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TAC Assessment of Multiple Species and Single Fishing Gear†

- case study on mackerel and jack mackerel caught by the large purse seine fleet -

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ABSTRACT

This paper provides a total allowable catch assessment model for single fishing gear and multiple species fishery in South Korea. To estimate appropriate allowable biological catch of mackerel and jack mackerel caught by the large purse seine fleet within the territorial waters of South Korea, this paper uses an extended Beverton-Holt yield per recruit model and a biomass-based cohort analysis. The extended Beverton-Holt yield per recruit model adds two terms, a relative bycatch index (w_i) and a relative instantaneous fishing mortality index (a_i), to the original Beverton-Holt model. The reason for adding new terms is because the bycatch of those species caught by the large purse seine fleet is able to affect the instantaneous fishing mortality as well as the recruitment of each species. In conclusion, this paper suggests that the current allowable biological catch level of mackerel needs to be lowered to prevent overfishing of jack mackerel with the small stock due to bycatch.

Key words: TAC Assessment Model, Multiple Species, Single Fishing Gear, Korean TAC System, Allowable Biological Catch, Mackerel, Jack Mackerel

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*** John M. Gates, a professor and fisheries specialist, University of Rhode Island, passed away in 2010. One of his great joys was use of mathematical programming. Although he is not near us, he will be remembered as a gentle, kind, and endearing man who was charmingly absentminded.

1. Introduction

The territorial waters of South Korea are in a temperate marine zone. More than 200 species are found in the territorial waters of South Korea and approximately 37 fishing gears have fished off there. As a result, multiple species have been caught by multiple fishing gears so that most Korean fishing gears have targeted multiple species.

Meanwhile, the Korean government has enforced Total Allowable Catch (TAC) system since 1999 and also has gradually extended TAC species. Particularly, multiple species[1] with high commercial value will be added to the list of TAC species in the near future (Ryu, *et al*., 2002; Ryu, Nam, and Gates, 2006). Therefore, assessment models of TAC set-up suitable to multiple species fisheries of South Korea will be needed.

The Korean TAC assessment model is based on the Allowable Biological Catch (ABC) estimation designed to ensure that Spawning Stock Biomass (SSB) remains at or above the precautionary biomass level (Kell, *et al*, 2006). Data used in the analysis depend on biological information for individual species and its past catching history (Baik, *et al*., 2004). In particular, the TAC assessment model[2] has only considered single species and single fishing gear. It has not considered interactions[3] among multiple species and multiple fishing gears.

As a result, it is not easy to explicitly estimate ABCs of the targeted TAC species. It is able to over- or under-estimate the ABCs of the targeted TAC species. The reason for this is because it treats as exogenous variables such as biological, technical and economic interactions, and environmental factors. As an example, the TAC of the sardine has especially been higher than its catch proportion since the TAC system began in 1999. The environmental factor such as a sudden rise of water temperature has been rarely reflected in the TAC of the sardine. In addition, in most Korean TAC species with high bycatch rate, the TACs used since 1999 appear to have been inadequate to conserve the resource of TAC species by not reflecting the omission of bycatches. Thus, this paper provides an extended TAC assessment model considering technical interactions[4] to re-estimate TAC

1 Among multiple species (e.g., hairtail, flounder, puffers, redlip croaker, conger eel) with high commercial value, squid officially added to the list of TAC species in 2007. Also, the Korean TAC species are 11 species in 2012.

2 The Korean TAC assessment model, which does not consider technical interactions such as the bycatch component, uses the single species Beverton-Holt yield per recruit model to most TAC species (Beverton and Holt, 1957).

3 Interactions − (a) biological interaction is the interaction between fish stocks, and within fish stocks, caused by predation and food competition, (b) economic interaction is the competition between fleets, e.g. between an industrial fishery and an artisanal fishery. The more one fleet catches of the limited resource the less will be left for its competitors. (c) technical interaction means that the fishery on one stock creates fishing mortality on other stocks because the fishery is either a multiple species fishery or because of inevitable bycatches (Venema, 1998).

4 This paper just provides a type of multiple species and a fishing gear with a technical interaction considering a bycatch component, but hereafter, this case study needs to provide several types like a single species & multiple fishing gears and multiple species & multiple fishing gears considering three interactions.

levels for multiple species (i.e., mackerel and jack mackerel) caught by a single fishing gear (i.e., the large purse seine fleet).

The purposes of the paper are first to set up a TAC assessment system considering technical interactions, as an auxiliary and precautionary means, for overcoming limitations of the TAC assessment model, and for rational operation of the Korean TAC system, secondly, to develop an extended TAC assessment model for estimating significant TAC of multiple species selected. Finally, the paper from results analyzed suggests policy directions of the Korean TAC system.

Table 1. The Korean TAC System: 9 Species and 5 Fisheries (1999~2003)

Fishing Gears	Species	1999		2000		2001		2002		2003	
		TAC (ton)	Catch Proportion (%)	TAC (ton)	Catch Proportion (%)	TAC (ton)	Catch Proportion (%)	TAC (ton)	Catch Proportion (%)	TAC (ton)	Catch Proportion (%)
Large Purse Seine	Mackerel	133,000	115	170,000	49	165,000	96	160,000	79	158,000	74
	Jack Mackerel	13,800	47	13,800	68	10,600	90	10,600	100	11,000	100
	Sardine	22,660	42	22,600	3	19,000	0.6	17,000	0	13,000	0
Off-Shore Trap	Red Snow Crab	39,000	65	39,000	78	28,000	69	28,000	64	22,000	92
	King Crab	-	-	-	-	-	-	1,220	78	1,000	61
Diver	Purplish Washington Clam	-	-	-	-	9,500	64	9,000	59	9,000	52
	Fun Mussel	-	-	-	-	4,500	33	2,500	57	2,500	65
Village	Cheju Island Top Shell	-	-	-	-	2,150	90	2,058	96	2,150	91
Off-Shore Gill Net Trap	Blue Crab	-	-	-	-	-	-	1,550	97	13,000	38
Total		208,460	93	245,400	51	238,750	81	231,928	72	231,650	70

Source: Ryu, J., Nam, J., and Gates J. M., 2006. Limitations of the Korean Conventional Fisheries Management Regime and Expanding Korean TAC System toward Output Control System, Marine Policy 30: 510-522.

The paper is organized as follows. Section 2 shows the theoretical approach of TAC assessment about multiple species and single fishing gear with a technical interaction based on a modified Beverton-Holt yield per recruit model and a surplus production model. Section 3 provides the basic structure of an extended TAC assessment model. Section 4 analyzes the optimal ABC level of the single gear and multiple species case using the extended yield per recruit model and biomass-based cohort analysis and also discusses and compares the ABC levels analyzed by the extended TAC assessment model to the current Korean TAC assessment model. Section 5 contains concluding remarks about implications and limitations of the Korean TAC system for single gear and multiple species assessment.

2. Theoretical approach of multiple species and single fishing gear

Most analyses of multiple species fisheries have ignored the effects of joint catch due to a premise that the each unit of effort is directly applied to each species. The premise is reasonable, because the bycatch component of a species is small relative to the targeted catch of the species (Pascoe, 1995). However, the Korean fisheries have experienced high bycatch rate among TAC species.

Table 2. Bycatch Rate (bi)oftheKoreanTACSpecies

(unit: %)

Fishing Gears	Species	1977	1980	1985	1990	1995	2001	Average
Large Purse Seine	Mackerel	14.35	6.58	16.71	8.9	35.28	23.26	17.5
	Jack Mackerel	19.84	64.61	33.18	45.1	58.38	57.07	46.4
	Sardine	12.1	26.34	17.09	8.63	6.65	8.93	13.3
Off-shore Trap	Red Snow Crab	-	-	-	-	0.05	3.22	1.6
Diver	Fun Mussel	40.13	16.16	27.01	35.97	7.99	7.06	22.4
Village	Cheju Island Top Shell	59.63	47.17	53.51	67.81	75.42	74.67	63.04
Off-shore gill net trap	Blue crab	32.44	53.44	50	-	22.66	61.31	64.78

Source: Ryu, J. *et al*., 2002. A Study on Annual Expansion Program of TAC Target Species, Ministry of Maritime Affairs and Fisheries (MOMAF), 167 pp.

Analyses which do not consider technical interactions such as the bycatch component, can cause a bias in TAC estimation by species. Nevertheless, the Korean TAC assessment has used the single species Beverton-Holt yield per recruit model[5] in most TAC species (Beverton and Holt, 1957; Baik, *et al*., 2004). A theoretical limitation of this model is that the instantaneous fishing mortality (F) in the model does not reflect each species' bycatch.

However, the instantaneous fishing mortality from bycatches can differentially affect yields per recruit in real world. Hence, for multiple species fisheries with high bycatch rates of target species, yield per recruit by species needs to be more accurately estimated

5 Beverton and Holt (1957) developed, as yield per recruit model, a theory of fishing of Baranov (1918) using the von Bertalanffy (1938) curve which described growth in fish length. The single species Beverton and Holt yield per recruit model can be described as

$$Y / R = F \exp(-M(t_c - t_r)) \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \exp[-nK(t_c - t_0)]}{F + M + nK} \cdot (1 - \exp[-(F + M + nK)(t_L - t_c)]).$$

where Y/R represents yield per recruit in weight (g), F represents instantaneous fishing mortality coefficient, M represents instantaneous natural mortality coefficient, U_n represents summation parameters (U_0=1, U_1=-3, U_2=3, and U_3=-1), t_c represents mean age (years) at first capture, t_r represents mean age (years) at recruitment to the fishing area, W_∞ represents asymptotic weight, t_0 represents hypothetical age the fish would be zero length, K represents the Brody growth coefficient, and t_L represents the maximum age (years).

by inserting additional terms in the model. Specifically, an extended Beverton-Holt yield per recruit model for single fishing gear and multiple species adds two terms [a relative bycatch index (w_i) and a relative instantaneous fishing mortality index (a_i)] to the original Beverton-Holt model. The reason for adding new terms is that bycatch of mackerel and jack mackerel caught by the large purse seine fleet can affect the instantaneous fishing mortality and recruitment of each species. The new terms capture the changes in fishing mortality and stock of each species due to bycatches.

As previous literatures with related to multiple species and fishing gears, Murawski (1984) provided a detailed account of a single fishery and multiple species yield per recruit model which is quite similar conceptually to that presented by Beverton and Holt. Murawski also extended the model to examine the case where several fisheries exploit differing mixtures of the same stocks and applied both the single and multiple fisheries models to the Georges Bank otter trawl fishery (Murawski, 1984; Murawski, Lange and Idoine, 1991). Daan (1987) and Pascoe (1994) have developed a model where the catch of one species is a function of the effort applied to that species as well as the effort targeted on other species in the fishery. It implies that there are separate target and bycatch catchability coefficients (Pascoe, 1995). Seo and Zhang (2001) provided a multiple species yield per recruit model which uses individual catch rate of the multiple species (hair tail, small yellow croaker, white croaker and pomfret) caught by the Korean pair trawl fishery.

In addition, Anderson (1975, 1977) developed a theoretical two-species model where the catch of one species was a function of the effort directed at that species as well as the effort directed at the other species. This approach based on the surplus production model (Schaefer, 1954; 1957) provides a strong theoretical basis for the extended Beverton-Holt single gear and multiple species yield per recruit model. A theoretical multiple species and a fishing gear model can be interpreted as shown in the following Figure 1.

Yields caught of either type of fish depend upon the effort used and the size of the respective population. Each species has a population equilibrium curve (PEC), as shown in Figure 1(a). Since the two populations are independent, the curves are derived from the relevant intersection between individual fishing effort and equilibrium population such that the equilibrium population size decreases as fishing effort increases. Thus, in the absence of fishing effort, mackerel has an unexploited equilibrium population size of P_3. Similarly, the natural equilibrium size of jack mackerel is P_1. As effort increases, a new equilibrium is reached at a lower population size due to the increase in catch. Particularly, when fishing effort reaches E_2, the stock species B is destroyed at zero but that of mackerel is at P_2. If fishing effort reaches E_4, the population of mackerel is depleted as well.

When each species is at a sustainable yield such as the Figure 1(b), the total sustainable yield is the sum of the two sustainable yields. For instance, when fishing effort of both species is E1, the equilibrium yields of those are Y_1 and Y_2 respectively. Therefore, the total sustainable yield (Y_1+Y_2) at this level of fishing effort comprises those two quantities as shown in the Figure 1(c), and the revenue earned by multiplying relative prices by the sustainable yields depends upon the price of the two species and the volume of each catch.

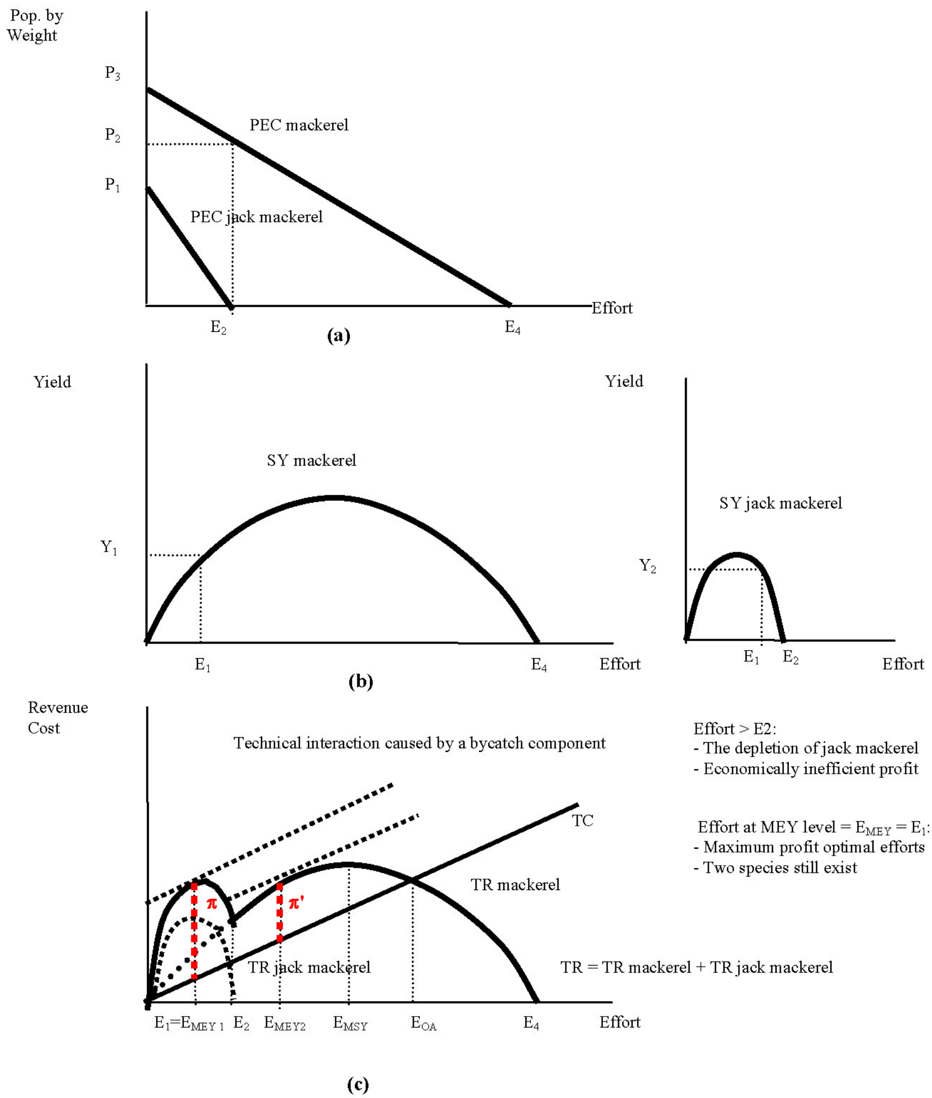


Figure 1. A Theoretical Approach on Mackerel and Jack Mackerel Caught by the large purse seine fleet with Technical Interaction

Economically, E_{MEY1} or E_1 is more efficient than E_{MEY2}, E_{MSY}, and E_{OA}, because although fishing effort is less, profit (π) of E_{MEY1} is the highest at the given the total cost (TC). In addition, both species are biologically still remaining in E_{MEY1}, but are not in E_{MEY2}. At that point with E_{MEY2}, jack mackerel is completely depleted. Also, total revenue arises entirely from the catch of mackerel. Thus, in this theoretical multiple species and a fishing gear example, E_{OA} at open-access fishery and E_{MSY} regulation destroy jack mackerel that could have been of value to another sector of society (i.e. social welfare loss) such as sports or recreational fishing. E_{MEY2} regulation also destroys jack mackerel (Anderson, 1975; 1977).

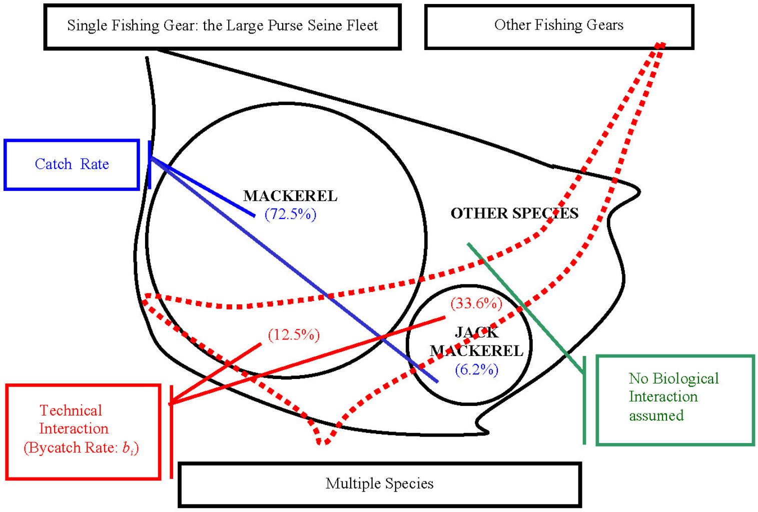
In conclusion, in a fishery with two technically-related species, exclusive focus which only considers one species without considering the bycatches of the other species, may result in depletion of one or both species. Therefore, although two species are biologically independent, bycatch between two species due to fishing activity of the single fishing gear can result in depletion of the bycatch species.

3. An extended TAC assessment model

This paper provides a case of technical interaction shown in mackerel and jack mackerel caught by the large purse seine fleet in Korean waters. Mackerel and jack mackerel caught by the fleet was averagely 72.5 percent and 6.2 percent from 1994 to 2003 respectively (MOMAF, 2004). The extended TAC assessment model applies a modified Beverton-Holt single gear-multiple species yield per recruit model and biomass-based cohort analysis.

The model assumes that first, two species are independent so that there are no biological interactions between them, secondly, they are only caught by the selected fleet and other species (e.g., sardine, squid, hairtail) caught by the fleet are ignored, thirdly, there is a technical interaction in that the fleet generates fishing mortality to stocks of non-target species besides target species, and fourthly, bycatch rate of the two species caught by other gears(e.g., the large bottom trawl, the large trawl) is considered.

The basic structure on multiple species and single fishing gear is illustrated in Figure 2.



Source: Ministry of Maritime Affairs and Fisheries (MOMAF), 2004. http://fs.fips.go.kr/index.jsp

Figure 2. The Basic Structure of Multiple Species by Single Fishing Gear

3.1 An Extended Beverton-Holt Single Gear and Multiple Species Yield per Recruit Model

To more accurately estimate annual fishing mortalities (year^{-1}) such as F_{ABC} for multiple species and single fishing gear, the extended Beverton-Holt yield per recruit model can be transformed as Eq. 1. The extended model adds a relative bycatch index (w_i) and a relative instantaneous fishing mortality index (a_i) to consider technical interactions such as bycatch component.

$$Y/R = \sum_{i=1}^{s} w_i a_i F \exp(-M_i(t_{ci}-t_{ri}))\cdot W_{\infty i}\sum_{n=0}^{3}\frac{U_n \exp[-nK_i(t_{ci}-t_{0i})]}{a_i F + M_i + nK_i}\cdot(1-\exp[-(a_i F + M_i + nK_i)(t_{Li}-t_{ci})]) \quad \text{(Eq. 1)}$$

s : the number of species

w_i : the relative bycatch index of i species (bycatch rate of i species / average bycatch rate of all species targeted)

a_i : the relative instantaneous fishing mortality index of i species (= Fi / $\overline{F_w}$)

F : the instantaneous fishing mortality rate

$\overline{F_w}$: the weighted average instantaneous fishing mortality rate of s species

M_i : the instantaneous natural mortality coefficient of i species

t_{ci} : the mean age (years) at first capture of i species

t_{ri} : the mean age (years) at recruitment to the fishing area of i species

$W_{\infty i}$: the asymptotic weight parameter of i species
U_n : the summation parameters ($U_0=1,\ U_1=-3,\ U_2=3,\ U_3=-1$)
K_i : the Brody growth coefficient of i species
t_{0i} : the hypothetical age when the fish of i species would be zero length
t_{Li} : the maximum age (years) of i species

The weighted average instantaneous fishing mortality rate ($\overline{F_w}$) which reflects a bycatch component implies the ratio of the sum of instantaneous fishing mortality rate of i^{th} species (F_i) × the bycatch rate of i^{th} species (b_i), divided by sum of b_i. $\overline{F_w}$ can be expressed by

$$\overline{F_w} = \frac{\sum_{i=1}^{s} b_i F_i}{\sum_{i=1}^{s} b_i} \qquad \text{(Eq. 2)}$$

s : the number of species ($i = 1, 2, \cdots, s$)
b_i : the bycatch rate of species i

where b_i can be estimated by its target fishing gear and total annual catch. The b_i implies the proportion of the TAC target species i which is not caught by k fishing gear for the annual total catch.

$$b_i = 1 - C_k / TC_{all} \qquad \text{(Eq. 3)}$$

C_k : an annual catch caught by k fishing gear for a TAC target species i
TC_{all}: an annual total catch caught by all fishing gears for a TAC target species i

The level of fishing mortality at F0.1 is formally defined for a given recruitment age as that level of F where (Deriso, 1987)

$$\left.\frac{d(Y/R)}{dF}\right|_{F=F_{0.1}} = \left.\frac{(0.1)d(Y/R)}{dF}\right|_{F=0.0} \qquad \text{(Eq. 4)[6]}$$

6 This equation is used in the first order Taylor series approximation to project yield. This approximation is only valid for “small” F value. For “large” F values, higher order terms would be needed. For the case study, F is relatively low. $F_{0.1}$ means that the slope of the yield per recruit curve for the $F_{0.1}$ rate is only the one-tenth slope of the curve at its origin.

$F_{0.1}$ can be estimated by Eq. 1 and Eq. 4. In addition, F_{MAX} can be estimated by the highest level (g) of the extended Beverton-Holt yield per recruit obtained from changes in instantaneous fishing mortality. F_{MAX} means the rate of fishing mortality that produces the maximum yield per recruit. This is the point that defines growth overfishing.

3.2 An Extended Spawning Stock Biomass per Recruit Model

A spawning stock biomass per recruit (SSB/R) model has received much attention as a means to preserve reproductive potential of the population (Quinn and Deriso, 1999). The SSB/R was introduced by Shepherd (1982), Campbell (1985), Sissenwine and Shepherd (1987), Prager *et al*. (1987) and Gabriel *et al*. (1989). To estimate $F_{x\%}$ of mackerel and jack mackerel caught by the large purse seine fleet, the extended spawning stock biomass per recruit model is used as

$$\left.\frac{SSB}{R}\right|_{F=0} = \sum_{t=t_r}^{t_\lambda} m_t \cdot \exp[-M(t_c - t_r)] \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \exp[-nK(t_c - t_0)]}{(M + nK)} \cdot (1 - \exp[-(M + nK)(t_L - t_c)]) \quad \text{(Eq. 5)}$$

SSB : the spawning stock biomass
R : the particular level of recruitment
t_λ : the maximum age of species
m_t : the mature proportion by age t *of species*
mackerel ($m_1=0.02,\ m_2=0.68,\ m_3=0.95,\ m_4=0.96,\ m_5=1.00$)
jack mackerel($m_1=0.15,\ m_2=0.40,\ m_3=0.80,\ m_4=0.95,\ m_5 = 1.00$) (Baik, *et al*., 2004).

In addition, when $F=F_{0.x}$, SSB/R is as follows.

$$\left.\frac{SSB}{R}\right|_{F=F_{o.x}} = \sum_{t=t_r}^{t_\lambda} m \cdot \exp[-M(t_c - t_r)] \cdot W_\infty \sum_{n=0}^{3} \frac{U_n \exp[-nK(t_c - t_0)]}{(F + M + nK)} \cdot (1 - \exp[-(F + M + nK)(t_L - t_c)]) \quad \text{(Eq. 6)}$$

where % SSB/R (or % SPR) means the proportion of SSB/R $_{F=F0.x}$ divided by SSB/R$_{F=0}$ in absent of fishing effort. To find X%, it can be derived as Eq. 7.

$$\frac{SSB/R|_{F=Fo.x}}{SSB/R|_{F=0}} = X\% \quad \text{(Eq. 7)}$$

$F_{0.x}$: the instantaneous fishing mortality of each level such as $F_{0.1}$, $F_{0.2}$, or $F_{0.3}$.

3.3 A Biomass-Based Cohort Analysis Model

To estimate biomass (B_{ij}) by cohort (age) of j species in year i and instantaneous fishing mortality (F_{ij}) of j age-species in year i, the biomass-based cohort analysis is used as Eq. 8 (Pope, 1972). However, the result of each species' biomass (B_{ij}) in this model estimated by Baik, *et al*. (2004) is directly used.

$$B_{ij} = B_{i+1j+1}e^{(M-G_j)} + C_{ij}e^{(\frac{M-G_j}{2})} \qquad \text{(Eq. 8)}$$

B_{ij} : the biomass in weight by cohort (age) of j age-species in early of year i
C_{ij} : the catch in weight by cohort (age) of j age-species in year i
M : the instantaneous natural mortality rate
G_j : the instantaneous growth rate of j age-species

For the last year and maximum age, the biomass-based cohort analysis can be estimated by Eq. 9.

$$B_{ij} = C_{ij}\frac{(F_{ij} + M - G_j)}{F_{ij}(1-e^{-(F_{ij}+M-G_j)})} \qquad \text{(Eq. 9)}$$

F_{ij} : the instantaneous fishing mortality of j age-species in year i

The instantaneous fishing mortality of j age-species in year i (Fij) can be estimated by Eq. 10.

$$F_{ij} = \ln(\frac{B_{ij}}{B_{i+1j+1}}) - M + G_j \qquad \text{(Eq. 10)}$$

The instantaneous growth rate of j age-species (G_j) can be estimated by Eq. 11.

$$G_j = \ln(\frac{W_{j+1}}{W_j}) \qquad \text{(Eq. 11)}$$

W_{j+1} : the weight of $j+1$ age-species
W_j : the weight of j age-species

3.4 Estimation Equation for Annual Allowable Catch (ABC)

To estimate ABC of multiple species, ABC estimation equation of tier 1~3 information suitable to the Korean ABC estimation model (Baik, *et al*., 2004) is used.

$$ABC = \sum_{i=0}^{t_\lambda} \frac{B_{ij} F_{ABC}}{M + F_{ABC}} (1 - e^{-(M + F_{ABC})}) \qquad \text{(Eq. 12)}$$

ABC : the annual allowable catch of species
F_{ABC} : the annual allowable catch of species

Finally, to compare the current Korean ABC for single species and single fishing gear with ABC for multiple species and single fishing gear, this paper applies F_{ABC} of the two models and calculates the associated ABCs. In addition, ABC of each species caught by the large purse seine fleet is calculated by ABC of each species and recent average catch rate of each species caught by the large purse seine fleet.

ABC of each species caught by the large purse seine fleet
= ABC of each species X recent average catch rate (2000~2003)

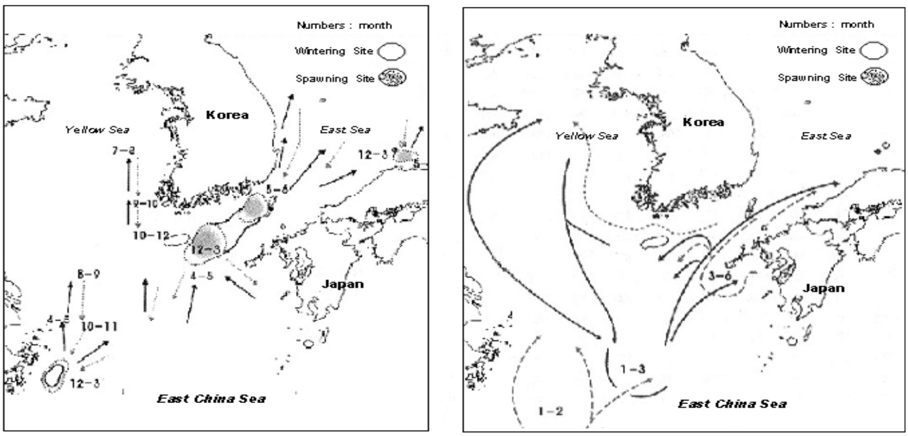
4. Analysis and results

This section analyzes the optimal TAC level for the study fishery and compares the TAC level of the extended model with that of the current Korean TAC assessment model.

4.1 Target Species and Gear

Mackerel caught in Korean territorial waters belongs to two different stocks − East China Sea and Tsushima stocks. The main spawning areas of these stocks are near the East China Sea (Dec.~Mar.), Cheju Island (Dec.~Mar.) and Tsushima Island (May~June). Mackerel mainly inhabits the Yellow Sea, the East China Sea, the East Sea and the southern waters of S. Korea. Jack mackerel inhabits the Yellow and the East China Seas, the southern waters of S. Korea, and the western waters of the Kyushu region. The main spawning areas of jack mackerel are near the middle of the East China Sea (Feb.~Mar.), the western of the Kyushu region (Apr.~Mar.), and Cheju Island (June~Aug.).

These two species live in almost the same places as shown in Figure 3. These two species are caught by the large purse seines fleets and have high potential of bycatches. Major species (i.e. mackerel, jack mackerel, sardine, squid) caught by the same fleets have been regarded as major species in the current Korean TAC system. Therefore, the multiple species and the large purse seine fleet can be an appropriate empirical model of the alternative TAC model.



(a) mackerel (b) jack mackerel

Source: National Fisheries Research and Development Institute (NFRDI) 2005. http://www.nfrda.re.kr/sea-fish-info/fis/fdata5.html

Figure 3. Migrations of Mackerel and Jack Mackerel

4.2 Analysis Data

Selection of Major Target Species Caught by the Large Purse Seine Fleet

To compare TAC of each species estimated by two models, sardine, hairtail, and squid species were excluded in this model. The reason for this is because sardine species had low bycatch and catch rates, and also hairtail and squid species did not belong to TAC target species until 2005. Therefore, mackerel and jack mackerel species with high catch rate and bycatch rate are used in this model. These two species occupy, on average, about 80% of total catches of the large purse seine fleet during the past 10 years (Table 3). In addition, the average bycatch rate of the two species shows mackerel (17.5%) and jack mackerel (46.4%), respectively (Table 2).

Table 3. Catches and Percentage Composition of Major Target Species Caught by the Large Purse Seine Fleet (1994~2003)

(unit: ton, %)

Year	Gear	Large Purse Seine Fleet				
	Species	Mackerel	Jack Mackerel	Sardine	Others	Sum
1994	Catches	197,761	35,036	35,335	42,835	310,967
	Percentage	64	11	11	14	100
1995	Catches	159,820	7,521	13,078	47,576	227,995
	Percentage	70	3	6	21	100
1996	Catches	386,877	10,790	15,837	39,833	453,337
	Percentage	85	2	3	9	100
1997	Catches	139,293	12,867	6,844	25,785	184,789
	Percentage	75	7	4	14	100
1998	Catches	148,892	15,296	5,661	35,188	205,037
	Percentage	73	7	3	17	100
1999	Catches	155,728	7,913	16,791	49,495	229,927
	Percentage	68	3	7	22	100
2000	Catches	109,025	14,288	2,161	54,514	179,988
	Percentage	61	8	1	30	100
2001	Catches	177,935	10,729	123	43,034	231,821
	Percentage	77	5	0	19	100
2002	Catches	126,519	18,965	8	36,357	181,849
	Percentage	70	10	0	20	100
2003	Catches	113,121	13,558	14	31,969	158,662
	Percentage	71	9	0	20	100
Average	Catches	171,497	14,696	9,585	40,659	236,437
	Percentage	72.5	6.2	4.1	17.2	100

Source: Ministry of Maritime Affairs and Fisheries (MOMAF), 2004. http://fs.fips.go.kr/index.jsp

4.2.1 Biological Parameters of Target Species

To compare the current Korean F_{ABC} of respective mackerel and jack mackerel with F_{ABC} of these two species, the extended TAC assessment model uses biological parameters estimated by National Fisheries Research and Development Institute (NFRDI) in 2004 except instantaneous fishing mortality (F_i) of jack mackerel. The reason for this is that $F_{current}$ of jack mackerel last year was much higher than that of it in the past years. Thus, Fcurrent of jack mackerel is assumed as 0.6. in this model (Table 4). The instantaneous fishing mortality (F_i) can be estimated from the Ricker Formula, $F_{current} = 1 - exp\ (-F_i)$.

Table 4. Biological Parameters of the Two Species

Species	Parameters											
	M (yr^{-1})	t_0 (year)	t_c (year)	t_L (year)	W_i (index)	a_i (index)	m_i	W_∞ (g)	L_∞ (cm)	K (yr^{-1})	F_i	$F_{current}$ (yr^{-1})
Mackerel	0.52	-0.428	1.01	10	0.542	0.513	0.125	2249.55	51.67	0.299	0.40	0.33
Jack mackerel	0.53	-0.809	0.53	7	1.458	1.181	0.336	1047.17	429.9	0.248	0.92	0.60

Note: $F_{current}$ represents the current levels of fishing mortality.
Source: Baik *et al*., 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 (NFRDI). 237pp.

4.3 Results

4.3.1 Estimation of F_x and $F_{x\%}$

This paper analyzes how $F_{x\%}$ changes from the change in F_i of the current Korean TAC assessment model and the extended TAC assessment model. This paper estimates appropriate $F_{x\%}$ and $F_{0.x}$ of two models to compare the current Korean TAC assessment model with the extended TAC assessment model. This model provides F_{MAX}, F_{ABC} and $F_{0.1}$ as F_x and $F_{50\%}$, $F_{40\%}$, $F_{35\%}$, $F_{30\%}$, *and* $F_{25\%}$ *as* $F_{x\%}$ (Table 4).

F0.1 at current mean age of first capture estimated by the current TAC assessment model was 0.17/year (mackerel) and 0.18/year (jack mackerel) respectively. $F_{0.1}$ at current mean age of first capture estimated by the extended TAC assessment model was 0.16/year. And also F_{MAX} estimated by the current TAC assessment model was 0.69/year (mackerel) and 0.58/year (jack mackerel) respectively. F_{MAX} estimated by the extended TAC assessment model was 0.86/year.

In addition, $F_{x\%}$ at the lower bound F_{ABC} estimated by the current TAC assessment model was 30% (mackerel) and 35% (jack mackerel) respectively. $F_{x\%}$ at the lower bound F_{ABC} estimated by the extended TAC assessment model was 50%. $F_{x\%}$ at the upper bound F_{ABC} estimated by the current TAC assessment model was 25% (mackerel) and 30% (jack mackerel). $F_{x\%}$ at the upper bound F_{ABC} estimated by the extended TAC assessment model was 40% (Table 5).

Table 5. Comparison of F_x and $F_{x\%}$ between Two Models

(unit: year -1, g)

Species	F_{MAX}	$F_{50\%}$	$F_{40\%}$	$F_{35\%}$	$F_{30\%}$	$F_{25\%}$	$F_{0.1}$	F_{ABC}	Y/R at F_{ABC}
The Current TACAM for Mackerel	0.69	0.18	0.23	0.26	0.30	0.35	0.17	0.30~ 0.35	84.0~ 88.1
The Current TACAM for Jack mackerel	0.58	0.16	0.21	0.24	0.27	0.31	0.18	0.24~ 0.27	30.4~ 31.7
The Extended TACAM for Multiple Species	0.86	0.27	0.38	0.45	0.53	0.64	0.16	0.27~ 0.38	77.7~ 88.5

Note: TACAM means TAC assessment model.

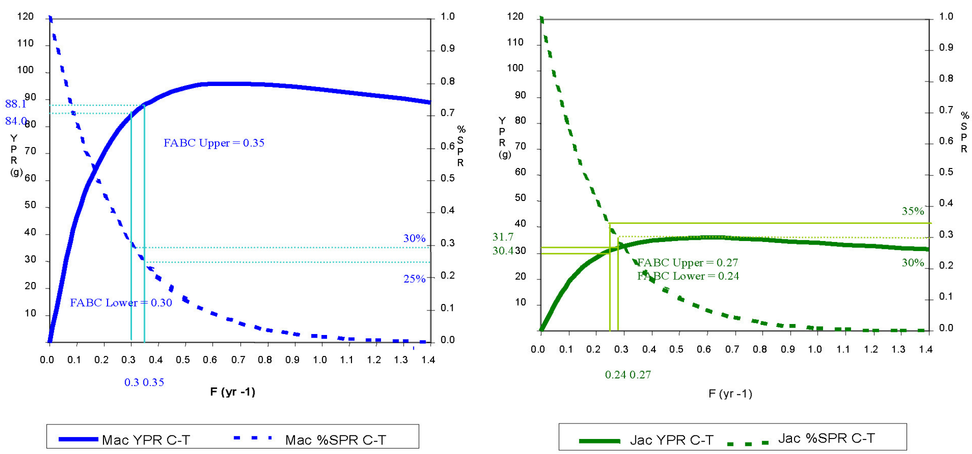
4.3.2 Estimations of Y/R (or YPR) and SSB/R (or SPR)

This paper analyzes how Y/R and SSB/R change from the change in respective F_x and $F_{x\%}$ in the models. This paper estimates an appropriate F_{ABC} through the relationship between Y/R and F_x and between SSB/R and $F_{x\%}$. This paper compares Y/R with SSB/R at F_{ABC} of the two models. F_{ABC} estimated by the current TAC assessment model was 0.30/year~0.35/year (mackerel) and 0.24/year~0.27/year (jack mackerel) respectively. Also, F_{ABC} estimated by the extended TAC assessment model was 0.27/year~0.38/year. At this point, Y/R of individual species by the current TAC assessment model was estimated as 84.0g~88.1g (mackerel) and 30.4g~31.7g (jack mackerel) respectively. Y/R by the extended TAC assessment model was estimated as 77.7g~88.5g. In addition, X% of SSB/R for individual species by the current TAC assessment model was 25%~30% (mackerel) and 30%~35% (jack mackerel) respectively. X% of that by the extended TAC assessment model was 40%~50% (Table 6).

Table 6. Comparison of Y/R and SSB/R between Two Models

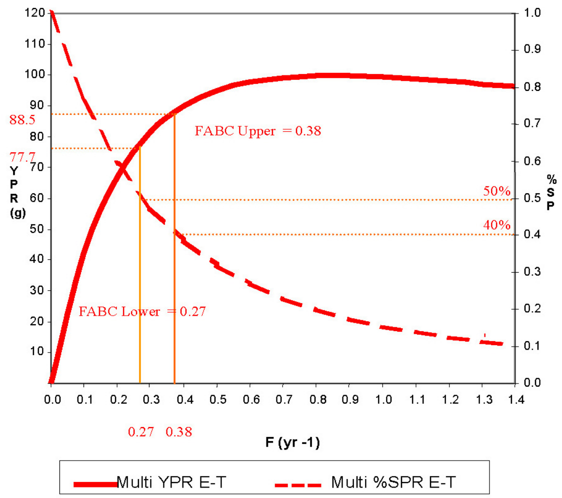
(unit: g, year^{-1})

Species	Y/R at F_{MAX}	Y/R at $F_{50\%}$	Y/R at $F_{40\%}$	Y/R at $F_{35\%}$	Y/R at $F_{30\%}$	Y/R at $F_{25\%}$	Y/R at $F_{20\%}$	FABC (year^{-1})	Y/R at F_{ABC}
Current TACAM for Mackerel	96.10	65.18	75.76	79.73	84.00	88.09	90.90	0.30~ 0.35	84.0~ 88.1
Current TACAM for Jack Mackerel	35.91	24.32	28.17	30.41	31.71	33.07	34.27	0.24~ 0.27	30.4~ 31.7
TACAM for Multiple species	99.76	77.71	88.53	92.76	95.95	98.43	99.69	0.27~ 0.38	77.7~ 88.5



Note: Mac YPR C-T (g): Mackerel's Yield per Recruit: Current Korean TACAM
Jac YPR C-T (g): Jack Mackerel's Yield per Recruit: Current Korean TACAM
Mac %SPR C-T (%): Mackerel's % Spawning Stock Biomass per Recruit: Current Korean TACAM
Jac %SPR C-T (%): Jack Mackerel's % Spawning Stock Biomass per Recruit: Current Korean TACAM

Figure 4. The Current Korean TACAM for Mackerel and Jack Mackerel



Note: Multi YPR E-T(g): Mackerel and Jack Mackerel's Yield per Recruit: Extended TACAM

Multi %SPR E-T (%): Mackerel and Jack Mackerel's % Spawning Stock Biomass per Recruit: Extended TACAM

Figure 5. Extended TACAM for Mackerel and Jack Mackerel

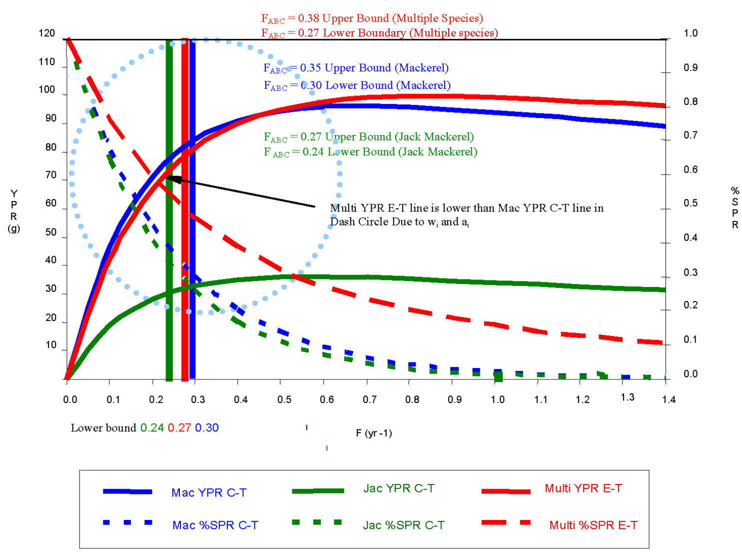


Figure 6. Comparison of YPR(or SSB/R) and % SPR between Two Models

Before explaining these results in detail, this paper needs to mention about an upper bound of F_{ABC} for multiple species estimated by the extended TAC assessment model. The upper bound of F_{ABC} for multiple species is meaningless, because the relative bycatch index (w_i) and the relative instantaneous fishing mortality index (a_i) of mackerel with comparatively abundant stock and the lower bycatch rate cause a positive effect to the extended Beverton-Holt single gear and multiple species yield per recruit model. In other words, yield per recruit of mackerel obtained by added w_i and a_i of mackerel is much greater than that of jack mackerel obtained by them of jack mackerel. As a result, the upper bound of F_{ABC} for multiple species can be overestimated. Therefore, in the extended TAC assessment model designed to protect small bycatch species like jack mackerel, the upper bound of F_{ABC} for multiple species does not have significant meaning. For this reason, this study only focuses on the lower bound of F_{ABC} for multiple species.

In the case of mackerel, the lower bound F_{ABC} level (0.27: red bar) of TAC for multiple species was lower than that (0.30: blue bar) of mackerel estimated by the current Korean TAC assessment model. The reason for this is that added w_i and a_i decrease the yield per recruit in the extended Beverton-Holt model. As shown in Fig. 6, red Multi YPR E-T curve for multiple species is lower than blue Mac YPR C-T curve for each mackerel within a dash-circle, meaning a valid annual fishing rate range.

To protect jack mackerel's stock, the large purse seine fleet should less catch mackerel. If F_{ABC} is set up at 0.3 level due to bycatch, jack mackerel's stock can fall. Especially, basing on the lower bound F_{ABC} level (0.24: green bar) and the lower level (30,41g) of current yield per recruit of jack mackerel, jack mackerel stock may be depleted. Therefore, if F_{ABC} of mackerel is reduced as the lower bound level (0.27) in the multiple species model, the associated bycatch reduction would be expected to improve the jack mackerel stock.

In addition, this result suggests that jack mackerel be caught at the lower bound F_{ABC} level (0.24). The reason for this is that the extended TAC model just is an auxiliary and precautionary means of the current Korean TAC assessment model for protecting bycatch species with small stock. So, the lower bound (0.24) of jack mackerel estimated by the current TAC assessment model should be maintained as a conservation measure. As shown in above, to prevent the depletion of small stock species, F_{ABC} (0.3 level) of the mackerel targeted by the large purse seine fleet can be overestimated. Therefore, in an aspect of small stock's conservation, the lower bound F_{ABC} level (0.27) of TAC for multiple species should be considered when the TAC of each species is set up.

4.3.3 ABC Estimation

The recent average catch rate of mackerel and jack mackerel caught by the large purse seine fleet is 87% and 72% respectively. ABC of each species caught by the fleet was estimated by multiplying the recent average catch rate (2000~2003) to the single species ABC (Table 7).

Table 7. Comparison of ABC between Two Models

Species	Mackerel by the current Korean TACAM		Jack Mackerel by the current Korean TACAM		Mackerel of TACAM for Multiple Species	
	Total Catch (100%)	Large Purse Seine (87%)	Total Catch (100%)	Large Purse Seine (72%)	Total Catch (100%)	Large Purse Seine (87%)
$F_{critical}$	F25%, F30%		F30%, F35%		F40%, F50%	
ABC (ton)	147,348 ~191,706	128,192 ~166,784	7,712 ~9,884	5,552 ~7,116	134,350 ~205,488	116,884 ~178,774
F_{ABC} ($year^{-1}$)	0.30~0.35		0.24~0.27		0.27~0.38	

ABC levels of mackerel and jack mackerel that can be caught by the large purse seine fleet in 2005 estimated by the current Korean TAC assessment model were 128,192ton~166,784ton and 5,552ton~7,116ton respectively. ABC level of mackerel that can be caught by the large purse seine fleet in 2005 estimated by the extended TAC assessment model was 116,884ton~178,774ton. Appropriate ABC of mackerel that can be caught by the large purse seine fleet based on the lower bound F_{ABC} (0.27) of multiple species is less than that of mackerel estimated by the current Korean TAC assessment model. This result fundamentally corresponds to the theoretical approaches mentioned to section 2.

5. Conclusion

This paper provided a type of TAC assessment model for multiple species and single fishing gear. To overcome several limitations with the current Korean TAC assessment model, this paper suggested theoretical approaches with related to technical interactions among multiple species. To examine whether or not the current TAC level of mackerel and jack mackerel in TAC target species is appropriate, the extended TAC assessment model for multiple species and single fishing gear used the extended Beverton-Holt yield-per-recruit model based on biological parameters of NFRDI (2004). As a result, this paper estimates that the current TAC level of mackerel has been somewhat overestimated and suggests that the mackerel TAC level needs to be lowered to prevent overfishing of the small stock of jack mackerel due to the bycatch rate.

The extended TAC assessment model for multiple species and single fishing gear compensates or backs up ABC estimation by species of single fishing gear by computing ABC of multiple species. For example, the average fishing mortality among multiple species due to bycatch can partially reduce a bias of fishing mortality that single species and single fishing gear assessment does not detect. Thus, the extended TAC assessment model can be adopted as an auxiliary and precautionary means for overcoming limitations of the current TAC assessment model as well as for supporting rational operation of the Korean TAC system. Conversely, this implies that the extended TAC assessment model has a limit of estimating each ABC by species, because it does not provide an appropriate fishing mortality rate (F_{ABC}) for individual species. It just offers a certain fishing mortality combined by the multiple fishing gears, considering bycatch inflicted by fishing gears. Henceforth, when adding multiple species with high commercial value in the Korean TAC system, the Korean government needs to allocate optimal volume of target species by fishing gear, considering technical interactions such as bycatch rate as well as biological interactions such as the predator- prey relationship.

In conclusion, the results obtained by this case study accord with a prior expectation in the sense that target TACs are lower when bycatch is taken into account. Conversely, in view of the modest difference in TACs between the current TAC assessment model versus alternative extended model, it could be argued that these differences are well within the precision of model capabilities and that the gains from the added complexity are not worth the cost. While this rationale is comforting, should be tested under a range of input scenarios to determine how robust the robustness of results.

The use of F_{ABC} based on round weight of fish harvested may be questioned as a policy target for several reasons. First, F_{ABC} does not adequately consider the costs of harvest. As F goes to F_{MSY}, the marginal cost of additional harvests explodes toward infinity. The harvests of the marginal entrant are subsidized by reduced yields of existing fishermen. Secondly, along the sustainable Beverton-Holt yield curve, percentage change in total yields is equal to percentage change in numbers of fish caught times percentage change in mean weight per fish harvested ($\%\Delta Y = \%\Delta N \times \%\Delta MW$). At maximum yield per recruit, $\%\Delta N$ and $\%\Delta MW$ are equal in absolute magnitude but of opposite sign. However, in the study fishery, price per gram increases with fish size so that maximum revenue per recruit occurs at an F lower than F_{MAX} of yield per recruit (Gates, 1974). It is arguable that maximum revenue per recruit is the point at which overfishing begins, rather than F_{MAX} of yield per recruit. More investigations of this economic discussion are needed. Thirdly, the importance of revenue considerations for profitability as producers' surplus is obvious. However, the fish size-price premia imply significant gains in consumers' surplus with F value lower than the usual F_{ABC}.

Finally, this paper hopes that the extended TAC assessment model will be corresponded to suggestions of Conroy (1993) and Box (1979) cited below. *"All model results, regardless of how well the model has been constructed, should be viewed as indicative rather than as fact". "All models are wrong, but some are useful! Models are best used to compare alternative policies. Certainty is not given to us; Even a virgin fishery can collapse due to exogenous events, so how much precaution is enough?".*

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