6 ECOPATH-ECOSYSTEM MODELLING OF THE GULF OF THAILAND

6.1 INTRODUCTION

The Gulf of Thailand has been used as a case study in numerous analyses to illustrate how fisheries development may impact ecosystem resources, for example May *et al.* (1979), Pauly (1979) and Beddington and May (1982). The main reasons for this interest are that the demersal resources of the Gulf of Thailand were virtually unexploited until the early 1960s and that the state of the demersal resources since then has been documented continuously through standardized research vessel trawl surveys.

These research vessel surveys are conducted by the Thai Marine Fisheries Division to investigate the state of the marine resources following the introduction of German otterboard trawling in 1960 (Tiews, 1962). From 1960 to 1965 the trawl surveys were done in at pre-specified stations. From 1966 onwards, the Gulf of Thailand was divided into nine areas, Area I to Area IX and about 500 stations or grids were defined, each grid covering 225 nm² (15nm * 15 nm). Initially the surveys were conducted on a monthly basis, with a variable number of stations being covered. In more recent years the number of stations covered by the surveys has been reduced due to the high costs involved. From 1994 onwards, the routine surveys are done on a bi-monthly basis, with daytime and nighttime operations alternating between years (Vibunpant *et al*., 2000).

The demersal fisheries in the Gulf developed rapidly after their introduction in the mid 1960s, while the CPUE of the trawl surveys showed a progressively decreasing trend from 1966 to 1995. In 1966, the average CPUE of the total catch by research vessels was 172.9 kg/h. A sharp decline occurred from 1966 to 1975 with the CPUE declining to 61.5 kg/h. From 1975 to 1983 the decreasing trend was rather stagnant with the CPUE around 50 kg/h and it slightly increased in 1984 to reach 62.1 kg/h. Thereafter, the CPUE declined again and it reached a minimum of 21.5 kg/h in 1995.

The present report uses ecosystem modelling to investigate bio-economic aspects of resource utilization in the Gulf of Thailand. The ecosystem model used for the analysis is developed using the ECOPATH with ECOSIM software (available at www.ecopath.org) and it draws on a series of previous models. Pauly and Christensen (1993) thus constructed two preliminary ECOPATH models of the Gulf of Thailand, one covering the 0-10 m depth zone and another covering the 10-50 m depth zone. These models were constructed based mainly on catch statistics data from FAO and they did not incorporate the research vessel information from the Gulf of Thailand.

Subsequently, Christensen (1998) constructed two mass-balance trophic models based on information from the research vessel surveys. One of these described the initial phase of fisheries development in the mid-1960s and the other the phase of severe depletion of the early-1980s. Christensen further used the dynamic simulation model ECOSIM to study if the changes in catch composition and abundances over the time period could be explained by the impact of the fisheries and he concluded that this was likely. More recently, Vibunpant *et al*. (2000) described a trophic model of the coastal fisheries ecosystem in the Gulf of Thailand. Also, work is presently in progress as part of an ADB-funded regional technical assistance (ADB-RETA 5766) to develop an ecosystem model of the Gulf of Thailand. This section in the present report is based on an updated model developed in synergy between the ADB-RETA and the present FAO/FISHCODE sponsored activity.

6.2 ECOSYSTEM MODELING AND ITS RELEVANCE FOR THE WORKSHOP OBJECTIVES

The workshop was designed to study bio-economic aspects of the demersal fisheries of the Gulf of Thailand and as described in Section 3.6 the workshop applied three different model types to address the workshop's objectives. One of these was a generic ecosystem model, ECOPATH with ECOSIM, which has been widely used throughout the world for ecosystem modelling and which is increasingly being used for ecosystem-based management of fisheries. As it incorporates ecological considerations to the question of how to manage fisheries it provides a useful addition to more traditional approaches to fisheries management. The model builds on information obtained through the traditional stock assessments. ECOPATH is a mass-balance model that can be constructed based on fairly easily accessible biological and ecological parameters. The basic equations through which mass-balance is achieved state that:

Production = Predation mortality + fishing mortality + biomass accumulation + net migration + other mortality

and

Consumption = Production + unassimilated food + respiration

ECOPATH models are in general constructed so as to include all functional groups (or ecological 'guilds') and fisheries living in and impacting an ecosystem. Models often include 30 or more functional groups and are often parameterized using available information from the ecosystem in question, supplemented with published data from various other sources. In many recent applications, the FishBase database (www.fishbase.org) has been used to supply published information and the database has indeed been modified to incorporate a search routine to extract information of use for ECOPATH modelling for any given ecosystem.

The ECOPATH approach differs from the other models being used at this workshop through incorporation of ecosystem groups with the aim of covering all functional groupings A consequence of this is also that it is required to incorporate information about the pelagic fisheries in the Gulf of Thailand to get a more complete picture of the resource utilization and to include that there is considerable interaction between the demersal and pelagic resources of the Gulf.

ECOPATH requires input of the following information for each ecosystem group:

- Biomass (in t/km²);
- Total mortality rate (= production/biomass) ($year^{-1)}$;
- Consumption/biomass ($year^{-1}$);
- Diet composition;
- Landings and discards by fleet (in t/km²/year).

ECOPATH incorporates a basic bio-economic model based on the following information:

- Cost (fixed and variable) of fishing by fleet;
- Landing prices by ecosystem group and by fleet.

The basic ECOPATH model is used to give a static description of the ecosystem and to ensure that the data material is sufficient and compatible, and that mass-balance is ensured. A series of checks is made to ensure that the material is physiologically acceptable and that the result is a plausible ecosystem description. The ECOPATH approach incorporates a series of facilities to explicitly consider uncertainty in the data material, including a Bayesian Monte Carlo approach, but these tools were not formally used at the workshop due to time constraints.

Once an ECOPATH model has been parameterized and balanced using the ECOPATH with ECOSIM software, it can be analysed in a temporal or spatial context in order to address various management questions. The temporal analyses are performed using the ECOSIM module of the software, while the spatial analyses rely on the ECOSPACE module, also integrated in the software. Both of these modules use the underlying ECOPATH model for the basic parameterization, while requiring only a fairly limited set of additional parameters for their application.

The basics of ECOSIM consist of biomass dynamics expressed in the form of coupled differential equations derived from the ECOPATH production equation given above. ECOSIM bases the crucial assumption for prediction of consumption rates on a simple Lotka-Volterra or ‘mass action’ assumption, modified to consider ‘foraging arena’ properties. Following this, prey can be in states where it is either vulnerable to predation or not, for instance when not feeding by hiding in crevices of coral reefs or inside a school. It is then only subject to predation (available prey) when having left its shelter to feed (see Figure 6.1).

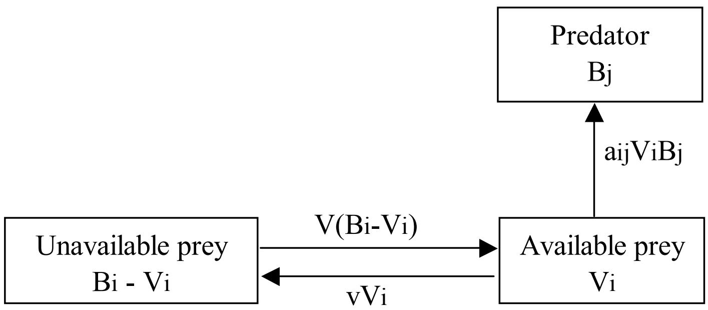

Figure 6.1 Simulation of flow between available (V_i) and unavailable (B_i - V_i) prey biomass in ECOSIM. a_{ij} is the predator search rate for prey i, v is the exchange rate between the vulnerable and not-vulnerable state. High v-values lead to top-down control and low v-values to bottom-up control. Based on Walters *et al.* (1997)

To better represent ontogenetic shifts in ECOSIM groups can be split into juvenile and adult components and ECOSIM then applies a Deriso-Schnute Delay-Difference Model to keep track of the number that recruits from juvenile to adult stages and the numbers at age/size in the adult groups (Walters *et al.*, 2000).

The ECOSPACE model is a dynamic, spatial version of ECOPATH, incorporating all key elements of ECOSIM (Walters *et al.*, 1998). ECOSPACE dynamically allocates biomass across a grid map while accounting for advection and movements, modified by whether a cell is defined as ‘preferred habitat’ or not, user-defined increased predation risk and reduced feeding rate in non-preferred habitats, a level of fishing effort that is proportional, in each cell, to the overall profitability of fishing in that cell. The distribution of fishing effort can also be made sensitive to costs (e.g. sailing costs). Given its recent origin, only a few applications of ECOSPACE have been published. Given its structure, ECOSPACE allows users to explore the potential of using the introduction of protected areas as a tool to mitigate and perhaps reverse various ecosystem effects of fishing.

The ECOPATH model developed at the workshop can be used to address five of the six objectives put forward for the workshop to consider, see Tables 3.1 and 6.1, but due to time constraints only few of the possible analyses were actually performed.

Table 6.1 Workshop objectives and a summary of how they can be addressed using ecosystem modelling based on the ECOPATH with ECOSIM (EwE) approach using the Gulf of Thailand model constructed during the workshop

	Workshop objectives	EwE approach for addressing objective
a	Ban of pushnet fisheries	The EwE model incorporates six fleet categories, including a pushnet category. The pushnet effort can be reduced in the model and the ecosystem and economic consequences can be quantified.
b	Expansion of non-trawl zones from 1.6 (3 km) to 3 nautical miles	Can be simulated using the ECOSPACE module of EwE. Requires information on spatial distribution and preferences of ecosystem resources that were not available at the workshop. Because of this and because of time constraints the objective was not pursued at the workshop.
c	Impact of current regulations re closed seasons and areas	The ECOSPACE module of ECOSIM is explicitly constructed to address questions of this type. However, due to time constraints and lack of suitable information at the workshop the objective was not pursued at the workshop.
d	Increase of minimum mesh sizes to 2.5 or 3 cm	EwE at present does not explicitly consider size selectivity. The objective can however be addressed by simulating reduced fishing mortalities for the smaller sized fish species (including the ‘trashfish’).
e	Reduction in the numbers of trawlers within categories	The EwE model constructed here includes six fleets (trawlers, pair trawlers, pushnetters, beam trawlers, purse seiners and other gears). Simulations reducing effort for each of these can be run and the impacts quantified. However, due to time constraints this was not pursued during the workshop.
f	Effect of increase in fishing license fees	Requires more detailed economic analyses than incorporated in the ECOPATH approach.

6.3 THE GULF OF THAILAND ECOPATH MODEL

6.3.1 Ecosystem groupings and parameters

An ECOPATH model describing the 1973-state of the Gulf of Thailand and incorporating 40 functional groupings was constructed based on the model described by Christensen (1998), but updated to incorporate more groups as well as detailed information on catch compositions, notably for the pelagic fisheries, as well as CPUE estimates and biomass estimates from swept-area trawl survey analysis. The forty groups included a marine mammal group, twenty-three fish groups, four of which were split in adult and juvenile stages to make up a total of twenty-seven fish groups, nine groups of invertebrates, plus two primary producers and a detritus group.

The biomass of fish groups from research vessel data for 1973, the P/B ratios (or Z, total mortality) of fish groups and the diet compositions of preys and predators were input as a basic input of the ECOPATH model. ECOSIM can incorporate time series of biomass as well as landings and fishing efforts by fleets. As for economic parameters, the ECOPATH model uses fish market prices and fixed and variable costs by fleet as described above.

The total mortalities (Z) of fish groups input in the ECOPATH model were based on the Z values in Christensen (1998), as were the consumption/biomass ratios. As part of the fitting to time series in ECOSIM it was necessary to change (or rather reduce) some of the original mortality rates. However, for most groups where changes were necessary the approach adopted was not to use the total mortality rate as input, but instead use an EE value of 0.95 (corresponding to assuming that the ECOPATH model explains 95% of the mortality for the groups in question) and then let the program estimate the mortality rate utilizing mass-balance constraints.

The diet compositions for the consumers in the model were extracted from a series of publications and FishBase (Intong, 1977, 1980 and 1982; Yamashita *et al.,* 1987; Sribyatta, 1996; Suwanrumpha, 1995; Christensen, 1998; FishBase (www.fishbase.org, Froese and Pauly, 2000).

6.3.2 Fleet composition and landings

The operations of demersal as well as pelagic fisheries were taken into account in this ecosystem model study. A total of six fleets were defined, including otterboardtrawl (OBT), pair trawl (PT), pushnet (PN), beam trawl (BT), purse seines (Thai PS, Luring PS) and other gears (OG), including shellfish collecting, fish gillnet, shrimp gillnet, crab gillnet, bamboo stake trap, squid light luring fishing, squid trap, fish trap, *Acetes* scooping, hook and line, mackerel encircling gillnet and king mackerel gillnet.

Normally, it is necessary to specify the landings and discards of each fleet, but in this study discards are not specified since fish that is not used for consumption is usually landed as ‘trash fish’ and hence it is assumed that there are no discards. Fleet-specific prices are used to quantify the income by fleet. Based on fish prices, enforcement costs and other costs for each fleet, the model can calculate the total rent by gear (total value of catch less fishing costs). Costs are divided between fixed and variable costs, where the (fleet-level) fixed costs include management and enforcement costs. The variable costs are categorized as effort-related costs and sailing-related costs.

In 1997-1998 researchers of the Marine Fisheries Division, Department of Fisheries sampled the trashfish compositions in the catches of the various fishing fleets (OBT, PT, PN, PS). There is no trashfish caught by other gears (OG) due to the rather large mesh sizes used. Four groups of the most abundant juvenile fish species were extracted from the trashfish catches of each fleet as shown in Table 6.2.

Table 6.2 Percent of juvenile groups in catches of trash fish by otterboard trawlers (OBT), pair trawlers (PT) and pushnetters (PN)

Ecosystem group \ Fleet	OBT	PT	PN
Juvenile small pelagics	1.5	23.7	0.6
Juvenile Carangids (e.g. horse mackerels)	1.1	4.6	5.0
Juvenile Saurida (lizard fish)	3.4	4.8	0.1
Juvenile Nemipterus (threadfin breams)	7.2	1.0	0.1

*6.3.3 CPUEs and biomasses from research vessel surveys (*PRAMONG 2 *and* 9*)*

Time series of CPUE of daytime fishing from the research vessels, PRAMONG 2 and PRAMONG 9 were available for 1973-1995, except for 1990, 1992 and 1994, when the vessels operated during nighttime. The nighttime data were not used in this study. These time series of CPUE were also used as estimated relative biomass time series in the ECOSIM temporal simulation.

The mean CPUE of the research vessel for 1973 was used to estimate biomass by the swept-area method. The equations used to estimate the biomass were based on the following parameters:

A = Total area = 101,384 km^2

a = Swept area = D*h*X2 km^2

where

D = V*t = 2.5*1 (trawling speed of 2.5 knots for 1 hour)

h = head rope length = 39 m

X2 = 0.5

result

a = (2.5*1.852)*(0.039*0.5) = 0.090255 km^2

6.3.4 Landing data for commercial fleets

Landing data for the six commercial fleets: OBT, PT, PN, BT, PS and OG in 1973 were distributed over the 40 ecosystem groupings in the ECOPATH model, including splitting up of the trashfish to separately include catches of four groups of juvenile small fish, i.e., small pelagics, *Caranx*, *Saurida* and *Nemipterus* (see Table 6.2). These four juvenile groups were extracted from trashfish using the percentage composition of juvenile fish in the trashfish catches of each gear with trashfish catches (OBT, PT, PN and PS). The landings by group were divided by the total fishing area (304,000 km^2) of the Gulf of Thailand to estimate landings per unit area.

Relative time series of group-specific landings ($t/km^2/year$) for the commercial fleets in the Gulf of Thailand from the years 1973 to 1993 were used to compare with the predicted catches from the temporal simulation of ECOSIM.

6.3.5 Effort data from the commercial fleets

The CPUE data from the research vessels PRAMONG 2 and PRAMONG 9 for the years 1973 to 1993 were used to standardize the fishing effort (operating hours) of the four commercial fleets (OBT, PT, BT, PN) by dividing the total landings of each fleet by the CPUE. Time series of relative fishing efforts (fishing hours) by fleet for the years 1973 to 1993 were estimated by setting the effort of the year 1973 as the standard.

The fishing efforts (number of fishing hours) of purse seine (PS) and other gears (OG) were directly converted into relative fishing efforts by setting the effort of the year 1973 as the standard. Time series of the relative fishing efforts for the years 1973 to 1993 were used as database for the temporal simulation of ECOSIM.

The fishing efforts of purse seines and other gears were estimated by assuming a yearly increase in effort of 3%, to create a 200% increase in effort over the twenty-year time series.

Table 6.3 Depth zones and distance from shoreline as input in the ECOSPACE module of ECOPATH with ECOSIM

Zone	Water depth (m)	Distance from shoreline (nm)	Distance from shoreline (km)
1	0-6	0-1.6	0-3
2	6-9	1.6-3.0	3-5.5
3	9-20	3-12	5.5-22
4	20-50	12-35	22-65
5	>50	>35	>65

6.3.6 Fish prices

The fleet-specific market fish price for each group was estimated from landing prices for 1997 (Department of Fisheries, 1998). The fish group price is estimated by taking an average of all sizes and the most abundant species was taken as a representative of each respective group (Table 6.4).

Table 6.4 Fish group price (Baht per kg) by species for each fleet, 1997

Group Name	OBT	PT	BT	PN	PS	OG
Rastrelliger spp.	22.43	22.43	22.43	22.43	27.77	30.00
Scomberomorus	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
Sciaenidae	17.50	17.50	17.50	17.50	0	0
Saurida spp.	10.90	10.90	10.90	10.90	0	0
Lutjanidae	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	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
Cephalopods	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
Medium demersal piscivores	19.06	19.06	19.06	19.06	0	0
Medium demersal benthivores	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 pelagic	2.55	2.55	2.55	2.55	5.00	5.00
Juvenile Caranx	2.55	2.55	2.55	2.55	0	0
Juvenile Saurida	2.55	2.55	2.55	2.55	0	0
Juvenile Nemipterus	2.55	2.55	2.55	2.55	0	0

Source of data: Fishery Economic Division, Department of Fisheries, 1998

6.3.7 Operating costs and profit

Fixed Cost is included an institutional cost such as fishery research cost, management cost, administrative cost and enforcement cost. The fixed cost of the Department of Fisheries of the year 1998 was used in this estimation.

Fishing Cost The fishing costs were obtained from the surveys in the year 1998 of the Fishery Economic Division, Department of Fisheries. This cost was split into Effort-related costs and Sailing-related costs. The Sailing-related costs comprise gasoline and lubricants, while the Effort-related costs were taken as the difference between total Fishing costs and the Sailing-related costs.

Total Revenue is the profit of each fleet estimated by using the catch data based of the years 1993 and 1995 of the surveys of the Fishery Economic Division of the Department of Fisheries (Table 6.5).

Table 6.5 Estimated costs and profit of each fleet in the ECOPATH model, estimated as percentages of the value of the total landings by fleet

Fleet	Fixed costs (%)	Effort-related costs (%)	Sailing-related costs (%)	Profit (%)
Otterboard 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

The assumptions on costs and revenue (and hence profit) are very important for the subsequent optimizations using ECOSIM. When trying to optimize profit ECOSIM will tend to increase effort for the most profitable fleets (here pair trawlers and purse seiners) and reduce the effort for the less profitable fleets, (here beam trawl, pushnet and other gears). In consequence, one should only use the model to study economic consequences of optimizing fishing effort if one has reason to believe that the underlying economic parameters are sound.

6.3.8 Optimization of fishing effort

EwE includes an ‘open loop’ policy exploration simulation, where a goal function for policy optimization is defined on four weighted policy objectives:

1. Maximize fisheries rent;

2. Maximize social benefits;

3. Maximize mandated rebuilding of species;

4. Maximize ecosystem structure or ‘health’.

The first of these, maximizing profits, is based on calculating profits as the value of the catch (catch * price, by species) less the cost of fishing (fixed + variable costs). Giving a high weight to this objective often results in phasing out most fleets except the most profitable ones as well as the wiping out of ecosystems groups competing with or preying on the more valuable target species.

The second objective, maximizing social benefits, is expressed through the employment supported by each fleet. The benefits are calculated as the number of jobs relative to the catch value, these are fleet specific. Therefore social benefits are largely proportional to fishing effort. Optimizing efforts often leads to even more extreme (with regards to overfishing) fishing scenarios than optimizing for profit.

The maximization of mandated rebuilding of species (or guilds) is incorporated to capture that external pressure (or legal decisions) may force policy makers to concentrate on preserving or rebuilding the population of a given species in a given area. In ECOSIM this corresponds to setting a threshold biomass (relative to the biomass in ECOPATH) for the species or group and optimizing towards the fleet effort structure that will most effectively ensure this objective.

The last objective included, maximizing ecosystem structure (or 'health') seeks to optimize the abundance of long-lived groups in the ecosystem.

ECOSIM uses a non-linear optimization procedure to iteratively improve an objective function by changing relative fishing rates. The optimization runs the ECOSIM model repeatedly while varying these parameters and testing alternative parameter values so as to locally approximate the objective function as a quadratic function of the parameter values and using this approximation to make parameter update steps.

The objective function can be thought of as a ‘multi-criterion objective’, represented as a weighted sum of the four objectives: economic, social, legal, and ecological. Assigning alternative weights to these components is a way to see how they conflict or trade-off with one another in terms of policy choice.

The fishing policy search routine described above estimates time series of relative fleet sizes that would maximize a multi-criterion objective function. In ECOSIM, the relative fleet sizes are used to calculate relative fishing mortality rates by each fleet type, assuming the mix of fishing rates over biomass groups remains constant for each fleet type, i.e., reducing a fleet type by some percentage results in the same percentage decrease in the fishing rates that it causes on all the groups that it catches. However, density-dependent catchability effects can be entered and if so reductions in biomass for a group may result in fishing rates remaining high despite reductions in total effort by any/all fleets that harvest it. Despite this caveat, the basic philosophy in the fishery policy search is that future management will be based on control of relative fishing efforts by fleet type, rather than on multi-species quota systems.

6.4 APPROACH AND RESULTS

The ECOSIM model was fitted to the available time series data using the approach outlined in Section 6.4.1.

6.4.1 Tuning ECOSIM to time series data[11]

The better the data, the better the model when evaluating how ECOSIM (or any other model for that matter) behaves. Information about the underlying system is of crucial importance. With time series data at disposal it becomes possible to tune the ECOSIM model so as to be in agreement with the observed trends. While the experience level is still pretty low when it comes to tuning, it is possible to give some guidelines on how to go about this process.

For the balancing, it is useful to think of how growth and mortality are modelled in ECOSIM. Mortality is considered as a linear function of biomass (solid line in Figure 6.3), while the population increase will be a non-linear function of the biomass (dotted line in Figure 6.3). This non-linear function corresponds to the consumption times the gross food conversion efficiency (from ECOPATH, where it is estimated as base production over base consumption). For a given biomass, the population will increase or decrease depending on the area between the lines. Therefore, the growth (or the decline) of a given population can be modified by changing either the mortality rate or the food consumption. In turn, food consumption is a function of complex predator-prey relationships modelled using a variable 'vulnerability' setting for top-down versus bottom-up control.

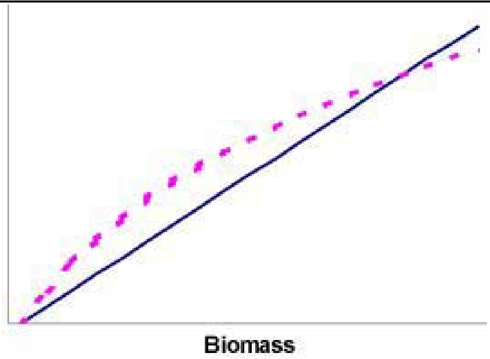

Figure 6.3 The solid line shows the predicted mortality calculated as Z.* B, and the dotted line the population growth estimated as a function of the consumption. The area between the lines can be considered 'surplus production'.

The incorporation of this can be illustrated using a model of the Gulf of Thailand from research vessel surveys (Christensen, 1998) using default settings throughout (most notably a default vulnerability setting of 0.3 for all predator-prey interactions) produces the fit shown in Figure 6.4 for the 'large piscivores' group. During the time period covered the fishing intensity increased with more than an order of magnitude. The model (solid line) shows a clear decline in biomass over the time, while the CPUEs from the surveys (dots) indicate much less decline over time. As described above, the Z values of the fish group can be accessed and be used as input. Assuming that the survey data are "correct" the best fit of the model is achieved when the solid line follows the dots.

During the time period, the fishing intensity increased with more than an order of magnitude. The model (solid line in Figure 6.4) shows a clear decline in biomass over time, while the

[11] From Christensen *et al*. 2000

CPUE from the surveys (dots) indicates much less decline over time. As described above, it has some handles that can be used to manipulate how ECOSIM models the growth of the population. Panel B thus shows the effect of raising the group's total mortality rate (P/B) from 0.8 $year^{-1}$ to 1.2 $year^{-1}$. The effect of this is to make the group more able to tolerate the grossly increased fishing intensity over time, but it is also clear that a 50% increase in the initial mortality rate setting is insufficient to optimize the fit over time. A second handle is therefore invoked. The vulnerability setting affects how the consumption is influenced by changes in predator and prey abundance. Using the default setting of 0.3 (Figure 6.4; panels A and B) leads to mixing with top-down and bottom-up control. Changing the value to 0.01 for all prey of the large piscivores makes the prey's availability largely independent of changes in the abundance. As the increased fishery leads to a reduction in the biomass of large piscivores those remaining will have a good time (from a food perspective), their consumption rate will increase and this will tend to counterbalance the increased fishing pressure. The result is increasing resilience as can be seen from panels C and D in Figure 6.4. Comparing panels B and C shows that the fit is better through incorporating bottom-up control, while panel D shows the best fit of overall.

The panels E and F show the effect of using top-down control for the interactions between the large piscivores and each of its prey groups. It is apparent that this does not result in any improvement in fitting between model and CPUE, but just the opposite. Hence, in the present case the best fit is obtained using the settings of Panel D.

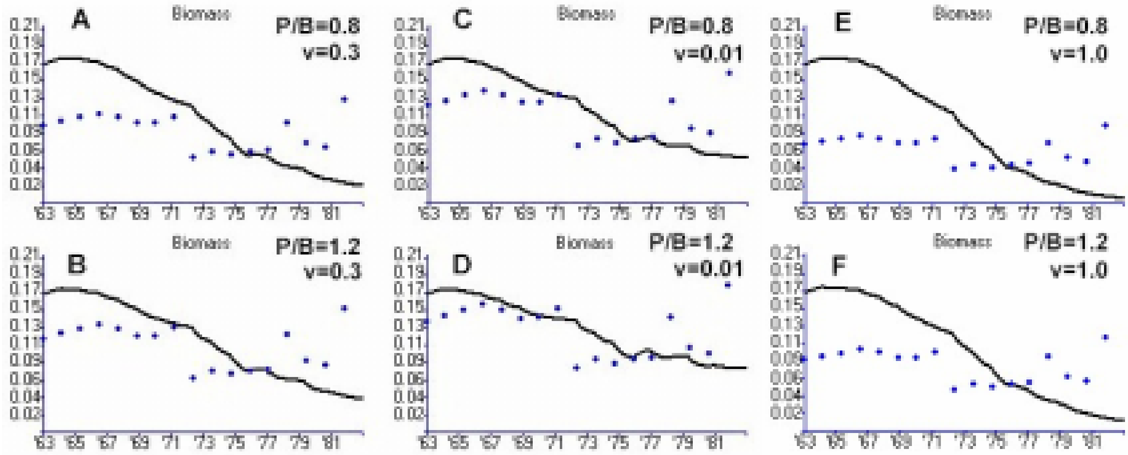

Figure 6.4. Biomass over time (lines) for 'large piscivores' in the Gulf of Thailand. P/B is the production/biomass ratio (equals Z, the total mortality) for the group, while v is the vulnerability setting describing how the group interacts with each of its prey groups. Dots represent CPUE from surveys.

6.4.2 Results

The fit resulted in an overall sum of squares of deviations (observed – predicted) of 117.9 for the 21 time series available.

An overview of the fits obtained is given in Figure 6.5. A fairly reasonable fit is obtained for most groups indicating that the model can reproduce the known history of the ecological resources of the Gulf of Thailand.

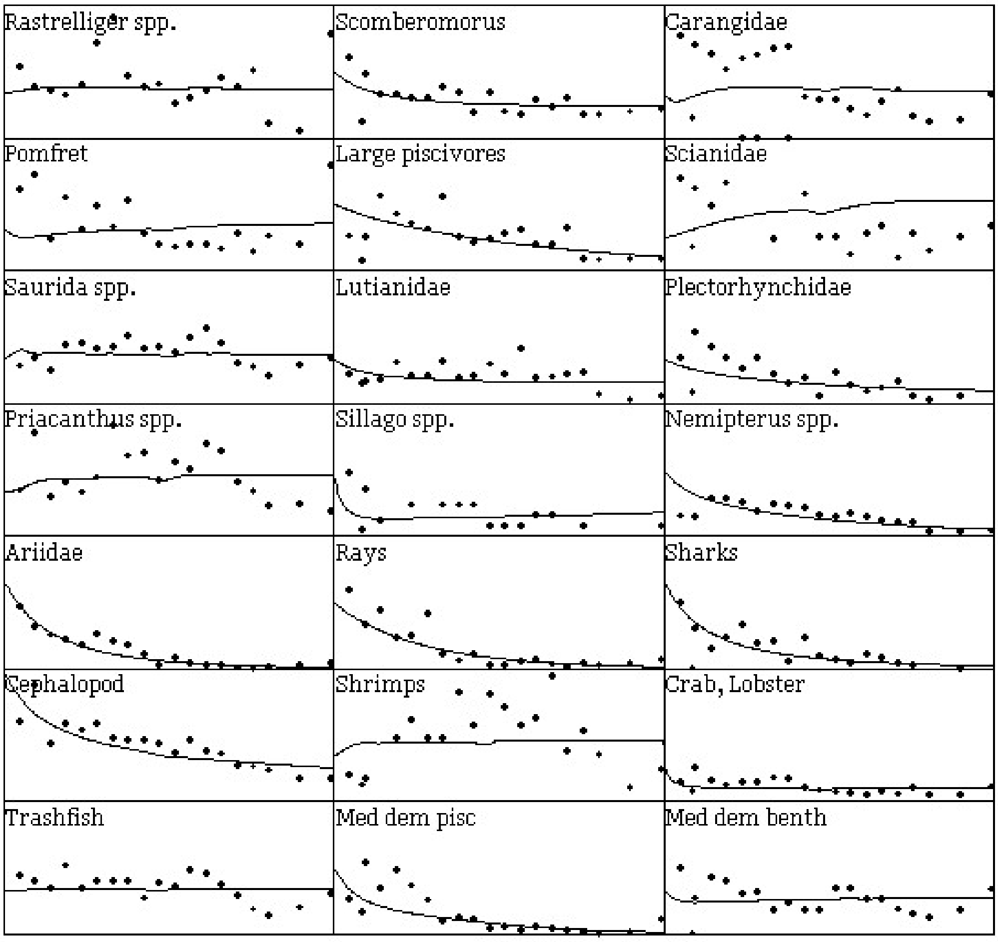

Figure 6.5 Fit to time series for the ECOSIM model of the Gulf of Thailand, 1973-1993

To address the workshop's first objective a simulation was run where the 21 years was with fishing as described above and using the fitted model, see Figure 6.5. The simulation was however extended to run 36 years with the fishing effort from the 21st year being carried forward for the rest of the simulation period. The pushnet fishery was stopped after 21 years, and results were then extracted after 35 years. The key results from this simulation are shown in Table 6.6. The catch levels and overall value of the catch were found to decline marginally if the pushnet was banned not indicating any direct benefit from the ban. This can be assumed to reflect the overall very low catch level represented by the pushnet fleet. Banning a marginal activity cannot be expected to have major overall effects.

An additional simulation was run to simulate the effect of a ban of the small mesh fishery (see Table 6.6). Here, the pushnet fishery was stopped after 21 years, while the catch composition for all gears was changed from the beginning of the simulation to exclude trashfish and juvenile fish from the catches. The main result from the simulation is that the overall catch level would decrease markedly (to 50%), while the value of the catch would only decrease marginally (4%). Overall the reduced catches of small fish do not lead to any marked improvement in the state of the system, indicating that such a measure is inadequate to change the gross overfishing in the Gulf of Thailand.

Table 6.6 Simulation results in catch and value from the original situation to a stop of the pushnet fishery and a stop extended to the 'small-mesh' fishery (resulting in stopping the trash-fish fishery and the fishery for four juvenile groups)

	Catch (tonnes $km^{-2} \cdot year^{-1}$)			Value (10^3 Baht$\cdot km^{-2} \cdot year^{-1}$)		
Fleet	**Original situation**	**Pushnet ban**	**Pushnet and small-mesh ban**	**Original situation**	**Pushnet ban**	**Pushnet and small-mesh ban**
Otterboard trawl	2.15	2.21	0.725	30.3	31.4	28.2
Pair trawl	0.738	0.753	0.33	9.59	9.95	8.26
Beam trawl	0.002	0.002	0.002	0.102	0.105	0.106
Pushnet	0.113	0	0	4.01	0	0
Purse seine	0.304	0.304	0.313	5.65	5.64	5.78
Other gears	0.422	0.429	0.442	56.6	57.9	59.9
Total	**3.74**	**3.70**	**1.812**	**106**	**105**	**102**

Table 6.7 Simulation results for value, cost and rent in 1993 (at the end of the time series simulation) for the Gulf of Thailand fisheries (unit is 10^3 Baht · km^{-2} · $year^{-1}$). The effort column gives the effort by fleet in 1993 relative to the effort in 1973

Fleet	Value	Cost	Rent	Effort ratio (1993/1973)
Otterboard trawl	31.1	31.6	-0.483	2.45
Pair trawl	9.99	14.7	-4.72	1.74
Beam trawl	0.096	0.08	0.016	0.09
Pushnet	3.96	3.41	0.55	1.51
Purse seine	5.63	3.42	2.21	1.69
Other gears	52.7	41.5	11.2	1.8
Total	104	94.7	8.81	

In the present preliminary study the optimization module of EwE introduced above was used in a search for how to optimize the rent of the fisheries of the Gulf of Thailand, and to see how the social factor (jobs in the sector) could be optimized. These simulations take the 1973 ecosystem as the starting point and seek to find the fishing effort for each of the six fleets that would optimize rent and jobs, respectively.

Comparing the simulations based on the Gulf of Thailand time series (Table 6.7) with the run seeking to optimize rent (Table 6.8) indicates that rent may be optimized by applying a considerable lower fishing effort than actually observed in the Gulf. The simulation indicate that rent would be optimized by lowering the effort level relative to the 1973 level for four of the fleets, and increasing it for only pair trawls and other gears. Overall the profit is seen to increase by approximately one third by using the optimized effort levels.

Table 6.8 Results for 1993 for optimization of rent for the Gulf of Thailand fisheries, taking the 1973 situation as starting point and applying a constant effort for each of the six fleets for 1973-1993. The effort column gives the effort by fleet in 1993 relative to the effort in 1973

Fleet	Value	Cost	Rent	Effort ratio (1993/1973)
	thousand Baht/km^{-2} /year			
Otterboard trawl	5.47	4.79	0.683	0.359
Pair trawl	12.2	12.0	0.194	1.41
Beam trawl	0.473	0.379	0.094	0.405
Pushnet	0.824	0.692	0.132	0.3
Purse seine	1.45	0.867	0.579	0.418
Other gears	47.3	37.4	9.99	1.62
Total	67.7	56.1	11.7	-

A second simulation was performed to optimize the social factor using the non-linear optimization routine of EwE. This is done using as the value of the landings as proxy for the employment created, and results in the effort levels indicated in Table 6.9. As can be seen the results indicate that the maximum value of the landings that can be obtained from the Gulf of Thailand is around 107,000 Baht/km^2/year, or a few percentage points more than estimated for 1993. This, however, comes with highly increased costs and indicates an unrealistic situation where all fleets are unprofitable due to overfishing.

Table 6.9 Optimizing for value of the landings in the Gulf of Thailand, taking the 1973 situation as starting point and applying a constant effort for each of the six fleets for 1973-1993. The effort column gives the effort by fleet in 1993 relative to the effort in 1973.

	Value	Cost	Rent	Effort (1993/1973)
	thousand Baht/km^{-2} /year			
Otterboard trawls	9.82	10.8	-1.01	0.832
Pair trawls	15.5	21.7	-6.18	2.556
Beam trawls	0.955	1.05	-0.097	1.111
Pushnets	0.869	0.934	-0.065	0.419
Purse seines	2.01	3.39	-1.39	1.681
Other gears	78.0	84.5	-6.45	3.672
Total	107	122	-15.2	

Additional simulations could be run to address several of the other workshop objectives as discussed earlier, but time did not allow this during the workshop. Also, the simulations presented here are very preliminary and would need considerable more effort allocated to be done in a more satisfactory manner. Yet, we conclude that ecosystem-based modelling is a feasible approach to explore fisheries management issues in the Gulf of Thailand.

7 COMPARISON OF MODELLING FINDINGS BY THE THREE GROUPS

The intended scope of the workshop was to analyse the effects of the following management measures:

a) **Complete ban on pushnet fisheries within 3 years;**

b) Expansion of the non-trawl and non-pushnet zones from 1.6 nm (3 km) to 3 nm;

c) The impact of current regulations concerning closed seasons and areas;

d) Increase the minimum mesh size of shrimp trawl gear to 2.5 cm and finfish trawl gear to 3 cm;

e) **Reduction of the numbers of various categories of trawlers;**

f) Increase fishing licence fees.

Due to data constraints and limited time, not all of these measures could be subjected to a detailed analysis. Data constraints prevented an analysis of an expansion of the non-trawl and pushnet zones from 1.6 to 3 nm and of current regulations concerning closed areas and seasons. Only management measures (a) and (e) could be subjected to a more detailed analysis.