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Use of simple bioeconomic models to estimate optimal effort levels in the Korean coastal flounder fisheries

Dong-Ryul Chae and Sean Pascoe[a]

Centre for the Economics and Management of Aquatic Resources (CEMARE), University of Portsmouth, Boathouse No 6, College Road, HM Naval Base, Portsmouth, PO1 3LJ, UK

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Abstract – The Korean fishing industry is currently subject to overexploited resources arising from excessive levels of fishing effort. Measures to reduce effort in the industry have been instigated. However, for the mixed gear, multi-species inshore fleet, determining the appropriate level of effort is problematic. This is made more difficult through limited catch and effort data. In this paper, a simple surplus production bioeconomic model for the flounder fishery is developed based on different effort standardisation approaches to estimate the optimal level of effort in the fishery. The model is based on a subset of catch and effort data, and implications of this for the assessment of global effort levels are considered. The results indicate that even with poor information, relatively robust estimates of necessary reductions in fishing effort can be derived.

Key words: Bioeconomic modelling / Flounders / Korean fisheries

Résumé – Utilisation de modèles bio-économiques simples pour estimer les niveaux d'effort optimaux dans les pêcheries côtières coréennes de plies. La pêche industrielle coréenne est actuellement confrontée à une surexploitation des ressources, due à des niveaux excessifs de l'effort de pêche. Des mesures ont été prises pour réduire cet effort de pêche. Cependant, il est problématique de déterminer le niveau approprié de l'effort pour la flottille côtière qui utilise plusieurs engins de pêche et cible plusieurs espèces. Il est encore plus difficile de limiter les captures et l'effort de pêche. Dans cette étude, un modèle bio-économique simple de surplus de production est appliqué à la pêcherie de plies. Il est développé à partir de différentes méthodes de standardisation de l'effort pour estimer le niveau optimal de l'effort dans cette pêcherie. Le modèle utilise un jeu limité de données de capture et d'effort, et les conséquences de cette approche, sur l'évaluation du niveau d'effort total, sont estimées. Les résultats indiquent que, même avec une information réduite, des estimations relativement robustes des réductions nécessaires de l'effort de pêche peuvent être obtenues.

1 Introduction

The Republic of Korea (South Korea) is a peninsula located in the northeast part of the Pacific Rim. Since the Korean government was established in 1948, Korean fishery leaders have developed many regulatory methods to manage fishery resources. These include controlling fishing time and area, restricting fishing gear and technology, limiting the number of fishing boats and various types of fishing licenses to protect the fishery resource. However, over-exploitation has still developed and is the most serious problem currently facing Korean fisheries.

A structural adjustment programme was implemented in 1990 with the aim of reducing total fishing effort. The programme was enhanced in 1999 to assist fishers affected by recent international fishery treaties with both Japan and China, as well as to promote fisheries in general. A total of 668 vessels were removed in 1999 as a result of the Korean-Japan Fishery Agreement, and a further 167 in 2000 (Korean Overseas Information Service 2003).

The enhanced programme was aimed mainly at the offshore fleet, which declined substantially as a result. In contrast, the number of inshore vessels has increased by roughly 17% over the period 1997-2002 (Ministry of Maritime Affairs and Fisheries 2004). These vessels operate using a range of fishing gears and catch a wide variety of species[1]. Information on the inshore vessels is limited. While catch is recorded, the level of effort expended by each gear type is not uniformly collected. Further, catch information is not available on an individual boat basis.

Developing a bioeconomic model for such a mixed fishery with relatively poor data requires many assumptions to be

[a] Corresponding author: sean.pascoe@port.ac.uk

[1] Coastal gillnets catch up to 45 different species while Danish seiners catch almost 60 different commercial fish species as well as a number of shellfish and crustaceans.

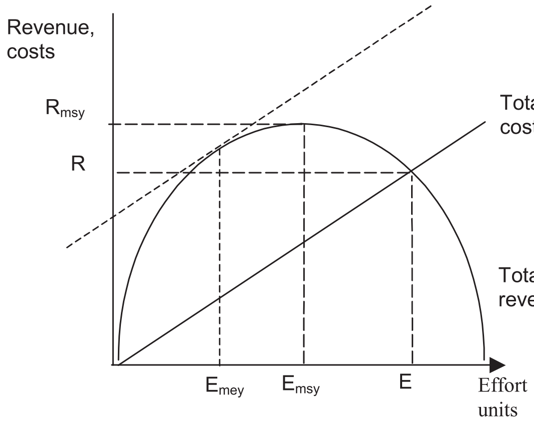

Fig. 1. Key bioeconomic reference points for single species fishery.

made. In this study, a surplus production model was estimated for the flounder fishery. Flounder is a key species (in terms of value) for all coastal gear types, and used as the basis for deriving the level of fishing effort that corresponds to maximum sustainable yield (msy) and maximum economic yield (mey).

2 Methodology

2.1 Theoretical basis

If the fishery is overexploited, then reducing fishing effort will result, in the longer term, in an increase in the stock and also higher yields. Two well established long run reference points are the effort level associated with maximum sustainable yield (E_{msy}) and the effort size associated with maximum economic yield (E_{mey}) (Fig. 1). Ideally, any capacity reduction programme should aim to reduce the effort level to bring the fishery closer to one of these measures[2].

In the case of mixed fisheries, several species are caught simultaneously. Consequently, the optimal level of effort, and thereby fishing capacity, depends on the combined catches. Three species are caught simultaneously (Fig. 2a). However, as they have different biological characteristics, the catch composition varies depending on the level of effort. Species 1 is the dominant species at all levels of effort. At high levels of effort, the catch may consist only of species 1 and 3, as species 2 is fished to extinction. Conversely, at low levels of effort, the contribution of the three species to the total revenue is relatively equal. The profit maximising level of fishing effort at the individual species level is given by points B, C and D, while the overall profit maximising level of fishing effort is given by point A. Again, these are the levels of effort with the marginal cost (the slope of the cost curve) is equal to the marginal revenue (the slope of the revenue curves).

The situation is again illustrated (Fig. 2b), where species 3 dominates the catch at medium levels of effort, while species 1 dominates the catch at high levels of effort. Again, the profit maximising level of catch at the individual species level is B, C and D, while the profit maximising level of effort for the fishery as a whole is given by point A.

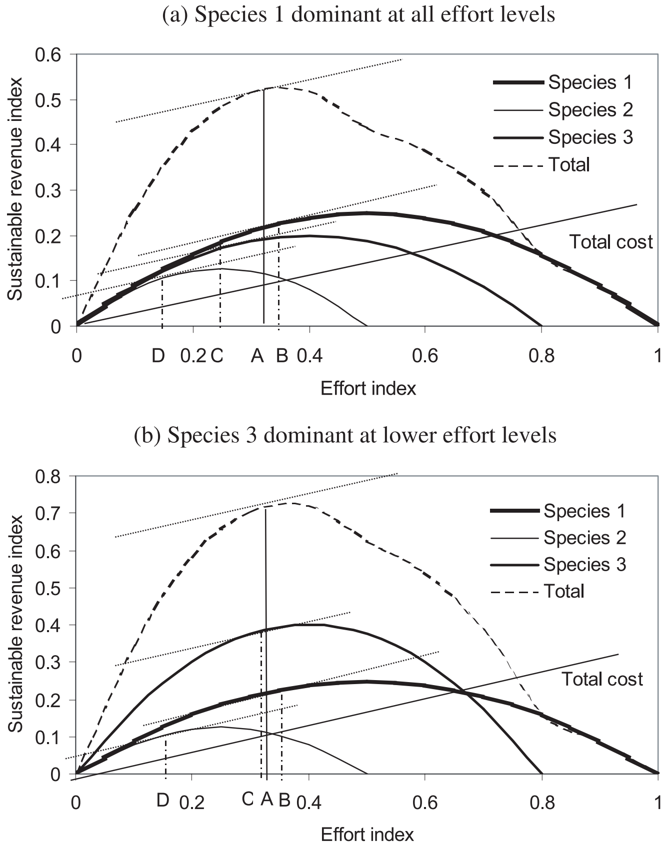

Fig. 2. Examples of multi-species optimal effort levels.

Some common features may be observed (Figs. 2a,b). Firstly, the profit maximising level of effort for the fishery as a whole is greater than that required to maximise profits for some individual species and less than that for other species. Second, the profit maximising level of fishing effort in the multispecies fishery is close to the maximum sustainable revenue for the fishery as a whole. Finally, and more significant for the purposes of this study, the optimal level of fishing effort is relatively close to that of the economically optimal level for the dominant species. Given this, an approximation of the optimal level of fishing effort can be derived from the analysis of the dominant species alone.

This feature can be demonstrated mathematically. The parabolic revenue function for each species s illustrated in Fig. 2 can be expressed as $R_s = a_sE - b_sE^2$, where R_s is the revenue obtained from landing species s, E is the level of fishing effort expended in the fishery and a_s and b_s are coefficients representing the combined effects of price, growth, recruitment and natural mortality. The cost of fishing can be represented by $C = cE$, where C is the total cost of fishing while c is the marginal cost of an additional unit of fishing effort (assumed constant for simplicity). The level of rent generated in the fishery is given by $\pi = \sum_s R_s - C$.

The level of effort that produces maximum sustainable revenue (E_{msr}, equivalent to maximum sustainable yield in the

[2] The optimal level of fishing effort will depend largely on the objectives of fisheries management. For example, see Pascoe and Mardle (2001).

Table 1. Main species caught as "flounder" in Korean coastal areas.

English name	Scientific name
Sand flounder/ Longsnout flounder	*Limanda punctatissima*
Willowy flounder	*Tanakius kitaharai*
Korean flounder	*Glyptocephalus stelleri*
Stone flounder	*Kareius bicoloratus*
Pointhead flounder	*Cleisthenes pinetorum herzensteini*
Slime flounder	*Microstomus achne*
Finespotted flounder/ Ridged-eye flounder	*Pleuronichthys cornutus*
Barfin flounder	*Verasper moseri*
Roughscale sole	*Clidoderma asperrimum*
Marbled sole	*Limanda yokohamae*
Roughscale sole	*Clidoderma asperrimum*
Flounder, Brown sole	*Limanda herzensteini*
Shotted halibut	*Eopsetta grigorjewi*
Spotted halibut	*Verasper variegatus*

aggregated revenue function) is given by

$$\frac{\mathrm{d}\sum R}{\mathrm{d}E} = \sum_s a_s - 2\sum_s b_s E = 0 \quad (1)$$

such that

$$E_{\mathrm{msr}} = \frac{\sum_s a_s}{2\sum_s b_s}. \quad (2)$$

As (2) is a ratio of two sets of coefficients, then

$$\hat{E}_{\mathrm{msr}} \begin{matrix}<\\=\\>\end{matrix} E_{\mathrm{msr}} \quad as \quad \frac{a_s}{2b_s} \begin{matrix}<\\=\\>\end{matrix} \frac{\sum_s a_s}{2\sum_s b_s} \quad (3)$$

where $\hat{E}_{\mathrm{msr}} = \frac{a_s}{2b_s}$ is the approximation of E_{msy}. Potentially, $\hat{E}_{\mathrm{msy}}$ could exactly equal E_{msy} if the ratio of the coefficients of the main species was identical to the ratio of the sum of coefficients. In any case, the greater the contribution of the main species coefficients to the combined total, the closer the approximation will become.

Similarly, the level of effort that produces maximum economic yield is obtained when rent is maximised. That is

$$\frac{\mathrm{d}\pi}{\mathrm{d}E} = \sum_s a_s - 2\sum_s b_s E - c = 0 \quad (4)$$

and

$$E_{\mathrm{mey}} = \frac{\sum_s a_s}{2\sum_s b_s} - \frac{c}{2\sum_s b_s}. \quad (5)$$

Again in this case, $\hat{E}_{\mathrm{mey}} \to E_{\mathrm{mey}}$ as $\frac{a_s}{2b_s} \to \frac{\sum_s a_s}{2\sum_s b_s}$ but $\hat{E}_{\mathrm{mey}} < E_{\mathrm{mey}}$ as $\frac{c}{2b_s} > \frac{c}{2\sum_s b_s}$. That is, the approximation will tend to underestimate the level of effort producing MEY, although the extent of this underestimation depends on the overall contribution of the main species to the total revenue and the extent to which $\frac{a_s}{2b_s} \begin{matrix}>\\=\\<\end{matrix} \frac{\sum_s a_s}{2\sum_s b_s}$. The tendency was for the use of the dominant species to result in an overestimate of E_{mey} and E_{msy} (Fig. 2). As with MSY, the greater the contribution of the main species, the closer the approximation to the true optimal level of effort.

In many fisheries, such as the fishery under investigation in this study, the estimation of optimal effort levels is made further difficult by lack of information at the species level. In the case of the flounder fishery, several different species are caught but recorded only as flounder (Table 1). The combined estimated revenue curve is not then the sum of the individual revenue curves, but a smoothed average revenue curve. The shape of this revenue curve will largely depend on the growth assumptions underlying the surplus production function. If a logistic growth model is assumed (e.g. Schaefer 1957), then the resulting average model will be parabolic by construction (Fig. 3a). Given that the cumulative revenue curve is generally skewed to the left, the average yield curve is most likely to result in an overestimate of E_{mey} and E_{msy}. However, if an exponential growth model is assumed for the aggregated surplus production function (e.g. Fox 1970), then the aggregated model may provides a reasonable representation of the cumulative total yield curve (Fig. 3b), even if the underlying growth functions of the individual species within the aggregated functions are logistic by nature.

In this study, the limited data result in both situations occurring. That is, information is only available on the main species caught, and this information consists of aggregated catch information.

2.2 Effort standardisation

A further complication arises in many mixed, inshore fisheries – namely the existence of a variety of gear types targeting the same group of species. The simple models presented above assume that some common measure of fishing effort exists. Several multispecies, multifleet bioeconomic models have been developed that determine total fishing mortality through summation of the partial fishing mortality of the individual fleet segments (e.g. Pascoe and Mardle 2001). However, parameterising such models requires considerably more information than is often available for inshore, artisanal fleets.

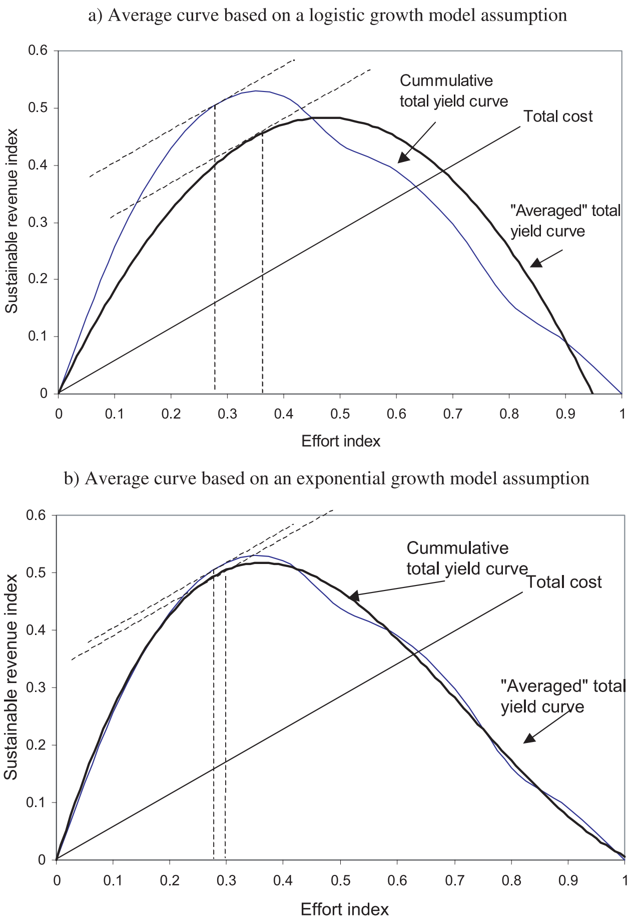

Fig. 3. Comparison of cumulative and average total yield curves.

An alternative approach is to standardise the fishing effort based on one of the fleet segments and derive the model using this effort measure. This can be achieved by dividing the total fishery catch by the catch per unit of effort of the standard fleet segment to derive an equivalent measure of total standard fishing effort. This can be given by $E_T = C_T/(C_s/E_s)$, where E_T is the total standardised effort, C_T is the total catch, C_s is the catch of the reference fleet segment and E_s is the effort of the reference fleet segment. In this case, the estimated total effort is in equivalent units as that of the reference fleet.

The resulting estimate of total effort will be influenced by the choice of reference fleet. Estimation of the models using effort standardised using several fleets and comparison of the results provides information on the robustness of the measures.

The standardisation process effectively assumes that technical change has not improved the efficiency of the vessels, and that a unit of effort at the start of the time series is equivalent to a unit of effort at the end of the data period. This is a fairly unrealistic assumption in most cases, but is necessary in the absence of additional information. With varying changes in technology in different gear types over time, divergences in the standardised effort series may provide some indication of the impact of technical change on effort production.

The standardisation process also assumes that the set of vessels within the reference fleet is relatively consistent from year to year, such that changes in catch rates reflect changes in stock abundance rather than changes in fleet composition. Again, this is potentially an unrealistic assumption and a source of potential bias. However, in the absence of better data such an assumption is necessary.

2.3 Production function estimation

With limited data, the options for developing complex bioeconomic models are relatively limited. One approach that requires minimal data is the use of surplus production models, which require only a time series of catch and effort data. As noted above, this is complicated in the case of multi-gear fisheries, but standardisation of effort based on one gear type allows at least an estimate of the level of overcapacity to be derived.

Two main types of surplus production models exist – those based on the logistic growth function and those based on the exponential growth function. Several methods for estimating the surplus production models from data also exist (e.g. Schaefer 1957 and Schnute 1977 for the logistic growth model and Fox 1970 and Clarke et al. 1992 for the exponential growth model). There are generally no a priori reasons why one functional form would be preferable to another, and the usual approach is to estimate the range of models and assess which best represents the data (Clarke et al. 1992).

In this paper, only the results from the Clarke et al. model (1992) (hereafter referred to as the CYP model) are presented. The other models were also estimated and were found to perform generally poorly. Full details of the other model estimations can be found in Chae (2003). The CYP model assumes an exponential growth function. The functional form of the model is given by

$$\ln\left(\overline{U}_{t+1}\right) = \frac{2r}{2+r}\ln(qk) + \frac{2-r}{2+r}\ln\left(\overline{U}_t\right) - \frac{q}{2+r}\left(\overline{E}_t + \overline{E}_{t+1}\right) \quad (6)$$

where $\overline{U}$ is a average catch per unit effort for a given year, $\overline{E}$ is the total effort expended in year t, r is intrinsic growth rate, q is catchability coefficient (instantaneous rate of fishing mortality per unit of fishing effort, so $q < 1$), and k is carrying capacity of the environment. The equation can be estimated using linear regression techniques, regressing the dependent variable, based on catch per unit of effort, against catch per unit of effort and the level of effort, the function form being given by

$$\ln\left(\overline{U}_{t+1}\right) = \beta_0 + \beta_1 \ln\left(\overline{U}_t\right) + \beta_2\left(\overline{E}_t + \overline{E}_{t+1}\right) \quad (7)$$

where $\beta_0 = \frac{2r}{2+r}\ln(qk)$, $\beta_1 = \frac{2-r}{2+r}$, and $\beta_2 = -\frac{q}{2+r}$. These terms can be re-arranged to solve for the structural parameters r, q and k.

From this, the structural form of the sustainable revenue-effort relationship can be derived, given by

$$R_t = pqkE_t\,e^{-(q/r)E_t} \quad (8)$$

where p is the price of the species, assumed to remain constant. If we assume that the marginal cost per unit of effort is also constant (i.e. each additional unit of effort costs the same), then

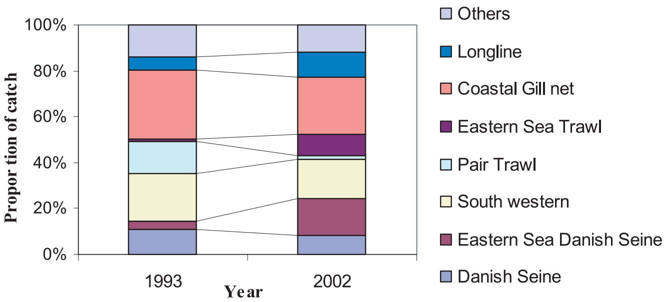

Fig. 4. Contribution of each gear to the total Flounder catch, 1993 and 2002 (source: KOSIS, Korean Statistical Information System).

profits are maximised when the marginal revenue is equal to the marginal cost, such that

$$\frac{\mathrm{d}P}{\mathrm{d}E} = pqk\,\mathrm{e}^{-(q/r)E}\left(1 - \frac{q}{r}E\right) - c = 0. \tag{9}$$

From this, the level of effort that maximises profits can be determined (see Appendix 1).

3 The Korean coastal flounder fisheries

The Korean fishing fleet consists of a range of fishing activities catching a wide variety of species, including 60 fish species, 13 crustacea species, 19 shellfish species, 7 mollusca species, and 6 other aquatic animals. Pelagic species dominate the fish catch, with three species, anchovies, mackerels and hair tail, comprising 65% in the catches in terms of volume, and nearly 50% in terms of value. The remaining 57 fish species each contribute less than 5% to the overall catch (in terms of value and volume), with most species contributing less than 1%. Of these remaining species, flounders are the most important species in terms of value, and are the main species in terms of value of the inshore fleet segment.

The flounder fishery is exploited by a number of different gear types segments, including Danish seine, pair trawl, otter trawl, long lines, coastal gill nets, and others (Fig. 4). The key species exploited in the fishery are listed (Table 1). While several species exist in the catch, they are usually recorded only as single species. Data on the levels of activity of the different gear types varies in quality by area. For example, in the south-western zone, catch is taken by both Danish seiners and pair trawl, but the catch taken by each gear is not separated. Over the period 1993 to 2002, there has been a general shift away from pair trawl to Danish Seine and otter trawl, and an increase also in the use of longline (Fig. 4).

The flounder fisheries are currently managed through a system of input controls. These prohibit fishing activities in certain areas, restrict fishing gears and technologies, and limit the number of boats through a licensing system. However, concern exists that the fleet is overcapitalised, with catches of flounder having trended downwards since the late 1970s. In response, the Korean government has introduced capacity reduction measures aimed at reducing the size of the fleet, particularly the larger sized vessels which are believed to have had a detrimental impact on juveniles and the marine environment since 1994 (Shin 1999).

Catch data for the fisheries are relatively available. MOMAF (The Korean Ministry of Marine Affairs and Fishery) records monthly landings for 38 fishing gears relating to 105 marine fishery species. However, for the Korean flounders fishery, collecting effort data is not straightforward. Data on days fished, produced by NFFC (National Federation of Fisheries Cooperatives), are not recorded for 8 of the gear types participating in the coastal fisheries. For these reasons, it is difficult to decide one gear type for calculating average CPUE and so finding an alternative method is prerequisite to develop a bioeconomic model. Thus, some possible alternatives are contrived in this section; using both the way of standardisation by relatively important gear types and simple sum up of engine power.

4 Results

4.1 Effort standardisation

The modelling framework adopted in this study requires a single measure of fishing effort. As noted above, a simple approach is to standardise fishing effort based on the catch per unit of effort of a reference fleet. In this study, three separate reference fleets were considered: Danish Seine vessels, South-western zone vessels (combination of Danish seine and pair trawl), and coastal gill net vessels. A further standardisation was made using the total engine power of the eight main fleet segments, implicitly assuming that the catch per unit engine power was relatively homogeneous across the different gear types.

The Danish Seine and South-western vessels were selected not only because these two occupy relatively high positions in terms of total catches, but also because effort data (fishing days a year) were available. These were based on a sample of vessels rather than the whole fleet, but provided a reliable estimate of average catch per day fished for these vessels. For the gill net vessels, only total vessel numbers were available. These boats fish on average 180 days a year, and this was applied to derive a total effort measure for the fleet segments (and consequently a measure of catch per unit of effort). However, this may introduce bias into the analysis if the true average varied from year to year. Previous research reports published by the Korean government have assumed days fished ranged between 150 to 200 days a year when calculating compensation payments for fishery damages (Chang et al. 2002).

An alternative to the estimation of effort based on days fished of a reference fleet was to use the total engine power of the fishing fleet used in catching flounders. Information was available on engine power of eight fleet segments, including Pair Trawl, Danish Seine, South-western, East Sea Trawl, Coastal Gill-nets, Offshore Long-line, Coastal Long-line, and Set-net vessels. These vessels were responsible for more than 80% of the total flounder catches in Korea over the period examined.

The resulting standardised effort levels were converted into and index with 1988 as the base year (Fig. 5). Effort levels standardised using the Danish Seine and South-western vessels as the reference fleets were relatively stable over the period examined (1998 to 2001). From this, it is could be inferred

Table 2. Regression results standardised by Danish Seine (DS), South western (SW), Coastal Gillnets (CG), and by total engine power of 8 main fishing gears (TH).

	DS	DS-#	SW	CG	TH
Adjusted R^2	0.599	0.855	0.257	0.913	0.865
Durban-Watson test	0.600	1.129	1.283	2.194	1.769
F-statistics	9.946**		3.073	63.633**	39.486**
t-statistics (Constant)	5.595**	11.205**	1.458	2.926*	−2.239*
t-statistics (U)	−2.236*	−6.189**	0.341	0.741	2.247*
t-statistics (E)	−4.304**	−8.108**	−0.886	−3.462**	−2.013
r	9.77	623.20	1.40	9.77	0.65
q	0.22	13.73	0.03	0.22	0.16×10^{-5}
k	4616	74	30 543	4616	58 727

* Significant at 5% level; ** significant at 1% level.

\# A Cochrane-Orcutt procedure was used to correct for first order autocorrelation for the model.

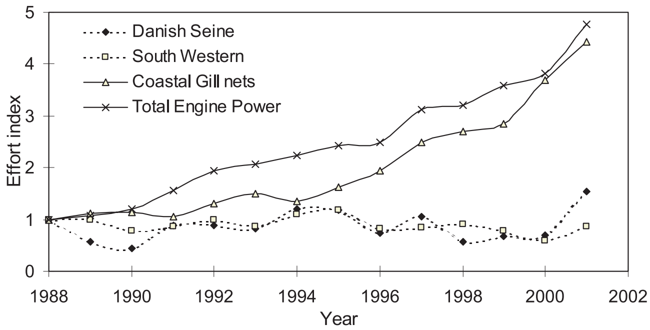

Fig. 5. Index of standardised fishing effort using different reference fleets and effort measures.

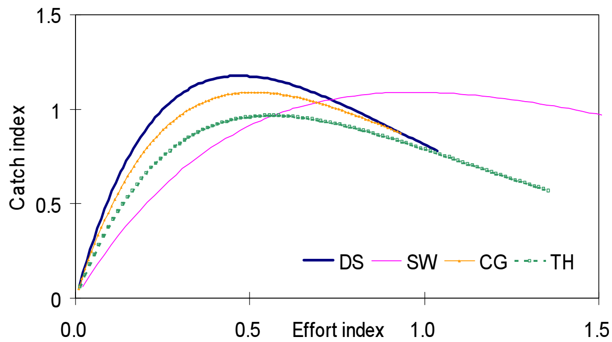

Fig. 6. Derived catch – effort relationships from the different models. Each relationship has been derived using different effort standardisation – DG: Danish Seiners; SW: South-western; CG: Coastal Gillnet; TH: total engine power. The bases of the catch and effort indexes are the levels in 2001.

that the effort control plan, adopted in 1994, has been effective in controlling the fishing effort in the fishery as a whole. In contrast, the effort level standardised using Coastal Gill nets vessels as the reference fleet and total engine power increased gradually over the period examined. This suggests that effective effort has tended to increase despite the capacity reduction programmes in place. While the number of days fished has not appeared to have increased, the total engine power employed has increased substantially. The gill net fleet segment would not benefit from increased engine power the same as the more mobile gears (e.g. Danish seiners, otter trawlers and pair trawlers). As a result, this fleet segments has been experiencing decreasing catch per day fished relative to the mobile gear vessels, which have incorporated larger engines to offset the reduces stock availability in order to main catch rates.

4.2 Surplus production models

Four separate surplus production models were estimated using the functional form in Eq. (6), one each for the different fishing effort series derived above. From the model results (Table 2), the parameters were jointly significant in all models except that using the south-western vessels as the means of standardising vessels. As the parameter values *per se* are not meaningful (as they are parameters of a functional form rather than structural model), only the *t*-statistics are reported. However, the derived *r*, *q* and *k* parameters are reported. Autocorrelation was found to be a problem for the model using the Danish seine effort data, so was re-estimated using the Cochrane-Orcutt procedure. With the exception of the model based on the south-western vessels, the models generally had high adjusted-R^2 terms, indicating that the models have good explanatory power. However, as each model had a different dependent variable (as the effort measure was different in each case), it is not possible to use the adjusted-R^2 to determine the most appropriate model.

The derived structural parameters provide some insight into the estimated characteristics of the stock. The models based on the Danish seine and coastal gillnet effort both suggest that the stock is very fast growing (high *r*) with a small carrying capacity (low *k*). In contrast, the model based on the engine power effort series suggests a slow growing stock (low *r*) and a high carrying capacity (high *k*). The latter model is more likely to be the most appropriate as the growth rates in the other models are unrealistically high.

Despite the substantial differences in the estimated growth and unexploited biomass, the derived relationship between yield and effort for the models is generally similar (Fig. 6), again with the exception of the model based on the south-western vessels. Both catch and effort have been normalised with 1 representing the 2001 level of effort (and associated sustainable yield).

Table 3. Bioeconomic reference points derived from the different models using different standardised effort (DS-#Danish Seine corrected using the Cochrane Orcutt procedure; CG Coastal Gillnets; TH total engine power of 8 main fishing gears).

	DS-#	CG	TH	Average
Sustainable yield				
MSY	17 055	15 793	13 983	15 610
MEY	15 477	14 764	12 827	14 356
OAY	15 015	12 745	11 992	13 251
Associated effort level				
E_{msy}	45.38	1098	4 151 104	-
E_{mey}	28.21	743	2 656 196	-
E_{oay}	72.3	1981	6 895 760	-
Relative to 2001				
E_{msy}	0.471	0.512	0.563	0.515
E_{mey}	0.293	0.346	0.360	0.333
E_{oay}	0.751	0.924	0.935	0.870

4.3 Bioeconomic reference points

As seen in Eqs. (8) and (9), price and cost information are essential factors in bioeconomic analyses. The average price was calculated by dividing the total value of flounder catches by the total quantity. Fishing costs collected from a sample survey[3] for five main fleet segments (Danish Seine, South western, East Sea Danish Seine, East Sea Trawl, and Offshore Long Line) were used. Estimates of cost per unit of effort for each effort measure were based on an estimate of the total costs for the fishery as a whole extrapolated from the survey data dived by the imputed total standardised effort.

The key bioeconomic reference points considered were the maximum sustainable yield, maximum economic yield, the open access equilibrium yield and their associated effort levels. Details on the derivation of these measures are given (Appendix 1). The open access equilibrium yield and effort level provide an indication of the maximum effort that the fishery can sustain economically, although all economic rents at this point have been fully dissipated. An estimate was not made using the south-western standardised effort data due to the poor performance of the regression model.

Despite the difference in effort trends using the different standardisation approaches, and the resulting differences in derived parameter values from the regression models, the bioeconomic reference points were relatively similar for each model (Table 3). The associated effort levels cannot be directly compared (as they are in different units), but the reference effort levels relative to the 2001 effort level were also relative similar. This suggests the results are reasonably robust despite the data difficulties.

5 Discussion and conclusion

Determining the optimal long run level of fishing effort is problematic in the absence of detailed information. In this paper, we have demonstrated that estimates of optimal effort levels can be derived from very limited and incomplete data. The results of the different analysis also suggest that such measures may be reasonably robust despite the poor and, in this case, conflicting information on effort trends over time.

The measures developed in this paper, however, are only approximations, as the true measures would require information on the catches of all species. However, we have demonstrated that where one species dominates a fishery, then the economically optimal level of effort relating to this species is relatively close to that for the fishery as a whole. This is sufficient to determine the relative extent of excess effort (e.g. little or lot), and an approximation of the degree to which effort may need to be reduced in order to achieve the maximum rents.

The catch data that were available were aggregated to produce a "multispecies" surplus production model. The substantially better fit of the CYP model, based on an exponential growth function, may be an artefact of the use of aggregated data. As illustrated in Fig. 3b, such a model is likely to be a better approximation of the summed revenue curves than a logistic model. Ralston and Polivina (1982) suggest that aggregating species into a single surplus production model may, in fact, result in more robust estimates of optimal yields and effort levels than considering each species individually.

The results of the analysis suggest that, in the Korean flounder fishery, the effort level in 2001 is generally in excess of the open access equilibrium level. However, this is based on a sub-set of the entire catch, while the actual revenue will include the catches of several other species for which information were not available. As a result, the estimated open access equilibrium level of effort for a single species (or subset of species) in a multispecies fishery will be less than that of the fishery as a whole. Consequently, no conclusions can be drawn regarding the economic sustainability of the fishery at the existing levels of fishing effort.

However, even if the current level of effort is sustainable, at this point the fishery has substantial excess levels of fishing effort as greater yields and levels of economic rent could be achieved with lower levels of fishing effort. To achieve the maximum level of economic rent in the fishery, effort will need to be reduced by more than 60%. The actual magnitude of this rent cannot be estimated, as it will also include revenues associated with the other species.

The continuing existence of excess levels of fishing effort in the fishery indicates that the existing fleet reduction plan has not been effective in terms of reducing overcapacity in the fishery. Further, the growth in total engine power over time despite

[3] These data were collected and provided by NFFC.

the reduction in boat numbers suggests that effort is expanding rather than contracting in the fishery. For example, although the number of vessels in the Danish seine fishery was reduced by 38% between 1988 and 2001 (from 91 to 56%), average engine power increased by 44% (from 297 to 429) during the same period.

In order to reduce effort and rebuild the overfished stocks, it is necessary to further slim down the fleet operating in the flounder fishery. By reducing the number of fishing vessels, it is possible to increase long-term economic benefits from the Korean flounder fishery resources, and also to promote the development of robust and environmentally sound fishing grounds.

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Appendix 1. Bioeconomic reference points from the exponential growth model

The CYP model used in this study is based on the assumption of exponential growth model and is based on the Gompertz growth function, given by

$$G(B_t) = rB_t \ln(k/B_t). \quad \text{(A.1)}$$

Where r and k are the instantaneous growth rate and carrying capacity as described previously in Sect. 2.3. In equilibrium, the catch is equal to the growth rate, given by

$$C_e = rB \ln(k/B) \quad \text{(A.2)}$$

where C_e is catch at equilibrium. Assuming that catch per unit of effort is proportion to the biomass, Eq. (A.2) can be re-specified as

$$C_e = \frac{r\overline{U}}{q}\left[\ln\left(\frac{U_\infty}{q}\right) - \ln\left(\frac{\overline{U}}{q}\right)\right] \quad \text{(A.3)}$$

where U_∞ is the catch per unit of effort that would occur if the stock was at an unexploited level ($U_\infty = qk$) and $\overline{U}$ is the mean catch per unit of effort. Expanding out the right hand side results in the cancellation of the ln(q) terms so that Eq. (A.3) can be simplified as

$$C_e = \frac{r}{q}\left[\ln U_\infty - \ln \overline{U}\right]. \quad \text{(A.4)}$$

Dividing Eq. (A.4) through by $\overline{U}$ results in

$$E = \frac{r}{q}\left[\ln U_\infty - \ln \overline{U}\right] \quad \text{(A.5)}$$

where E is the level of effort expended in the fishery. This can be rearranged to produce

$$\ln \overline{U} = \ln U_\infty - (q/r)E. \quad \text{(A.6)}$$

Exponentiating Eq. (A.6), the mean catch per unit effort in this model can be expressed as

$$\overline{U} = U_\infty \exp[-(q/r)E] \quad \text{(A.7)}$$

and hence catch can be expressed as

$$C = U_\infty E \exp[-(q/r)E] \quad \text{(A.8)}$$

or

$$C = qkE \exp[-(q/r)E]. \quad \text{(A.9)}$$

The values of r, q and k can be derived from catch and effort data using the functional forms of the model proposed by Fox (1970) and Clarke et al. (1992) (the CYP model). In this study, the CYP model was found to be the most appropriate functional form for deriving the parameters of the above structural model (see Sect. 4.2 and Chae 2003).

Given the values of r, q and k, the level of effort that maximises catch in the exponential model is given by the first order condition

$$\frac{dC}{dE} = qk \exp(-(q/r)E)(1 - (q/r)E) = 0. \quad \text{(A.10)}$$

Dividing both sides by $qke^{-(q/r)E}$ and solving the resulting equation for E gives

$$E_{msy} = r/q. \quad \text{(A.11)}$$

The maximum sustainable yield itself can be found by substituting Eq. (A.11) back into Eq. (A.9). i.e. $C_{msy} = qkE_{msy} \exp[-(q/r)E_{msy}]$.

Total revenue (TR) can be expressed as a function of fishing effort by multiplying Eq. (A.9) by price, p

$$TR = pqkE \exp[-(q/r)E]. \quad \text{(A.12)}$$

For simplicity, it is assumed that the price does not vary with the level of catch. Also, a constant marginal cost of effort is assumed, and total cost is again derived as a function of effort (i.e. $C = c\,E$, where c is the marginal cost of an additional unit of effort). Total profits in the fishery is given by subtracting total costs from revenue, such that

$$\pi = p\,q\,k\,E\,e^{-(q/r)E} - cE. \quad \text{(A.13)}$$

From this, the level of effort that produces the maximum economic yield, E_{mey}, can be found using the first order condition for profit maximization

$$\frac{d\pi}{dE} = pqk \exp(-(q/r)E)(1 - (q/r)E) - c = 0 \quad \text{(A.14)}$$

E_{mey} cannot easily be expressed as a function of the model parameters due to the exponential function. At best, the relation can be expressed as

$$E_{mey} = \frac{r}{q}\left[1 - \frac{c}{pqk}\exp\left(-(q/r)E_{mey}\right)\right]. \quad \text{(A.15)}$$

This can be solved iteratively, or using solver functions in spreadsheets. Once the value of E_{mey} has been estimated, the maximum economic yield itself can be derived by $C_{mey} = qkE_{mey} \exp[-(q/r)E_{mey}]$.

The effort level under the open access equilibrium can be expressed as

$$E_{oae} = \frac{r}{q}\left[\ln(pqk) - \ln(c)\right] (A.16) \quad \text{(A.16)}$$

while the open access equilibrium level of catch is given by $C_{oae} = qkE_{oae} \exp[-(q/r)E_{oae}]$.

References

Chae D., 2003, A study of Problems and Improvement Plans for Applying Bioeconomic modelling to Korean Coastal Fisheries: Focused on the case of Flounders Industry, Master's dissertation, University of Portsmouth.

Chang H., Lee S., Mok J., Roh Y., 2002, Study on establishing standard criterion for investigating damages in fishery rights related with harbour construction, Korean Maritime Institute, South Korea.

Clarke R.P., Yoshimoto S.S., Pooley S.G., 1992, A bioeconomic analysis of the North-western Hawaiian Islands lobster fishery. Mar. Resour. Econ. 7, 115-140.

Fox W.J. Jr., 1970, An exponential surplus yield model for optimizing exploited fish populations. Trans. Am. Fish. Soc. 99, 80-88.

Korean Overseas Information Service, 2003, Industrial Development: Fisheries [available from http://www.korea.net/economy/overview/industrialdeve_rel_4.asp].

Ministry of Maritime Affairs and Fisheries, 2004, Fisheries Statistics, 2004 [available from http://www.momaf.go.kr/eng/ship/stat/d_stat_list.asp?sort=2].

Pascoe S., Mardle S., 2001, Optimal fleet size in the English Channel: a multi-objective programming approach. Eur. Rev. Agric. Econ. 28, 161-183.

Ralston S., Polivina J.J., 1982, A multispecies analysis of the commercial deep-sea hand line fishery in Hawaii. Fish. Bull. 80, 435-448.

Schaefer M.B., 1957, A study of the dynamics of the fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Comm. 2, 247-285.

Schnute J., 1977, Improved estimates from the Schaefer production model: Theoretical considerations. J. Fish. Res. Board Can. 34, 583-603.

Shin Y., 1999, The Definition, Problems, and Policy Direction of Structure reform in Korean Coastal and Offshore Fisheries, Korean J. Fish. Bus. Adm. 31, 39-53.