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14

Development of Fisheries in the Gulf of Thailand Large Marine Ecosystem: Analysis of an unplanned experiment

Daniel Pauly and Ratana Chuenpagdee

ABSTRACT

The main ecological features of the Gulf of Thailand (GoT) Large Marine Ecosystem are briefly outlined, to serve as context for a sketch of the development of the fisheries therein. This development took place in the absence of large environmental changes and, except for some squabbles over the incursion of trawlers into the EEZ of Cambodia, in the absence of international conflicts over straddling stocks. This situation may be seen as representing a nearly ideal 'experimental' setting for studying the direct effect of rapidly growing fisheries on the abundance and composition of tropical multispecies resources and on the ecosystem within which these resources are embedded.

This analysis consists of three mutually supporting elements: (1) a narrative, highlighting the sequence of events leading to the present, overcapitalized fisheries and their much depleted resource base; (2) a comparative study, using the multidimensional Rapfish approach, of the impact, in terms of sustainability, of the different gears operating in the GoT; and (3) a demonstration that these fisheries, by fishing down the food webs of the GoT, have fundamentally altered, and continue to alter, the functioning of that ecosystem, albeit in a manner that may still be reversible. These results indicate that a drastic reduction of fishing effort, especially by bottom trawlers, is the only way to halt further ecological degradation of this Large Marine Ecosystem.

INTRODUCTION

The Gulf of Thailand (GoT), with an area of about 350,000 km^2 is a typical Large Marine Ecosystem (LME) in terms of its size (Sherman and Duda 1999). However, it differs from a number of other LMEs in being, to a large extent, part

However, it differs from a number of other LMEs in being, to a large extent, part of the EEZ of a single country (Figure 14-1), thus minimizing straddling stocks issues. Moreover, the GoT appears largely unaffected by the massive regime

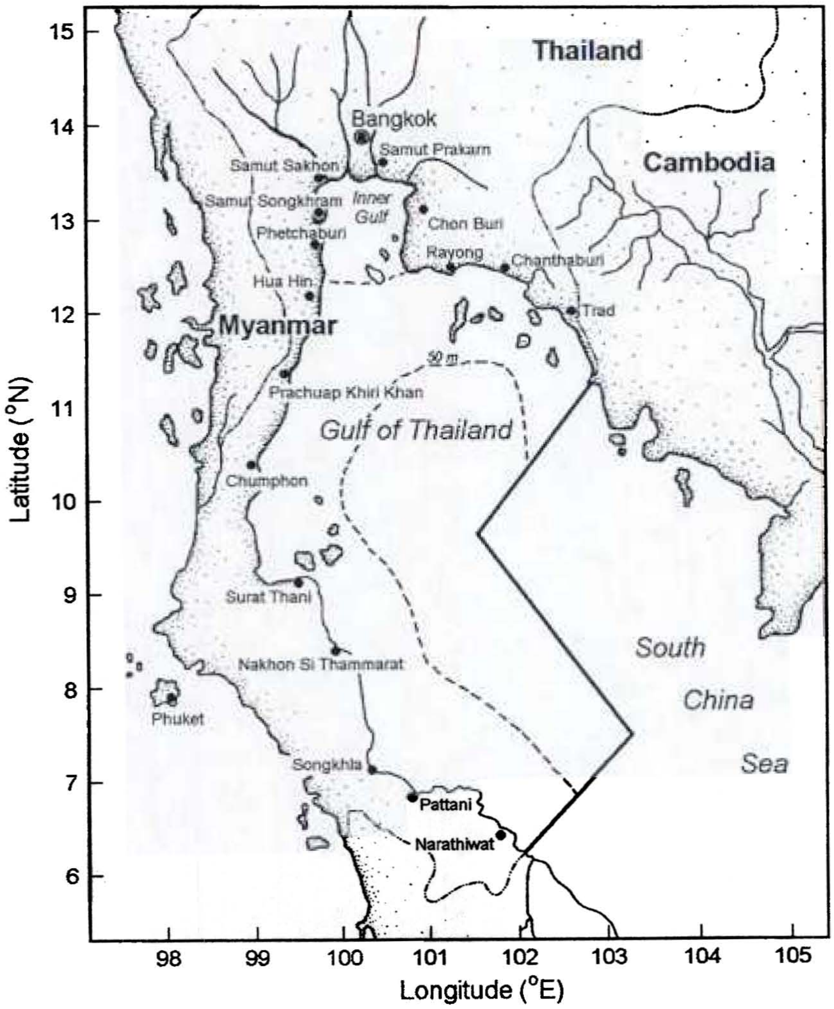

Figure 14-1. Map of the Gulf of Thailand, highlighting features mentioned in the text.

shifts that beset other areas of the Pacific, e.g., the Humboldt Current System (Alheit and Bernal 1993), or the Central/North Pacific (Polovina et al. 1995).

These features lead to a situation where ecosystem effects of fishing can be evaluated in 'pure' form, as it were, without having to account for the confounding effects of, e.g. foreign fleets operating within the GoT, or environmental fluctuations.

In this contribution, we rely on this situation to analyze the impact of fisheries on the GoT LME. In a sense, we thus use the GoT as the site of a giant, if unplanned experiment in fisheries development, conducted in a 'control' LME.

THE PHYSICAL SETTING

The GoT as defined in Figure 14-1 consists of three subsystems:

1) The shallow 'Inner Gulf' (≈10,000 km^2);
2) A band of shallow grounds (down to 50 m), bordering the East and West coasts, reaching to the Cambodian coast on the East, to the border of Peninsular Malaysia on the West (≈ 150,000 km^2), and supporting the bulk of the demersal trawl fishery;
3) A Central Basin (≈ 190,000 km^2), with depths ranging from 50 to 80 m, and a shallow sill (about 50 m) that limits water exchanges with the open South China Sea (Piyakarnchana 1989; Eiamsa-Ard and Amornchairojkul 1997).

The oceanography of the biogeochemical province of which the Gulf of Thailand is a part is discussed in Longhurst (1998), largely based on Wyrtki (1961), and does not need reiterating here. However, we must mention the relatively high primary production prevailing in the GoT, recently boosted by increased nutrients from rivers and shrimp farms, and increasingly leading to harmful algal blooms, oxygen depletion, food poisoning and other pollution effects, particularly in the Inner Gulf (Eiamsa-Ard and Amornchairojkul 1997, Longhurst 1998, Piyakarnchana 1999).

DEVELOPMENT OF THE TRAWL FISHERIES

Until the early 1960s, Thai fisheries had been driven mainly by their own, internal dynamics. This was reflected in an emphasis on small pelagics (mainly Indian mackerels, *Rastrelliger* spp. and anchovies, *Stolephorus* spp.), caught by artisanal fishers operating mainly fixed gears, and supplying local markets.

Most important among these was the supply of anchovies for making 'fish sauce' (*Nam Pla*; Ruddle 1986, Pauly 1996).

In the early 1960s, a Thai-German bilateral project introduced and widely demonstrated the use of the light 'Engels' trawl for catching demersal fish, i.e., a gear much more suited to the bottom type and demersal resources of the GoT than the gear used in a previous, unsuccessful attempt in the area (Tiews 1965, 1972; Butcher 1996).

The subsequent development of the Thai trawl fishery has often been depicted as a showcase of successful transfer of appropriate developed-country technology to a tropical developing country, i.e., 'North-South'. However, detailed analysis (Butcher 1996, 1999) reveals that the technological 'package' that was transferred had been perfected in the Philippines, notably in Manila Bay, at the end of the Second World War (Tiews and Caeces-Borja 1959; Silvestre *et al.* 1987). Thus, the developed-country contribution here consisted mainly of facilitating a 'South-South' technology transfer, i.e., overcoming the isolation of developing-country scientists and managers. There is probably a deep lesson here, as already noted by Tiews (1965).

The rapid build-up of trawling effort in the GoT was fuelled from two sources:

1) Extremely high rates of profit by the first trawl operators, quickly reinvested into more trawlers; and perhaps more importantly,
2) Relatively cheap loans, mainly from the Manila-based Asian Development Bank—loans, for further fisheries development, which markedly reduced the cost of entry into the fishery (Mannan 1997).

A detailed economic analysis of the GoT demersal trawl fishery is given in Panayotou and Jetanavanich (1987), providing details on the various 'market failures' involved here. Also this study analyzes the exacerbating effect of the global fuel price increases of 1973 which, jointly with the declaration of EEZ by neighboring countries, gradually forced the return into the GoT of a large numbers of trawlers that had been operating outside (Butcher 1999).

What we wish to stress here is the ecological impact of the massive increase in trawling effort that occurred from the early 1960s on, and which resulted by the early 1980s in a strong decline in catch per unit effort, from about 300 kg/hour in 1961 to about 50 kg/hour in the 1980s (Figure 14-2), and 20-30 kg/hour in the 1990s (Eiamsa-Ard and Amornchairojkul 1997).

Demersal catches, which had earlier increased in response to the build-up of effort began to stagnate, and to slowly decrease (Figure 14-2), while the catch composition changed both within species (toward smaller individuals; Pope

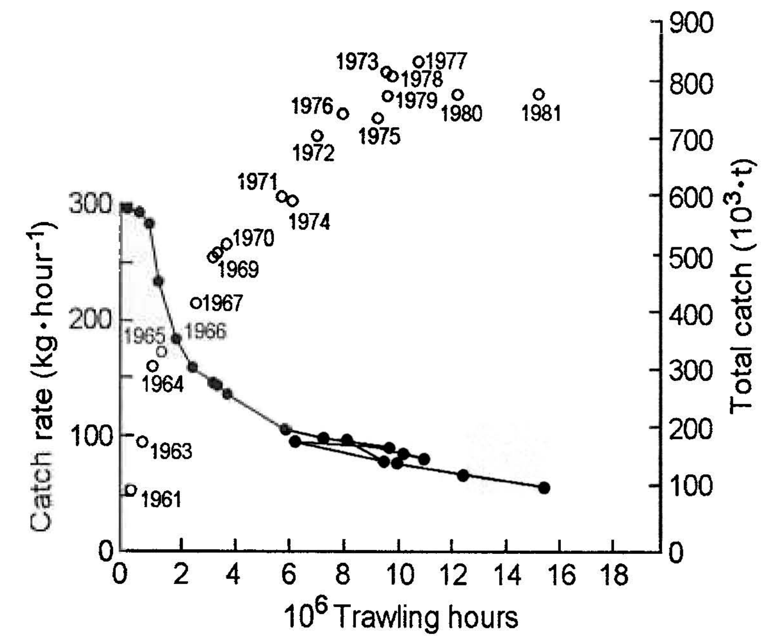

Figure 14-2. Catch and relative abundance of demersal resources vs. effort by Gulf of Thailand trawlers, during the period (early 1960s to early 1980) when the fisheries 'developed' (from Boonyubol and Pramokchutima 1984). Note the concavity of the Catch/effort plot, implying changes in composition of the multispecies catch (see text).

1979; Pauly 1980), and between species (toward a mix consisting predominantly of small, short-lived species; Pauly 1979, Beddington and May 1982).

In addition to the traditional *Nam-Pla* factories, the simultaneous development of the Thai aquaculture industry provided a ready outlet for the small, but increasingly valuable and ill-named 'trashfish' landed by trawlers (Hayase and Meemeskul 1987; Csavas 1993). Sumaila (1999) discusses the now global phenomenon of rapid value increases in small fishes 'subsidizing' the overfishing of larger fishes, a phenomenon which classical economists may view as yet another market failure.

MULTISPECIES AND ECOSYSTEM ANALYSES

The rapid development and scale of the trawl fishery in the GoT soon attracted the attention of stock assessment scientists, who attempted to provide a basis for estimation of 'Maximum Sustainable Yield' (MSY) in tropical multispecies fisheries. The key conceptual steps involved here are briefly recalled (see also Hongskul 1979). The first of these attempts was based on the famous 'Gulland equation', which suggests that Potential Yield = 0.5 x natural mortality x unexploited biomass (Gulland 1971), widely applied through Southeast Asia. This equation, based on the logic of single-species yield per recruit analysis, has been widely criticized (see e.g. Beddington and Cooke 1983).

However tenuous the derivation of Gulland's equation was, this became far worse when a single natural mortality (M) estimate was used to represent all the trophic interactions within a multispecies stock. The high value of M = 1 per year commonly used in Southeast Asia, represented, moreover, only the short-lived components of the multispecies stock (see M estimates for Southeast Asian fishes in www.fishbase.org), and hence led to P_y estimates that were biased upward.

Next were estimates based on what came to be called the Total Biomass Schaefer Model (TBSM), wherein the logic of surplus-production models (Schaefer 1954, i.e., that growth rate of biomass is a parabolic function of biomass itself) was assumed to apply to an ensemble of interacting species (Brown *et al.* 1976, Marr *et al.* 1976, FAO 1978).

However, it soon became obvious that the linear decline of catch per unit effort expected under the Schaefer model did not occur. Rather, as seen in Figure 14-2, the relation between catch/effort and effort in the GoT demersal trawl fishery was strongly non-linear, which led to the TBSM being replaced, for pragmatic reasons, by a model assuming such non-linearity, the 'exponential' surplus-production model of Fox (1970).

The deeper implication of the concavity of catch/effort and effort plots such as in Figure14-2 was not appreciated at the time. We now understand that it was due to rapid depletion, at a low level of fishing mortality, of the less resilient components of the multispecies resources, followed by a less steep decline of its more resilient components, a theme to which we return below.

Pope (1979) was the first to address the multispecies issue in the GoT demersal fishery head on, based on a multispecies Lotka-Volterra model that included trophic interactions. While pointing out that the parameters of this model could not, in practice, be estimated from observed data, he could show that, for any parameter set, multispecies MSY will be always less for an exploited species mix consisting of predators and preys than for the sum of all the individual species MSYs.

Perhaps more importantly, the model also showed that if the species mix is exploited by a non-selective gear such as a bottom trawl (i.e., a gear with fixed ratios of the fishing mortalities it applied to each species), 'true system MSY' cannot be achieved, even if fishing effort is regulated so as to correspond to the apex of a parabolic yield-effort curve. This, of course, results from technological interactions, i.e., from the fact that it is impossible to optimally exploit both large, slow-growing fish and small, fast-growing fish using the same fishing mortality and mesh size.

Another approach for tackling the multispecies issue in the GoT was to construct a dynamic simulation model and to explore its behavior under different management regimes (Larkin and Gazey 1982). Here, the problem was that already faced by Pope (1979), i.e., the parametrization of the model's coupled differential equations. Larkin and Gazey (1982) identified several elegant shortcuts to such parametrization. However, the modeling approach implied therein remained opaque to most practitioners, and had no follow-up.

The application by Christensen (1998) of the now widely-used Ecopath/Ecosim modeling approach to that part of the GoT exploited by the demersal fishery resolved several of the issues addressed by Larkin and Gazey (1982). Thus, the Ecopath software, designed to accommodate the type of data typically collected by fisheries scientists (see Christensen and Pauly 1992, and www.ecopath.org), enabled the rapid parametrization of two food webs for two states ('unexploited', i.e., early 1960s; 'depleted', i.e., early 1980s) of the system in question, based on the vast amount of diet composition, mortality and biomasss information available on GoT fishes (see also www.fishbase.org), and earlier used for a simpler model of the GoT (Pauly and Christensen 1993, Pauly and Christensen 1995, Pauly *et al.* 2000).

The dynamic simulation module of the software, Ecosim (Walters *et al.* 1997), was then used to perform various tests, including some envisaged, but not conducted in Larkin and Gazey (1982). The most interesting of these was to fish the 'unexploited model' with the same rapid increase of effort that occurred in reality. The result after two decades of simulation was a system configuration closely resembling that in the 'depleted' model. Conversely, relaxing fishing effort in the 'depleted model' led to a reestablishment of the food web configuration prevailing in the early 1960s.

As might be seen from Figure 14-3, the species groups most affected by the trawl fishery were crabs/lobsters, rays, sharks, and other large fishes, while penaeid

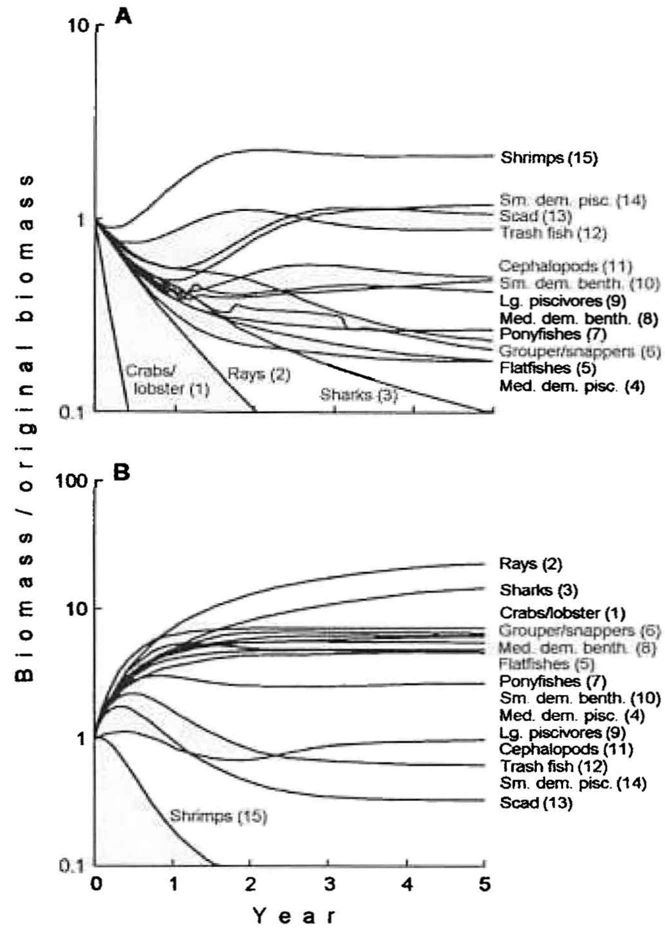

Figure 14-3. Relative changes in the biomass of key components of the Gulf of Thailand Large Marine Ecosystem, as predicted by the Ecosim software of Walters et al. (1997), given the baseline Ecopath models constructed by Christensen (1998). A: Changes from unexploited state (early 1960s), following a 16-fold increase of baseline fishing mortality, and mirroring the changes observed by research trawl surveys; B: Changes from exploited state (early 1980s), following a 16-fold decrease in fishing mortality. The sequence of numbers in A (from crab/lobster (1) to shrimps (15) indicated which groups declined most under fishing. This sequence is reversed in B, suggesting that the effects of fishing pressure would be largely reversible.

shrimps, squids and small fishes (including 'trash fishes') increased. Conversely, crabs/lobsters, rays, sharks, and other large fishes recovered when simulated fishing effort was reduced, while penaeid shrimps, squids and small fishes were reduced by the predatory pressure thus re-established.

These results, which corroborate earlier hypotheses concerning the impact of large predators on shrimps and squids in the GoT (Pauly 1984, 1988), also suggest that the GoT is not presently stuck in some 'alternative stable state' independent of fishing mortality (Beddington and May 1982) but, rather, would rebound if fishing effort were to be reduced. Moreover, the sequence of species impacts suggests that this ecosystem suffers from the 'Fishing down the marine food web' syndrome (Pauly *et al.* 1998), our next topic.

FISHING DOWN THE GULF OF THAILAND FOOD WEBS

Large fish tend to be piscivorous, which puts them near or at the top of marine food webs, and thus gives them high trophic levels (TL). Conversely, small fish and invertebrates such as squids and penaeid shrimps tend to feed on plankton, or bottom organisms and detritus, low in the food web.

Therefore, unselective fishing aimed at maximizing total catch – the 'biomass trash fish production' of James et al. (1991) - will tend to reduce the average TL levels in a system's food web. Also, this should be reflected in the mean TL of aggregate fisheries catches from a given area.

Following demonstration of such decline of mean TL in different parts of the world, and for the world's fisheries as a whole (Pauly et al. 1998), we investigate here the occurrence of this phenomenon in the GoT LME. This was done using three databases:

A) Nominal catches (1950-1976) for Thailand in FAO area 71 (Western Central Pacific), i.e., excluding catches from the Andaman Sea/Indian Ocean coast of Thailand;

B) Catch statistics (1977-1997) of the Thai Department of Fisheries (DOF) for the Gulf of Thailand as defined in Figure 14-1;

C) Species-specific TL estimates from FishBase (see www.fishbase.org).

Figure 14-4 presents the results of this analysis, of which a detailed spreadsheet is available on request. As might be seen from Figure 14-4A, catches from the GoT built up rapidly in the 1960s and 1970s, and fluctuated thereafter. While we are aware that it would be easy to over-interpret these fluctuations (which may be due in part to our heterogeneous database, and to landings originating from

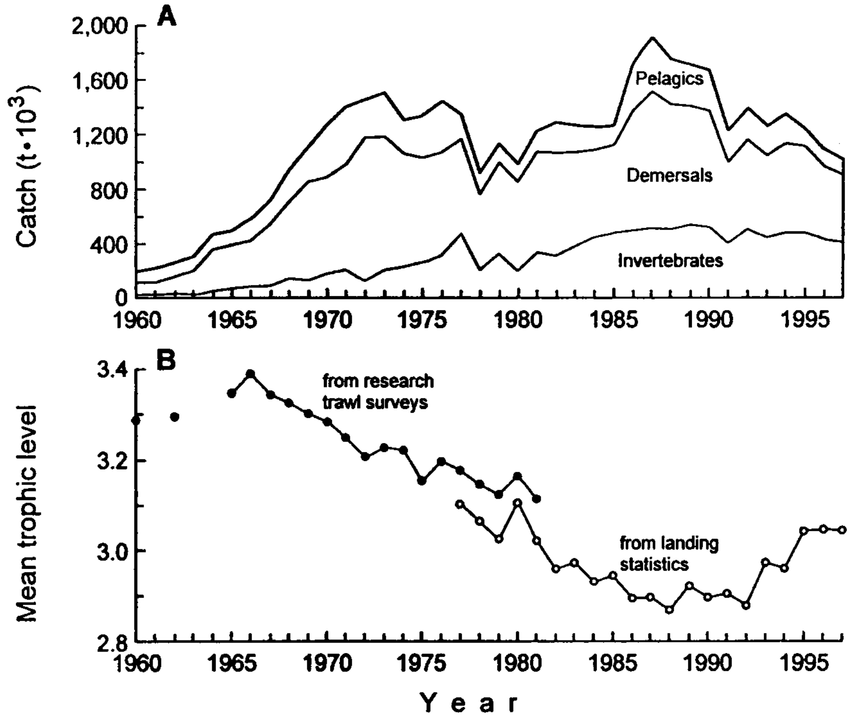

Figure 14-4. Major features of the Gulf of Thailand fisheries and their underlying ecosystem. (A) Catches, by major species groups (excluding tuna and other large pelagics). Note stagnation and decline of demersal catches, following their rapid increase in the 1960s and 1970s. Also note increasing contribution of small and medium pelagics, and overall decline in the 1990s. (B) Trophic level (TL) trends in the catch of research trawlers (reflecting relative abundances in the ecosystems), and in the total landings (both series excluding large pelagics). Lower TL in 1977 to 1997 series are due to inclusion of small pelagics and other low-TL organisms caught by gears other than trawl (see text).

outside the GoT, but not reported as such), we believe they largely reflect a stagnation, then decline of the demersal component of the catch, partly masked by an increased contribution of small and mid-sized pelagic fishes to the overall catch from the GoT.

Figure 14-4B confirms this analysis: the rapid decline of mean TL levels in the survey catch/effort data confirm that the high TL-level species of the GoT were quickly depleted, with small, low-level species soon becoming dominant in the ecosystem. Mean TL levels based on landings data, covering the years 1977 to 1997, show even lower, if fluctuating values, due to the inclusion, in the computation of mean TL, of low–TL fishes (mainly small pelagics) caught by gears other than trawls. We conclude from this that 'fishing down the marine food webs' occurs in the GoT, and that fishing profoundly modified the ecosystem in which these food webs are embedded.

This is important in view of the widespread perception that 'pollution' is the key problem of the GoT. Indeed, it is quite possible (see Parsons 1996) that the fisheries, by removing the upper parts of the natural food webs, have contributed to the observed increase of jellyfish and other consumers of herbivorous zooplankton, i.e., to a trophic cascade leading to phytoplankton blooms and the ensuing oxygen depletions reported by Piyakarnchana (1999).

Thus, the issue for Thai managers is to reduce fishing effort, i.e., to identify and hopefully target those gears and fisheries which most contribute to the unsustainable trends demonstrated here: our next and last topic.

COMPARING THE GULF OF THAILAND FISHERIES USING THE RAPFISH METHOD

Table 14-1 summarizes the key features of the GoT fisheries. Information on each of these fisheries was gathered from the literature cited herein, and in Thailand, from the DOF and other sources. This information was encoded, by choosing from 3-4 options the values of a large number of preset attributes detailed in Pitcher (1999). However, this was done here only in terms of ecological sustainability. Thus, economical, technological, and other dimensions of sustainability (notably compliance to the FAO Code of Conduct) are not reported upon here, although they are important elements of a full Rapfish analysis (Pitcher 1999). The data set resulting from this was analyzed using a form of Multi-Dimensional Scaling, a robust non-parametric method that is largely insensitive to non-linearity and other potentially biasing properties of the input data (Pitcher 1999). Figure 14-5 presents the key result of this analysis, displaying the relative position of each fishery on the sustainability scale.

As might be seen, the fully developed demersal trawl fishery of the 1980s is that closest to the anchor point for low sustainability, followed by the fisheries using Push nets (1980s) and Mackerel purse seines (1990s). All other fisheries have similar, relatively high sustainability scores, although they differ in a number of other attributes leading to differences in the position on the vertical axis (see Figure 14-5).

Table 14-1. Major fisheries, gear and target species in the Gulf of Thailand Large Marine Ecosystem. Figure 14-5 presents an evaluation of the ecological sustainability of these fisheries.

Fishery	Gear	Main target species	Mean catch ($t \cdot year^{-1}$)
Trawl fishery 1960s	Bottom trawl	Fish and shrimps	See Figure 2
Trawl fishery 1980s	Bottom trawl [a]	Threadfin breams	8,434
		Big-eyes	6,321
		Lizardfish	5,586
		Flatfish	4,842
		Croaker	4,007
		'Trash fish'	424,693
		Shrimp & prawns	75,020
	Pair trawl[a]	Threadfin breams	3,443
		Indo-Pacific mackerel	2,960
		Big-eyes	2,135
		Lizardfish	1,580
		Trevallies	1,529
		'Trash fish'	97,716
		Squid & cuttlefish	19,754
Mackerel purse seine 1980s	Purse seine[a]	Sardinellas	21,100
		Indo-Pacific mackerel	12,927
		Indian mackerel	6,144
		Longtail tuna	6,214
		Scads	5,626
	Lighted purse seine[a]	Sardinellas	81,675
		Indo-Pacific mackerel	30,434
		Scads	28,824
		Indian mackerel	23,716
		Big-eye scad	19,524
Mackerel purse seine 1990s	Purse seine	All species (incl. Sardinellas, Indo-Pacific mackerel, Scads, Indian mackerel and Big-eye scad)	[c,d]50,5077
Anchovy purse seine 1980s	Anchovy purse seine	Anchovy	[a]27,033 [b]41,857
Anchovy purse seines 1990s	Anchovy purse seine	Anchovy	[c,d]11,7153
Crab gill net 1980s	Crab gill net[a]	Crabs	7,124
Fish gill net 1980s	Encircling gill net[e]	Indo-pacific mackerel	27,358
		King mackerel	18,112
		Indian mackerel	17,245
Shrimp gill net 1980s	Shrimp gill net	Shrimps	[d,f]8633
Squid cast net 1980s	Squid cast net	Squids	[d,f]1,238
Squid trap 1980s	Squid trap	Squids	[d,f]6,231
Push net 1980s	Push net[a]	Shrimps	1,7216
		'Trash fish'	1,5946
Hook and lines 1980s	Hook and long line		[f]4,674

(a) Mean for 1980 to 1984, Inner GoT;
(b) Mean for 1982 to 1984, Inner GoT;
(c) Mean for 1990 to 1994, including. Outer parts of GoT;
(d) Based on total catches from the gear;
(e) Mean for 1981 to 1984, Inner GoT;
(f) Mean for 1988 to 1989, including the outer GoT.

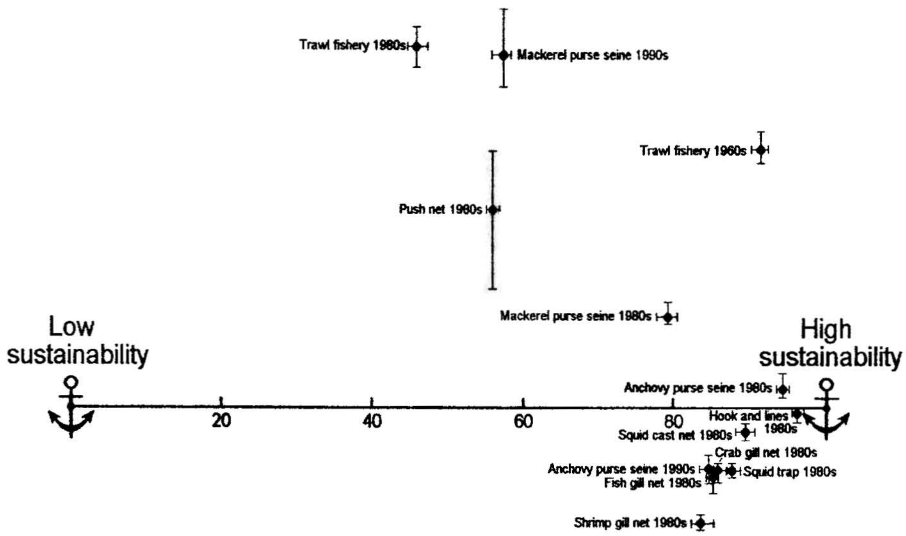

Figure 14-5. Comparison of the ecological sustainability score of the fisheries in Table 1, using the Rapfish method. The anchor point for low sustainability represents a 'model' fishery, given the lowest possible scores on all attributes, and conversely for the other anchor point. This analysis identifies the 'developed' bottom trawl fishery of the 1980s as the worst of all fisheries in Table 14-1 in terms of the horizontal axis, representing ecological sustainability.

CONCLUSIONS

It is now obvious that reducing fishing effort in the GoT and, more precisely, to retire a large fraction of the demersal trawlers operating therein is the only alternative to a continued degradation of that LME. All analyses performed so far converge to the same diagnosis, which is largely free of the potentially confounding effect of large environmental fluctuations.

Needless to say, this does not preclude addressing as well, the numerous other management issues that have led to coastal degradation in and around the Gulf of Thailand (Chuenpagdee 1996). In either case, these are not international issues; they are a matter for the Thai people to resolve, acting in their own best interest. This might involve a shift from the current centralized management regime to a more participatory approach at the community level, as well as an analysis of various policy options (Chuenpagdee et al. 2001), using inputs from scientists, academics, and the public at large.

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