

Resource Management and Optimization
1989, Volume 6(3), pp. 253-271
Reprints available directly from the publisher.
Photocopying permitted by license only.
© 1989 Harwood Academic Publishers GmbH
Printed in the United States of America

BIOLOGY AND MANAGEMENT OF TROPICAL MARINE FISHERIES¹

DANIEL PAULY

*International Center for Living Aquatic Resources Management (ICLARM), MC P.O.
Box 1501, Makati, Metro Manila, Philippines.*

CONTENTS

INTRODUCTION	254
1.1 Differences between Tropical and Temperate Fisheries Resources	256
1.2 Models for Tropical Stock Assessments	263
1.3 Management of Tropical Fisheries	267

The need for a transition from the *development* to the *management* of tropical marine resources is noted. The biological characteristics relevant to their exploitation and management are reviewed, with emphasis on the qualitative and quantitative differences from the characteristics of similar resources of temperate waters.

The major models available for assessing and managing tropical stocks are briefly reviewed, with emphasis on slight changes which may render the results of yield-per-recruit and surplus yield models easier to interpret, as well as on the ELEFAN system of microcomputer programs, for the detailed analysis of length data.

The suggestion is made that fishery biologists have progressed farther toward achieving their goal, related to the assessment of fisheries, than fisheries managers have progressed toward theirs.

¹ICLARM Contrib. No. 188.

TABLE I

Contribution of the tropical regions to the world's marine fish catch of 68 million tonnes in 1981, based on data in FAO (1983).⁽¹⁾

Note large catches from the western side of the African and American continents, due to the upwellings there.

Catches are expressed in millions of tonnes per year.

Tropical America		Tropical Africa		Tropical Asia		Oceania
Pac. Coast	Atl. Coast ^a	Atl. Coast ^b	Indian Oc. Coast ^c	West Asia ^d	S.E. Asia ^e	Tropical waters ^f
4.33	.92	36				1.45

^aIncluding Caribbean Islands

^bIncluding Cape Verde Islands

^cIncluding Madagascar, Comoros, Seychelles, Mauritius and Réunion.

^dSouthern part of Arabian Peninsula, India, Maldives, Sri Lanka, Bangladesh and Burma.

^eASEAN countries, Vietnam, Kampuchea and southern parts of China (incl. Hong Kong and Taiwan).

^fPapua New Guinea, northern Australia and tropical Pacific Islands and states.

1. INTRODUCTION

Tropical countries presently contribute represents about 30% of the world marine fish catch of about 67 million tons (Table I). The enormous amount of fish that this figure represents does not, however, give a real idea of the importance that fish (including allied products such as molluscs and crustaceans) have in a large number of developing countries, where often 1/3, or even 1/2 of the total animal protein intake of their populations (especially the poor) consists of fish. Additionally, much foreign exchange is also generated by the export of shrimps and tunas.

Yet despite their importance, tropical fisheries are most often badly managed (if at all)—the resources generally are overexploited and the fisheries are overcapitalized. These problems are often aggravated by notions, still encountered among many officers of bilateral and international aid agencies, and especially of development banks, that tropical marine fish resources are generally underexploited and in need of further “development” schemes. The schemes, more often than not, consist essentially of loans to import more, larger fishing vessels or to mechanize artisanal fisheries which are perceived as “inefficient.” These ideas, which were perfectly valid a few decades ago, when development projects

TABLE II
Percent coverage of "tropical topics"^a in six heavily cited
"core journals"^b in marine biology, as compared with
tropical topics in three "non-core" journals from tropical
developing countries (from Pauly 1984).⁽³⁾

	Vol.	Year	Total pages	Pages with tropical topics	% coverage of tropical topics
<i>"Core journals"</i>					
J. Mar. Biol. Assoc. U.K.	63	1983	945	0	0.0
Can. J. Fish. Aquat. Sci.	38	1981	1923	8	0.4
Bull. Jap. Soc. Sci. Fish.	49	1983	1939	29	1.5
Limnol. Oceanogr.	26	1981	1182	87	7.4
U.S. Fish. Bull.	79	1981	812	145	17.3
Aust. J. Mar. Freshw. Res.	33	1982	1132	234	20.7
<i>"Non-core journals"</i>					
Bol. Inst. Oceanogr. S. Paulo	24-28	1974-79	1379	1003	72.7
Indian J. Fish.	26-28	1973-81	833	816	98.0
Fish. Res. J. Philippines	1-5	1976-80	920	912	99.0

^aAll articles based on material and data obtained or originating between the tropics of Cancer and Capricorn.

^bAs defined in Garfield (1980).⁽⁴⁾

led to some successes, may still be applicable to some parts of the world, but are rapidly becoming obsolete—even dangerous—in most parts of the tropics. Indeed since fishing vessels are only harvesting machines, they amount in most cases to the equivalent of exporting combine harvesters to the Sahel to increase the agricultural output of the farmers there.

Compounding the problem is the fact that, in spite of recent advances, the biological basis of tropical fisheries is understood only crudely (2); indeed the relative neglect of tropical fisheries research in the "international literature" appears very clearly when the relevant journals are surveyed (Table II). This problem is further complicated by the enormous diversity of life histories and adaptations among the organisms exploited, as well as the diversity of fisheries, gear types and social conditions, which represent serious (but not overwhelming) constraints on resources assessments and fisheries management.

However, various refinements of standard assessment techniques to-

gether with the judicious application of new methods recently developed for use in tropical waters, should go a long way in helping fisheries scientists working in the tropics to perform stock assessments. Several of the standard and a few of the new approaches will be discussed further below.

1.1 Differences between Tropical and Temperate Fisheries Resources

In spite of the neglect alluded to above of tropical marine resources in the scientific literature, broad generalizations about the differences which distinguish them from the marine resources of high latitudes have emerged. These may be grouped into three classes: (i) quantitative differences, (ii) qualitative differences, (iii) qualitative differences caused by large quantitative differences. Quantitative differences are defined as those differences which can be described by a continuous function of any quantifiable variable, such as temperature. This scheme distinguishes qualitative differences due to quantitative changes of given (and quantifiable) variables (as in iii) from those qualitative differences that are of (still) unknown origin (as in ii).

Other things being equal, tropical marine fish and invertebrates differ from their temperate counterpart in quantitative terms by generally having smaller asymptotic (maximum) sizes (weight or length), shorter life spans, reduced intensity of seasonal oscillations in a number of cyclical features (growth, fat content, migratory behaviour, etc.), higher fecundities, and higher natural mortality ("turnover rate" in the virgin stock).

Table 3 gives an example of tropical-temperate comparison in mackerels, important resources of both the tropical and temperate seas. It should be noted here that the various features of tropical mackerels listed in Table 3 do not *in themselves* render population dynamics studies or stock assessments particularly difficult. However, problems are encountered when attempts are made to infer the behaviour of an exploited stock of, say, *Rastrelliger brachysoma*, based on experience gained working on *Scomber scombrus*. On the other hand, when appropriate methods are used to study tropical fish, their various features often turn from apparent disadvantages to obvious advantages, a fact that is discussed in some detail below.

Tropical fishes have a higher natural mortality rate than their temperate

TABLE III
Comparisons of vital characteristics in two species of mackerels
(*Rastrelliger brachysoma*, *Scomber scombrus*) occurring in tropical
(Southeast Asia) and temperate (British) waters, respectively (from
data on Collette and Nauen, 1983;⁽⁶⁾ Hongskul, 1974;⁽⁷⁾ Lockwood
1978;⁽⁸⁾ Anderson and Paciorekowski 1980;⁽⁹⁾ Hamre 1980;⁽¹⁰⁾ and
Rao 1967).⁽¹¹⁾

Characteristics	<i>R. brachysoma</i>	<i>S. scombrus</i>
Maximum reported fork length (cm)		50
Typical growth parameter estimates ^a		
L _∞ (cm)	21	40–45
K (per year)	3.4	0.22–0.31
Age at first maturity (years)	≤1	2–3
Mean length at first maturity (cm)	16–20	30–35
Longevity (years)	2	>12
Natural mortality (per year)	7.3	0.13–0.40
M/K ratio	2	
Relative fecundity (mature ova/g female body weight)	760 ^{b;c}	695 ^c

^aParameters of the von Bertalanffy growth equation.

^bRefers to the closely related species *R. kanagurta* which has eggs of the same size as *R. brachysoma*.

^cNote that there are two spawning seasons per year in Southeast Asian *Rastrelliger* spp. against one in *S. scombrus*.

counterparts (see Table 3), as established by Pauly (5) from a very large data set (175 stocks of fish from temperatures ranging from –1.8 to +30°C); the relationship linking M with its predictor variables is

$$\log_{10}M = -0.007 - 0.279 \log_{10} L_{\infty} + 0.654 \log_{10}K + 0.463 \log_{10} T \dots 1)$$

where M is the instantaneous rate of natural mortality, on an annual basis, L_∞ (in cm) and K (annual basis) are parameters of the von Bertalanffy Growth Function (VBGF) and T is the mean annual water temperature in the water body inhabited by a given stock (in °C).

This equation, which was estimated for the practical purpose of providing reasonable estimates of M for routine stock assessment work in the tropics and elsewhere, has a number of theoretical implications as well. Among other things, it can be used to fully illustrate what is meant here by “quantitative” differences between tropical and temperate fishes.

When the equation was proposed, the following hypothesis was offered

to explain the surprisingly high partial correlation between M and habitat temperature:

“Fishes occurring at higher temperatures have more chances to have encounters with “hungry” predators (rather than satiated ones) because, other things being equal, tropical fishes have to eat more than the temperate fishes in order to satisfy their higher metabolic needs (12). This should force predatory fishes to eat more prey fishes per unit time than their cold-water counterparts, which would then result in higher natural mortality in the prey fishes” (5).

Evidence is available showing that, other things being equal, fishes living in warm water eat more than their cold water counterparts (13).

Some qualitative differences between tropical and temperate ecosystems (both terrestrial and marine) have been reviewed by Robinson (14). With respect to marine ecosystems, he used, quite unsurprisingly, coral reef communities to illustrate his contention that major qualitative differences do occur between tropical and temperate ecosystems. He concentrated on three phenomena which have no obvious counterparts in temperate waters:

- cleaning symbioses (e.g., between cleaner wrasses and various reef fishes),
- mutualistic associations (damselfish/sea anemone, goby/snapping shrimp), and
- mimicry (e.g., by *Aspidontus taenaiatus* posing as a cleaner wrasse).

Robinson (14) concluded his review of tropical biology by suggesting that in tropical communities, species interactions may be more intensive and/or numerous than in temperate communities even after accounting for the number of species involved in the interactions (which is generally higher in the tropics and thus by itself would provide for more “sites” for interaction). This point is schematically illustrated in Fig. 1. Although Robinson’s hypothesis is falsifiable in principle, it seems to have been rarely tested rigorously (at least as far as aquatic systems are concerned), despite its obvious relevance to fishery research (2).

Two cases will be discussed here of instances where the quantitative differences between the values of vital characteristics of tropical and temperate fishes also lead to qualitative differences. In the examples selected here, the qualitative difference leads to an intriguing puzzle for ecologists in the first case, and to a problem for fishery management in the second.

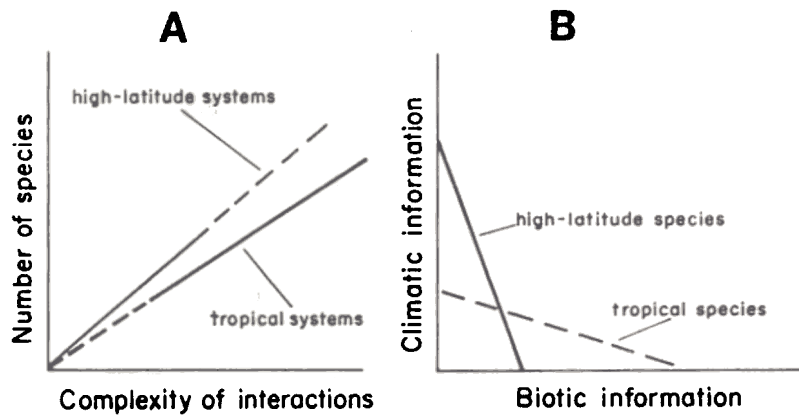


FIGURE 1. Schematic representation of Robinson's hypotheses that (A) tropical ecosystems involve—in comparison with high-latitude ecosystems—an increased complexity of biological interactions for any given number of species, and that (B) tropical species contain more "biological information" (= ability to deal with the highly evolved strategies of their preys and predators), but can deal less effectively with abiotic stresses than their high latitude counterparts (adapted from Robinson 1978). (14)

A number of ecologists have suggested that the tropics and especially coral reefs are characterized by an abundance of "specialists" (i.e. K-selected species, see Mac Arthur and Wilson, (15)), while high latitude populations, exposed to large variations of abiotic factors, are often seen as consisting of "generalists" (r-selected species). Yet, at least as far as fishes are concerned, the most unequivocal case of K-selection seem to be the fishes of extremely cold Northern Canadian lakes, whose apex predator (the salmonid *Salvelinus alpinus*) displays, in most populations, size-frequency distributions in which the bigger fish are more abundant than the smaller ones (Fig. 2A).

As shown by Powell (18), this "K-configuration" implies for adult fish a low value of the ratio M/K (< 1) (i.e. of the ratio of mortality to growth; see equation (1) for definition of M and K) in the population concerned. Equation (1) suggests that, in the tropics, low values of M/K are very unlikely, a result confirmed empirically by Munro (19) (20) who found high (>3) values of M/K to be typical of the large coral reef fishes he investigated (the sizes he considered match those of the salmonids in Fig. 2A). High values of M/K , however, preclude a K-configuration (18), and it must be thus concluded that larger coral reef fishes generally display a typical "r-configuration", such as occur in generalists. K-configurations

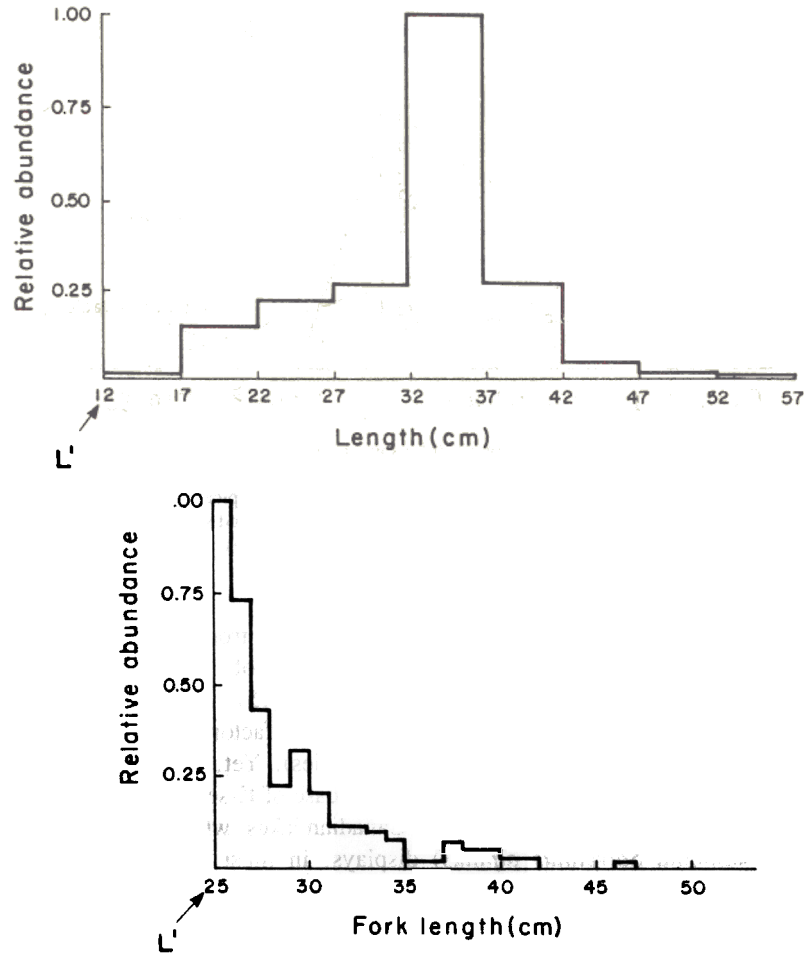


FIGURE 2. Size-frequency distribution of the salmonid (*Salvelinus alpinus*) in an unexploited Northern Canadian lake (adapted from Johnson 1981) (16): Size-frequency distribution of the jack *Caranx ruber* in an unexploited Jamaican coral reef (adapted from Thompson and Munro, 1973) (17). Note that *Caranx ruber*, a reef fish, has a r-configuration, rather than the K-configuration one would expect on from a "specialist". (L' refers to the lowest size at which samples are representative of the population).

may occur in small coral reef fishes e.g., pomacentrids in which the slow growing, sexually mature individuals holding territories are subjected to a predation mortality much lower than that affecting juveniles without

territories; in such cases, the concept of K-selection and Johnson's "K-configuration" would match.

The second case considered here of quantitative changes leading to qualitative differences relates to the yield-per-recruit model of Beverton and Holt (21) (22), commonly used in stock assessment and resource management. Beverton and Holt (23) presented a compilation of M and K values, from which a number of M/K values with a range of about 0.2 to 5, and a median of 1.5 could be computed. However, this generalization was based overwhelmingly on temperate stocks, estimates of K and M from tropical stocks being very rare when their review was written.

Fig. 3A shows the yield per recruit obtained for a typical temperate fish with a low M/K value. As might be seen, the curve has a pronounced maximum corresponding to the relatively low fishing mortality ("F_{msy}") generating Maximum Sustainable Yield (MSY). Fig. 3B, on the other hand, presents the yield per recruit obtained from a typical tropical fish with a high M/K value. As might be seen, the clear maximum of Fig. 3A has disappeared, and is replaced by an ill-defined plateau at very high fishing mortalities.

Clearly, attempts at maximizing yield per recruit in such case would lead to doom because maximizing yield per recruit leads, in such cases, to extremely low stock biomasses, and hence, to equally low catch per effort and potential recruitment failures.

In such cases, the yield per recruit concept can be used meaningfully only in conjunction with additional information or assumptions on the appropriate level of fishing mortality. One approach, based on the assumption that the optimum fishing mortality (F_{opt} ≈ F_{MSY}) should be approximately equal to the natural mortality prevailing in a stock, leads to the well-known equation

$$MSY \approx 0.5MB_0 \quad 2)$$

where B₀ is the size of the unexploited stock (25). The equation has, however, been shown to overestimate yields in most situations (26).

Another approach is the "F_{0.1}" concept, i.e., an arbitrary limit to fishing mortality set at a level such that the marginal increase in yield-per-recruit is 1/10 of its value near the origin of the curve (26) (see Fig. 3B).

These various considerations can be used to derive simple generalizations for use with most small to medium-sized tropical fish, in which the

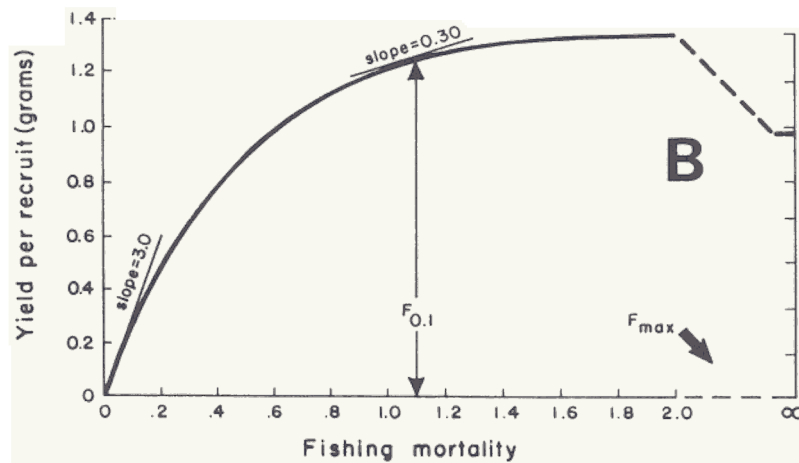
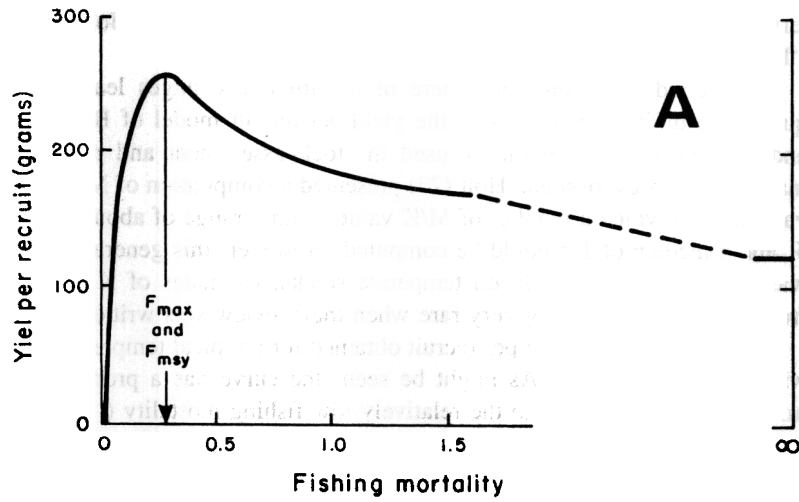


FIGURE 3. A: Typical yield-per-recruit curve of a large temperate fish with a comparatively low M/K ratio; the North Sea plaice, *Pleuronectes platessa*, with $M/K = 1$ (adapted from Beverton and Holt 1957) (21). B: Typical yield per recruit curve of a small tropical fish with a high M/K ratio: the Southeast Asian threadfin bream *Nemipterus marginatus*, with $M/K = 4$ (from data in Pauly and Martosubroto, 1980) (24). Note also definitions of $F_{0.1}$ which may serve in such situation as replacement for F_{msy} because F_{max} is clearly ill-suited for the purpose.

TABLE IV
Options for managing a tropical stock with high M/K ratio (>2) by manipulating mesh size (and hence mean size at first capture) and fishing effort (and hence fishing mortality) (adapted from the yield-per-recruit Y/R tables in Beverton and Holt⁽²²⁾).

Option	Relative size of fish caught ^a	Fishing mortality ^b	Results (in terms of Y/R)
	large	low	underfishing
	large	high	eumetric fishing, ^c high yield per recruit
	small	low	eumetric fishing, ^c low yield per recruit
	small	high	overfishing

^aAs defined by the ratio of mean length at first capture: asymptotic length, with 0.5 as cutoff point.

^bAs defined by the ratio $F/(F+M)$, with 0.5 as cutoff point.

^c“Eumetric” fishing is defined by the line linking the combinations of size at first capture (mesh size) and fishing mortality which maximize yield per recruit.

yield-per-recruit model of Beverton and Holt (21) (22) is reduced to the 4 options model in Table IV.

Such generalizations, when applied judiciously, can considerably reduce the costs of preliminary resources assessment and fishery management, and in fact, rules similar to those in Table 4 have been used by Sinoda *et al.* (27) to derive a simple, yet powerful method to compute the optimum trawl mesh size (weighted by gross catch or catch value per species group) in tropical multispecies demersal stocks.

1.2 Models for Tropical Stock Assessments

As suggested above, only slight adjustments are necessary to adapt yield-per-recruit approaches to tropical conditions. This situation is similar in the case of surplus-yield models (28) (29) (30) (31) (32), the other major class of models used in stock assessments.

In their present form, these models require only catch and effort data (except for the model of Csirke and Caddy (33), which requires estimates of total mortality instead of effort data), and thus seem ideally suited to the poor data base characteristic of many tropical fisheries. Moreover, all of these “time-structured” models (called so because they require time series

of catch and ancillary data) can also be structured in space under the assumptions of (1) comparable virgin stocks along a coast line and (2) similar dynamics under exploitation (17) (34). Indeed, as pointed out in Caddy and Garcia (35), structuring in time *and* space is possible by using catch data from different areas, and different years, with their corresponding values of effort.

One important advantage of applying surplus production models to stocks of short-lived tropical fish (or shrimps) is that the often implicit assumption of equilibrium built into these models is generally more likely to be met than in stocks of long-lived temperate fishes, in which e.g. a depleted biomass takes several years to respond to decreases in effort.

On the other hand, it must be realized that the application of surplus yield models to multispecies stocks—although commonly done—is fraught with theoretical problems and practical pitfalls. One of the problems, demonstrated quite elegantly by Pope (36) is that “technological interactions” (*sensu* Pope, i.e., the fact that certain gears, especially trawlers, generally cannot select for or against certain species) must lead to sub-optimum exploitation at both low and high fishing intensities (e.g., by catching large number of the young of large species when aiming at smaller species or *vice versa*).

Another problem is the replacement under exploitation of one species by another (or by one species group by another). This feature, which is quite frequent in demersal and pelagic fisheries, (37) (38) evidently renders graphs of “catch” against effort quite dubious.

The effects of species replacements also often render the concept of (bulk) “MSY” in multispecies fisheries illusory because the fishery, as effort increases and the “mining” of one species (group) after another proceeds, does not necessarily lead to domed plots of “catch” on effort, but rather to flat-topped curves with no discernible maximum.

In such cases, the concept of MSY will have to be abandoned, but on grounds far more serious than the rather frivolous reasons given by Larkin (39) for its retirement.

Instead, and in analogy to the case of flat-topped yield-per-recruit curves discussed above, the concept of $f_{0.1}$ can be used, this level of effort (f) being defined as the fishing effort corresponding to a marginal increase of catch equal to 1/10 of its increase at low level of effort. While this $f_{0.1}$ concept is as arbitrary as in the $F_{0.1}$ concept, fishing regulations based on it could inject some rationality into schemes for the management of multispecies fisheries in which the ephemeral (i.e. non-sustainable) “max-

imum'' is bound to show up only in retrospect, after a fishery has become overcapitalized and the resource depleted.

In addition to applying the two "workhorse" models for stock assessments (the yield-per-recruit and surplus-yield models), fishery biologists now have at their disposal a suite of recently developed auxiliary methods which either happen to be well-suited for tropical conditions, or have been explicitly developed with such conditions in mind. Aging by means of daily rings may serve here as a representative of the first group of methods.

Daily rings were apparently first seen and described by Hickling (40) but were not identified as such. They were first recognized for what they are by Pannella (41). Since then, several workers, notably Brothers et al. (42) and Brothers (43) have established the ubiquitous and daily nature of these rings beyond reasonable doubt. Moreover, these and other studies have established that it is the rings of small, fast growing fishes which are easiest to read, i.e. precisely those fish which could not be aged previously by means of annual rings.

Still, aging by means of daily rings remains a tedious affair and, at least for routine assessments, the most effective procedure seems to age only as few fish as are needed to test inferences on growth obtained from the analysis of easy to obtain length-frequency data.

Length-frequency (L/F)-based methods to obtain information useful for fish stock assessments have a long history. Indeed, they began when fishery biology established itself as a discipline of its own (44). However, it is only recently that stock assessment methodologies based explicitly and predominantly on L/F data or on catch at length (C/L) data have become available (45). One such methodology was developed by Jones (46) and its application to animals as different from each other as penaeid shrimps (47) and West African hake (48) demonstrate its versatility.

A comprehensive package of microcomputer programs for the analysis of L/F and C/L data called ELEFAN (*E*lectronic *L*ength *F*requency *A*nalysis) has recently been developed in the 1980s illustrates the class of methods developed explicitly for use under tropical conditions (49) (50). The package (which can be used in conjunction with Apple II or IBM PC microcomputers or their compatibles) includes routines for the estimation of values of the following statistics from L/F data alone:

- growth parameters (inclusive of parameters to express the intensity and timing of seasonal growth oscillations) (see Fig. 4A),
- total mortality, as based on a length-converted catch curve (or from

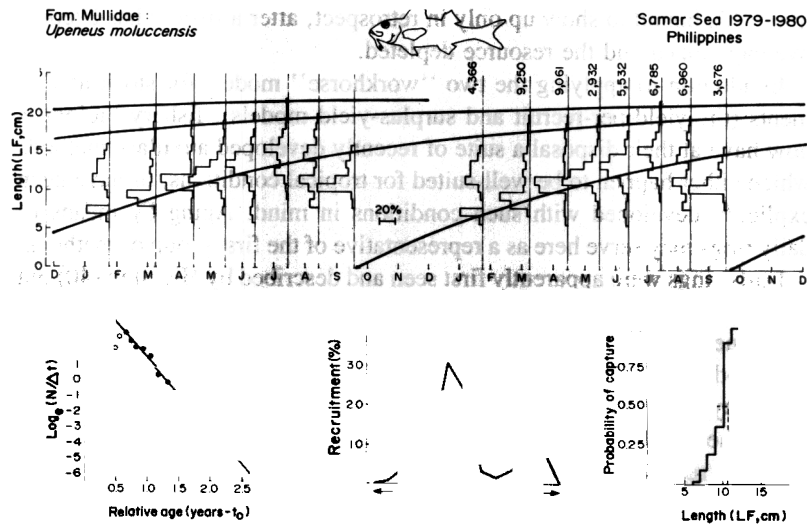


FIGURE 4. Typical outputs of ELEFAN I and II. A: length-frequency data with superimposed growth curve (note that the same data are plotted twice along the time axis, and sample sizes given only once). The growth parameters describing the growth curve, estimated by ELEFAN I are $L_{\infty} = 19.5$ cm, and $K = 1.2$. B: length-converted catch curve, derived by ELEFAN II from the length-frequency data in A and the estimated values of L_{∞} and K ; the slope of the straight, descending portion of the curve leads to a total mortality estimate of $Z = 7.0$. C: recruitment pattern derived by projection onto the time axis of data in A; note bimodality, suggesting two recruitment pulse per year and explaining modes in A not explained by single growth curve. D: selection pattern, derived from catch curve in B and suggesting a mean length at first capture $L_c = 10.5$ cm.

- the mean length in the catch), from which natural mortality as estimated from equation (1) can be subtracted to obtain a preliminary estimate of fishing mortality (see Fig. 4B),
- recruitment patterns, i.e. graphical representations of the seasonality of recruitment (see Fig. 4C),
- selection patterns, i.e. plots of the probability of capture against length (see Fig. 4D).

Fig. 4 gives a representation of the various outputs of the ELEFAN I and II programs, in which these routines are incorporated. A particularly interesting feature (not illustrated here) is that the analysis can be performed iteratively, using the selection curve obtained in a first run to correct the available L/F data for selection, then running the growth analysis with the debiased data.

When monthly catch data in weight are available for a period of time, along with the corresponding L/F data representative of the monthly catches, two different forms of Virtual Population Analysis can be performed with the C/L data obtained from the catch and L/F data, using the ELEFAN III program described in Morgan and Pauly (51) and whose outputs are:

- estimation of absolute recruitment (by month or as an annual average),
- biomass and number by size group and/or month,
- fishing mortality, by size group and/or month.

Results of the application of ELEFAN III to a 30-year time series of monthly C/F data on the Peruvian anchoveta was presented by Pauly et al. (52)

Such versatility has never before been available for the analysis of catch composition data in which fish have not been aged individually. Indeed, as it now seems, this methodology, when applied to stocks in which the basic assumptions (fast growth, short life span, representative L/F data) are not too strongly violated should put fishery biologists with good time series of L/F and especially of C/F data in the position of being able to investigate features of exploited aquatic stocks which were previously not amenable to study.

These programs, several of which are now being tested for use in routine assessments (53) thus illustrate the contention above that tropical fisheries biologists may have an "edge" over fishery managers in their ability to get their work done.

1.3 Management of Tropical Fisheries

Unfortunately, virtually all tropical countries are developing countries. This implies in most cases:

- low industrial output,
- small proportion of the population involved in manufacturing,
- large, increasing population of poor farmers, many of them landless and often drifting into fishing for employment,
- limited support for (fishery) research, and,
- an administration generally not well-versed in problems of fishery management.

For a number of reasons which cannot be discussed here, these features often result, with regard to the fishery sector, in:

- foreign fleets, mainly from developed countries, exploiting tropical stocks (e.g. pelagics off West Africa, tunas in the South Pacific),
- developing countries exporting large and increasing amounts of fish protein to developed countries (54),
- a “dual” fishery sector, consisting of an industrial mechanized fleet and a small-scale artisanal fishery, with various direct and indirect subsidies (research, tax breaks and other subsidies) going into the industrial sector (55) and therefore,
- huge problems with the fisheries as a whole, such as:
 - overfishing and overcapitalization,
 - non-enforcement of fishery regulations,
 - non-availability of reliable fishery statistics for use in planning and stock assessment.

Reviews of some of these problems, with special emphasis on tropical countries are given in Larkin (56) and Smith et al. (55).

Which of these problems would yield first, if attacked wholeheartedly, is difficult to say. Certainly, any appropriate solution would have to involve a wide range of measures ranging from the political sphere (e.g. land reforms, improvement in research funding, restriction on emigration of scientists trained at public expenses) to the administrative (e.g., enforcement of fishery regulations, increases of license fees to regulate effort).

Certainly, the new Law of the Sea and the ensuing declaration of Exclusive Economic Zones by a large number of countries are encouraging in this respect, as they have given developing countries the legal power to deal with at least one of the problems above (the foreign fleets). Solutions for the other problems will be harder to attain and require great efforts and costs.

ACKNOWLEDGMENT

I would like to thank Dr. J.L. Munro of ICLARM, for helpful comments on the draft of this contribution.

REFERENCES^a

- 1) FAO. 1983. Yearbook of fishery statistics, 1981. Vol. 52. Rome, 357 p.
- 2) Caddy, J.F. and G. Sharp. 1986. An ecological framework for marine fishery investigations. FAO Fisheries Technical Paper. No. 283. Food and Agriculture Organization of the United Nations, Rome, 151 p.
- 3) Pauly, D. 1984. Who cites your publications when you work in the tropics? ICLARM Newsletter 7(2): -7.
- 4) Garfield, E. 1980. The literature of marine biology. *Biologia Morya* (3): 3-20. Translated from Russian 1982 by Plenum Publishing Corporation.
- 5) Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *Journal du Conseil international pour l'Exploration de la Mer* 39(3): 175-192.
- 6) Collette, B.B. and C.E. Nauen. 1983. FAO species catalogue. Vol. 2 Scombrids of the World. FAO Fisheries Synopsis No. 125, Vol. 2, Food and Agriculture Organization of the United Nations, Rome. 137 p.
- 7) Hongskul, V. 1974. Population dynamics of Pla-tu, *Rastrelliger neglectus* (van Kampen) in the Gulf of Thailand. *Proceedings of the Indo-Pacific Fisheries Council* 15(111): 297-342.
- 8) Lockwood, S.J. 1978. The fecundity of mackerel *Scomber scombrus* L. International Council for the Exploration of the Sea. Council Meeting/H:19 Pelagic Fish Committee.
- 9) Anderson, E.D. and A.J. Paciorkowski. 1980. A review of the Northwest Atlantic Mackerel Fishery. *Rapport et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer* 177:175-211.
- 10) Hamre, J. 1980. Biology, exploitation and management of the Northeast Atlantic mackerel. *Rapp. Rapport et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer*. 177: 212-242.
- 11) Rao, V.R. 1967. Spawning behaviour and fecundity of the Indian mackerel *Rastrelliger kanagurta* (Cuvier) at Mangalore. *Indian Journal of Fisheries* 14(1): 171-186.
- 12) Winberg, G.G. 1960. Rate of metabolism and food requirements of fishes. Minsk, USSR. Translation Series, Fisheries Research Board of Canada. 194, 239 p.
- 13) This should have referred to (2) and (12)
- 14) Robinson, M.H. 1978. Is tropical biology real? *Tropical Ecology*. 19(1): 30-52.
- 15) Mac Arthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, 203 p.
- 16) Johnson, L. 1981. The thermodynamic origin of ecosystems. *Canadian Journal of Fisheries and Aquatic Science* 38(5): 571-590.
- 17a) Thompson, R. and J.L. Munro 1983. The biology, ecology and bionomics of the jacks, Carangidae. Chapter 8, p. 82-93 *In: J.L. Munro (ed.) Caribbean Coral Reef Fishery Resources. ICLARM Studies and Reviews 8.* [Erroneously cited as 'Thomson and Munro '1973' in legend of Figure 2].
- 17b) Munro, J.L. and Thompson 1983. The Jamaican fishing industry. Chapter 2, p. 10-14 *In: J.L. Munro (ed.) Caribbean Coral Reef Fishery Resources. ICLARM Studies and Reviews 8.* [Presents a space-structured surplus production model, as implied on p. 264].
- 18) Powell, D.G. 1979. Estimation of mortality and growth parameters from the length-frequency in the catch. *Rapport et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer*. 175: 167-181.
- 19) Munro, J.L. 1975. The biology, ecology, exploitation and management of Caribbean reef fishes. Part V.m. Summary of biological and ecological data pertaining to Caribbean reef fishes. *Res. Rept. Zool. Dept., Univ. West Indies* 3(V .m.) 24 p. [Reprinted in Munro 1983].

^a This corrects the numbering of the references in the original version of this contribution.

- 20) Munro, J.L. (Editor) 1983. Caribbean Coral Reef Fishery Resources. ICLARM Studies and Reviews 8, International Center for Living Aquatic Resources Management, Manila, Philippines, 258 p.
- 21) Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. II. Vol. 19, 533 p.
- 22) Beverton, R.J.H. and S.J. Holt. 1964. Tables of yield functions for fishery management. FAO Fisheries Technical Paper. 38, 49 p.
- 23) Beverton, R.J.H. and S.J. Holt. 1959. A review of the life-spans and mortality rates of fish in nature and their relation to growth and other physiological characteristics. Ciba Foundation Colloquia on Ageing. 5: 142-180.
- 24) Pauly, D. and P. Martosubroto. 1980. The population dynamics of *Nemipterus marginatus* off Western Kalimantan, South China Sea. Journal of Fish Biology. 17: 263-273.
- 25) Gulland, J.A. 1971. The fish resources of the oceans. FAG/Fishing News (Books), Ltd. Surrey, England.
- 26a) Beddington, J.R. and J.G. Cooke. 1983. The potential yield of fish stocks. FAO Fisheries Technical Report. 242, 47 p.
- 26b) Gulland, J.A. and L.K. Boerema. 1973. Scientific advice on catch levels. United States Fishery Bulletin 71: 325-335. [refers to 2nd occurrence of '26' on p. 261]
- 27) Sinoda, M., S.M. Tan, Y. Watanabe and Y. Meemeskul. 1979. A method for estimating the best cod end mesh size in the South China Sea area. Bulletin of the Choshi Marine Laboratory of Chiba University. 11: 65-80.
- 28) Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission. 1: 27-56.
- 29) Schaefer, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the tropical Pacific Ocean. Bulletin of the Inter-American Tropical Tuna Commission. 2: 247-268.
- 30) Pella, J.J. and P.K. Tomlinson. 1969. A generalized stock production model. Bulletin of the Inter-American Tropical Tuna Commission. 13: 419-496.
- 31) Fox, W. W. 1970. An exponential yield model for optimizing exploited fish populations. Transactions of the American Fisheries Society. 99: 80-88.
- 32) Schnute, J. 1977. Improved estimates from Schaefer production model: theoretical considerations. Journal of the Fishery Research Board of Canada. 34(5): 583-603.
- 33) Csirke, J. and J.F. Caddy. 1983. Production modelling using mortality estimates. Canadian Journal of Fisheries and Aquatic Science. 40: 43-51.
- 34) Marten, G.G. 1979. Predator removal: its impact on fish yields in Lake Victoria (East Africa) Science (Washington). 203: 646-647.
- 35) Caddy, J.F. and S. Garcia. 1983. Production modelling without long data series. p. 309-313. In: FAO Fisheries Reports. No. 278 (Supplement), FAO, Rome.
- 36) Pope, J.G. 1979. Stock assessment in multispecies fisheries. South China Sea Fishery Development and Co-ordinating Programme. SCS/DEV/79/19, FAO, Manila.
- 37) Daan, N. 1980. A review of replacement of depleted stocks by other species and the mechanisms underlying such replacements. Rapport et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer. 177: 405-421.
- 38) Pauly, D. 1979. Theory and management of tropical multispecies stocks: a review, with emphasis on the Southeast Asian demersal fisheries. ICLARM Studies and Reviews No. 1. International Center for Living Aquatic Resources Management, Manila, Philippines. 35 p.
- 39) Larkin, P.A. 1977. An epitaph for the concept of maximum sustainable yield. Transactions of the American Fisheries Society. 106: 1-11.
- 40) Hickling, C.F. 1931. The structure of the otolith of the hake. Quarterly Journal of Microscopic Science. 74: 547-561.
- 41) Pannella, G. 1971. Fish otoliths: daily growth layers and periodical patterns. Science (Washington) 173:1124 p. 37.

TROPICAL MARINE FISHERIES

- 42) Brothers, E.B., C.P. Mathew and R. Lasker. 1976. Daily growth increments in otoliths from larval and adult fishes. United States Fishery Bulletin. 74: 1-8.
- 43) Brothers, E.B. 1980. Age and growth studies on tropical fishes. p. 119-136. *In* S. Saila and P. Roedel (eds.) Stock assessments for tropical small-scale fisheries. International Center for Marine Resources Development, University of Rhode Island.
- 44) Petersen, C.G.J. 1891. Eine Methode zur Bestimmung des Alters und Wuchses der Fische. Mitteilungen des Deutschen Seefischerei-Verbandes. 11: 226-235.
- 45) Pauly, D. and G. Morgan. 1987 (editors). Length-based Methods in Fisheries Research. ICLARM Conference Proceedings. 13, 468 p. Manila.
- 46) Jones, R. 1981. The use of length-composition data in fish stock assessment (with notes on VPA and Cohort Analysis). FAO Fisheries Circular. 734, 55 p.
- 47) Jones, R. and N. van Zalinge. 1981. Estimates of mortality rates and population size for shrimps in Kuwait waters. Kuwait Bulletin of Marine Science. 2: 273-288.
- 48) Anon. 1979. Report of the *ad hoc* working group on hake (*Merluccius merluccius*, *M. senegalensis*, *M. cadenati*) in the Northern zone of CECAF/ECAF Ser.178/9. 93 p. FAO, Rome.
- 49) Pauly, D. and N. David. 1981. ELEFAN I. a BASIC program for the objective extraction of growth parameters from length-frequency data. Meeresforschung. 28(4): 205-211.
- 50) Pauly, D. 1987. A review of the ELEFAN system for analysis of length-frequency data in fish and aquatic invertebrates. p. 7-34. *In*: D. Pauly and G. Morgan (editors). Length-based Methods in Fisheries Research. ICLARM Conference Proceedings. 13.
- 51) Morgan, G. and D. Pauly. 1987. Analysis of length-frequency data: some available programs and user's instructions. p. 373-462. *In*: D. Pauly and G. Morgan (editors). Length-based Methods in Fisheries Research. ICLARM Conference Proceedings. 13.
- 52) Pauly, D., M.L. Palomares and F.C. Gayanilo, Jr. 1987. VPA estimates of monthly population length composition, recruitment, mortality, biomass and related statistics of Peruvian anchoveta, 1953 to 1981, p. 142-166. *In*: D. Pauly and I. Tsukayama (editors). The Peruvian anchoveta and its Upwelling Ecosystem: Three Decades of Change. ICLARM Studies and Reviews 15, Manila.
- 53) Morgan, G. 1983. Application of length-based stock assessments to Kuwait fish stocks. ICLARM Newsletter. 6(4): 3-4.
- 54) Kent, G. 1983. The pattern of fish trade. ICLARM Newsletter. 6(2): 12-13.
- 55) Smith, I.R., D. Pauly and A.N. Mines. 1983. Small-scale fisheries of San Miguel Bay, Philippines: options for management and research. ICLARM Technical Reports 11, 80 p.
- 56) Larkin, P.A. 1982. Direction and future research in tropical multispecies fisheries p. 309-328 *In*: D. Pauly and G.I. Murphy (editors). Theory and Management of Tropical Fisheries. ICLARM Conference Proceedings. 9.