Trophic Model of the Coastal Fisheries Ecosystem in the Gulf of Thailand

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Abstract

The biomass of 40 ecological groups, the diet composition of prey and predators, production/biomass (P/B) and consumption/biomass (Q/B) ratios, and catches were used as basic input to parameterize an Ecopath model of the Gulf of Thailand. Following construction of a mass-balance ecosystem model, a time-dynamic simulation model (Ecosim) was used to simulate the impact of change in fishing effort. This was done using time series data to validate the historic fisheries development in the Gulf of Thailand prior to using the model for forward-looking simulations. The time series data used in the analyses were catch and effort data from research vessel trawl surveys and landings data for six groups of fishing gear operating in the Gulf during the period 1973 to 1993. The fish market price and fixed and variable costs of each fleet (as well as profit) were also used as input for the time-series simulations using Ecosim. The results depict changes in biomass and trophic interactions in time (Ecosim) and space (Ecospace). The model was also used to investigate management options or measures for the fisheries of the Gulf of Thailand. Recommendations for future studies using Ecopath with Ecosim are also presented.

Introduction

Trawl surveys were conducted by the Marine Fisheries Division to monitor marine resource trends since the introduction of otter board trawling in 1960 (Tiews 1962). From 1960 to 1965, the trawl surveys were done in selected areas for specific purposes. Since 1966, the Gulf of Thailand has been divided into nine areas, Area I to Area IX. About 500 stations or grids were designed, each station representing 225 nm^2 (15·15 nm). The early surveys were conducted by research vessels (Pramong 2 and Pramong 9) on a monthly basis every year. Station numbers of surveys were different in each year. Recently, the number of stations was reduced to about 50 due to the expenses connected with operating research vessels. From the year 1994 onwards, the surveys were conducted every two months, with daytime and night time operations alternating between years. In 1995, data collected by research vessels were daytime operations. In this study, the study area is the coastal area of the Gulf of Thailand. Survey data collected during 1973 to 1995 are used in the analysis.

The study area is located between 6º N to 13º 30' N latitudes and 99º E to 104º E longitudes with a seabed area of 304 000 km^2 (Fig. 1). The Gulf of Thailand is relatively shallow with a mean depth of about 58 m. The distance from each station to shoreline ranges from 3.5 to 43 nm. The water depth of trawling stations ranges from 14 - 50 m with an average of 30 m. The Gulf of Thailand is affected by two strong monsoon winds, the Northeast Monsoon (October to February) and the Southwest Monsoon (May to October). Monsoon winds and tidal currents create complex water circulation patterns and local upwelling. The flow in the inner Gulf is clockwise during the Northeast monsoon and counterclockwise during the Southwest monsoon. The velocity of water current in 1994 and 1995 was 0.0 - 53.0 cm•s^{-1} with an average of 17.6 cm•s^{-1} (Musikasung et al. 1995). Heavy rainfall occurs during October to December ranging between 182 and 2 613 mm, and during June to August the range was 62 - 357 mm (Department of Meteorology (Thailand), 1995). In 1995, water temperature range was 27.8 - 30.0º C with an average of 29º C. Dissolved oxygen ranged from 4.5 to 6.6 mg•L^{-1}, with an average of 5.8 mg•L^{-1} (Naval Hydrographic Department 1995). Water salinity in the outer part of the Gulf ranges from 31.4 to 32.7 ppt, it is lower in the inner part due to freshwater inflow.

There are numerous nutrient-rich rivers which run into the Gulf of Thailand, notably, the: Chao Phraya, Tachin, Bangpakong and Mae Khlong rivers in the inner Gulf. Other rivers in the Eastern and Southern Gulf are Walu in Trad; Rayong river, Phetchaburi river, Lang Suan river in Chumphon; Tapi in Surat Thani; and Songkhla, Pattani and Kolok river in Narathiwas. An advantage for fisheries development in the Gulf (especially trawl fisheries) is the shallow continental shelf with a mean water depth of 45 m, and that the bottom substrate consists of loose mud, soft mud, sandy mud, muddy sand and sand (Naval Hydrographic Department 1995; Shepard et al. 1949).

The Gulf of Thailand functions as a two-layered shallow estuary with lower-salinity surface water flowing out of the Gulf, while high-salinity and colder water entering from the South China Sea. In the Gulf of Thailand, as elsewhere, primary production is high in coastal areas near river mouths, and decreases with depth and distance from the shoreline. In 1995, chlorophyll-a ranged from 0.77 to 13.42 mg•l^{-1}, with an average of 5.2 mg•l^{-1} nearshore. The offshore water 2 km from the shoreline had 1.63 mg•L^{-1} chlorophyll-a (Musikasung et al. 1995). Average primary production is 2.49 gC•m^{-2} •day^{-1} in the inner gulf and 2.96 gC•m^{-2}•day^{-1} offshore. The concentration of phosphate in the inner gulf ranged from 1.02 to 1.59 mg-at N•l^{-1} from 1984 to 1989. Nitrate concentration ranged from 9.15 mg-at N•l^{-1} in 1984 to 24.86 mg-at N•l^{-1} in 1989 (Suvapepun 1991).

In 1996, total marine landings from the Gulf amounted to 1.904 million t or about 70% of the country's total production from marine capture fisheries. Landings consisted of 33.1% pelagic fish, 12.4% demersal fish, 31.7% trashfish*, 5.4% shrimps, 6.1% squids and cuttlefish and 11.4% others. The value of each category accounted for 28.0%, 14.3%, 5.9%, 16.1%, 21.3%, and 14.4% respectively (Department of Fisheries (Thailand) 1999a). The number of registered fishing gears in Thailand in 1996 was 17 950, which consisted of 6 840 otter board trawl (38.1%), 2 179 shrimp gill net (12.1%), 1 843 pair trawl (10.3 %), 1 747 squid cast net (9.7%), 1 482 crab gill net (8.3%), 1 327 purse seine (7.4%), 872 fish gill net (4.9%), 722 push net (4.0%), 289 beam trawl (1.6%) and 649 others (3.6%) (Department of Fisheries (Thailand) 1999b).

Trawl surveys in the Gulf of Thailand showed a decreasing trend in CPUE from 1966 to 1995. In 1966, the CPUE was 172.9 kg•hr^{-1}. A sharp decline occurred from 1966 to 1975 with CPUE going down to 61.5 kg•hr^{-1}. From 1975 to 1983, the rate of decrease slowed with the CPUE going down to about 50 kg•hr^{-1}; and slightly increased in 1984 to 62.1 kg•hr^{-1}. Thereafter, the CPUE continuously declined and reached a minimum of 21.5 kg•hr^{-1} by 1995.

A number of ministerial laws and regulations have been issued in response to the marine resources situation in the Gulf of Thailand, this include Department of Fisheries (Thailand) 1997:

* Trashfish is used to include fishes with little value in the fresh fish market. It includes juveniles or undersized individuals of "economically valuable" species, as well as fishes not prefered for human consumption.

- Prohibition of motorized trawl and push net fishing within 3 km of the shoreline was issued on July 29, 1972;
- Prohibition of coral and coral reef fishing was issued on January 10, 1978;
- Prohibition of squid fishing using light attraction with mesh sizes of less than 3.2 cm was issued on November 5, 1981;
- Prohibition of landing any berried crabs *(Scylla serrata, Portunus pelagicus, Charybdis ferriatus)* was issued on July 11, 1983;
- Prohibition of fishing all species of marine turtles including their eggs was issued on March 13, 1989;
- Prohibition of purse seine fishing with light attraction and with mesh size of less than 2.5 cm was issued on November 14, 1991;
- Prohibition of any fishing using light attraction with mesh size less than 2.5 cm was issued on March 15, 1966. Anchovy fishing boats with sizes (LOA) of less than 16 m as well as lift net and 'drop net' were exempted from the regulation;
- Requirement that shrimp trawls should install and use Turtle Excluding Device for fishing was announced on September 16, 1996;
- Prohibition of motorized push net fishing in Pattani Gulf and the coastal area of Pattani Province was issued on February 26, 1998;
- Prohibition of ''drop net' and lift net with light targeting anchovy in the area of Songkhla Province was issued on July 28, 1998 (Songkhla Provincial Office 1998).

Exemption from these regulations can be granted only to activities involving scientific research upon approval of the Director-General of the Department of Fisheries.

The objectives of this study are to use Ecopath with Ecosim to depict changes in biomass and trophic interactions over time (Ecosim) and space (Ecospace), as well as to simulate the likely impacts of the following management directions:

1. Effect of a push-net fishery ban;

2. Effect of a stop to fishing of four juvenile fish groups and trashfish;

3. Effect of a stop to fishing of four juvenile fish groups combined with push-net fishery ban;

4. Optimization of fishing effort considering the impacts on fish community structure and yields.

5. Preferred effort levels for fishing fleets incorporating economic, social and ecosystem considerations.

Materials and Methods

Basic Model Parameterization

A total of 40 ecological groups were used to model the coastal fisheries ecosystem in the Gulf of Thailand. The groups are given in Table 1 along with the basic input parameters for the model. The catch-per-unit of effort (CPUE in $kg \cdot hr^{-1}$) from trawl surveys (using the research vessels Pramong 2 and Pramong 9) in the Gulf of Thailand for 1973 to 1995 were used to estimate biomass. Only day light hauls were included, and the trawl stations are indicated as numbers in Fig. 1. The biomass (B) was estimated using the swept area method Sparre and Venema 1992, viz:

$$B = \frac{\overline{CPUE}}{a \cdot X_1} \cdot A \qquad (1)$$

where:
$\overline{CPUE}$ is mean CPUE ($kg \cdot hr^{-1}$); A is the total areas (101 384 km^2); a is the area swept by the trawl per hr (0.09029 km^2); and X_1 is the proportion of fish in path of the gear retained by the net (0.5).

The swept area was estimated from the equation:

$$a = t \cdot v \cdot h \cdot X_2 \qquad (2)$$

where:
t is the time spent trawling (= 1 hr); v is the trawling velocity (= 2.5 knots); h is the head rope length of the trawl (= 39 m); and X_2 is the effective width of the trawl relative to the headrope length (= 0.5).

The intake of food by species or group of species was estimated from an empirical equation for estimation of consumption to biomass ratio (Q/B; $year^{-1}$) for finfishes (Palomares and Pauly 1989):

$$Q/B = 3.06 \cdot W_\infty^{-0.2018} \cdot T_c^{0.6121} \cdot A_r^{0.5156} \cdot 3.53^{Hd} \qquad (3)$$

where:
T_c is the mean habitat temperature (in this study equal to 29º C); W_∞ is the asymptotic weight of the fishes (maximum weight of fish in adjacent countries obtained from FishBase were used in case no W_∞ was available); A_r is the aspect ratio of the caudal fin of the species/group; and H_d is the food type (0 for carnivores and 1 for herbivores and detritivores).

The aspect ratio of 26 species (Appendix A) of fish was measured by projecting a line along the horizontal axis of the fish body and taking measurements at right angle to the line (Pauly 1989; Sambilay 1990). Specimens were collected at the Songkhla landing place in December 1998. The aspect ratio is defined as:

$$A = h^2 / s \qquad (4)$$

where:
h is the height; and s is the surface area of the caudal fin.

In cases where the aspect ratio is unavailable, Q/B was estimated from:

$$Q/B = 10^{6.37} \cdot 0.0313^{TK} \cdot W_\infty^{-0.168} \cdot 1.38^{Pf} \cdot 1.89^{Hd} \qquad (5)$$

Where:
W_∞ and H_d are as defined above; T_k is the mean annual habitat temperature (in the Gulf of Thailand, T_k = 1,000/(29 + 273.1)); and P_f is 1 for apex and pelagic predators and zooplankton feeders, and 0 for other feeding types.

Table 1. Basic parameters (defined in the Methods section) for the Ecopath model of the Gulf of Thailand, 1973. Values in parenthesis are estimated by Ecopath to fit mass-balance constraints.

Ecological group	Biomass. ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q	Biom.acc. ($t \cdot km^{-2} \cdot year^{-1}$)
Rastrelliger spp.	(0.187)	3.00	–	0.95	0.25	0
Scomberomorus spp.	0.016	(0.07)	(0.35)	0.95	0.20	-0.003
Carangidae	0.083	(1.34)	(5.37)	0.95	0.25	-0.007
Pomfret	0.008	(0.88)	(4.418)	0.95	0.20	0.001
Small pelagic fish	(0.452)	3.00	–	0.95	0.25	0
False trevally	(0.003)	2.00	–	0.95	0.20	0
Large piscivores	0.054	1.20	–	(0.68)	0.20	-0.001
Sciaenidae	(0.031)	1.50	–	0.95	0.20	0
Saurida spp.	0.054	2.00	–	(0.44)	0.20	0.012
Lutianidae	0.016	0.80	–	(0.54)	0.20	-0.004
Plectorhynchidae	(0.008)	0.80	–	0.95	0.20	0
Priacanthus spp.	0.071	2.00	–	(0.30)	0.20	0
Sillago spp.	(0.111)	2.00	–	0.95	0.20	0.086

Table 1. Basic parameters (defined in the Methods section) for the Ecopath model of the Gulf of Thailand, 1973. Values in parenthesis are estimated by Ecopath to fit mass-balance constraints. (continued)

Ecological group	Biomass. (t·km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	EE	P/Q	Biom.acc. (t·km^{-2}·year^{-1})
Nemipterus spp.	0.093	2.50	–	(0.66)	0.25	-0.004
Ariidae	0.018	2.00	–	(0.68)	0.20	-0.006
Rays	0.048	0.50	–	(0.26)	0.20	-0.01
Sharks	0.013	0.50	–	(0.57)	0.20	-0.005
Cephalopod	0.344	2.00	–	(0.82)	0.25	-0.1
Shrimps	(0.232)	5.00	–	0.95	0.25	0
Crab, Lobster	(3.520)	3.00	–	0.95	0.25	0
Trashfish	0.524	4.00	–	(0.88)	0.25	-0.045
Small demersal fish	(0.158)	3.00	–	0.95	0.25	0
Medium demersal piscivore	0.024	2.00	–	(0.47)	0.20	0
Medium demersal benthivore	0.092	2.00	–	(0.59)	0.20	-0.042
Shellfish	(0.169)	3.00	–	0.95	0.20	0
Jellyfish	2.000	5.00	–	(0.00)	0.25	0
Sea cucumber	1.000	4.50	–	(0.00)	0.20	0
Seaweeds	1.000	15.00	–	(0.00)	–	0
Coastal tuna	(0.019)	0.80	–	0.95	0.20	0
Sergestid shrimp	(0.051)	10.00	–	0.95	0.25	0
Mammals	0.100	0.05	30.00	(0.00)	–	0
Pony fishes	(0.066)	3.50	–	0.95	0.25	0
Benthos	33.000	5.00	–	(0.65)	0.20	0
Zooplankton	17.300	40.00	–	(0.20)	0.25	0
Juvenile small pelagics	(0.073)	4.00	–	0.95	0.25	0
Juvenile *Caranx* spp.	(0.025)	4.00	–	0.95	0.25	0
Juvenile *Saurida* spp.	(0.018)	4.00	–	0.95	0.25	0
Juvenile *Nemipterus* spp.	(0.022)	4.00	–	0.95	0.25	0
Phytoplankton	30.000	200.00	–	(0.44)	–	0
Detritus	10 000	–	–	(0.17)	–	0

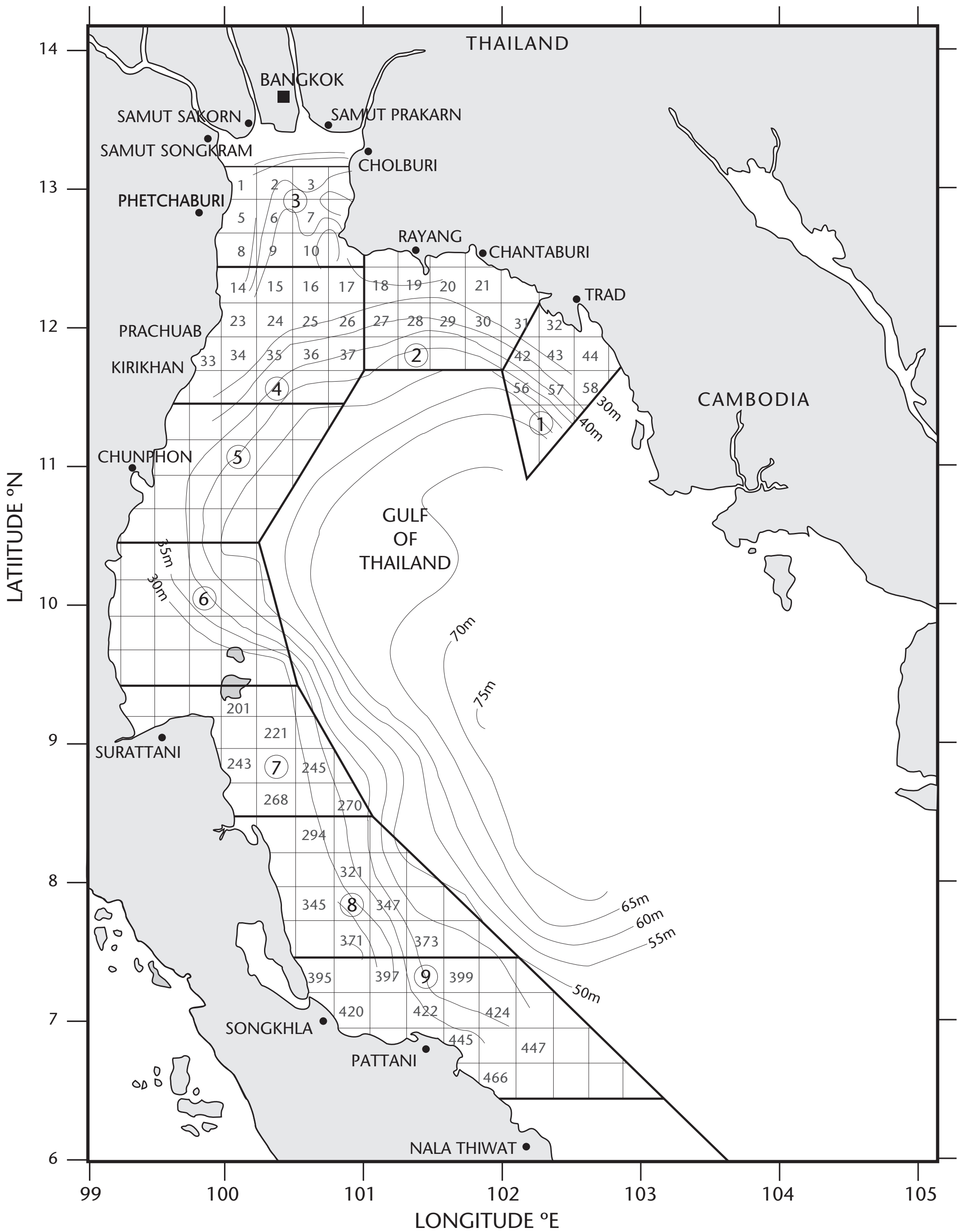

Fig. 1. Map of the Gulf of Thailand covered by the ecosystem model. Numbers indicate trawl stations which were used for biomass estimation.

Annual catch in the Gulf of Thailand from 1973 were taken from statistical data of the Department of Fisheries and regrouped into 40 ecological groups (Table 2). Diet composition for each group was obtained from available literature and is summarized in Table 3.

Table 2. Catch (t·km^{-2}·year^{-1}) from Thai waters of the Gulf of Thailand (1973). ("other gear": shrimp gillnet, fish gillnet, swimming crab gillnet & trap).

Ecological group	Otter board trawl	Pair trawl	Beam trawl	Pushnet	Purse seine	Other gear	Total
Rastrelliger spp.	0.016	0.033	0	0	0.070	0.047	0.166
Scomberomorus spp.	0	0.001	0	0	0	0	0.001
Carangidae	0.006	0.008	0	0	0.008	0	0.022
Pomfret	0.002	0.001	0	0	0	0	0.003
Small pelagic fish	0	0	0	0.015	0.069	0.029	0.113
False trevally	0.001	0	0	0	0	0	0.001
Large piscivores	0.013	0.005	0	0	0	0	0.018
Sciaenidae	0.024	0.014	0.001	0.001	0	0	0.040
Saurida spp.	0.025	0.007	0	0	0	0	0.032
Lutjanidae	0.009	0	0	0	0	0	0.009
Plectorhynchidae	0.003	0	0	0	0	0	0.003
Priacanthus spp.	0.022	0.007	0	0	0	0	0.029
Sillago spp.	0.001	0.002	0	0	0	0	0.003
Nemipterus spp.	0.027	0.007	0	0	0	0	0.034
Ariidae	0.012	0.003	0	0	0	0	0.015
Rays	0.011	0.002	0	0	0	0	0.013
Sharks	0.007	0.001	0	0	0	0	0.008
Cephalopod	0.062	0.087	0.001	0.001	0	0	0.151
Shrimps	0.076	0	0.011	0.023	0	0.108	0.218
Crab, Lobster	0.016	0.088	0.001	0.004	0	0	0.109
Trashfish	0.553	0.114	0.007	0.02	0	0	0.694
Small demersal fish	0	0.038	0.001	0.003	0	0	0.042
Medium Demersal piscivore	0	0.001	0	0	0	0	0.001
Medium Demersal benthivore	0.006	0.001	0	0	0	0	0.007
Shellfish	0	0	0	0	0	0.426	0.426
Coastal tuna	0	0	0	0	0.011	0	0.011
Sergestid shrimp	0	0	0.001	0.004	0	0.036	0.041
Juvenile small pelagics	0.011	0.085	0	0	0	0	0.096
Juvenile *Caranx* spp.	0.008	0.017	0	0.001	0	0	0.026
Juvenile *Saurida* spp.	0.026	0.017	0	0	0	0	0.043
Juvenile *Nemipterus* spp.	0.054	0.004	0	0	0	0	0.058
TOTAL	0.991	0.543	0.023	0.072	0.158	0.646	2.433

Table 3. Diet compositions for the Ecopath model of the Gulf of Thailand (1973), the predator numbers refer to the Prey numbers.

Prey	Predator																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	29	30	31	32	33	34
1 *Rastrelliger* spp.	–	0.2	0.1	–	–	–	0.2	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	0.12	–	0.1	–	–	–
2 *Scomberomorus* spp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3 Carangidae	–	0.2	–	–	–	–	0.1	–	–	0.1	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	0.14	–	0	–	–	–
4 Pomfret	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	0.02	–	–	–	–	–
5 Small pelagic fish	–	0.1	0.2	0.1	–	0	0.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.2	–	0.4	–	–	–
6 False trevally	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.05	–	–	–	–	–
7 Large piscivores	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	0.01	–	–	–	–	–
8 Sciaenidae	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
9 *Saurida* spp.	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10 Lutjanidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
11 Plectorhynchidae	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	-0	–	–	–	–	–
12 *Priacanthus* spp.	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–
13 *Sillago* spp.	–	–	–	0	–	–	0	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	0.06	–	–	–	–	–
14 *Nemipterus* spp.	–	–	–	0	–	–	0.1	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	0.07	–	–	–	–	–
15 Ariidae	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	0	–	–	–	–	–	0	–	–	–	–	–	–	–	–
16 Rays	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
17 Sharks	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
18 Cephalopod	–	0.1	–	–	–	–	0.1	–	0.2	0.1	–	–	–	–	–	–	–	0	–	–	–	–	0	–	–	0.05	–	0.1	–	–	–
19 Shrimps	–	0.1	0.1	0.1	–	–	–	0.15	–	0.1	0.1	0	0	0	0.1	0.1	0.1	0.1	–	–	–	0	0.1	0.1	–	–	–	–	–	–	–
20 Crab, Lobster	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	–	0.01	–	–	–	0	–
21 Trashfish	–	0.05	0.2	0.2	–	–	0.1	0.15	0.3	0.3	–	0	–	–	–	–	0.1	0.1	–	–	–	–	0.2	0	–	–	–	0.2	–	–	–
22 Small demersal fish	–	0.05	0.1	0.2	–	–	0.1	0.1	0.2	0.1	–	–	–	–	–	–	0.1	–	–	–	–	–	0.3	–	–	0.05	–	0.1	–	–	–
23 Medium demersal piscivore	–	–	–	–	–	–	0.2	–	–	0.1	–	–	–	–	–	–	0.2	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–

Table 3. Diet compositions for the Ecopath model of the Gulf of Thailand (1973), the predator numbers refer to the Prey numbers. (continued)

Prey	Predator																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	29	30	31	32	33	34
24 Medium demersal benthivore	–	–	–	–	–	–	0.1	–	0.2	–	–	–	–	–	–	–	0.1	–	–	–	–	–	0.2	–	–	0.03	–	–	–	–	–
25 Shellfish	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	0.1	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–
26 Jellyfish	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
27 Sea cucumber	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
28 Seaweeds	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
29 Coastal tuna	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
30 Sergestid shrimp	–	–	–	–	–	0	–	0.1	–	0.1	–	–	–	–	0.1	–	–	0.1	–	–	–	0	–	–	–	–	–	–	–	–	–
31 Mammals	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–
32 Ponyfishes	–	–	0.1	–	–	–	–	0.1	0.1	–	–	0	–	–	–	–	–	0	–	–	–	–	0	0	–	–	–	–	–	–	–
33 Benthos	–	–	0.1	0.2	–	–	–	0.2	0.1	0.1	0.8	0	1	1	0.8	0.8	0.1	–	0	1	0.3	0	0.1	0.8	–	–	0	0.2	0	0.1	-
34 Zooplankton	0.9	0.1	0.2	0.2	1	0	–	–	–	–	–	0	–	0	–	–	–	0.6	0	–	0.3	0	–	–	0	–	0	0.1	0	0.1	–
35 Juvenile small pelagics	0.1	0.03	–	–	–	0	–	0.03	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	0.02	–	–	–	–	–
36 Juvenile *Caranx* spp.	–	0.03	–	–	–	0	–	0.03	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	0.02	–	–	–	–	–
37 Juvenile *Saurida* spp.	–	0.03	–	–	–	–	–	0.03	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	0.02	–	–	–	–	–
38 Juvenile *Nemipterus* spp.	–	0.03	–	–	–	–	–	0.03	–	–	–	–	–	–	–	–	–	0	–	–	–	–	–	–	–	0.02	–	–	–	–	–
39 Phytoplankton	0.1	–	–	–	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.3	–	–	–	1	–	–	–	–	0.2	1
40 Detritus	–	–	–	–	–	–	–	0.1	–	–	0.1	–	–	0	–	0.1	–	–	1	1	0.3	–	–	0	–	–	1	–	0	0.6	0

Estimates of primary production were obtained from (Lursinsap 1980; Lursinsap 1982) (Lursinsap and Taocharlee, 1989). The factor of 7.47 (Cushing, 1973) was used to convert gram carbon to wet weight. Hence, 1 gC•m^{-2}•day^{-1} of primary production corresponds to (7.47* 365*10 000)/ 1 000 t•km^{-2}•year^{-1} of production.

The percentage contribution of four juvenile fish groups to trashfish catch from otter board trawls, pair trawls and purse seines are given in Table 4.

Table 4. Percentage contribution of juvenile ecological groups in catches of trash fish of each fleet.

Juvenile Ecological Groups	Fishing Fleet		
	Otter board trawl	Pair trawl	Pushnet
Juvenile small pelagics	1.5	23.7	0.6
Juvenile *Caranx* spp.	1.1	4.6	5.0
Juvenile *Saurida* spp.	3.4	4.8	0.1
Juvenile *Nemipterus* spp.	7.2	1.0	0.1

Economic Data

The market price of each group was estimated from landed prices during the year 1997 (Department of Fisheries (Thailand), 1998). The value was estimated as the mean price for all sizes of the most abundant species comprising the group (Table 5). The cost and revenue structure for fishing fleets/gears operating in the Gulf of Thailand were estimated for the modeling exercise (Table 6). Fixed cost includes institutional costs such as fishery research, management and administrative cost, and enforcement cost. Fixed cost was estimated from expenditures of the Department of Fisheries for the year 1998. Fishing cost is categorized into effort-related cost and sailing-related cost. Sailing-related cost consist of gasoline and lubricant, while the effort-related cost includes all variable costs. Estimates of fishing cost were obtained from the 1998 surveys conducted by the Fishery Economic Division, Department of Fisheries. Total revenue and the profit of each fleet was estimated by using the catch data based of 1993 and 1995 of the surveys of the Fishery Economic Division of the Department of Fisheries.

Investigating Impact of Multi-fleet Harvesting Strategies

The investigations were made using the ‘Fishing Policy Search’ option of the Ecosim module of Ecopath (Christensen et al. 2000) for a description of this optimization routine. As Ecosim simulations are very sensitive to the assumption of top-down versus bottom-up control, the simulations were run with varying vulnerability settings. The vulnerability setting regulates how prey in a given predator-prey interaction changes between being vulnerable and non-vulnerable to the predator (Walters et al. 1997; Walters et al. 2000). The rationale for this is that at a given moment in time, not all prey biomass are vulnerable to predators. Predator-prey relationships in nature are often limited by behavioural and physical mechanisms, such as schooling behaviour and diel verticalmigration patterns in clupeid fish, or spatial refuges used by many reef fish that considerably limit exposure to predation. The model is designed so that users can specify the type of trophic control in the food web. For low predator biomass or high exchange rate (v_{ij}), the functional relationship approximates a mass-action flow implying a strong top-down effect. For high consumer biomass or low exchange rates, the functional relationship approaches a donor-controlled (bottom-up) flow rate. In this study, the v_{ij} values were fixed at 0.2, 0.3 and 0.5 in each strategy to test the trophic control hypotheses. A discount rate of 4% was used in all simulations. Five different strategies were studied using the Ecosim optimization routine, four of which are summarized in Table 7.

Table 5. Fish group price (Baht/kg) by fishing fleet, 1997*.

Ecological groups	Otter board trawl	Pair trawl	Beam trawl	Push net	Purse seine	Other gear
Rastrelliger spp.	22.43	22.43	22.43	22.43	27.77	30.00
Scomberomorus spp.	67.64	67.64	67.64	67.64	55.88	72.70
Carangidae	15.46	15.46	15.46	15.46	17.21	0
Pomfret	103.47	103.47	103.47	103.47	0	151.99
Small pelagic fish	15.94	15.94	15.94	15.94	7.50	7.50
False trevally	80.00	80.00	80.00	80.00	35.00	0
Large piscivores	25.00	25.00	25.00	25.00	0	0
Scieanidae	17.50	17.50	17.50	17.50	0	0
Saurida spp.	10.90	10.90	10.90	10.90	0	0
Lutianidae	54.70	54.70	54.70	54.70	0	0
Plectorhynchidae	54.70	54.70	54.70	54.70	0	0
Priacanthus spp.	10.67	10.67	10.67	10.67	0	0
Sillago spp.	30.00	30.00	30.00	30.00	0	60.00
Nemipterus spp.	13.59	13.59	13.59	13.59	0	0
Ariidae	30.00	30.00	30.00	30.00	0	0
Rays	12.86	12.86	12.86	12.86	0	30.00
Sharks	17.00	17.00	17.00	17.00	0	20.00
Cephalopod	56.22	56.22	56.22	56.22	40.00	70.00
Shrimps	72.08	72.08	72.08	72.08	0	198.17
Crab, Lobster	44.06	44.06	44.06	44.06	0	70.00
Trashfish	2.55	2.55	2.55	2.55	0	4.00
Small demersal fish	17.00	17.00	17.00	17.00	0	0
Mededium Demersal piscivore	19.06	19.06	19.06	19.06	0	0
Medium Demersal benthivore	29.70	29.70	29.70	29.70	0	0
Shellfish	7.98	7.98	7.98	7.98	0	0
Jellyfish	1.83	1.83	1.83	1.83	0	4.00
Sea cucumber	17.00	17.00	17.00	17.00	0	25.00
Seaweeds	7.50	7.50	7.50	7.50	0	10.00
Coastal tuna	21.00	21.00	21.00	21.00	26.00	0
Sergestid shrimp	14.85	14.85	14.85	14.85	0	15.00
Ponyfishes	2.55	2.55	2.55	2.55	0	5.00
Juvenile small pelagics	2.55	2.55	2.55	2.55	5.00	5.00
Juvenile *Caranx* spp.	2.55	2.55	2.55	2.55	0	0
Juvenile *Saurida* spp.	2.55	2.55	2.55	2.55	0	0
Juvenile *Nemipterus* spp.	2.55	2.55	2.55	2.55	0	0

*** Source of data: Fishery Economic Division, Department of Fisheries (Thailand) 1998.**

Table 6. Catch and revenue structure by fishing fleet used as input for modelling.

Fleet	Fixed cost (%)	Effort related cost (%)	Sailing related cost (%)	Profit (%)
Otter board trawl	1.2	49.2	35.4	14.2
Pair trawl	0.7	43.1	27.7	28.6
Beam trawl	0	57.3	39.9	2.8
Pushnet	0.7	30.5	66.7	2.1
Purse seine	1.1	42.1	26.9	29.9
Other gears	1.4	56.5	40.7	1.4

Table 7. Summary of strategies examined using the Ecosim routine for optimization of fishing effort.

Strategy	Net economic value	Social value	Eco-system value	Vulner-ability
1. Economic consideration	1	0.0001	0.0001	0.2 0.3 0.5
2. Social consideration	0.0001	1	0.0001	0.2 0.3 0.5
3. Ecological consideration	0.0001	0.0001	1	0.2 0.3 0.5
4. Weighted compromise	1	1	1	0.2 0.3 0.5

Results and Discussion

Ecopath Model Results

The Ecopath model developed here is fairly detailed, but an overview of the groups included and their biomasses and trophic levels can be obtained from the simplified flowchart given in Figure 2. The figure indicates a predominance of groups feeding around trophic level 3, i.e. first order carnivores. This may be indicative of a severely exploited system, where top predator biomasses are minimal, and where the system is dominated by small-sized, fast-growing prey fishes and invertebrates. The predominance of low-trophic level groups in the system is also apparent when examining the biomass by trophic level as estimated from network analysis (Table 8). Overall, this supports the notion that the system has been severely modified through removal of top predators.

Table 8. Biomass by trophic level in the Gulf of Thailand 1973 model.

Trophic level	Biomass ($t \cdot km^{-2} \cdot year^{-1}$)
VI	0.003
V	0.048
IV	0.565
III	8.787
II	50.595

Figure 3 shows a mixed trophic impact analysis for the Gulf of Thailand (1973) ecosystem model. The analysis shows that the bottom trawls have major impact on a large number of groups. Interestingly, bottom trawls even have a positive impact on Carangidae and Pomfrets even though the gear catches them both. Such 'beneficial predation' (as it is termed technically) is caused by bottom trawls favoring groups by negatively impacting their predators and competitors. Sharks show the same form of beneficial predation with Carangidae and Pomfrets.

Time Series Fitting Using Ecosim

In order to use the Ecosim model for policy exploration it is desirable to study how well the model can replicate events in an ecosystem. For the present study this was done by using time series data for relative effort over time (Table 9) to force the Ecosim simulations. This being done, the simulations are studied for correspondence between predicted biomasses over time, and observed biomasses based on trawl survey CPUE. The correspondence is then sought to be improved via the process detailed in Christensen et al. (2000). The end result is a fit as shown in Figure 4.

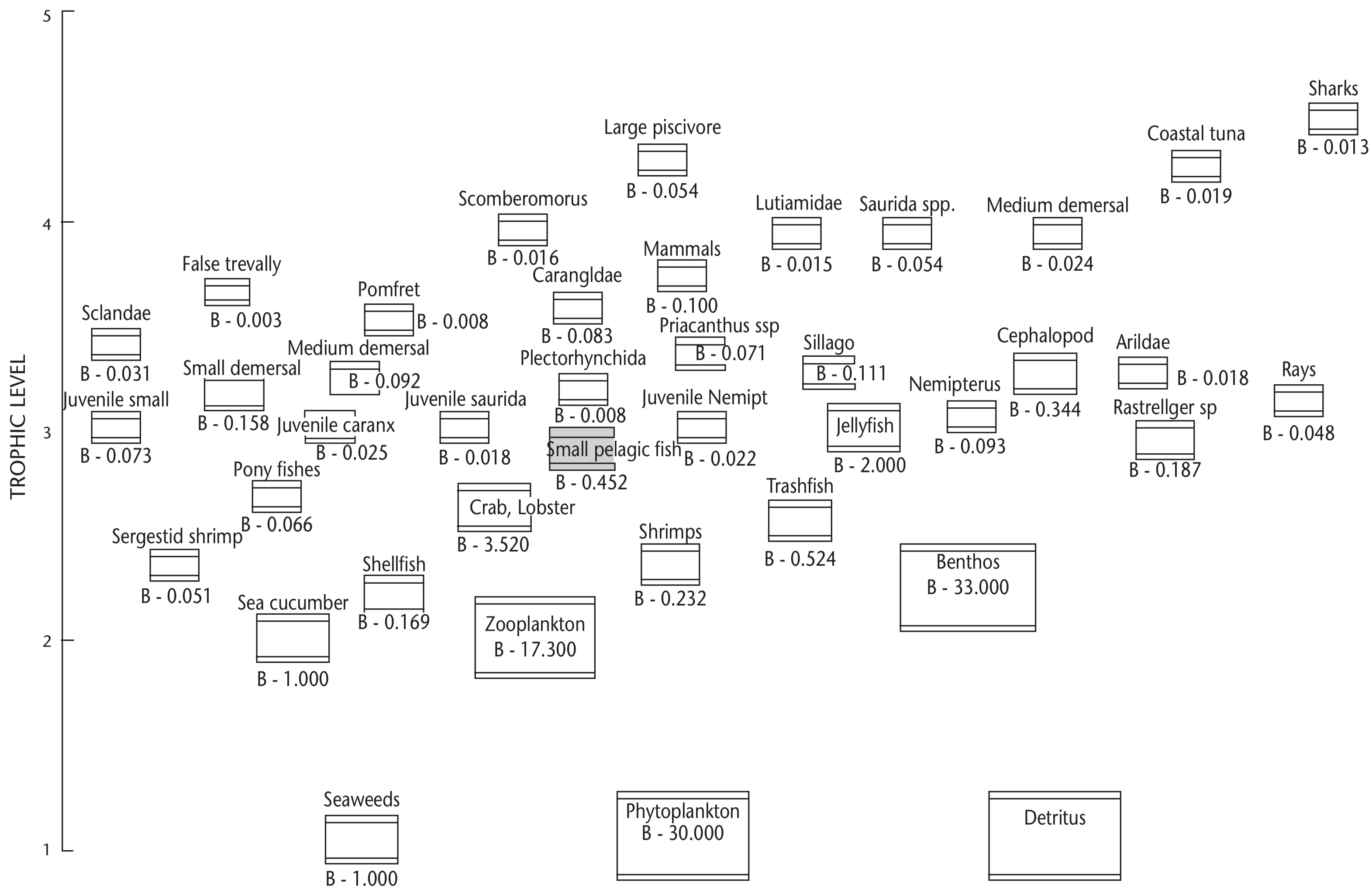

Fig. 2. Ecological groups included in the Gulf of Thailand ecosystem model. The groups are arranged by trophic level on the Y-axis, and the box size is a function of biomass (B).

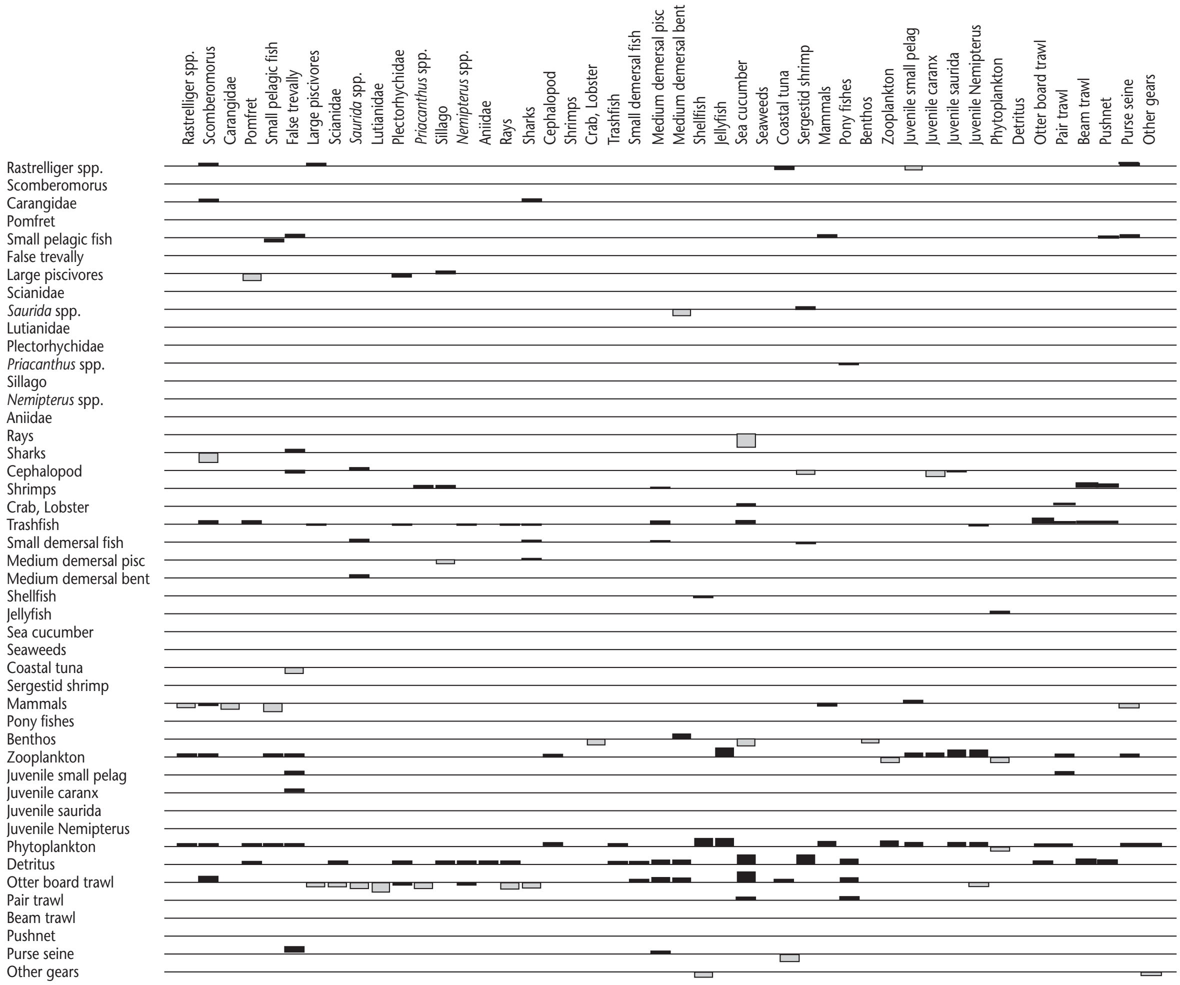

Fig. 3. Mixed trophic impact showing the impacting (rows) and impacted groups (columns). Positive impacts are shown above the baseline, and negative below. The impacts are relative, but comparable between groups.

Table 9. Relative effort time series data for "forcing" Ecosim simulations.

Year	Otter trawl	Pair trawl	Beam trawl	Push-net	Purse-seine	Other gear
1973	1	1	1	1	1	1
1974	1.00	1.00	1.00	1.00	1.00	1.00
1975	0.81	0.82	0.50	0.81	1.04	1.03
1976	0.95	1.14	0.59	0.93	1.13	1.06
1977	0.78	0.92	0.61	0.73	1.20	1.09
1978	1.28	1.39	1.69	1.35	1.32	1.13
1979	1.19	1.11	1.01	1.02	0.97	1.16
1980	1.05	0.98	0.73	1.19	1.08	1.19
1981	1.19	1.87	2.10	1.68	1.09	1.23
1982	1.43	1.09	3.51	1.94	1.23	1.27
1983	1.45	1.10	2.74	4.54	1.22	1.30
1984	1.49	1.17	1.76	1.51	1.22	1.34
1985	1.00	0.94	0.44	0.84	1.55	1.38
1986	1.12	1.00	0.21	0.61	1.70	1.43
1987	1.57	1.40	0.11	0.67	1.91	1.47
1988	2.35	1.88	0.05	1.18	1.77	1.51
1989	2.73	2.57	0.08	0.95	1.92	1.56
1990	3.64	2.98	0.13	1.39	2.09	1.60
1991	3.32	2.36	0.10	1.41	2.25	1.65
1992	3.10	1.83	0.13	1.89	1.70	1.70
1993	2.60	1.87	0.07	1.62	1.64	1.75

Fisheries Status in 1973 Compared to 1993

Results from Ecosim simulations based on the fitted time series (1973 - 1993) show that the total catches of 1.454 t•km^{-2} in 1973 was shared by otter board trawl (36.24%), pair trawl (28.8%), beam trawl (1.51 %), pushnet (5.16%), purse seine (10.2 %) and "other gear" (18.1%) (Table 10). The percentage catches in 1993 by otter board trawl increased to about 41% and the catches by pair trawl, beam trawl, pushnet and purse seine were less than that in 1973 while only "other gears" slightly increased (Table 10 and 11). Comparing 1973 and 1993, it is obvious that the catch, catch value or revenue, and cost were lower in 1973 than in 1993 but the profit of all fleets were higher. It is estimated that the profit of all fleets in the gulf decreased over time. Finally, considerable profit would be lost if the fisheries of the Gulf of Thailand keeps growing in the absence of appropriate regulations.

Simulations of Management Measures/ directions

Effect of Pushnet Fishery Ban

The effect of a pushnet fishery ban was simulated using Ecosim by conducting simulations including and excluding fishing effort by the pushnet fleet. The results are given in Table 12. The catch, revenue, cost and profit of the six fishing fleets in 2000 (with a ban of pushnets) were not very different from those in 1993. Only otter board trawl could gain a little more catch and revenue but lesser profit than the year 1993. The push net fishery ban has no effect on the fisheries situation.

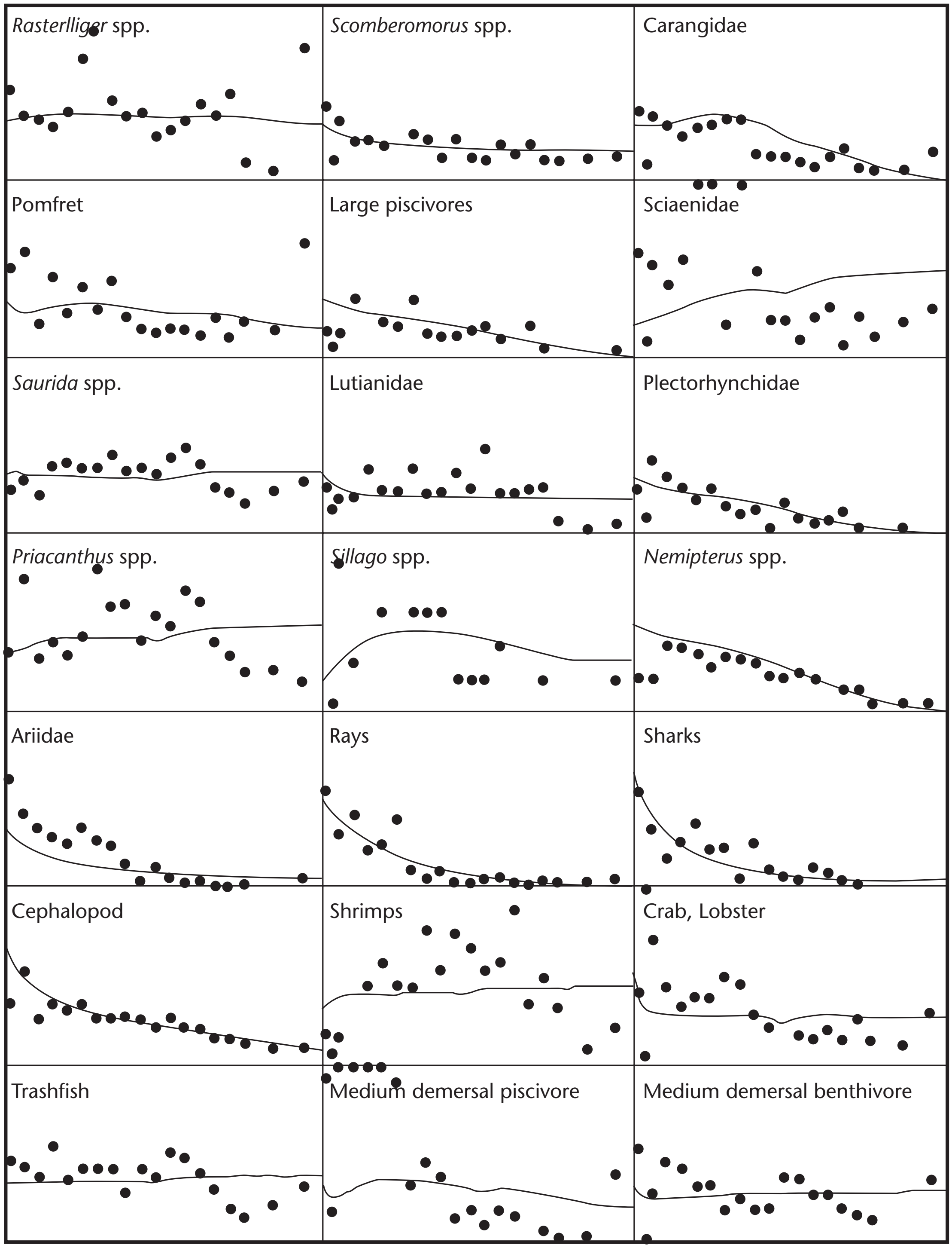

Fig. 4. Time series fit from Ecosim simulation over the period 1973 - 1993. The dots are biomass estimates based on trawl survey CPUE, while the lines shows biomass trends predicted by Ecosim.

Table 10. The fishery status in 1973.

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	0.527	10.266	13.661	-3.395
Pair trawl	0.419	6.643	10.716	-4.073
Beam trawl	0.022	1.106	0.865	0.241
Pushnet	0.075	2.738	2.082	0.656
Purse seine	0.148	2.474	2.610	-0.136
Other gear	0.263	29.278	21.210	8.068
TOTAL	1.454	52.505	51.140	1.365

Table 11. The fishery status in 1993.

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	0.971	21.348	31.138	-9.790
Pair trawl	0.620	10.781	14.431	-3.650
Beam trawl	0.002	0.086	0.084	0.002
Pushnet	0.097	3.573	3.341	0.232
Purse seine	0.231	3.732	3.442	0.290
Other gear	0.449	48.415	44.225	4.190
TOTAL	2.370	87.936	96.660	-8.724

Table 12. Ecosim results incorporating "Pushnet fishery ban from 1993 up to 2000".

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	1.027	22.103	32.693	-10.590
Pair trawl	0.632	10.860	18.195	-7.335
Beam trawl	0.002	0.089	0.078	0.011
Pushnet	0	0	0	0
Purse seine	0.235	3.7690	4.425	-0.656
Other gear	0.459	50.151	40.349	9.802
TOTAL	2.354	86.972	95.74	-8.768

No Fishing of Four Juvenile Fish Groups and Trashfish

The effect of "no fishing of four juvenile groups and trashfish group" was observed through Ecosim simulations for the year 1993 through 2000 (Table 13). It is apparent that catches are lesser in all fleets whilst revenues are higher with lower costs. The costs are almost the same as the fisheries in 1993. Overall, the fisheries can gain more profits especially the otter board trawlers. This is because the fisheries are catching higher price, big-sized fish by enlarging the cod-end mesh size of trawlers since trawlers are catching a high percentage of juvenile fishes and trashfish. In this case, however, there may be implementation difficulties. Trashfish demand to supply fishmeal for aquaculture and fowl rearing remains strong. Importing trashfish and using the sardine catches to fill the trashfish demand of fishmeal factories may be one of the viable solutions.

No Fishing of Four Juvenile Groups Combined with Pushnet Fishery Ban

The effects of "no fishing of four juvenile groups and pushnet fishery ban" from 1993 to 2000 were simulated by Ecosim (Table 14). Results show slightly smaller catch and higher profit overall of the fisheries as compared to the "no fishering of juvenile fish and trashfish" scenario. Other gears gains much more profit relatively than the other five fleets/gears making 2.679 thousand Baht•km^{-2} by catching only 0.44 t•km^{-2}. The pair trawl fleet still has minus profit as in all other cases. This case gives the highest profit at 7.734 thousand Baht•km^{-2} with a total catch of 8.4 t•km^{-2}.

Table 13. Ecosim results incorporating "no fishing of four juvenile groups and trashfish group".

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	6.393	36.711	31.138	5.573
Pair trawl	1.888	14.325	14.431	-0.106
Beam trawl	0.002	0.082	0.084	-0.002
Pushnet	0.133	3.397	3.341	0.056
Purse seine	0.225	3.976	3.442	0.534
Other gear	0.430	45.144	44.225	0.919
TOTAL	9.071	103.634	96.66	6.974

Table 14. Ecosim results incorporating "no fishing of four juvenile groups combined with pushnet fishery ban".

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	5.930	36.607	31.828	4.779
Pair trawl	1.800	14.087	14.357	-0.270
Beam trawl	0.003	0.096	0.094	0.002
Pushnet	0	0	0	0
Purse seine	0.227	3.986	3.442	0.544
Other gear	0.440	46.904	44.225	2.679
TOTAL	8.400	101.680	93.946	7.734

Optimization of Fishing Effort

To optimize fishing effort of the fisheries, Ecosim search assuming 10% profit in all fisheries at initial state was run through 2000. Results indicate that the fisheries could catch 2.421 t•km^{-2} with total profit of 4.343 thousand Baht•km^{-2} (Table 15). The best performing fleet was the "other gear", which would give highest profit of 18.641 thousand Baht by catching 0.882 t•km^{-2}.

The optimization of fishing with variable profit as initial state indicates that overall fisheries profit is negative. Pair trawl would give highest negative profit while other gear would give highest profit of 61.763 thousand Baht•km^{-2} by catching 1.772 t•km^{-2}.

Harvesting Strategies Based on Economic, Social and Ecosystem Considerations

Table 16 gives the results of economic optimization with three values of vulnerability: 0.2 (bottom- up control), 0.3 (mixed control), and 0.5 (top-down control). The best economic value is shown at v = 0.3 which gives the net economic value, social value, ecosystem stability and total values 0.6, 1.3, 1.0 and 0.9, respectively. The optimum fishing effort over time was obtained by reducing PT by 20%, reducing beam trawl and pushnet by 50% increasing otter board trawl by about 40%, and increasing purse seine and other gear by about 10% and 100%, respectively.

In the Ecosim optimizations targeting maximum social benefits (i.e. jobs which equates to increasing the value of the catch), the best results obtained were 1.6 for the social factor, with an economic value of 0.5, and an ecosystem stability value of 0.8 (all expressed relative to the 1973-level). The optimum fishing effort over time was obtained by increasing (relative to the 1973 level) beam trawl by 60% and pushnet by 75%, while otter board trawl, purse seine and other gear were reduced by 100%, 20% and 430%, respectively, to serve the social objectives.

The optimization for ecosystem stability did not give consistent results, and needs further work before they can be considered.

The set of simulations seeking to optimize economic, social and ecosystem considerations, simultaneously indicate that best output was obtained using a mixed control setting (v = 0.3). Optimum effort was obtained by increasing pair trawl, beam trawl, pushnet and purse seine by about 20%, 72%, and 98% respectively; while otter beam trawl and "other gear" have to increase by about 32% and 180%, respectively, all compared to the 1973 level.

Table 15. Optimum fishing search results with initial setting of 10% profit for all fleets.

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	0.013	0.108	0.301	-0.193
Pair trawl	1.457	17.401	31.283	-13.882
Beam trawl	0.001	0.055	0.046	0.009
Pushnet	0.009	0.277	0.240	0.037
Purse seine	0.119	2.002	2.271	-0.269
Other gear	0.822	98.669	80.028	18.641
TOTAL	2.421	118.511	114.170	4.343

Table 16. Optimum fishing search results with initial setting of variable profit.

Fishing Fleet	Catch (10^3 Baht·km^{-2})	Revenue (10^3 Baht·km^{-2})	Cost (10^3 Baht·km^{-2})	Profit (10^3 Baht·km^{-2})
Otter board trawl	0.013	0.644	0.993	-0.349
Pair trawl	1.752	72.963	169.24	-96.277
Beam trawl	0.01	0.634	0.459	0.175
Pushnet	0.027	1.207	0.868	0.339
Purse seine	0.097	1.174	1.653	-0.479
Other gear	1.772	184.757	122.994	61.763
TOTAL	3.673	261.379	296.21	-34.831

Conclusion

In this study, the time series of effort data for purse seine and other gears were based on an assumed rate of effort increase of 3% per year for the period considered. It would be preferable to use actual rather than assumed data. It is also clear that the software used is still under development, and more experience should be sought before using it for actual management. However, we find the approach very promising, and expect it to be widely used.

Among the estimations and simulations performed using Ecosim, the option of "no fishing for juvenile fish combined with a pushnet fishing ban seems to give highest profit although prawn trawl still had negative profit, losing 0.27 thousand Baht in catching 1.8 t•km^{-2}). "No fishing of the juvenile groups" could be obtained by increasing cod-end mesh sizes, although it is not clear by how much. Before implentation, it would be necessary to conduct some experiments on the effect of increasing the cod-end mesh sizes of shrimp and finfish trawls to 2.5 and 3.0 cm, respectively. The experiments should be conducted using commercial fishing boats, and comparison with results from further simulations using Ecosim.

A pushnet fishery ban has been put in place by the Department of Fisheries since 22 June 2000. The DOF is trying to find the best way for fishers to improve the fishery situation and a public hearing has been held in early July 2000, where the preliminary results from the analysis presented here were discussed. At present, the pushnet fishery ban has been postponed for political reasons.

Further simulations on optimum fishing levels and the impact of current regulation concerning closed season and area (both inshore and offshore) using Ecosim and Ecospace for management purposes should be conducted. Data preparation for further simulation studies should be recommended to concerned parties. It is possible to use Ecopath with Ecosim and Ecospace to simulate the development of the fisheries, resources and ecosystem over time, and to study the implications of various management policies. The decision-makers and/or the researchers should be able to test management strategies through ecosystem simulation studies, using Ecosim to evaluate various options for optimizing fishing effort for the Thai fisheries taking into consideration both economic, social and ecological considerations, with the aim of promoting responsible and sustainable development.

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Appendix A. Aspect ratios of marine fishes in the Gulf of Thailand (1998).

Species	N	Caudal fin height (cm)	Caudal fin surface area (cm^2)	Aspect ratio(A_r) ($h^2 \cdot s^{-1}$)
Atule mate	10	6.53	9.23	4.62
Chirocentrus dorab	6	9.70	21.51	4.37
Pampus niger	10	8.95	17.65	4.54
Rastelliger spp.	10	4.84	5.70	4.11
Scomberomorus commerson	12	10.22	23.80	4.39
Selaroides leptolepis	10	2.91	3.36	2.52
Epinephelus aureolatus	8	6.31	23.73	1.68
Epinephelus sexfasciatus	9	2.53	5.70	1.12
*Lutjanus lineolatus (Lutjanus lutjanus**)*	9	5.09	10.10	2.57
Lutjanus malabaricus	11	7.96	37.46	1.69
Mullidae	6	7.28	12.23	4.33
Nemipterus hexodon	10	5.83	10.44	3.26
Nemipterus mesoprion	10	4.84	6.83	3.43
Nemipterus peronii	10	7.03	11.21	4.41
Priacanthus macracanthus	3	6.43	14.4	2.87
Priacanthus tayenus	10	6.56	14.58	2.90
Platycephalidae	12	3.74	8.01	1.75
Saurida elongata	6	8.13	17.5	3.78
Saurida undosquamis	10	6.70	11.11	4.04
Scolopsis taeniopterus	10	6.15	11.43	3.31
Siganidae	10	4.42	7.04	2.78
Nemipterus tambuloides	10	6.74	11.05	4.11
Rachycentron canadus	7	11.40	45.48	2.86
Epinephelus morrhua	9	5.52	19.34	1.58
Euthynnus affinis	10	9.61	15.07	6.13
Thunnus tonggol	9	10.38	19.98	5.39

Note: ** valid name in FishBase 2000.