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Theory and Management of Tropical Multispecies Stocks

A Review, with Emphasis on the Southeast Asian Demersal Fisheries

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INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

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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:

"Dont bite my finger--look where it is pointing."

DANIEL PAULY
August 1979
Manila

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

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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 incompability 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
Pomadasydae	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

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 $\approx$ 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

Table 4 *(cont'd)*

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

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 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.

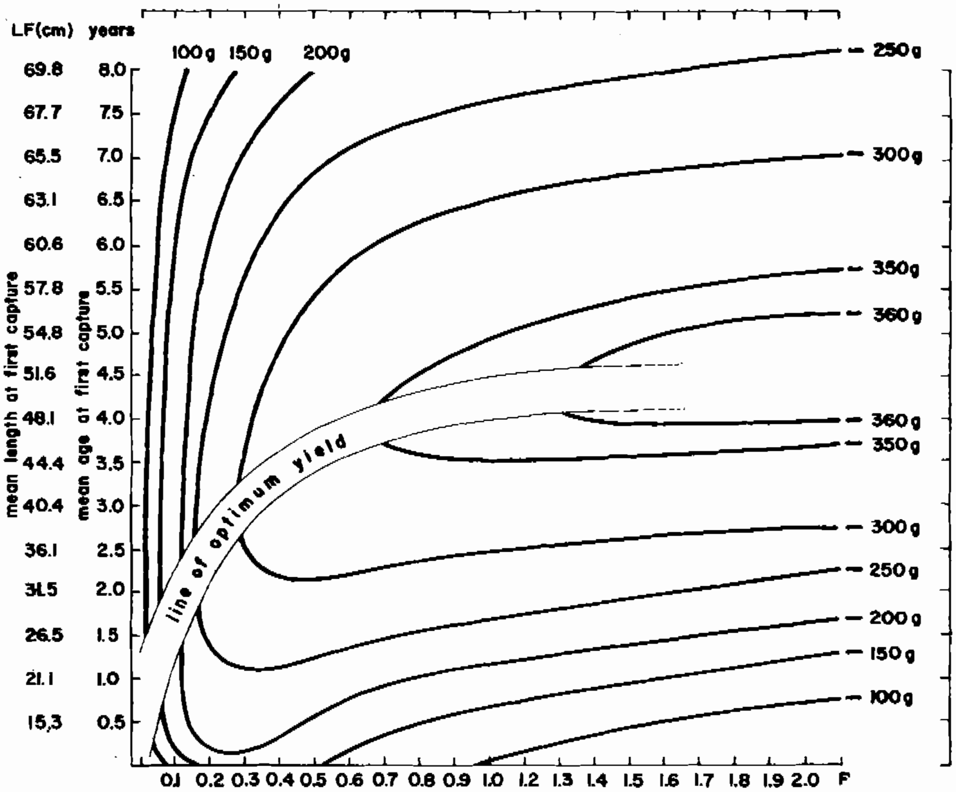
3. The growth, in time, of the fish biomass toward B_∞ may be described by a logistic curve, the first derivative of which, $\frac{dw}{dt}$, has a maximum at $\frac{B_\infty}{2}$ and zero values at B_∞ and B = 0 (Fig. 2A).

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)

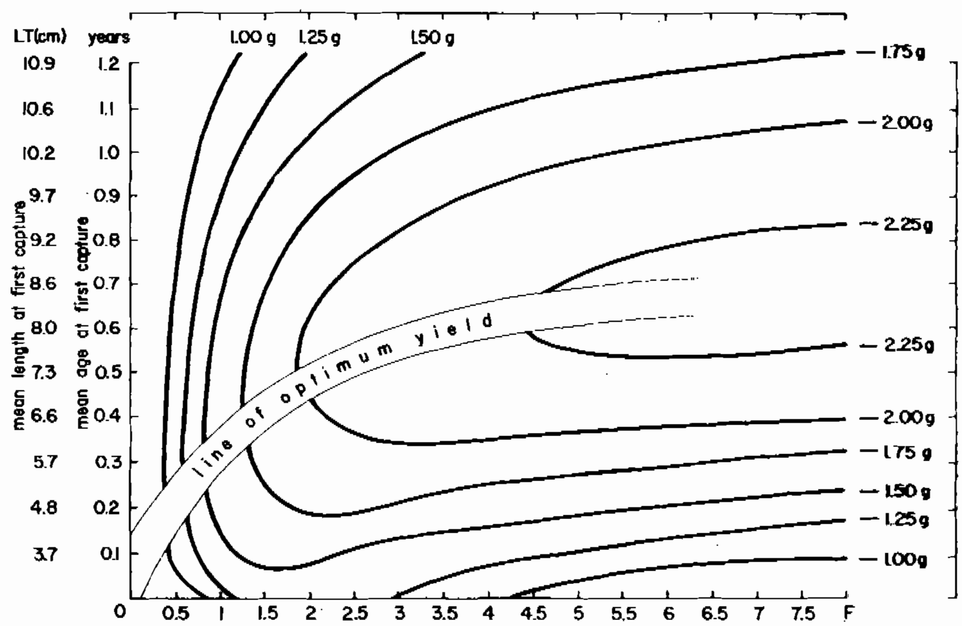
5. The maximum surplus yield in 4. can be sustained indefinitely (hence, the term maximum sustainable yield), as long as the biomass of the exploited stock is maintained at $\frac{B_\infty}{2}$.

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 $\frac{B_\infty}{2}$ 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



A



B

Fig. 1. Yield isopleth diagrams for two fishes common in the Sunda shelf area: A, *Lutjanus sanguineus* and B, *Leiognathus splendens*.

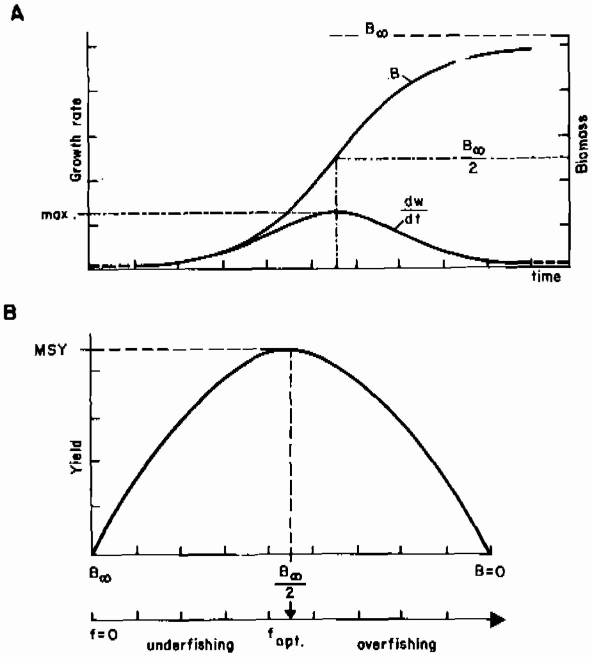


Fig. 2. The simple Schaefer Model showing A, the logistic curve and its first derivative, and B, the Yield-Biomass and Yield-Effort relationships.

stock will increase recruitment.

2. When food supply is limited, food is less efficiently converted to fish flesh by a large stock than by a smaller one. Each fish of the larger stock gets less good individually; hence, a larger fraction is used merely to maintain life, and a smaller fraction for growth.

3. An unfished stock tends to contain more older individuals, relatively, than a fished stock. This makes for decreased production, in at least two ways. (a) Larger fish tend to eat larger foods, so an extra step may be inserted in the food pyramid, with consequent loss of efficiency of utilization of the basic food production. (b) Older fish convert a smaller fraction of the food they eat into new flesh—partly, at least because mature fish annually divert much substance to maturing eggs and milt."

The main reason why larger fishes convert a smaller fraction of their food into new flesh, however, is due to the fact that while oxygen is needed for synthesis of body substance, the relative gill size ($= \frac{\text{gill surface}}{\text{body weight}}$) decreases sharply as fish get larger, down to a point where the body is so badly supplied with 0_2 that all of it is used for maintenance, with none left for synthesis of new body substance (Pauly 1979a). Pella and Tomlinson (1969) proposed modifications of the basic Schaefer Model such that MSY would be obtained at stock sizes $\neq \frac{B_\infty}{2}$ (see Ricker 1975). Whatever modification of the basic Schaefer Model applies best has no effect on the line of arguments presented below, so, for simplicity's sake, $\frac{B_\infty}{2}$ is used here as the optimal stock size.

Gulland (1976) discussed various time-lag effects which may be considered when applying the Schaefer Model to the stocks of the region, but no attempt has been made here to consider these lag effects, as it is unlikely that any of the exploited stocks of the region ever reached any kind of equilibrium (see below). Rather, I will consider whether or not it is appropriate to apply the Schaefer Model to a multispecies stock, as is commonly done for the demersal trawl fisheries of Southeast Asia (Table 6 for a survey of applications of this model in the region).

Since this question would soon become labyrinthous if a real multispecies stock were to be described, the assumptions underlying the application of the TSMB will be discussed in the light of a multiple stock consisting of two trophic levels only, with small "prey" fishes feeding on basic animals (say, benthic invertebrates) and larger piscivorous predators feeding exclusively on these prey fishes. As will be seen, the addition of more trophic levels, as is the case in real ecosystems, does not in the least negate the following line of argument.

The assumptions made for the derivation of the simple Schaefer Model are—must be—paralleled by assumptions applying to the TMSB and these assumptions must be demonstrated to be realistic. A failure to do so would demonstrate that the model does not apply. (The number of the assumptions to follow corresponds to those made for the derivation of the simple Schaefer Model).

1) Any assemblage of fish species newly colonizing a given, finite ecosystem grows in weight until it reaches the maximal carrying capacity in terms of fish food of this ecosystem, after which its net growth ceases. The

Table 6. Examples of applications of the TBS Model and the "XMB" Model.

Area	Authors	Model
George Bank (USA)	Brown et al. (1976)	TBSM
Gulf of Thailand	Marr et al. (1976)	TBSM
	FAO (1978)	TBSM
Malacca Strait		
Indonesian waters	Sujastani et al. (1976)	TBSM
Malaysian waters	Lam Ah Wang and Pathansali (1977)	TBSM
Thai waters	SCSP (1976b)	TBSM
Philippines		
Visaya and Samar Seas	SCSP (1976a)	TBSM
Various regions (Sulu and Bohol Seas, Moro Gulf)	SCSP (1977)	TBSM
Indonesia		
Java Sea	Saeger et al. (1976)	XMBM
Southern tip of South China Sea	Martosubroto and Pauly (1976)	XMBM

biomass reached then may be called B_∞.

2) B_∞ more or less corresponds to the total fish biomass in the virgin stock.

3) The growth in time of the total fish biomass may be described by a logistic curve, with $\frac{dW}{dt}$ having a maximum at $\frac{B_\infty}{2}$ (Fig. 2A).

4) The fishing effort which reduces the total fish B_∞ to half its original value produces the highest net growth of the stock, hence also the maximum surplus yield available to man.

5) The maximum surplus yield can be sustained over any period of time as long as the total stock biomass is maintained at $\frac{B_\infty}{2}$.

Assumption 1 is realistic, as it is quite evident that the total fish biomass of any finite ecosystem has to stabilize about some mean value. This value will depend on the primary productivity of the ecosystem in which the stock occurs, on the age of the ecosystem, and on its stability. (Young, unstable ecosystems do not allow for the development of a number of species able to utilize all the niches provided and there is thus a less efficient utilization of the primary production of the system.)

Assumption 2 is acceptable, by definition.

Regarding Assumption 3, the growth in time of the whole species assemblage cannot be described by one single logistic curve. The various constituent fish species all have different growth, mortality, and recruitment rates, which result in widely varying instantaneous rates of increase and hence in differently shaped population growth curves. This feature is best illustrated by the well-known phenomenon of succession, characteristic of newly colonized areas (see Ricklefs 1973). Note that the first derivative of each single species growth curve still has its maximum at the singles species' $\frac{B_\infty}{2}$.;

Assumption 4 leads us to the key question of this investigation, namely, whether the value of B_∞ for the total stock is indeed, as implicitly assumed, the sum of B_∞ values of the various constituent species.

Any stock that is at its B_∞ is, so the Schaefer model implies, unproductive. This means that all the food used by this stock will be used up stock maintenance; and there will be no net stock growth. In a multiple stock, however, the piscivorous fishes, which may be at their B_∞, do obtain food from their prey fishes. Hence, there is a net production by the prey fishes, so the prey fish stock must be at a stock size smaller than their B_∞.

The question now arises: at what stock size can the prey fish stabilize? Obviously, the predator could "decide" to simply exterminate their prey, in which case the predators would ruin their food base. This strategy is quite self-defeating and indeed the continuous presence of predator and prey indicates that another strategy is operating.

Slobodkin (1962) speaks of "prudent predators" which do not exterminate their prey by overexploitation, and Clark (1954) writes that "in an area where the predator and prey population have struck more or less of a balance we may find that the predators are limiting themselves . . . in the sense that they are devouring only the increment to the prey population each year. In such a situation, the predator population may continue indefinitely to take a limited number of the prey without endangering the breeding stock of the species on which it depends."

To summarize, the predators do take some of the prey fishes; thus, the prey stock is smaller than B_∞. On the other hand, it takes less than it could, so the prey stock is maintained at a size larger than $B = 0$. Also, note that the predator stock will tend to increase its own biomass as much as possible, which requires a maximum amount of food on a sustained level. The best strategy for the "prudent predator" is therefore to reduce the stock size of their prey to $\frac{B_\infty}{2}$, as the simple Schaefer model suggests. Indeed, in a well-balanced, mature ecosystem, this is the most probable strategy. Note that while it cannot be demonstrated that the biomass of the prey fishes is, in a virgin stock, at $\frac{B_\infty}{2}$, one must assume that it is lower than B_∞, since a surplus yield is being extracted by the predators. If the Schaefer Model and the concept of the "prudent predators" apply, $\frac{B_\infty}{2}$ is the most likely assumption in stable, balanced ecosystems. Thus, the total biomass B_∞ would not consist of the sum of the B_∞ of the constituent species, but of the B_∞ of the predators + the $\frac{B_\infty}{2}$ of the prey species.

Assumption 4 would therefore not apply.

Assumption 5 cannot apply if assumption 4 does not apply. Here, however, we may attempt to anticipate what will happen if we reduce the total stock to its $\frac{B_\infty}{2}$. As mentioned above, this would cause the predators to decline to their $\frac{B_\infty}{2}$ and the prey to a stock size smaller than their $\frac{B_\infty}{2}$, hence to reduce the surplus yield available to the predators. If the predators are not quickly decimated by the fishery, they will thus continue to exploit their prey at a relatively increased rate and further reduce their prey's biomass which further reduces the surplus yield from the prey stock, and so on. The result could then be that our "prudent predator," now assisted by the fishery, would more or less exterminate their prey, and vanish thereafter. The prey fishes, as a whole would thus diminish faster than their predators.

Gulland (1976) writes as to species interaction in the stocks discussed here that "the species composition will not remain constant as the amount of fishing increases. Long-lived fishes, or those particularly vulnerable to the fishing gear will decrease more than short-lived fish. Since the former group will include most of the larger predatory fishes, the resulting decline in the natural mortality of some prey species may exceed the increase in fishing mortality and these species may increase. Changes of this type have been clearly observed in the Gulf of Thailand where catches of rays decreased more than ten-fold between 1963 and 1974, while those of squids actually increased."

As will be noticed, Gulland (1976), in opposition to the pattern derived here, suggests that the large predatory fishes should decrease faster than the prey fishes in an exploited stock. To support this suggestion, Gulland (1976) used the rays as representative of the large, predatory (?) fishes and the squid as representative of the small prey fishes.

So there are two different, even opposite conceptions: one, presented above stating that the prey fishes, being already exploited in the virgin stock, are likely to decrease faster than their predators and the other stating that the predators, being larger and having a greater longevity, should generally decrease faster than the small, short-lived prey fishes, whose biomass should even increase once the predators are removed.

The detailed analysis of the changes of the catch-per-effort data of the Gulf of Thailand fishery later in this report reveals that the previously-abundant, small prey fishes decreased much faster than their predators, and that therefore the stock interactions seem to follow the pattern suggested here. It thus appears that the Total Biomass Schaefer Model, as presently used, is of no heuristic value.

Also, it appears that even the single-species Schaefer Model is likely to produce unreliable estimates of MSY and optimum effort when applied to fish populations other than peak or near peak predators (such as halibut, tuna, cod, and sharks).

A similar point was made by Murphy (1972) who investigated the Peruvian anchovy shortly prior to its collapse and stated

> "... we should note that the anchovy population was yielding at close to its maximum [to their predators, the guano birds] before man entered the scene. This is in accordance with ecological theory and, in particular with the prudent predator and efficient prey concept advanced by Slobodkin (1962)."

and

> "... clearly, as shown here and as shown by the collapse of several major clupeoid resources [including the subsequent collapse of the Peruvian anchovy], our simplistic notions of the effect of fishing and the reality of the maximum sustainable yield are in need of revision ...

Although the Schaefer model is consistent with ecological theory, it should be noted that experimental confirmation of its assumptions, at least as far as fish are concerned, are exceedingly scarce. In fact, I am aware of the work of only Silliman and Gutsell (1958) in this context. Interestingly enough, these authors used a "peak predator" for their experiment; that is, the guppies used in their experiments were not preyed upon and their population reacted only to exploitation by man (Silliman and Gutsell 1958).

The views presented here that small prey fishes in nature are generally at their $\frac{B_\infty}{2}$ in the virgin stock and that only the larger fishes (peak predators) are in the virgin stock near their B_∞ may be considered a first step in reassessing our "simplistic notions," as this would explain both why the Schaefer Model could be used with considerable success to monitor tuna fisheries, for example, while the same model, used uncritically, fails to explain the collapse of various clupeoid fisheries (Murphy 1977). Thus, it may be concluded that the Schaefer Model remains valid, but that the logic underlying its derivation must be kept in mind when the model is used, especially the fact that the reaction of a fish population to exploitation is the same whether the exploitation expresses itself as natural predation or as fishing, and that a fully exploited stock can, in the model's own terms, be driven to virtual collapse by a further reduction of its size.

SOME OPTIONS FOR FISHERY MANAGEMENT

The simplified representation of a multispecies stock used above (piscivorous predators plus their prey fishes plus the latter's food organisms) can be used at this stage to illustrate the effect of a given fishery operating at one or several of the trophic levels within a multispecies stock, as well as to illustrate the kind of stock interaction likely to occur. An attempt has been made here to present a set of fishing "strategies" and their likely outcome in a series of graphs which qualitatively depict the main interactions likely to occur within the stock in question. The various strategies presented here are in most cases "possible" strategies, which can be realized by regulating (or by not regulating!) the fishing effort and the mean length at first capture, the latter feature determining, for all purposes, the trophic level at which the fishery is operating. (Small meshes catch predominantly "prey fishes"; large meshes let the prey fishes escape and catch mainly predators.)

Option I—The Fairyland Strategy (Fig. 3A). This strategy would consist of fishing any given multispecies stock at the level of effort suggested by the TBSM and to hope that yields near the MSY derived from this model will be sustained. The reasons why this is not a real world strategy have been given above. (See also the analysis of decline of the Gulf of Thailand trawl fishery later in this paper.)

Option II—Garden of Eden Strategy (Fig. 3B). This strategy is presented here as a possible option mainly in order to show the concept of the structure and dynamics of the virgin stock, in opposition to the Fairyland interpretation. Note that the Garden of Eden strategy may

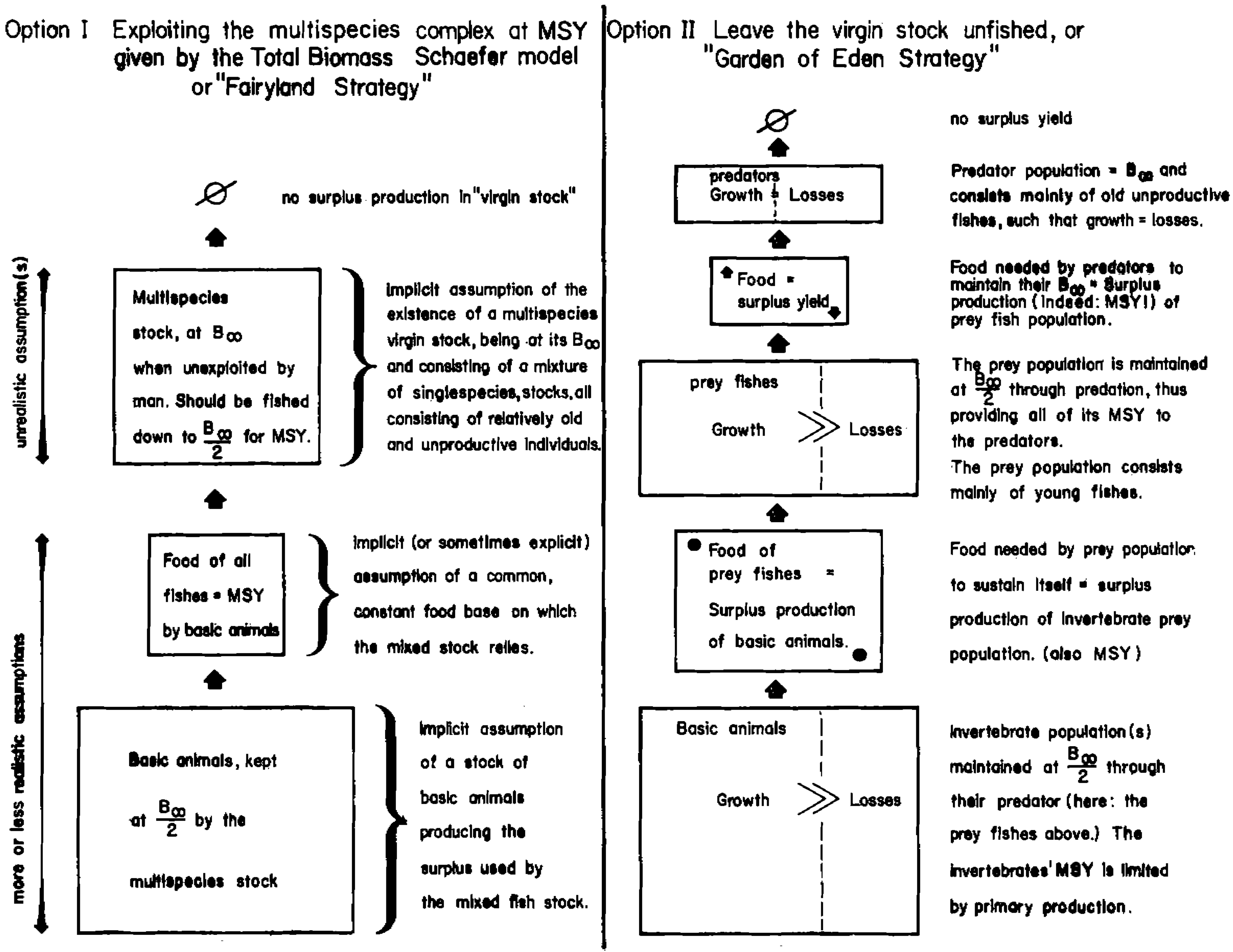


Fig. 3. Two different concepts of a virgin stock: A, the Fairyland Strategy, and B, the Garden of Eden Strategy.

be considered a real world option where underwater natural parks or similar (non-) uses of the resource are considered.

Option III–Tuna Strategy (Fig. 4A). This strategy would consist of skimming off the MSY from the peak predators by using an adequately selective fishing technique (e.g., using wide cod-end meshes in the case of demersal fishes). The MSY obtained in this way would be indeed sustainable as seems to be the case in the fisheries from which this strategy derives its name.

Option IIIa–Whale Strategy (Fig. 4B). This strategy may be considered a variant of the Tuna strategy. It consists of overfishing the peak predators such that their biomass decreases to zero, as a result of which the prey animals' biomass would increase to B_∞. In such a case, there will be a loss of the whole yield of the fishery unless ways are found to exploit the former prey population upon which the whales fed. The Whale strategy quite obviously is a real world strategy.

Option IV–North Sea Strategy (Fig. 5A). Here, the strategy consists of overexploiting the peak predators until predation exerted on the prey fishes becomes negligible. This should lead to an increase of the prey fishes' biomass to their B_∞ (as above). However, this is prevented by fishing the prey fishes immediately, thus transferring the MSY previously eaten by the predator into the catch of the fishery. In terms of weight, this strategy may be the most productive and it can produce sustainable yields. It certainly is a real world strategy, even if what presently happens in the North Sea does not fully correspond to the idealized strategy presented here.

Option IVa–Lilliput Strategy (Fig. 5B). This is a quite unproductive variant of the previous option in which it is also the prey fishes which are exploited, but without previous removal of the predator population. It may correspond more or less to what is happening in some multispecies stocks exploited exclusively by artisanal fishermen using inshore gear selecting for small fishes (e.g., lift nets, fish corrals, bagans, and kelongs).

Option V–Gulf of Thailand Strategy (Fig. 6A). This strategy consists of fishing both the predators and the prey fishes, (e.g., by using very small meshes) and to steadily increase the effort. In the long run, this results in a collapse of the prey and predator fish stocks, followed by an increase of the biomass of the basic food animals (zooplankton, zoobenthos) as well as the relative or even absolute increase of certain generalists, e.g., trash fish. A detailed account of the Gulf of Thailand strategy and its effect on a resource is given later in the paper. Sadly enough, this strategy is also a real world one.

Option Va–"Hit and Run" Strategy (Fig. 6B) may be considered a variant, or an amplification, of the Gulf of Thailand Strategy. Although it seems to be practiced quite often by certain distant water fleets, not much is known as to the long-run returns from such a fishery. Nor is it known whether a clean-swept tropical fish community ever recovers to its previous structure and if so, how long it takes.

Possible yields, both in weight and economic returns for the various strategies presented here, are quite difficult to estimate. Clark (1976) found that the biologically devastating "Whale" and "Hit and Run" strategies. may bring higher economic returns under certain conditions than strategies aiming at sustainable yields. Before attempting to suggest any strategy for the demersal fisheries of the region, it would seem appropriate to analyze some of them in greater detail to obtain some criteria to use in comparing the various strategies.

Gulf of Thailand Trawl Fishery: Analysis of Decline

The following analysis of the decline of the Gulf of Thailand trawl fishery is intended to represent an example of the manner in which some of the fisheries of the region could be analyzed, at least preliminarily. This analysis, it should be noted, relies mainly on Table 4 of Ritragsa (1976) for the catch-per-effort data on Fig. 4A in FAO (1978) for the effort data. Thus, some of the results obtained here may not be fully comparable with those that can be obtained by using the more recent data published by SCS (1978) which were not available to me when the analysis was undertaken. The figures given on stock size, effort, catch per effort, etc., should thus be viewed as approximation valid only within the frame of the present study.

The Gulf of Thailand (Fig. 7) covers an area of about 300,000 km^2 of water, 55% of which are less than 50 m deep ("inshore") and 45% range between 50-85 m ("offshore"). This definition of the investigation area largely corresponds to South China Sea Statistical Zones IA and IB SCS (1978a). The development of the trawl fishery in the Gulf of Thailand, particularly the decline of the total catch rates, has been reviewed by several authors (Gulland 1972; Tiews 1973; Marr et al. 1976; FAO 1978; SCS 1978a) so that there is no need to review this matter here. On the other hand–except for an early note by Tiews et al. (1967) and a recent paper by Pope (1979)–little attention has been devoted to the concurrent stock interaction, as reflected in the changes of the composition of the total catch over time. As will be shown below, these changes in composition, hence also of the standing stock, may yield considerable insight into the processes that took place within the total stock as effort increased.

The raw data of the present analysis are given in Table

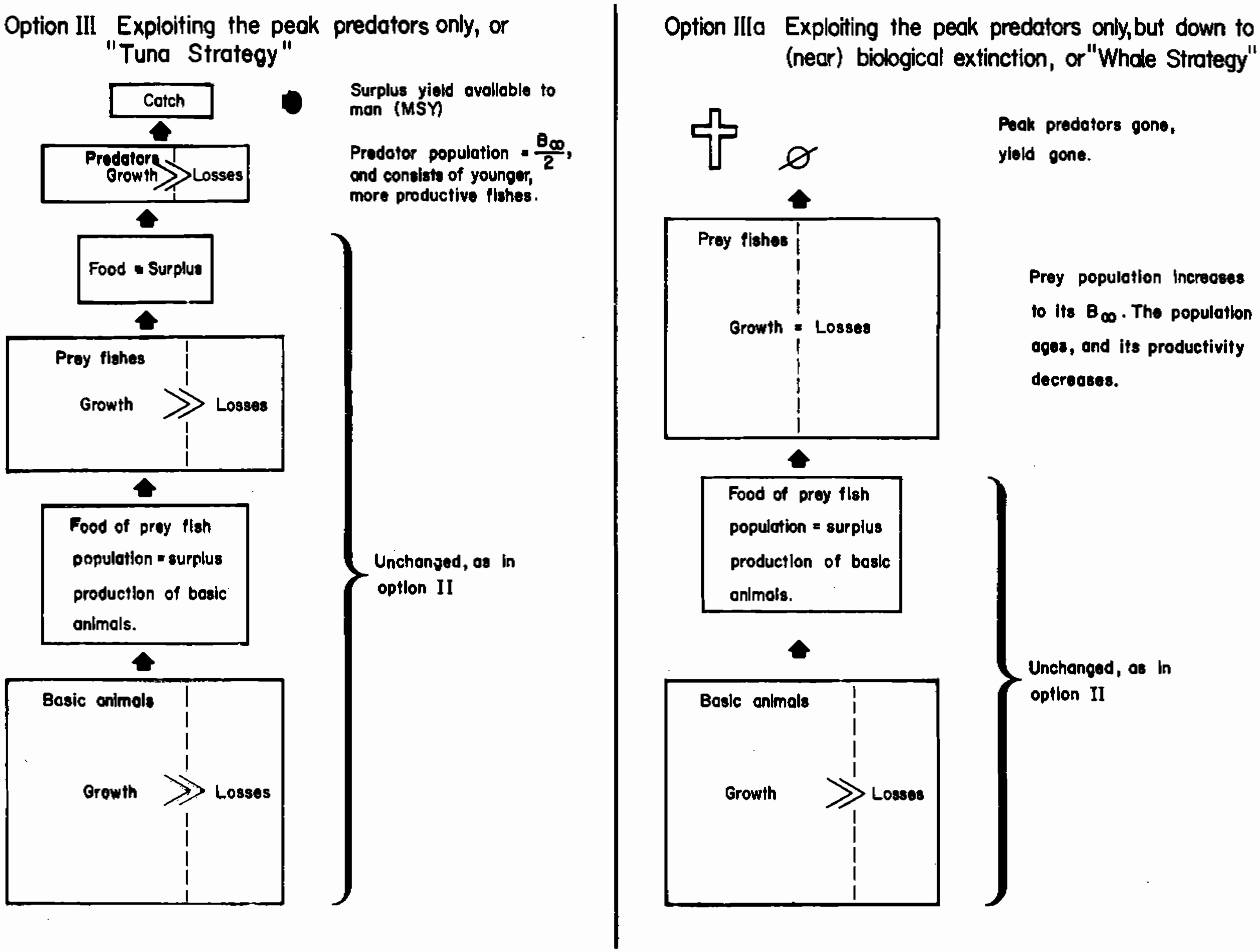


Fig. 4. Two strategies for exploiting peak predators: A, the Tuna Strategy, and B, the Whale Strategy.

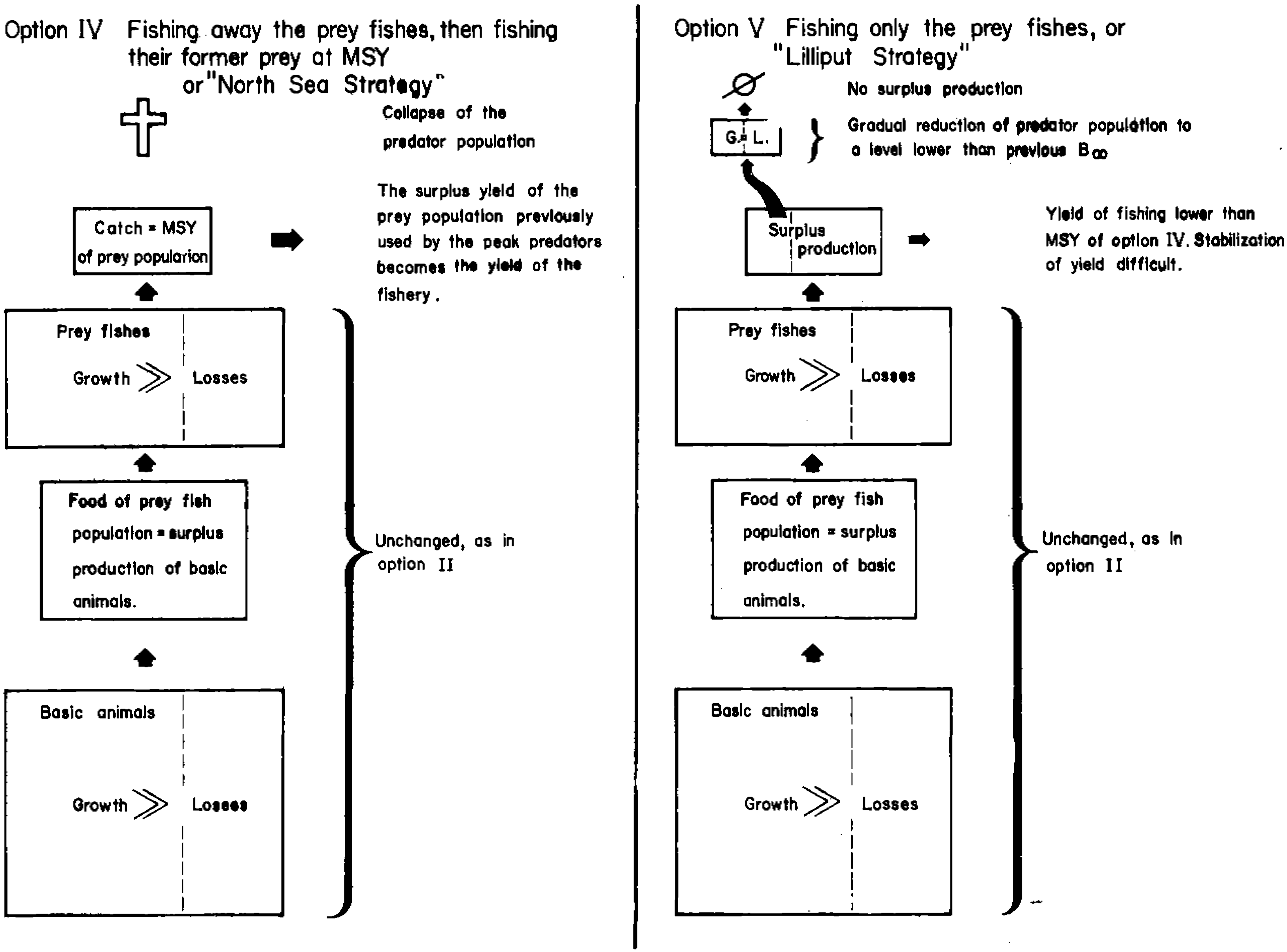


Fig. 5. Two strategies for exploiting "prey" fishes: A, the North Sea Strategy, and B, the Lilliput Strategy.

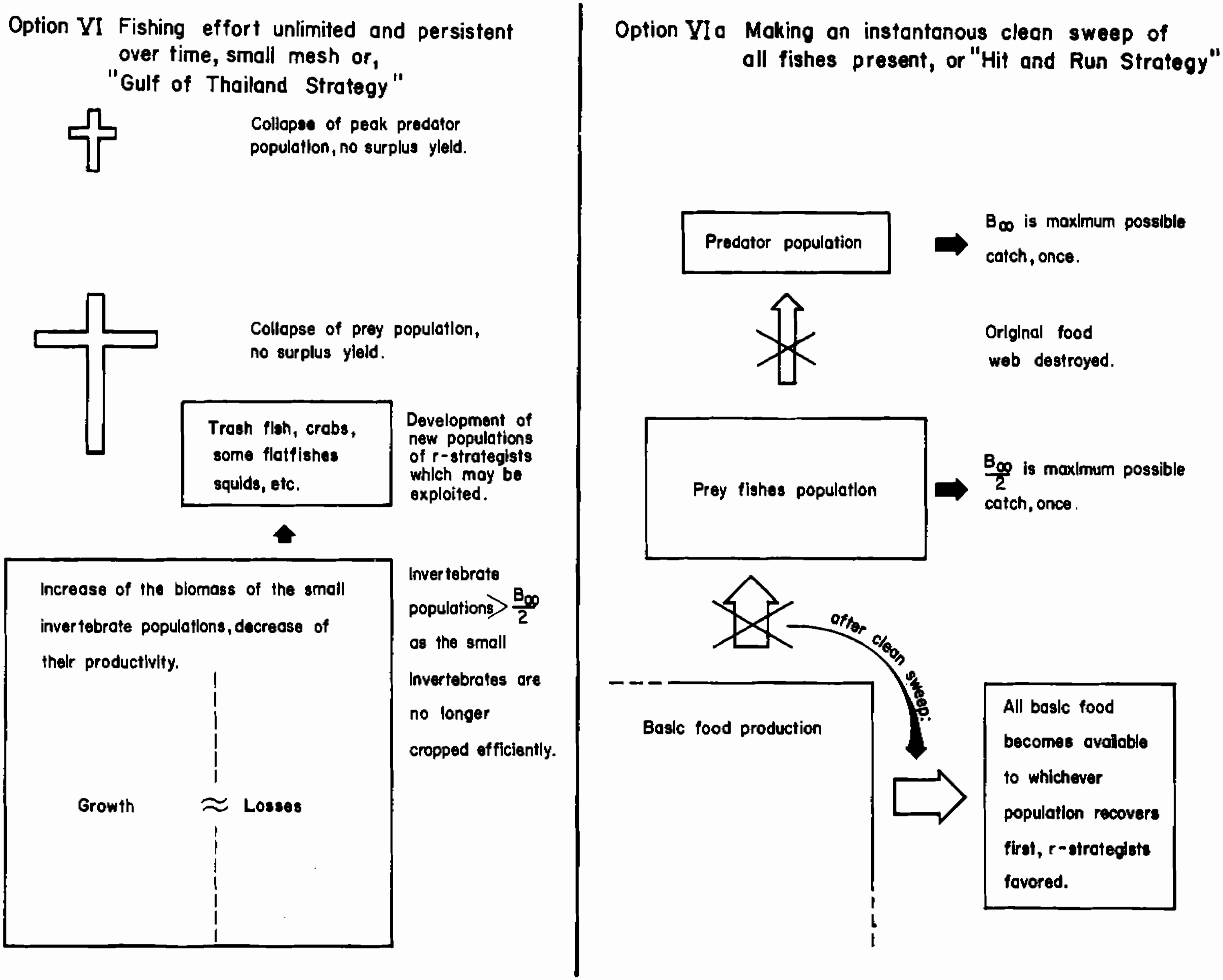


Fig. 6. Two strategies for overexploiting a stock: A, the Gulf of Thailand Strategy, and B, the "Hit and Run" Strategy.

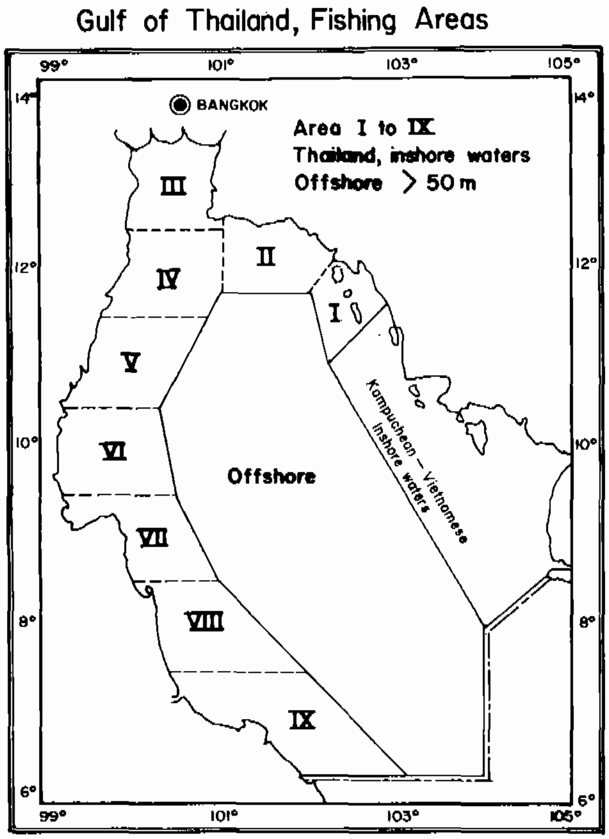


Fig. 7. The Gulf of Thailand, by subareas. Adapted from Ritragsa 1976.

7 (= Table 4 of Ritragsa 1976). The data consist of mean catch per hour in the (inshore) areas I to IX (Fig. 7) of *M/V Pramong 2*, by taxonomic groups, for the years 1963 to 1972 inclusive (except for 1964 and 1965 in which no large-scale surveys were conducted). First, the relationship of catch per effort and effort, by taxa and/or other groupings was analyzed. For 42 taxa and groupings, the natural logarithm of the mean catch per effort was plotted against effort (as given in Table 12). All the plots have a slope "b", which is an indicator of the rate at which the stock declined or increased, and a y-intercept "a", whose anti-log gives an approximate value of the virgin stock size at f = 0, (near 1960). The results are summarized in Table 9.

A first insight into what happened within the Gulf of Thailand multispecies stock over this time period may be obtained by ranking the various taxa by their values of b as given in Fig. 8, which helps in identifying groups of taxa with similar rates of decline or increase. Six groups of taxa may be readily identified:

1) Large feeders on zoobenthos whose large size and high longevity indeed contribute to their rapid decrease. The group consists exclusively of the Rhinobathidae and the rays.

2) Small demersal prey species consisting especially of the Leiognathidae, Gerridae and Mullidae, which in the virgin stock comprise almost half of the total stock. These fishes best represent the "prey" fishes discussed previously. The crabs *Thenus* spp. also seem to belong to this group.

3) Intermediate predators consisting of the various basses and snappers and the sea-catfishes, all of which are known predators on or may be expected to prey on the fishes of the second group.

4) Large predators comprising the sharks, the groupers, and the congereel, the latter being one of the taxa which significantly increased as the total catch decreased.

5) A quite homogenous assemblage of pelagic fishes whose value of b is not significantly different from 0 (see Table 8), that is, as one would expect, the demersal trawl fishery has no noticeable effect on the pelagic fishes. For lack of a better alternative the squids (*Loligo*) which significantly increased as the total catch decreased have been included in this group.

6) *Sepia*, crabs (bottom invertebrates), *Psettodes erumei*, Bothidae and Cynoglossidae, which all are relatively small-sized and occurred in very small quantities in the virgin stock.

Obviously, other groupings may be considered. On

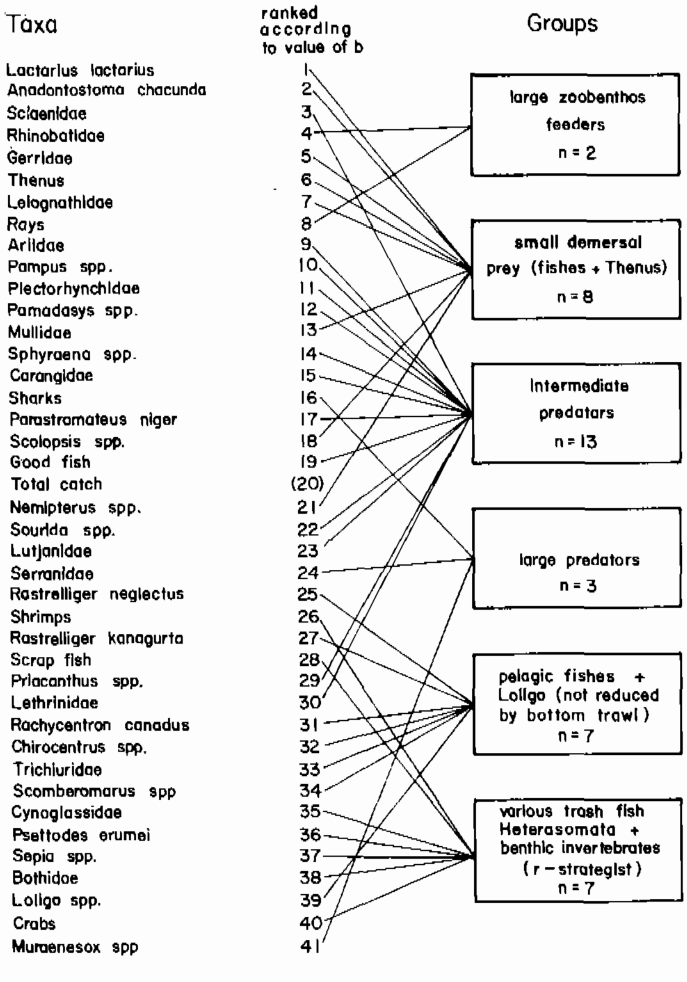


Fig. 8. Taxa caught in the Gulf of Thailand demersal trawl fishery, ranked according to their rate of decrease.

the other hand, it should be kept in mind that shifting one taxon from one group to the next does not really change the main point demonstrated here, namely that in the Gulf of Thailand the bulk of the small prey fishes have diminished faster than their predators.

At this point, it may be useful to note that the ranked list of Table 7 may be reproduced by another set of data from another fishery of the region. SCS (1976) presented data on the decline of catch rates in the Thai waters of the Malacca Strait, which have been analyzed here in the same manner as the Gulf of Thailand data. The results are given in Table 9. If the taxa common to both Tables 8 and 9 are ranked according to their values of b, two series of ranked taxa are obtained whose rank correlation can be tested (Table 10). The Spearman Rank Correlation coefficient between the two lists is $r_s = 0.684$, which is significant ($P = 0.001$). In other words, the decline of catch rates over time for individual taxa are similar in the two areas. It thus appears that the pattern of decline that occurred in the Gulf of Thailand could well represent the typical pattern common to various stocks of the region, although data

Table 7. Average annual catch composition in kilograms per hour of trawling by *M/V Pramong 2* in areas I-IX (< 50 m) 1963-1972 (except for 1964 and 1965 in which large-scale surveys were not conducted) (from Ritragsa 1976).

Groups of fish	1963	1966	1967	1968	1969	1970	1971	1972
Sharks	2.1	1.86	1.64	1.04	0.60	0.75	0.60	0.54
Rhinobathidae	–	0.62	0.65	0.84	0.43	0.40	0.48	0.06
Rays	14.8	9.63	4.77	2.17	2.99	2.86	1.35	1.22
Anadontostoma spp.	–	0.24	0.15	0.30	0.36	0.21	0.11	0.02
Chirocentrus spp.	0.2	0.19	0.13	0.30	0.17	0.23	0.15	0.10
Saurida spp.	11.3	5.34	4.52	5.42	5.29	6.64	3.07	3.32
Tachysuridae	7.4	3.39	2.14	1.79	1.31	1.44	0.98	0.45
Muraenesox spp.	0.1	0.24	0.16	0.21	0.66	0.26	0.28	0.21
Sphyraena spp.	2.1	1.74	1.37	0.74	1.14	1.43	0.35	0.31
Serranidae	0.8	1.23	1.37	1.05	0.95	0.86	0.51	0.33
Priacanthus spp.	5.6	4.08	7.17	6.22	7.45	7.38	5.21	1.89
Sillago spp.	–	–	–	–	–	0.04	0.01	0.02
Lactarius lactarius	0.6	0.59	0.19	0.23	0.10	0.02	0.03	0.01
Carangidae	19.7	9.89	9.11	9.90	9.25	9.08	3.89	3.83
Rachycentron canadus	0.2	0.24	0.33	0.23	0.21	0.22	0.09	0.13
Lutjanidae	1.5	4.76	4.02	3.83	3.01	2.25	0.99	0.56
Nemipterus spp.	18.4	15.31	11.78	7.46	7.40	8.61	7.31	4.73
Gerridae	–	–	5.93	3.13	3.06	2.55	1.49	0.85
Leiognathidae	71.5	20.02	10.87	14.37	10.59	10.25	2.98	4.86
Pomadasys spp.	0.4	0.41	0.32	0.21	0.30	0.16	0.05	0.06
Scolopsis spp.	7.6	4.74	3.28	2.65	3.91	2.82	1.91	1.38
Plectorhynchidae	1.3	1.17	1.37	0.95	1.09	0.63	0.23	0.14
Sciaenidae	18.3	2.60	4.54	2.68	0.63	1.46	0.61	0.70
Lethrinidae	0.2	0.47	0.86	0.33	0.28	0.25	0.11	0.16
Mullidae	16.1	5.90	9.74	7.24	6.14	3.77	2.74	1.91
Trichiurus haumela	0.9	1.01	1.24	1.46	0.74	0.94	0.69	0.85
Rastrelliger kanagurta	–	0.42	0.66	0.63	0.96	0.86	0.47	0.36
Rastrelliger neglectus	0.8	0.19	0.37	0.52	1.03	1.54	0.40	0.16
Scomberomorus spp.	0.4	0.61	0.47	0.82	1.08	0.56	0.33	0.38
Pampus spp.	0.4	0.27	0.16	0.19	0.13	0.09	0.05	0.05
Parastromateus niger	–	–	0.21	0.38	0.37	0.51	0.20	0.14
Psettodes erumei	0.4	0.99	0.63	0.58	0.65	0.56	0.71	0.51
Bothidae	–	0.63	0.33	0.38	0.35	0.32	0.52	0.58
Cynoglossidae	–	0.12	0.06	0.04	0.14	0.07	0.24	0.31
Sepia spp.	–	2.80	1.87	2.10	2.33	2.62	2.28	2.97
Loligo spp.	6.1	8.04	9.13	10.61	11.61	8.55	11.03	14.23
Thenus spp.	2.0	0.72	0.34	0.35	0.29	0.19	0.13	0.11
Shrimps	0.6	0.27	0.12	0.09	0.11	0.15	0.26	0.22
Crabs	0.7	0.92	0.61	0.70	0.86	1.32	1.15	1.61
Caesio	–	0.06	0.07	0.06	0.09	–	–	–
Good fish	220.0	111.71	102.67	92.19	88.06	82.85	53.99	50.29
Scrap fish	28.9	19.06	12.37	13.73	14.68	14.59	12.31	12.85
Total average	248.9	130.77	115.05	105.92	102.74	97.44	66.30	63.12

Table 8. Analysis of decline of the Gulf of Thailand stocks, by taxa, based on data covering the period 1963 to 1972.

Taxa	No. of yr for which data are available	Significant decrease (P = .05) b =	No significant decrease b =	Significant increase (P = .05) b =	"a"	r^2	Catch rate in virgin stock	Exploited stock (f = 10.0)	Exploited in % of virgin	Mean length
Sharks	9	−0.260	–	–	1.114	0.711	3.05	0.23	7.4	80
Rhinobathidae	8	−0.559	–	–	1.769	0.606	5.87	0.027	0.4	150
Rays	9	−0.457	–	–	3.210	0.866	24.79	0.26	1.0	60
Anadontostoma chacunda	8	−0.658	–	–	1.271	0.677	3.56	0.005	0.1	14
Chirocentrus spp.	9	–	−0.090	–	−1.357	0.227	0.26	0.10	40.7	40
Saurida spp.	9	−0.204	–	–	2.527	0.820	12.52	1.62	13.0	35
Ariidae	9	−0.447	–	–	2.474	0.941	11.86	0.14	1.1	40
Muraenesox spp.	9	–	+0.142	–	−2.076	0.229	0.13	0.52	413.2	150
Sphyraena spp.	9	−0.343	–	–	1.423	0.737	4.15	0.13	3.2	40
Serranidae	9	–	−0.157	–	0.471	0.359	1.60	0.33	20.8	45
Priacanthus spp.	9	–	−0.127	–	2.172	0.242	8.78	2.47	28.1	20
Sillago spp.	3	–	–	–	–	–	–	–	–	20
Lactarius lactarius	9	−0.735	–	–	0.852	0.734	2.34	0.0015	0.1	20
Carangidae	9	−0.285	–	–	3.338	0.920	28.16	1.64	5.8	30
Rachycentron canadus	9	–	−0.125	–	−1.104	0.316	0.33	0.10	28.5	70
Lutjanidae	9	–	−0.196	–	1.595	0.218	4.93	0.70	14.1	50
Nemipterus spp.	9	−0.220	–	–	3.176	0.798	23.95	2.64	11.0	13
Gerridae	8	−0.553	–	–	3.650	0.913	38.49	0.153	0.4	10
Leiognathidae	9	−0.506	–	–	4.639	0.932	103.47	0.654	0.6	10
Pomadasys spp.	9	−0.388	–	–	−0.0007	0.719	1.00	0.021	2.1	35
Scolopsis spp.	9	−0.282	–	–	2.352	0.923	10.51	0.63	6.0	15
Plectorhynchidae	9	−0.392	–	–	1.297	0.673	3.66	0.07	2.0	35
Sciaenidae	9	−0.580	–	–	3.177	0.796	23.96	0.07	0.3	30
Lethrinidae	9	–	−0.125	–	−0.752	0.125	0.471	0.135	28.7	30
Mullidae	9	−0.354	–	–	3.229	0.867	25.25	0.725	2.8	18
Trichiurus haumela	9	–	−0.039	–	0.119	0.080	1.13	0.761	67.6	50
Rastrelliger kanagurta	8	–	−0.133	–	0.107	0.196	1.11	0.29	26.6	18
Rastrelliger neglectus	9	–	0.149	–	−0.088	0.115	0.92	0.21	22.6	15
Scomberomorus spp.	9	–	0.035	–	−0.466	0.025	0.63	0.44	70.3	60
Pampus spp.	9	−0.393	–	–	−0.326	0.897	0.72	0.014	2.0	20
Parastromateus niger	7	–	0.283	–	0.129	0.448	1.14	0.08	5.9	15
Psettodes erumei	9	–	+0.037	–	−0.654	0.064	0.52	0.75	144.6	30
Bothidae	8	–	+0.081	–	−1.237	0.122	0.29	0.65	225.6	15
Cynoglossidae	8	–	+0.00017	–	−2.368	0.367	0.09	0.09	100.2	18
Sepia spp.	8	–	+0.049	–	0.640	0.133	1.90	3.09	162.6	15
Loligo spp.	9	–	–	+0.126	1.729	0.790	5.63	19.94	354.3	20
Thenus spp.	9	−0.512	–	–	1.089	0.965	2.97	0.018	0.6	15
Shrimps	9	–	−0.142	–	−1.051	0.172	0.349	0.084	24.1	10
Crabs	9	–	–	+0.135	−0.649	0.511	0.522	2.014	385.8	15
Caesio	4	–	–	–	–	–	–	–	–	–
Good fish	9	−0.253	–	–	5.598	0.996	269.9	21.47	8.0	–
Scrap fish	9	−0.132	–	–	3.292	0.684	26.9	7.22	26.9	–
Total catch	9	−0.236	–	–	5.683	0.994	293.8	27.8	9.5	–
Total in FAO (1978)	13	−0.227	–	–	5.712	0.984	302.6	31.2	10.3	–

Table 9. Decline of catch rates, by taxa, Thai (Andaman Sea) waters. Table is compiled from Tables 4 and 7 in SCS (1976).

Taxa	1966	1967	1968	1969	1970	1971	r^2	b	1971 in % of 1960
Sharks	11.7	3.2	5.2	4.2	1.1	1.4	0.754	−0.988	12.0
Rays	4.0	2.4	5.8	3.1	1.4	1.5	0.590	−0.557	37.5
Ariidae	8.5	8.2	4.3	5.0	0.9	0.7	0.830	−1.305	8.2
Saurida spp.	23.1	11.2	4.5	3.6	0.5	0.6	0.931	−1.935	2.6
Sphyraenidae	11.3	1.8	4.7	2.5	0.2	0.6	0.778	−1.660	5.3
Serranidae	1.6	0.3	4.1	2.5	4.4	2.2	0.297	+0.698	137.5
Lutjanidae	0.8	0.6	6.0	3.0	2.0	0.9	0.033	+0.211	112.5
Nemipteridae	13.0	9.4	9.3	13.5	2.5	2.8	0.665	−0.807	21.5
Leiognathidae	121.0	22.9	4.3	5.7	5.8	2.7	0.524	−1.330	2.2
Sciaenidae	33.6	17.4	0.6	1.9	1.2	0.3	0.519	−1.764	0.9
Mullidae	44.	15.3	7.1	4.6	1.7	2.1	0.895	−1.519	3.9
Trichiuridae	6.5	32.0	1.7	3.2	12.1	2.0	0.040	−0.297	186.2
Loligo + *Sepia*	4.0	2.4	5.8	3.0	9.9	6.4	0.451	+0.459	160.0
Total catch	404.7	294.3	215.4	190.8	97.0	115.9	0.939	+0.685	28.6
Effort (in million research vessel hours)	0.041	0.215	0.442	1.134	1.887	1.607			

Table 10. Rank correlation between rates of decline of various taxa from the Gulf of Thailand and the Thai Andaman Sea waters. Table is based on data in Tables 8 and 9.

Gulf of Thailand	Rank		Andaman Sea, Thai waters
Sciaenidae	1	9	Synodontidae
Leiognathidae	2	5	Sphyraenidae
Rays	3	1	Sciaenidae
Ariidae	4	2	Leiognathidae
Mullidae	5	4	Ariidae
Sharks	7	7	Sharks
Total catch	8	9	Nemipteridae
Nemipteridae	9	8	Total catch
Synodontidae	10	3	Rays
Lutjanidae	11	13	Trichiuridae
Serranidae	12	11	Lutjanidae
Trichiuridae	13	14	*Loligo* + *Sepia*
Loligo + *Sepia*	14	12	Serranidae

$r_s = 0.684$

$z = 2.46$

from more areas should be analyzed in this manner to test this inference.

The varied behavior of different fish stocks exploited by the same fishery also may be illustrated by making "stock assessments" by taxa, rather than for the total stock. Since such stock assessment have very little heuristic value, only three of them have been made, using three taxa representing typical groups: 1) the Leiognathidae, representing the smaller prey fishes, 2) the Nemipteridae, representing the larger prey fishes and/or the small predators, and 3) the Lutjanidae, representing the large predators. The data used for the stock assessments are given in Table 11 and the three resulting yield curves appear in Fig. 9.

Note two important features:

1) At high levels of effort, the small prey fishes disappear, leaving no food for the piscivorous predators.

2) There is no single optimum level of effort which will simultaneously produce the MSY for all three stocks. Note also that going from the Total Biomass Schaefer Model to smaller units such as Family or Genera, without considering stock interaction, does not help to understand the dynamics of the stocks.

The rapid decline of such important fishes as the Leiognathidae, a decline more rapid than that of the total catch, has been reported by Tiews et al. (1967) from the Gulf of Thailand and by Pauly (1977) from the Indonesian waters of the Malacca Strait.

An explanation which I previously advanced to explain why the Leiognathidae tend to diminish faster

Table 11. Simple Schaefer model as applied to three important fish groups.

	Plot of c/f against f[a]				Yield estimates	
	r	n	a	b	f_{opt}[b]	MSY[c]
Leiognathidae	−0.890	8	65.5	−10.94	3.0	98.0
Nemipteridae	−0.900	8	20.1	− 2.32	4.3	43.8
Lutjanidae	−0.355	8	3.9	− 0.302	5.3	8.44

[a]Data of Tables 7 and 13.
[b]In million trawling hours.
[c]In thousand metric tons per year.

Equations used: (see Ricker 1975, p. 315-316)

$$f_{opt} = \frac{a}{2b} \qquad Y = af - bf^2$$

$$MSY = \frac{a^2}{4b}$$

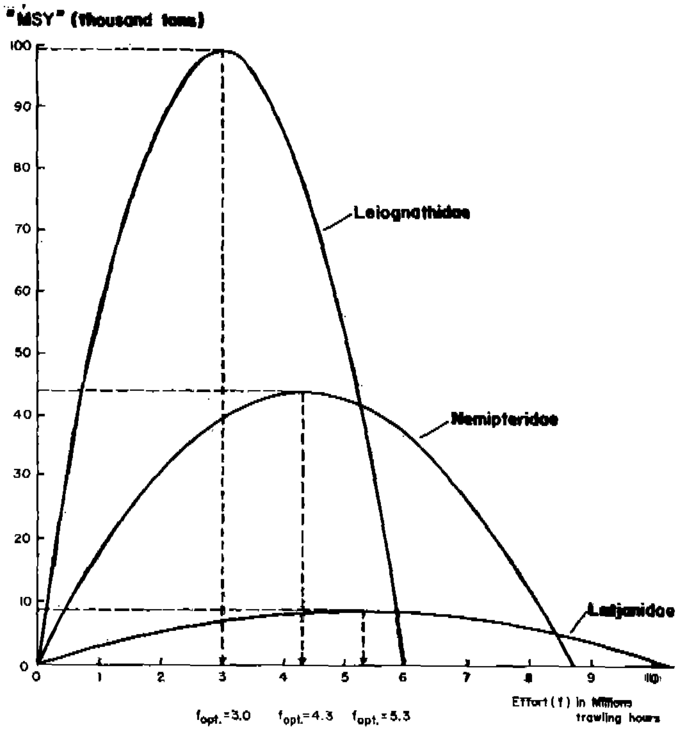


Fig. 9. "Yield assessments" for three fish families, Gulf of Thailand trawl fishery.

than the total stock was that firstly, the Leiognathidae occur in very shallow waters and are therefore more accessible to any gear than the total stock; and secondly, they occur in water generally also yielding shrimps, so they are subjected to a disproportionately high fishing intensity as compared with species in other parts of the area (Pauly 1977).

These explanations, in light of the present analysis, do not seem to suffice. Now, considering the previous critique of the Total Biomass Schaefer Model, it would appear that these fishes, which in 1960 contributed about one quarter of the total inshore catches, have diminished rapidly because they are, in the virgin stock, already fully exploited by the various predators and their stock was at f = 0, already at its $\frac{B_\infty}{2}$. Any further decrease of the stock's biomass in such a case would cause a more or less rapid collapse of the stock, followed by the collapse of their predators' stocks. This is probably what happened in the Gulf of Thailand.

Other questions which arise relate to the animals of the sixth group; that is, those invertebrates and fishes which manage to increase their biomass both in relative and in absolute terms as the total multispecies stock decreased. Obviously, these animals have not increased their biomass simply because they are small-sized (cf., the decrease in the small-sized Leiognathidae). Rather, the hypothesis is advanced here that these animals increased because of a set of specific ecological interactions which may be described as follows (for simplicity's sake, the Leiognathidae will be taken as sole representative of group 2 and group 6 will be here represented by the flat fishes (Heterosomata) only:

1) In the balanced, stable virgin stock, the Leiognathidae represent the high-efficiency, optimally adapted specialist, and their biomass by far outweighs that of the Heterosomata.

2) In the virgin stock, the low-efficiency, opportunistic Heterosomata, fail to achieve dominant status, in spite of their superior reproductive capacity, because they are out-competed by the Leiognathidae.

3) The Leiognathidae, on the other hand, are kept in check by their own predators, which are more or less specialized in preying upon Leiognathidae and depend less on Heterosomata because there are so few Heterosomata in the virgin stock.

4) When fishing reduces the number of leiognathids and their predators, the remaining predators tend to overexploit the remaining leiognathids, as discussed above.

5) The bottom invertebrates previously cropped by the leiognathids thus become available to the Heterosomata, which also see the overall number of predators in the system decrease.

6) As predation upon the egg, larval and juvenile stages of the Heterosomata decrease and as the number of their better adapted competitors decreases, a much larger number of Heterosomata eggs will survive and develop into larvae. Similarly, a much larger number of larvae survive, metamorphose, and become recruited to the fishery and to the adult stocks. This improved

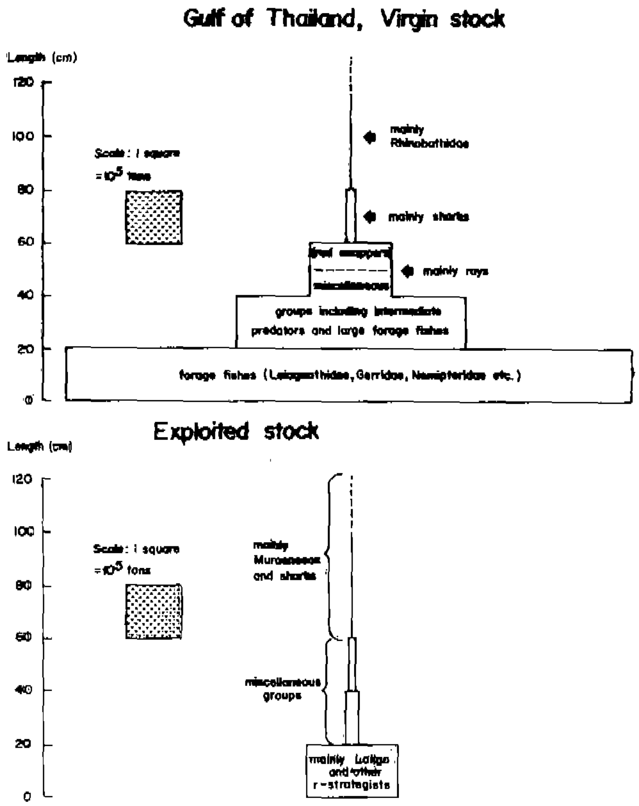


Fig. 10. Size distribution of A: Virgin Stocks and B: Exploited Stocks in the Gulf of Thailand.

recruitment finally helps the Heterosomata to gradually increase their stock size, despite the heavy fishing pressure.

The above mechanism now seems to be supported by more than just circumstantial evidence. Among other things, the line of argument appears consistent with the available data from the Gulf of Thailand, with our knowledge of general ecological patterns, and with the body of data available, e.g., on the biology of flatfishes. In fact, the stock-recruitment relationship proposed by Beverton and Holt (1957) for plaice refers to a typical generalist whose high reproductive capacity makes the number of recruits practically independent of the number of spawners over an extremely wide range of number of spawners. (See Beverton and Holt 1957, p. 44 and onward or Ricker 1975 for a review.)

While this strategy makes the plaice a rather successful animal in its North Atlantic habitat, this strategy could well imply too much waste in the more stable and predicable tropical environment. So, in the virgin stocks, the tropical relative of the plaice would tend to achieve a limited biomass only. When changes are brought into this ecosystem, however, the well adapted specialists (e.g., the Leiognathidae) will have problems adapting, and the generalists (e.g., the flatfish) increase. By inference, we may have thus gained here a first insight into tropical stock-recruitment relationships: the fact that the flatfishes differ markedly from the other fishes of similar sizes in their response to the fishery suggests the possibility that these fishes also differ in their stock-recruitment relationship, with the specialists (such as the Leiognathidae) producing a much reduced number of recruits when their stock size is reduced, while the flatfish should produce more recruits as the total biomass of the multispecies demersal stock is reduced. [This latter point incidentally which was a mere hypothesis when the first version of this paper was written, could be confirmed by estimating the number of recruits produced by the various stocks over the period 1963 to 1972 (Pauly 1979b; Pauly in prep.)].

Another line of inquiry may be opened by comparing the taxonomic composition of the virgin stock to that of the exploited stock. For this purpose, the pertinent catch rate values must be converted to biomass, or standing stock estimates. One first converts the catch rates values (kg/h) to density estimates (t/km^2) by the swept-area method, then multiplies the density estimate by the total area whose standing stock is to be estimated.

The following formula was used for transforming catch rates to density estimates:

$$d = \frac{C}{(0.67) \cdot H \cdot (2.8) \cdot (1.85) \cdot (0.5)}$$

where

d is the density in t/km^2

C is the catch rate in kg/h

H is the length of the trawl's head rope in m (here about 36 m)

2.8 is the trawling speed in knots, and

1.85 converts knots to km/h.

The value 0.67, on the other hand, is a constant which adjusts the headline length to the spread of the towed net, whereas 0.5 expresses the proportion of fish which escape to the side and above the net. The values of 0.67 and 0.5 have been used here as suggested by Shindo (1973) and as previously reported by Isarankura (1971) from experiments in the Gulf of Thailand. These values have been often used for conversions of catch rates to density estimates where Thai trawls have been used (Isarankura 1971; Saeger et al. 1976). (Slightly different values have been recently used by SCS (1975a), where an adjustment factor for the headline length of 0.4 was suggested, and escapement factors of 0 and 0.4 to 0.6 were considered.)

The catch rates of, and hence the density estimates based on Ritragsa (1976) apply only to inshore waters ($<$ 50 m). For offshore waters ($\geqslant$ 50 m) the catch rates have to be adjusted by some conversion factor. This was done here by using the ratio between the inshore and offshore catch rates by taxa calculated from data in Anon (1967) from the then virtually unexploited demersal stock off Eastern Peninsular Malaysia. This ratio was used to lower or to raise the density values estimated from the antilogarithms of "a" (extrapolation to zero effort of the catch rates given in Ritragsa 1976; see Table 8) which estimate catch rates in the virgin inshore stock. The biomass of the total virgin stock was then obtained by multiplying the density estimates by the inshore or offshore surface area and, finally by adding values of the offshore and inshore stocks (Table 13).

This procedure possibly overestimates the size of the offshore stock (cf. total inshore and offshore densities in Table 13), but as a whole the present estimate of total virgin standing stock for the whole Gulf of Thailand is about the same as estimated by SCS (1978a, p. 44) for statistical area IA and B (namely 1.6 million mt, or 5.2 t/km^2). The advantage of the present procedure, however, is that the virgin stock size has also been estimated individually for each taxon or grouping which enables a rough reconstruction of the virgin community (see below). The exploited stock was constructed more simply by multiplying the estimated virgin biomass for each taxon by the ratio of the catch rate at zero effort (as estimated by "a" in Table 8) to the catch rate that would be obtained at an effort of 10 million trawling hours, as extrapolated from the plots of catch rates against effort in Table 8. The reason for this extrapolation which is slightly (17%) above the maximum effort ever recorded from the Gulf of Thailand (8.563 million trawling hours in 1973, according to the recent review

Table 12. Changes in some important variables in the Gulf of Thailand trawl fishery, 1960-1973.

Year	Remarks		Effort (f) (million vessel hours)	Catch (c) (tons)	c/f (kg/h)	c/f in % of 1960 level	% of trash fish in total catch[a]
1960			0	0	(303)	100	(9.0)
1961			0.370	110	296	98	(9.4)
1962			(0.600)	166	(276)	91	9.0
1963			0.820	211	257	85	11.6
1964	start of fishing outside the Gulf		1.780	402	226	75	(10.9)
1965	start of fishing outside the Gulf	± optimal effort, according to TBSM	2.170	375	177	58	(11.3)
1966	start of fishing outside the Gulf	± optimal effort, according to TBSM	3.420	448	131	43	14.6
1967			3.970	457	115	38	10.8
1968			4.180	456	109	36	12.3
1969			4.350	457	105	35	14.3
1970			4.750	456	96	32	15.0
1971			6.165	450	73	24	18.6
1972			6.780	454	67	22	20.4
1973			8.510	426	50	17	(22.4)
	Extrapolation (≈ late seventies)		10.000	(310)	(31)	(10)	(26.3)

[a]% value of trash fish in total catch is extrapolated from a linear regression of % trash fish against effort.

by SCS 1978a, p. 43) is to make more visible the main trends that occurred within the Gulf of Thailand demersal stocks. Thus, the "exploited stock" discussed here is somehow artificial, constructed as it is to emphasize my points.

The exploited stock so constructed has a total biomass of 0.2 million mt, or 0.68 mt/km^2. This corresponds to 12.7% of the estimated virgin stock size, and compares well with the value of 15.7% obtained by comparing the 1961 and 1975 catch per effort values given in SCS (1978a, Fig. 6). Here again the advantage is that standing stock values were estimated individually, for each taxonomic grouping, which allows for a rough reconstruction of the exploited community.

For the reconstruction of both the exploited and the virgin communities, estimates of the mean size of the various taxa are needed. The values used here are the means of the "common" sizes reported from the various species of which the various taxa consist, which themselves had been taken from the FAO Species Identification Sheets (Fischer and Whitehead 1974) and other taxonomic works. The estimates are quite rough (Table 8) but should give an idea of the size distribution in the virgin (Fig 10A) and exploited stocks (Fig. 10B). Figure 10A corresponds to the classical ecological "pyramid" with a wide base of small forage fish, which are preyed upon by intermediate predators, themselves preyed upon by larger predators, etc. The picture is clear and easy to interpret. Indeed, the figure suggests the existence of three main tropic levels:

1) Leiognathidae, Gerridae, and Nemipteridae forming the bulk of the forage fishes, themselves feeding on "basic" benthic invertebrates.

2) *Saurida* spp., Ariidae, Lutjanidae, etc. representing the intermediate predators and feeding on the forage fishes, and

3) Large sharks, Muraenesocidae, etc., the peak predators feeding on the intermediate predators and on the forage fishes. The Carangidae, Priacanthidae, and other fishes of intermediate sizes may be attributed partly to the first, partly to the second level.

If this model applies, then the model of the ecosystem presented in Fig. 3B lacks one level, and the use of the Total Biomass Schaefer Model becomes even more erroneous. Fig. 10B, which depicts the structure of the exploited stock, shows that the virgin food chain described above is largely replaced by a food chain based on a significant proportion of small generalists (Heterosomata, trash fish) and by squid, with mainly *Muraenesox* as peak predator. The total biomass of the benthos feeders being reduced to a small fraction of their original value, it may be expected that the standing stock of invertebrate zoobenthos should have increased in size and decreased in productivity, as demonstrated in a remarkable study by Hayne and Ball (1956) who illustrated the case depicted in Fig. 6A. Fortunately, benthos samples, which could be used to reject or confirm the hypothesis presented here concerning changes in the structure of the benthic communities, have been taken in the last years by personnel of the Marine Fisheries Laboratory, in Bangkok. If the interactions suggested above apply, and if indeed there are three trophic levels within the demersal standing stock in the Gulf of Thailand, then the Total Biomass Schaefer Model, indeed would not apply. A final point concerning this model may be made here.

FAO (1978), after presenting some cases where the Total Biomass Schaefer Model has been applied, writes:

Table 13. Estimates of standing stock in mt for the Gulf of Thailand. For explanation of calculation, see text.

Taxa	Inshore density t/km^2	Virgin stock Inshore biomass (mt)	Offshore density (mt/km^2)	Offshore biomass (mt)	Total biomass (mt)	Exploited stock Total biomass (mt)
Sharks	0.049	8,097	0.017	2,290	10,387	768
Rhinobathidae	0.094	15,584	0.094	12,690	28,274	113
Rays	0.399	65,814	0.399	53,865	119,679	1197
Anadontostoma chacunda	0.057	9,451	0	–	9,451	10
Chirocentrus spp.	0.004	690	0.001	180	870	354
Saurida spp.	0.201	33,239	0.401	54,101	97,340	11,354
Ariidae	0.191	31,487	0.129	17,353	48,840	537
Muraenesox spp.	0.002	345	0.002	270	615	2,540
Sphyraena spp.	0.086	11,018	0.162	21,883	32,901	1,053
Serranidae	0.026	4,247	0.040	5,341	9,588	1,994
Priacanthus spp.	0.141	23,310	1.069	144,364	167,674	47,116
Sillago spp.	(0.001)	106	0.001	87	193	100
Lactarius lactarius	0.038	6,212	0	–	6,212	6
Carangidae	0.453	74,761	0.641	86,570	161,331	9,357
Rachycentron canadus	0.005	876	0.005	717	1,593	454
Lutjanidae	0.079	13,088	0.076	10,244	21,332	3,313
Nemipterus spp.	0.385	63,584	0.443	59,764	123,348	13,568
Gerridae	0.619	102,185	1.370	184,928	287,113	1,148
Leiognathidae	1.665	274,697	0.076	10,252	284,949	1,710
Pomadasys spp.	0.016	2,654	0.002	270	2,924	61
Scolopsis spp.	0.169	27,902	0.040	5,333	33,235	1,994
Plectorhynchidae	0.059	9,718	0.007	929	10,647	213
Sciaenidae	0.385	63,600	0.048	6,464	70,064	210
Lethrinidae	0.008	1,250	0.006	810	2,060	241
Mullidae	0.405	67,035	0.051	6,887	73,922	2,070
Trichiurus haumela	0.018	3,000	0	–	3,000	2,028
Rastrelliger kanagurta	0.018	2,947	0	–	2,947	784
Rastrelliger neglectus	0.015	2,442	0	–	2,442	552
Scomberomorus spp.	0.010	1,673	0.004	506	2,179	1,532
Pampus spp.	0.012	1,911	0	–	1,911	38
Parastromateus niger	0.018	3,027	0	–	3,027	179
Psettodes erumei	0.008	1,381	0.005	617	1,998	4,377
Bothidae	0.005	770	0.004	540	1,310	2,955
Cynoglossidae	0.001	239	0	–	239	239
Sepia spp.	0.031	5,044	0.015	2,001	7,045	11,455
Loligo spp.	0.091	14,947	0.034	4,557	19,504	69,103
Thenus spp.	0.048	7,885	0.019	2,615	10,500	63
Shrimps	0.006	927	0.001	162	1,089	262
Crabs	0.008	1,386	0.006	864	2,250	8,680
Caesio	(0.001)	159	0.001	135	294	300
Total		958,688		697,589	1,656,277	204,028
(density values)	(5.81)		(5.17)		(5.52)	(0.68)

"These overall Schaefer models generally seem to fit the data rather better than the fits experienced with their various component stocks. This could occur for several reasons. Some of these are:

a) Total biomass does react in a simpler way to overall fishing effort than does the biomass of individual stocks, i.e., the production model gives a more realistic description of total biomass than it does of the biomass of individual species.

b) The better fit results simply from the averaging process.

c) The overall biomass/overall effort fit is an artifact of the method of fitting in the time series of species exploitation. For example, exploitation starting on lower density high-value species with low mortality, e.g., haddock, and then moving on to the high density low value-high mortality species, e.g., silver hake.

d) Because the shifts in the preference of the commercial fisheries between species are not taken account of in the statistics of nominal effort, the available effort data give a more accurate index of mortality exerted on the total biomass than they do of the mortality on any individual species.

Which of these is true only time will answer, but there is at least a possibility that (a) is the correct one and if it is, then total biomass models do provide reliable information on the behavior of the fish stocks. Such a model suggests a simple biomass criterion for obtaining the overall yield from an entire system and while it does not explicitly refer to interactions between species, it must implicitly consider them."

As discussed previously, the likelihood for alternative (a) to be correct is very slight and it appears that the model is not realistic. The last point made here is that it is option (b) which is the more likely of the alternatives listed and that the apparent "good fit" of the total biomass data is indeed an artifact arising from the averaging process.

In support of this conclusion, Table 8 provides estimates of "a" and "b" for 38 taxa, and these values, obtained from plots of catch/effort against effort, are of the very type that is used in stock assessments. The regressions which provided the estimates of "a" and "b" also provided estimates of r^2, which estimates goodness of fit (r^2's used instead of r to avoid negative signs). The correlation coefficient between the values of r^2 and that of "a" (that is, of the natural logarithm of virgin stock size) is 0.714 and highly significant (critical value for r, with 37 dF = 0.4 for P = 0.001). This simply means that whatever effect trawling had on a stock was clearest on those taxa which had a larger mean catch/effort; that is, on those taxa which occurred at more stations and/or in larger numbers. Clearly, we have here a better fit because of averaging processes.

Toward a New Approach in the Investigation and Management of Tropical Multispecies Stocks

The two previous sections were intended to show that:

1) The simple models commonly used in the region do not produce reliable estimates of sustainable yield.

2) There is therefore an urgent need to reassess previous estimates of "sustainable" yield on the basis of a model accounting for stock interactions.

3) The present data on some of the stocks of the region allow for at least a preliminary study of the interactions which occur in stocks subjected to heavy fishing pressure.

4) It may therefore be possible to preliminarily assess the impact of the fishing technique generally used (small meshes, high effort) on the various stocks of the region on a more detailed basis than done hitherto.

5) For detailed analysis and prediction of events, more and better biological (and statistical) data are needed on the stocks in question, especially on a species basis.

If indeed the TBS and XMB models produce erroneous results as suggested above, then the various yield estimates made in the region, e.g., those listed in Table 6, will all be too high. These stocks will continue to diminish more or less rapidly even if fishing effort is adjusted to what is presently thought to be the optimal level of effort (to say nothing of the effects of a level of effort higher than this "optimum" level).

Clearly, there is then a need for fishery scientists and general ecologists working in the region to help confirm or reject the views expressed above concerning these models, and should the critique be confirmed, to then reassess the various yield estimates, possibly on the basis of adapted versions of the "Tuna" or "North Sea Strategies" (Figs. 4A and 5A).

This work would consist of two steps:

1) Divide the "virgin" stock into an appropriate number of trophic levels (two or three) and attribute to each trophic level the corresponding value of B_∞ or $\frac{B_\infty}{2}$ values for the various taxa.

2) Suggest at which trophic level (or size, for all practical purposes) the fishery should operate for maximum biological yield or economic returns, and suggest a fishing technique (mesh size or otherwise selective gear) appropriate to the selected strategy. This work would be greatly facilitated if more comparative studies on the stocks of the region were conducted, especially concerning changes in the relative catch composition.

The preliminary study made above of data from the Gulf of Thailand demonstrates that our knowledge of stock interactions could be considerably increased by a thorough analysis of some of the extant data from the fisheries of the region. Also, analyses such as those made here may help to identify those taxa which, over the whole region, tend to be very sensitive to the stress imposed by the fishery and which should thus be treated separately in stock assessments. The prerequisite for work of this kind, and of any kind of work on these stocks for that matter, is, however, that the statistical data from the various fisheries of the region, presently scattered in a wide number of reports which are not easily accessible and in publications in various languages of the region, be made available to the scientific community in compact, yet exhaustive form.

Unless this is done, there will be no possibilities for comparative studies and it will be necessary to wait for more spectacular collapses to occur for theoretical generalizations to be made.

Another field which needs added emphasis is the problem of mesh sizes. Jones (1976) reviewed the question of mesh regulation in the demersal fisheries of the South China Sea area. One of his findings was that "the calculation of a single optimum mesh size for the fisheries as a whole depends on finding a balance between different species. Any such compromise mesh size may involve the loss of a substantial proportion of the smaller species, including shrimp and may not be readily acceptable to many fishermen."

Jones (1976), in this statement, relates to two problems:

a) The first problem is that the optimum mesh size to use by the fishery as a whole has yet to be estimated. We thus have a scientific problem.

b) The second problem is that this optimum mesh size will probably be such that it may indeed "not be readily acceptable to many fishermen." So we also have a problem of enforcement.

It may well be, however, that there is no single optimum mesh size for the fisheries as a whole, and that indeed the very idea of a single fishery is the key to some of the present problems. It appears quite difficult, for example, to conceive a compromise mesh size which would allow for shrimping without catching a large number of undersized fish. Here, it would appear that the best strategy would be to rigidly separate the two fisheries for example by developing and introducing special shrimp trawls that would catch shrimp to the complete exclusion of fish.

On the other hand, it would seem that the problem of finding the optimal mesh size for the finfish fishery may be solved, following the suggestion made earlier that yield be sustained by fishing at one distinct trophic level–that is also, for all purposes, at one distinct size range (North Sea or Tuna Strategies, Figs. 5A and 4A).

In any case it is quite obvious that the mesh sizes of 20 mm and less presently in use in most Southeast Asian trawl fisheries will have to be increased if the fish stocks are to remain productive. It is possible that in the seriously depleted stocks of the Gulf of Thailand and in the Malacca Straits, the losses of small fishes which would result from a dramatic increase in mesh size could be, at least partially, offset by an increased efficiency in catching the remaining large and middle-sized fishes, while at the same time allowing the stocks of small fishes to recover (SCS 1978b, p. 5). Data which could be used to check this possibility are presently not available, but are urgently needed, as no one really knows at what rates the stocks would reconstitute themselves after an increase in mesh size or a reduction in fishing effort.

The lack of sufficient data on the biology of the various species is, on the other hand, a problem which I believe could be significantly alleviated in a relatively short period of time. Contrary to a relatively widely held view, quite a large number of studies have been conducted on the biology of various fish species of the region. The main problem with these studies is, however, that most of them are not available to the scientific community because they have not been published in widely circulated journals. (See, for example, the exhaustive study on the population dynamics of *Rastrelliger* published in Indonesian by Sujastani (1974) or the data presented by Morsuwan (1970) and Phettongkam and Thasananulkit (1972), the latter of which could be used by Pauly (1978a) to estimate growth parameters in both *Selaroides leptolepis* and *Sciaena russelli*.)

Many biological studies undertaken in the region, in addition to being poorly accessible, have two additional drawbacks:

1) They often do not thoroughly analyze the data on which they are based. Thus, for example, length-frequency analysis generally stops short of actually estimating growth parameters, which alone can be used for yield assessments (as, for example, in the two latter papers cited above).

2) They are seldom comparative studies (again owing to the non-accessibility of related literature). Thus, the results often cannot be interpreted meaningfully for lack of the frame of reference provided by related studies.

Although quite large, the number of species which contribute to the fisheries of the region is not infinite. So, it would be possible to compile basic data on, say, the 200 most important species of the region, granted a serious attempt were made to access the data files and unpublished reports of the various research bodies of the region and to extract, standardize, and edit the relevant information.

For each species three basic kinds of information are needed for stock assessments. First, data on growth and mortality are necessary. For all purposes, growth should be in terms of L_∞ and K or W_∞ and K. Reasonable estimate of M, the exponential coefficient of natural mortality, can then be obtained by one of the following equations:

$$\log M = 0.1228 - 0.1912 \log L_\infty + 0.7485 \log K + 0.2391 \log T$$

or

$$\log M = -0.1091 - 0.1017 \log W_\infty + 0.5312 \log K + 0.3598 \log T$$

where L_∞ is expressed in cm (TL), W_∞ in g and mean environmental temperature (T) in °Celsius. The equations apply to any species of fish, at any temperature above 3.5°C (see Pauly 1978b for derivation and confidence intervals about the estimates). Similarly, a rough estimate of t_0 can be obtained from values of L_∞ and K by the following expression:

$$\log(-t_0) = -0.392 - 0.275 \cdot \log L_\infty - 1.038 \log K$$

derived from data in Pauly (1978a).

Improved methods for estimating the growth parameters L_∞ and K from length frequency distributions are available (Pauly 1978a) and it appears by now that the estimation of growth parameters for a very large number of species of the region could be achieved with no major difficulties. Indeed, original and literature estimates of growth parameters for more than 100 species of fish occurring in Southeast Asian and Indian Ocean waters have been compiled recently (Pauly 1978a) and it appears that many more could be obtained by using the less accessible and the very recent literature.

A second type of data needed for assessing stocks in the region is that useful in determining the position of all exploited and potentially exploitable species in the food web. From the above analysis of the Gulf of Thailand stocks, it appears that before recommending any given fishing strategy, the fish biomass occurring at each trophic level should be assessed. (Thus, for each species, a study, even if cursory, should be made on the type of food consumed (phytoplankton or zooplankton or zoobenthos or fishes) with size range of prey as related to predator size. Also, such studies should identify the main predators of a given species. There is, finally, a distinct need for studies on the fertility of fishes, whose results could be used to back up studies on stock-recruitment relationships in some of the major stocks of the region. The three fields of study mentioned here, and the data they provide, would provide a basis for attempts to model a whole tropical ecosystem possibly along lines similar to those explored by Andersen and Ursin (1977).

A Program for ICLARM

The problems discussed in the previous sections of this paper represent serious constraints to the development and national management of this and the region's other resources, as well as to those of many other tropical regions of the world. Clearly, this is a field where ICLARM's contribution would be most appreciated, as some of the problems appear intractable at the level of the individual scientists and most probably at the level of most of the region's countries.

Areas in which ICLARM assistance and activities would be helpful are:

a) The convening of a workshop of competent ecologists, fishery scientists knowledgeable in population dynamics, and fisheries managers, with the goal of reassessing the stocks of the region on the basis of the present critique of the models previously used, and to determine if indeed the waters of this region are as productive on a continuous basis (in terms of fishery harvest) as assumed to date.

b) The initiation, support, and publication of a comprehensive compilation of data pertaining to the fisheries of the region, which would incorporate all basic data (see above) which could be possibly gathered from the extant published and unpublished literature scattered in the region.

c) Assigning a competent team of fishery systems analysts the task of attempting to incorporate the data and information gathered in a) and b) into an adequate model to 1) stimulate the effect of the various fishery strategies outlined here, suggest the best strategy to use, and 2) estimate the catch or returns which could be expected from such a strategy.

The three program areas given above are arranged in their logical and only possible chronological order. The first program area—the convening of a workshop—could proceed along the following lines:

1) Gathering of responses to the ideas expressed in the present report.

2) Generalization, extension, and reformulation, by ICLARM staff, of some of the ideas expressed here, with subsequent distribution of a brief report in which concrete proposals for a workshop would be made.

3) Actual convening of a meeting with call for papers, reports, and raw data on the state of the various fisheries of the region, with emphasis on:

a) data on distribution and stock size of more or less virgin stocks by taxa as gathered in surveys and from statistical data at the onset of the fishery.

b) data on the decline of specific stocks

c) data on "alternative" methods of exploitation (large mesh sizes, hook and line fishing of demersal stocks, etc.)

The results of this workshop could be presented in three parts: (1) text containing submitted papers, (2) exhaustive tables containing all raw data available on the stocks and their composition over time and on the concurrent effort expended to fish them, and (3) an atlas of maps showing the density of the most important stocks by taxa in the virgin stocks of the region and/or at the onset of the various fisheries. Such an atlas would provide a basis for subsequent choices of strategies, as the virgin stocks of different regions are an objective standard for comparison, and a state toward which the stocks might return following a decrease of fishing.

These three volumes could be compiled and edited by ICLARM staff in cooperation with appropriate institutions, agencies, and individuals in the region.

The second area in which ICLARM could be helpful would then be in the gathering of basic data on the biology of, say, the 200 most important species of the region. The actual compilation of these basic data could be also done by ICLARM staff or under an agreement between ICLARM and an appropriate institution of the region.

The work would first necessitate acquiring the data, namely, encouraging the various research institutions of the region to make available to the team in charge of the project whatever data they have on file which are not also readily accessible in scientific journals and similar publications. Such data might also require translation. Secondly, the data would require standardization and processing, and then could be published in tabulated form, with an exhaustive introductory text, in the various national languages of the region. The latter measure would ensure that the compilation would fulfill its role of helping to advance research on the stocks of the region at all levels of research, including the various local fishery colleges and similar institutions. The data could be presented as in the books by Carlander (1969, 1977) who compiled life history data for North American freshwater fishes.

The third area in which ICLARM could greatly help decision makers dealing with sea fisheries of the region concerns the field of stock management theory itself. As mentioned above, it now appears to be possible to model more or less realistically a whole marine ecosystem (Andersen and Ursin 1977). The problems associated with models such as the one proposed by Andersen and Ursin (1977), however, seem quite overwhelming. They require a tremendous body of biological data and therefore cannot be presently adapted to any stock or stocks of this region. They require more or less continuous access to a large computer capable of rapid operation and are therefore quite costly. In addition they require such a level of expertise on the part of the biologists (particularly in mathematics) that it is quite difficult at present to recruit a team both capable and willing to work on the stocks of the region (These 3 points incidentally also apply to the model presented by Pope 1979).

The role of ICLARM could thus be to commission a team of competent fish population dynamists, theoretical ecologists, and systems analysts to develop a multispecies interaction-yield-optimization model which could be used as a basis for managing the fisheries of the region. This team probably would have to be drawn from several countries and by a pooling of resources, which probably no single country of the Region could provide by itself.

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