Marine Resource Economics, Volume 11, pp. 85–103 0738-1360/96 $3.00 + .00

Effort Dynamics and Alternative Management Policies for the Small Pelagic Fisheries of Northwest Peninsular Malaysia

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Abstract *The dynamics of fish stocks are an important consideration in determining appropriate fishery management policy. Equally crucial are the dynamics of fishing effort. Both these dynamics have been incorporated in a simulation model to analyze the bio-socioeconomic impacts of four alternative limited entry management policies for the multispecies, multigear small pelagic fishery of northwest Peninsular Malaysia. Fishing effort dynamics are determined by the difference in profits and opportunity costs. Several management alternatives are evaluated at equilibrium. Performance variables such as equilibrium catch, social profits, consumer surplus, social benefits, direct fishery employment and income of individual crew are used in the evaluation. The implications for policy makers are discussed.*

Key words Fishing effort dynamics, license fee, limited entry licensing, opportunity cost of effort, simulations.

Introduction

Fishery systems have very complex interactions between resource stocks and the factors such as labor and capital used to harvest the stocks. Sound management of these systems should take into account all the biological, economic and social factors (Fletcher *et al.* 1988; Anderson 1985; Wilson 1982; Beddington and May 1980). While the population dynamics of fish stocks has been given much attention in the past, other factors such as the adjustment dynamics of fishing effort have been given less consideration in the fishery management literature (Charles 1989).

Undoubtedly, fishery regulations will affect the fish stocks being managed. On the other hand, fishermen in the real world will also respond accordingly to the types of regulation being imposed. Understanding the adjustment processes of fishing effort is crucial for designing and implementing efficient and equitable fishery management policies (Terkla *et al.* 1985). Doeringer *et al.* (1986) argue that the behavioral responses of fishermen in supplying effort need to be taken into account in fishery management, in particular with regard to effort controls.

When systems are dynamic, the appropriate tools for analyzing optimal manage-

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ment strategy include optimal control and dynamic programming (Clark 1990; Cohen 1987; Anderson and Ben-Israel 1981; Hilborn 1979; Holling 1978). However, due to the complexity inherent in tropical fisheries systems, these techniques suffer from the problems of intractability and "curse of dimensionality" (Schriber 1991; Clark 1990; Fair 1974). Consequently, they have limited practicability and are suited only for the discovery of general principles (Arnason 1990).

One other technique to be used to study complex fishery systems is simulation. This technique does not suffer from the above problems (Schriber 1991) but it may not yield theoretically optimal results. Moreover, system simulation models can be used to understand the effect of different management policies on the fishery system components (Arnason 1990; Richardson and Gates 1986; Grant *et al.* 1981). The purpose of this paper is to describe a simulation model which incorporates both fish population dynamics and the dynamics of fishing effort. The model is used to examine the bio-socioeconomic effects of alternative management policies for the small pelagic fishery of northwest Peninsular Malaysia.

The small pelagic fishes are among the most important species groups harvested in northwest Peninsular Malaysia, contributing annually from 1980 to 1989 about 37% of the total fish catch and over 90% of total pelagic landings (Department of Fisheries Malaysia 1981–90). In terms of value, small pelagic fishes contributed about 17% and 68% of the wholesale value of total fish and total pelagics in 1989. The four most important small pelagic species groups, namely, Indian mackerel, scads, sardine, and tuna are incorporated in the model. These fish accounted for approximately 52% of total fish landings in northwest Peninsular Malaysia between 1980 and 1989. Small pelagic species in the region are predominantly caught by three types of gear: purse seine, trawl, and drift net. The combined landings of these gears made up at least 80% of the total catch for each small pelagic species group. These dominant gear types are also explicitly included in the model.

The model involves numerous assumptions. The next section describes various components of the model. This is followed by a description of the simulations for four alternative management policies. The results of the simulations are presented in the following section, and a discussion of fishery policy implications is given in the final section.

The Model

The broad structure of the model has three components: (1) the biological, (2) the socioeconomic, and (3) the management. The biological submodel describes the population dynamics of the small pelagic fishery. In the socioeconomic component, the benefits and costs of fishing operations are presented. The dynamics of fishing effort are described in the management component section.

Biological Submodel

The population dynamics of each small pelagic fish stock is represented by surplus production models because data on the population parameters for these species in Malaysia are either sparse or mostly unavailable (Chullasorn and Purwito 1986). The rate of change of fish stock $\dot{X}_i$ is determined by natural reproductive dynamics and harvesting

$$\dot{X}_i = F(X_i) - H_i \tag{1}$$

where $F(X_i)$ is the natural growth rate of fish stock i which is dependent on the current size of the population $X_i = X_i(t)$. The quantity harvested per unit of time is represented by $H_i = H_i(t)$. The net growth rate $\dot{X}_i$ is obtained by subtracting the rate of harvest H_i from the rate of natural growth $F(X_i)$.

Functional relationships commonly used to represent the natural growth rate of fish stock are either the logistic (Schaefer 1957; Schnute 1977) or the Gompertz (Fox 1970). These specifications are as follows:

$$\text{Logistic:} \qquad F(X_i) = r_i X_i[1 - (X_i/K_i)] \tag{2}$$

$$\text{Gompertz:} \qquad F(X_i) = s_i X_i \ln (K_i/X_i) \tag{3}$$

where r_i is the intrinsic growth rate, K_i is the environmental carrying capacity, and s_i is the constant associated with the intrinsic growth rate for species i.

The rate of harvest of species i (H_i) is assumed proportional to aggregate standardized fishing effort (E) and the biomass of the stock (X_i); that is

$$H_i = q_i X_i E \tag{4}$$

where q_i is the catchability coefficient.

The standardized fishing effort, measured in number of fishing days needs further deliberations. In a multigear fishery, there is heterogeneity in the types of gear used, vessel sizes, engine power, ancillary and fish-finding equipment. Combinations of these inputs have different effects on the fish stocks. Thus standardization of fishing effort is required which involves first estimating the relative fishing power for the vessels and gears as follows (Gulland 1983)

$$P_{cj} = U_{cj}/U_s \tag{5}$$

where P_{cj} is the estimated fishing power of vessels using gear j in tonnage class c; U_{cj} is the average catch per unit of effort for vessels using gear j in tonnage class c; and U_s is the average catch per unit of effort for vessels of a particular gear in a particular tonnage class which is used as the standard. The average catch per unit of effort for drift net vessels is used as the standard in computing the relative fishing power of other gears. This is because the number of drift nets in use is the largest among the gear types and data on fishing days of the drift net fleet are not categorized by tonnage classes. The fishing power of a particular gear type (P_j) is then the weighted average fishing power among its various tonnage classes. The weights used are the ratio of the number of vessels in a particular tonnage class to the total number of vessels for the gear. The estimates of the average fishing power for various gear types are shown in table 1. Once average fishing power has been calculated, the standardized fishing effort exerted by gear j is computed as

$$E_{jt} = P_j T_{jt} V_{jt} \tag{6}$$

where E_{jt} is the standardized fishing effort of gear j at time t; P_j represents average relative fishing power of gear type j; T_{jt} is the average fishing days of vessels j at time t; and V_{jt} denotes the number of vessels j at time t.

If stock i is in steady state equilibrium, then $\dot{X}_i = 0$. The biological parameters of stock i can be estimated by substituting specific form of $F(X_i)$ and H_i into equation (1). With logistic form for $F(X_i)$, Schaefer (1957) shows that the yield-effort function becomes

Table 1
Description and Values of Biological and Technical Parameters

Parameter	Definition	Value
r_i	Intrinsic growth rate per year for	
	Indian mackerel	2.308
	Tuna	0.194
s_i	Constant associated with intrinsic growth rate per year for	
	Scads	0.027
	Sardine	0.044
K_i	Environmental carrying capacity (mt) for	
	Indian mackerel	187,040
	Scads	3,214,726
	Sardine	743,973
	Tuna	83,714
q_i	Catchability coefficient for	
	Indian mackerel	9.8011×10^{-5}
	Scads	0.3905×10^{-5}
	Sardine	0.7658×10^{-5}
	Tuna	0.7884×10^{-5}
P_j	Average relative fishing power for	
	Trawl	12.66
	Purse seine	35.87
	Drift net	1
θ_{ij}	Proportion of catch of species *i* by gear *j*	
	Indian mackerel - trawl	0.271
	Purse seine	0.591
	Drift net	0.138
	Scads - trawl	0.185
	Purse seine	0.794
	Drift net	0.021
	Sardine - trawl	0.214
	Purse seine	0.755
	Drift net	0.031
	Tuna - trawl	0.001
	Purse seine	0.814
	Drift net	0.185

Source: Tai 1992.

$$H_{it} = q_i K_i E_t - (q_i^2 K_i / r_i) E_t^2 \qquad \text{if } E_t \leq r_i / q_i \tag{7}$$

With the Gompertz form for $F(X_i)$, the yield-effort model as shown by Fox (1970) is thus

$$H_{it} = q_i K_i E_t \exp[-(q_i / s_i) E_t] \tag{8}$$

Without making the assumption of steady state equilibrium, Schnute (1977) transformed the Schaefer model and estimated the parameters with the following dynamic equation

$$\ln[\overline{U}_{it} / \overline{U}_{i,t-1}] = r_i - q_i[(E_t + E_{t-1})/2] - [r_i/(q_i K_i)][(\overline{U}_{it} + \overline{U}_{i,t-1})/2] \tag{9}$$

where $\bar{U}_{it} = \sqrt{(U_{it}U_{i,t-1})}$ is the average catch per unit of fishing effort for species i at time t.

Tai (1992) has found that the Schaefer and Schnute model provides the best fit for the tuna and Indian mackerel species, respectively, while the Fox model fits well for the scads and sardine species. Based on these relationships, the biological parameter values which represent the 'average' conditions for 1968 to 1990 were estimated and are presented in table 1.

In the simulations, equations (7) or (8) are used to calculate H_{it}, the harvest of i at time t, which is then allocated among the three gear types. The allocation is done by assuming that the ratio of the catch of species i by gear j to the aggregate catch of species i is a constant proportion (θ_{ij}),[1] *i.e.*,

$$H_{ijt} = \theta_{ij}H_{jt} \tag{10}$$

with $\theta_{ij} = \bar{H}_{ij}/\bar{H}_i$, where $\bar{H}_{ij}$ and $\bar{H}_i$ are respectively the time-averaged harvest of species i by gear j and the time-averaged total harvest of species i. The values of θ_{ij} are presented in table 1.

Socioeconomic Submodel

This submodel describes the computations of variables which will be used to evaluate the performance of several management policies to be discussed in a later section. The performance variables include equilibrium harvest, social profits, consumer surplus, social benefits, individual crew income and direct fishery employment.

Social Benefit

The social benefit derived from a fishery is the sum of consumer surplus, resource rent and producer surplus. The producer surplus comprises the intramarginal rent of highliner vessels (Copes 1972). However, it is difficult to separate the resource rent and producer surplus in this study due to the aggregated nature of the data. Hence, resource rent and producer surplus are aggregated into the social profit from exploiting the fishery. This social profit corresponds to revenues over and above payments necessary to keep the factors of production in their present use (assuming capital and labor are paid at their opportunity costs). The social profit function (π_t) is as follows:

$$\pi_t = \Sigma_j[\Sigma_i(P_{it}H_{ijt}) + BC_{jt} - (c_j + \gamma_j)E_{jt} - Y_{jt} - FC_{jt}] \tag{11}$$

where P_{it} represents ex-vessel price of species i, BC_{jt} denotes revenue from by-catch for gear j; c_j and γ_j represents trip expense and opportunity cost per unit of standardized effort for gear j respectively;[2] Y_{jt} denotes crew expense for gear j at time t; and FC_{jt} is the fixed cost for gear j.

Fish prices are considered as fixed and exogenous when they are determined internationally or when landings represent a very small proportion of the overall market. The prices of sardine and tuna are determined in this way. On the other hand,

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[1] Ideally, harvest of species i by gear j at time t, H_{ijt} ought to be estimated from data on effort directed by gear j to species i. However, these data are unavailable and hence this assumption is made to approximate H_{ijt} from H_{it}.

[2] One unit of standardized effort is equivalent to one thousand standardized fishing days.

the prices for Indian mackerel and scads are variable in response to the conditions of supply and demand in the domestic market. Following DeVoretz (1982), the price equations for Indian mackerel and scads are specified in log-linear form as follows:

$$\ln P_{it} = \alpha_{0i} + \alpha_{1i} \ln Q_{it} + \Sigma_u \alpha_{ui} \ln P_{ut} + \alpha_{4i} \ln I_t \quad (12)$$

where P_{it} = ex-vessel price of species *i* at time *t*; Q_{it} = total quantity supplied of species *i* at time *t*; P_{ut} = prices of small pelagic species other than *i* at time *t* and I_t = per capita income at time *t*. The coefficients for the price equations for Indian mackerel and scads have been estimated and discussed in Tai (1992) and are shown in table 2.[3]

Revenue from by-catch is computed by multiplying the total catch of species other than the small pelagic and their corresponding average price. It is assumed that revenue from by-catch is proportional to the weight of small pelagic catches which implies that the mix of small pelagic species and by-catches in the harvest remains unchanged over time. This assumption is made because it is not possible to model explicitly the catches and revenues from fish other than the small pelagics as there are more than fifty species or species groups harvested by the gears. The factor of proportionality for each gear type (BC_j) as shown in table 2 is derived by computing the average of the ratio of by-catch revenue to the small pelagic catches of each gear type from 1980 to 1989.

Fishing costs comprise fixed, variable, and opportunity costs. Fixed cost (FC_{jt}) consists of depreciation of fishing assets, and is incurred irrespective of whether a fishing unit is operative.

$$FC_{jt} = F_j V_{jt} \quad (13)$$

where F_j is constant fixed cost per vessel obtained from Md. Ferdous (1990) as shown in table 2 and V_{jt} denotes the number of vessels of gear type *j*. Variable costs consist of trip expense and crew cost. Trip expense includes the costs of fuel, oil, ice, food, nets, and expenses for fish aggregating devices such as floating lamps. Trip expense per unit of standardized effort for each gear type (c_j) is shown in table 2.[4] Crew cost is computed as in (14) based on share system which is the dominant system of crew remuneration.

$$Y_{jt} = [\Sigma_i (P_{it} H_{ijt}) + BC_{jt} - c_j E_{jt}] Sh_j \quad (14)$$

where Sh_j denotes crew share of the net proceeds from sale of fish for gear type *j* as shown in table 2 obtained from Md. Ferdous (1990). The opportunity cost of effort for gear *j* (γ_j) represents the benefits foregone by keeping input factors to produce a unit of fishing effort in their present use. In practice, it is very difficult to measure the opportunity cost of fishing effort. The opportunity cost can be estimated from an

[3] The data for estimating the price equations were from the following sources: the ex-vessel prices were adapted from the Malaysian Fisheries Development Authority reports, quantity supplied data were from the Annual Fisheries Statistics, and the per capita income data were obtained from the Economic Reports. These equations were estimated using the Seemingly Unrelated Regression technique to account for possible presence of contemporaneous correlations between the error terms of the equations.

[4] Average trip expense per standardized fishing day for gear type *j* (c_j) is computed as follows. (1) Calculate the trip expense per standardized fishing day in year *t* by multiplying the annual trip expenses per vessel obtained from Md. Ferdous (1990) by the number of vessels, then adjusting by the consumer price index in year *t* (1980 = 100) and dividing by the total standardized effort in year *t*. (2) Compute the average trip expense per day fished for the years between 1980 and 1990.

Table 2
Description and Values of Economic Parameters

Parameter	Description	Value
BC_j	Proportion of by-catch revenue to small pelagic catch for	
	Trawl	10.707
	Purse seine	0.107
	Drift net	3.495
c_j	Trip expenses (RM / std. day)	
	Trawl	15.63
	Purse seine	8.65
	Drift net	31.29
F_j	Fixed cost (RM / vessel)	
	Trawl	3,012
	Purse seine	5,436
	Drift net	499
Sh_j	Crew share	
	Trawl	0.5
	Purse seine	0.5
	Drift net	0.67
γ_j	Opportunity cost (RM / thousand days)	
	Trawl	9,068
	Purse seine	10,824
	Drift net	7,480
Cr_j	Average crew member per vessel	
	Trawl	4
	Purse seine	17
	Drift net	2
Ω_j	Effort response parameter (thousand days)	
	Trawl	0.0627
	Purse seine	0.0365
	Drift net	0.0043
α_{0i}	Intercept of price equation for	
	Indian mackerel	–6.337
	Scads	2.169
α_{1i}	Coefficient of quantity supplied in price equation for	
	Indian mackerel	–0.123
	Scads	–0.082
α_{2i}	Coefficient of ex-vessel price of	
	Scads in Indian mackerel price equation	0.511
	Indian mackerel in scads price equation	0.487
α_{3i}	Coefficient of ex-vessel price of sardine in price equation for	
	Indian mackerel	0.124
	Scads	0.308
α_{4i}	Coefficient for per capita income in price equation for	
	Indian mackerel	1.246
	Scads	1.259

Source: Tai 1992.

equation describing the dynamics of effort as suggested by Wilen (1976). This will be discussed in more detail in the management submodel.

Consumer surplus is derived from consumption of Indian mackerel and scads since these species have downward sloping demand curves. The demands for sardine and tuna are perfectly elastic as their prices are determined exogenously. The change in Marshallian consumer surplus (Cs_t)[5] is estimated by first transforming the price equation (12) into a quantity-dependent demand equation and then integrating the area under the demand function between the prices as follows:

$$CS_t = \int_{P10}^{P11} [(\beta_{10} P_{20}^{\beta 12} I^{\beta 13}) P_1^{\beta 11}] dP_1 + \int_{P20}^{P21} [(\beta_{20} P_{11}^{\beta 21} I^{\beta 23}) P_2^{\beta 22}] dP_2 \qquad (15)$$

Here P_{10} and P_{11} are the prices of Indian mackerel in period 0 and 1 respectively, P_{20} and P_{21} are the prices of scads in period 0 and 1 respectively, I denotes per capita consumer income and the β's are the coefficients of the quantity dependent demand equations for Indian mackerel and scads.

Direct Employment and Individual Crew Income

Direct fishery employment (DE_t) is computed as follows:

$$DE_t = \Sigma_j (Cr_j V_{jt}) \qquad (16)$$

where Cr_j denotes average number of crews per vessel j obtained from Md. Ferdous (1990) as shown in table 2 and V_{jt} is the number of vessels j in operation.

Individual crew income for gear $j(CY_{jt})$ is estimated by dividing total crew expenses (Y_{jt}) by direct employment for gear j

$$CY_{jt} = (Y_{jt}/DE_{jt}) \qquad (17)$$

Management Submodel

This submodel describes the dynamics of fishing effort which are likely be affected by fisheries management policies and regulations, in particular with regards to effort control policies.

The original impetus for incorporating fishing effort dynamics into the "traditional" fishery systems came from Smith (1968). In his model, Smith postulated that fishing effort changed over time in response to the availability of profits in the fishery. Recently, several researchers have examined factors in addition to profit which determine the dynamics of fishing effort. For example, Wilen (1976) incorporated a "cutoff" rate of return to entrepreneurs; Opaluch and Bockstael (1984) considered some threshold of potential returns in alternative employment (or opportunity cost); and Krauthamer *et al.* (1987) examined several social, cultural, and psychological factors.

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[5] When there are simultaneous price changes, the Marshallian consumer surplus suffers from the path-dependency problem (Johansson 1991). However, if a path is consistently followed such as allowing first the price of Indian mackerel to change, followed by the change in price of scads, the path-dependency problem may not be serious when comparing alternative fisheries management policies.

The dynamics of fishing effort for gear type j is postulated to follow a differential equation:[6]

$$\dot{E}_{jt} = \Omega_j[(\pi_{jt}/E_{jt}) - \gamma_j] \tag{18}$$

where $\dot{E}_{jt}$ denotes time rate of change of effort for gear j at time t; $\pi_{jt} = [\Sigma_i(P_{it}H_{ijt}) + BC_{jt} - c_jE_{jt} - Y_{jt} - FC_{jt}]$; γ_j is the opportunity cost of a unit of standardized effort for gear j; and Ω_j is a "response parameter" indicating how fast effort of gear j responds to excess profits. Equation (18) shows that whenever π_{jt} per unit of standardized effort for gear j is greater than γ_j, effort entry will occur. On the other hand, effort will exit the fishery when π_{jt} per unit of standardized effort is less than γ_j. In an equilibrium fishery, $\dot{E}_{jt} = 0$ as there is no entry or exit of fishing effort of gear j. This happens only if π_{jt} per unit of standardized effort equals γ_j.[7]

The Ω_j and γ_j are estimated directly from equation (18) using seemingly unrelated regression to take into account the contemporaneous correlations between the error terms (Kennedy 1985) and the results are shown in table 3. Except for the $\Omega\gamma$ of the drift net fleet, the parameter estimates for all gear types are significant and are correctly signed. The R^2 ranged from 0.21 for trawl to 0.35 for purse seine and are reasonable since the social and cultural variables which are important determinants of effort dynamics could not be included in the equations due to lack of data.

The estimated coefficients Ω_j show that for every Ringgit Malaysia (RM)[8] increase in profit per thousand standardized fishing days, fishing effort for trawl, purse seine and drift net fleet will increase by 0.0627, 0.0365, and 0.0043 thousand

Table 3

Seemingly Unrelated Regression for Dynamics of Effort by Gear Type

	Gear Type		
	Trawl	Purse Seine	Drift Net
Ω	0.0627**	0.0365***	0.0043***
	(2.88)	(3.77)	(3.84)
$\Omega\gamma$	–568.57*	–395.06***	–32.16
	(–1.67)	(–4.95)	(–1.39)
R^2	0.21	0.35	0.31
γ	9,068	10,823	7,479

Source: Tai 1992.
Figures in parentheses denote t-ratios.
*** = significant at the 1% level.
** = significant at the 5% level.
* = significant at the 10% level.

[6] This formulation of effort dynamics follows that of Wilen (1976). Some authors (*e.g.* Allen and McGlade 1986; Clark 1985) have postulated that effort entry or exit is proportional to aggregate profit rather than per unit effort profit. This may be unrealistic because it implies that effort entry or exit would be the same for two fisheries having the same aggregate profit, but one with a higher effort level and lower profit per unit of effort compared to the other.

[7] The effort dynamics equation shows a symmetrical entry and exit response for fishing effort. However, fisheries management policies to be considered in this paper will always result in π_j being greater than γ_j, hence entry of effort will occur. Thus the effort dynamic equation can be treated as effort entry rather than exit equation.

[8] Ringgit Malaysia (RM) is the currency unit of Malaysia.

standard days respectively. The opportunity cost per thousand standardized days (γ_j) for purse seine is the highest.

Policy Simulations

The above model is used to simulate the relative bio-socioeconomic impacts of effort control policies for the small pelagic fishery of northwest Peninsular Malaysia. The description and values for the biological and economic parameters are shown in tables 1 and 2 respectively. Standardized effort by gear type is the control variable in the simulations and the initial values for trawl, purse seine and drift net fleets are set at 10.18, 2.65, and 1.217 million days respectively as shown in table 2. These initial values are supplied to the model to compute the values of the performance variables for the first period. The values of standardized fishing effort are then revised in the next period based on the predicted effort changes for the first period and all values of the performance variables are recalculated. These calculations are reiterated until the last period (which corresponds to the equilibrium values of the performance variables) is reached.

Four alternative effort control policies as shown in table 4 are evaluated using the model. Policy 1 involves maintaining current fishery management policy and perpetuating the present situation in the fishery. Current fishery management policy in Peninsular Malaysia involves limiting the number of vessels through the issuing of licenses (Jahara 1988; Sulaiman and Ch'ng 1987). If the number of licenses issued corresponds to the level of effort commensurate with the objectives of management, then policy 1 is desirable and no further action needs to be taken. With policy 1, the dynamics of effort is described by equation (18).

On the other hand, it may still be possible to improve the bio-socioeconomic performance of the fishery by further restricting the number of vessels to reduce fishing effort. In order to determine the greatest possible bio-socioeconomic improvements, the number of vessels is further restricted as described by Policies 2A through 2D. Policy 2A involves reducing effort by 40% from policy 1 level while effort levels for policies 2B, 2C, and 2D represents reduction of 50%, 60%, and 70% respectively from policy 1 level.[9] The dynamics of effort under policies 2A, 2B, 2C, and 2D can still be described by equation (18). Note that policies 1, 2A, 2B, 2C, and 2D essentially restrict the number of vessels. Fishing effort can still be increased by raising the number of days each vessel fishes up to some maximum. Denoting the maximum number of days a vessel of type *j* can fish per year by Md_j, the maximum standardized effort per year for each gear type (ME_{jt}) can be calculated as

$$ME_{jt} = P_j V_{jt} Md_j \tag{19}$$

where P_j is the average fishing power, V_{jt} is the number of vessels at time t, Md_j is the maximum number of fishing days per vessel and subscript j is for gear type. The value of Md_j is assumed to be 300, 280, and 280 days for each trawl, purse seine, and drift net vessel respectively.[10]

Fishery management policy which merely restricts the number of vessels will

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[9] Simulations are conducted for policy scenarios where the number of vessels is reduced in steps of 10% from policy 1 level. Since the greatest bio-socioeconomic improvements lies within the scenarios as described by Policies 2A through 2D, only the results of these policy scenarios will be presented and discussed in this paper.

[10] Some days will be lost in a year due to repair and maintenance of vessels and gears, bad weather and rest for fishing crews. Obviously, vessels do not have to operate up to the maximum days per year. However, the possibility of earning rents will likely to induce vessels to operate at the maximum number of days.

Table 4
Description of Alternative Policies and the Corresponding Initial Values of Effort in Simulations

Policy	Description	Initial Value of Effort (1,000 Days)
1	Present management policy by restricting number of vessels through limited entry licensing	
	Trawl	10,180
	Purse seine	2,650
	Drift net	1,217
2A	Further restricting effort by 40% of policy 1 level	
	Trawl	6,108
	Purse seine	1,590
	Drift net	730
2B	Further restricting effort by 50% of policy 1 level trawl	
	Trawl	5,090
	Purse seine	1,325
	Drift net	609
2C	Further restricting effort by 60% of policy 1 level	
	Trawl	4,072
	Purse seine	1,060
	Drift net	487
2D	Further restricting effort by 70% of policy 1 level	
	Trawl	3,054
	Purse seine	795
	Drift net	365
3	Restricting effort to policy 2C level and imposing license fee to appropriate completely the rents generated	
	Trawl	4,072
	Purse seine	1,060
	Drift net	487
4	Restricting effort to policy 2C level, increasing opportunity cost of effort by 50% and imposing license fee to appropriate completely the rents generated	
	Trawl	4,072
	Purse seine	1,060
	Drift net	487

not be effective. A limited entry licensing policy that successfully restricts fishing effort initially to some desire level will generate economic rent. The rent will induce remaining fishermen to increase their effort either through "capital stuffing" their vessels or by increasing their fishing times, thereby defeating the initial intent of the policy. The incentive to expand effort needs to be curtailed by imposing fees to appropriate all the rent generated in the fishery after fishing effort is reduced to the desired level. Hence policy 3 describes a scenario where the fishing effort is restricted to the desired level coupled with levying of a license fee to completely appropriate the rent in the fishery.[11] The desired level of effort corresponds to the greatest bio-socioeconomic improvements as determined in the simulations of the various scenarios for policy 2. With this policy, the equation for fishing effort dynamics becomes:

[11] Note that technological progress will increase fishing power of vessels and thus will increase fishing effort over and above the desired level. In this case, the number of vessels needs to be restricted further in order to maintain effort at the desired level.

$$\dot{E}_{jt} = \Omega_j[(\pi_{jt}/E_{jt}) - \gamma_j - \phi_j] \quad (20)$$

where ϕ_j denotes the license fee per unit of effort for gear j. When the fishery is managed so that the desired level of effort is attained and then a license fee is levied to appropriate completely the rent generated in the fishery, $\dot{E}_{jt}$ will be zero. This then will allow the full license fee to be calculated from equation (20).

Increased opportunity cost of fishermen's effort is a possible fishery management policy which supplements limited entry licensing with full fees (policy 4). Panayotou (1980) and Smith (1981) argued that a possible solution to fishery problems in developing countries lies outside the fishery sector. This is because incomes from fishery for these countries are low and maintaining a high level of employment is a principal development goal. One way of reducing fishing effort is by creating more employment outside the fishing sector and transferring surplus fishing inputs into the nonfishing sectors. As more jobs are available and demand for inputs in the nonfishing sectors increases, the opportunity costs of effort would be increased. Moreover, fishermen can be retrained to acquire skill for engaging in more productive jobs. This will also increase the opportunity cost of effort. The equation for effort dynamics for policy 4 is as follows:

$$\dot{E}_{jt} = \Omega_j[(\pi_{jt}/E_{jt}) - (1 + \sigma)\gamma_j - \phi_j] \quad (21)$$

where σ denotes percent increase in the opportunity cost per unit of effort. For this study, it is assumed that σ takes the value of 0.5,[12] a 50% increase in the opportunity cost per unit of effort in the long run.

Simulation Results

The simulation results for policies 1, 2A, 2B, 2C, and 2D are presented in figures 1a through 1c. In figure 1a, fishing effort for policy 1 is seen to increase greatly in the first year from the initial conditions. The increase is gradual thereafter until the equilibrium level of effort at 19.25 million days is reached. However, for policies 2A through 2D, the strong increase in the first year results in effort reaching immediately the equilibrium levels which are constrained by the maximum effort as shown in equation (19).

The biological consequences of alternative policies 1, 2A, 2B, 2C, and 2D as presented in figure 1b show that aggregated catch of the small pelagic species in northwest Peninsular Malaysia is the lowest for policy 1, but the highest for policy 2C. However, in terms of individual small pelagic species, policy 2A and 2B give the highest equilibrium catch for tuna and Indian mackerel respectively, while the equilibrium catches of scads and sardine are the highest for policy 2D (table 5). The results imply that if management policy is aimed at maximizing aggregate catch of small pelagic fish then policy 2C should be chosen. With this policy however, the scads and sardine stocks are biologically overexploited while those for Indian mackerel and tuna are biologically underexploited.

The evolution of aggregate social benefits[13] for policies 1, 2A, 2B, 2C, and 2D is shown in figure 1c. The equilibrium aggregate social benefits is the highest for

[12] Ideally the value of σ should be determined empirically by ascertaining its trend of increase. However, the assumption is made here because it is difficult to empirically estimate the opportunity cost of fishing effort since this requires a lot of time-series data from other sectors in the economy.

[13] Aggregate social benefits comprise the sum of total social profits and consumer surplus from the small pelagic fisheries. The consumer surplus from the by-catch is excluded, however.

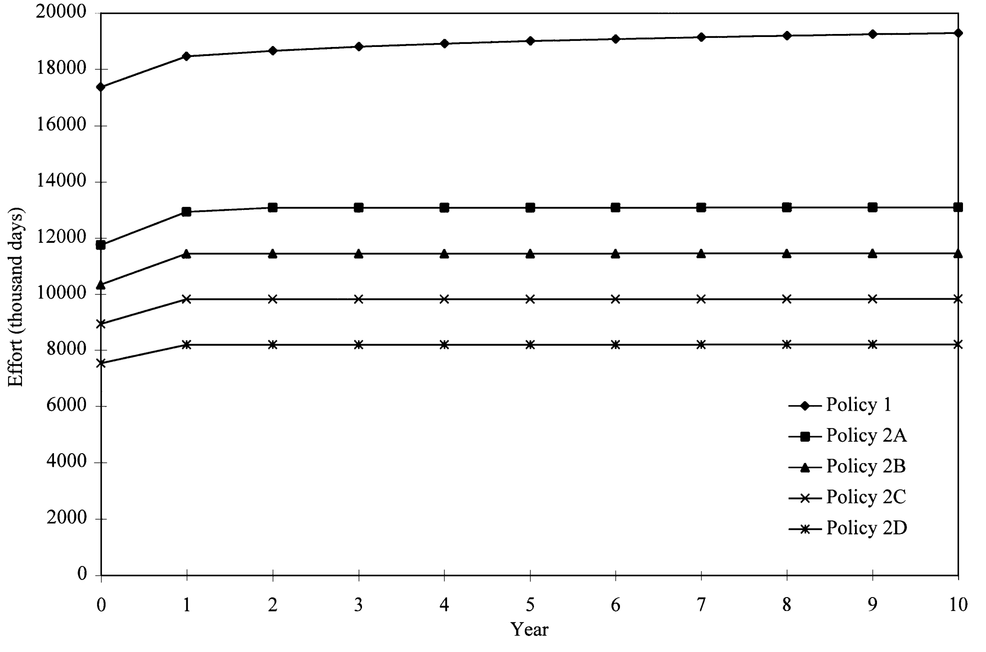

Figure 1a. Evolution of Fishing Effort for Policies 1, 2A, 2B, 2C, and 2D

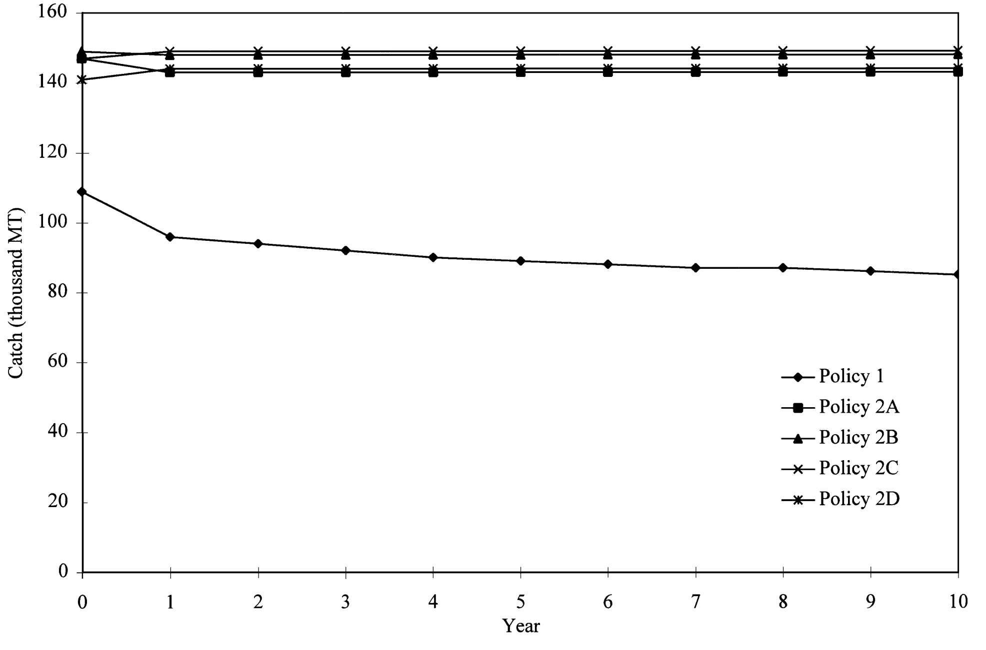

Figure 1b. Evolution of Aggregate Catch for Policies 1, 2A, 2B, 2C, and 2D

Table 5
Harvest Level (mt) of Small Pelagic Species for Alternative Policies

Policy	Indian Mackerel	Scads	Sardine	Tuna
MSY	107,900	31,545	12,172	4,080
1	64,520	14,500	3,975	2,805
2A	106,600	24,280	7,802	4,079
2B	107,900	26,980	9,044	4,075
2C	105,000	29,380	10,270	3,927
2D	98,010	31,110	11,340	3,637

Table 6
Equilibrium Individual Crew Income and Direct Employment for Policies 1, 2A, 2B, 2C, and 2D

	Individual Crew Income (RM thousand)			Direct Employment (man-year)		
Policy	Trawl	Purse Seine	Drift Net	Trawl	Purse Seine	Drift Net
1	14.89	5.31	4.01	12,780	6,134	22,400
2A	52.96	14.53	13.20	7,669	4,133	13,440
	(+256)	(+174)	(+42)	(–40)	(–33)	(–40)
2B	67.12	18.37	16.38	6,390	3,440	11,200
	(+351)	(+246)	(+76)	(–50)	(–44)	(–50)
2C	85.37	23.50	20.36	5,110	2,748	8,960
	(+473)	(+343)	(+118)	(–60)	(–55)	(–60)
2D	111.40	31.06	25.90	3,835	2,056	6,720
	(+648)	(+485)	(+178)	(–70)	(–66)	(–70)

Note : Figures in parentheses represent percentage increase (+) or decrease (–) from policy 1 level.

policy 2C (RM574.4 million). Thus, policy 2C is the appropriate management policy if the aim is to maximize aggregate social benefits.

Income to individual crew members for all gear types increases as fishing effort is reduced from policy 1 level. As shown in table 6, income to individual crew members for all gear types is the highest for policy 2D. On the other hand, direct fishery employment for all gear types decreases as fishing effort is reduced (table 6). Hence, the results show that there is a trade-off between income to individual crew members and direct employment. The proper choice of an appropriate policy based on these trade-offs is essentially the task of policy makers.

The results imply that present management of the fishery can be improved by further restricting fishing effort. Based on the biological, social, and economic performance, policy 2C appears desirable and provides improvements in the fishery compared to policy 1.

The impacts of incorporating the dynamics of fishing effort in the simulation for policy 2C are discernible in table 7. With effort dynamics, total effort was initially at about 8.9 million standardized days, but then reached the maximum equilibrium level of about 10 million standardized days in year 2 while total fishing effort remained at 8.9 million standardized days without effort dynamics. The increased in effort with consideration of the effort dynamics results in lower aggregate social benefits as well as reduced social profits and income to crew members for all gear types (table 7). However, aggregate catch, consumer surplus and direct employment for all gear types increase in this case. Higher aggregate catch with effort increases

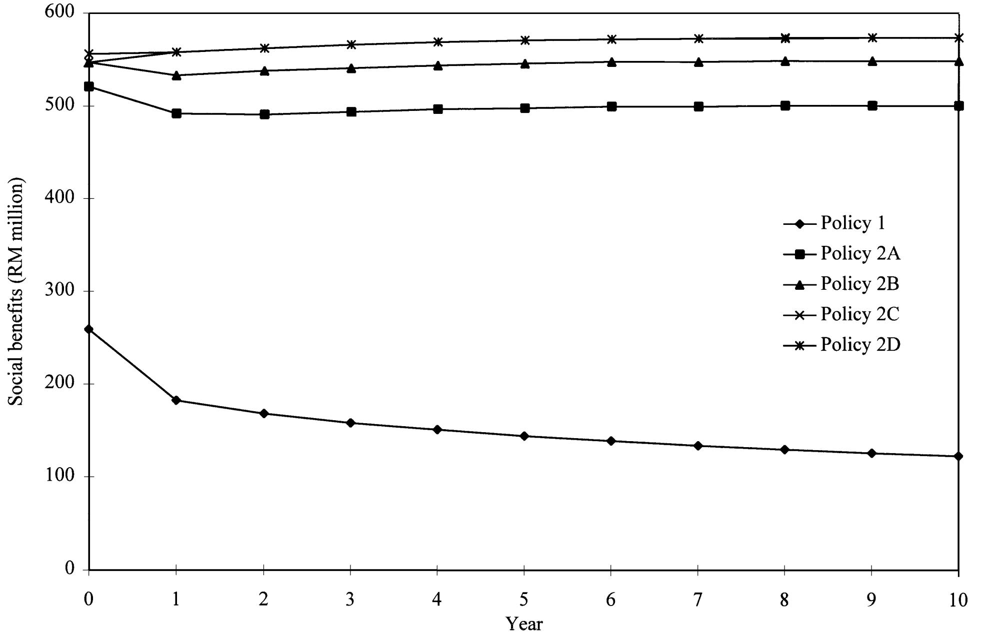

Figure 1c. Evolution of Aggregate Social Benefits for Policies 1, 2A, 2B, 2C, and 2D

is mainly due to increased catch of Indian mackerel which is the dominant species harvested in the mixed small pelagic stock. The result is expected since this species is biologically underexploited at the policy 2C level of effort as discussed earlier. The higher catch of Indian mackerel also causes the increase in consumer surplus.

The above results show that with considerations of effort dynamics, limited entry licensing by itself will not produce the desired outcome in the long run. This is because positive rents are generated in the rationalized fishery which provide incentives for remaining fishermen to increase their fishing effort. In order to maintain effort at the desired (policy 2C) level, additional measures are needed to curtail the incentives to expand effort after the initial reduction of effort to policy 2C level. As discussed earlier, the additional measures include imposition of full license fee (policy 3) or a combination of increasing the opportunity cost of fishing effort by 50% and the imposition of full license fee (policy 4).

The equilibrium values of the performance variables for policies 3 and 4, compared to those for policy 1, are shown in table 8. The results show that equilibrium aggregate effort for policies 3 and 4 remained at 8.9 million standardized days. However, there exist little differences between the values of the performance variables for policies 3 and 4, except that aggregate social benefit is higher for policy 4. In addition, the amount of license fee levied per vessel of all gear types for policy 4 is lower (table 9).[14] This is because with a higher allowance for opportunity cost of

[14] Annual license fee for each gear type is computed in the model based on the number of standardized fishing days. However, for practical purpose, it is easier to levy license fee on a per vessel basis. The license fee per vessel is computed by first converting total fishing days for each gear type into number of vessels equivalent, and then dividing the total license fees by this figure. With technological progress, the number of vessels needs to be reduced further in order to maintained effort at the desired level as explained earlier. This will increase the license fee per vessel which will need to be recalculated.

Table 7
Comparison of Policy 2C Performance With and Without the Dynamics of Fishing Effort

	Without Effort Dynamics	With Effort Dynamics
Aggregate effort (thousand days)	8,948	9,830
Catch (mt)		
Indian mackerel	101,700	105,000
Scads	30,430	29,380
Sardine	10,880	10,270
Tuna	3,787	3,927
Aggregate	146,800	148,600
Consumer surplus (RM million)	18.46	49.46
Social profit (RM million)		
Trawl	430.4	393.0
Purse seine	70.5	50.0
Drift net	89.0	82.0
Total	589.9	525.0
Aggregate social benefits (RM million)	608.4	574.4
Employment (man-year)		
Trawl	4,748	5,110
Purse seine	2,284	2,748
Drift net	5,181	8,960
Total	12,210	16,820
Crew income (RM thousand)		
Trawl	91.4	85.4
Purse seine	31.2	23.5
Drift net	35.5	20.4

fishing effort, the resource rent to be appropriated in the form of license fee will be lower. With higher opportunity cost and lower license fee imposed, policy 4 appears to be more socially and politically acceptable as compared to policy 3, although both policies are biologically and economically desirable.

Conclusion

This paper attempts to incorporate biological and effort dynamics in a simulation model to evaluate the impacts of four fisheries management policies on the small pelagic fishery system in northwest Peninsular Malaysia. The analysis is based on several assumptions regarding biological, social, and economic variables. These policies are: (1) the present situation in the fishery; (2) further reduction of effort by limiting the number of vessels through a limited entry licensing system; (3) limited entry licensing and imposition of license fees; and (4) limited entry licensing, imposition of license fee and increasing the opportunity costs of fishing effort.

The results show explicitly that the fishery system will not achieve any desired outcome through limited entry licensing policy alone. Under this policy, fishermen have sufficient incentives to expand their effort through "capital stuffing" their vessels and/or increasing their fishing days, even though the number of vessels has been restricted. The incentives for expanding effort need to be curtailed.

The key implications for policy makers are first, that present fishery management policy falls short of the desired level and further biological, social, and eco-

Table 8
Comparison of the Equilibrium Values of Fishery Performance Indicators for Policies 3 and 4 from Policy 1 Level

	Policy 1	Policy 3	Policy 4
Aggregate effort (thousand days)	19,250	8,948 (–54)	8,948 (–54%)
Catch (mt)			
Indian mackerel	64,520	101,100 (+57)	101,100 (+57)
Scads	14,500	30,580 (+111)	30,580 (+111)
Sardine	3,975	10,970 (+176)	10,970 (+176)
Tuna	2,805	3,762 (+34)	3,762 (+34)
Aggregate	85,810	146,412 (+71)	146,412 (+71)
Consumer surplus (RM million)	18.49	47.43 (+157)	47.42 (+157)
Social profits (RM million)			
Trawl	82.31	0 (–100)	0 (–100)
Purse seine	0.04	0 (–100)	0 (–100)
Drift net	24.75	0 (–100)	0 (–100)
Total	107.10	0 (–100)	0 (–100)
Aggregate social benefit (RM million)	125.50	566.40 (+352)	579.30 (+362)
Employment (man–year)			
Trawl	12,780	4,704(–63)	4,703(–63)
Purse seine	6,134	2,075 (–66)	2,075 (–66)
Drift net	22,400	5,114 (–77)	5,106 (–77)
Total	41,320	11,890 (–71)	11,880(–71)
Crew income (RM thousand)			
Trawl	14.89	91.39 (+514)	91.42 (+514)
Purse seine	5.31	31.23 (+488)	31.24 (+488)
Drift net	4.01	35.44 (+784)	35.50 (+785)

Note: Figures in parentheses represent percentage change from policy 1 values.

Table 9
Full License Fee per Vessel (RM thousand) by Gear Type for Policies 3 and 4

Vessel Type	Policy 3	Policy 4
Trawl	327	312
Purse seine	432	390
Drift net	32	31

nomic improvements are possible. Second, effort reduction can be more effective if the opportunity costs of effort can be raised. To achieve this end, policies such as increased employment opportunities outside the fishing sector and improving the skills of fishermen through job-training are called for. However, the specific relationships between these policies and the opportunity costs of effort requires further research. Finally, license fees need to be imposed to appropriate completely the rent generated in the rationalized fishery.

The data requirements for systems study of a multispecies, multigear fishery are great. Suitable time-series data on effort, fish stocks, and economic parameters are needed to estimate the relationships in the fishery system model. Unfortunately, efforts to date have not been sufficient in collecting and consolidating existing data in preparation for such a study. Consequently, many simplifying assumptions have been made in the analyses in this paper. The assumption of equilibrium yield in the surplus production models is particularly restrictive. Subject to data availability, other biological or ecological models could be used to represent the dynamics of the fish stocks. For the dynamics of effort, it is assumed that the time rate of change in fishing effort is proportional to the difference between current fishery rents and the possible profit in alternative economic activities or opportunity costs. Of course, other assumptions regarding the behavior of fishermen in their supply of fishing effort are also possible. For example, Charles (1989) suggested that fishermen might adjust their collective fishing effort in order to fully utilize available labor and capital inputs, or to maintain either constant fishery rents or fishers incomes. These alternative behavioral relationships can be explored in future research.

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