TAC assessment for single species and multiple gear fisheries with an application to the Korean hairtail fishery

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ABSTRACT

This paper describes a Total Allowable Catch assessment model for a single species and multiple gear types as an improvement on TAC assessment based on a single species and a single gear type. A case study is included for a hairtail species caught mainly by the Korean pair trawl and large otter trawl gears. We use a surplus production model based on the exponential growth model to estimate biological reference points. Fishing effort for the two gears is standardized and used in a general linear model. The Fox bioeconomic model is then used to estimate economic reference points. In the Korean hairtail fishery, the TAC assessment model for a single species and multiple gear types yielded values for each reference point that were more conservative.

Key words: TAC assessment system, general linear model, standardized fishing effort, maximum sustainable yield, maximum economic yield, net revenue of ABC

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1. Introduction

Fisheries across the world are often composed of multiple or single species and multiple gear types (S×G or 1×G) rather than a single species and a single gear type (1×1). Nevertheless, the common Total Allowable Catch (TAC) assessment is based on the 1×1 case (Zhang, Kim and Yoon, 1992; National Fisheries Research and Development Institute (NFRDI), 2004), excluding other gear types that catch the given single species. However, this 1×1 case is rare in fisheries. As a result, the TAC, as conventionally calculated, can be overestimated or underestimated. Additionally, a 1×1 assessment model does not consider the allocation of Acceptable Biological Catch (ABC)[1] between multiple gear types, because it considers only one gear type.

In general, the 1×1 assessment model has two versions. The first version considers only catches of a single species caught by a single gear. When only catch and effort data are available, Maximum Sustainable Yield (MSY) can be estimated by a surplus production model.[2] Then, an ABC no greater than MSY can be estimated by the ABC determination system. Here, in general, ABC of the single species and the single gear equals TAC. The second version considers total catch of a species caught by all gear types, but fishing effort is based on one representative gear type among the all gear types. Reference points can also be estimated by a surplus production model with the same data limitations noted above, but the estimated ABC, in general, is proportionally distributed to each gear type based on gear and gear-specific catch rates (often smoothed by averaging).[3] Thus, an ABC of a single species and multiple gears should be greater than a TAC of a single species distributed by gear type. However, these approaches exclude fishing efforts or catches by other gear types involved in catching the given single species. This exclusion can affect TAC estimation. To overcome the above-mentioned limitations of a 1×1 assessment model, this paper proposes an alternative procedure.[4]

Section 2 of this paper defines terminology and premises of an estimation method for multiple gear types that harvest hairtail. Section 3 states the theory of our proposed alternative TAC assessment for a multiple gear fishery. We assume application to pair

1 ABC is generally used to set the upper limit of the annual TAC. It is calculated by applying the estimated (or proxy) harvest rate to the estimated exploitable stock biomass (The Pacific Fishery Management Council and National Marine Fisheries Service 2006).

2 Surplus production models are basic tools used to establish safe harvest levels for a given gear type when only catch and effort data are available. They are also called "lumped parameter" models because they abstract from age class structure and many other biological determinants of birth, growth senescence and death. While these determinants are important, many cannot be controlled by a typical fisheries agency, nor can they be forecast from typical catch-effort fisheries data.

3 In Korea, the catch rate is averaged for the latest 3 years of hairtail caught by each fishing gear.

4 The current Korean stock assessment approach uses several assessment methods depending on the quality and quantity of data. The several assessment methods generally involve the Beverton-Holt yield per recruit model, the biomass-based cohort analysis and the surplus production model. Due to data limitations, this paper uses only on the surplus production model.

and large otter trawls in the Korean fishery for hairtail. Section 4 provides data analysis and results estimated for the proposed alternative TAC assessment model and also compares the results for the 1×1 and our proposed assessment models. Section 5 contains concluding remarks about implications and limitations for our proposed TAC assessment model.

2. Terminology and premises

A common characteristic of Korean fisheries is that either a single gear is used to catch multiple species or multiple gear types are used to catch a single species (Lee, 1991; Seo and Zhang, 2001). Hairtail is a typical single species-multiple gear case; the multiple gear types, include pair trawls, stow nets and large otter trawls (Ministry of Maritime Affairs and Fisheries (MOMAF), 2006).

One approach to TAC assessment in 1×G cases is to standardize all fishing effort associated with catches of the given single species caught by multiple gear types (Lee, 1991; Quinn and Deriso, 1999; Seo and Zhang, 2001). This approach may be more workable than the two versions of the 1×1 assessment model in single species and multiple (or mixed) fisheries. An idea for TAC assessment in 1×G cases with limited data is to incorporate the catch and fishing effort of other gears used to harvest a chosen single species. Such effort is excluded in 1×1 assessment model. The TAC results may also approximate reality more closely than those of the 1×1 assessment model. However, due to data limitations, this paper only provides a 1×2 case involving hairtail caught by pair and large otter trawls. This case may nonetheless be helpful in describing and explaining the TAC assessment model of the 1×G cases.

Premises used in the 1×2 assessment model are as follows. First, there is an economic interaction between the two gears, because the more pair trawls catch of the limited hairtail stock, the less hairtail remains for large otter trawls to catch. Second, only catches of hairtail by the two trawl gear types are considered. Third, the fishing costs for each gear type are different.

3. Theoretical approaches of TAC assessment model

3.1 Standardization of fishing effort

About 50% of the hairtail in Korean waters is caught by pair and large otter trawls (MOMAF, 2006). Since units of fishing effort for these gear types differ, the units need to be standardized. This standardization can provide reference point estimates that are more relevant than those of the 1×1 assessment model. The general model of catch per unit effort (CPUE) is:

$$\hat{CPUE} = CPUE_r \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon} \tag{1}$$

where $CPUE_r$ is the reference $CPUE$ at one level of each of the factors. Subscript i refers to the factors and subscript j refers to the levels of each factor. P_{ij} represents the relative fishing power for the j^{th} level of the i^{th} factor. For the reference level of each factor, P_{ij} is set to 1. A superscript dummy variable X_{ij} is equal to 1 when a datum refers to the j^{th} level of the i^{th} factor and 0 otherwise. ε is a normal random variable with mean 0 and constant variance, σ^2. A natural logarithmic transformation of equation (1) results in a GLM[5]

$$\ln \hat{CPUE} = \ln CPUE_r + \sum_i \sum_j X_{ij} \ln P_{ij} + \varepsilon \tag{2.1}$$

or,

$$Y = \beta_0 + \sum_k \beta_k X_k + \varepsilon, \quad \{k\} = \{i\} \cup \{j\} \tag{2.2}$$

where the subscript k subsumes i and j. The Y- intercept β_0 is the reference natural log CPUE and the parameters $\{\beta_k\}$ are natural logarithms of the power coefficients (Lee, 1991; Quinn and Deriso, 1999; Seo and Zhang, 2001).

The standardized natural log CPUE ($\ln \hat{CPUE}$) can be estimated by explanatory variables: $\ln CPUE$ and X_{ij}. The standardized $\hat{CPUE}$ can be estimated by exponentiating the $\ln \hat{CPUE}$. A standardized fishing effort ($\hat{E}_{pt}$ or $\hat{E}_{lt}$) of hairtail caught by each gear can be calculated by the equation (3):

$$\begin{aligned} &C_{T_t} = C_{pt_t} + C_{lt_t}, \quad \hat{E}_{T_t} = \hat{E}_{pt_t} + \hat{E}_{lt_t}, \\ &\hat{CPUE}_{T_t} = \hat{CPUE}_{pt_t} + \hat{CPUE}_{lt_t}; \quad \hat{E}_{pt_t} = \frac{C_{pt_t}}{\hat{CPUE}_{pt_t}} \quad and \quad \hat{E}_{lt_t} = \frac{C_{lt_t}}{\hat{CPUE}_{lt_t}} \end{aligned} \tag{3}$$

where C_{T_t} is total annual catch of hairtail by pair and large otter trawls. C_{pt_t} and C_{lt_t} are annual catch of hairtail by pair and large otter trawls, respectively. $\hat{E}_{T_t}$ is total annual standardized fishing effort summed across annual standardized fishing effort ($\hat{E}_{pt_t}$ and $\hat{E}_{lt_t}$) of the two gears. $\hat{E}_{pt_t}$ and $\hat{E}_{lt_t}$ are annual standardized fishing effort of hairtail caught by pair and large otter trawls, respectively. $\hat{CPUE}_{T_t}$ is total annual standardized $CPUE$ of

5 GLM considers consistency in trends over various combinations of factors. Another use of the GLM is in forecasting missing values of CPUE for some combination of factors. The missing data can be estimated from the predictive equation. For the GLM model, see Gavaris (1980) and Quinn and Deriso (1999).

haitail caught by the two gear types. $\hat{CPUE}_{pt_t}$ and $\hat{CPUE}_{lt_t}$ are the annual standardized $CPUE$ for hairtail caught by pair and large otter trawls, respectively. For all variables, the subscript t references the data year.

Given C_{T_t} and $\hat{E}_{T_t}$, an MSY of a yield curve for hairtail can be estimated by a surplus production model. Here, whether we use the Fox or Schaefer model, the results are determined by the empirical relationship between $\hat{E}_{T_t}$ and $\hat{CPUE}_{T_t}$. The MSY of the 1×2 case can be allocated as MSY_{pt} and MSY_{lt} by equation (4).

$$MSY_{pt} = C_{MSY_{pt}} = C_{MSY}\left(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}\right) \text{ and } MSY_{lt} = C_{MSY_{lt}} = C_{MSY}\left(\frac{\hat{E}_{lt}}{\hat{E}_{pt}+\hat{E}_{lt}}\right) \quad (4)$$

where $\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}$ or $\frac{\hat{E}_{lt}}{\hat{E}_{pt}+\hat{E}_{lt}}$ is the rate of standardized fishing effort for each gear type. $C_{MSY_{pt}}$ or $C_{MSY_{lt}}$ represents the MSY of hairtail caught by each gear type when aggregate MSY is partitioned based on past effort and catch data (Lee, 1991; Seo and Zhang, 2001).

3.2 Fox model: MSY and ABC estimations

3.2.1 Fox yield curve induced by Gompertz growth function

The Fox yield (asymmetric) curve based on the Gompertz growth function has been used as an alternative to the Schaefer (symmetric) curve based on the logistic growth function (Fox, 1970). The Fox yield curve has three premises.[6] Given its premises, the Fox yield curve can be expressed by the Gompertz growth function:

$$C_{e_t} = CPUE_{\infty} \exp\left(-\frac{q}{r}\hat{E}_{T_t}\right) \cdot \hat{E}_{T_t} \quad (5)$$

where C_{e_t} is the annual sustainable yield of hairtail caught by the two gear types at year t. $CPUE_{\infty}$ is the initial CPUE that would occur if the stock were at an unexploited level ($CPUE_{\infty} = q \cdot k : k$ is the carrying capacity of the environment). q is the catchability coefficient. r is the intrinsic growth rate.

6 Three premises with Fox yield curve are as follows: i) the sustainable yield is equal to the growth of the population, ii) CPUE is proportional to the stock biomass and iii) the sustainable yield is equal to fishing effort times the mean CPUE.

3.2.2 Effort Averaging Method (EAM)

To estimate the $CPUE_{\infty} = q \cdot k$ and q/r necessary to derive equation (5), we need to use the EAM. The EAM uses $\hat{CPUE}_{T_t}$ and $\hat{E}_{T_t}$ estimated by the GLM. The EAM equation is:

$$\ln \hat{CPUE}_{T_t} = \ln(qk) - (q/r)\hat{E}_{T_t} \tag{6}$$

Consequently, the Fox yield curve in the 1×2 case can be stated as $CPUE_{\infty} = q \cdot k$ and q/r.

3.2.3 MSY estimation

E_{MSY} that maximizes yield in equation (5) can be given by the first order condition:

$$\frac{\partial C_{e_t}}{\partial \hat{E}_{T_t}} = \frac{\partial\left(CPUE_{\infty}\exp(-\frac{q}{r}\hat{E}_{T_t})\cdot\hat{E}_{T_t}\right)}{\partial \hat{E}_{T_t}} = 0$$

$$= -\frac{q}{r}CPUE_{\infty}\exp(-\frac{q}{r}\hat{E}_{T_t})\cdot\hat{E}_{T_t} + CPUE_{\infty}\exp(-\frac{q}{r}\hat{E}_{T_t}) \tag{7}$$

Dividing both sides of equation (7) by $\frac{q}{r}CPUE_{\infty}\exp(-\frac{q}{r}\hat{E}_{T_t})$ and solving the resulting equation for $\hat{E}_{T_t}$ gives:

$$\hat{E}_{T_t} = E_{MSY} = \frac{r}{q} \tag{8}$$

By substituting E_{MSY} for $\hat{E}_{T_t}$ in equation (5), MSY can be estimated by equation (9):

$$C_e = MSY = C_{MSY} = \frac{CPUE_{\infty}r}{q\exp(1)} \tag{9}$$

3.2.4 ABC estimation

Table 1 shows the Korean tier ABC determination system for setting TAC (NMFS, 2004).[7] ABC of the 1×2 case can be calculated by the estimated CPUE and the estimated

7 Zhang and Lee (2001) constructed the Korean tier ABC determination system for setting TAC. Critical points (e.g. $B_{X\%}$ and $F_{X\%}$) within the 5 Tiers have been partially changed by the decision makers. We use the latest version (2004) of Korean tier ABC determination system for setting TAC.

MSY based on tier 4 information. The ABC determination system lists, at each of 5 tiers, the quality and quantity of information required for the available stock assessment methods. The method chosen for a particular fish stock, in general, depends on available data information provided to each tier.

Table 1. Korean tier ABC determination system for setting TAC

Tiers	Information Available Levels
* Tier 1	Information available : Reliable estimates of B, F, B_{MSY}, f_{MSY}, $F_{X\%}$ and M 1a) Stock status : $B/B_{MSY}>1$ $F_{ABC} \leq$ low value out of f_{MSY} or $F_{35\%}$ 1b) Stock status : $\alpha < B/B_{MSY} \leq 1$ $F_{ABC} \leq$ low value out of either $f_{MSY} \times (B/B_{MSY}-\alpha)/(1-\alpha)$ or $F_{35\%}$ 1c) Stock status : $B/B_{MSY} < \alpha$: $F_{ABC}=0$
* Tier 2	Information available : Current B, $B_{X\%}$, $F_{X\%}$, M 2a) Stock status : $B/B_{35\%}\%>1$ $F_{ABC} \leq F_{35\%}$ 2b) Stock status : $\alpha < B/B_{35\%} \leq 1$ $F_{ABC} \leq F_{35\%} \times (B/B_{35\%}-\alpha)/(1-\alpha)$ 2c) Stock status : $B/B_{35\%} \leq \alpha$: $F_{ABC}=0$
* Tier 3	Information available : Current B, $F_{0.1}$, M $F_{ABC} \leq F_{0.1}$
* Tier 4	Information available : Time-series catch (Y) and effort (or CPUE) data 4a) Stock status : $CPUE/CPUE_{MSY}>1$ $ABC \leq MSY$ 4b) Stock status : $\alpha < CPUE/CPUE_{MSY} \leq 1$ $ABC \leq MSY \times (CPUE/CPUE_{MSY}-\alpha)/(1-\alpha)$ 4c) Stock status : $CPUE/CPUE_{MSY} \leq \alpha$: ABC=0
* Tier 5	Information available : Reliable catch history Y $ABC \leq 0.75 \times Y_{AM}$(average catch over an appropriate time period)

1) Equation used to determine ABC in tiers 1~3 :

$$ABC = \frac{BF_{ABC}}{M + F_{ABC}}(1 - e^{-(M+F_{ABC})})$$

where, B : biomass, M : instantaneous coefficient of natural mortality,
F_{ABC} : instantaneous coefficient of fishing mortality determined by the data available and the stock status

2) In tiers 1, 2 and 4, α=0.05

Note: recent years usually represent latest 3 years.
Source: NFRDI. 2004. Stock assessment and fishery evaluation report of year 2005 tac-based fisheries management in the adjacent Korean water, National Fisheries Research And Development Institute, Yae Moon Press.

3.3 Fox bioeconomic model: Maximum Economic Yield (MEY) and NR estimations

3.3.1 MEY estimation

To estimate MEY, we need net revenue (NR). The NR can be estimated by subtracting total cost (TC) from total revenue (TR). NR is:

$$NR_t = P\left[CPUE_\infty \exp(-\frac{q}{r}\hat{E}_{T_t})\cdot \hat{E}_{T_t}\right] - TC_t \tag{10.1}$$

$$= P\left[CPUE_\infty \exp(-\frac{q}{r}\hat{E}_{T_t})\cdot \hat{E}_{T_t}\right] - \alpha m\,\hat{E}_{T_t} \tag{10.2}$$

where NR_t is the annual net revenue, P is the average market-sale price (won/kg) of hairtail used by the two gear types.[8] TC_t is the annual total cost. As before, the subscript t on variables references the year. α is the weighted average unit cost (won/haul) of the two gear types.[9] m is the annual weighted average rate of hairtail landed value caught by each gear type.[10] TR_t is estimated by P multiplied by catch in equation (5).

The levels of effort (E) that produce MEY and E_{MEY} can be found by using the first order condition for profit maximization:

$$\frac{\partial NR_t}{\partial \hat{E}_{T_t}} = \frac{\partial\left(P\left(CPUE_\infty \exp(-\frac{q}{r}\hat{E}_{T_t})\cdot \hat{E}_{T_t}\right) - \alpha m\,\hat{E}_{T_t}\right)}{\partial \hat{E}_{T_t}} = 0$$

$$= P\left[-\frac{q}{r}CPUE_\infty \exp(-\frac{q}{r}\hat{E}_{T_t})\cdot \hat{E}_{T_t} + CPUE_\infty \exp(-\frac{q}{r}\hat{E}_{T_t})\right] - \alpha m \tag{11}$$

Unlike the E_{MEY} equation of the Gordon-Schaefer model, E_{MEY} of the Fox model cannot be easily expressed in closed form. At best, the relation can be expressed as follows:

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8 P represents the year 2000 value of (hairtail) market-sale price when the base year 2000 is normalized to be 100. The price is based on consumer price index of Korean commercial fish over 10 years (1995~2004).

9 α is the year 2000 value of (hairtail) unit cost when the base year 2000 is normalized to be 100. The value is based on the producer price index of Korean commercial fish over 10 years (1995~2004). Also, the α can be estimated by the annual number of days at sea, the number of hauls per day, the number of ships, the total cost per ship and the producer price index. The unit cost (α)=[annual total cost per ship (won/ship)/(annual number of days at sea × number of hauls per day)]×producer price index.

10 m can be estimated by dividing total landed values of all species caught by a chosen gear type to total landed values of hairtail caught by the gear type. The reason for using hairtail production is so that one needs only the fishing cost of hairtail caught by the chosen gear type. In particular, since the production has a positive relationship between landed value and fishing labor charge, the rate of hairtail landed value was used as an alternative measure of fishing cost.

$$\ln(E_{MEY}) - 2(\frac{q}{r})E_{MEY} = \ln(\frac{\alpha rm}{CPUE_{\infty} qp}) \tag{12}$$

By substituting E_{MEY} for $\hat{E}_{T_t}$ into equation (10.2), NR can be maximized by equation (13):

$$NR|_{\hat{E}_{T_t}=E_{MEY}} = P\left[(CPUE_{\infty}\exp(-\frac{q}{r}E_{MEY})\cdot E_{MEY}\right] - \alpha m E_{MEY} \tag{13}$$

Particular solutions can be obtained numerically.

3.3.2 NR Estimation at the Level of ABC

TR at the level of ABC can be estimated by equation (14).

$$TR_{ABCpt} = P_{pt}\cdot C_{ABCpt} = P_{pt}\cdot C_{ABC}(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}),$$

$$TR_{ABClt} = P_{lt}\cdot C_{ABClt} = P_{lt}\cdot C_{ABC}(\frac{\hat{E}_{lt}}{\hat{E}_{pt}+\hat{E}_{lt}}) \tag{14}$$

where TR_{ABCpt} is the total revenue of hairtail caught by pair trawls at the level of ABC, P_{pt} is the annual average market-sale price of hairtail caught by pair trawls and C_{ABC} is the ABC of hairtail caught by the two gear types. TR_{ABClt} can be solved by the same method as above.

TC_{ABCpt} or TC_{ABClt} is the annual total cost at ABC level of hairtail caught by each gear. TC_{ABC} can be estimated by a, m and the annual number of hauls ($\hat{E}_{ABC}$).

$$TC_{ABCpt} = a_{pt}\cdot m_{pt}\cdot \hat{E}_{ABC}(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}) \text{ and } TC_{ABClt} = a_{lt}\cdot m_{lt}\cdot \hat{E}_{ABC}(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}) \tag{15}$$

NR_{pt} or NR_{lt} at the level of ABC can be estimated by equations (16.1) and (16.2). NR_{ABCpt} and NR_{ABClt} are:

$$NR_{ABC\,pt} = P_{pt}C_{ABC}(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}) - a_{pt}\cdot m_{pt}\cdot \hat{E}_{ABC}(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}) \tag{16.1}$$

$$NR_{ABC\,lt} = P_{lt}C_{ABC}(\frac{\hat{E}_{lt}}{\hat{E}_{pt}+\hat{E}_{lt}}) - a_{lt}\cdot m_{lt}\cdot \hat{E}_{ABC}(\frac{\hat{E}_{pt}}{\hat{E}_{pt}+\hat{E}_{lt}}) \tag{16. 2}$$

$C_{ABC_{pt}}$ and $C_{ABC_{lt}}$ can be estimated by multiplying the rate of fishing effort of each gear type to C_{ABC}. $\hat{E}_{ABC_{pt}}$ and $\hat{E}_{ABC_{lt}}$ can be also estimated by multiplying the rate of fishing effort of each gear type to $\hat{E}_{ABC}$. Net revenue curves of hairtail caught by each gear type at the level of ABC within a proportional range between 0 and 1 of fishing effort can be drawn by assuming constant shares for each gear. The constant shares we have assumed are historically (data) based. A rights-based system that allows transferability would encourage economic efficiency, but may be politically controversial (Seo and Zhang, 2001).

4. Data analysis and results

4.1 Data analysis

4.1.1 Catches and catch rate of target species and target gear types

Hairtail is selected as a target species in part because it has a high commercial value and is heavily exploited. It has been caught by pair trawls, large otter trawls, stow nets, long lines, large purse seines, jigging and other gear types. In addition, it is not included as a species in the current Korean TAC, but will be in the near future.[11]

The main fishing zones of the pair trawls, stow nets, large purse seines and jigging gear associated with hairtail are the southern area of the Yellow Sea (Huk-San Island, Il-Hyang-Cho, Socotra, Cheju Island etc.), the northern area of the East China Sea and the seas near Thushima Island. In addition, the large otter trawls, large purse seines and jigging gear which harvest hairtail have mainly been active in the seas around Cheju Island and Thushima Island (NFRDI, 2004).

Catches and catch rate of hairtail by gear type for the 10-year period 1995~2004 are based on Fisheries Statistic Data (MOMAF, 2006).

The two gear types in the hairtail fishery had high catch rates for the decade 1995~2004 (the most recent data available). Note that the average catch rate of stow nets (20.1%) is higher than that of large otter trawls (17.8%) as shown in Table 2, but we choose large otter trawls for our study. This is because the average catch rate of stow nets has dramatically decreased every year since 1997 in the 10-year period examined except 2004, when a vessel buy-back program was instituted for stow net vessels (MOMAF, 2003).

11 At present, the hairtail species is not included in the Korean TAC species, but the stock assessment for this species has been continually carried out by National Fisheries Research and Development Institute (NFRDI).

Table 2. Catches and catch rate of hairtail caught by each gear type (1995~2004)

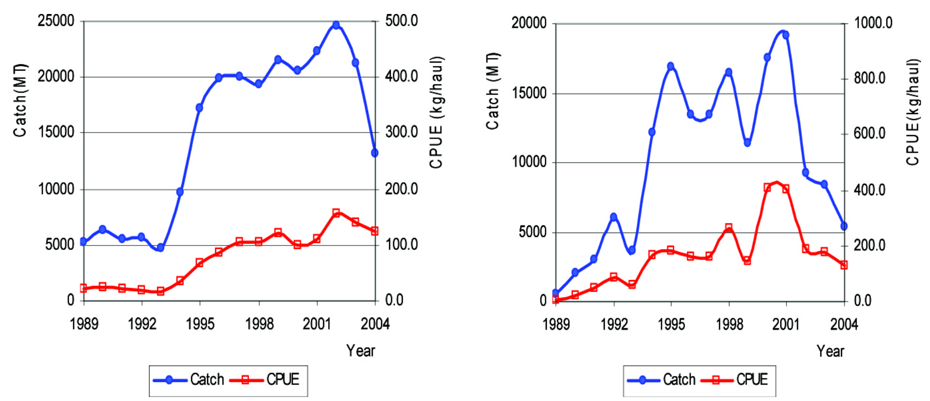
(Unit: MT and %)

Year	Pair Trawl		Large Otter Trawl		Stow Net		Long Line		Large Purse Seine		Jigging		Others	
	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate
1995	17,173	18.2	16,875	17.8	41,062	43.4	5,091	5.4	3,966	4.2	7,694	8.1	2,735	2.9
1996	19,893	26.7	13,459	18.1	25,732	34.6	4,906	6.6	3,704	5	4,987	6.7	1,780	2.4
1997	19,988	29.8	13,493	20.1	19,537	29.1	4,591	6.8	2,907	4.3	4,379	6.5	2,275	3.4
1998	19,291	25.8	16,430	22	21,061	28.1	5,114	6.8	3,020	4	5,666	7.6	4,239	5.7
1999	21,443	33.3	11,449	17.8	9,516	14.8	4,683	7.3	4,867	7.6	7,081	11	5,395	8.4
2000	20,549	25.4	17,543	21.6	5,863	7.2	9,316	11.5	10,685	13.2	6,401	7.9	10,693	13.2
2001	22,317	27.9	19,136	24	5,318	6.7	12,422	15.5	9,642	12.1	6,946	8.7	4,117	5.2
2002	24,533	40.8	9,264	15.4	3,178	5.3	13,069	21.7	2,943	4.9	5,106	8.5	2,079	3.5
2003	21,182	33.7	8,358	13.3	4,839	7.7	9,603	15.3	5,932	9.4	2,266	3.6	10,681	17
2004	13,199	19.9	5,404	8.2	16,056	24.2	8,412	12.7	4,687	7.1	2,123	3.2	16,410	24.8
Average	19,957	28.1	13,141	17.8	15,216	20.1	7,721	10.96	5,235	7.18	5,265	7.18	6,040	8.65

Source: MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.
http://www.momaf.go.kr/info/statistics/

4.1.2 Fishing effort and CPUE of hairtail

Fishing effort units used in this analysis are the annual number of hauls based on the annual total number of ships, the annual number of days at sea and the number



(a) Pair trawls (b) Large otter trawls

Source: MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.
http://www.momaf.go.kr/info/statistics/
MOMAF. 2003. A study on the structural adjustment of offshore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.
MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

Figure 1. Relationship between catches and CPUE of hairtail for each gear type (1989~2004)

of hauls per day. CPUE is estimated by the observed actual catches and number of hauls (Table 6).

In addition, the relationship between catches and the CPUE of hairtail caught by the pair trawl and the large otter trawl respectively demonstrates similar trends as shown in (Fig. 1).

4.1.3 Economic parameters estimates for hairtail

Table 3 shows all data information (e.g., the number of total ships, the number of annual days at sea, fishing cost per ship, rate of landed value and consumer and producer indexes, etc.) necessary to estimate economic parameters. As economic parameters, we use the fishing cost per ship, the market-sale price of hairtail, the unit cost and the rate of hairtail landed value of each gear type. Fishing cost per ship, market-sale price of hairtail and unit cost are average values, expressed in terms of year 2000 value (Table 4).[12]

Table 3. Total ships, days at sea, fishing cost per ship, market-sale price for target species and gear types

year	Pair Trawl						Large Otter Trawl						Consumer Index (Com. Fish)	Producer Index (Com. Fish)
	Total Ships (no.)	Annual Days at Sea (days)	Fishing Cost per Ship (10^3won/ship)	Market-Sale Price (won/kg)	Unit Cost (won/haul)	Rate of Landed Value (%)	Total Ships (no.)	Annual Days at Sea (days)	Fishing Cost per Ship (10^3won/ship)	Market-Sale Price (won/kg)	Unit Cost (won/haul)	Rate of Landed Value (%)		
1995	357	257	1,071,174	1,780	1,503,102	0.115	95	249	1,002,920	1,481	1,017,615	0.201	71.25	74.1
1996	347	270	1,128,607	1,985	1,736,107	0.143	95	259	1,205,220	2,102	1,342,647	0.214	82.28	81.8
1997	337	253	1,187,095	2,022	2,110,961	0.133	94	242	1,307,337	1,545	1,433,588	0.150	101.97	87.0
1998	304	243	1,192,836	2,170	1,131,846	0.112	92	226	1,357,048	1,427	2,207,719	0.141	107.56	87.1
1999	287	253	1,493,639	1,271	1,617,393	0.144	90	258	1,536,137	963	2,753,414	0.076	104.9	95.9
2000	206	252	1,654,890	1,138	1,669,638	0.145	70	266	1,748,835	1,213	2,889,204	0.125	100.0	100.0
2001	201	301	1,792,789	1,669	1,792,687	0.196	62	292	1,918,267	1,176	2,511,338	0.141	100.6	102.0
2002	143	312	2,155,571	1,110	1,964,990	0.172	62	297	2,069,832	659	2,636,012	0.066	108.4	112.9
2003	131	280	2,438,981	1,300	2,113,408	0.233	60	220	1,852,050	659	2,354,806	0.051	106.7	111.3
2004	95	285	1,071,174	1,117	2,159,219	0.115	58	211	1,879,948	608	2,627,688	0.027	103.2	124.0

Source: National Federation of Fisheries Cooperatives (NFFCs). 1995~2004. Annual fisheries business statistic report.
MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries. http://www.momaf.go.kr/info/statistics/
MOMAF. 2006. Fisheries and vessel statistic data. Ministry of Maritime Affairs and Fisheries. http://www.momaf.go.kr/info/statistics/
MOMAF. 2003. A study on the structural adjustment of offshore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.
MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

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12 The annual fishing cost per ship represents the weighted average fishing cost per ship. It is expressed as the year 2000 value of the annual fishing cost per ship when the base year 2000 is normalized to be 100. The annual fishing efforts are the average of annual fishing hauls per ship from 1995 to 2004. The annual number of hauls per ship can be estimated by the annual number of days at sea and the number of hauls per day of ship due to knowing total number of ships.

Table 4. Economic parameters' estimates of hairtail caught by pair trawls and large otter trawls

Gear	Fishing Cost per Ship (thousand won/ship)	Fishing Efforts (hauls/ship)	Market-Sale Price (P: won/kg)	Unit Cost (a: won/haul)	Rate of Landed Value (m: %)
Pair Trawl	1,682,950	853	1,519	1,765,369	0.151
Large Otter Trawl	1,595,634	798	1,135	2,196,907	0.119
Average	1,639,292	-	1,327	1,981,138	0.135
Sum	-	1,651	-	-	-

Source: National Federation of Fisheries Cooperatives (NFFCs). 1995~2004. annual fisheries business statistic report.
MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.
http://www.momaf.go.kr/info/statistics/
MOMAF. 2003. A study on the structural adjustment of offshore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.
MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

4.2 Analysis results

4.2.1 Standardized fishing effort

This analysis is undertaken only with respect to two factors (year and gear) with 16 levels (1989~2004) of the year factor and 2 levels (pair trawl and large otter trawl)

Table 5. Coefficients' estimates and statistics

Factor level	Coef.	Est.	S. E	t Stat	P-value	P_{ij}
Ln (U)	β_0	2.845	0.361	7.890	0.000	17.2
1990	β_1	0.649	0.495	1.313	0.209	1.9
1991	β_2	0.977	0.495	1.976	0.067	2.7
1992	β_3	1.187	0.495	2.400	0.030	3.3
1993	β_4	0.931	0.495	1.882	0.079	2.5
1994	β_5	1.813	0.495	3.665	0.002	6.1
1995	β_6	2.176	0.495	4.398	0.001	8.8
1996	β_7	2.249	0.495	4.547	0.000	9.5
1997	β_8	2.344	0.495	4.739	0.000	10.4
1998	β_9	2.590	0.495	5.235	0.000	13.3
1999	β_{10}	2.364	0.495	4.780	0.000	10.6
2000	β_{11}	2.794	0.495	5.648	0.000	16.3
2001	β_{12}	2.833	0.495	5.727	0.000	17.0
2002	β_{13}	2.630	0.495	5.316	0.000	13.9
2003	β_{14}	2.539	0.495	5.132	0.000	12.7
2004	β_{15}	2.328	0.495	4.706	0.000	10.3
P_t	β_{16}	-0.647	0.175	-3.701	0.002	0.5

Note: factors considered are year (1989~2004) and gear (1,2).
p-value: 95% significant level ($p<0.05$)

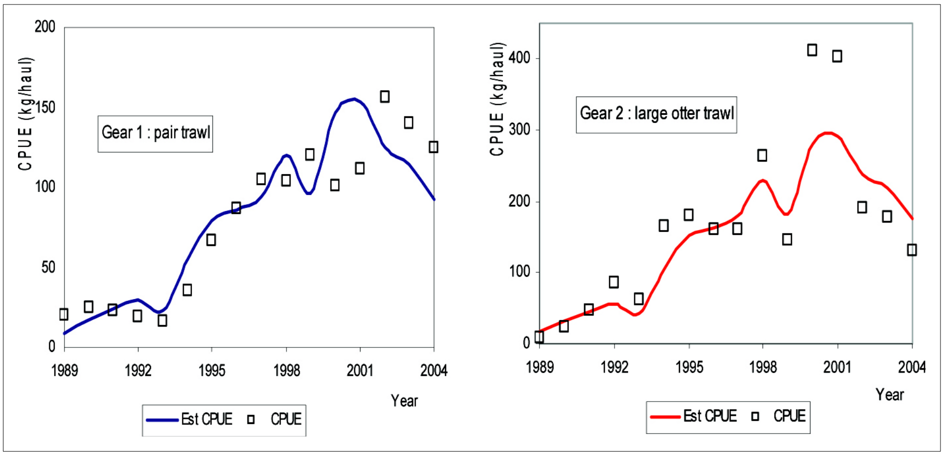

Figure 2. Observed and estimated CPUE of hairtail as function of year and gear type (1989~2004)

of the gear factor. The year variable is a qualitative one and indicates that not all years are the same. This may be indicative of the many other determinants that are omitted from a lumped parameter model. From a scientific perspective, their omission and replacement with qualitative variables is undesirable but reflects the status quo of data availability. For convenience, the reference CPUE is based on year 1989 data and the large otter trawl gear type.

The GLM run by the equation (2.2) fits the data well, with an R^2 of 0.876 and an F-statistic of 6.658 with 16 observations and 15 degrees of freedom ($p<0.05$). Table 5 provides estimates of β coefficients, statistics, p-value and estimates of the relative fishing power coefficients associated with the GLM regression. All are highly significant for every year except years 90, 91 and 93. Estimates of year 91 and 93 are also significant within ($p<0.1$). Estimates of the relative fishing power coefficients can be calculated by exponentiating the estimates of β coefficients.[13] The reference CPUE of the large otter trawl obtained from the intercept is 17.2. CPUE differs somewhat from that of the reference year 1989 in all years except for years 2000 (16.3) and 2001(17.0). The CPUE for the pair trawl averages 50% of the large otter trawl, a significant difference. This difference could be due to unequal catchability using each of the two gear types. This implies that fishing effort of the two gear types needs to be standardized in the GLM (Quinn and Deriso, 1999).

Fig. 2 shows the good fit of the model between both the observed actual CPUE and the standardized CPUE over 16 years, with the exception of actual CPUE in 2000 and 2001 for the large otter trawl. A reason for the relatively high increase in CPUE for

13 This non-linear transformation is biased downward in absolute terms, but the relative values of fishing power are not. Goldberger (1968) gives a first order approximation for non-linear bias which would be appropriate in forecasting the dependent variable.

the large otter trawl in 2000 and 2001 is that catches of hairtail by stow net were reduced in 2000~2003 due to a buy-back program for stow net vessels. However, the data are believed to be correct and observations for these two years have not been excluded.

From the observed actual catch and standardized $\hat{CPUE}_{T_t}$ yielded by the GLM, we obtain the standardized $\hat{E}_{T_t}$ of hairtail caught by the two gear types as shown in Table 6.

In addition, from equation (4), we can calculate the rate of standardized fishing effort of each gear distributed between the two gears. The average rate over 16 years (1989~2004) is 0.76 and 0.24, for each gear type, respectively (Table 7).

Table 6. The observed actual data and estimates of GLM (1989~2004)

Year	Observed Actual Data							GLM							
	Catches (MT)			CPUE (kg/haul)		Fishing Efforts (hauls)		Stan. CPUE (kg/haul)		Stan. Fishing Efforts (hauls)			Est. Stan. ln CPUE (kg/haul)	Est. Stan. CPUE (kg/haul)
	PT	LT	PT+LT	PT	LT	PT	LT	PT	LT	PT	LT	PT+LT	PT+LT	PT+LT
1989	5,175	521	**5,696**	20.3	7.6	254,953.5	68,330.0	9.0	17.2	574,925	30,301	**605,226**	2.24	**9.41**
1990	6,277	2,080	**8,357**	24.8	22.8	252,655.3	91,110.2	17.2	32.9	364,276	63,192	**427,469**	2.97	**19.55**
1991	5,551	3,060	**8,611**	22.7	48.1	244,293.8	63,634.2	23.9	45.7	232,095	66,979	**299,074**	3.36	**28.79**
1992	5,692	5,976	**11,668**	19.4	85.5	292,739.8	69,854.4	29.5	56.4	192,887	106,016	**298,903**	3.66	**39.04**
1993	4,662	3,638	**8,300**	16.1	61.7	288,939.0	58,922.3	22.8	43.6	204,144	83,397	**287,541**	3.36	**28.87**
1994	9,712	12,110	**21,822**	35.5	164.0	273,935.6	73,842.0	55.2	105.4	176,034	114,909	**290,943**	4.32	**75.00**
1995	17,173	16,875	**34,048**	66.6	180.2	257,851.4	93,628.2	79.3	151.4	216,635	111,442	**328,076**	4.64	**103.78**
1996	19,893	13,459	**33,352**	87.0	159.9	228,660.6	84,158.0	85.3	163.0	233,091	82,558	**315,650**	4.66	**105.66**
1997	19,988	13,493	**33,481**	104.7	160.6	190,952.5	83,992.5	93.8	179.2	213,036	75,286	**288,321**	4.75	**116.12**
1998	19,291	16,430	**35,721**	104.3	263.5	185,008.8	62,359.2	119.9	229.1	160,858	71,721	**232,580**	5.03	**153.59**
1999	21,443	11,449	**32,892**	120.4	145.3	178,038.9	78,768.5	95.7	182.9	223,992	62,609	**286,600**	4.74	**114.77**
2000	20,549	17,543	**38,092**	100.6	410.9	204,180.4	42,698.4	147.1	281.0	139,667	62,421	**202,088**	5.24	**188.49**
2001	22,317	19,136	**41,453**	111.0	402.5	201,011.4	47,541.7	153.0	292.2	145,908	65,496	**211,404**	5.28	**196.08**
2002	24,533	9,264	**33,797**	156.4	190.3	156,869.3	48,683.2	124.8	238.4	196,550	38,855	**235,405**	4.97	**143.57**
2003	21,182	8,358	**29,540**	140.1	177.1	151,180.7	47,189.9	114.0	217.7	185,842	38,389	**224,230**	4.88	**131.74**
2004	13,199	5,404	**18,603**	125.0	130.2	105,617.5	41,495.4	92.3	176.3	142,995	30,649	**173,644**	4.67	**107.13**

Note: PT is pair trawls and LT is large otter trawls
Source: MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries. http://www.momaf.go.kr/info/statistics/
MOMAF. 2003. A study on the structural adjustment of off shore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.
MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

Table 7. Average rate of fishing efforts of the two gears for hairtail (1989~2004)

(Unit: %)

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Ave.
Effort Rate pt	0.95	0.85	0.78	0.65	0.71	0.61	0.66	0.74	0.74	0.69	0.78	0.69	0.69	0.83	0.83	0.82	0.76
Effort Rate lt	0.05	0.15	0.22	0.35	0.29	0.39	0.34	0.26	0.26	0.31	0.22	0.31	0.31	0.17	0.17	0.18	0.24

To evaluate the relationship between the standardized $\hat{E}_{T_t}$ and the standardized $C\hat{P}UE_{T_t}$ (Schaefer, 1954; Fox, 1970), we use SPSS 14.0, the Curve Estimation Method (CEM). Results of the CEM regression show, respectively, linear (0.493), logarithmic (0.547) and exponential (0.681) R^2 values and linear (13.6), logarithmic (16.89) and exponential (29.91) F statistics. Consequently, the analysis shows that the relationship is closer to being exponential than linear. Thus, we use the Fox model derived from the Gompertz growth function.

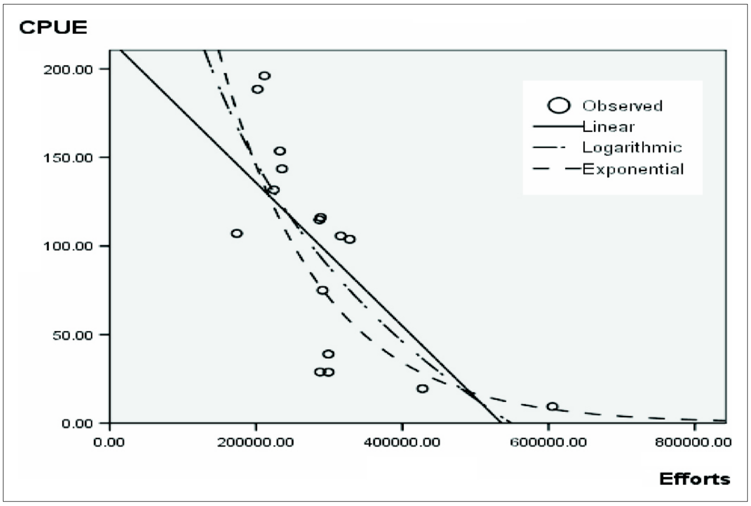

Figure 3. Relationship of estimated fishing effort (E) and estimated hairtail CPUE standardized for two gear types

4.2.2 EAM: estimations of $CPUE_{\infty}$ and q/r

The EAM in equation (6) estimates coefficients of $CPUE_{\infty}$ and $-q/r$. The coefficients of the two parameters are 615.91 and -7.22×10^{-6}, respectively. The EAM regression shows that R^2 is 0.68 and p-values are 2.86×10^{-10} and 8.30×10^{-5} ($p<0.05$), respectively.

4.2.3 Estimates of MSY (C_{MSY}) and E_{MSY}

MSY(C_{MSY}) and E_{MSY} estimated by equations (8) and (9) are 31,383 metric tons (MT) and 138,504 hauls, respectively. From the average rate of standardized fishing effort (the pair trawl=0.76 and the large otter trawl=0.24) of each gear type, MSY and E_{MEY} of hairtail for each gear can be estimated: MSY (C_{MSY}) and E_{MEY} of hairtail caught by the pair trawls are 23,778 MT and 105,263 hauls. MSY and E_{MEY} of the large otter trawls are 7,605 MT and 33,241 hauls. Moreover, the results of the regression fixed between the observed catches and the Fox yield curve with the same horizontal line of standardized fishing effort ($\hat{E}_r$) show that R^2 is 0.36. The p-value of the independent variable (observed catches) is 0.0112 ($p<0.05$). The reason for the somewhat low R^2 may be the extremely high CPUE (410.9 and 402.5) of large otter trawls for hairtail in 2000 and 2001. Fig. 4 shows the fitted Fox yield curve based on observed actual catch and standardized fishing effort.

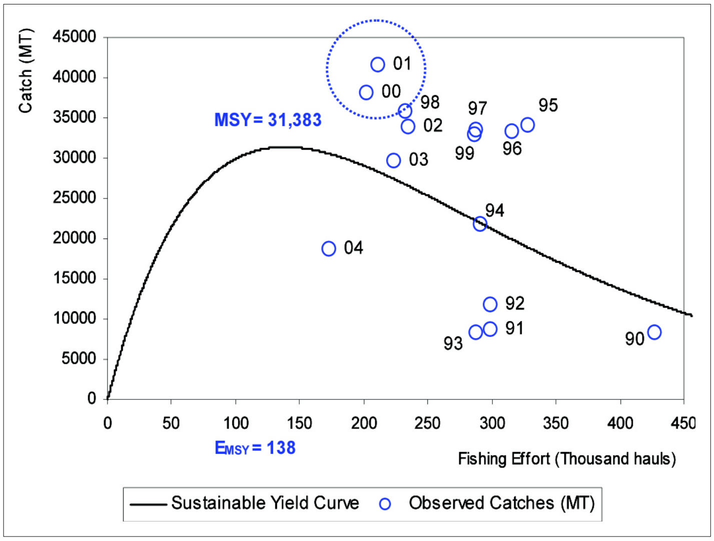

Figure 4. Sustainable yield curve, MSY and E_{MSY} for hairtail in the Korean pair trawl and the large otter trawl based on the Fox model

4.2.4 Estimates of ABC

The TAC for hairtail is related to time series catch and effort data. Since the CPUE: $CPUE_{MSY}$ ratio is between 0.05 and 1, the hairtail TAC falls under 4b) of Tier 4 in Table 1. The CPUE represents the average CPUE of the latest 3 years (2002~2004). This average CPUE is about 128 kg/haul as shown in Table 6. $CPUE_{MSY}$ can be estimated by MSY/E_{MSY}, so the $CPUE_{MSY}$ is about 227 kg/haul. Thus, the $CPUE:CPUE_{MSY}$ ratio is about 0.56.

By the Korean tier ABC determination equation [$=ABC \leq MSY \times (CPUE/CPUE_{MSY} - \alpha)/(1-\alpha)$] at 4b) of Tier 4, the ABC of hairtail caught by the two gear types is about 15,283 MT. The large difference between MSY and ABC is due to a rapid decrease in recent CPUE (2002~2004). The level of ABC is about 49% of the level of MSY. Based on fishing effort rates for pair trawlers (0.76) and other trawlers (0.24), the ABC_{pt} of hairtail caught by pair trawlers is 11,615 MT; ABC_{lt} of hairtail caught by otter trawlers is 3,668 MT.

Fig. 4 shows that recent catches of hairtail by pair and large otter trawlers have been excessive. Fishing effort has been in excess of the level of fishing efforts at MSY and also recent catches since 1995 (with the exception of year 2004) have also exceeded sustainable yield. In addition, CPUE of hairtail caught by the two gear types has been steeply decreasing since 2001. As a result, even though inputs of fishing effort were only slightly reduced in 2004, the catch dramatically decreased. This result shows that hairtail stock is rapidly decreasing. Therefore, to protect the hairtail stock from overfishing and depletion, we suggest that it needs to be included in the list of Korean TAC target species.

4.2.5 Estimates of MEY and E_{MEY}

MEY and E_{MEY} of hairtail caught by the two gear types are estimated by equations (12) and (13) and the economic parameters of Table 4.[14] The estimated MEY is about 25,184 MT and standardized fishing effort at the level of MEY is about 66 thousand hauls. NR at the level of MEY is approximately 15.9 billion won.[15]

Total operating ships (about 40 ships) of the two gear types at the level of MEY can be estimated by dividing annual average fishing effort (1,651 hauls) summed in Table 4 into the E_{MEY} (65,715 hauls). In addition, the total operating ships of each gear type at the level of MEY can be estimated by multiplying the average rate (0.76, 0.24) of fishing effort of each gear type in Table 7 by the total number of operating ships (about 40 ships), i.e., approximately 30 pair trawlers and 10 large otter trawlers.

The estimated MEY of hairtail caught by the two gear types is about 80% of the estimated MSY; the estimated E_{MEY} is about 47% of E_{MSY}. This means that, when E_{MSY} is reduced by 53% to reach E_{MEY}, the MEY, which is also a sustainable yield, falls by only 20%. Harvesting costs would presumably fall by 53%. In short, current fishing effort of the two gear types for hairtail is excessive. Realization of this cost reduction is absolutely dependent on coupling the TAC with a cost-effective rights based system.

Since the hairtail stock has recently been overfished as shown in Fig. 4, it is not possible for fishing effort at the level of MEY to achieve maximum net revenue due to the currently depleted state of stocks. In other words, given the depleted status of the resource, the fishing effort at the level of MEY can gradually recover the resource, but cannot achieve the maximum net revenue until the resource recovers to the steady state biomass associated with MEY. In addition, since pair trawlers and large otter trawlers have been used for catching other species, the revenues of ships of the two gear types that harvest species other than hairtail should also be taken into account.

Fig. 5 shows that the net revenue at MEY is higher than at MSY when the resource

14 To estimate MEY and E_{MEY} in equations (12) and (13), we use Maple 8 program and Excel Goal Seek program.

15 The current exchange value of 1 dollar is about 944 won (http://www.keb.co.kr 03/16/2007).

recovers. Hence, if the hairtail resource is allowed to recover, operating at MEY can be much more efficient than operating at the level of MSY in terms of fishing effort and net revenues.

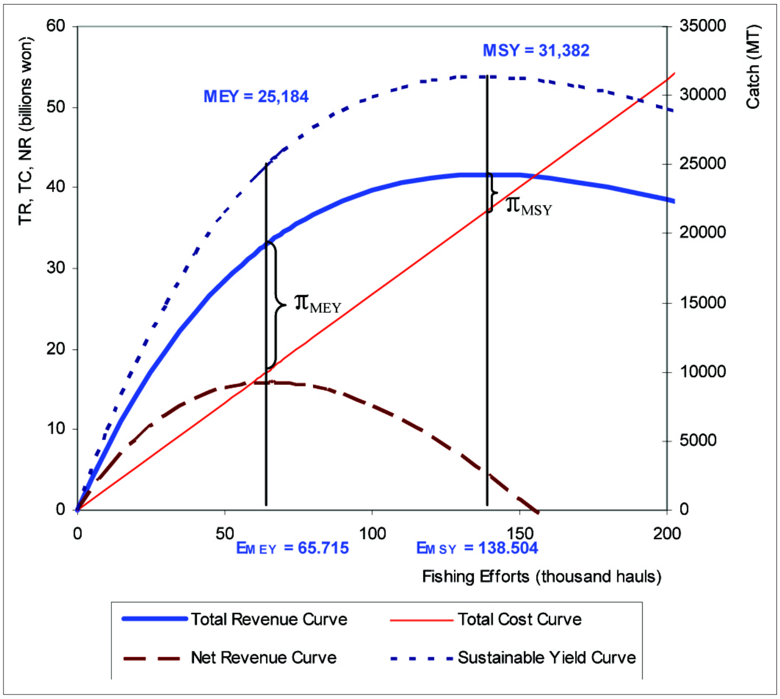

Figure 5. Total revenue, total cost and net revenue of the Korean pair trawler and large otter trawler harvesting hairtail: estimates based on the Fox bioeconomic model

4.2.6 Estimates of NR at the level of ABC

Hairtail net revenues of the two gears can be estimated by equations (16.1) and (16.2). At the current proportional levels (pt=0.76 and lt=0.24) of fishing efforts between the two gears, NR of pair trawlers is about 11.4 billion won and NR of large otter trawlers is about 2.2 billion won. Also, total NR of the two gear types is about 13.6 billion won. This result implies that pair trawlers input much more fishing effort than do large otter trawlers. As a result, pair trawlers have earned much more, in net revenue terms, than large otter trawlers. This result may be due to a lower unit operating cost and higher market-sale price of hairtail caught by pair trawlers (Table 4).[16] Fig. 6 shows the empirical relationship between net revenue and fishing effort.

16 Indeed, price differences are sufficiently common in fisheries, that econometric models based on duality should examine the behavioral implications of heterogeneous prices. See, for example, Ty and Gates (1992).

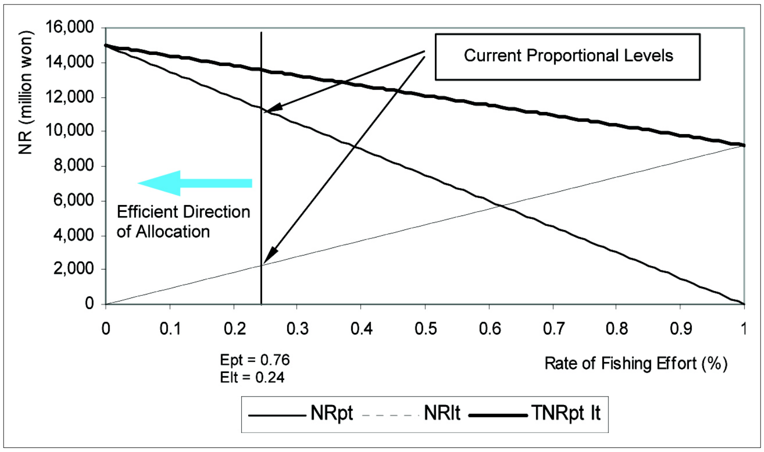

Figure 6. Relationship between net revenue and the rate of fishing efforts

4.2.7 1×1 Assessment model versus 1×2 assessment model

Table 8 shows the comparison between two versions of the 1×1 assessment model and an alternative 1×2 assessment model of the 1×G case. The two versions of the 1×1 case and the 1×2 model have significantly different estimates for reference points MSY, ABC and MEY. For example, the total MSY (31,383 MT) estimated by the 1×2 model is less than the total MSYs (36,972 MT and 38,849 MT) estimated by the two versions of the 1×1 case. In cases of individual fishing gear, the MSY (23,778 MT) of the pair trawlers estimated by the 1×2 model is less than the MSYs (29,129 MT and 27,941 MT) of the pair trawlers estimated by the two 1×1 versions. The MSY (7,605 MT) of the large otter trawlers estimated by the 1×2 model is also less than the MSYs (7,843 MT and 10,907 MT) of the large otter trawlers estimated by the two 1×1 versions. The total ABC (15,283 MT) estimated by the 1×2 model is less than the total ABCs (17,548 MT, 38,849 MT) estimated by the two 1×1 versions. With respect to type of fishing gear, the ABC (11,615 MT) of the pair trawlers estimated by the 1×2 model is less than the ABC (27,941 MT) of the pair trawlers estimated by the second version model of the 1×1 case. However, the ABC (11,615 MT) of the pair trawlers estimated by the 1×2 model is greater than the ABC (9,705 MT) of the pair trawlers estimated by the first version of the 1×1 case. The reason is that the CPUE:$CPUE_{MSY}$ ratio has a small proportion (0.37) due to the high $CPUE_{MSY}$ while the current CPUE is increasing. The ABC (3,668 MT) of the large otter trawlers estimated by the 1×2 model is also much less than the ABC (7,843 MT and 10,907 MT) of the large otter trawlers estimated by the two versions of the 1×1 case. Also, the total C_{MEY} (25,184 MT) estimated by the 1×2 model is less than the total C_{MEY} (31,542 MT) estimated by the first version of the 1×1 case.

These results indicate that the total MSY and ABC estimated by the two versions of the 1×1 case can be overestimated and also the hairtail fishery can be overfished as judged by the reference points (e.g., MSY, ABC) relative to recent effort and catch rates. The alternative (1×2) model of the 1×G case yielded values for each reference point that were more conservative.

Table 8. Comparison of MSY, ABC and MEY between the two versions of the 1×1 case and the 1×2 case

model / Reference Points	First Version of the 1×1 Case			Second Version of the 1×1 Case			The 1 × 2 Case		
	Pair Trawl	Large Otter Trawl	Total	Pair Trawl	Large Otter Trawl	Total	Pair Trawl	Large Otter Trawl	Total
MSY (MT)	29,129	7,843*	36,972	27,941*	10,907*	38,849*	23,778	7,605	31,383
ABC (MT)	9,705	7,843*	17,548	27,941*	10,907*	38,849*	11,615	3,668	15,283
C_{MEY} (MT)	27,161	4,381	31,542	-	-	-	-	-	25,184

Note: * all values are same, because $CPUE/CPUE_{MSY}$ is greater than 1 and ABC equals TAC in 1×1 cases.

5. Conclusions

This paper has demonstrated that the common TAC assessment based on two versions of the 1×1 model case can generate biological and economical bias, when applied to more complex fisheries that involve multiple species and/or gear types. The results analyzed from a Korean case study also show that MSY, ABC, or MEY estimated by the two version models of the 1×1 model case is somewhat greater than the one estimated by the 1×2 model. More specifically, the 1×1 model overestimated the MSY by about 18 percent (1st version) and about 24 percent (2nd version), the ABC by about 15 percent (1st version) and about 254 percent (2nd version) and the MEY by about 15 percent(1st version). These results show that the 1×1 model can generate a decline in the stock of a certain species due to the bias of the analyzed result. In addition, for problems of TAC allocation which can occur as a result of competition for a certain species between vessels of different gear types, the 1×2 model shows that the TAC of each gear type at the ABC level is economically inefficient. Moreover, the 1×2 model suggests the direction of change (more pair trawler, fewer otter trawlers) in sectoral allocations, assuming that a more efficient gear mix is allowed to evolve.

There are several limitations of analysis on single species and multiple gear types. First, there is a lack of biological and technical information necessary to the analysis. In this analysis, due to data limitations, the surplus production model was used. Second, the 1×2 model mentioned as a case study can facilitate understanding of the analysis process, but the model has a limit in not considering other gear types commonly used for catching hairtail. Thus, as an extension of the present analysis, a study needs to be done on a 1×G model that considers all gear types. The study should address whether or not the 1×G model is more conservative than the 1×1 model by using other methods (e.g., sensitivity analysis and theoretical comparative analysis, etc.). In addition, as a technical issue, when a 1×G model is applied, one must standardize fishing effort for different fishing gear types. By showing that such details matter, we hope this analysis will be a spur for acquisition of a more complete data series. It is also hoped that the paper may help in evolving a rights based system so that both resource conservation and efficient resource harvesting can be achieved. The TAC system alone is unlikely to achieve either.

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Data and Documentation. Data sources, models and estimation procedures are expected to be documented to permit replication by other researchers. Data used in the analyses should be made available to other researchers for replication purposes. Submission of appendices, model documentation and other supporting materials is encouraged to facilitate the review process.