10. MULTISPECIES/MULTIFLEET PROBLEMS

So far, the models and methods described have dealt mostly with a single stock exploited by one fleet. However, this situation is the exception rather than the rule. In most cases a fleet exploits several stocks and several fleets compete in exploiting the same resources. In this connection we operate with three main types of interaction between components of a multi-species/multifleet system:

1. Biological interaction
2. Economic interaction
3. Technical interaction

Biological interaction is the interaction between fish stocks, and within fish stocks, caused by predation and food competition.

Economic interaction is the competition between fleets, e.g. between an industrial fishery and an artisanal fishery. The more one fleet catches of the limited resource the less will be left for its competitors.

Technical interaction means that the fishery on one stock creates fishing mortality on other stocks because the fishery is either a multispecies fishery or because of inevitable by-catches.

This chapter presents a brief discussion of some aspects of these three kinds of interaction. It is not intended to explain the models at a level which would enable the reader to apply them in practice. One good reason for not doing this is that many aspects of the models are still not well investigated and not well understood. Therefore, most stocks also in temperate waters are still assessed by means of single species models.

Various approaches to models taking interactions into account have been suggested during the last decade. The majority of the models are extensions of the single species/single fleet models presented in the foregoing chapters, so that the theory of the simple systems is a necessary background to multispecies/multifleet theory. Multispecies/multifleet assessment with special reference to tropical fish stocks is reviewed in e.g. FAO (1978), Pope (1979, 1980), Saila and Roedel (1980) and Pauly and Murphy (1982).

10.1 SURPLUS PRODUCTION MODELS APPLIED TO MULTISPECIES/ MULTIFLEET SYSTEMS

The simplest way to deal with the multispecies/multifleet system is to apply the surplus production models (cf. Chapter 9) to the total catch of all species and the total effort by all fleets. Fig. 10.1.1 shows a plot of the total yield of the Gulf of Thailand trawl fishery against total trawl effort (from Pauly, 1984, after SCSP, 1978). Applying, for example, the Schaefer model (Eqs. 9.1.2 and 9.1.5) to the yield of all species caught by all fleets would give an estimate of the total MSY for the sea area in question. This approach, however, combines so many complex interactions in such a simple model that its general applicability can be questioned. For example, the surplus production model assumes that the curve is reversible which cannot be true if each stock follows the Schaefer model. This aspect is illustrated in Fig. 10.1.2 which shows a hypothetical fishery on three species. After effort level F1 (see figure) species A is eradicated and after level F2 species B has gone. Thus, going back in effort from, say, level F3 would, according to the Schaefer model, be along the curve for species C.

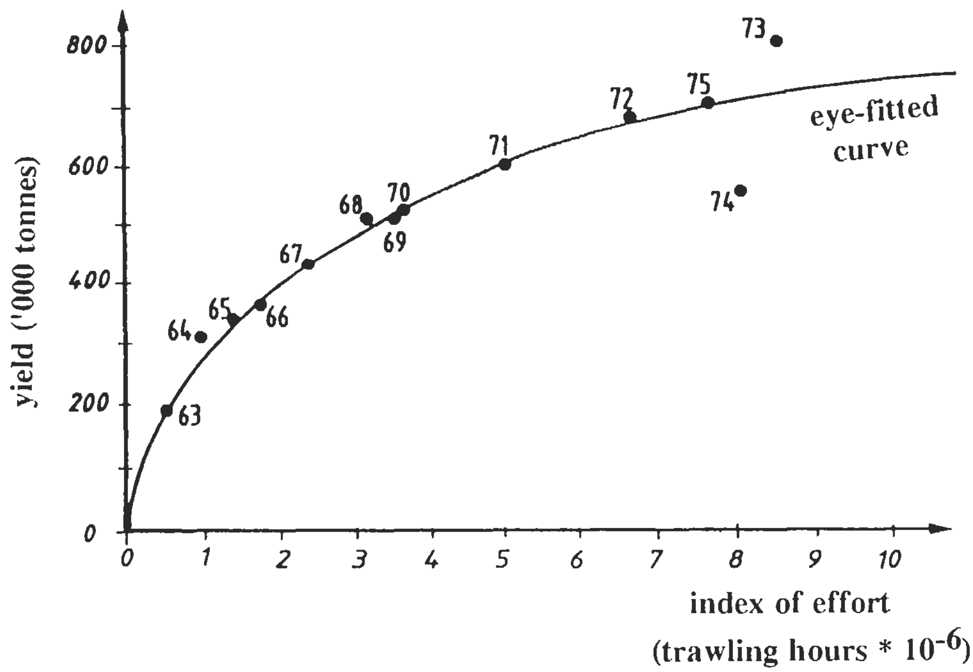

Fig. 10.1.1 **Catch and effort from the Gulf of Thailand trawl fishery (from Pauly, 1984. Data derived from SCSP, 1978)**

Further, if we assume each stock to conform to the Schaefer model, the total yield of all three stocks may not be a parabola, but the descending part of the total yield curve will resemble an exponential decay curve, as illustrated in Fig. 10.1.2.

In practice, however, a picture is often observed, as in Fig. 10.1.1, in which a steady increase in effort does not produce a drop in total yield of all species combined. The curve appears to have a continued upwards trend. This probably would come to an end at some high effort level. Yet, it is difficult at the moment to find examples in tropical demersal fisheries of a collapse of the total yield from all species. For a demersal multispecies fishery we expect the following changes together with the effort increase (Pauly, 1984):

1. A decrease (perhaps extinction) of very large fish, which are easy to catch, old and slow-growing

2. A decrease in the average size of fish caught

3. An increase in the relative contribution of low-value small-sized fish. The removal of the large predators on the food fishes results in a reduced natural mortality

4. Increase of previously insignificant components of the system (e.g. squids or jellyfish) which is also explained by removal of predators and food competitors

Thus, the interpretation of results from the simple surplus production model applied to a multispecies fishery is not straightforward. For a further discussion of these aspects, see for example, Caddy (1980), Marten and Polovina (1982), Ursin (1982) and Pauly (1984). The surplus production models can, however, be extended so that species interaction is explicitly accounted for in the model as will be discussed in the next section.

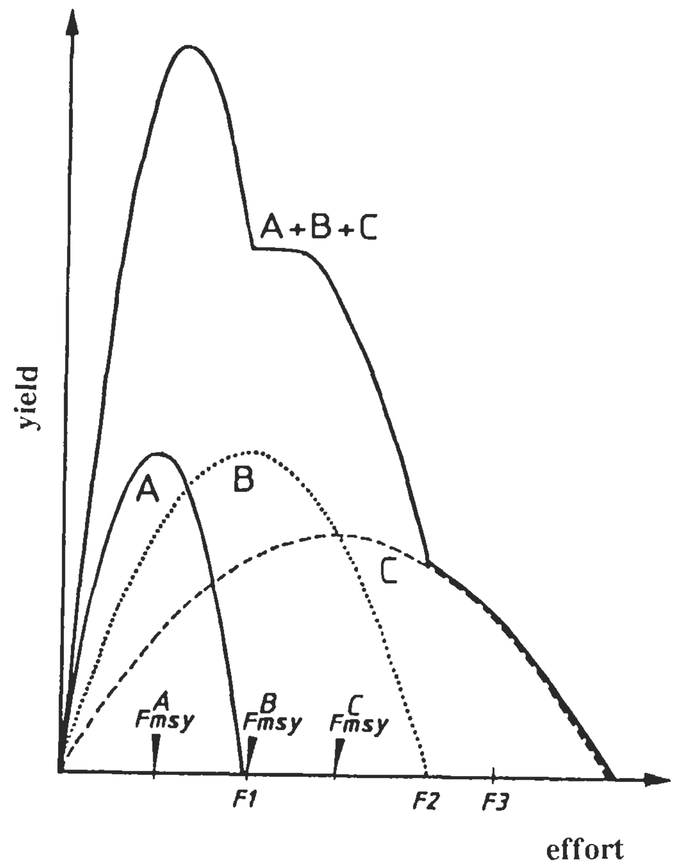

Fig. 10.1.2 **Illustration of the changes of yields in a fishery on three species according to the simple Schaefer model**

10.2 BIOLOGICAL INTERACTION

Several authors have more or less successfully extended single species assessment models to cover biological interactions between species. This is done by introducing terms for mutual predation and food competition. The most promising of these models probably is the "Multispecies VPA" (Helgason and Gislason, 1979; Gislason and Helgason, 1985; Pope, 1979a; ICES, 1984, 1986, 1987 and Gislason and Sparre, 1987). Essentially, it consists of a number of parallel VPAs, one for each fish stock in the sea area considered. The second of the two VPA equations (Eqs. 5.1.5 and 5.1.6):

$C = F*\bar{N}$ (number caught) and

$D = M*\bar{N}$ (number of natural deaths) is extended to:

$D = (M1 + M2)*\bar{N}$

where M2 is the "*predation mortality*" and M1 the "*residual natural mortality*" (i.e. natural mortality caused by diseases, starvation, old age, etc.). Predation mortality for prey species no. i, M2(i) is in principle derived from the following expression (Andersen and Ursin, 1977):

$$M2(i) = (1/\bar{N}(i)) * \sum_{j(pred.)} (\text{predator } j\text{'s consumption of prey no. } i)$$

while M1 has to be a "guesstimate" just like the total natural mortality (M) in an ordinary VPA (see Section 5.1).

The consumption of prey by predators is estimated from data on stomach contents of predators (Sparre, 1980 and Gislason and Sparre, 1987). In addition to catch data, the multispecies VPA also requires stomach content data and data on food requirements (from feeding experiments) as input. The multispecies VPA was tested in ICES for the North Sea for the first time in 1984 (ICES, 1984; Sparre, 1984; Gislason and Sparre, 1987), but it has not yet been used as the basis for management of the fisheries.

Pope (1980a) developed a version of multispecies VPA based on length data. This method is the extension of Jones' length cohort analysis to multispecies length cohort analysis.

Pope (1979, 1980) also extended the surplus production model (the Schaefer model) to the multispecies case by introducing biological interaction parameters. In the case of two species Pope's model reads (cf. Eq. 9.1.2):

```
prey:      Y1/f1 = a1 + b1*f1 + c1*f2

predator:  Y2/f2 = a2 + b2*f2 - c2*f1
```

If the interaction parameters, c1 and c2, have zero value we get two independent Schaefer models. When the interaction parameters are positive (c1 > 0 and c2 > 0) we can interpret the two-species model as a predator/ prey system since the interaction term c1*f2 produces a higher yield of the prey species when effort on the predator is increased, i.e. when the predators are removed. The interaction term for the predator, c2*f1, has the opposite effect. If effort on the prey is increased the predator gets short of food and the stock is thus less productive, resulting in a reduction in yield from the predator stock.

10.3 ECONOMIC INTERACTION

The economic interaction of several fleets was already introduced with the age-based Thompson and Bell model (Section 8.6) to which the reader is referred. Economic interaction can also be described by the Beverton and Holt yield per recruit model (Beverton and Holt, 1957), but we shall not go into that here.

10.4 TECHNICAL INTERACTION

In fisheries the catch consists of a mixture of different species. Pauly (1984, p. 161) gives a table showing a typical trawl catch from the Java Sea. It contains over 55 species distributed over 29 different families. However, the ten most abundant species in that trawl haul constituted 70% of the catch. The most abundant single species constituted 32% of the total catch in weight. Disregarding the rare species, we often end up with, say, 5 to 15 species which are important from a commercial and/or ecological point of view.

10.4.1 A yield per recruit model for mixed fisheries

To illustrate the problem we consider a simple system of two species, A and B. A is a large slow-growing species and B is small fast-growing species. A has a low natural mortality and B a high one. The typical shapes of Y/R curves for species with the characteristics of A and B are shown in Fig. 10.4.1.1. If A is the target species of the fishery and B is the (inevitable) by-catch then a Y/R-curve for B has little practical applicability. Management measures have to be directed at the fishery for the target species, A. If there is a simple relationship between

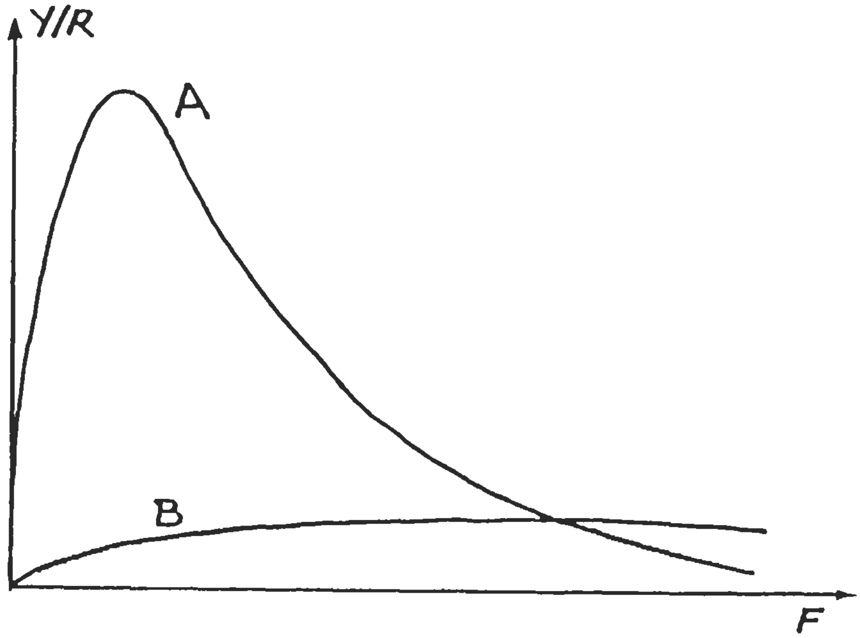

Fig. 10.4.1.1 **A: Y/R-curve for a large slow-growing species with a low natural mortality**
B: Y/R-curve for a small fast-growing species with a high natural mortality

the fishing mortality of the two species, for example a linear one:

```
F(A) = k*F(B)
```

where F(A) and F(B) are the fishing mortalities on A and B respectively and k is a constant, the effects of various fishing strategies on A can easily be transformed to B.

Two Y/R-curves cannot be added since they are in different units ("per A recruit" is something different from "per B recruit").

If estimates of relative recruitment are available we can transform the Y/R curves into comparable units (Sparre, 1980; Murawski, 1984). For example, if the number of recruits of A (on an average) is 0.001 times that of B we can express the yield for A in "per recruit" and the yield for B in "per 1000 recruits", and we can then add the two curves. However, if the prices per kg of the two species are different it may make more sense from a management point of view to multiply by the price before adding. If A preys on B the situation becomes more complicated and simple adding of yield curves may lead to erroneous conclusions (Sparre, 1979). To handle this situation a multispecies VPA (Sparre, 1980) might be adequate.

Munro (1983) developed an alternative approach which is less data demanding than the multispecies VPA approach. His model probably represents the simplest way of extending the Beverton and Holt model to take into account species interaction. Murawski (1984) developed an extension of the Beverton and Holt Y/R analysis in which technical interaction in a mixed-species fishery is accounted for.

10.4.2 Assessment of mixed fisheries based on length-frequency data

Suppose a certain type of commercial gear catches a mixture of three major species, called A, B and C. One may think of a bottom trawl catching up to 50 different species of which three make up the bulk of the catch. It may well be so that none of these species can be considered the target species.

Thus, the catch consists of a mixture of species which is not determined by the fishing operation but by the availability of the fish. The species in question inhabit the same fishing grounds and are caught together. We assume length-frequency data from all three major species to be available, and also that the prices per kg differ between species and between size categories within species.

In this case one cannot treat each species separately and subsequently sum the results in terms of yield. Before a summation makes sense the yield must be converted into units of value. A fishery may for example catch shrimps as the target species and squid as a by-catch. From the point of view of the fishermen the catch of shrimps is far more important than the catch of squid. Moreover, even if yield is converted into value it is still not possible to sum the results of single species assessments such as the length-based Thompson and Bell analyses. It will usually be so that the effort level which for species A gives the maximum sustainable economic yield, MSE, will not be the MSE level for species B and C.

The approach suggested below combines all species in the estimation of MSE. This assessment of a mixed fishery based on length-frequency data works as follows:

Step 1: Do a single species length-based cohort analysis on each species separately. This gives estimates of the current fishing pattern for each species, e.g. if species A ranges in length from 5 to 25 cm the F-pattern can be denoted:

FA(5,6),FA(6,7),FA(7,8),.....,FA(25,∞).

Thus, species A is measured in 1 cm classes. If species B ranges from 15 to 100 cm and is measured in 5 cm classes the fishing pattern estimated from cohort analysis may be denoted:

FB(15,20),FB(20,25),FB(25,30),.....,FB(100,∞)

and the results for species C may be

FC(10,12),FC(12,14),FC(14,16),.....,FC(50,∞).

For each species we further get the numbers in the first length group (the recruitment number) from length-based cohort analysis.

Step 2: Perform three separate length-based yield analyses of the Thompson and Bell type for the three species, as illustrated by Table 8.7.4. Use the same F-factor for each of the three fishing patterns in each prediction. Add up the values of the yields of the three species. The result of this exercise is a table similar to Table 8.7.4. This table contains the yield, biomass and value for each species together with the sum of values.

You may, for example, calculate 16 predictions as is done in Table 8.7.4, where each prediction is made as in Table 8.7.3 with the assumptions on fishing patterns listed below:

First prediction:

```
0,0,..................................0
0,0,..................................0
0,0,..................................0
```

Second prediction:

```
0.2*FA(5,6),0.2*FA(6,7),...........,0.2*FA(25,∞)
0.2*FB(15,20),0.2*FB(20,25),.......,0.2*FB(100,∞)
0.2*FC(10,12),0.2*FC(12,14),.......,0.2*FC(50,∞)
```

Third prediction:

```
0.4*FA(5,6),0.4*FA(6,7),...........,0.4*FA(25,∞)
0.4*FB(15,20),0.4*FB(20,25),.......,0.4*FB(100,∞)
0.4*FC(10,12),0.4*FC(12,14),.......,0.4*FC(50,∞)
............
............
```

Sixteenth prediction:

```
3.0*FA(5,6),3.0*FA(6,7),...........,3.0*FA(25,∞)
3.0*FB(15,20),3.0*FB(20,25),.......,3.0*FB(100,∞)
3.0*FC(10,12),3.0*FC(12,14),.......,3.0*FC(50,∞)
```

Step 3: Use the sum of values to determine the optimum effort level.The assumption behind the method is that when you increase the fishing mortality on species A by, say, 20% the fishing mortality on species B and C will automatically be increased also by 20%.

This approach may, for example, be used to assess the combined effect of mesh size changes. If selection ogives are estimated for each species you may use the logistic model (cf. Section 6.1) to determine the fishing pattern. That is, the fishing patterns for the three species are determined by the 50% and 75% retention lengths and the fishing mortality Fm for size classes under full exploitation (cf. Fig. 6.1.1.4) multiplied by the F-factor, X. The effect of, say, a 20% increase in mesh size is estimated by calculating three new fishing patterns, using the parameters:

```
Species A:  1.2*L50%A,    1.2*L75%A,    X*FmA
Species B:  1.2*L50%B,    1.2*L75%B,    X*FmB
Species C:  1.2*L50%C,    1.2*L75%C,    X*FmC
```

and then do the length-based Thompson and Bell analysis for a suitable range of X (F-factor) values, enabling you to determine the F-level for MSE.

Computer programs

The above suggested computational procedure involves a large number of calculations and it is recommended to use a computer. The LFSA-package contains the program "MIXFISH" which can perform this assessment of a mixed fishery. The program carries out the single species length-based Thompson and Bell analysis for each species as well as the combined assessment and it calculates the MSE in each case, using iteration techniques. A similar program has been incorporated in FiSAT.

10.4.3 Multifleet mixed fisheries

We discussed in Section 8.6 the case of two competing fleets (economic interaction) and in Section 10.4.2 the case where one type of boat caught several species (technical interaction or mixed fishery). Most fisheries have features of economic interaction and technical interaction as well as biological interaction (Section 10.2). In this section we shall ignore the biological interaction and consider only the combination of economic interaction and technical interaction.

Table 10.4.3.1 shows an example of input data for a multifleet mixed fishery. We are considering seven different pelagic species and four different gears (fleets). Here we assume that only these four gears (fleets) exploit the seven stocks considered. The basic data are numbers caught by size group (or age group):

```
C(y,s,g,i) =  number of length class (or age group) i fish of species s
              caught by gear (fleet) g during time period y

              s = 1,2,...,7              g = a,b,c,d
              i = 1,2,...,n(s)           y = y1,y1+1,...,y2
```

Table 10.4.3.1 actually shows only a small fraction of the data. It is just one table in a time series, and each i-index symbolizes a whole length-frequency of i = 1,2,...,n(s) observations, where n(s) is the number of length classes in the length range of species s. The right-hand column of the table contains the total number caught:

```
               d
C(y,s,i) =     Σ  C(y,s,g,i) =   number of length class (or age group) i fish
              g=a                of species s caught by all gears (fleets)
                                 during time period y
```

These numbers by length (or age) group and by time period form the input for individual cohort analyses or VPAs for each species.

Suppose in the following that we are working with length groups and have performed Jones' length-based cohort analyses. We have used as input the average number caught over a time period of several years and have estimated the average number in the population and the overall fishing mortalities for each species. The output of the seven analyses of the example can be summarized as shown in Table 10.4.3.2.

Each entry in Table 10.4.3.2 represents an array (a vector):

```
N(s) = (N(s,1),N(s,2),...,N(s,n(s))

F(s) = (F(s,1),F(s,2),...,F(s,n(s))
```

where each vector element corresponds to a length group. Each such F of a length group stems from the combined fishing mortality created by all four gears (fleets). The total F for each of the length groups can be redistributed on the four gears (fleets) using:

```
F(s,g,i) = F(s,i)*C(s,g,i)/C(s,i)
```

Table 10.4.3.3 illustrates the total fishing mortality partitioned into fishing mortalities by gear (or by fleet). The type of data given in Table 10.4.3.3 together with the estimate of the stock numbers (Table 10.4.3.2) form the input for a "length-based mixed fisheries Thompson and Bell catch prediction". The first step is to make assumptions on the F-arrays for each gear (fleet), as discussed in Section 10.4.2. This could, for example, be the assumption of a ten percent increase of the gill net fishery, in which case all arrays in the gill net column should be multiplied by 1.1. Other assumptions could be made for the other gears.

Table 10.4.3.1 Example of catch input data for multifleet mixed fisheries for a single time period (e.g. a year). C(s,g,i) = number of length class i fish of species s caught by gear g.
s = 1,2,...,7; g = a,b,c,d; * = sum of all gears i = 1,2,...,n(s);

s	g \ gear \(fleet) species \	a gill net	b long lines	c purse seine	d pole and line	total catch VPA input
1	Yellowfin tuna	C(1,a,i)	C(1,b,i)	C(1,c,i)	C(1,d,i)	C(1,*,i)
2	Skipjack tuna	C(2,a,i)	C(2,b,i)	C(2,c,i)	C(2,d,i)	C(2,*,i)
3	Kawakawa	C(3,a,i)	C(3,b,i)	C(3,c,i)	C(3,d,i)	C(3,*,i)
4	Frigate tuna	C(4,a,i)	C(4,b,i)	C(4,c,i)	C(4,d,i)	C(4,*,i)
5	Seerfish	C(5,a,i)	C(5,b,i)	C(5,c,i)	C(5,d,i)	C(5,*,i)
6	Marlin	C(6,a,i)	C(6,b,i)	C(6,c,i)	C(6,d,i)	C(6,*,i)
7	Sail-fish	C(7,a,i)	C(7,b,i)	C(7,c,i)	C(7,d,i)	C(7,*,i)

Table 10.4.3.2 Output from the seven individual length-based cohort analyses

s	species	population numbers	fishing mortality
1	Yellowfin tuna	N(1)	F(1)
2	Skipjack tuna	N(2)	F(2)
3	Kawakawa	N(3)	F(3)
4	Frigate tuna	N(4)	F(4)
5	Seerfish	N(5)	F(5)
6	Marlin	N(6)	F(6)
7	Sail-fish	N(7)	F(7)

The second step is to sum up the fishing mortalities for each species. The third step is to make a length-based Thompson and Bell catch prediction on each stock. The fourth step is to distribute the catches by length group between the fleets and convert the catches into values. Finally, the values of catches of different species are summed up for each fleet and for the total multifleet fishery.

Table 10.4.3.3 Fishing mortalities partitioned into gear (fleet) components estimated from cohort analysis and the numbers caught by each gear

s	\ g \ gear \ (fleet) species \	a gill net	b long lines	c purse seine	d pole and line	total fishing mort.
1	Yellowfin tuna	F(1,a)	F(1,b)	F(1,c)	F(1,d)	F(1,*)
2	Skipjack tuna	F(2,a)	F(2,b)	F(2,c)	F(2,d)	F(2,*)
3	Kawakawa	F(3,a)	F(3,b)	F(3,c)	F(3,d)	F(3,*)
4	Frigate tuna	F(4,a)	F(4,b)	F(4,c)	F(4,d)	F(4,*)
5	Seerfish	F(5,a)	F(5,b)	F(5,c)	F(5,d)	F(5,*)
6	Marlin	F(6,a)	F(6,b)	F(6,c)	F(6,d)	F(6,*)
7	Sail-fish	F(7,a)	F(7,b)	F(7,c)	F(7,d)	F(7,*)

Computer program

The microcomputer package BEAM 4 (Bio-Economic Analytical Model No. Four, Sparre and Willmann, 1992) consists of two sub-models. The biological/technical sub-model of BEAM 4 is the age-based multifleet mixed fisheries version of the Thompson and Bell model. Although BEAM 4 is based on age compositions, it contains options to convert input given as length compositions or commercial size categories into age composition data.

The BEAM 4 model also has options to account for migration of fish and fleets between geographical areas. The economic sub-model of BEAM 4 links the Thompson and Bell analysis to a cost and earning analysis of the harvesting sector and the processing sector of a fishery.