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Notes on tropical multispecies fisheries, with a short bibliography of the food and feeding habits of tropical fish[1/]

by Daniel Pauly[2/]

INTRODUCTION

With a few exceptions, the models commonly used in fish population dynamics and stock assessment are based on single species stocks, the

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1/ These notes are summarized from a longer paper titled "The Nature, Investigation and Management of Tropical Multispecies Fisheries", which was distributed to the participants of the Training Course. The latter paper reviews, among other things, several 2-species simulation models, especially the "pedagogic model" of Pope (1979), for the implementation of which the full listing of a HP/67/97 calculator program is provided. Also, issues of management are discussed, particularly the concept of $F_{o.1}$ as used in conjunction with the total yield from exploited multi-species stocks, which often does not decline with increasing effort. Copies of this paper are available on request from the author.

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assumption being that such things as growth, mortality and recruitment of a given single-species fish stock are little affected by what happens to the stocks of other species also occurring in the habitat of the species under investigation.

In tropical, especially demersal fisheries, this approach is untenable because generally, no one species is singled out by the fishery. Thus, there is no "by-catch" except in shrimp fisheries when most of the fish caught (often 90% of the total weight of the catch) are thrown overboard.

When the management policy for a given fishery is to maximize yields, three forms of overfishing must be prevented: (1) growth overfishing, i.e., taking fish that are too small. (Yield-per-recruit analysis is a standard method to detect and quantify growth overfishing), (2) recruitment overfishing, i.e., taking so many adult fish that recruitment of young fish to the fishery is affected. (Preventing this involves the study of "stock-recruitment relationships"), (3) ecosystem overfishing, i.e., inducing changes in stock composition through excessive fishing such that once abundant species decline without the subsequent compensatory increase of another (group of) species.

When unselective gear is used in heavily exploiting a community of widely different fishes, some large and long-lived, the others small and short-lived, it is not possible to prevent growth and recruitment overfishing of the more sensitive stocks. With increasing effort, some species will then decline rapidly resulting in alteration of the original food chain and catch composition and often in ecosystem overfishing as well. These and related problems are reviewed in FAO (1978), Pope (1979) and Pauly (1979). Computer-based simulation models have been suggested as a method to deal with the complexities of such interactions. This approach is best represented by the "North Sea model" of Andersen and Ursin (1977). At present, such models cannot be applied to tropical multispecies stocks: the data base simply does not exist which would make such exercises meaningful.

However, smaller simulation models, involving only a few trophic groups and the transfers between them can be used to test and validate hypotheses concerning the interactions within an exploited multispecies stock. This approach is best exemplified by Larkin and Gazey (1982) who designed a simulation model of the Gulf of Thailand stocks and fisheries and used it for testing mechanisms suggested by Pope (1979) and Pauly (1979) to explain the observed changes in catch rates of different species groups.

Method for constructing quantitative "box models"

While the mathematical simulation of multispecies systems is generally so complex as to discourage all but very mathematically-oriented biologists, constructing box models of an ecosystem is both rather easy and necessary, if only to identify the main energy pathways within a system under study. Quantitative box models (see Walsh, 1981 for a very interesting example) consist of four elements, the first two of them structural, the others quantitative.

Those elements are: (a) the taxa included in each box; (b) the direction of energy transfer between each box (i.e., the direction of the arrows linking the boxes with each other); (c) the average biomass represented in each box; and (d) the average energy transfer between boxes (i.e., the quantities represented by the arrows). (See Fig. 1).

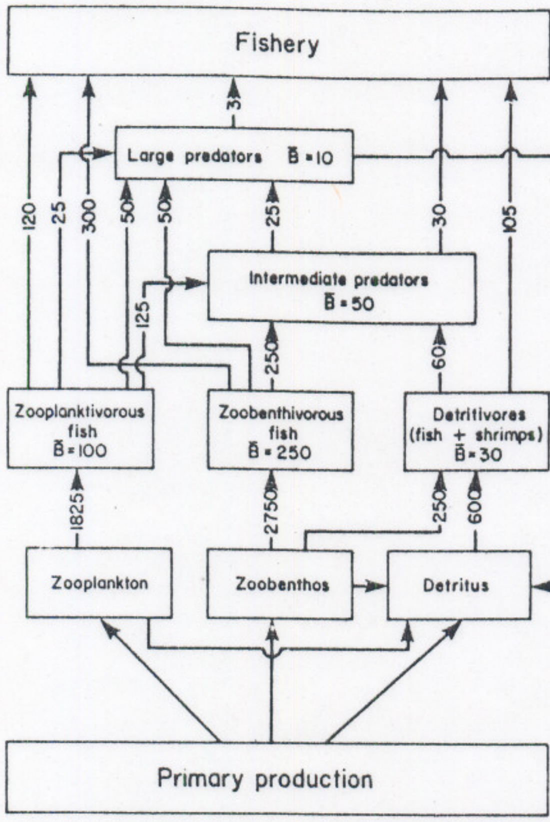

Fig. 1 Quantitative box model of a multispecies system exploited by a fishery, based on the data of Table 1 and the methods of computation outlined in the text. Note that while zooplankton and zoobenthos consumption (by fish and shrimps) could be estimated, their production and standing stock could not. It should be noted that this model applies only to those parts of the stocks that are accessible to the fishery, as implied in the equations used for the various computations. Thus, the fact is not considered in this model that fish "change boxes" in the course of their ontogeny.

Identifying the groups of species to be included in the various boxes involves criteria relating to the size of the animals, to their distribution and especially to their feeding habits. Since food and feeding habits cannot be determined for all species concerned, exhaustive use should be made of the available literature (see p. 30 for bibliography) and of generalizations relating the morphology of fishes to their feeding habits.

Obviously, grouping fish (and invertebrates) into boxes on the basis of their food and feeding habits makes the drawing of the arrows which link the various boxes quite easy. Putting numbers into the boxes and along the arrows is a little more complicated.

The first step is to obtain the mean standing stock in each box (or at least in most of them). The most straightforward method to obtain standing stock estimates is to conduct a trawl survey, in the case of demersal stocks, or an acoustic survey, in the case of pelagic stocks. In both cases, tagging-recapture experiments can also be conducted from which biomass and a number of other important parameters can be estimated.

These methods, however, are rather expensive, and in the following a method to bypass the problem is shown -- at least as a first approach. For this it will be necessary to make a brief excursion into fish mortalities. It will be recalled that in fishery biology, mortalities are generally expressed as exponential rates, i.e.

$$N_t = N_o \cdot e^{-Zt}$$

which states that the number of fishes (N_t) left after a certain time (t) is a function of N_o, the original number of fish, and Z, the total mortality rate. Z is defined as Z = F + M, where M is the natural mortality rate.

Methods to estimate Z from the mean length of the fish in the catch, or from length-converted catch curves are discussed in a variety of papers, including Pauly (1980a). Methods to obtain reasonable estimates of F are the swept-area method in the case of demersal fisheries (Gulland, 1969), and the subtraction from Z of an independent estimate of M, e.g., as obtained from the empirical equations of Pauly (1980b). Table 1 gives a data set obtained in this fashion.

Table 1. Hypothetical example of data from a multispecies fishery for use in the construction of a quantitative box model

Trophic groups	Catch (Y) (arbitrary units)	Mortalities*		
		Z	M	F
Large predators	3	0.5	0.2	0.3
Intermediate predators	30	1.1	0.5	0.6
Zooplanktivorous fish	120	2.7	1.5	1.2
Zoobenthivorous fish	300	2.4	1.2	1.2
Detritivores (fish & shrimps)	105	5.5	2.0	3.5

* pertaining to representative species within each group

The interesting thing about the values of F is that now they can be used to estimate, in conjunction with the yield data, the mean standing stock, or biomass (B) via the equation:

$$Y/F = \bar{B}$$

which can be used to put numbers into our boxes. It will generally not be possible to obtain estimates of $\bar{B}$ for all fishes included in each box; as a first approximation, however, all the fishes in a given box may be assumed to have the same fishing mortality (they will have similar sizes and niches and occur at similar places, so it is not a completely unreasonable assumption). Putting numbers along the arrows linking boxes with each other is now relatively simple:

- for the arrow linking fishes with the fishery, we use the yield data themselves, i.e.

  $$Y = F \cdot \bar{B}$$

- for the arrows linking predators and their prey, we use

  $$Q = M \cdot \bar{B}$$

  where M is the natural mortality of the prey and their biomass and Q is the wet weight of prey consumed by the predators.

- when a predation arrow goes to two or more predators, the value of Q is divided up in proportion to the biomass of each predator box (see Fig. 1).

From a box model quantified such as in Fig. 1, the following quantities may be estimated: a) food consumption per day and per unit of weight of the animals in each box (divide the amount (Σ Q) going into a box by $\bar{B}$, and then by 365) and b) the conversion rate within each box (calculated by dividing all matter leaving a box ($\Sigma \left[Y + Q \right]$) by all matter entering it).

The values of a) generally should fall between 3% and 6%/day, and those of b) 5% to 25%. These ranges can also be used to complete empty boxes in the model, when values of Y and F are unobtainable, e.g., for zooplankton (see Fig. 1).

Quantitative box models, constructed along principles such as outlined here can serve the following purposes: 1) summarizing the data available on a multispecies system; 2) allowing for an integration of fishery with ecological data; 3) identifying those parts of the system where gaps in knowledge occur; and 4) assessing the possible impact of exploiting one stock or the other.

Useful references that may be consulted when dealing with food chains and box models are Winberg (1971), Steele (1973) or Slobotkin (1980).

Multispecies fisheries

Fortunately, finding out what is necessary to meaningfully manage a multispecies fishery is most often less complicated than trying to understand how the system works in biological terms. Throughout much of the world, as a rule, once exploitation of a stock has begun, the fishery rapidly moves toward overfishing because, in the absence of effective regulations, the point of equilibrium of a fishery occurs when the average costs of fishing are as high as the gross returns from the fishery (Smith, 1981).

Thus, managing a fishery (as opposed to developing one) is for most purposes synonymous with attempting to reduce or redirect fishing effort, in order either to increase the catch and/or reduce economic losses due to overcapitalization, i.e., increase the income of those remaining in the fishery (see Smith, 1981).

Fishery research in tropical multispecies systems

Evidently, it is impossible to define a research programme that applies to all multispecies stocks. However, the following elements should be included in any basic fishery research programme: (a) monitoring total catch and catch-per-effort of the fishery; (b) monitoring catch-per-effort of various "indicator" species representing various groups of fish (e.g., large-, medium-, and small-sized; (c) thorough study of the biology and population dynamics of the most abundant and of the most valuable species; (d) an attempt to construct a "box model" of the system in question (see above); (e) an attempt to identify gears that would selectively remove certain groups of species and which would thus provide a basis to redirect effort from overfished to underfished components of the system.

The latter step which involves the identification of those components of a multispecies system that are over-and underfished might serve as a primary justification for the construction of models of such systems.

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