A Bioeconomic Analysis for Fisheries Sustainability Indicators

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Abstract : For the integrated management of sustainable fisheries, some meaningful sustainability indicators need to be developed and agreed upon covering all the dimensions of sustainability, such as ecological, socioeconomic, community, and institutional sustainability. As a contribution to developing sustainability indicators, optimum sustainable yield and its international standards such as maximum sustainable yield(MSY), maximum economic yield(MEY), open access equilibrium(OAE), and dynamic MEY for six recommended fisheries are developed using bio-economic models. For selecting the appropriate model, five models - Schaefer, Schnute, Walters and Hilborn, Fox, and the CY&P models are tested using effort and catch data for six fisheries. None of the models except the CY&P model satisfies statistical standards such as goodness-of-fit and significance. Generally, the CY&P model produced a reasonable fit and is statistically significant for all of six fisheries. The MSYs for horse mackerel, common mackerel, and spanish mackerel excluding sardines estimated by the CY&P model are within suitable ranges of the annual average actual catch. With regard to anchovy, the model fits well and the estimated effort of MSY and yield of MSY, 114,040 horsepower and 116,670 tonnes is likely to be quite

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suitable compared with average of actual effort and yield, 107,905 horsepower and 96,160 tonnes, respectively. However, note that the estimated effort of MEY is about 57,000 HP, and yield of MEY is 95,000 tonnes, which are approximately 50% and 18% lower than those of MSY, respectively. Open access equilibrium, Eoae and Coae is 75,000 HP and 108,000 tonnes, which is between MSY and MEY, respectively. For a special environment of squid's growth rate, the model is adjusted. This paper makes a contribution for estimating several sustainability indicators for fisheries using bioeconomic models, with the modified model for squid species.

Ⅰ. Introduction

Sustainable development has been the hot debate among environmentalists, economists and sociologists since it was put on the international agenda by the World Commission on Environment and Development(WCED) in 1987. Among various definitions for sustainable development, the WCED (1987)'s definition is most widely accepted: development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. Development in this sense relates to the quality of life and should not be confused with economic growth, although obviously both are closely linked within our modern world systems.

An ecosystem-based view of sustainability focuses on maintenance of ecosystem health (Costanza *et al*., 1992) or ecosystem resilience (Holling, 1986). Sustainable development recognizes the interdependencies of human economies with their environment, and highlights the need for scientific understanding of ecosystem functioning and change.

Such an idea of sustainability can be integrated into the interactions between ecological, socio-economic, community, and institutional sustainability (Charles, 1994). However, in achieving the four components of sustainability there are some reasons for failure within the context of fisheries. First, fundamentally the divergence of views across fishery paradigms over the exact elements of sustainability has prevented any practical consensus on policy directions. Second, sustainable development policy has often focused more on the macro level (global, national or regional systems)[1] rather than on the micro

1) At the macro level, there are various alternative measures of sustainability: green Net National Product, genuine savings, ecological footprint, environmental space, net primary productivity, the Index of Sustainable Economic Welfare, and the Genuine Progress Indicator (Hanley et al., 1999).

level (community-based, typically small-scale systems). In fisheries, the macro approaches may be needed in inherently large-scale situations, such as transboundary resources, foreign fishing in coastal waters, or national accounting calculations of resource depletion. However, an appropriate balance between them is important. Third, a role of the balance between fishery sustainability and overall societal sustainabilty reduces sustainability of the fishery resource and the fishery system on the whole. It is well known that fisheries are often employers of last resort in rural areas; by absorbing surplus labour from elsewhere in society, the fishery serves a stabilizing role from the macro perspective of national policy making.

This paper is to review an integrated framework fisheries sustainability indicators and status of Korean fisheries indicators, and to estimate optimal sustainable yield such as maximum sustainable yield (MSY) and maximum economic yield (MEY), open access equilibrium (OAE), and dynamic MEY for six recommended species (anchovy, squid, horse mackerel, sardine, common mackerel and spannish mackerel), selecting their appropriate bioeconomic models.

This paper first illustrates the identification/assessment of current and future environmental problems in coastal marine sector using the driving forces-pressure-state-impact-response (DPSIR) framework, and possible measures and instruments for sustainable coastal governance. Next, fisheries sustainability indicators focused on the four dimensions of sustainability (ecological, economic, social, and institutional dimensions) are presented. Finally, MSY, MEY, OAE, and dynamic MEY for six species are developed, using five bio-economic models.

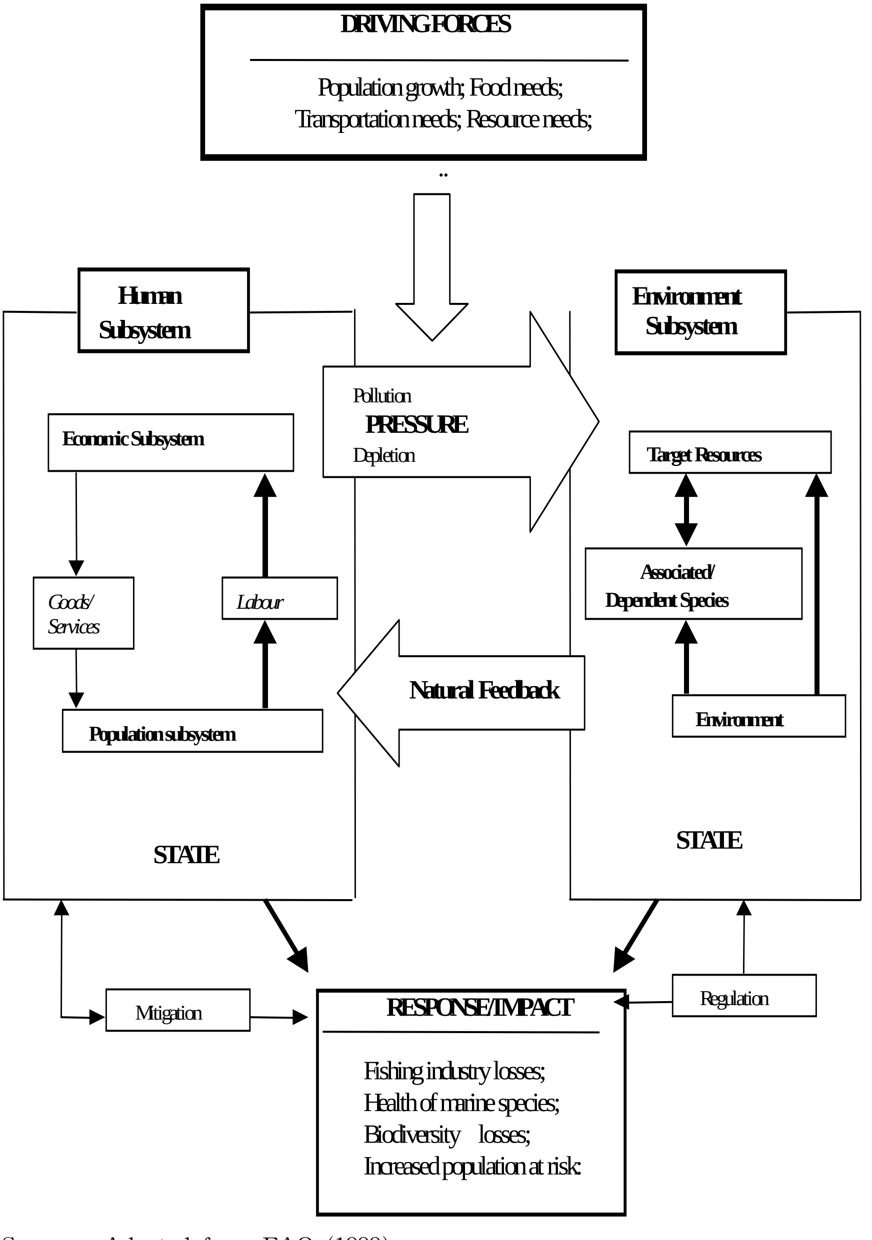
Ⅱ. Integrated Environmental Management for Sustainable Fisheries

1. An Integrated Framework for Fisheries Sustainability Indicators

The development of appropriate frameworks for sustainability measurement brings the identification/assessment of current and future environmental problems. The DPSIR framework addresses a set of questions related to the linkage between causes, effects and actions (<Figure 1>). What is causing the resource conditions, or the social and economic conditions in fisheries to change (driving force)? What are the effects of fishing and other human activities on the resource and marine environment, as well as on the economic and social conditions of the fishing industry and people (state)? What actions could be taken to respond to changes in the state of the resource and marine environment or in the state of industry and people (response)?

The FAO (1999) and OECD (1998) suggest that a sustainability system for fisheries comprises of four dimensions: ecological; economic; social and institutional dimensions. The FAO (1999) provides a sustainable development reference system (SDRS) with a focus on a system of fisheries sustainability indicators. The guidelines list some examples of economic and social criteria for evaluating the economic and social dimensions of effects of changes in policy and other driving forces in <Table 1>. However, even after scoping the problem, selecting the appropriate framework and determining dimensions,

<Figure 1> DPSIR framework for integrated environmental assessment of fisheries



Source : Adapted from FAO (1999)

criteria, objectives and possible indicators and reference points, the choice of indicators for an SDRS should be restricted to a limited number of effective indicators considering: policy priorities; practicality/feasibility; data availability; cost-effectiveness; understandability; accuracy and precision; robustness to uncertainty; scientific validity; acceptability to users/stakeholders; ability to communicate information; timeliness; formal foundation; and adequate documentation (FAO, 1999). This paper focuses on estimating the optimal sustainable yield such as MSY, MEY, OAE, and dynamic MEY using bioeconomic models.

<Table 1> Examples of criteria for the main dimensions of sustainability

Dimensions	Criteria
Economic	Harvest; Harvest value; Fisheries contribution to GDP; Fisheries exports value (compared with total of exports); Investment in fishing fleets and processing facilities; Taxes and subsidies; Employment; Income; Fishery net revenues
Social	Employment/participation; Demography; ;Literacy/education; Protein/consumption; Income; Fishing traditions/culture; Indebtedness; Gender distribution in decision-making
Ecological	Catch structure; Relative abundance of target species; Exploitation rate; Direct effects of fishing gear on non-target species; Indirect effects of fishing: tropic structure; Direct effects of gear on habitats; Biodiversity (species); Change in area and quality of important or critical habitats; Fishing pressure - fished vs. unfished area
Governance	Compliance regime; Property rights; Transparency and participation; Capacity to manage

Source : FAO (1999)

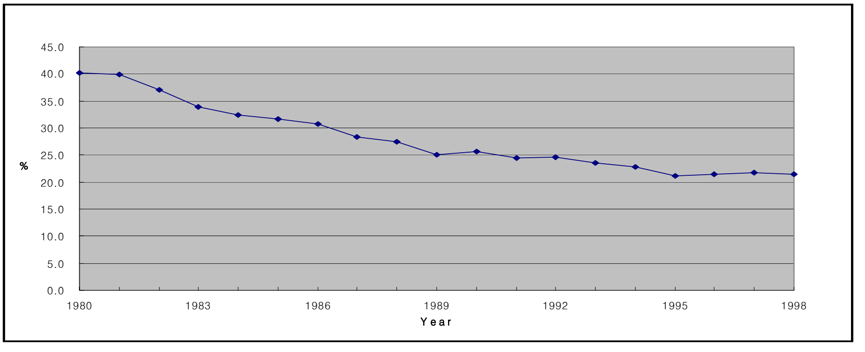
2. Status of Korean fisheries

Indicators are underpinned by data and statistics. Therefore, data availability and its costs are major issues in the selection of indicators and indexes. Data availability and their quality and quantity vary greatly by countries and fisheries. Especially, uneven availability of data and statistics between developed and developing countries may generate a substantial difficulty in creating indicators for assessing progress towards sustainable development at global or regional levels.

An indicator is a quantitative or qualitative value or a variable, representing the relation between two statistics values, and an index is a composite indicator comprised of more than two indicators. In Korea, indicators or indexes in the field of fisheries are very few. The situation is becoming worse for the official indicators or indexes. As official indicators, there are management indicators, Engel coefficients and price indexes. Management indicators are generated by the National Federation of Fisheries Co-operation. They are provided in the Fishery Management Survey Report. The management indicators comprise three indicators, namely, profitability indicators, productivity indicators and stability indicators. The Fishery Management Survey commenced in 1962 launched internally by the Administration of Fisheries. It has been conducted by the National Federation of Fisheries Co-operation since 1976 when it took over the task from the Administration. Fourteen types of boat fisheries that work in the adjacent seas around the Korean Peninsular are surveyed using sampling methods.

The Engel coefficient, percentage of income consumed by food and clothes, is shown in the Fishery Household Economy Report. It may be contended that the smaller the coefficient is, the greater the welfare will be, and in the context of the fisheries, the higher the possibility of the introduction of sustainable development as a concept. The sustainable development of fisheries may be a luxury for fishers with substantially low income. <Figure 2> shows the trend of the Engel coefficient for Korean fishery-dependent households. The coefficient is getting lower year by year.

<Figure 2> Trends of the Engel coefficient of Korean fishery households



showing the increased income to fishery-dependent households and the greater consumption of income for social and cultural activity, signalling the higher quality of life. <Table 2> gives sample of management indicators used in the fourteen licensed fishing industry that are operated in the Korean adjacent sea.

<Table 2> Trends of management indicators in licensed fishing industry

Year	Main Indicator (unit : %)				
	Ratio of income to sales	Total capital turnover	Ratio of debt to total assets	Ratio of equity	Ratio of value-added to sales
1980	15.7	1.5	41.0	70.9	55.1
1981	16.4	1.5	39.9	71.5	50.9
1982	19.4	1.5	26.6	79.0	54.4

Trends of management indicators in licensed fishing industry(Continued)

Year	Main Indicator (unit : %)				
	Ratio of income to sales	Total capital turnover	Ratio of debt to total assets	Ratio of equity	Ratio of value-added to sales
1983	20.2	1.6	25.5	80.0	54.3
1984	17.0	1.4	28.9	77.6	49.5
1985	16.4	1.3	26.9	78.8	49.0
1986	20.1	1.4	41.2	70.8	52.5
1987	19.2	1.2	33.8	74.7	52.3
1988	18.0	1.1	34.6	74.3	56.3
1989	18.7	1.2	35.8	73.6	55.6
1990	15.5	1.1	34.4	74.4	53.5
1991	16.7	1.1	29.8	77.1	56.5
1992	13.4	1.1	29.2	77.4	55.0
1993	16.4	1.2	30.2	76.8	55.6
1994	17.5	1.2	30.1	76.9	56.4
1995	15.3	1.1	35.2	74.0	55.7
1996	14.9	1.1	37.0	73.0	53.9
1997	9.5	1.1	42.7	70.1	49.1
1998	7.3	1.1	52.5	65.6	47.1

Source : NFFC, *Fishery Management Survey Report.*

From a viewpoint of indicator-related activity for the sustainable development of fisheries, several problems can be found.

Firstly, as reviewed, very few indicators are compiled in the field of fisheries. In spite of much statistics compiled, there has been very little effort to generate economic and social indicators. Ratio indicators can play an important role in assessing the progress of fishery sectors. For example, the contribution of fishery protein to the total protein can reflect the importance of fisheries in the health and nutrition of people. Harvest value in constant prices is a deflated-type indicator, which can be used as an indicator to describe the importance of fishery in the national economy. In this respect, fisheries have potential for the development of an indicator industry. This issue will be mentioned below.

Secondly, biological and ecological data and statistics are in a poor condition, which is regrettable since they are potentially important for creating sustainable development indicators in fisheries. Particularly for ecological data such as the effects of gear on habitats, biodiversity, data on fishing pressure in the fished area is not produced and seems not likely to be produced in a foreseeable future.

Thirdly, a problem lies in the designation of statistical agency. The Ministry of Maritime Affairs and Fisheries (MOMAF) and other fisheries institutions play very limited roles in producing approved (official) statistics. Fisheries need very specific expertise, because much of their activities are offshore and continuously moving, making monitoring much more complicated than land-based, stationary activity. Nevertheless, the concept of sustainable development is deeply involved in the biological and ecological characteristic of fisheries and so it will need more specific expertise. Therefore, most of the ecological data and information will need to be generated by fisheries-oriented institutions. In this respect, fisheries oriented institutions would perhaps include the National Fisheries Research and Development Institute, to be designated as statistical agency prescribed in the Statistics Law.

Fourthly, they are *ex-post* rather than *ex-ante*, measures of what has happened rather than what will happen. As such, they do not tell us about the future and should be noted that sustainable development is future oriented (Radford, 1995). So we have to focus on the indicator of well being but on the conditions for achieving sustained increase in those indicator.

Finally, the indicators that are available are not likely to be the indicative of fisheries sustainability. They are only references, as an input to sustainability indicators. Another problem with the indicators in <Table 2> is surely that they are basically financial ratios, and as such may not tell us much about the true state of resources or productivity.

Ⅲ. A Bioeconomic Analysis for Sustainable Fisheries

1. Background

The concept of sustainable yield has long dominated the analysis of renewable resources (Schaefer, 1954; Beverton and Holt, 1957). The best known proxy for sustainability is MSY, defined as the largest annual catch that can be taken while maintaining resource sustainability. With the rationalization paradigm to overcome the open access dynamics, the strategy of MEY[2] has become popular. As with the optimal sustainable yield (OSY), MSY and MEY represent main reference points for fisheries sustainability and benchmarks for fishery management, and they serve as important components for implementing total allowable catch (TAC) regime.

Korea manages fishing capacity through input controls (licence limitation, limitation of engine powers), output controls (total allowable catch: TAC), technical controls (such as fishing grounds,

2) MEY is the sustainable level of catch that produces the greatest economic profits.

fishing seasons, size of fish, and minimum size of mesh) and fleet reduction programmes. A maximum number of licence permission systems have historically been Koreas main fishery management tool, limiting the entry.

In 1996 Korea introduced a TAC system through the revision of the Fisheries Act. It was to fall in line with the global trends in fisheries management, particularly according to the requirement in the UN Law of the Sea. The Fisheries Act prescribes the adoption of a TAC as the fisheries management system and Fishery Resources Preservation Rules prescribes the detailed process to implement the TAC. Korea is now in the preparatory stage for implementing a full-scale TAC, which will be implemented from 2001. Since 1999, five species comprising of the common mackerel, sardine, horse mackerel, spanish mackerel and queen crab have been selected as sampled species for TAC determination and have been investigated in order to assess their stocks using the allowable biological catch (ABC) by the National Fisheries Research and Development Institute (Zang, 2000). ABC is a biological model for assessing fisheries stocks which can be a reference point for TAC determination. If the preparatory stage proves to be successful, the TAC system will be extended to more core species. In this respect, TACs in Korea are just in their initial stage. Another problem is that TACs are not assessed on a periodical basis. For any data to be used as a component for indicators, it needs to be observed or measured regularly.

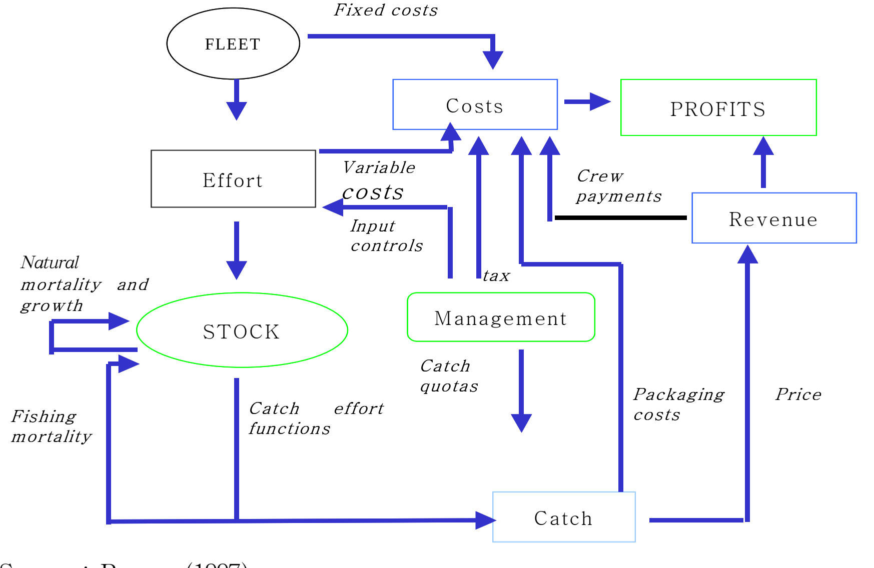
2. Methodology

The general purpose in managing fisheries is to ensure that the resource is exploited in an optimal fashion. Generally, MEY is associated with a lower catch level and a higher stock level than

MSY,[3] imply that an objective of resource conservation is more amply achieved under MEY than MSY, as such MEY may, possibly as a side effect, produce greater ecological benefits than MSY.

To determine these two targets, biological models can provide an estimate of MSY and the level of effort that is associated with that yield, while a bio-economic model is required for the estimation of MEY, which considers both the revenues and costs associated with harvesting the stock. The development of a bio-economic model is a multidisciplinary task, combining the biological components of catch and effort with the economic components, revenues and costs. An example of how the various components of a bio-economic model may interact is given in <Figure 3> (Pascoe, 1997).

<Figure 3> Diagrammatic representation of a fisheries bio-economic model



Source : Pascoe (1997)

3) Clark (1973) demonstrates that a rational fishery using MEY may not be biologically sustainable: the optimal pursuit of maximum rents (MEY) could drive fish stocks to extinction.

As a different approach from the ABC model, bio-economic models can be employed to estimate MEY, OAE and dynamic MEY as well as MSY. The ABC model uses more biological data like fishing mortality and age structure of population, but it cannot be extended into MEY, OAE, and dynamic MEY, and their survey cost is likely to be high.

1) Sustainability

Five different biological production models are assessed for their applicability to some of Korean fisheries, including (1) three logistic growth models, namely the Schaefer (1957) model, the Schnute (1977) model and the Walters and Hilborn (1976) model modifying the Schaefer model; (2) two exponential growth models, namely the Fox (1970) model, and Clarke, Yoshimoto and Pooley (1992) modifying the Fox model.[4] The distinct difference between the two is that growth function (G) is symmetrical or parabolic in three logistic growth models, implying the possibility of stock extinction in an extreme case while in two exponential growth models it is asymmetrical, based on the Gompertz curve. Both are related to the intrinsic growth rate of the stock (r), the biomass (B) and the environmental carrying capacity (k), which is the maximum stock level or virgin biomass, as follows:

(1) For logistic growth models: $G = rB(1-B/k)$;

(2) For exponential growth models: $G = rBln(k/B)$

Using the assumption of C = qBE, where E is the rate of fishing effort, q is the catchability coefficient, and catch per unit effort (CPUE) is defined by U =qB = C/E, current biomass is given by B

4) Hereafter Walters and Hilborn model is referred to as W&H model, and Clarke, Yoshimoto and Pooley model as CY&P model.

= U/q. And the level of effort (E_{MSY}) $dC/dE=0$, as given in <Table 3>

<Table 3> Equations of static and dynamic bio-economic models

Level	Parameter	Logistic growth models	Exponential growth models
Catch	Equation	$qkE(1-qE/r)$	$qkE\ exp(-(q/r)E)$
MSY	Effort(E_{msy})	$r/2q$	r/q
	Catch(C_{msy})	$kr/4$	$qkE_{msy}\ exp(-(q/r)E_{msy})$
	Biomass(B_{msy})	$k(1-qE_{msy}/r)$	$k\ exp(-(q/r)E_{msy})$
	net rent(π_{msy})	$pCmsy-vEmsy$	$pCmsy-vEmsy$
MEY	E_{mey} [1)]	$r(1-v/(pqk))/(2q)$	$r/q[1-(v/pqk)exp((q/r)E_{mey})]$
	C_{mey}	$kr[1-(v/(pqk))^2]$	$qkE_{mey}/\ exp(E_{mey}\ q/r)$
	B_{mey}	$C_{mey}/(qE_{mey})$	$C_{mey}/(qE_{mey})$
	π_{mey}	$pCmey - vE_{mey}$	$p\ C_{mey} - v\ Emey$
DMEY[1)]	$B_{dmey}(B^*)$	$(k/4)[1+(v/(pkq))-/r]+ SQR([1+(v/(pqk))-/r]^2+ [8v/(rpkq)])$	$LN(k/B^*)=(1+/r)[1-(v/pq)/B^*]$
	C_{dmey}	$rB^*(1-B^*/k)$	$rB^*\ LN(k/B^*)$
	E_{dmey}	$C_{dmey}/(qB_{dmey})$	$C_{dmey}/(qBdmey)$
	π_{dmey}	$pC_{dmey} - vE_{dmey}$	$pC_{dmey} - vE_{dmey}$
OAE	E_{oae}	$r(1-v/(pqk))/q$	$r/q[LN(pqk)-LN(v)]$
	C_{oae}	$qkE_{oae}(1-E_{oae}/r)$	$qkE_{oae}\ exp(-(q/r)E_{oae})$
	B_{oae}	$k\ exp(-(q/r)E_{oae})$	$k(1-qE_{oae}/r)$
	π_{oae}	p Coae $- vEoae$	p Coae $- vEoae$

Note : 1) The equations relating to the exponential growth models, i.e. Fox and CY&P, were solved either iteratively (Emey) or by using the solver function in Excel (DMEY). δ is the discount rate (here 8 percent is applied for the analysis) considering people‘s time preference (Pyo, 2000).

2) v is a constant marginal cost of effort which can be replaced with cost per unit of catch (w) multiplied by the catch per unit of effort. That is, $v=wqB$.

3) p is the average price for the fish, being assumed that the price does not vary with the level of catch for simplicity. In many cases, price does vary with the level of catch. This can affect the results.

4) SQR stands for square root.

2) Optimality and bio-economic models

Once the yield-effort equations are established for the various models, reference points important for evaluating anticipated fishing effort could be determined by incorporating cost and revenue data. Given constant price (p) and cost for each unit of effort, then MEY and the level of effort for MEY, E_{mey} can be derived using the first order condition for profit maximization. And also the open access equilibrium (OAE) and the level of effort for OAE, E_{oae} can be estimated by setting net profit (π) equals 0.

Static OAE or MEY disregards any difference between present and future values of funds. The idea behind this is that the fishery is managed as a capital good, maximizing net present value (Clark, 1985). Such dynamic bio-economic models can be determined as given in <Table 3>. Clark (1990) developed dynamic models to derive such as optimal biomass (B_{dmey}), optimal yield (C_{dmey}), and optimal effort (E_{dmey}) shown in <Table 3>, considering time preference under an infinite time period.

For a thorough understanding of the stock behaviour the critical parameters are therefore the intrinsic growth rate, the environmental carrying capacity in terms of food, dissolved oxygen, space availability and the impact of fishing in terms of catchability. Underlying all the above models is the main assumptions that (i) age structure of the population does not affect growth rate, so that the fishery is based on all age classes; (ii) changes in biomass from year to year are only affected by natural growth rather than environmental factors; (iii) changes in the population occur instantaneously.

3) Data Formulation

From the basic catch and effort data, CPUE (or U) or its approximation and the associated level of effort were then computed. Two models of Schaefer and Fox use the finite difference approximation $dU/dt \approx (\overline{U}_{t+1} - \overline{U}_{t-1})/2$, where $\overline{U}_t$ is the average CPUE for a given year[5]:

Schaefer: $(\overline{U}_{t+1} - \overline{U}_{t-1})/(2\overline{U}_t) = r - (r/(qk))(\overline{U}_t) - q(\overline{E}_t)$,

Fox: $(\overline{U}_{t+1} - \overline{U}_{t-1})/(2\overline{U}_t) = (r - \ln(qk)) - r\ln(\overline{U}_t) - q(\overline{E}_t)$,

where $\overline{E}_t$ is the total effort expended in year *t*. The parameters *r*, *q*, *k* are estimated by a Pearson or Ordinary Least Squares (OLS) regression analysis with a time series of catch and effort data. Many bio-economic studies incorporate biological parameters estimated by the Schaefer and Fox models. Schnute (1977) argues that a major problem with the Schaefer and Fox models is that they can predict next years CPUE without specifying next years anticipated effort, contradicting almost all theory on fisheries biology. Another problem involves the finite difference approximation, which assumes that CPUE is linear over the course of a given year (Clarke *et al.*, 1992).

Schnute (1977) develops a modified version of the Schaefer model using an integration procedure:

Schnute: $\ln(\overline{U}_{t+1}/\overline{U}_t) = r - (r/(qk))(\overline{U}_t + \overline{U}_{t+1})/2 - q(\overline{E}_t + \overline{E}_{t+1})/2.$

CY&P (1992) develop a model which follows Schnute's lead and applies a similar approach to the Fox model, using a Taylor approximation[6]:

$$CY\&P: \ln(\overline{U}_{t+1}) = (2r/(2+r))\ln(qk)) + ((2-r)/(2+r))\ln(\overline{U}_t) - (q/(2+r))(\overline{E}_t + \overline{E}_{t+1}).$$

Walters and Hilborn (1976) developed the difference equation method which is relatively more simple than the Schnute model[7]:

5) For detailed calculation process, see Pascoe (1997).
6) For detailed calculation process, see Clarke et al. (1992) or Pascoe (1997).
7) For detail, see Pascoe (1997).

Walters and Hilborn: $\frac{\overline{U}_{t+1}}{\overline{U}_t} - 1 = r - (r/(qk))(\overline{U}_t) - q\overline{E}_t.$

Since these are only estimates, regression analysis also tells us how close or far they are from the actual figures. Testing different models was thus aimed at determining which one provides best estimates for more accurate management decisions to be made.

4) Catch and effort data

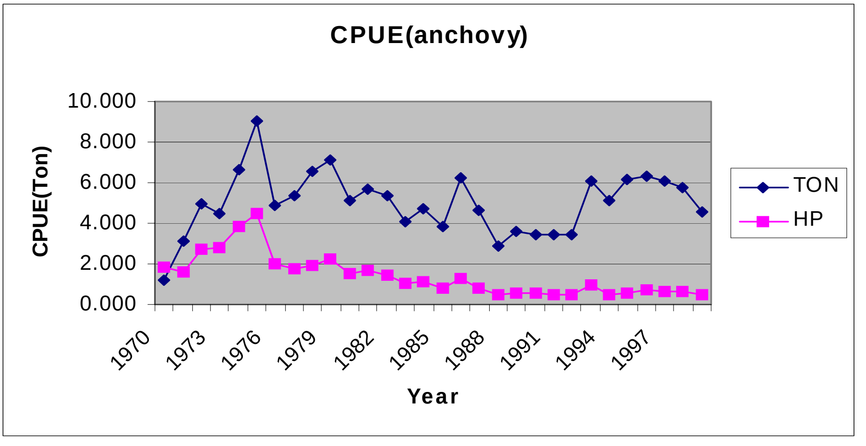
Fishing effort is a key variable underlying bio-economic analysis. An assumption of all models is that the level of catch is a function of the level of effort and the level of the biomass, that is, $C_t = qB_tE_t$. Unfortunately most observable measures of effort, such as days fished, are highly unreliable. As a result, models that do not attempt to standardize effort can result in erroneous results. Standardizing effort over time, however, is more complex. Most fisheries models also assume that effort is randomly distributed across a fishery, and that CPUE is proportional to the biomass (Pascoe, 1997).

Here, six fishes[8) including anchovy, squid, horse mackerel, sardine, common mackerel, and spanish mackerel- are selected for analysis. MSY, MEY, OAE, and dynamic MEY are evaluated using the five bio-economic models indicated earlier. Some examples of effort proxies in fisheries analysis include: days fished; hours trawled; days*boat size; days*engine size; day*boat size*engine size; hours trawled*net headrope length; days*crew size; total pot lifts; km nets*hours soaked*lifts, all of which depends on type of fishery. Here horsepower for anchovy, days fished for squid, km nets*lifts for

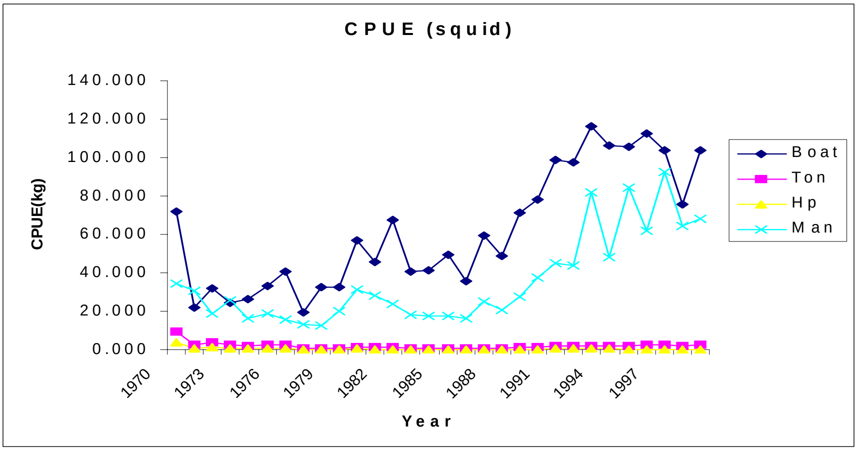
8) Horse mackerel, sardine, common mackerel and spanish mackerel were selected for TAC, and anchovy and squid are good cases for estimating optimum sustainable yield as fishery of single specie.

others are used in this analysis (see Figure 4). Catch and effort data for 1970~1999 are presented in Pyo and Chang (2000).[9)]

<Figure 4(a)> Trends of CPUE according to measures of fishing effort in anchovy

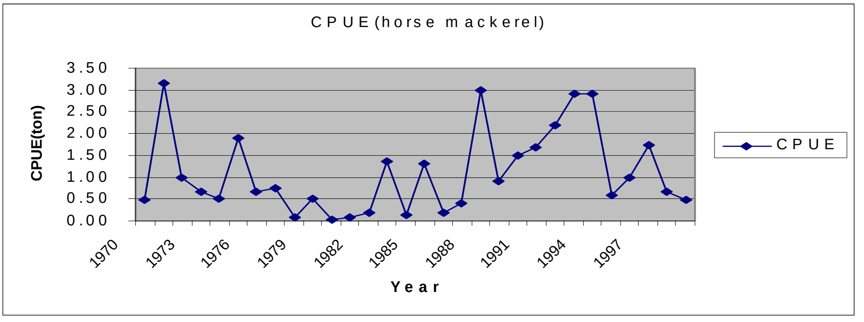


<Figure 4(b)> Trends of CPUE according to measures of fishing effort in squid

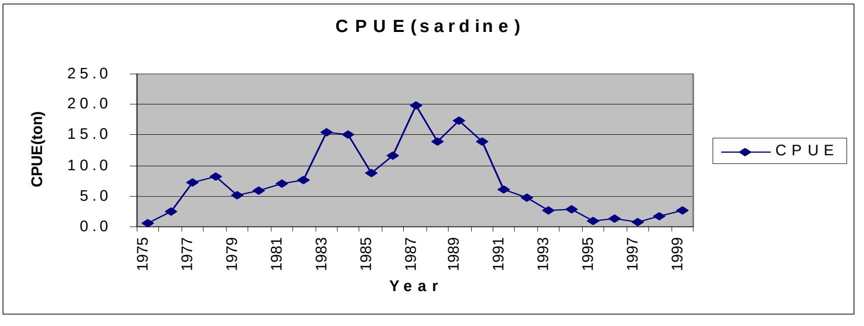


9) The data for sardine is available only from 1975, and for spanish mackerel, from 1981.

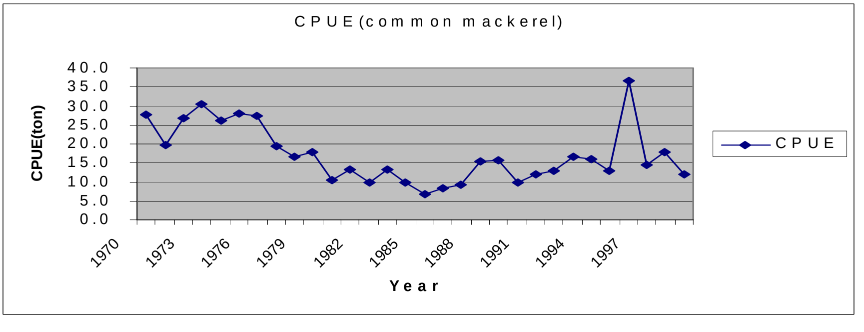
<Figure 4(c)> Trends of CPUE according to measures of fishing effort in horse mackerel



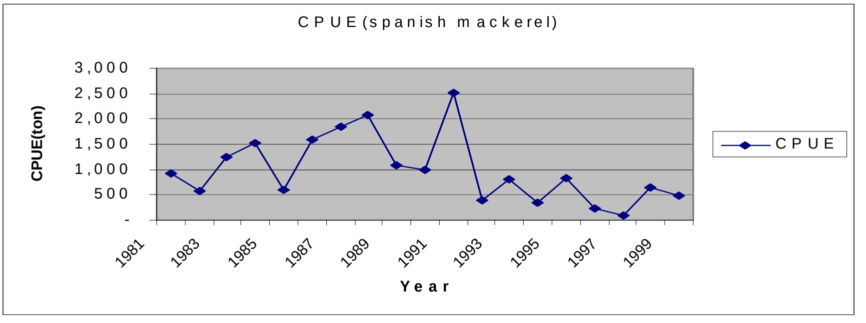
<Figure 4(d)> Trends of CPUE according to measures of fishing effort in sardine



<Figure 4(e)> Trends of CPUE according to measures of fishing effort in common mackerel



<Figure 4(f)> Trends of CPUE according to measures of fishing effort in spanish mackerel



5) Price and cost of effort

Average constant price and cost data 1994 1999, adjusted for inflation, are used here <Table 4>. Unit cost data are a function of catch, not effort, that is, $w = total\ cost / catch = total\ cost / (CPUE * effort)$, which means a marginal cost of effort, $v = w * CPUE = wqB$ which is used in the analysis of MSY, MEY, OAE and DMEY.

<Table 4> Average price and cost

Unit : $/ton

Item	Anchovy	Squid	Horse mackerel	Sardine	Common mackerel	Spanish mackerel
Unit Price	1,044	1,599	894	445	616	2177
Unit Cost[1]	882	1,530	760	400	554	2068

Note : 1) It is cost per unit of catch.

3. Results and discussions

For MSY, MEY, OAE, and dynamic MEY of the six fishes, the Schaefer, Schnute, Walters&Hilborn, Fox, and CY&P production models are estimated using OLS.[10] As shown in Pyo and Chang (2000), surprisingly all models except the CY&P model do not fit the data well: low R-square, and insignificant t-statistics for all fishes,[11] while CY&P model has coefficients with the proper signs and t-statistics significant at the 1%, 5%, or 10% level.[12] As expected in the models, all of the models and fishes (except anchovy) have problems of autocorrelation, indicated by the Durbin-Watson test. To correct for this, the Cochrane-Orcutt procedure was applied, which improved all of models. Due to the poor performance of all the models except CY&P model, the subsequent analysis focuses on the CY&P model only.[13] Such a result demonstrates the importance of appropriate model choice. Estimated equation and statistics of CY&P model are summarized in <Table 5>, and a comparison of the estimated natural logarithmic function of CPUE and actual one is illustrated in <Figure 5> which are fitted well.

<Table 5> Estimated equations and statistics

Fish	Independent variable	Estimated coefficient	Standard Error	R2	Adjusted R2	t-statistics	D-W Statistics	Collinearity Statistics
Anchovy	Constant E+E1 LN(U)	0.623 -2.670E-6 0.391	0.213 0.11E-5 0.178	0.831	0.818	2.922*** -3.164*** 2.196**	1.904	Tolerance 0.212 VIF 4.715

10) See Pyo and Chang(2000) for detail.

11) According to recent studies including Clarke et al.(1992), better fits for regression are generally derived from the CY&P model compared to other models since its functional form is more straightforward than those of other models.

12) As shown in <Table 3>, exceptionally the equation for squid fixing r=1, squid (r=1), is low R-square and the coefficient of effort has not significant at lower than 10% level. Squid (r=1) will be explained later.

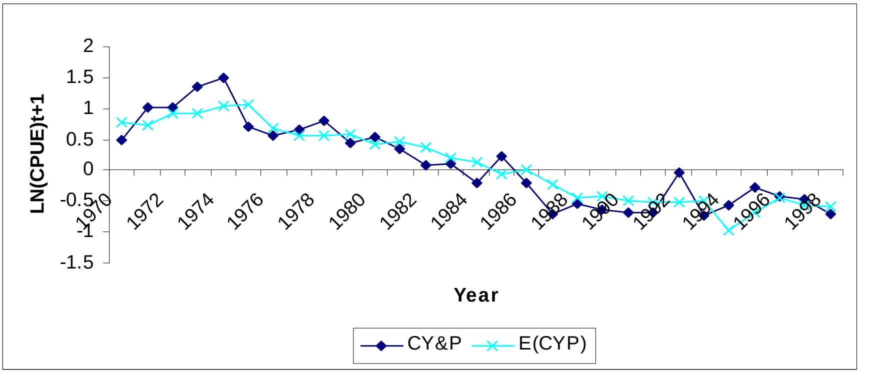
13) The results of other models are illustrated in Appendix V of Pyo (2000).

Estimated equations and statistics(Continued)

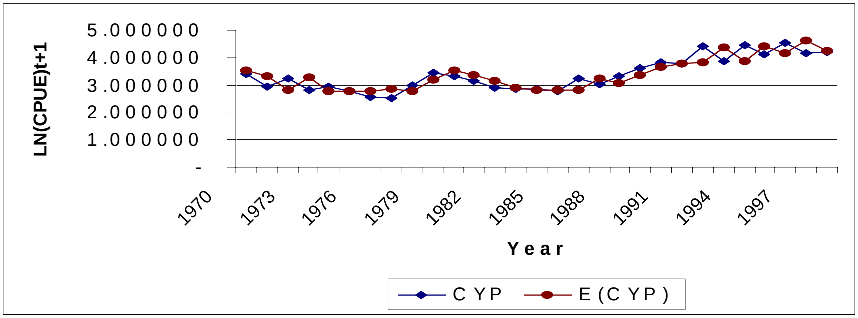
Fish	Independent variable	Estimated coefficient	Standard Error	R2	Adjusted R2	t-statistics	D-W Statistics	Collinearity Statistics
Squid	Constant E+E1 LN(U)	0.43992 -2.1E-07 0.930812	0.30146 0.8E-7 0.07253	0.903	0.890	1.459 -2.640*** 12.832***	1.818	Tolerance 0.900 VIF 1.111
Squid (r=1)	Constant E+E1	-1.83141 -1.7E-07	0.51562 1.6E-7	0.04	-0.04	-3.552*** -1.043	2.265	Tolerance 1.000 VIF 1.00
Horse mackerel	Constant E+E1 LN(U)	-0.0113 -7.44E-06 0.7227	0.3802 2.001E-5 0.1362	0.543	0.486	-0.0293 -0.3718 5.3064***	1.907	Tolerance 1.000 VIF 1.000
Sardine	Constant E+E1 LN(U)	0.8074 -3.069E-5 0.8342	0.4617 2.399E-5 0.1280	0.693	0.644	1.7489* -1.2794 6.5155***	1.940	Tolerance 0.925 VIF 1.081
Common mackerel	Constant E+E1 LN(U)	0.7689 -5.84E-06 0.7456	0.5433 9.84E-6 0.1568	0.673	0.633	1.4153 -0.5935 4.7563***	1.958	Tolerance 0.591 VIF 1.692
Spanish mackerel	Constant E+E1 LN(U)	2.5157 -7.072E-3 0.6479	1.4629 0.0110 0.2081	0.675	0.456	1.7197* -0.6425 3.1131***	2.142	Tolerance 0.971 VIF 1.030

Note : * significant at 10% level; ** significant at 5% level; *** significant at 1% level.

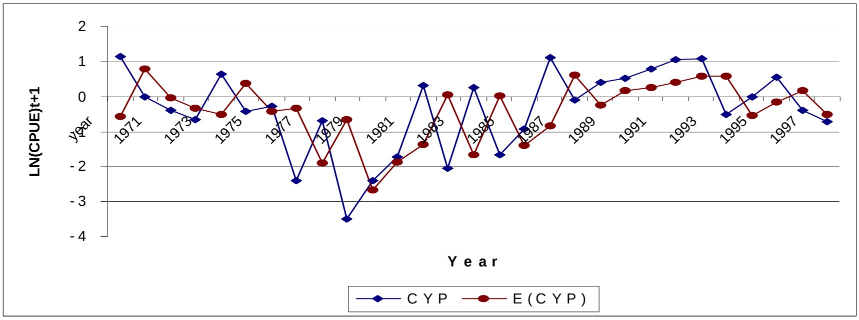
<Figure 5(a)> Natural logarithm of actual versus estimated CPUE for anchovy



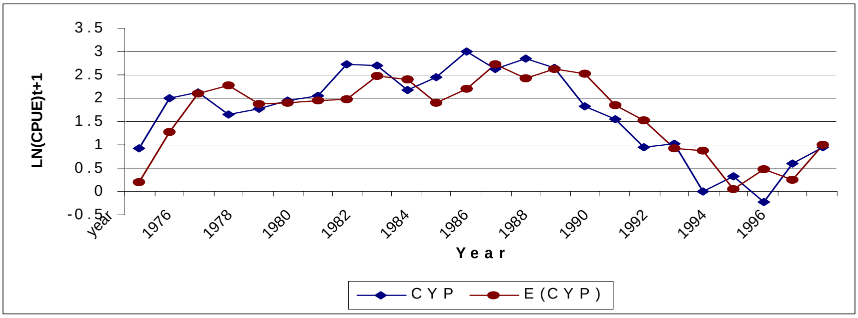
<Figure 5(b)> Natural logarithm of actual versus estimated CPUE for squid



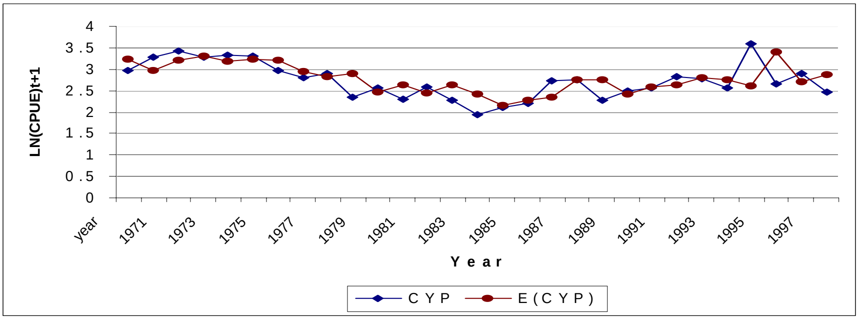
<Figure 5(c)> Natural logarithm of actual versus estimated CPUE for horse mackerel



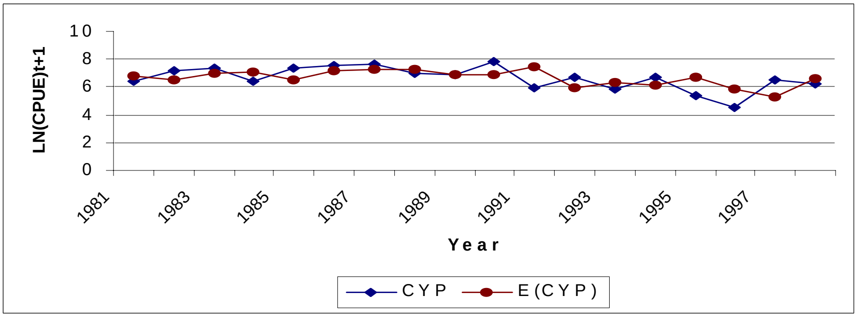
<Figure 5(d)> Natural logarithm of actual versus estimated CPUE for sardine



<Figure 5(e)> Natural logarithm of actual versus estimated CPUE for common mackerel



<Figure 5(f)> Natural logarithm of actual versus estimated CPUE for spanish mackerel



Estimates of parameters- *r, q, k*, and MSY, MEY, OAE, and dynamic MEY are estimated in <Table 6>, with the MSY estimated using the ABC model in previous section for comparison. In a comparison of CY&P and ABC model, MSYs for horse mackerel, common mackerel, and spanish mackerel excluding sardine estimated by CYP model are within ranges of those of ABC model, while the MSY for sardine estimated by the CY&P model is 3 to 6.5 times more than those of ABC model. However, the MSY of sardine estimated by the CY&P model can be compared to historical data of the annual actual catch of 130,000 ~ 190,000 tonnes, from 1983 to 1990, even though recent actual catches has abruptly declined to between 10,000 and 44,000 tonnes.

With regard to anchovy, the model fits well, with an R-squared of 0.82 and statistically significant coefficients at 1% level for coefficients of constant and effort, and 5% level for the CPUE coefficient as well as with no problems of autocorrelation, multi-collinearity and heteroscedasticity. As shown in <Figure 6> and <Table 6>, the effort of MSY (a point of S in <Figure 7>) and yield of MSY, 114,040 horsepower and 116,670 tonnes is likely to be quite suitable compared with average of actual effort and yield, 107,905 horsepower and 96,160 tonnes, respectively. However, note that effort of MEY (a point of E in <Figure 7>) is about 57,000 HP, and yield of MEY is 95,000 tonnes, which are approximately 50% and 18% lower than those of MSY, respectively. Open access equilibrium, Eoae (a point of O in <Figure 7>) and Coae is 75,000 HP and 108,000 tonnes, which is between MSY and MEY, respectively. Another interesting fact is that the dynamic results of biomass, yield and effort are between static MEY and OAE. That is, the results of dynamic MEY at 0% (no discounting) and ∞ indicate values estimated for static MEY and OAE.

In the case of squid, it has the best fit with the data (R-square = 0.90) which was improved from 0.72 after following the Corchrane-Orcutt procedure, and with the good t-statistics. The results obtained, whilst being statistically significant, did not seem to be realistic. In other words, for an example of MSY, the estimated effort of MSY is about ten times lower than average actual effort, and the estimated yield of MSY is about one thousand times greater than average actual one. This may be attributed to the intrinsic growth rate, estimated to be 0.072, which is very low. Given the short-lived nature of squid, it seems more appropriate in this instance to adopt an instantaneous growth rate, such that r=1. Therefore, for a special environment of squids growth rate, the model should be adjusted. The intrinsic growth rate would be fixed at 1, which means r would be constant. Under the assumption the CY&P model is reformulated:

$$\ln(\overline{U}_{t+1})-\frac{1}{3}\ln(\overline{U}_t)=\frac{2}{3}\ln(qk)-\frac{q}{3}(\overline{E}_t+\overline{E}_{t+1})$$ [14)]

The equation of squid (r=1) is estimated by the reformulated model. Even though the equation has not explainable fitness, the results are more reasonable than those of original model. For example, the estimated effort and yield of MSY is quite realistic compared to average actual ones. Also OAE is below the range of MSY, and relatively close to MEY and MSY, which means the slope of TC is quite steep, and the ratio of total costs to total revenue is much higher. Their distances depend on the shape of models curve and the slope of TC.

<Table 6> Estimated r, q, k, MSY, MEY, OAE and dynamic MEY in CY&P model

Parameter	Anchovy	Squid	Squid (r=1)	Horse mackerel	Sardine	Common mackerel	Spanish mackerel
r	0.875629	0.071667	1.000000	0.321980	0.180801	0.291526	0.427332
q	7.678E-6	4.350E-07	_	1.73E-05	6.69E-05	1.34E-05	0.017166
k	3.623E+5	1.3269E+9	-1.7E-07	5.56E+04	1.95E+06	1.53E+06	7.3841E+4
Emsy	114,044	164,733	1,960,784	18,635	2,701	21,780	24.89
MSY	116,697	34,984,612	46,246	6,581	129,466	164,586	11,608
Bmsy	133,272	488,152,188	46,246	20,444	716,125	564,665	27,164
π(msy)[2)]	18,904	2413938	3,190	881	5,825	10,204	1,265

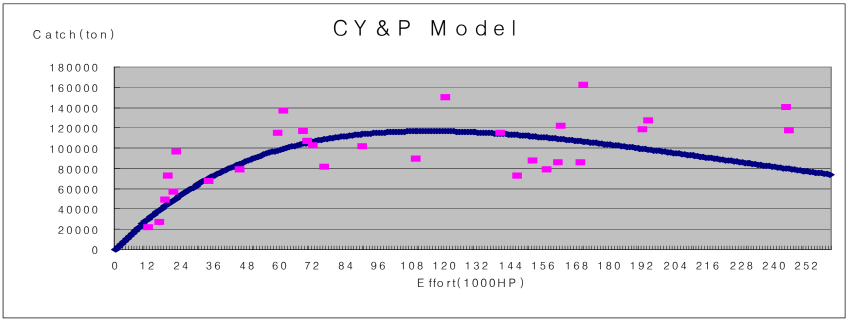
14) This equation is derived by:
$\ln(\overline{U}_{t+1})=(2\times 1/(2+1))\ln(qk))+((2-1)/(2+1))\ln(\overline{U}_t)-(q/(2+1))(\overline{E}_t+\overline{E}_{t+1})$,
where r is substituted into 1.

Estimated r, q, k, MSY, MEY, OAE and dynamic MEY in CY&P model
(Contined)

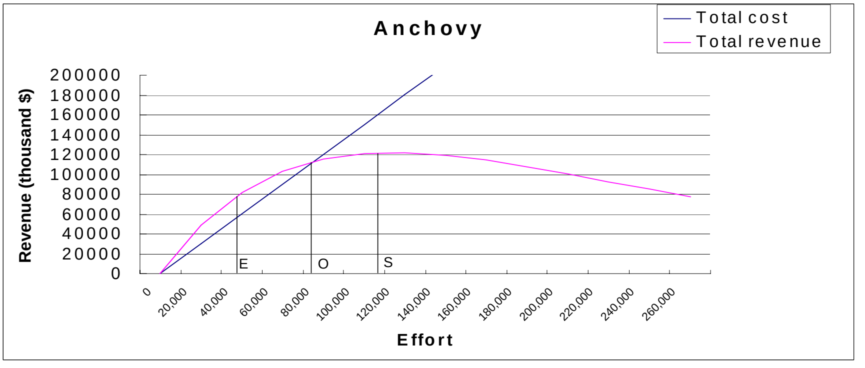
Parameter	Anchovy	Squid	Squid (r=1)	Horse mackerel	Sardine	Common mackerel	Spanish mackerel
Effort[3]	107,905	1,563,699	1,563,699	8,612	8,135	7,247	13.0
Catch[3]	96,160	49,795	49,795	13,207	72,635	121,775	15,744
ABC model[1]	–	–	–	5,000 ~ 13,000	20,000 ~ 40,000	132,000 ~197,000	10,000 ~ 18,000
Emey	56,085	73,912	879,758	9,125	1,271	10,246	11.23
Cmey	95,399	27,242,519	36,011	5,369	103,448	131,483	9,067
Bmey	221,542	847,211,595	80,262	34,057	1,215,918	958,929	47,023
π(mey)[2]	15,454	1,879,733	2,484	719	4,655	8,151	988
Eoae	75,315	81,178	966,249	12,151	1,559	12,556	12.51
OAE	108,231	28,629,667	37,845	6,077	114,052	144,916	9,594
Boae	123,026	673,038,216	63,761	19,336	82,3017	650,040	36,727
π(oae)	0	0	0	0	0	0	0
Bdmey	215,264	68,1635,699	78,481	31,659	1,083,670	888,520	44,710
Cdmey	98,114	32,541,259	36,974	5,735	114,755	141,579	9,585
Edmey	59,363	109,734	923,769	10,486	1,582	11,907	12.49
π(dmey)[2]	15,894	2,245,346	2,551	768	5,164	8,777	1,044

Note : 1) This item represents MSY estimated by ABC model introduced in section 4.1.
2) π(msy), π(mey) and π(oae) represent static annual net rent (thousand dollars) while π(dmey) is net present value at the discount rate of 8% over the infinite time period.
3) For a comparison of estimated results, actual average effort and catch of the period (1970 to 1999) are added.

<Figure 6> An example of relationship between effort and yield of anchovy in CY&P model



<Figure 7> An example of revenue-effort and cost function of anchovy in CY&P model



Note : The point of E is effort of MEY, S is MSY, and O is OAE.

Ⅳ. Conclusion

For the integrated management of sustainable coastal wetlands and fisheries, some meaningful sustainability indicators need to be developed and agreed upon covering all the dimensions of sustainability, such as ecological, socio-economic, community, and institutional sustainability. This study reviewed potential sustainability indicators for wetlands and fisheries with the identification/assessment of environmental problems using the driving forces-pressure-state-impact-response framework. There are so many examples of sustainability indicators, but scoping the problem, selecting the appropriate framework and determining dimensions criteria, objectives and reliable indicators and reference points are more important. In particular, Korean fisheries sustainability indicators are in their initial stage, therefore efforts at developing some key dimensions of sustainability (e.g. maximum sustainable yield, minimum spawning stock biomass, fishing effort, capacity, rent, by-catch, biodiversity, and habitat) are entirely justified.

As a contribution to developing sustainability indicators, optimum sustainable yield and its international standards such as MSY, MEY, OAE, and dynamic MEY for six recommended fisheries were developed using bio-economic models. For selecting the appropriate model, five models - Schaefer, Schnute, Walters and Hilborn, Fox, and CY&P models are tested in effort and catch data of six fishes. Surprisingly all the models except CY&P model fail to satisfy statistical standards such as fitness and significance. Generally, the CY&P model holds good fitness and statistically significant level for all of six fisheries. However, the CY&P model for squid, where the intrinsic growth rate is high, could not explain MSY, MEY, OAE, and dynamic MEY appropriately. This study makes a contribution to develop the modified model for the intrinsic growth rate of 1. The reformulated model could represent the results reasonably even though the estimated equation has not good fitness.

Although most of the CY&P models appear to have good fits and validated results for some cases, these models also seem to be quite sensitive to parameters which means a more stable model should be developed and data should carefully be handled. In particular biological and technical interactions such as multispecies, predator prey relationship, age structure and mortality should be taken into account. In addition, economic factors and fishing efforts such as price, cost, technical change and a reasonable function of fishing inputs should simultaneously be considered.

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