ICLARM STUDIES AND REVIEWS NO. 1

ISSN 0115-4389

Theory and Management of Tropical Multispecies Stocks

A Review, with Emphasis on the Southeast Asian Demersal Fisheries

DANIEL PAULY

ICLARM

INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

Theory and Management of Tropical Multispecies Stocks

A Review, with Emphasis on the Southeast Asian Demersal Fisheries

DANIEL PAULY

ICLARM

INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT
MANILA, PHILIPPINES

Theory and Management of Tropical Multispecies Stocks:
A Review, with Emphasis on the Southeast Asian Demersal Fisheries

By DANIEL PAULY

Reprinted 1983

Printed in Manila, Philippines

correct citation:
Pauly, Daniel. 1979. Theory and management of tropical multispecies stocks: A review, with emphasis on the Southeast Asian demersal fisheries. ICLARM Studies and Reviews No. 1, 35 p. International Center for Living Aquatic Resources Management, Manila.

ISSN 0115-4389

ICLARM Contribution No. 19

Preface

The present review is mainly an attempt at critically reviewing the demersal fisheries of Southeast Asia and the models used for managing them. As most people working in the region will agree, much is wrong with these fisheries: many are overcapitalized; they are always extremely difficult to monitor; and they are beset with problems related to effective enforcement of any selected management scheme.

Possibly because of what appear to be intractable practical problems, the theory behind the stock-assessment models and the rules of thumb derived therefrom used in the region have been notably neglected, the result being that models which now appear unrealistic have been used for years.

The present paper may thus be seen as an attempt to question these rules and models and I hope to set the stage for a fresh look at the problems and their possible solution. I realize, however, that this will appear quite presumptuous; after all, haven't our models very well explained the collapse of the sardine, herring and anchoveta stocks?

The first version of the present paper was written while I was a consultant at ICLARM's Manila headquarters, from 15 June to 20 August 1978. Several important papers on the fisheries of the region had not been available to me at that time (especially SCS 1978 a and b, Lawson 1978, and Pope 1979). I have attempted, when preparing the final draft, to incorporate appropriate references to these papers. I have made no attempt, however, to process the raw data given in these papers, which in all cases differ only in details from the data used here. In the case of SCS (1978 a and b), the use of the new set of effort data on the Gulf of Thailand fishery would have forced me to recalculate most of my tables, but would not have changed the conclusions reached here.

It is these conclusions which matter most. They differ greatly from those of other authors dealing with this, or similar sets of data. As far as my conclusions are concerned, I suggest, along with Warren S. McCulloch: "Don't bite my finger–look where it is pointing."

DANIEL PAULY
August 1979
Manila

Contents

Preface . . . iii
Abstract . . . 1
Introduction . . . 1
Review of marine fisheries of Southeast Asia, with emphasis on demersal fisheries . . . 3
Artisanal fisheries . . . 4
Characteristics of tropical multispecies stocks with emphasis on demersal stocks in Southeast Asia . . . 6
- Biological characteristics . . . 6
- Characteristics of fisheries arising from biological characteristics . . . 7
- Problems related to the statistical data . . . 7
- Fishery research problems . . . 8
- Institutional problems . . . 8

Review and critique of methods presently used in multispecies stock assessment . . . 8
- XMB model . . . 11
- TBS model . . . 12
- Some options for fishery management . . . 16

Gulf of Thailand trawl fishery: Analysis of a decline . . . 18
Toward a new approach in the investigation and management of tropical multispecies stocks . . . 30
A program for ICLARM . . . 32
Acknowledgments . . . 33
References . . . 34

Theory and Management of Tropical Multispecies Stocks: A Review, with Emphasis on the Southeast Asian Demersal Fisheries

DANIEL PAULY

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

Pauly, Daniel. 1979. Theory and management of tropical multispecies stocks: A review, with emphasis on the Southeast Asian demersal fisheries. ICLARM Studies and Reviews No. 1, 35 p. International Center for Living Aquatic Resources Management, Manila.

This paper consists of four main parts: a) the marine fisheries of Southeast Asia, b) the mathematical model(s) used to monitor these fisheries and predict yields; c) the Gulf of Thailand trawl fishery as a case study; and d) possible new approaches in the study and management of the region's fisheries.

In a) the total marine catch of 10 countries in the region is discussed. The specific biological characteristics of the demersal stocks in the region are stated, emphasis being given to the multiplicity of the species and to some theoretical and practical problems caused by this species diversity.

In b) the Total Biomass Schaefer Model is discussed. It is demonstrated that this model, by not accounting for predation of small fishes, tends to overestimate the maximum sustainable yield (MSY) that can be taken from the stocks. Overestimating MSY is demonstrated to be the key feature of another model, also in use in the region, which assumes more or less eumetric fishing of all stocks.

In c) the Gulf of Thailand demersal trawl fishery is analyzed and shown to confirm the inferences made above. The rates of decrease of different taxa are discussed in detail, emphasis being given to the fact that contrary to a widely held opinion, it is the small, abundant "prey" fishes which, as a whole, declined fastest, not their predators.

Finally, in d) an alternative approach to the management of the stocks in the region is proposed which essentially consists of making yield estimates at distinct, selected trophic levels and determining appropriate fishing techniques. The need is emphasized to reassess previous estimates of MSY and to collate extant data on the fishing and biology of the fishes in the region.

A program is proposed for ICLARM which would help to implement this new approach and to develop a generalized theory of multispecies stocks relevant for use in the tropics and in Southeast Asia.

Introduction

In the past two decades, the sea fisheries of several tropical countries, particularly in Southeast Asia, have expanded at a pace unmatched in most areas of the world. New gear and fishing technologies have been tested and introduced and new productive fishing grounds brought under exploitation (see Marr 1976 for a review of the expansion and scope for development of the fisheries of the region).

The development of a new fishing industry in most countries of the region occurred concurrently with an overall increase of the fishing pressure exerted by a growing number of artisanal fishermen exploitating nearshore resources, and the areas of conflicts between artisanal and commercial fisheries increased correspondingly. These growing conflicts and the serious depletion of some heavily exploited stocks, as well as the new trends in the Law of the Sea, have forced several governments to reassess their fishery development policies and to restate the main objective to be achieved by their fisheries. Robinson (1976) listed the following objectives of fishery development based on answers to a questionnaire sent to the Fisheries Department of 20 countries bordering the Indo-Pacific:

Stated objectives	No. of countries stating this
To produce enough fish for domestic requirements	13
To develop exports	13
To improve the socioeconomic conditions of fishermen	6
To promote generall all-around expansion of fisheries	5
To develop fish farming, aquaculture and brackishwater fisheries	5
To introduce modern equipment and develop distant water fisheries	4
To create employment (not necessarily of fishermen)	3
To develop cooperatives of fishermen's associations	3
To prepare development projects	2
To evaluate fish potential	2

Only three of these objectives actually relate to goals outside of the fishing sector itself, namely:

1) to produce enough fish for domestic requirements;
2) to develop exports; and
3) to provide employment.

Generally, governments expect the commercial fishery to achieve the second objective, while the third objective is to be achieved mainly by the artisanal fishery. The first goal is achieved by the combined landings of both the commercial and the artisanal fisheries.

An additional and often very decisive governmental objective which has been frequently ignored in the fishery literature is to create possibilities for new investments by the private sector (that is, to increase gross national product).

There are different reasons why a fishery can be developed, and while this need not be the case, there are also times and situations in which various objectives can become mutually incompatible because of the truism that one cannot maximize more than one factor at a time. Thus, for example, it is generally not possible both to obtain the highest possible yield from a fishery (in weight or economic returns) and to maximize employment. Or, to take another example, it is to date impossible to develop a highly efficient export-oriented shrimp fishery and to simultaneously manage the shrimp-associated stocks of small, low-value fishes for maximum sustained yield.

In addition to the frequent incompatibility of the four goals listed above, there is also a grave conflict between short- and long-term objectives.

Thus, for example, if the fourth objective listed above is the one that shapes the development of the fishery, then under certain conditions it makes sense to invest heavily in a new fishery and to increase the fishing effort up to a point where the stock collapses, if the initial returns are very high and can be reinvested with similarly high returns in another venture (Clark 1976). This is possibly what is happening in several of the region's fisheries (although not necessarily on a planned basis). A similar conflict between the short- and long-term objectives occur every time a government or development agency tries to alleviate the plight of the artisanal fishermen by providing them with improved fishing gear at reduced cost (e.g., engines for their small boats and synthetic nets instead of natural fiber nets). This strategy may at first better the situation of these fishermen, but actually makes the problem only worse as artisanal fishermen sooner or later find themselves with ever decreasing yields and involved in more direct conflicts with the commercial fishermen (for a recent review of the kind of conflicts involved here, see Lawson 1978).

The different objectives listed above offer considerable latitude for choice on the part of the governmental agencies in charge of planning the fisheries development of their countries. On the other hand, the ultimate limitation for achieving these objectives will always be given by the sizes of the fish stocks themselves, and more specifically, by their response to the fisheries exerted upon them. The present report, therefore, aims at reviewing the character of the stocks exploited by some fisheries of the region and at pointing out the bottlenecks preventing us from:

1) understanding the biology and dynamics of these stocks; and
2) thereby being able to make use of these stocks according to the objectives selected.

Following an identification of these bottlenecks, I suggest a series of steps which could be taken to achieve 1) and 2).

In this report, no preference is expressed for any of the four objectives listed previously. These objectives are set by the fisheries agencies of the various countries in accordance with their specific needs, and as seen from a biological standpoint, all are equally legitimate.

The conflict between short- and long-term interest, on the other hand, has an altogether different character and here wrong choices can have devastating effects on renewable stocks.

Several fisheries throughout the world have been virtually annihilated by various quick-money strategies, leaving no resources to exploit and no choices to make. To the extent that such strategies, of which several will be illustrated in this report, are allowed to be followed or to remain open options for the development of the various fisheries of the region, there exists the possibility or even likelihood of the loss of valuable resources.

Review of the Marine Fisheries of Southeast Asia, with Emphasis on Demersal Fisheries

Several extensive reviews of the status of Southeast Asian marine fisheries are available, such as Tiews (1976) on a country and regional basis and Marr (1976) on a regional basis, so that there is no need to do more here than briefly summarize the key data pertaining to the fisheries of the region.

The data of FAO (1977) suggest a total catch of aquatic products of about 14 million mt for the 11 countries of the region of which 58% (8 million mt) originates from marine waters (Table 1).

Two countries (China and Kampuchea) have freshwater catches exceeding their marine catches. In the remaining 9 countries, the marine catch contributes an average of 85% of the total aquatic catch. This last figure emphasizes well the relative significance of the marine fisheries of most Southeast Asian countries.

Of the total marine catch for the whole region, 7 million mt (about 90%) consists exclusively of fish. The remaining 1 million mt consists to a large extent of crustaceans (especially shrimp and crab) and molluscs (especially squid and bivalves). Generally, the data for invertebrates are not detailed enough to allow a taxonomic breakdown and further analysis on a regional basis, so no attempt will be made to discuss these here. (see Gulland 1971 for discussions of the shrimp, crab, and molluscan resources of the region).

Of the 7 million mt of marine fishes mentioned above, only 4 million mt can be more or less safely attributed to the demersal category (FAO 1977). If the marine fishes landed in Brunei, China, Kampuchea, and Vietnam are assumed to consist of 50% demersal and 50% pelagic fishes, then in the whole region the catch of demersal and pelagic fishes is almost equal (3.7 vs 3.5 million mt, respectively; see Table 1).

In this paper, emphasis is given to the demersal fisheries, so it is the 3.7 million mt of fish presumably caught by the demersal fishery which will be considered here.

In terms of their demersal fish catch, the countries of the region may be grouped as follows:

1) A first group consisting of China and Thailand, with catches near 1 million mt each (but note that the figure for China is quite a rough estimate).

2) A second group with demersal catches ranging between 0.2 and 0.4 million mt, consisting of Indonesia, the Philippines, Taiwan, Malaysia, and Vietnam.

3) A third group, with relatively small catches, up to slightly more than 0.1 million mt, consisting of Hong Kong, Kampuchea, Singapore, and Brunei.

In the first group, Thailand has a distant water fleet, and most of the catch originates from waters outside the Gulf of Thailand (Marr et al. 1976), while the Gulf of Thailand itself is overexploited (Marr et al. 1976 and

Table 1. Nominal catch in countries of the region, mainly 1976. Data are compiled from FAO (1977) except for Taiwan data. Separation of pelagic and demersal fish are according to FAO (1977).

Country	All freshwater[a] products	Marine[b] Crustaceans	Miscellaneous[c] marine products	Marine fishes	Pelagic marine fishes	Demersal marine fishes	Total
Brunei	4	587	–	974	(487)[e]	(487)[e]	1,565
China	4,568,000	–	–	2,312,000	(1,156,000)[e]	(1,156,000)[e]	6,880,000
Hong Kong	5,238	15,741	10,468	126,490	14,865	111,625	157,937
Indonesia	408,646	76,439	33,167	929,748	545,489	384,259	1,448,000
Kampuchea	73,900	600	–	10,200	(51,000)[e]	(51,000)[e]	84,700
Malaysia	3,844	68,217	47,414	397,428	139,932	257,496	516,903
Philippines	223,157	35,471	59,409	1,111,774	749,047	362,727	1,429,811
Singapore	654	898	201	14,676	303	14,373	16,429
Taiwan[d]	119,100	(40,100)[f]	(40,100)[f]	450,800	217,400	233,400	650,100
Thailand	176,000	135,968	171,988	1,156,400	280,507	875,933	1,640,396
Vietnam	176,300	78,500	35,100	723,600	(361,800)	(361,800)	1,013,500
Total	5,754,483	452,521	397,847	7,234,130	3,516,830	3,709,100	13,839,341

[a]Mainly fishes (including diadromous and brackishwater) but including some freshwater crustaceans, molluscs, and frogs.
[b]Shrimps and prawns, crabs, lobsters, sergestids, and stomatopods.
[c]Mainly molluscs, with holothurians, jellyfishes, turtles, and seaweeds.
[d]Taiwan data refer to 1971 and originate from Table 7 in Marr (1976).
[e]The figures in brackets are rough estimates based on assuming that 50% of the total marine catch consists of pelagic or demersal fishes.
[f]Assuming that the difference between total marine catch and marine fishes consist of 50% marine crustaceans or miscellaneous marine products.

present paper). Possibly, this group as a whole will not in the near future produce more than the 2 million mt caught presently.

The second group consists of countries which, with the exception of Taiwan, have no distant water fleet and in which there seems to be some limited scope for expansion of the fisheries, as well as perhaps an increase of the catch through improved fishing techniques and fishery management. Possibly, the present catch for this group, which is presently of 1.6 million mt could be increased to 2 million tons.

The third group, consisting of Brunei, Hong Kong, Kampuchea, and Singapore is characterized by extremely short coastlines (mean = 212 km) and a significant increase of the aggregate catch for this group (0.18 million mt) is quite unlikely, except in the form of cooperative ventures with neighboring countries (Marr 1976).

As a whole, the present demersal fish catch of the region may increase from the present 3.7 million mt to, say, 4 million mt, or by about 8%. Aoyama (1973) estimated for the early seventies a total catch of 2.5 million mt, for the region, with a potential increase of about 1 million mt. From this, it would seem that now in the late seventies there is, as a whole, little room left for expansion of the demersal fisheries. The above figure of 4 million mt thus could represent the upper range of an estimate of the potential demersal yield of the region.

As will be shown later in this report, the methods used in this region for the estimation of potential yield and of maximum sustainable yield tend to produce overestimates which are very probably not sustainable. It is therefore possible that the 3.7 million mt of demersal fishes presently caught in the region may be difficult to sustain. Based mainly on extrapolations from the Gulf of Thailand, SCS (1978a) on the other hand, suggested the possibility of an increase in the demersal catch of the Sunda Shelf area from presently 2 million mt to 2.7 million mt, or 35%. It is suggested that this increase would come about by increasing effort in most areas (exclusive of the Gulf of Thailand) and especially by fishing in deeper waters.

In the data by FAO (1977), the taxonomic breakdown of the marine demersal catch of 6 countries is detailed enough to allow for the compilation of a list of those fish taxa that are most important to the demersal fisheries of the region. Some of the taxa (generally families) are reported from a few countries only, although they certainly occur in the catch of all countries. The most prominent example are the Leiognathidae, which are not reported by FAO (1977) from Thailand, although large amounts of them are known to be used for producing fishmeal for chicken feed and directly as duck and catfish food.

Because of nonreporting, the groups of small, low-value taxa in Table 2 are under-represented, and there is a bias toward high-value, large fish. Still, the list in Table 2 provides an indication of the character of the demersal resources, of their taxonomic diversity, and of the predominance of small, low-value fishes in the catch. These two latter aspects, taxonomic diversity and size distribution, will be discussed in greater detail later in this review.

Artisanal Fisheries

Reference will be made several times in this paper to the large number of artisanal fishermen in many countries of the region. There appear to be few estimates of number of artisanal fishermen on a regional basis, so an attempt is made to obtain a rough estimate of their number. The procedure for the estimation involves two steps:

1) The total annual marine catch (Table 1) by coun-

Table 2. The 18 most important taxa in the demersal fisheries of the region in 1976, as compiled from landing data in FAO (1977)[a].

Taxa	Reported landings (mt)	No. of countries reporting	% of total
Leiognathidae	143,118[b]	4[b]	20.1
Nemipteridae	116,826	6	16.4
Lutjanidae	74,249	6	10.4
Synodontidae	53,183	6	7.5
Sciaenidae	52,566	6	7.4
Serranidae	44,696	4	6.3
Polynemidae	33,766	4	4.7
Priacanthidae	27,293	3	3.8
Mullidae	27,193	5	3.8
Sharks	26,026	6	3.7
Ariidae	24,055	5	3.4
Rays and skates	22,623	5	3.2
Pleuronectidae	20,988	5	2.9
Formio niger	15,070	2	2.1
Muraenesox	11,246	3	1.6
Menidae	8,865	1	1.2
Pomadasyidae	5,460	3	0.8
Lethrinidae	4,975	2	0.7
Total	712,198		

[a]Of the 10 countries listed in Table 1, FAO (1977) gives a more or less detailed breakdown by taxa from Hong Kong, Indonesia, Peninsular Malaysia, Philippines, Singapore, and Thailand only.

[b]No leiognathids are reported from Thailand, although it is known that a considerable number of these fishes are landed and used, e.g., as duck food. Leiognathids probably make up a large part of the "non-identified marine fishes" reported from Thailand (754,796 t in 1976).

try is reduced to that proportion of the total marine catch which is thought to be taken by the artisanal fishermen. The data used for this conversion were taken mainly from Table 1 in SCS (1973) (and see footnotes in Table 3).

2) The artisanal catch is divided by estimates of catch per fisherman. Of these, six independent values were available (see footnotes in Table 3), while their weighted mean was used for the four countries where no data were available. This mean value, 1.33 t per fisherman-year, is close to the Indonesian and Philippine estimates, both of which seem to be the most reliable ones. However, the total number of artisanal fishermen operating in the region, estimated here at 3.5 million, is probably an underestimate, for two reasons:

1) The annual catch per fisherman is based on full-time artisanal fishermen. In addition to these, there are a large number of artisanal fishermen operating part-time, which reduces the average catch/effort.

2) The estimates of catch/effort are in many cases based on studies conducted a decade ago, when catch/effort may have been higher, because there were fewer fishermen and less fishing.

Thus, the number of artisanal fishermen, including part-timers, may be substantially higher than estimated here, possibly as high as 5 million.

The artisanal fishermen, whatever their exact number, catch more than half of the marine fish catch of the region (58%). They may affect the commercial fisheries by reducing recruitment to the stocks of older fish exploited further offshore by the commercial fisheries. Conversely, the commercial fisheries reduce the stock of inshore (generally younger) fishes available to the artisanal fishermen by reducing the parent stocks (see Tiews and Caces-Borja 1965 for a case study).

Whichever of these two alternatives is found to apply, it appears that the two fisheries influence each other and compete for more or less the same stocks.

Table 3. Estimated numbers of traditional fishermen (marine) and annual per-fisherman catch in the Southeast Asian region, compiled with the assistance of Dr. Ian R. Smith, ICLARM.

Country	Total marine catch (mt[a])	% From small-scale fisheries[d]	Marine catch, small-scale (mt)	Estimated no. of small-scale fishermen	Annual catch per fisherman (mt)
Brunei	1,561	28[b]	437	325[l]	(1.33)
China	2,312,000	98[c]	2,265,760	1,678,000[l]	(1.33)
Hong Kong	152,699	7	10,689	7,900[l]	(1.33)
Indonesia	1,039,354	98[e]	1,018,567	860,800[g]	1.18
Kampuchea	10,800	20	2,160	1,600[l]	(1.33)
Malaysia	513,059	23	118,004	65,000[h]	1.82
Philippines	1,206,654	55[f]	663,660	500,665[f]	1.33
Singapore	15,775	29	4,575	650[i]	6.98
Taiwan	531,000	46	244,260	181,000[l]	(1.33)
Thailand	1,464,396	13	190,371	60,000[j]	3.17
Vietnam	837,200	25	209,300	187,500[k]	1.12
Total or (weighted average)	8,084,498	(58)	4,727,783	3,543,440	(1.33)

[a]Even though separate national statistics are available in a few cases, for purposes of consistency, marine catch estimates are compiled from FAO (1977), except for Taiwan data which originate from Table 7, Marr (1976).

[b]Based on average of Sarawak and Sabah as reported in Table 1, SCS (1973).

[c]Estimate by author based on Solecki (1966). SCS (1973) estimate is 100% for 1971.

[d]Based on 'other fisheries' category, Table 1, SCS (1973), unless noted otherwise. Malaysia includes lift nets.

[e]Sidarto and Atmowasono (1977).

[f]Samson (1977). SCS (1973) estimate is 59% for 1970.

[g]Fisheries Statistics of Indonesia, 1972.

[h]SCS (1973) reports 26,000 vessels in coastal fishing. Assuming ratio of fishermen to vessels of 2.5:1, estimated number of fishermen is 65,000.

[i]SCS (1973) reports that one-third of Singapore's 794 vessels in 1971 were engaged in coastal fishing. Assuming 2.5 fishermen per vessel gives estimated 650 fishermen.

[j]Aubray and Isarankura (1974) report 36,000 fishing craft, all but 3,200 devoted to artisanal fishing, and a fisheries population of 270,000. Fisheries Record of Thailand, Department of Fisheries (1975) reports 64,277 fishermen. The number of traditional fishermen is probably in the neighborhood of 60,000, not including sea mussel collectors whose numbers are not known.

[k]SCS (1973) reports 75,000 vessels in coastal fishing. Assuming a ratio of 2.5 fishermen per vessel, estimated number of fishermen is 187,500.

[l]Neither estimates of numbers of small-scale fishermen, nor per fisherman annual catch estimates are available for Brunei. China, Hong Kong, Kampuchea, and Taiwan. Numbers of fishermen are estimated for these countries using the weighted average of 1.33 mt catch per fisherman for other countries in the region.

This will have to be considered every time modernization or development schemes are considered.

Characteristics of Tropical Multispecies Stocks with Emphasis on Demersal Stocks in Southeast Asia

BIOLOGICAL CHARACTERISTICS

The first and most obvious feature of the stocks in question is the multitude of species occurring on the fishing grounds. The following are some trawl surveys conducted in the region, together with the number of fish species recorded:

Eastern Peninsular Malaysia, 341 species (Anon 1967)

Java Sea and southern tip of South China Sea, 230 species (Widodo 1976)

Visaya Seas (Philippines), 173 species (Aprieto and Villoso 1977)

Note that these figures are lower limits and depend on the numbers of the stations covered. Current estimates for the total number of fish species in the Indo-Pacific Area are as high as 6000-7000 species (Carcasson 1977), of which a large proportion occurs in the region.

In general, single hauls with 50 species or more are quite frequent. For a preliminary review of some implications of this multitude of species, see Marr (1976).

A second, very marked feature of the stocks is that in general, most of the component species are small-sized. In shallow waters, the bulk of the catch generally comprises Leiognathidae, which have a mean maximum length of about 12 cm. (One species, *Leiognathus equulus*, reaches up to 30 cm. The figure of 12 cm refers to the rest of the leiognathid species, which are all small-sized.) In deeper waters, the bulk of the catch is often represented by Gerridae, with a similarly small length. Large fish, on the other hand, are much less common, the whole picture being that of a typical "food pyramid."

A third, very important feature of the stocks is that the peak occurrence of many of their constituent species is in shallow waters. Thus, for example the Leiognathidae have the maximum of their biomass at a depth of about 25 m (Pauly 1977) while the Trygonidae (rays) are most abundant at 10-20 m (Anon 1967).

Migratory movements of demersal species have been little studied in the region. Tagging studies in the Gulf of Thailand suggest "that the demersal fishes do not make any extensive migrations" (Chomjurai and Bunag 1970). On the other hand, there is ample evidence that most species are represented by larger specimens in the offshore, deeper waters. This can be demonstrated for a large number of species, for example, on the basis of the extensive length-frequency data presented by Martosubroto and Pauly (1976) which cover approximately 90 species (ca 40,000 measured specimens) from the Java and South China Seas.

As a whole, however, these data also suggest that there are no distinct gaps or discontinuities separating the young from the adults, or the reproductive stages from the reproductive stocks.

Finally, it appears that the species assemblage in the region of which the stocks are a part are peak communities, the outcome of a long, common, evolutionary history in an extremely stable environment (Eckman 1967). That assemblages of fish species in tropical ecosystems differ from the species assemblages occurring, say, in the North Atlantic, is quite obvious.

On the other hand, it is similarly obvious that acknowledging the existence of these differences between high-latitude and tropical ecosystems has seldom prevented fishery biologists from applying principles derived from high-latitude marine ecosystems to the fundamentally different tropical marine ecosystems. Garrod (1973) wrote that (high latitude) "multiple stock fisheries resources form a robust system" which "can tolerate wide variations in fishing mortality. . .without adverse effects."

However, before applying this concept of a "robust system" to tropical marine ecosystems, the following questions should be answered:

1) Is the statement correct as a whole, or does it exclude certain groups of species, for example, the clupeoids (see Murphy 1977)?

2) If the statement does apply, at least to predominantly demersal systems, then why are high latitude multiple-species systems robust? Is it because of their "system" property? or rather because high latitude systems are composed of single species each of which can withstand high variations in fishing mortality?

Obviously, the answers to these last questions are crucial to the management of multiple-species stocks. A positive answer to the first question would, for example, imply that the knowledge derived from, say, the North Atlantic fisheries and the stock interactions observed there can be generalized and then applied to a tropical situation. On the other hand, a positive answer to the second question would imply that the tropical marine ecosystems of this region may not be robust at all.

Ecological theory, as reviewed in recent texts (e.g., Ricklefs 1973) does not seem to provide a clear-cut answer to these questions, at least when fish communities are considered. It seems generally accepted, however, that tropical fishes interact most strongly with the biotic components of their environment, while temperate fishes seem to be more strongly affected by the abiotic components of their environment (e.g., Nursall 1977). This is confirmed by the recent demonstration that natural mortality (as caused mainly by predation), which in fishes is a function of both size and growth rate, is also a function of environmental temperature (Pauly 1978b). This relationship, demonstrated on the basis of literature data on 122 fish stocks, suggests that natural mortality (M) in tropical fishes is, other things being equal, twice as high in tropical as in temperate waters.

Another feature of tropical communities seems to be the predominance of specialist species, adapted to a certain set of more or less constant environmental conditions and to their specific prey and predator organisms. In this respect tropical communities would thus differ from those of temperate areas, where more opportunistic or generalist species tend to predominate (Dobzhansky 1950; Pianka 1970; Ricklefs 1973). This would suggest that tropical fish communities should consist in the main of "K-selected" species (specialists) as opposed to temperate fish communities in which r-selected species (generalists) predominate (see Pianka 1970 for a discussion of the concepts of r- and K-selection).

An attempt will be made later to discuss some of the implications of the high mortality rates. An attempt also will be made to apply the concept of specialists vs generalists to explain some of the interaction that has occurred in the exploited stocks of the Gulf of Thailand.

CHARACTERISTICS OF FISHERIES ARISING FROM BIOLOGICAL CHARACTERISTICS

An effect of the multitude of species on the demersal fishing grounds is the occurrence of a multitude of species in the catch. Note that this statement is not as trivial as it sounds, since it implies that there has been no selective fishing attempted for any given species or group of species. So, the closest one gets in the region to any single species fishery is by "shrimping," with subsequent discard of most of the (fish) catch.

The predominance of small-sized fishes on the fishing grounds forces the fishermen to use very fine-meshed gear so as to catch both the large valuable fishes as well as the less valuable small fishes which contribute to the value of the catch by sheer bulk.

The occurrence of the largest part of the stock in shallow waters has two important consequences for the fishery. First, it is possible for a large number of artisanal fishermen operating even with low efficiency in very shallow waters to significantly reduce the stock, even if mainly by impairing recruitment to these stocks (for an example see the discussion of the "bagan" fishery in Java in Pauly 1977b).

Secondly, the commercial fishery is more or less forced to operate in shallow waters and thus to compete with the artisanal fishermen for the same resource. (It should be noted, however, with respect to points made in this and the preceding paragraphs that there is probably a substantial self-reinforcing component at work. As the trawl fishery developed, the average size of individual fish decreased, as did their abundance. Thus, to maintain catch rates, fishermen decreased mesh size and moved into other fishing grounds including the more inshore areas.)

As the reproductive stages of most fishes are in reach of the commercial and especially the artisanal fishery, and as both fisheries will catch fish of any size from a few centimeters upward, there is a marked tendency for the catch in Southeast Asian demersal fisheries to consist to a significant extent of the juveniles of the valuable large-sized fishes. This feature is likely to affect recruitment to the adult stock whenever the spawning stock has been significantly reduced. Therefore, in the demersal fisheries of the region, there is the likely possibility that "recruitment overfishing" occurs, in addition to the "growth overfishing" induced by the small meshes in use. (For a definition of the various forms of overfishing as occurring in tropical stocks, see Pauly 1979b).

The fact that the stocks are composed of an assemblage of species with a very long, common evolutionary history has the grave implication that any fishery, by removing specific prey fishes, will disrupt and eventually destroy the original food web and lead to the emergence in the system of often less valuable generalists. Generalists seem to be represented by various groups of trash fish and by the Heterosomata in the region.

This feature of a changing species dominance pattern under the influence of a fishery seems to be characteristic of tropical multispecies demersal stocks, and it has been reported for a number of stocks from various areas of the world. Thus, in West Africa for example, the exploitation of the demersal (and pelagic) stocks has produced a tremendous increase of the trash fish ***Balistes capriscus***, a previously inconspicuous species now dominating the catches, e.g., in Ghana (M.A. Mensah, Tuna Fishery Research Center pers. comm.) and off Togo (Beck 1974).

David Eggleston (pers. comm. to J. Marr) reports similar changes in species composition of demersal stocks off Hong Kong and of a marked decrease in the average size of the fish of the exploited stocks. Also interesting is his report of a decrease in the proportion of deep-bodied fishes believed due to mesh selection and a corresponding increase of the proportion of slender-bodied fishes.

PROBLEMS RELATED TO THE STATISTICAL DATA

Here again, the multitude of species is the predominant problem. In the statistics of many countries this species multitude is summarily dealt with and reduced to its simplest expression, namely: "various sea fishes." This greatly reduces the usability of these statistics for purposes of fishery management. Some crude differentiation is often made, however, and it frequently pertains to the value of the fish. So, we often have "good fish," marketed whole, iced, and used for human consumption, and "trash fish," used as duck or other animal feed and which consist of three different categories: the young of highly valuable fish, e.g., the Lutjanidae; smaller-sized fishes (e.g., the Leiognathidae) which in the virgin stock forms the bulk of the food of the large, valuable fishes; and real trash fish, that is, fishes not used for direct human consumption and not forming a significant part of the food of the larger valuable fishes. These fishes are represented by such families as the Triacanthidae, Aluteridae, and Ostracionidae, and include those fishes which tend to increase, along with the Heterosomata, as the biomass of the fishes of the first two groups is seriously reduced. Because of the simultaneous existence of two fisheries, one commercial and one artisanal, the latter using a multitude of different gear, each with different "power factor," in most cases it is not possible to obtain, for any given stock, a series of mutually compatible effort data against which the catch per effort could be plotted.

FISHERY RESEARCH PROBLEMS

Fishery research, which ideally should provide the basis for sound fishery management is faced in the case of tropical multispecies stocks with a series of practical, theoretical, and institutional problems which have greatly hampered its development and which in most cases have altogether prevented an understanding of the dynamics of the stocks that were being investigated.

There are four main problems. First, perhaps up to late sixties, a big problem in the region was that associated with properly identifying and naming the various fishes which contributed to the fishery. With the completion of the FAO identification sheets (Fischer and Whitehead 1974) and of revisions for various important families, this taxonomic problem seems now to have been largely removed. The problem remains, however, that many of the identification keys are not readily available in the various local languages such that they could be used at all levels in all countries in the region.

Secondly, previous problems of species identification are a major cause for the unavailability to the fishery scientist of a body of data sufficient for his needs gained from the fisheries statistics of their countries. In high-latitude countries, the statistical services which go along with the commercial fisheries tend to generate, at little added cost, a tremendous body of data which are extremely useful to the fishery scientist. This additional source of information is absent in most tropical fisheries.

Another problem gravely affecting the development of fishery biology as related to multispecies stocks is the heavy dependence of scientists of tropical countries on methods, concepts, theories, and expertise from high-latitude countries, often with little or no attempt to really adapt the imported concept or theory to the tropical situation.

Finally, in addition to the nonapplicability of certain concepts and methods to the management of tropical fisheries, there is also the more general problem that there is presently no general theory of the interactions between the various species of exploited multispecies stocks which could be applied to tropical stocks.

INSTITUTIONAL PROBLEMS

The institutional problems of tropical countries relating to their sea fisheries are quite numerous, and no attempt will be made here even to do more than list them.

- A) Scientific Research
  - 1) Not enough scientists
  - 2) Not enough funds for these scientists
  - 3) Not enough supporting facilities (libraries, research laboratories, and ships)
- B) Research Policy
  - 1) Often no clear definition of research programs
  - 2) Often no support of such programs over an adequate period of time
- C) Management of Fisheries
  - 1) Often no explicit policy concerning the emphasis of fishery development, particularly with regard to the artisanal fisheries
  - 2) Inability to enforce fishery regulations

(See Tiews 1976; Caces-Borja 1975 for discussions of the problems listed here.)

Rather than further expand this review of tropical multispecies stocks and the various problems associated with fisheries based upon them, an attempt has been made here to emphasize the particular character of these stocks by comparing them and their associated problems with those of high-latitude demersal fisheries, and of tropical and high latitude coastal and oceanic pelagic fisheries (Table 4). The main emphasis of the table is on concise formulations of main problems. Obviously, this table is by no means exhaustive, nor need all statements made in it be taken literally. The only impression that Table 4 intended to convey is that almost all problems that can occur in a fishery do occur in a tropical multispecies fishery.

Review and Critique of Methods to Assess Multispecies Stocks

The problems discussed above, especially the lack of detailed fisheries statistics and of data on the biology of the various exploited fish species, have up to now precluded the use of most of the sophisticated models developed for application on single-species fisheries. Two simple models, on the other hand, have been widely applied to estimate potential yields, or maximum sustainable yields (MSY), for the multispecies fisheries of the region. The first of these may be called the "XMB Model" (XMBM) and the second the "Total Biomass Schaefer Model" (TBSM).

XMBM

This model was discussed by Gulland (1971) and consists of a combination of the simple Schaefer (1954) model with some concepts taken from Beverton and Holt (1957, 1964), resulting in:

$$MSY \approx X \cdot M \cdot B_{\infty}$$

where

X is a proportionality constant, usually set at 0.50,

M is the exponential coefficient of natural mortality, and

B_{∞} is the virgin biomass (weight) of the stock in question.

The assumptions made by Gulland (1971) for the derivation of this model are that (1) MSY is taken when the exploited biomass is reduced by the fishery to half the size of the virgin biomass, and (2) at the optimum level of effort needed to produce MSY, the fishing mortality (F) caused by this effort is equal to M.

If these two assumptions apply, then:

$$MSY \approx \tfrac{1}{2} M \cdot B_{\infty}$$

Assumption one applies only if the Total Biomass Schaefer Model applies, and this will be discussed further below. The second assumption may or may not apply. As will be shown, the possible error introduced by this assumption is small compared to the error introduced by the use of the TBSM.

Another approach used by Gulland (1971) for the derivation of the same model and based on the yield tables of Beverton and Holt (1964) results in

$$MSY = X \cdot M \cdot B_{\infty}$$

with $X \approx 0.50$ if the mean length at first capture (L_c) is 40-70% of the asymptotic length (L_{∞}) in the stock in question. In this case, and at a high level of effort, more or less eumetric fishing will occur and the maximum yield will be taken from the stock. This model certainly applies to single-species stocks from which it was derived, as it is possible to adjust the value of L_c in this case, (through the regulation of mesh size) such that eumetric fishing will result.

In the case of the multispecies trawl fisheries of the region, the model does not apply for two reasons. First, optimizing sustainable yield from a fishery taking both large fishes (mainly piscivorous) and small fishes (mainly the large fishes' prey) requires the use of a model which takes predation into account (e.g., the model of Pope 1979). This question, however, will be discussed in greater detail in conjunction with the TBSM (see below). Secondly, the stocks consist of different fish species varying so much in their asymptotic sizes that is utterly impossible for any given combination of effort and mesh size to fish eumetrically more than a few species at a time, while most other species remain either over- or underfished (which in both cases produce a smaller yield).

To fully demonstrate this second point, yield isopleth diagrams were constructed for two fish species, both very common in the region. The first species is the red snapper, *Lutjanus sanguineus*, which is here taken to represent the large, high-value predators and whose relatively large size and high longevity suggest a "large mesh" approach. The second species is the slipmouth *Leiognathus splendens*, which is the most abundant slipmouth species as well as probably the most abundant single species (at least in virgin stocks) in the Sunda Shelf Area (Pauly 1977b). This fish may here represent the small, abundant low-value fishes which form the bulk of the food of predators, such as *L. sanguineus*.

The parameter values and the formula used for the derivation of the yield isopleth diagrams are given in Table 5, and the diagrams themselves appear as Figs. 1A and B. Their interpretation is relatively simple. If we use the probable value of F = 2.0 for the fishing mortality inflicted upon the demersal stocks of the Gulf of Thailand in the early seventies and assume that the cod-end mesh size of about 20 mm recorded from this area (Jones 1976) results in a value of $L_c \approx 8$ cm in *Lutjanus sanguineus* and of about 5 cm in *Leiognathus splendens* (both values are probably overestimates) then it follows that:

1) The stock of *Lutjanus sanguineus* is grossly overfished, the yield-per-recruit being five to seven times smaller than could be obtained by using a mesh size resulting in $L_c \approx 45$ to 50 cm.

2) The stock of *Leiognathus splendens* is also overfished and the yield-per-recruit could be increased by about 50% by increasing L_c to about 6 to 7 cm.

3) An increase in mesh size resulting in eumetric fishing on *L. sanguineus* would cause a complete loss of the *L. splendens* catch (which would not be retained in the net by the large mesh).

4) Thus, one can fish eumetrically either *L. sanguineus* or *L. splendens*, but not both.

5) Finally, if *L. sanguineus* and *L. splendens* can indeed be thought to represent the "large" and the "small" fishes occurring in multispecies stocks, then it follows that any yield estimate based on the sum of the eumetric yields of both groups is an overestimate of the

Table 4. Summary of characteristics of different types of fisheries.

Type of fishery	High latitude demersal	Coastal and coastal upwelling pelagic	Oceanic and oceanic upwelling pelagic	Tropical multispecies demersal
Temperature range, and range of temperature fluctuations in °C	0 - 15/2 - 5	10 - 20/5 - 10	20 - 25/5 - 3	25 - 30/3 - 1
Resource base	A few important species, high in the food chain	One or two main species, low in the food chain, with assemblage of predators	A few (often one) species, peak predator(s)	A multitude of species, with wide range of sizes and trophic levels
Main taxa exploited	Gadoids Heterosomata	Clupeoids	Large scombroids	Various perciforms
Ecological strategy: r- or K-strategy? (see text)	Predominantly r-strategy	Predominantly r-strategy (?)	Predominantly r-strategy (?)	Predominantly K-strategy
Stock density in virgin stock (weight/area)	High	High, but fluctuating naturally	Low	Medium to high
Main gear used by fishery	Pelagic and demersal trawl	Pelagic seines	Pelagic seines, longlines, pole and line	Demersal trawl plus a multitude of artisanal gear
Depth of fishing	Whole water column, depth down to, say, 500 m	Surface	Surface and subsurface	Surface and bottom down to ≈ 100 m
Is there any significant artisanal fishery?	No	Generally, no (but see local exceptions, such as Ghanean *Sardinella* fishery)	No, except near some islands	Yes, often from the bulk of the fishery
Use of the fish landed	Production of varied high-priced fish products; much machine processing of catch on board of catching boats	Canning, medium quality fish, or fishmeal	High-priced products: canning and frozen fish	Marketing of iced fish. Much direct consumption by artisanal fishermen. Drying common, but generally no canning nor smoking. Export of some specific products (shrimps, squids) and production of some animal feed from trash fish. See Campbell (1975) for a review.
Quality and price of product	High	Medium	Very high	All products of widely varying quality and price

Are year class failures common?	Yes, but the stock tends to recover relatively well. Also effects dampened by presence of several to many year classes	Yes, and they often produce, together with fishing pressure, disastrous failures, with no or slow subsequent recovery of the stock	Apparently no	Not reported for any multi-species stock, but not to be ruled out for single species
Knowledge of the biology of the exploited species	Very good (some North Sea fishes probably belong to the best investigated nondomestic animals in the world)	Fair to good	Fair to good	Most species are totally uninvestigated
Main method routinely used for generating size-at-age data	Otoliths + spawning seasons	Scales + spawning seasons	Size frequencies + spawning seasons	None
Models used for fishery management and catch prediction	(a) Yield-per-recruit model (Beverton and Holt 1957), (b) Pope's Cohort Analysis	Logistic model by species (Schaefer 1954)	Logistic model by species (Schaefer 1954)	(a) Total biomass logistic model (see Table VI for examples of applications. (b) "XMB" Model (see text) Note that both models are inadequate (see text)
Advanced models that have been proposed and can be tested in the light of empirical data	2, 3 or N species interaction models (Beverton and Holt 1957) and especially Andersen and Ursin 1977 with model of the whole North Sea!)	Various models incorporating oceanographic, plankton and fishery data, as well as 2-species interaction models (e.g., sardine vs anchovy)	Modelling of oceanic ecosystem plus tuna population (see publications of the Inter. Am. Trop. Tuna Comm.)	Need to reassess models previously used and to develop new approach (see text)
Are the stocks at present exploited mainly by distant water fleets?	Yes	No	Yes	Ranging from exclusively local exploitation (e.g., by artisanal fishermen) to distant water fishery (e.g., by Thai trawlers)
Fishery operates mainly inside or outside of 200-mi Exclusive Economic Zone?	Inside	Inside	Both inside and outside; need for international management	Inside
Fishing carried out mainly by developed or developing country?	Developed	Both	Mainly developed	Mainly developing
Scope for expansion	Possibly none	Maybe	Maybe	Catch in certain areas could be increased, but need for good management and effective enforcement of regulations is urgent
Recent review papers	Garrod 1977; Bannister 1977	Murphy 1977	Rothschild and Suda 1977	FAO 1978, present paper

Table 5. Basic data for the yield-isopleth diagrams of Figs. 1A and B[a].

Parameter	Definition and unit	*Lutjanus sanguineus*	*Leiognathus splendens*
L_∞	Asymptotic length, cm	96.9 LF	14.3 LT
K_L	Growth constant, 1/year	0.147	1.04
W	Asymptotic weight, g	12,226	63.6
K_w	Growth constant, 1/year	0.154	0.952
t_0	"age" at curve origin, year	−0.67	−0.19
M	Natural mortality coefficient	0.33	1.83
N_0	Arbitrary number of recruits at age t_0	1	1
F	Fishing mortality coefficient	variable	variable
t_c	Mean age at first capture	variable	variable

The yield (Y) is then given by:

$$Y = F \cdot N_0 \cdot e^{-Mr} \cdot W_\infty \cdot \left(\frac{1}{Z} - \frac{3e^{-Kr}}{Z+K} + \frac{3e^{-2Kr}}{Z+2K} - \frac{e^{-3Kr}}{Z+3K} \right)$$

where $r = t_c - t_0$, and $Z = F + M$

[a]Sources of data:

Lutjanus sanguineus
L_∞, and K_L and length-weight conversion Han-Lin Lai and Hsi-Chiang Lin (1974).
M was obtained by equation 8 in Pauly (1978b) with T = 27.5°C.

Leiognathus splendens
L_∞ and K_L in Pauly (1978a); Length–weight conversion in Pauly (1977).
M was given in Pauly (1978b).
Yield equation: in Ricker 1975, p. 253, equation 10.21, simplified from Beverton and Holt (1957).

yield which can practicably be harvested notwithstanding the fact that the model does not account for such important interactions as predation. This point will be discussed further below.

The value of X = 0.50, which is commonly used for yield estimates in the region, has therefore no basis in fact whatsoever when real multispecies fisheries are considered, even if the unlikely assumption is made that there are no interactions (such as predator-prey relationships) between the stocks.

Estimates of yield based on the XMBM have often been criticized because of the difficulties involved in determining an overall value of M, or in estimating B_∞. The point made here, on the other hand, is that the model does not hold because of its inherent feature of assuming it is possible to fish each single stock with the appropriate mesh size, i.e., eumetrically.

TBSM

Schaefer (1954) derived a model which, in its most recent formulations (Ricker 1975), can be used to make yield assessments when a minimum of data are available (only catch and effort data are required) and which has been applied, with varying success, to a number of fisheries throughout the world.

The assumptions made for deriving this model were as follows:

1. Any fish population newly colonizing a given, finite ecosystem grows in weight until it reaches the maximal carrying capacity (most often in terms of available food) of this ecosystem, after which its increase in total weight ceases. The biomass reached then may be called for theoretical reasons, B_∞.

2. B_∞ more or less corresponds to the virgin (= unfished) biomass of the stock.

3. The growth, in time, of the fish biomass toward B_∞ may be described by a logistic curve, the first derivative of which, $\frac{dw}{dt}$, has a maximum at $\frac{B_\infty}{2}$ and zero values at B_∞ and B = 0 (Fig. 2A).

4. Thus, the fishing effort which reduces B_∞ to half its original value will produce the highest net growth of the stock, hence also the maximum surplus yield available to man (Fig. 2B)

5. The maximum surplus yield in 4. can be sustained indefinitely (hence, the term maximum sustainable yield), as long as the biomass of the exploited stock is maintained at $\frac{B_\infty}{2}$.

There is quite a lot of biological evidence to make these assumptions appear sound (Ricker 1975; Odum 1971). **Some reasons for the low surplus production at stock size $\geq \frac{B_\infty}{2}$ may be given here (from Ricker 1975):**

"1. Near maximum stock density, efficiency of reproduction, and often the actual number of recruits, is less than at smaller densities. In the latter event, reducing the