11. ASSESSMENT OF MIGRATORY STOCKS

Several of the methods presented so far are often insufficient when applied to migratory or schooling fish stocks. They were all based on the assumption that we can take representative random samples of the stock, for example, the whole range of length-frequencies. When stocks are not vulnerable to fishing, due to horizontal or vertical migrations to areas not covered by the fleet or normal fishing gears during parts of their life span, it is usually not possible to sample such stocks during these periods. This may simply lead to gaps in the samples for shorter or longer periods, but it is also possible that the samples taken represent different parts of the stock and in such cases it is likely that the data are misinterpreted. In particular, the length-based methods, such as modal progression analysis and catch curve analysis are difficult to apply in the case of migratory fish stocks.

The migrations of fish stocks which have been exposed to fisheries for centuries and to fisheries research for some 100 years (the herring in the North Sea, for example) are sufficiently well known to avoid bias in sampling and misinterpretation of results. The general knowledge of most tropical fish stocks, however, is often very limited and therefore sampling bias, incomplete coverage of the stock and misinterpretation of the data may easily occur.

In this chapter the problems related to migration will be illustrated. Some methods are given which may help in the interpretation of the length-frequency data obtained from migratory fish stocks. These methods should only be considered as first steps to solving complex problems.

11.1 THE CONCEPT AND STUDY OF MIGRATION

Harden Jones (1968) recognized three types of "migratory movements": drifting with the currents, random locomotory movements and oriented locomotory movements. In a later paper Harden Jones (1984) stated: "I use the word migration in the sense of coming and going with the seasons on a regular basis". Gerking (1953) defined the concept of "homing" as "the return to a place formerly occupied instead of going to other equally probable places". Homing is known to be an important feature of the migration of many fish stocks.

For fish stock assessment purposes, the explanation of why fish migrate is of little importance. The important thing is to know where the fish are at which time of the year.

In this manual we shall look at migration primarily as a source of bias. Migration is here defined as "*any systematic type of movement of individuals belonging to a stock*" (cf. the definition of bias given in Section 7.1). Random movements are not considered migrations in the present context because we are only interested in such types of migration that create bias for a length-frequency sampling programme. If a fish moves at random the movement will not change the relative probability of being sampled. The distinction between random movements and systematic movements is not obvious. The fish might encounter concentrations of food by moving randomly, and by random movement remain there until the food is nearly exhausted. If the movement of the food items is systematic (e.g., determined by current and other systematic oceanographic features) we would consider the above described feeding movement as a migration, although it was composed of random movements.

Migration is also characterized by being predictable, e.g., for some stocks we are able to predict at which time and where high concentrations can be found.

Most of the migrations causing bias are horizontal movements, along the coast, inshore/offshore or even between rivers/lagoons and marine areas. However, also relatively small vertical migrations and differences in distribution in the water column between different size groups (ages) of the same species may cause bias in our data.

Migrations creating bias may be classified into five main types, of which some are illustrated in Fig. 11.1.1.

1a. Daily vertical migration (e.g., at the bottom during day and in the water column during night).

1b. Daily horizontal migration (e.g., skipjack tuna has been observed to move away and return to a precise location each day (Yuen, 1970).

2. Spawning migration (i.e., annual return to spawning grounds followed by a movement to a feeding ground, or in the case of some cephalopods and penaeid shrimps with only one spawning during their life span, migration to the spawning grounds followed by extinction. Homing may be an important feature of this type of migration.

3. Size-dependent vertical migration of adults (e.g., skipjack tuna, the younger year classes occur in surface schools, whereas the older specimens move to greater depths).

4. Size-dependent horizontal migration (i.e., larger specimens move to deeper waters, while still undertaking the migrations mentioned above).

5. Migration of juveniles. Often juveniles undertake migrations different from those of the adults. The juveniles may remain in the upper layers day and night, whereas the adults are at the bottom during the day. They may also occupy special nursery grounds where the adults are not found. For many species a period in the estuarine or inshore waters is a special phase of life (see for example, Blaber and Blaber, 1980).

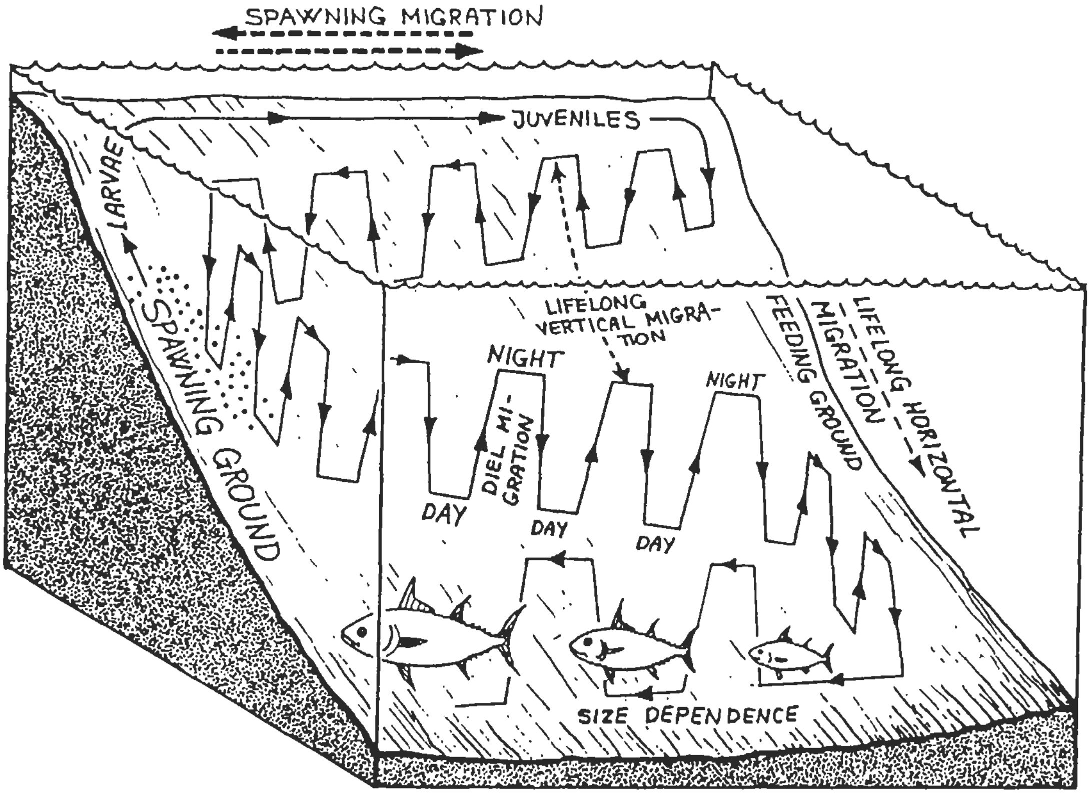


Fig. 11.1.1 **Schematic illustration of five types of potential bias created by migrations**

An important feature of the migration/bias complex inherent in especially spawning migration is the size-dependence. Often, schools with larger average body size arrive at the spawning grounds earlier than the smaller specimens of the same cohort. In addition to the bias problem in fish stock assessment there are other reasons why migration should be studied. One is that of stock sharing between countries (cf. Section 1.2), which is also behind the UNCLOS definition of highly migratory species.

The complex of problems involved in shared stocks contains the problems of stock identification and migration routes. Shared stocks and their management are discussed in, for example, Caddy (1982, 1987) and Caddy and Garcia (1986). Caddy (1982) classifies marine resources based on their movements relative to the EEZs (Exclusive Economic Zones) into five categories:

1. Stocks that lie almost entirely within a single national jurisdiction.
2. Non-migratory resources lying across the boundary between adjacent zones, and which are continuously available in each zone.
3. Migratory species moving across boundary areas only available in each zone on a seasonal basis.
4. High sea stocks that are only occasionally or partially available inside national zones.
5. High sea stocks which occur exclusively outside EEZs.

Especially for categories 3 and 4 the stock identification is a prerequisite for intelligent management of shared stocks. Stock identification and stock assessment has to be based on knowledge of the migration routes of the stock.

There are several ways to acquire knowledge about possible migrations of the species under study. An obvious and cheap way is to tap the knowledge of the fishermen, who surely have noticed seasonal or daily variations in the availability of the various target species.

Such fluctuations may also be reflected in the records of landings of various types of fishing boats (statistics) and a general knowledge of the movements of the fleets. Common echosounders are very useful for the detection of vertical migrations, while more sophisticated acoustic equipment can be used to map the distribution and estimate the abundance, in relatively short time, in particular of small pelagic fish.

The classical way to study movements (and growth) of fish and invertebrates is a tagging programme. Identification tags are attached externally or placed in the body cavity, the fish is measured and released at a known spot, and a reward is given for any tag returned with information on the date and place of capture. Such tagging programmes, if successful, may provide a lot of useful information on net displacements between the point of release and the point of recapture. They do not provide information on what has happened in between those moments and points.

Sophisticated acoustic and radio tags have been developed which allow the continuous observation of the movements of single fish as followed from a research vessel. The latest developments include tags that are released at a pre-set moment, pop to the surface and transmit to a satellite (applied in tuna research) and tags that record the compass bearing and tilt angle of an individual fish.

In Section 11.5 below some aspects of ordinary tagging programmes are discussed.

11.2 BIAS CAUSED BY MIGRATION

To illustrate the problem of bias caused by migration, consider a simplified hypothetical fish stock as illustrated in Fig. 11.2.1. This hypothetical fish stock spends one half of the year on the fishing grounds and the other half in an area where it is not exploited and which is also its nursery ground. The stock is composed of two components A and B (you may think of A as the fish recruited before the monsoon and B as the fish recruited after the monsoon). The two components undertake the same migrations but at different times of the year, as shown in Fig. 11.2.1. Suppose the species has a life span of only two years and suppose for simplicity that the migrations take place on the 1st of January and the 1st of July. Samples are available only from the fishing grounds.

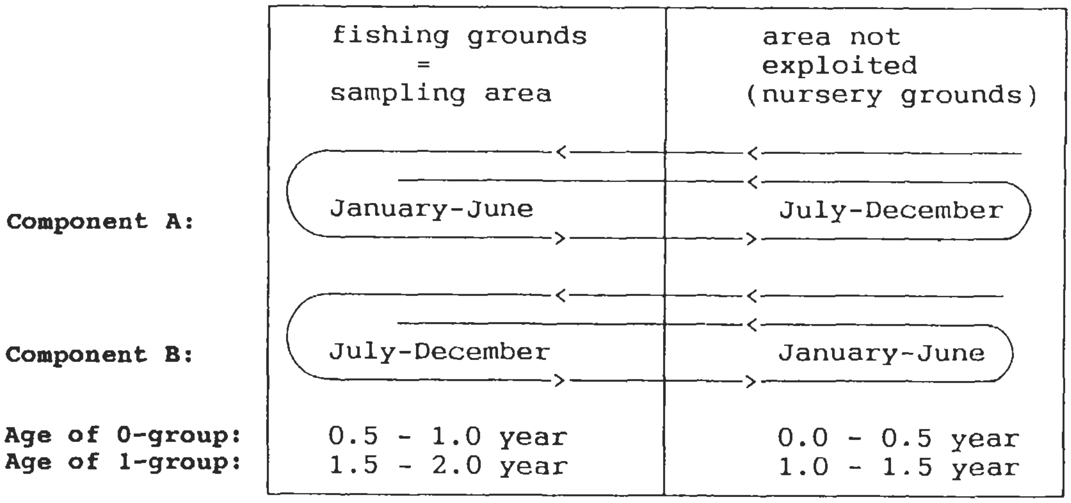


Fig. 11.2.1 Hypothetical simplified system to illustrate the main problem in obtaining random samples from a migratory stock

Assume further that we do not know the migration pattern, but erroneously believe that the entire stock is on the fishing grounds all year round. In this case we are in trouble when sampling data for estimation of growth parameters because the important data for the first half year of life are not available. We may wrongly explain the absence of small fish to be caused by gear selection. We may also observe an apparent negative growth during the period from June to August if we believe that the fish on the fishing grounds in June are the same as those in August. In June component A consists of 1 and 2 year old A-fish, which in July are replaced by 0.5 and 1.5 year old B-fish.

In this (not very realistic) example one would probably not need to sample the fishery for any long period before one guessed the reason for the missing data for small fish and the apparent negative growth. In reality pelagic fish stocks show a much more complex migratory behaviour and the risk exists that we wrongly interpret phenomena caused by migration as something else. One obvious example is to misinterpret migration as mortality. If, for example, the fish at a certain body size moves to deeper waters where it cannot be caught by the fishing gears it will appear to us as if the fish had died, because the larger fish do not occur in the samples.

The usual situation is that on a given date on given fishing grounds samples can be taken only from a certain fraction of the stock. Also the time of the day and the gear used may restrict the fraction of the stock available for sampling. This section is partly based on the work by

Sousa (1988) who discusses sources of bias when assessing stocks of small pelagics, with the scad *Decapterus russelli* in Mozambique waters as an example. The current knowledge of migration patterns of small pelagics in Mozambique waters is limited, and tagging experiments on small pelagics have not been conducted.

Severe difficulties, such as apparent negative growth were encountered when trying modal progression analysis on length-frequency samples. Fig. 11.2.2 shows an example of such a problematic time series of length-frequencies.

In the absence of exact data on migration routes, Sousa (1988) searched for plausible explanations of some of the apparent inconsistencies in the time series of length-frequencies. The first step was to suggest hypotheses for the migration pattern and the next, to test the hypotheses on the available data.

The reasoning assumes the existence of the migration patterns illustrated in Figs. 11.1.1 and 11.2.3. The hypotheses behind Fig. 11.2.3 are:

1) There are two peak recruitments per year. They are denoted: "Autumn cohorts" and "Spring cohorts".

2) Each year a certain time is spent on the fishing grounds, which are also the spawning grounds. The remaining part of the year the fish are away from the fishing grounds. The spring cohorts are not on the spawning grounds at the same time as the autumn cohorts.

3) The first half year of life is spent outside the fishing grounds.

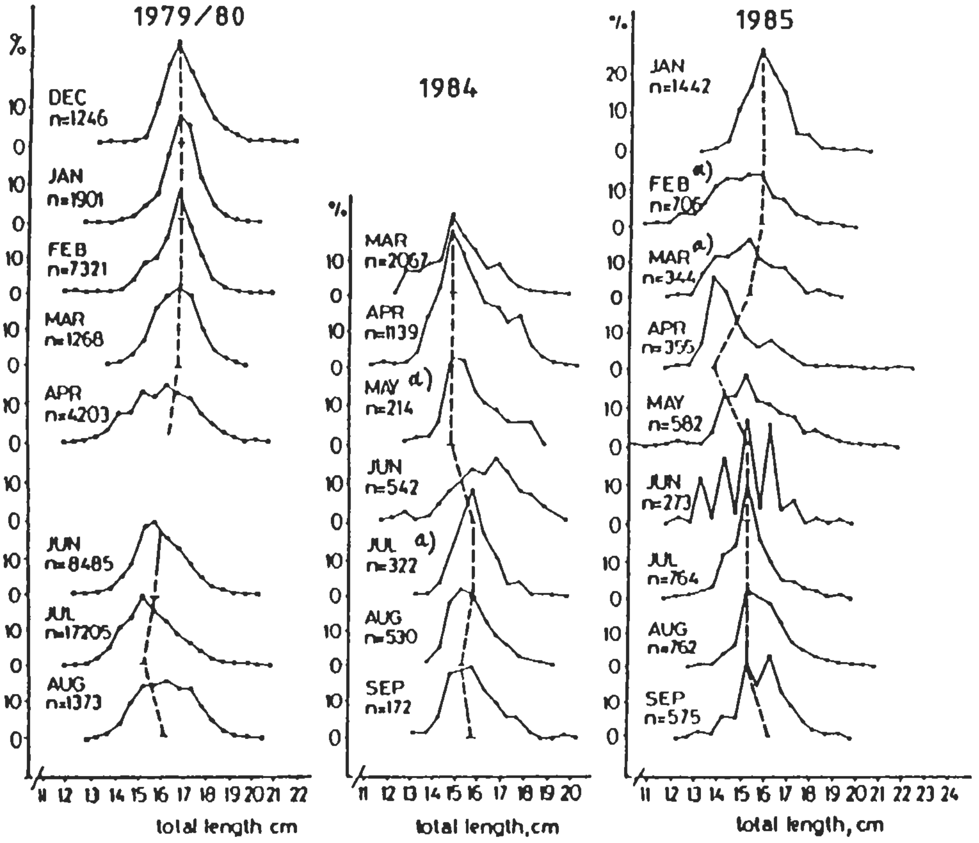


Fig. 11.2.2 **Selected series of length-frequencies of commercial catches of *Decapterus russelli*, Sofala Bank, Mozambique, illustrating the problems with the interpretation of modal progression (from Sousa, 1988)**

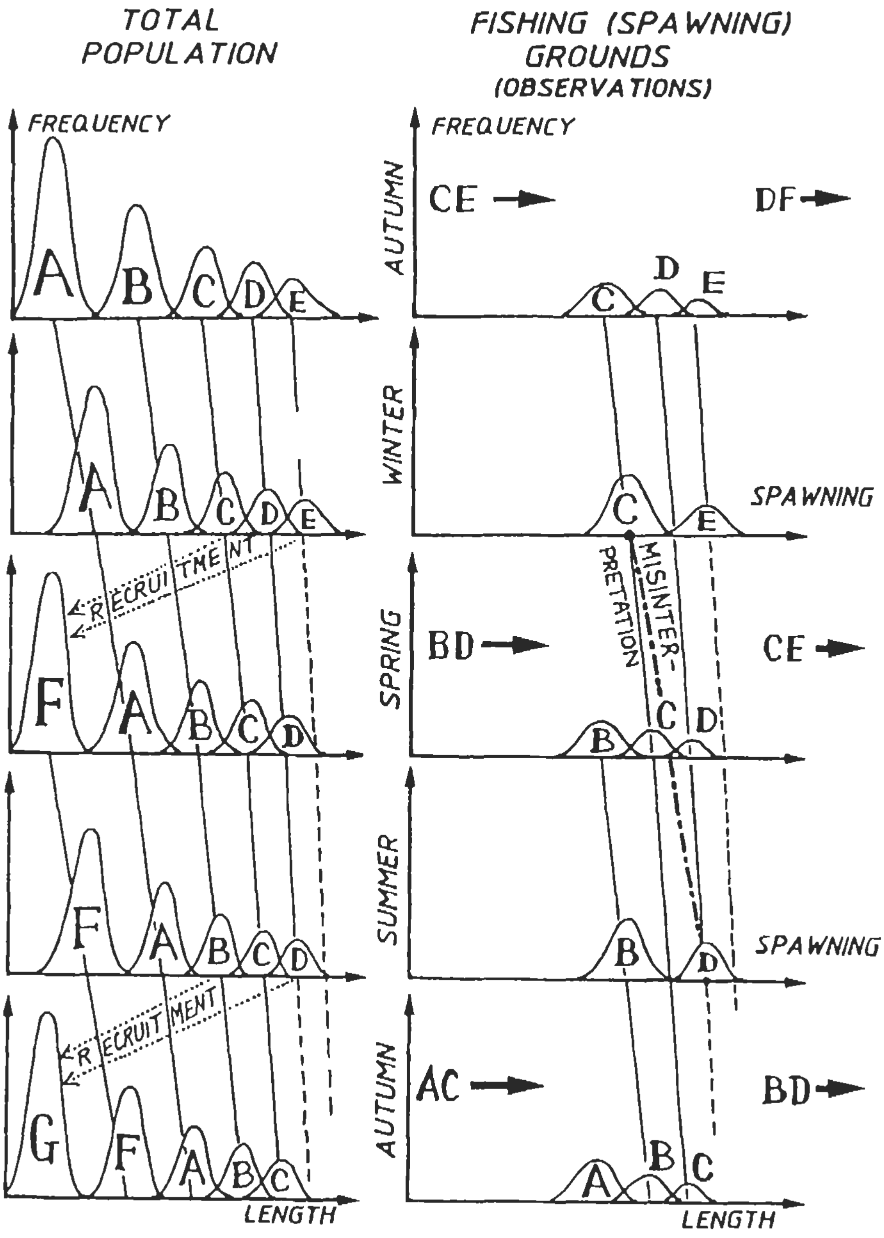


Fig. 11.2.3 **Schematic illustration of the hypothesis of the migration of small pelagics. One unrealistic simplification is that the cohorts do not overlap. For further discussion see text (from Sousa, 1988)**

The left-hand side of Fig. 11.2.3 illustrates the total population, where A, C and E are the autumn cohorts and B, D and F are the spring cohorts. The right-hand side of Fig. 11.2.3 shows that part of the stock which is on the fishing grounds. In the autumn the C and E cohorts are on their way to the fishing grounds and D and F are on their way out. Only a part of C and D has arrived and only a part of E and F has left. In winter C and E only are represented on the fishing grounds but all members of these cohorts are present. The graphs for spring and summer should be explained along similar lines.

This theory could explain why there appears to be so little progression in the length-frequency modes. The right hand side further illustrates the risk of connecting peaks from different cohorts.

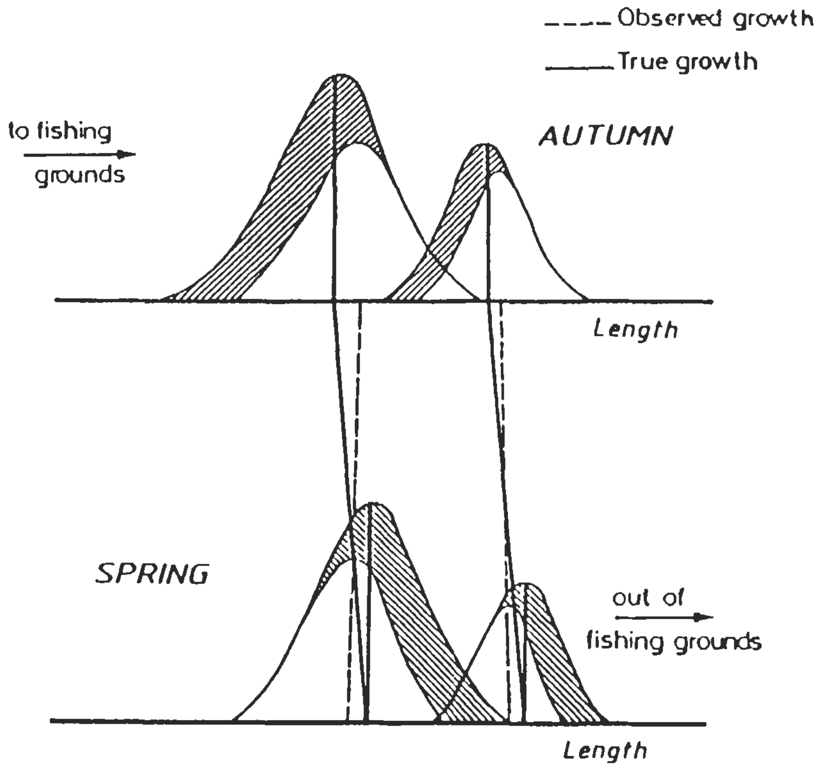


Fig. 11.2.4 Schematic representation of the bias caused by size-dependent migration. Dashed zones indicate that part of the population that is not sampled (from Sousa, 1988)

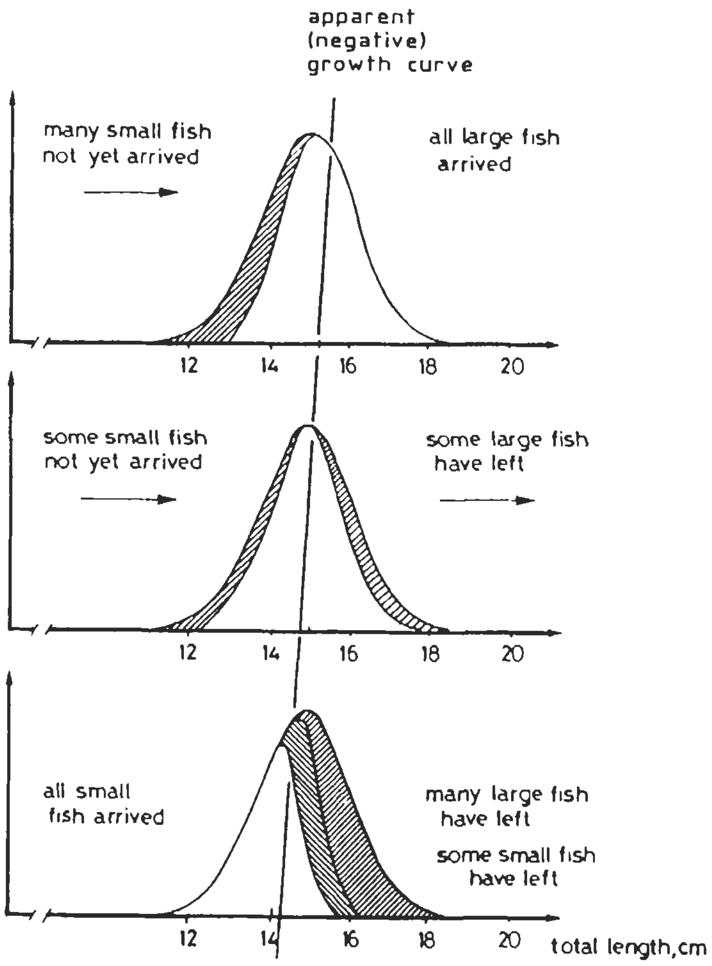


Fig. 11.2.5 Schematic representation of possible reasons why apparent negative growth can be observed (from Sousa, 1988)

In the simplified Fig. 11.2.3 (with no overlapping between cohorts) it is easy to connect the peaks properly, but with a real data set the overlapping between cohorts would make it much more difficult to do modal progression analysis.

Fig. 11.2.4 illustrates bias created by "*size-dependent migration*" in connection with estimation of growth rates. The example deals with two cohorts. The shaded areas represent the fractions of the two cohorts which are not in the sampling area (fishing grounds). You may say that they are the bias-creating part of the stock. The assumption behind Fig. 11.2.4 is that the annual migration (spawning/feeding) is size-dependent.

We assume that the cohorts arrive on the fishing grounds during autumn and leave them in the spring. In the autumn sample some of the small specimens (schools with small average size) have not yet arrived on the fishing grounds. The effect will be an over-estimate of the average body lengths of the two cohorts. In the spring sample the picture is reversed, all small fish have arrived but some larger fish have left the fishing grounds. Now the effect is an under-estimate of the average body lengths. The combined effect of these sources of bias is an under-estimation of the growth rate. What we will observe is the growth rate corresponding to the broken line, whereas the full line represents the true average population growth rate.

Fig. 11.2.5 presents a plausible explanation of apparent negative growth along the same lines as Fig. 11.2.4. Thus apparent negative growth may be explained as the combined effect of annual migration and size-dependence. Other explanations are possible, however. Apparent negative growth may also be caused by gear selection. If the fishery changes from season to season, e.g. changes its geographical distribution and/or gear, the effect may be an under-estimation of the growth rate. Selection may in some cases have the opposite effect, i.e. an over-estimation of the growth rate.

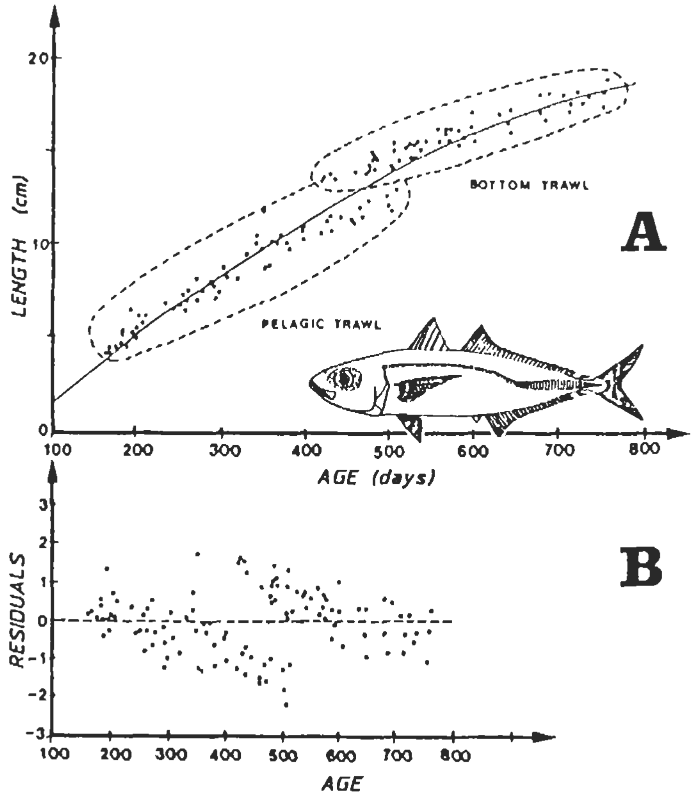


Fig. 11.2.6 **Growth curve of *Decapterus russelli* on Sofala Bank, Mozambique, based on age readings (daily rings) of fish sampled by the commercial bottom trawl fishery and by a pelagic trawl survey, both in 1982 (from Sousa, 1988)**

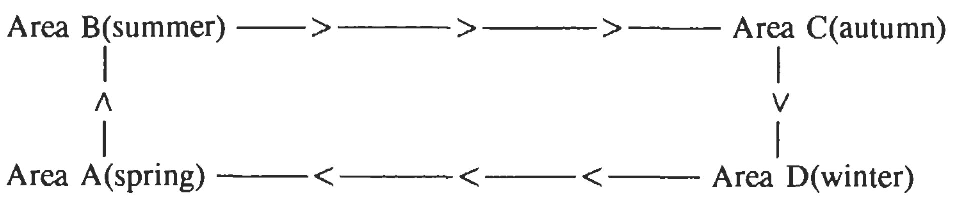
Fig. 11.2.6 illustrates bias caused by size-dependent vertical migration and/or gear selection. Fig. 11.2.6A shows age/length data obtained from otolith readings of 118 *D. russelli* caught by two different gears, bottom trawl and pelagic trawl (from Sousa, 1988). In this case daily rings were observed so that the age of fish is counted in days. Smaller specimens were caught by pelagic trawl and larger specimens by demersal trawl. The two groups appear to follow different growth curves. This can be explained by size-dependence of the lifelong vertical migration. The slower the individuals grow the longer they will remain in the upper layers. If growth curves were estimated for each group of fish the result would be two quite different growth curves. The growth curve shown superimposed on Fig. 11.2.6A is based on all observations. The picture becomes clearer in Fig. 11.2.6B where the residuals (deviations from the estimated growth curve in Fig. 11.2.6A) are plotted against age. Alternatively, it is possible that the findings presented in Fig. 11.2.6 may be explained by higher swimming speeds of larger specimens which reduces the catchability of the pelagic trawl for these size groups.

11.3 THE ANNUAL-RETURN MATCHED SAMPLES METHOD

The method presented in this section is a simple special case of the "*general matched samples method*", which will be discussed in the next section. The "matched samples method" is a simple method for the estimation of growth parameters and mortality rates of migratory stocks. As other simple methods it is based on rather strong assumptions. The question is whether these assumptions are reasonable approximations to the reality.

The method is based on the assumption that a fish stock follows a predictable migration route. If this migration route is known (e.g. from tagging experiments) in time and space we are in a position to follow the cohorts and to "match" samples so that they originate from the same cohort.

Consider a simple hypothetical model:



A, B, C and D symbolize geographical areas. We assume the stock to undertake the same migration each year and the timing for, say, the spring cohort is as indicated above. To "match" samples in the above model for the spring cohort means to perform the analysis based on samples taken:

In spring in area A, in summer in area B,
in autumn in area C and in winter in area D

The samples may originate from one area only, say, A, and in that case only samples collected in the spring (in different years) should be matched.

This model may fit to small pelagics like scads and Indian mackerels and it is known to fit the migration pattern of small pelagics in temperate waters (cf. Section 11.6). It can be used to estimate growth parameters, as described below.

11.3.1 Estimation of growth parameters by the annual-return matched samples method

Fig. 11.3.1.1 depicts a series of length-frequency samples taken every four months over a 2 years period. Note that the distributions in subsequent periods often indicate a negative growth. Following the model we can connect the modes in the distribution for the corresponding months in subsequent years (e.g. Jan.1982, Jan.1983 and Jan.1984), as in a normal modal progression.

The next step is then to use Chapman's method (Eq. 3.3.2.2), as the time interval Δt is relatively long, assumed to be one year throughout:

$$L(t+\Delta t)-L(t) = c*L_{\infty} - c*L(t) \text{ where } c = 1 - \exp(-\Delta t*K)$$

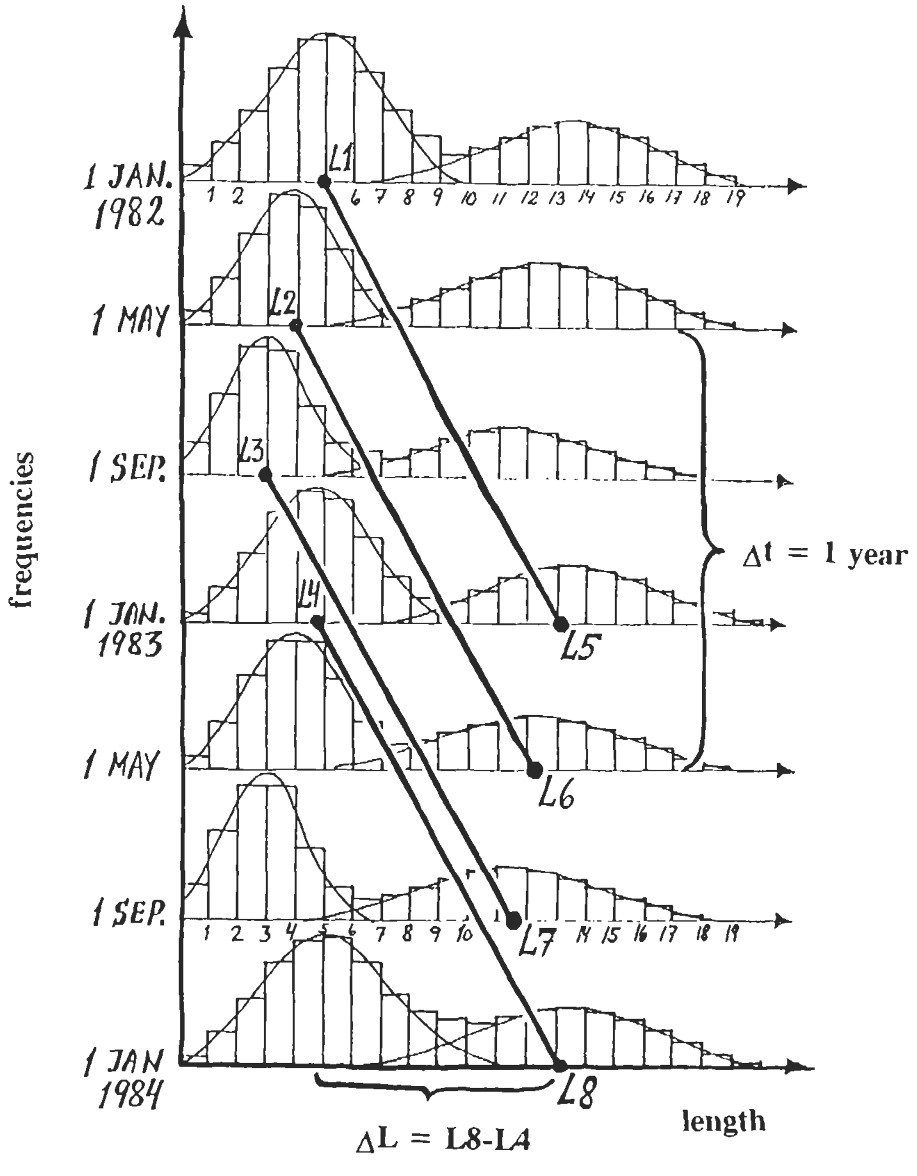


Fig. 11.3.1.1 Illustration of the estimate of growth parameters by the annual-return matched samples method. For further details, see text

There are four estimates of $\Delta L/\Delta t$ with $\Delta t = 1$ year, namely: (L5-L1), (L6-L2), (L7-L3) and (L8-L4). The mean value of the increments of these four observations is 8 cm while the mean of the mean lengths of the first modes is $(L1+L2+L3+L4)/4 = 4.25$ cm. Then we have:

the mean of $L(t+1) - L(t) = 8$ cm and $\bar{L}(t) = 4.25$ cm

$8 = c*L_\infty - c*L(t) = c*L_\infty - c*4.25$ or

$c = 8/(L_\infty - 4.25)$ or as

$K = -(1/\Delta t)*\ln(1-c)$ (see Section 3.3.2), we obtain:

$K = -(1/1)*\ln[1 - 8/(L_\infty - 4.25)]$

If we use 18 cm as a first rough estimate of L_∞ we get:

$K = -\ln(1 - 8/(18-4.25)) = 0.87$

Using $L_\infty = 18$ cm and $K = 0.87$ per year we obtain a modal progression from 4.3. to 12.2 cm at the ages 0.31 and 1.31 years (Fig. 11.3.1.1):

$$L(0.31) = 18*(1 - \exp(-0.87*0.31)) = 4.3 \text{ cm}$$
$$L(1.31) = 18*(1 - \exp(-0.87*1.31)) = 12.2 \text{ cm}$$

11.4 THE GENERAL MATCHED SAMPLES METHOD

This approach assumes that we have knowledge or a hypothesis of the migration route in time and space, and therefore are able to "match" samples so that they originate (or can be hypothesized to originate) from the same cohorts (cf. the beginning of the previous section).

To illustrate the features of the general matched samples method for estimation of total mortalities a simple hypothetical example was constructed. This simplified example deals with one cohort migrating through three areas, A, B and C. From A the cohort moves to B and then to C where it stays for a while; it moves back to B and ends where it started in A.

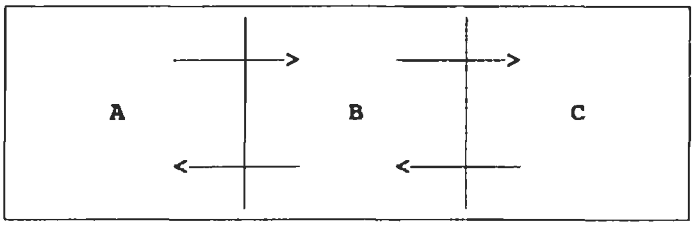


Table 11.4.1 and Fig. 11.4.1 show the example in numbers caught per unit of effort. The curves superimposed on the figure correspond to the growth parameters: $L_\infty = 10$ cm, $K = 2.0$ per year and $t_0 = 0$. The arrows in Fig. 11.4.1 indicate the migration between areas. Ignoring migration we would interpret the first part of the length-frequencies in area A as a cohort becoming extinct in May and we would estimate the mortality rates as follows (cf. Table 11.4.1):

$Z(JAN) = \ln(8465/5732) = 0.39$ per month

$Z(FEB) = \ln(5732/2911) = 0.68$ per month

$Z(MAR) = \ln(2911/986) = 1.08$ per month

$Z(APR) = \ln(986/167) = 1.77$ per month

Table 11.4.1 Hypothetical example to illustrate the "matched samples method"

	Area A (number caught per unit of effort)									
length	1	2	3	4	5	6	7	8	9	10	total
JAN		8465									8465
FEB			5732								5732
MAR				1758							2911
APR					1153						986
MAY					629	357					167
JUN						125	42				0
JUL											0
AUG											0
SEP							4	15	11		30
OCT								104	123	32	259
NOV								201	355	152	708
DEC								178	424	264	866
Total	0	8465	5732	1758	1782	482	46	498	913	448	20124
	Area B										
length	1	2	3	4	5	6	7	8	9	10	total
JAN											0
FEB			1433								1433
MAR				1905	1249						3154
APR					2306	1308					3614
MAY						1870	634				2504
JUN						271	606	111			988
JUL							94	74			168
AUG							50	98	30		178
SEP							98	351	239		688
OCT								422	499	129	1050
NOV								212	375	161	748
DEC								43	103	64	210
Total	0	0	1433	1905	3555	3449	1482	1311	1246	354	14735
	Area C										
length	1	2	3	4	5	6	7	8	9	10	total
JAN											0
FEB											0
MAR											0
APR					341	193					534
MAY						1252	424				1676
JUN						738	1650	302			2690
JUL							1650	1297			2947
AUG							690	1350	418		2458
SEP							216	771	526		1513
OCT								233	276	71	580
NOV								28	49	21	98
DEC											0
Total	0	0	0	0	341	2183	4630	3981	1269	92	12496

The real mortalities (including the entire cohort in all three areas) are (cf. Table 11.4.1):

$$
\begin{aligned}
Z(\mathrm{JAN}) &= \ln(8465/(5732+1433)) \\
&= \ln(8465/7166) && = 0.17 \text{ per month} \\
Z(\mathrm{FEB}) &= \ln((5732+1433)/(2911+3154)) \\
&= \ln(7166/6065) && = 0.17 \text{ per month} \\
Z(\mathrm{MAR}) &= \ln((2911+3154)/(986+3614+534)) \\
&= \ln(6065/5134) && = 0.17 \text{ per month} \\
Z(\mathrm{APR}) &= \ln((986+3614+534)/(167+2504+1670)) \\
&= \ln(5134/4346) && = 0.17 \text{ per month}
\end{aligned}
$$

The differences between the two sets of Z-values are called "*migration coefficients*".

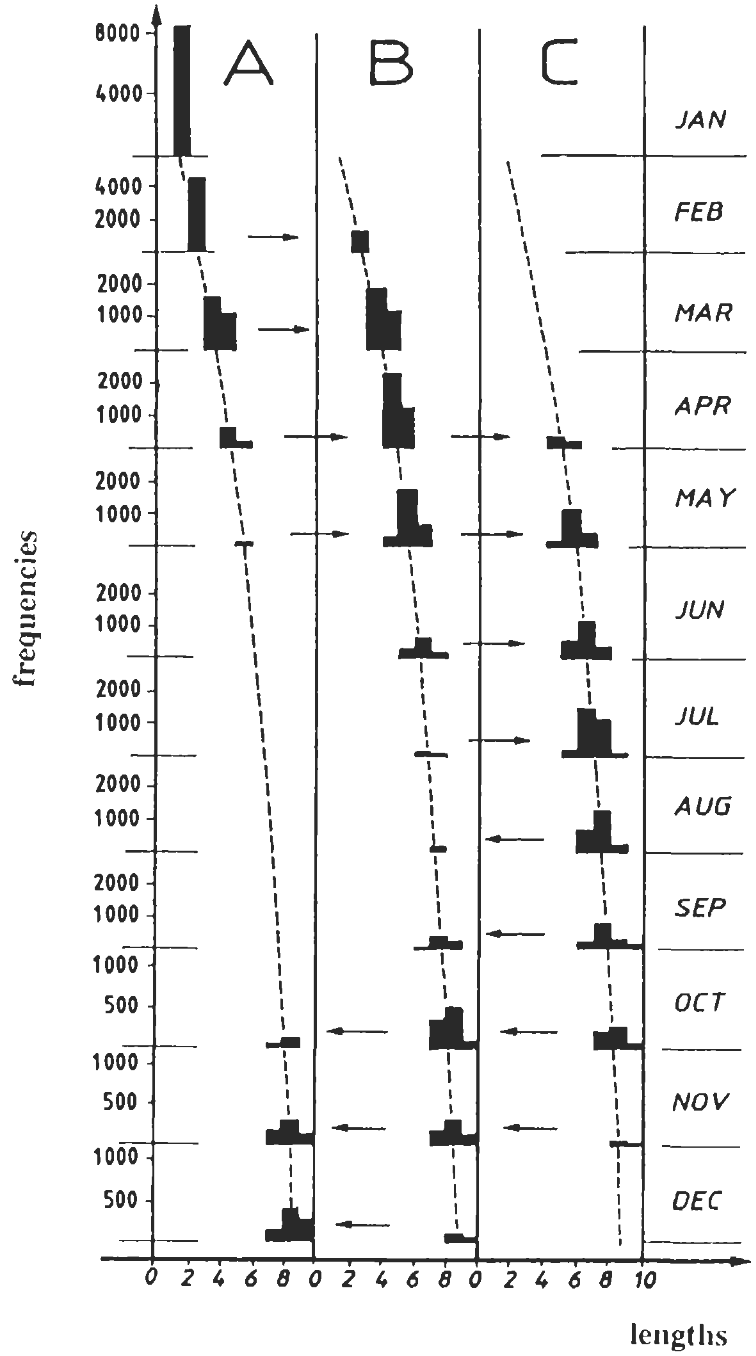


Fig. 11.4.1 **Hypothetical example to illustrate the estimation of mortality rates by the "matched samples method". Note that the scales differ from one month to another**

Fig. 11.4.2 illustrates the difficulties often encountered when trying to estimate growth curves for migratory species. Part C shows the migration route for the stock considered. In this hypothetical example we assume that the samples are obtained from the fishing grounds only. The fish are assumed to migrate to and from the fishing grounds depending on their size. During the first year of life they will be available on the fishing grounds when they are at lengths between L1 and L2 and for the second year between lengths L3 and L4.

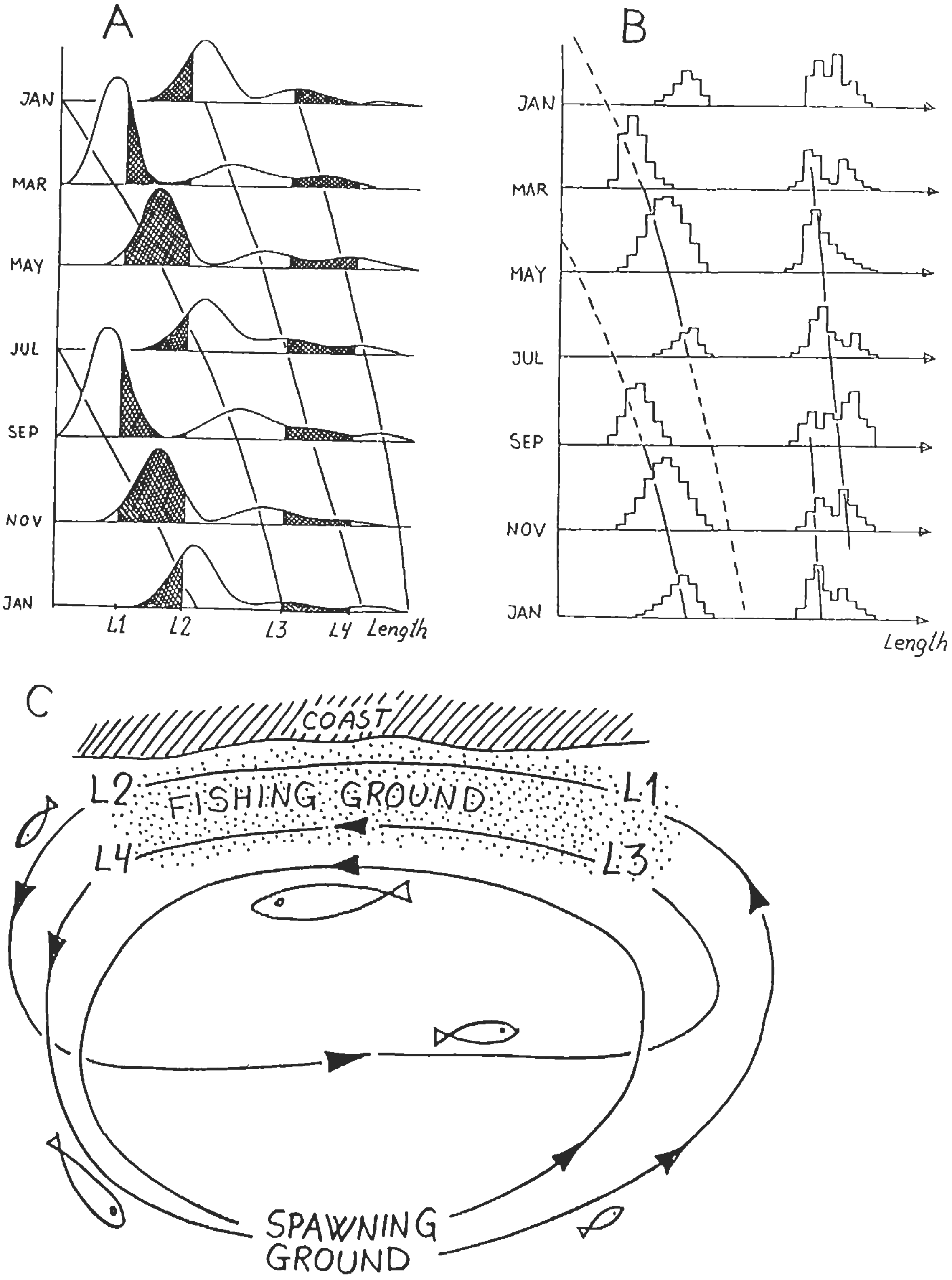


Fig. 11.4.2 **Illustration of bias problems when estimating the growth curve of a migratory species from "unmatched" samples**

Part A shows a time series of unbiased length-frequency samples and the growth curves we would estimate from these samples. These samples could be obtained from a sampling scheme which covers the entire distributional range in space and time. However, we would not be in a position to obtain such unbiased samples if all samples were taken on the fishing grounds only. If the fish arrived on the fishing grounds exactly at the lengths L1 and L3 and left exactly at the lengths L2 and L4 we would obtain the samples represented by the shaded parts of the length-frequency distribution on Part A. In practice we would, of course, not observe such a "knife-edge" recruitment to the fishing grounds, but something like the length-frequency samples shown in Part B which show two distinct groups of fish without any overlap in length-frequencies. The left-hand groups of small fish show some progression in the modes, whereas the length-frequencies of the larger fish are open to any interpretation. The intermediate length group is absent. This general pattern is often observed when sampling length-frequencies from a restricted area, i.e. an area which is only a small part of the distributional range of the stock in question.

The curves superimposed on Part B are the curves we would obtain from a modal progression based on those length-frequencies. These curves are steeper than the true growth curves drawn in Part A. The modes of the smallest fish of the samples in Part B show some progression, but less than the progression in the modes of Part A, which represent the true growth curve. The effect of size-dependent migration (cf. Section 11.2) is therefore an under-estimation of the growth rate of the small fish.

The apparent modes of the large fish in Part B are difficult to interpret in terms of growth. In practice, these modes may have little to do with growth but rather reflect random noise and/or bias from the sampling procedure. In this case the growth curves fitted to the large fish represent an under-estimate of the growth rate, but in other cases might produce an over-estimate. In general, one should be cautious when interpreting modal progression for length groups approaching the maximum length of the species.

11.5 ASSESSMENT BASED ON TAGGING DATA

The success of tagging experiments depends on the ability and willingness of the fishermen and others dealing with the catch to report on where and when the marked fish was caught. If the data are used also for estimation of growth parameters the size of the recaptured fish should be reported as well. The fishery must cover a relatively large part of the distribution in space and time of the stock to secure a reasonable number of recaptures for the estimation procedure. It is assumed that the tagged fish constitute a representative sample of the population, and thus have the same basic parameters as the untagged part. Models along these lines were suggested by Gulland (1955), Paulik (1963), Seber (1973) and Jones (1977). Seber (1973) presents a comprehensive discussion of the analysis of capture/recapture data.

Kleiber, Argue and Kearney (1983) suggested a model for assessment of Pacific skipjack tuna based on tagging data. This is the traditional catch curve model (Eq. 4.2.7) with modifications to take into account mortality due to tagging, shedding of tags and missing reports on recaptures. The basic equation of the model for estimation of population size, P, and "*attrition rate A*", (see definition below) reads:

$$r(t) = a*b*N_o*\exp(-t*A)*\frac{C(t)}{P*A}*[\exp(A) - 1] \qquad (11.5.1)$$

where

a = fraction of short-term survivors, while 1-a = short-term mortality, due to the trauma of being tagged
A = attrition rate (includes mortalities (F and M) and shedding of tags, while growth out of vulnerability to the gear and migration out of the area are also considered)
b = fraction of recaptured tags actually returned with usable recapture information
$C(t)$ = catch in biomass units during time period t
N_o = number of fish tagged (at time t = 0)
P = standing stock in biomass units (assumed constant in time)
$r(t)$ = number of tag returns during time period t
t = index of time period

To see that Eq. 11.5.1 is basically the same as the catch equation (Eq. 4.2.7) we introduce:

$N(t) = N_o*\exp[-(t-1)*A]$ = number of tagged fish at the beginning of time period t

$F(t) = C(t)/P$, fishing mortality

If we assume a = b = 1 and A = Z (no shedding or other type of attrition factors), after substitution and rearranging Eq. 11.5.1 becomes:

$$r(t) = N(t)*\frac{F}{Z}*[1 - \exp(-Z)] \quad \text{i.e. the catch equation (Eq. 4.2.7)}$$

The above description is only a short introduction of the basic equation. For a complete description of the model the reader is referred to the original work.

11.6 ESTIMATION OF THE GROWTH PARAMETERS OF A MIGRATORY STOCK: THE ATLANTIC MACKEREL

As mentioned in Section 11.2, seasonally migrating species sometimes migrate earlier in the season the older and bigger the fish are. The problem is analysed in well documented studies of a stock of the North Atlantic mackerel, *Scomber scombrus*. This stock lives north and west of the United Kingdom and Ireland. The main migration route is shown in Fig. 11.6.1. The stock undertakes an annual migration from the "over-wintering area" to the "spawning area", from the spawning area to the "feeding area" and from the feeding area back to the over-wintering area. The total distance travelled is in the order of 500-1000 nautical miles per year. Spawning takes place from March to July in the area south of Ireland (see Fig. 11.6.1).

We shall concentrate here on aspects related to size-dependent migration as discussed in Sections 11.2 and 11.3. Size-dependent migration of this stock has been demonstrated by, for example, Dawson (1986) and Eltink (1987). The following is based on these two papers, which arrive at similar conclusions from independent sets of observations.

Because it is a species of temperate waters it is relatively easy to read the age of *Scomber scombrus* from the otoliths. The findings of Dawson (1986) and Eltink (1987) were based on random samples of mackerel caught by commercial fishing vessels as well as research vessels on the spawning grounds during the spawning period. Samples were taken on a monthly basis and ages, lengths and maturity stages were recorded. The principal migration routes and the spawning grounds were known beforehand from other investigations (e.g. tagging experiments).

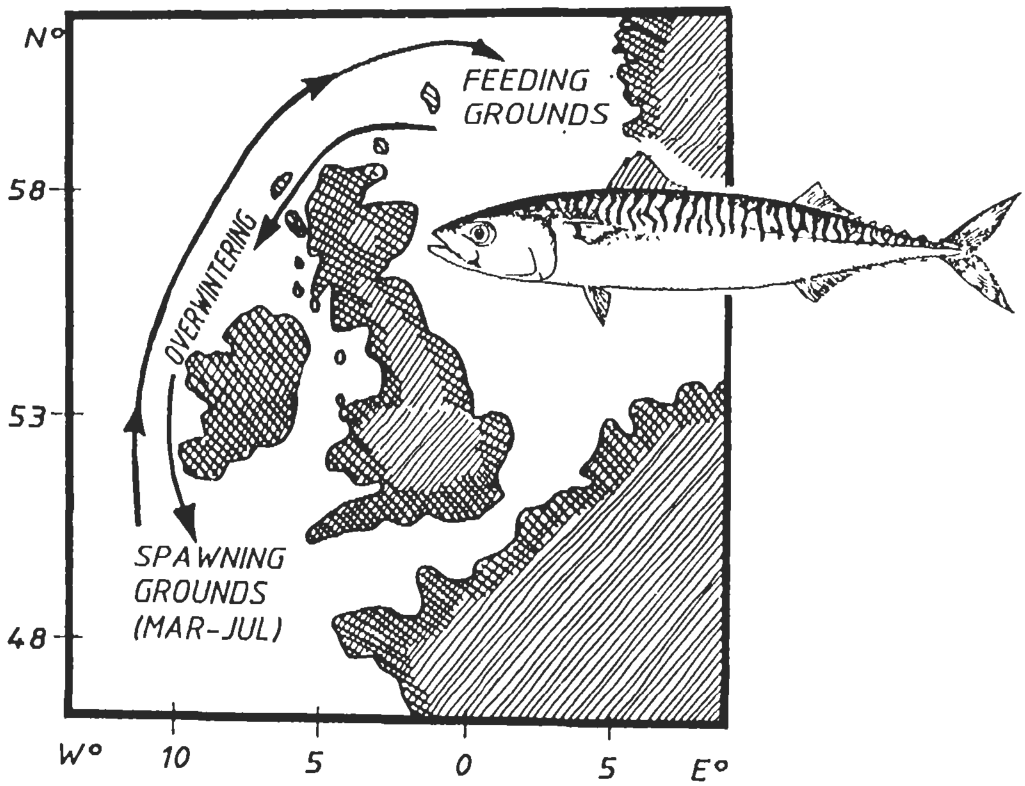


Fig. 11.6.1 The main annual migration route of a stock of Atlantic mackerel (*Scomber scombrus*) based on various sources including numerous tagging experiments (redrawn from Eltink, 1987)

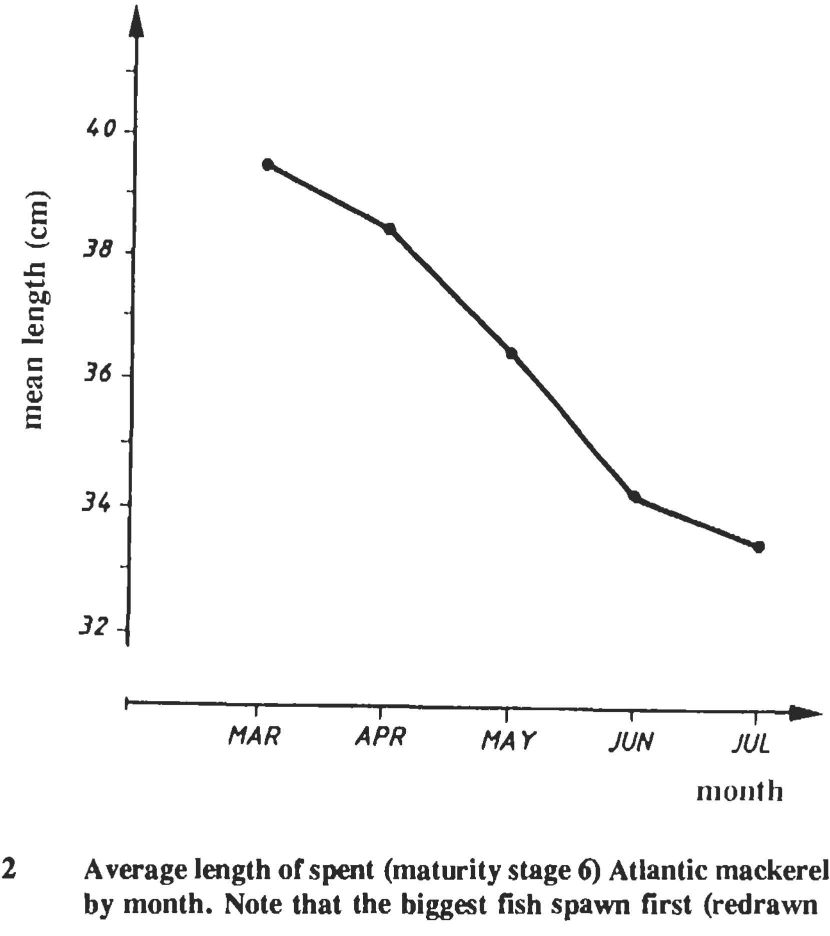


Fig. 11.6.2 Average length of spent (maturity stage 6) Atlantic mackerel (*Scomber scombrus*) by month. Note that the biggest fish spawn first (redrawn from Eltink, 1987)

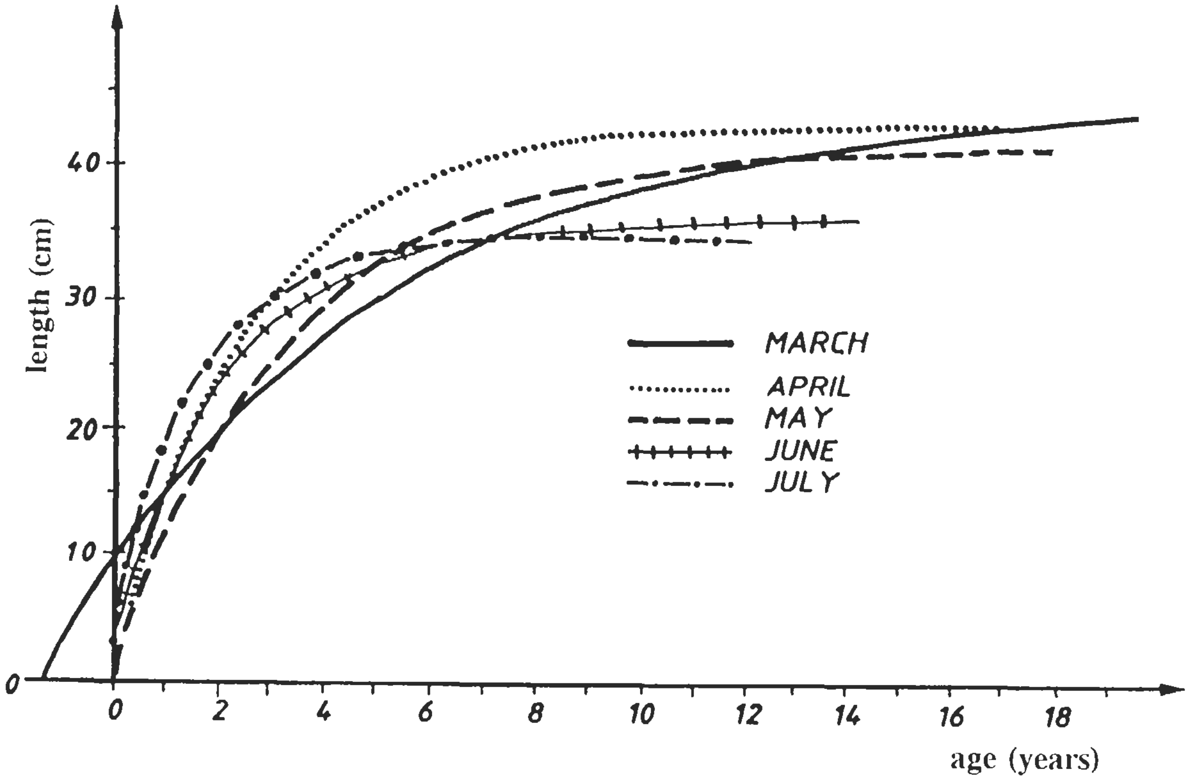


Fig. 11.6.3 **Growth curves for Atlantic mackerel (*Scomber scombrus*) estimated from age/length data of specimens sampled on the spawning grounds from March to July - illustration of a bias problem (from Dawson, 1986)**

The migration from the over-wintering area to the spawning grounds was found to occur in an age-size succession in which the old fish arrive before the young and leave earlier than they do. Even within an age group, the larger specimens arrive before the smaller ones. This is illustrated in Fig. 11.6.2 which shows the mean lengths of fish at maturity stage 6 of random samples collected on the spawning grounds for each month during the spawning season (Eltink, 1987). It shows that the bigger the fish are the earlier spawning occurs.

Fig. 11.6.3 (from Dawson, 1986) illustrates bias problems when estimating growth parameters for a migratory stock. The five growth curves were each estimated by the matched samples method (cf. Section 11.3). Each curve is estimated from data collected during a particular month on the spawning grounds. As could be expected, the data from the beginning of the spawning period (March) produce a curve for large slow-growing fish compared to the data collected at the end of the spawning period, which give a steeper curve with a smaller L_{∞}.