Pertanika J. Soc. Sci. & Hum. 3(1): 31-45 (1995) ISSN: 0128-7702

A Bioeconomic Analysis of the East Johore Prawn Fishery

KUSAIRI MOHD. NOH and TAI SHZEE YEW
Dept. of Natural Resource Economics
Faculty of Economics and Management
Universiti Pertanian Malaysia
43400 UPM Serdang, Selangor, Malaysia

Keywords: bioeconomic modelling, simulation, prawn fishery

ABSTRAK

Kajian ini melaporkan keputusan simulasi bioekonomi perikanan udang Johor Timur. Terdapat lebih kurang 17 spesies di Johor Timur tetapi model ini adalah berasaskan perikanan udang agregat yang diterokai oleh tiga kumpulan perkakas: tradisional (merangkumi perangkap dan pukat hanyut), pukat tunda kecil, dan pukat tunda besar. Model ini telah digunakan untuk simulasi beberapa skim pengurusan alternatif (1) peraturan kemasukan terhad (yang mempengaruhi bilangan bot) (2) peraturan saiz mata pukat (melalui umur tangkapan pertama) dan (3) kombinasi kedua-dua peraturan ini. Model asas dapat memberi gambaran keadaan sebenar yang memuaskan dan keputusan simulasi menunjukkan keperluan mengurangkan saiz kumpulan bot dan meningkatkan umur tangkapan pertama. Kombinasi terbaik diperolehi melalui pengurangan bilangan bot sebanyak 10% daripada tingkat semasa, yang dianggarkan sebanyak 800, dan peningkatan umur tangkapan pertama daripada nilai asas empat kepada enam bulan.

ABSTRACT

This study presents the results of the bioeconomic simulations of the east Johore prawn fishery. There are about 17 prawn species in east Johore but the model was based on an aggregated prawn fishery harvested by three methods: traditional (consisting of traps and drift nets), small trawlers, and large trawlers. The model was used to simulate several management alternatives (1) limited entry regulation (affecting the number of boats) (2) mesh size regulation (by varying the age at first capture) and (3) combinations of these two measures. The base model simulates the actual fishery fairly well and the simulation points to the need to reduce fleet size and increase the age at first capture. The best combination was obtained by a reduction of fleet size by 10% from the current level of about 800 vessels and an increase of age at first capture from the base value of four to six months.

INTRODUCTION

Bioeconomic modelling is a relatively new venture in Malaysian fisheries. To date only a handful of studies have been conducted using this approach. A few preliminary attempts have been made by Lui (1990), Yong *et al.* (1990) and Tai (1993). The reasons for adopting this approach in studying fisheries systems are discussed in Walters (1986), Grant (1986), Sivasubramaniam (1990), Sparre and Willman (1990) and Padilla and Charles (1994). Basically, it is argued that modelling is the perfect vehicle for understanding a fishery system. The modelling process helps in bringing out the often hidden assumptions that underlie most decisions. Furthermore, management and policy decisions can be tested out via the model before implementing them.

This study represents an attempt to model the East Johore prawn fishery. Prawns were chosen for the study because the life cycle is relatively short, and the exploited phase is usually around a year. The population dynamics aspects of prawns are thus relatively easier to model than other long-lived species. Their high market value adds another reason for studying prawns. East Johore was chosen because Johore is the only state in Peninsular Malaysia with a coastline that fronts two oceans - the Malacca Straits to the west and the South China Sea to the east. The possible extension of the research to include West Johore provides the unique opportunity of illustrating the management of a fishery on a stock by stock basis. A single state may need to have more than one fisheries management plan or policy depending on its resources.

THE EAST JOHORE PRAWN FISHERY

There are about 40 species of coastal penaeid prawns in the world (Garcia and Le Reste 1981). Malaysia has more than 20 important commercial species, generally categorized within 6 genera: Solenocera, Penaeus, Metapenaeopsis, Metapenaeus, Trachypenaeus and Parapenaeopsis (Chua 1978; Abu Talib and Mahyam 1986). The first genus is from the family Solenoceridae; the others belong to the family Penaeidae. East Johore has 17 commercially important prawn species of various sizes.

The average monthly prawn landings in East Johore were 273 mt from 1987 to 1990. As shown in Table 1, a major portion (37%) of these, were *Acetes* prawns (udang baring). These are very small inexpensive prawns (ex-vessel price of about RM0.14/kg in 1991). This is followed by minyak, pasir kecil, and kulit merah sedang contributing approximately 15, 13 and 11%, respectively, to the average monthly catch. Lobsters (lobok) constitute about 5.1% of total landings in the prawn fishery[1]. The 1991 average price for lobsters was RM26 per kg.

There are eight types of equipment involved in harvesting the prawn resources in East Johore, including the traditional equipment (drift nets (trammel nets), stationary traps (gombang and pompang)) and the trawlers, which are divided into five categories, A - E. Trawler A comprises those vessels of less than 10 gross registered tonnage (GRT), B between 10-24.9 GRT, C between 25-39.9 GRT, D between 40-69.9 GRT and E 70 GRT or more. The zones of operation are also clearly demarcated[2].

TABLE 1
Average monthly catch of individual prawn species, East Johore, 1987-1992

Species	Monthly Average	
	Catch (kg)	(%)
Lobok	13791	5.05
Harimau	7034	2.57
Puteh besar	12795	4.68
Puteh sedang	17123	6.26
Puteh kecil	1913	0.70
Kulit merah besar	122	0.04
Kulit merah sedang	29569	10.82
Kulit keras	9583	3.51
Kuning	647	0.24
Merah	1522	0.56
Pasir besar	419	0.15
Pasir sedang	1148	0.42
Pasir kecil	35675	13.05
Minyak	40808	14.93
Minyak jalur	160	0.06
Ekor biru	1210	0.44
Baring	99837	36.52
Total	273356	100.00

Source: Computed from data provided by the Dept. of Fisheries, Johore.

Drift nets are the most popular method used, followed by trawlers C and D. The stationary trap (gombang) is the least popular.

Fishing effort is measured in terms of number of fishing days. There is a marked difference in monthly fishing days between the types of equipment. Fishing days of all equipment types except for small trawlers, are reduced in the monsoon months. A unique feature of the East Johore prawn fishery is that during the monsoon months from November to March, special licences are issued to small trawlers

1. Lobsters are considered as a by-catch in the fishery. They certainly are not the main target species, and their market is separate from the other prawns.

2. The traditional equipment are allowed within five miles from the shore. Trawlers A and B are considered small trawlers, and operate between 5 to 12 miles from the shore. However, they are also allowed to operate within the five-mile zone during the monsoon from November to March. The large trawlers comprise trawlers C, D and E. Trawlers C and D are allowed to operate only within the 12 to 30 mile limit. Trawlers E are allowed to operate only beyond the 30-mile limit.

to trawl for prawns within the five-mile zone. The objective is purely to supplement fishermens' income during the monsoon months.

The monthly landings of prawns, the fishing effort and the catch per unit effort of the three categories of equipment are presented in Table 2. On average, the traditional equipment (in particular, the pompang) is the most important in catching prawns. They contribute about 45.8% of monthly average catch. However, the bulk of this catch comprises mainly the small inexpensive *Acetes*. The small trawlers are next contributing about 31.9%. The relative contributions to landings varies during the year. The contribution by traditional equipment is highest from July to September while that of small trawlers is highest around the monsoon months when they are allowed to trawl near shore. The contribution of large trawlers is highest from September to November and in January.

The productivity of the prawn equipment can be measured by the catch per unit of effort which can be computed by dividing landings by the fishing effort. As shown in Table 2, the small trawlers with a CPUE of 31.13 kg/day for an average month are the most productive in catching prawns. This is followed by the traditional gear (with a CPUE of 24.31 kg/day) and, lastly, the large trawlers.

THE BIOECONOMIC MODEL

The bioeconomic system model consists of two major subsystems: the biological and the economic. The mathematical relationships of these subsystems are discussed below. The model was used to simulate the prawn fishery under various alternative management policies and regulations. The performance of the fishery under these management policies and regulations is gauged by several performance variables such as harvest, profit, fishing effort of individual vessels and the number of vessels in the fleet.

The Biological Subsystem

The biological subsystem describes the population dynamics of the prawn fishery. Prawns are short-lived animals, having a life-span of about 1-2 years. They are typically catadromous, that is they migrate towards the sea to spawn. The larvae and post-larvae migrate inshore into nursery grounds in estuaries, lagoons and mangrove swamps. During the juvenile stage, prawns migrate seaward to shallow coastal waters where they continue to grow. Adult female prawns mature at about six months of age and have a high fecundity rate (up to half a million eggs per spawning). Prawns are generally exploited at two distinct stages of their life cycle: during the juvenile stage in the nursery ground or when they migrate seawards, and during the sub-adult and adult stage at sea (Garcia and Le Reste 1981).

The size and changes in the biomass of prawn stock are determined by recruitment, growth of individuals and natural and fishing mortalities. These factors are affected by environmental conditions such as water temperature, nutrient availability, salinity, weather and the presence of predators. In addition, wind direction and velocity also affect the recruitment and inshore migration of prawn stocks (Alias, personal communication). Even though the environmental factors are important in determining the size of the biomass, they are uncontrollable and thus are assumed exogenous to the biological subsystem.

The stock recruitment relationship for prawns is very unclear (Garcia and Le Reste 1981). It has been suggested that the stock recruitment curve for prawns should be of the Beverton-Holt type. The asymptotic curve implies that the reproductive potential remains constant even for large decreases in stock (Garcia and La Reste 1981). Recent evidence indicates that recruitment overfishing for penaeid prawns is a possibility and the stock recruitment relationship should not be disregarded (Penn and Caputi 1985).

In this study recruitment into the prawn stock is assumed to be continuous (Alias and Mathews 1990). The recruitment is represented by the Beverton-Holt function as below (Somers 1990):

$$R_t = A(SS_t)/[1 + (SS_t/D)] \quad (1)$$

where R_t is recruitment at time t; SS_t is spawning stock at time t; A is maximum recruitment per spawner at low spawner stock size; and D is the proportion of spawning stock needed to produce half of A. A and D are parameters and SS_t is assumed here to be the biomass of the cohort at age 16 months.

The biomass of the prawn stock consists of multiple cohorts. After recruitment into the fishery, a cohort biomass grows due to the growth of individuals, and is subjected to natural

TABLE 2
Average landings (kg), effort (days) and catch per unit of effort (kg/day) for prawn gear by month, East Johore, 1987-1992

	Traditional Gear[1/]			Small Trawlers[1/]			Large Trawlers[1/]		
Month	Landings	Effort	CPUE	Landings	Effort	CPUE	Landings	Effort	CPUE
Jan	30724	4670	6.58	173927	4680	37.16	86720	4072	21.30
Feb	31984	4350	7.06	182392	4204	43.39	50980	3285	5.52
March	28989	4705	6.16	158423	4566	34.70	50878	4591	11.08
April	32799	5366	6.11	34429	1417	24.30	44651	4694	9.51
May	26642	5732	4.65	35695	1341	26.62	42965	4724	9.10
June	32215	5412	5.95	44697	1468	30.45	61000	4819	12.66
July	199026	5301	37.54	36112	1604	22.51	60040	4965	12.09
August	362246	5302	68.32	39722	1722	23.07	50476	4873	10.36
Sept	539026	6254	86.19	53175	2933	18.13	79155	5031	15.73
Oct	241309	5940	40.62	74084	2298	32.24	85197	4959	17.38
Nov	24338	5082	4.79	100057	4246	23.56	75821	4547	16.67
Dec	19015	3840	4.95	110389	3713	29.73	55347	3578	15.47
Monthly Average	125321	5156	24.31	87103	2798	31.13	61083	4507	13.55

[1/] Traditional gear comprise drift nets and stationary traps (gombang and pompang); small trawlers comprise trawl vessels of less than 25 gross registered tonnage (GRT); large trawlers are trawl vessels of more than 25 GRT.

Source: Computed from data provided by the Dept. of Fisheries, Johore.

mortality due to predation, diseases, etc., which reduces the cohort biomass. The fishing mortality, which also reduces the cohort biomass, is assumed to occur only when the cohort has reached the age of 4 months because of the mesh size regulation currently being imposed.

The available biomass of a cohort at age t+1 which is related to that of age t, can be computed as follows (Ricker 1975):

$$B_{t+1} = B_t \exp\ [GR_t - M - F_t] \qquad (2)$$

where B denotes the biomass of a cohort and t refers to the age of cohorts. Note that at any time period, the total biomass (TB) is computed as the sum of biomass of cohorts of all ages i.e. month 1 to maximum. An upper limit of 16 months was imposed for a cohort such that it will be completely removed from the fishery within the period. M, the natural mortality, is assumed to be represented by a constant rate per month. This rate is assumed to be 0.167 per month as computed from Alias and Mathews (1990).

GR is the mean instantaneous rate of growth, and is given by:

$$GR_t = \text{Ln}\ [W_{t+1}/W_t] \qquad (3)$$

where W is the weight of prawn and is computed using the Von Bertalanffy growth equation

$$W_t = W_\infty\ [1 - \exp(-K(t-t_0))]^3 \qquad (4)$$

In the above equation, W_∞ is the maximum weight attained by an individual prawn, or the mean weight a prawn would reach if it were to grow indefinitely. K is the Brody growth coefficient and t_0 is a parameter that shifts the growth curve along the age axis, which in biological terms is the age at which body length

TABLE 3
Definitions and values of the model parameters and constants

Parameter	Definition	Values
A	Maximum recruitment per spawner at low spawner stock size[1]	1000
D	Proportion of spawning stock required to produced half of A[1]	0.135
M	Natural mortality[2]	0.167
W	Maximum weight (gm) of an individual prawn[2,3]	42
K	Brody growth coefficient[2]	0.91
t	Age (mth) of individual prawn entering fishing ground[6]	0.01
q	Catchability coefficient[4]	
	- traditional gear	7.35×10^{5}
	- small trawler	22.8×10^{5}
	- large trawler	17.25×10^{5}
c_1	Cost parameter[4,5] (RM/day)	
	- traditional gear	0.93
	- small trawler	7.71
	- large trawler	2.51
c_2	Cost parameter[4,5] (RM/day)	
	- traditional gear	3.73
	- small trawler	30.83
	- large trawler	10.06
FC	Fixed cost per vessel[4,5] (RM/day)	
	- traditional gear	1.57
	- small trawler	5.03
	- large trawler	1.63
Ø	Vessel entry-exit response[6]	
	- traditional gear	1×10^{-3}
	- small trawler	2×10^{-3}
	- large trawler	5×10^{-3}
Price	Prices by size of prawn[4] (RM/ton)	
	- small	252
	- medium	811
	- large	1770

Source:
1. Somers 1990
2. Alias Man and Mathews 1990; Anon 1990
3. Alias Man and Mathews 1990, and using length-weight relationship from Chullason, Somsak and Purwito 1986.
4. Estimated from data obtained from the Department of Fisheries, Johore.
5. Department of Fisheries 1988.
6. Assumed values

is zero. In otherwords t_o is to account for non-zero body length at age 0. The values for these parameters are presented in Table 3.

Fishing mortality, F, is assumed to be linearly related to fishing effort and can be computed as follows:

$$F_t = q\,E_t = S_j\,q_j\,E_{jt} \qquad (5)$$

where E_{jt} is the fishing effort of gear type j at time t, and q is the catchability coefficient for the entire stock. However, in a multigear fishery, the catchability coefficient of interest should be specific to gear type, i.e. q_j. This is because various gear types exert different impacts on the stock biomass. If the effort of gear type j directed to the prawn stock is increased relative to other gear, F_j will be increased relative to F and vice versa. However, data on directed effort by gear are unavailable. Lacking such data, q_j can be computed based on the assumption that the ratio of fishing mortality generated by a particular gear type to the total instantaneous fishing mortality is roughly equivalent to the proportion of total landings taken by that gear type (Murawski 1984). That is

$$F_j/F \;'\; H_j/H \qquad (6)$$

where H_j is the landings of gear type j and H is the total landings. This assumption together with equation (5) and after some manipulations, the catchability coefficient for gear type j can be calculated by the equation below:

$$q_j = [(H_j/H)(q)(E)]/E_j \qquad (7)$$

where E_j and E are respectively the time-averaged effort of gear type j and total effort. The value of q is calculated by converting the annual value given in Abu Talib and Mohd. Taupek (1990) into an average monthly value. The value of q_j for each gear type is presented in Table 3.

The total biomass of the multi-cohort prawn stock at time t (TB_t) is calculated as the sum of biomass of each cohort at time t.

The Economic Subsystem

The economic subsystem includes the catch, the costs and returns of a representative vessel of each equipment type, the dynamics of the prawn fishing fleets and prices. The three gear types considered in the study are traditional gear, small trawlers and large trawlers which differ in size (GRT), fishing power and cost structure.

An individual vessel can be viewed as a producer of effort (Anderson 1986: 57). In any production process, effort is actually produced from a multitude of inputs and it is assumed that the production of effort is subject to the law of diminishing returns. This gives rise to a quadratic relationship between cost and effort produced.

The total cost of a given fishing unit j (VTC_{jt}) is the sum of fixed and variable costs:

$$VTC_{jt} = FC_j + VARC_{jt} \qquad (8)$$

where FC_j is the fixed costs per vessel consisting of the costs of investment associated with vessels and fishing equipment, etc; and $VARC_{jt}$ is the variable costs component. As mentioned above, it is assumed that variable cost is a quadratic function of fishing effort of the representative vessel (e_{jt}) as follows:

$$VARC_{jt} = c_{1j}\,(e_{jt}) + c_{2j}\,(e_{jt})^2 \qquad (9)$$

where c_{1j} and c_{2j} are cost parameters associated with the production of effort by the representative vessel. Included in c_j are the costs of ice, food, fuel, crew remuneration and opportunity costs of fishing capital and labour. It should be noted that c_j should reflect only the costs associated with harvesting the prawn stock. However, all gear types considered in this study also catch fish species other than prawn, and these fish catches are not modelled explicitly in the study. Hence the costs should be apportioned accordingly. It is assumed that the share of costs associated with catching prawns is proportional to the ratio of revenue from prawn catch by gear type j to the total revenue from the catch of all fish species by the gear. These costs are presented in Table 3.

Given the assumed variable cost function, the marginal cost function for a representative vessel is:

$$VMC_{jt} = c_{1j} + 2\,c_{2j}\,(e_{jt}) \qquad (10)$$

The total revenue of a representative vessel j can be calculated as:

$$VTR_{jt} = P\ VH_{jt} \tag{11}$$

where VTR_{jt} and VH_{jt} denote total revenue and total catch of a representative vessel j respectively, and P is the average price of prawn. The total catch of a representative vessel j can be estimated as:

$$VH_{jt} = F_{jt}\ TB_t = q_j\ e_{jt}\ TB_t \tag{12}$$

where all the variables are as previously defined. Average revenue of effort (VAR_{jt}) is obtained by dividing VTR_{jt} by e_{jt} as follows:

$$VAR_{jt} = VTR_{jt}/e_{jt} = P\ q_j\ TB_t \tag{13}$$

In a constant price model, the catch of each individual vessel is too small to affect the price. Hence each individual vessel is considered a price-taker. Price is determined at the industry level by the intersection of the demand (or the average revenue) curve and the supply (sum of all individual vessel marginal cost) curve. The profit maximization level of an individual vessel effort is determined by the intersection of the price (i.e. the average revenue) and marginal cost of effort, assuming fishermen are profit maximizers (Anderson 1986). The resulting profit maximization condition is:

$$Pq_j\ TB_t = c_{1j} + 2\ c_{2j}\ (e_{jt}) \tag{14}$$

Solving for profit maximizing level of effort for a representative vessel yields:

$$e_{jt} = (P\ q_j\ TB_t - c_{1j})/2\ c_{2j} \tag{15}$$

Profit to a fishing unit j is the difference between its total revenue and total cost:

$$VPROFIT_{jt} = VTR_{jt} - VTC_{jt}$$

The supply of fishing effort for each gear type is the product of effort of an individual vessel and the number of participating vessels (N_{jt}).

$$E_{jt} = e_{jt}\ N_{jt} \tag{16}$$

The derivation of fishing effort of a representative vessel has been discussed previously. The dynamics of the fleet of each equipment type need further deliberation. The original impetus for incorporating fleet dynamics in fishery bioeconomic modelling was due to Smith (1968), who argues that the entry or exit of fishing vessels is determined by the level of profits or losses in a fishery. In particular, if profit exists, vessels will enter the fishery and vice versa. Using this argument, the entry-exit process of fishing vessels in this study is as follows:

$$(N_t - N_{t-1})_j = \varnothing_j\ (VPROFIT_{jt})(N_{t-1})_j \tag{17}$$

where N_t and N_{t-1} are number of fishing vessels of gear type j at time t and t-1, $\varnothing_j$ is the response parameter which shows the responsiveness of vessel j to profits. The value of $\varnothing_j$ is shown in Table 3.

Prices are important as they determine revenues, profits and the supply of fishing effort. Prices of prawns in this study are assumed constant. The constancy of prices is due to the fact that prawns are mainly destined for the export market. Hence, prices of prawns are primarily determined at the international market. However, these prices vary according to size. Prices of prawns by size groups are shown in Table 3.

SIMULATIONS AND MANAGEMENT CONSIDERATION

The Base Run

The model discussed in the last section, together with the values of the parameters and constants presented in Table 3, was used to simulate the

3. Sensitivity analyses were conducted on the model biological and economic parameters to determime the estimation errors and uncertainties in the parameter values. A total of 22 cases were considered when the value of the parameter is increased and decreased by 10%. The sensitivity analyses showed that the model exhibits greater sensitivity to changes in biological parameters than to economic parameters. For example, changes in the values of maximum recruitment per spawner, natural mortality and Brody growth coefficient caused the model results to deviate more from the base case results. This implies that more precise estimates of biological parameters for the prawn stock for East Johore would be very useful for improving the model performance.

base run of the East Johore prawn fishery. The average monthly number of vessels for each equipment type is used as the initial fleet size. The values are 287, 196 and 242 respectively for traditional gear, small trawlers and large trawlers.

The long-term results of the base run are presented in Table 4. These results are compared with the observed values of the perfomance variables. The catches of traditional gear and small trawlers are lower for the model results while those of large trawlers are higher. The total prawn catch for the model is about 14% lower than the actual observed value. The model results for fishing effort, are far lower for all gear types than the observed values. The low fishing effort for the base-run may be due to low prices or low total estimated biomass since vessel effort is computed using equation (15). It appears more likely that the problem of low fishing effort is caused by the latter. This is because most of the biological parameters used for the base-run are estimates, since these parameters are not available for the prawn resources in East Johore.[3] There is no significant difference in fleet size between the model's results and the observed values for the traditional gear and small trawlers (differences of 2.8% and 7.6% respectively). However, the number of large trawlers is about 35% higher than the observed value.

Simulation of Management Policies

Fishery management policies are often used throughout the world to improve the performance of a fishery. For the prawn fishery in East Johore, several management policies were examined using the simulation model to find out whether they could provide any improvement to the fishery, and how these improvements could be achieved. The policies examined include:

(1) Limited entry by restricting the fleet size.
(2) Mesh size regulation.
(3) Combination of mesh size regulation and limited entry.

Limited Entry

Table 5 shows the results of the simulations concerning changes in fleet size. In these

TABLE 4
Comparison between the results of base-case model and the observed values of some key variables

Variable	Gear[1]	Observed Values	Model Values
Effort (days)	TG	1719	967
	ST	1399	236
	LT	1502	927
Fleet (number)	TG	287	295
	ST	196	211
	LT	242	327
Harvest (tons)	TG	80	68
	ST	87	50
	LT	148	153
Total		315	271
Profit (RM)	TG	n.a[2]	11340
	ST	n.a	7109
	LT	n.a	25880
Total		n.a	44330

[1] Classified as: TG = traditional gear, ST = small trawlers and LT = Large trawlers.

[2] n.a = not available.

Table 5
Long-run results of limited entry regulation

Performance Variables	Gear[1]	Base Run	Percentage Change in Fleet Size			
			+10%	-10%	-20%	-30%
Effort (days)	TG	967	1083 (12.00)[2]	981 (1.45)	926 (-4.24)	865 (-10.55)
	ST	236	254 (7.63)	231 (-2.12)	219 (-7.20)	205 (-13.14)
	LT	927	789 (-14.89)	718 (-22.55)	677 (-26.97)	630 (-32.04)
Fleet (number)	TG	295	316 (7.12)	258 (-12.54)	230 (-22.03)	201 (-31.86)
	ST	211	216 (2.37)	176 (-16.59)	157 (-25.59)	137 (-35.07)
	LT	327	266 (-18.65)	218 (-33.33)	194 (-40.67)	169 (-48.32)
Harvest (tons)	TG	68	78 (14.71)	76 (11.76)	74 (8.82)	72 (5.88)
	ST	50	56 (12.00)	54 (8.00)	53 (6.00)	52 (4.00)
	LT	153	134 (-12.42)	130 (-15.03)	127 (-16.99)	123 (-19.61)
Total Harvest (tons)		271	268 (-1.11)	260 (-4.06)	254 (-6.27)	247 (-8.86)
Profit (RM)	TG	11340	13340 (17.64)	13500 (19.05)	13560 (19.58)	13580 (19.75)
	ST	7109	8139 (14.49)	8497 (19.52)	8668 (21.93)	8807 (23.89)
	LT	25880	23090 (-9.73)	23410 (-8.48)	23440 (-8.37)	23380 (-8.60)
Total Profit (RM)		44330	44560 (0.52)	45410 (2.44)	45660 (3.00)	45760 (3.23)

[1] Classified as: TG = traditional gear, ST = small trawlers and LT = large trawlers.

[2] Figures in parentheses represent percentage changes in the long-run values of the performance variables for limited entry regulations over the corresponding long-run values for the base-run

simulations the fleet size of each gear type is fixed at selected levels instead of allowing it to respond to profits from the fishing operation[4]. Four levels of fleet sizes were chosen - an increase of 10%, and decreases of 10, 20, and 30% relative to the current fleet size. The increase in fleet size is motivated by the fact that the government is constantly under pressure to increase the number of licences. As usual, the reduction in fleet size is in the interests of the overfishing problem.

4. An alternative approach would be to treat the targeted levels as upper levels. In view of the presence of profits in the fishery, there will be entry into the fishery as specified by equation (17). Hence this approach will have the same effect as that adopted in the current model.

In terms of harvest, the increase in fleet size caused a decrease in total harvest, though not by a very large amount (3 tonnes or -1.11%). The decrease was solely due to the reduction in catches of the large trawlers, which was reduced by slightly more than 12%. In the base run, this gear accounted for about 56.5% of long-run total catch. This percentage was reduced to 50.0% after the increase in fleet size. This percentage decrease was due to the fact that even though the final fleet size of 266 was higher than the current observed level (242), it was, however, lower than the level if allowed to expand of its own accord (327). For the small trawlers, the increase in final fleet size to 216 was also higher than the level obtained in the base run (211). However, the catch for this gear and its share of total catch increased by about 6 tonnes and 12.0% respectively. The increased fleet size for the traditional gear was also greater than what it would be if left on its own (316 versus 295). The catch from this group was increased by about ten tonnes and its share of total catch rose by about 7%.

Total profits increased marginally by 0.5% but that of large trawlers was reduced in absolute (by RM2790) and relative terms (by 10%). Profits of small trawlers increased by about 14% while that of traditional gears increased the most (17.6%).

The policy of fixing the fleet size to a level 10% lower than the current figure resulted in an increased catch for traditional gear (11.76%) and small trawlers (8.0%) relative to the long-run base values. The catch decreased for large trawlers (-15.0%). Total catch decreased by 4.0%. Aggregate profits rose by 2% from RM44330 to RM45410. The percentage increase in profit for traditional gears and small trawlers were 19.0% and 19.5% respectively, while it was reduced by 8.5% for large trawlers. Similar patterns were repeated for further decreases in fleet size.

In general these results seem to indicate that reductions in fleet size would increase aggregate profits. Although not included here, the results indicate that aggregate profits begin to decrease at about the 40% level with an aggregate profit of RM45190.

Mesh Size Regulation

The primary aim of mesh size regulation is to prevent the destruction of a fishery by maintaining a productive age structure of the stock. This is done by increasing the age at first capture, which allows younger fish to grow and reproduce, hence contributing to the biomass of the fish stock.

Although mesh size regulation may improve biological productivity of a fish stock, by itself its economic performance may not be optimal. This is because an increase in the stock may attract additional vessels into the fishery. Moreover, in the long run fishermen can easily bypass this regulation by increasing the fishing power of their vessel through "capital stuffing", the phenomenon whereby fishermen substitute one attribute of their vessel or gear (usually the regulated attribute) with other (non-regulated) attributes. Thus in the long run fishing effort is likely to increase. Consequently average cost of fishing is also likely to rise.

In modeeling mesh size regulation in this study, the age at first capture is increased from 4 months (base-case) to 5, 6, 7, 8, and 9 months. The long-run effects of these cases on some selected performance variables are presented in Table 6.

The results showed that increases in mesh size reduced catches. This is due to the reduction in total harvestable biomass caused by taking entire cohorts out of the fishery. Even though biomass of successive cohorts is increased due to increased numbers entering the fishery, this effect is smaller than the reduction in total biomass caused by the later age at first capture. Total harvest was reduced by about 11% for age 5 months compared to the long- run total harvest for the base case. As the age at first capture increases, the percentage reduction of total harvest also increases. Similar patterns are also observed for each gear type. The long-run aggregate profit increases until the highest profit is achieved at age at first capture of 8 months. Further increase in the age at first capture to 9 months results in a reduction of long-run aggregate profit. Fishing effort for all gear types increases, probably due to "capital stuffing" or increased prawn fishing days by fishermen of all gear types due to the incentives provided by the increase in profit levels. For similar reasons the number of vessels, in particular the small and large trawlers, also increased.

The above results indicate that increasing the age at first capture to 8 months by having a larger mesh size provides the best improvement to the prawn fishery.

Table 6
Long-run results of mesh size regulation

Performance Variables	Gear[1]	Base Run	Age at First Capture (months)				
			5	6	7	8	9
Effort (Days)	TG	967	977	1003	1056	1155	1088
			(1.03)[2]	(3.72)	(9.20)	(19.44)	(12.51)
	ST	236	239	247	262	292	271
			(1.27)	(4.66	(11.02)	(23.73)	(14.83)
	LT	927	940	976	1053	1270	1095
			(1.40)	(5.29)	(13.59)	(30.20)	(18.12)
Fleet (Number)	TG	295	295	296	297	298	297
			(0.00)	(0.34)	(0.68)	(1.02)	(0.68)
	ST	211	211	212	214	218	214
			(0.00)	(0.47)	(1.42)	(3.32)	(1.42)
	LT	327	328	333	342	360	345
			(0.310	(1.83)	(4.59)	(10.09)	(5.50)
Harvest (tons)	TG	68	60	52	45	39	33
			(-11.76)	(-23.53)	(-33.82)	(-42.65)	(-51.47)
	ST	50	45	39	34	30	25
			(10.00)	(-22.00)	(-32.00)	(-40.00)	(-50.00)
	LT	153	135	119	106	97	78
			(-11.76)	(22.22)	(-30.72)	(-36.60)	(-49.02)
Total Harvest (tons)		271	240	210	185	166	136
			(-11.44)	(-22.51)	(-31.73)	(-38.74)	(-49.82)
Profit (RM)	TG	11340	11600	12230	13550	16210	14390
			(2.29)	(7.85)	(19.49)	(42.94)	(26.90)
	ST	7109	7304	7792	8828	10950	9481
			(2.74)	(9.61)	(24.18)	(54.03)	(33.37)
	LT	25880	26540	28280	32070	40100	34350
			(2.55)	(9.27)	(23.92)	(54.95)	(32.73)
Total Profit (RM)		44330	45440	48300	54450	67260	58230
			(2.50)	(8.96)	(22.83)	51.73	(31.36)

[1] Classified as: TG = traditional gear ST = small trawlers, amd LT = large trawlers.

[2] Figures in parentheses represent percentage changes in the long-run values of the performance variables for the mesh size regulation over the corresponding long-run values for the base-run.

Combinations of Policies

Simulation runs were also conducted for combinations of fixed fleet sizes and age at first capture. This is motivated by the fact that policies in combination might affect the fishery differently than each of the individually enforced policies. Four combinations were selected. Two levels of age at first capture, ages 5 and 6 month, were combined with two levels of fleet size, 10% increase and decrease in current fleet. These levels were chosen because they represent feasible options. Larger changes are bound to be politically unacceptable. Table 7 shows the results of these simulations. Mix 1 refers to the combination of age 5 months and 10% increase, Mix 2 is the combination of age 5 months and 10% decrease,

TABLE 7
Long-run results of mixed regulation

	Gear[1]	Base Run	Regulation[2]			
			Mix 1	Mix 2	Mix 3	Mix 4
Effort (days)	TG	967	1094	988	1124	1012
			(13.13)[3]	(2.17)	(16.24)	(4.65)
	ST	236	257	233	265	239
			(8.90)	(1.27)	(12.29)	(1.27))
	LT	927	797	723	819	741
			(-14.02)	(-22.01)	(-11.65)	(-20.06)
Fleet (numbers)	TG	295	316	258	316	258
			(7.12)	(-12.54)	(7.12)	(-12.54
	ST	211	216	176	216	176
			(2.37)	(-16.59)	(2.37)	(-16.59)
	LT	327	266	218	266	218
			(-18.65)	(-33.33)	(-18.65)	(-33.33)
Harvest (tons)	TG	68	69	66	60	57
			(1.47)	(-2.94)	(-11.76)	(-16.18)
	ST	50	49	47	43	41
			(-2.00)	(-6.00)	(-14.00)	(-18.00)
	LT	153	118	114	103	99
			(-22.88)	(-25.49)	(-32.68)	(-35.29)
Total Harvest (tons)		271	236	227	206	197
			(-12.92)	(-16.24)	(-23.99)	(-27.31)
Profit (RM)	TG	11340	13630	13720	14420	14410
			(20.19)	(20.99)	(27.16)	(27.07)
	ST	7109	8349	8650	8916	9142
			(17.44)	(21.68)	(25.42)	(28.60)
	LT	25880	23590	23780	24950	24960
			(-8.85)	(-8.11)	(-3.59)	(-3.55)
Total Profit (RM)		44330	45570	46150	48290	48510
			(2.80)	(4.11)	(8.93)	(9.43)

[1] Classified as: TG = traditional gear, ST = small trawlers, and LT = large trawlers.

[2] The regulations are: Mix 1 = 10% increase in fleet size and age of first capture of 5 months; Mix 2 = 10% decrease in fleet size and age of first capture at 5 months; Mix 3 = 10% increase in fleet size and age of first capture at 6 months; Mix 4 = 10% decrease in fleet size and age of first capture at 6 months.

[3] Figures in parentheses represent percentage changes in the long-run values of the performance variables for the mixed regulation over the corresponding long-run values for the base-run.

Mix 3 is the combination of age 6 months and 10% increase, and finally Mix 4 is the combination of age 6 months and 10% decrease.

From Table 7 it can be seen that the combinations of policies resulted in decreases in catch except for Mix 1 for traditional gear which showed an increase of 1%. The decrease is larger for age 6 months (Mix 3 and Mix 4). Even though the catch was reduced, profits increased except for large trawlers. Again, the increase is larger for older age and for decrease in fleet size. In terms of percentage increases, traditional gear and small trawlers seem to benefit the most from these policies with increases in profits of 27% (Mix 3) and 29% (Mix 4), respectively.

In general, the combined policy of increasing the age at first capture to 6 months and a reduction of fleet by 10% gave the highest aggregate profit. This policy is superior in terms of aggregate profits for Mix 4 (RM48510) compared to the profit for the individual policy of age at first capture of 6 months without limited entry (RM48300) or reduction of fleet by 10% for age at first capture of 4 (RM45410).

CONCLUSION

Several conclusions can be drawn from the results obtained from this study. The simulations on the age at first capture indicate that there is an economic trade-off in postponing the capture of young prawns. The age at first capture of 8 months seems optimum but appears too drastic as a recommendation for practical implementation. This is a doubling of the present age at first capture and is unlikely to be supported by local fishermen and policy makers, who are generally not in favour of policies that entail substantial changes to present conditions. Regarding the level of fleet to be used to exploit the resource the results point to the reduction of the current level of investments in number of boats. A combination of policies regarding the age at first capture (i.e. mesh size regulations) and reduction of fleet size (i.e. limited entry regulations) appears to give the best result in terms of aggregate profit earned from the fishery.

These results, however, need to be treated with caution. The results are sensitive to changes in the values of the biological parameters and, to a lesser extent, the economic parameters. For example, changes in the values of maximum recruitment per spawner, proportion of spawner stock required to produce half of maximum recruitment, natural mortality and Brody growth coefficient caused the model results to deviate more from the base case results. The need for more detailed studies to obtain these parameters are obvious. This by itself is an important contribution of this study. It points to the importance of the stock as a unit of management. The biological parameters obtained in other areas are not necessarily applicable to another area. The biological studies must be repeated for every fishery in the country. The economic parameters are also important. Studies on the dynamics of fleet behaviour are much needed. Since the fishery can be regarded as a capital asset, the investment parameters, effort entry (investment) into and exit (disinvestment) from the fishery, are crucial in explaining the performance of the fishery. Basic costs and returns information need to be compiled together with the basic biological data collected. At present these studies are sporadic in nature with respect to time, gear and place.

Although a prawn fishery constitutes one of the most important fisheries in value terms, other fish species are also caught by the equipment involved in the prawn fishery. In this respect, management and hence modelling of tropical fisheries should not only take account of the multi-gear, multi-species aspect of the fishery; the interactions between the species are also important considerations. These characteristics should be the focus of future research concerning modelling tropical fisheries management.

ACKNOWLEDGEMENTS

This study was funded by a grant from the International Center for Living Aquatic Resource Management (ICLARM). This financial support is gratefully acknowledged. Over the course of the project several research assistants have helped in the collection and preliminary analyses of data. We wish to record the contributions of Mohd. Rashid Rabu, Ariffin Mohd. Nor, Salwana Mohd. Saad, and Maizatul Akmam. We would also like to thank the Department of Fisheries, particularly the Johore Department of Fisheries, for accommodating our numerous visits to the field. In particular we thank En. Aliman Salidin for help in data collection. Thanks are due to Pn. Zalila Samsudin for her patience and perseverance in turning sometimes unreadable scratchings into a word processsed manuscript. Finally, we would like to thank Anthony T.

Charles and an anonymous referee for their invaluable comments and suggestions to improve the paper. As usual both are absolved from remaining errors, which are entirely ours.

REFERENCES

ABU TALIB AHMAD and MAHYAM MOHD. ISA. 1986. Panduan mengenal-pasti jenis-jenis udang laut dagangan di Malaysia. Kuala Lumpur: Jabatan Perikanan, Kementerian Pertanian Malaysia.

ABU TALIB AHMAD and MOHD. TAUPEK MOHD. NASIR. 1990. Estimation of mortality rates for banana prawns, *Penaeus merguensis*, using a pseudo-catch curve methodology. In *Fisheries Research and Development Project* (ADB, 862-MAL), Kuala Lumpur: Department of Fisheries.

ALIAS MAN and C.P. MATHEWS. 1990. A first assessment of the *Penaeus merguensis* stock from the Kuala Sepetang Estuary, Perak. In *Fisheries Research and Development Project* (ADB, 862-MAL). Kuala Lumpur: Department of Fisheries.

ANDERSON, L.G. 1986. *The Economics of Fishery Management*. Baltimore: John Hopkins University Press.

ANON. 1990. On some aspects of the biology of the pink prawn *Metapenaeus affinis* (H. Milne-Edwards) and the Pukat Kenka Fishery of Kuala Kurau, Perak. In *Fisheries Research and Development Project* (ADB, 862-MAL). Kuala Lumpur: Department of Fisheries.

CHUA CHONG WENG. 1978. *Commercial Prawns of Peninsular Malaysia*. Kuala Lumpur: Department of Fisheries, Ministry of Agriculture Malaysia.

CHULLASON, SOMSAK and PURWITO MATROSUBROTO. 1986. Distribution and important biological features of coastal fish resources in Southeast Asia. FAO Fisheries Technical Paper 278. Rome: FAO.

GARCIA, S. and L. LE RESTE. 1981. Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. FAO Fisheries Technical Paper 203. Rome: FAO.

GRANT, WILLIAM L. 1986. *Systems Analysis and Simulation in Wildlife and Fisheries Sciences*. New York: John Wiley.

JABATAN PERIKANAN. 1989. Kajian kos dan pulangan perkakas-perkakas tradisional di Semenanjung Malaysia, 1988. Kuala Lumpur: Cawangan Perancang & Sistem Maklumat Pengurusan Perikanan, Jabatan Perikanan, Kementerian Pertanian Malaysia. 6 Mac.

LUI YEAN PONG. 1990. A simple surplus production model of the panaeid prawn fishery off the west coast of Peninsular Malaysia, In *Fisheries Research and Development Project* (ADB, 862-MAL). Kuala Lumpur: Department of Fisheries.

MURAWSKI, S.A. 1984. Mixed species yield-per-recruitment analysis accounting for technological interactions. *Can. J. Fish Aqt. Sc.* **41:** 897-916.

PADILLA, JOSE E. and ANTHONY T. CHARLES. 1994. Bioeconomic modeling and the management of capture and culture Fisheries. *NAGA the ICLARM Quarterly* **17(1):** 18-20.

PATHANSALI, D. 1976. Assessment of potential yields from coastal marine fisheries resources of Malaysia. Fisheries Bulletin No.5. Kuala Lumpur: Ministry of Agriculture.

PENN, J.W. and N. CAPUTI. 1985. Stock recruitment relationships for the tiger prawn, *Penaeus esculentus* fishery in Exmouth Gulf, Western Australia, and their implications for management. In *Second Australian National Prawn Seminar* ed. P.C. Rothlisberg, B.J. Hill and D.J. Staples, p. 165-173.

RICKER, W.E. 1975. Computation and interpretation of biological statistics of fish population. *Bulletin of Fisheries Research Board of Canada* **191.**

SIVASUBRAMANIAM, K. 1990. Bio-economics of small-scale fisheries, paper presented at the *FAO/BOBP Workshop on Bio-Economic Studies*, 2-12 October, Penang, Malaysia.

SMITH, V. 1968. Economics of production for natural resources. *Amer. Econ. Rev.* **58:** 409-431.

SOMERS, I.F. 1990. Manipulation of fishing effort in Australia's penaeid prawn fisheries *Australian J. Marine and Freshwater Research* **41(1):** 1-2.

SPARRE, P. and R. WILLMAN. 1990. *Analytical Bio-economic Simulation of Space Structured Multi-Species and Multi-Fleet Fisheries.* Rome: FAO.

TAI, S.Y. 1993. An evaluation of alternative fisheries management schemes for Malaysia. In *Malaysian Agricultural Commodity Forecasting and Policy Modelling,* ed. M.A. Fatimah, S. Md. Nasir and O. Mohd. Shahwahid. p.135-165. Serdang: Centre for Agricultural Policy Studies, University of Agriculture Malaysia.

WALTERS. C. 1986. *Adaptive Management of Renewable Resources.* New York: MacMillan.

YONG, A.H., S.C. PANG and A.B. BEJIE. 1990. A first multi-species bioeconomic model of Sarawak's prawn fishery. In *Fisheries Research and Development Project* (ADB, 862-MAL). Kuala Lumpur: Department of Fisheries.

(Received 23 August 1993)