13.0	–	–	57	60	207	1	226	3
13.5	–	–	58	55	383	0	102	1
14.0	–	–	55	23	440	0	44	0
14.5	–	–	68	9	333	0	32	0
15.0	–	–	61	50	180	0	43	0
15.5	–	–	67	29	202	0	53	0
16.0	–	–	71	19	354	0	58	0
16.5	–	–	71	13	607	0	45	0
17.0	–	–	60	26	688	0	32	0
17.5	–	–	65	44	760	0	19	0
18.0	–	–	72	57	734	0	13	0
18.5	–	–	102	26	699	0	6	0
19.0	–	–	102	35	508	0	0	0
19.5	–	–	101	14	361	0	1	0
20.0	–	–	93	25	237	0	–	–
20.5	–	–	69	4	136	0	–	–
21.0	–	–	66	1	62	0	–	–
21.5	–	–	68	1	19	0	–	–
22.0	–	–	60	1	45	0	–	–
22.5	–	–	56	0	29	0	–	–
23.0	–	–	52	0	5	0	–	–
23.5	–	–	51	0	11	0	–	–
24.0	–	–	37	0	23	0	–	–
24.5	–	–	35	0	2	0	–	–
25.0	–	–	36	0	7	0	–	–
25.5	–	–	24	0	7	0	–	–
26.0	–	–	24	0	6	0	–	–
26.5	–	–	11	0	0	0	–	–
27.0	–	–	7	0	6	0	–	–
27.5	–	–	8	0	–	–	–	–
28.0	–	–	7	1	–	–	–	–
28.5	–	–	3	0	–	–	–	–
29.0	–	–	4	0	–	–	–	–
29.5	–	–	5	0	–	–	–	–
31.5			1	0	–	–	–	–
Total no.	1,032	3,866	5,283	7,215	7,650	34	4,458	5,381
Weight (kg)	3.27	9.72	106.49	11.26	336.93	0.32	68.48	21.09

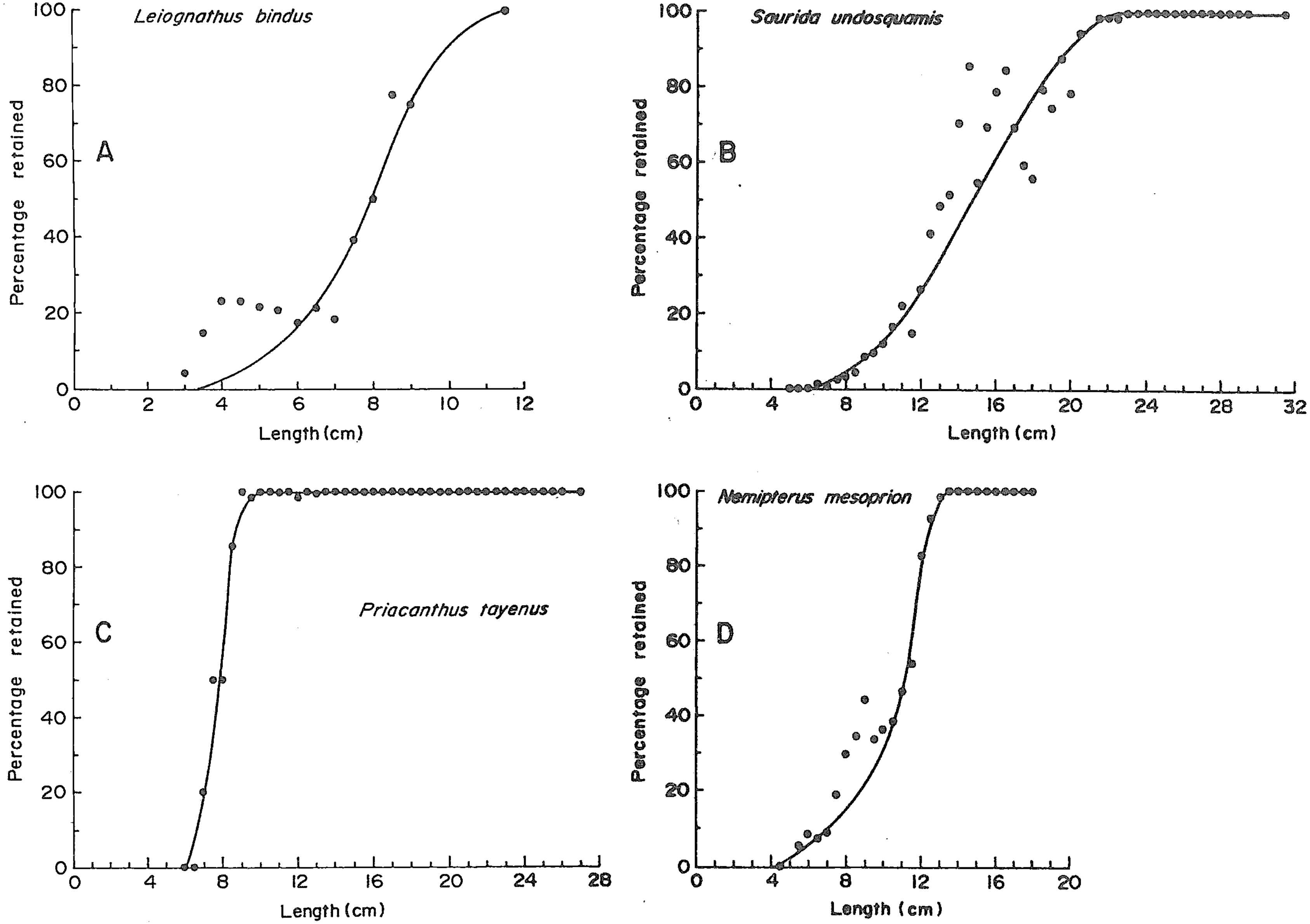

Fig. 2. Selection ogives of the four species representative of major groups in the Gulf of Thailand trawl fishery (based on data in Table 3).

registered fishing vessels, in most cases does not represent the actual effort of fishery, particularly for beam trawlers, shrimp trawlers and push netters. These vessels mostly belong to low-income fishermen in rural areas where the registration is not effective.

To correct for this error it is assumed that the actual numbers for these three types of vessels are close to twice those registered. Statistics for otter trawl and pair trawl are more reliable and no correction is applied.

Table 4. CPUE (kg/h) and effort (no. of vessels) by vessel category for 1983 for the Gulf of Thailand.

Vessel category	Vessel size (LOA; in m)	CPUE (kg/h)	Mean CPUE (kg/h)	Effort (no. of vessels)	
				Registered	Used in simulation
Otter trawler	14 – 18	52.24			
Otter trawler	19 – 25	103.25			
Otter trawler	25	144.16			
Otter trawler	all		99.88	3,212	3,212
Pair trawler	< 14	31.51			
Pair trawler	14 – 18	97.61			
Pair trawler	> 19	137.51			
Pair trawler	all		91.48	1,180	1,180
Beam trawler	all		22.46	3,637	7,274
Shrimp trawler	all		32.46	337	674
Push netter	all		20.69	941	1,882
Total				9,307	14,222

Sources : Marine Fisheries Statistics, 1983 based on sampling survey Department of Fisheries, Bangkok, Thailand and Thai Fishing Vessel Statistics (1983) Dept. of Fisheries, Bangkok, Thailand

The catchabilities were calculated from the fishing mortalities given in Table 2 and the effort and CPUE for 1983 given in Table 4. This was done as follows. The CPUE's were standardized using the push netters as unit. Then a constant factor was found which gives the fishing mortality given in Table 2 for the fully recruited part of the length distribution. Applying this factor to the normalized CPUE's and the efforts (Table 4) gives the catchabilities by trawl category and by species.

This is illustrated below for *L. bindus*.

Fishing mortality is found in Table 2 as 3.91/year. The constant factor q is found from

$$3.91 = \frac{q}{20.69}(\underbrace{99.88 \times 3212}_{\text{otter trawl}} + \underbrace{91.48 \times 1180}_{\text{pair trawl}} + \underbrace{22.46 \times 7274}_{\text{beam trawl}} + \underbrace{32.46 \times 674}_{\text{shrimp trawl}} + \underbrace{20.69 \times 1882}_{\text{push net}})$$

$q = 0.00012$ per push netter

So the catchability for *L. bindus* by otter trawl becomes

$$q \times 99.88/20.69 = 0.00060$$

The catchability by species and by fleet used in the simulations are given in Table 5.

Table 5. Coefficient of catchability of representative demersal fish for five fishing fleets in the Gulf of Thailand, calculated from CPUE estimates in Table 4 and F values in Table 2.

Species (group)	Otter trawler	Pair trawler	Beam trawler	Shrimp trawler	Push netters
Leiognathus bindus	0.00060	0.00056	0.00014	0.00020	0.00013
Saurida undosquamis	0.00046	0.00042	0.00011	0.00015	0.00010
Priacanthus tayenus	0.00093	0.00086	0.00021	0.00031	0.00019
Nemipterus spp.	0.00030	0.00028	0.00010	0.00010	0.00010

Recruitment

The recruitment rate was entered as 1,000,000 per year for those months when recruitment shows peaks according to Chullasorn and Martosubroto (1986), reproduced in Table 2. Other months were assumed to show no recruitment. This is obviously a crude approximation to a realistic recruitment pattern, but was chosen rather than introducing some patterns which also had little foundation. This choice of recruitment pattern introduces a seasonality in the calculated yield. This seasonality is most noticeable in the trash fish component and when interpreting the simulation results, this must be kept in mind.

Results of Simulations

The simulations are done on a constant recruitment basis. The results are presented by quarter of year after the mesh change is effective. Equilibrium yield in the 4 cm mesh situation is expressed as percentage of the corresponding yield with the 2.5 cm mesh size. The results are given for each species group separately.

The initial stock length distribution is the equilibrium stock at 1st January when the recruitment pattern and the mortalities generated by the 2.5 cm mesh size fishery have reached a steady state. These length compositions were calculated by seeding the initial length composition with all zeroes and simulating 6 years after which equilibrium was reached. This calculation was repeated for the fishery with 4 cm mesh applied to otter and pair trawlers, which gives the annual mean gain/loss by species and fleets. Further the yield calculations were done for the trash and the commercial fish catch component separately. Trash is distinguished from commercial fish by a specified length (Table 2). Those equal or below are all considered trash; those above are commercial fish.

The short-term effects were investigated by simulating two years. Both simulations start with the calculated equilibrium length compositions for the 2.5 cm fishery. One simulation is then a continuation of the 2.5 cm fishery, while the change to 4 cm for otter and pair trawl is simulated in the second run. The results are expressed as percentage of yield calculated by the second run of those calculated in the first.

The results for the four species groups for the five fleets are shown in Fig. 3.

The main feature of the results is the drop in the catch of trash fish, while no or very little short-term loss is found in the commercial fish. This latter result is rather obvious since the L_{50} for a 4 cm mesh is about 10 cm, which for most species is below the size that distinguishes trash from commercial fish. The long-term effects are summarized in Table 6.

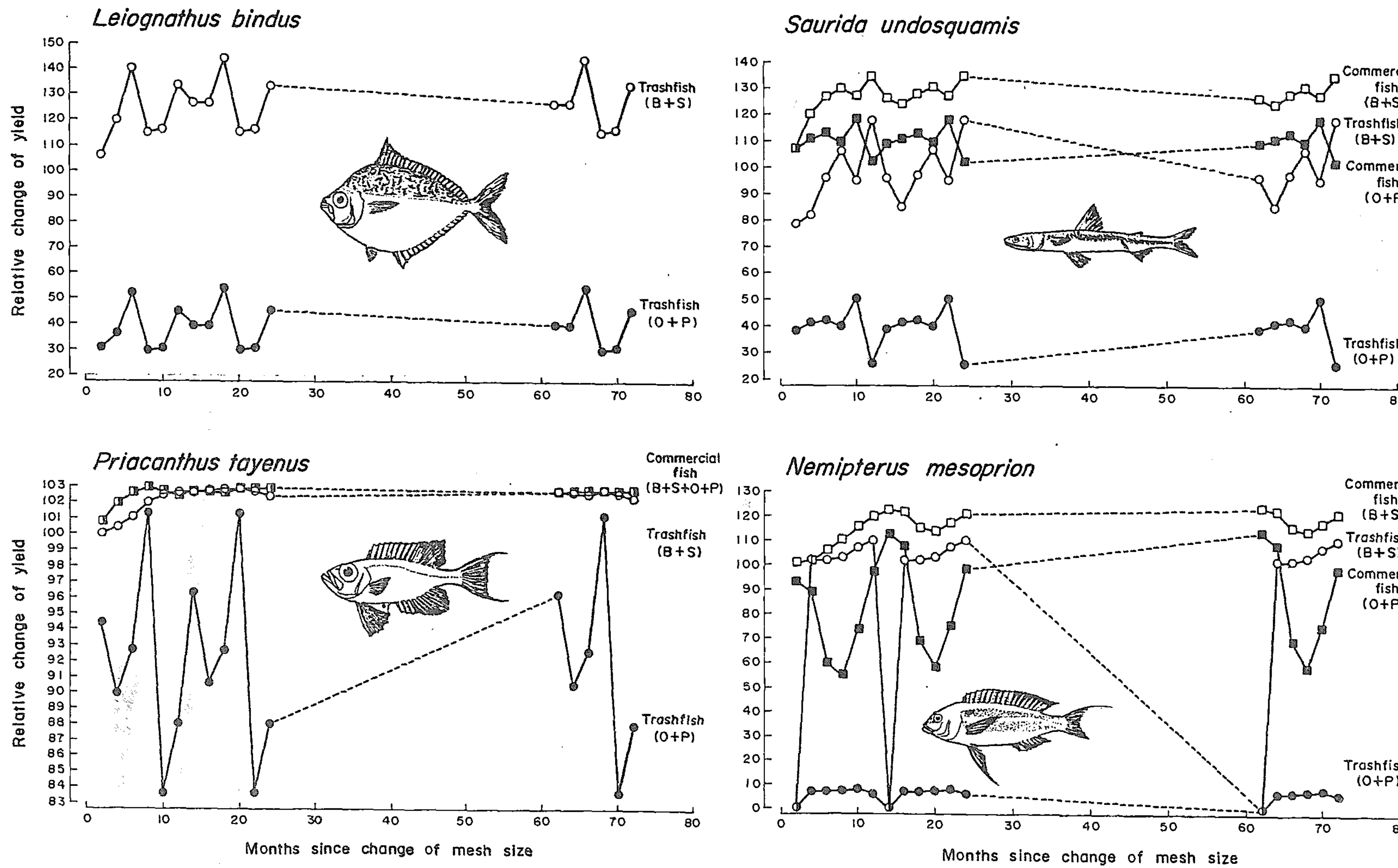

Fig. 3. Predicted changes in yield of Gulf of Thailand trawl fishery following a change from 2.5 cm to 4 cm for otter (O) and pair (P) trawlers (with no change of the 2.5 cm mesh used by beam (B) and shrimp (S) trawlers), expressed in % of yield at start of simulation (month 0). Note that period from 62 to 72 months can be considered to refer to equilibrium conditions (see Table 6 and text).

Table 6. Sample output of simulation program: changes in yield, in the trash fish and commercial components respectively one, two and several years after a mesh size increase in otter and pair trawlers (from 2.5 to 4.0 cm), in percent of the corresponding equilibrium yield before the change.[a]

Group species Genus category Time	Fleet[b]	Trash fish *Leiognathus* trash (% of original)	Fast growing, *Saurida* trash (% of original)	 comm. 	Fast growing, *Priacanthus* trash (% of original)	 comm. 	Slow growing, *Nemipterus* trash (% of original)	 comm.
After	O + P	38.8	40.1	97.6	93.5	100.4	7.0	83.4
1 year	B + S	120.1	109.2	123.4	102.0	100.4	102.0	107.7
After	O + P	41.3	40.4	100.5	94.1	100.8	7.0	91.6
2 years	B + S	124.9	109.0	126.6	102.4	100.8	102.0	115.2
New long-								
term equi-	O + P	41.3	40.4	100.5	94.1	100.9	7.0	91.6
librium	B + S	124.9	109.9	126.6	102.4	100.9	102.0	116.2

[a]Note that 100% means no change and the beam and shrimp trawlers are assumed to maintain their mesh size of 2.5 cm (see also Fig. 3).
[b]O + P = otter and pair trawlers; B + S = beam and shrimp trawlers.

Discussion

Simulations like the one presented here form a crude type of analysis, which can be difficult to make realistic. Many elements of tropical fish stock population dynamics are not known or known only approximately. Also the fleet and catch/effort statistics in many countries are far from the quality desired for such an exercise.

One main objective of this paper however is to demonstrate that such a simulation model can be set up and parameters found. There are many elements in the model which are doubtful but even so some essential features are still considered to be realistic:

1) There is little or no short-term loss of commercial fish from a moderate mesh size increase and this loss will only be experienced during the first year after the change takes place.
2) The gain of a mesh change will be realized quite fast, after one to two years.
3) The catch of trash fish will decrease significantly and be redistributed between the fleets. The overall loss is rather smaller than could be expected.

Long-term effects are usually discussed in yield-per-recruit terms (see Silvestre and Soriano, this vol.). Also there is a tendency to discuss optimum mesh sizes for a mixture of species. The approach presented here will allow a discussion both of short-term and long-term effects of any changes in mesh size. Furthermore, changes in effort (number of vessels) can be equally well addressed using the same model.

Fisheries management does not end with these considerations. Recruitment must be maintained and in some fisheries this is actually the dominant objective for management.

Such an approach to management would require the determination of the size of the spawning stock at some time. Based on that information and an assessment of the minimum spawning stock that should be maintained a catch limit may be determined.

The present model focuses upon yields in a fishery which is described by a simple measure of effort, while species interactions and biological models of recruitment are not included.

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Species Index

Geographic Index

Author Index

M-42/S8200E/1/8.88/2000
ISBN 92-5-102707-2