A SIMULATION METHOD FOR PREDICTING FUTURE POPULATION DYNAMICS WITH UNCERTAINTY

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ABSTRACT

Unfortunately, most of the stocks are damaged by natural disasters or human activities and rebuilding the stock are urgent requirements. Until now, in the stock management, some policies are commonly believed to valid but have not been confirmed. A simulation model of the population dynamics incorporating uncertainty has been already made by the authors. The typical believes of the stock management, "Ban rebuild stocks", "Large mesh rebuild stocks" were confirmed by the simulation model. Six stocks were randomly chosen mainly from the data of ICES for applying this simulation model. For applying the management policy of 1 year ban, 5 to 6 stocks had not significant effect compare with no regulation after around 5 years of the opening of the fishery. For 3 of 6 stocks, the effect of the enlarged the mesh size was not detected. In conclusion, the widely believed policies were valid for only a part of stocks. Thus the effects of the management policies should be confirmed before conducting and applying to stocks.

Keywords: ban, fishing regulations, population dynamics model, stochastic model

INTRODUCTION

There are some common beliefs which are widely believed among many scientists and managers in stock management. The typical beliefs were such as "ban or closing fishery rebuilds stocks", "large mesh rebuilds stocks", "conservation limits yield", "high fishing efforts make stocks collapse", and so on. However these beliefs are not always confirmed for each specific stock before conducting management, and sometimes stock managers proceed the stock management using the unconfirmed beliefs. Recently large part of the stocks has been damaged by natural disasters or human activities. To manage and rebuild these stocks have been widely required with careful consideration. For the management options, these beliefs have been often proposed without predicting its effects.

Fish population dynamics include wide range of uncertainties and the uncertainties should be incorporated in considering stock management. Before conducting management, predictions of the population dynamics under the various management options are essential procedure. For this purpose, the authors have already developed a prediction model or a fishery operation simulation model. The model was an age based population dynamics model incorporating large range of uncertainties in recruitment and gear selectivity. The effects of the management strategies can be confirmed or examined with this model.

In this study, two typical beliefs were applied to 6 randomly chosen stocks for confirming, in general, whether the beliefs lead sound managements or not by using the simulation model that has been already developed by the authors. The 2 chosen beliefs in this study were Belief 1: “Ban rebuilds stocks”, and Belief 2: “Large mesh rebuilds stocks”.

MATERIAL and METHOD

Population Dynamics Model

In this study the forward calculation of virtual population analysis was used to predict the future population. The number of population $N_{a,y}$ at age a and year y was calculated as follows with fishing mortality coefficient at age a and year y, $F_{a,y}$, and natural mortality at age a, M_a;

For stocks which have a plus group,

$\begin{cases} N_{a_r,y} = R_y \\ N_{a+1,y+1} = N_{a,y} e^{-(F_{a,y}+M_a)} \quad\quad a = a_r+1,\ldots,a_{\max}-2 \\ N_{a_{\max},y+1} = N_{a_{\max}-1,y} \dfrac{e^{-(F_{a_{\max}-1,y}+M_{a_{\max}-1})}}{1-e^{-(F_{a_{\max},y}+M_{a_{\max}})}} \end{cases}$	(Eq. 1)

For stocks which do not have a plus group,

$\begin{cases} N_{a_r,y} = R_y \\ N_{a+1,y+1} = N_{a,y} e^{-(F_{a,y}+M_a)} \quad a = a_r+1,\ldots,a_{\max}-1 \end{cases}$	(Eq. 2)

where a_r is age at recruitment, and $a_{\max}$ is the maximum age. Recruitment *R* appeared in Eq. 1 is calculated by using a non-parametric stock-recruitment model (Kimoto et al in submission). The predicted biomass B_y, spawning stock biomass SSB_y, and yield Y_y were calculated with average weight at age w_a, maturity rate m_a; as follows;

$B_y = \sum_{a=a_r}^{a_{\max}} N_{a,y} w_a$	(Eq. 3)
$SSB_y = \sum_{a=a_r}^{a_{\max}} N_{a,y} w_a m_a$	(Eq. 4)

$$Y_y = \sum_{a=a_r}^{a_{\max}} \frac{F_{a,y}}{F_{a,y}+M_a}\left\{1-e^{-(F_{a,y}+M_a)}\right\} N_{a,y} w_a \qquad \text{(Eq. 5)}$$

Harvest Strategies

Belief 1

Belief 1 was designed in 2 policies, (a) 1 year ban and (b) 3 years ban from the beginning of harvesting. After the ban, the fishery was operated same as the No regulation policy described below. For Belief 1-(a), the fishing mortality was set to zero in the first year of the simulation, and after the second year, fishing mortality were randomly selected from the past fishing mortality series. For Belief 1-(b), the fishing mortality were set to zero from the first year to the third year for closing fishery, and fishery operation after the opening was designed as same as no regulation.

Belief 2

It is assumed to halve the fishing mortality of a_r and a_{r+1} in the past fishing mortality series. The fishing mortality for all predicting year was selected randomly from the observed series halving F_{a_r} and $F_{a_{r+1}}$.

No regulation

To evaluate the effects of each Belief, population dynamics under no regulation was also simulated as control. It was designed as fishing mortality were randomly selected from the past fishing mortality series.

Evaluation

The future population was forecasted for 30 years in 1000 Monte Carlo iterations. The beginning of this simulation was the latest year which was 2005. The predicted B_y, SSB_y, Y_y, and the cumulative yield for 10 years $\sum Y$ were evaluated as the index of population and fishery conditions in the simulations. The cumulative yield was calculated as follows;

$$\sum Y = \sum_{y=2005}^{2014} Y_y \qquad \text{(Eq. 6)}$$

The results for 30 years from 2005 of each Belief were compared with No regulation in each Monte Carlo iteration. To compare the results between applied stocks, the median of 1000 Monte Carlo iterations in B_y, SSB_y, Y_y, and $\sum Y$ was calculated in each predicted year.

Application

The randomly chosen 6 different stocks were used for examining each Belief as examples. The data of 5 stocks were obtained from ICES report in 2005 [1] which were cod in ICES Divisions VIIe-k from 1971 to 2004, Haddock in Division Vb from 1961 to 2004, herring in Subdivision 30 (Bothnian Sea) from 1973 to 2004, plaice in Subarea IV (North Sea) from 1957 to 2004, and sole in Divisions VIIIa,b (Bay of Biscay) from 1984 to 2004. One stock was chosen from the stock assessment data of walleye pollock in Pacific from 1981 to 2004 published from Japanese Fisheries Agency (2005) [2].

RESULT and DISCUSSION

The predicted biomass had very similar trends to the spawning stock biomass on both Belief 1 and 2. For Belief 1 in figure 1 and 2, spawning stock biomass and yield were increased compared with no regulation for all stocks in the first closing year and just after the opening fishery. However after 5 years, the effects of ban went small in 5 of 6 stocks, and the spawning stock, biomass and yield were the almost same as them under no regulation policy. The probability that the cumulative yield was below no regulation was large. For only one stock, the effects of ban last for long time, so spawning stock biomass and yield kept increasing. The cumulative yield was higher than no regulation with high probability.

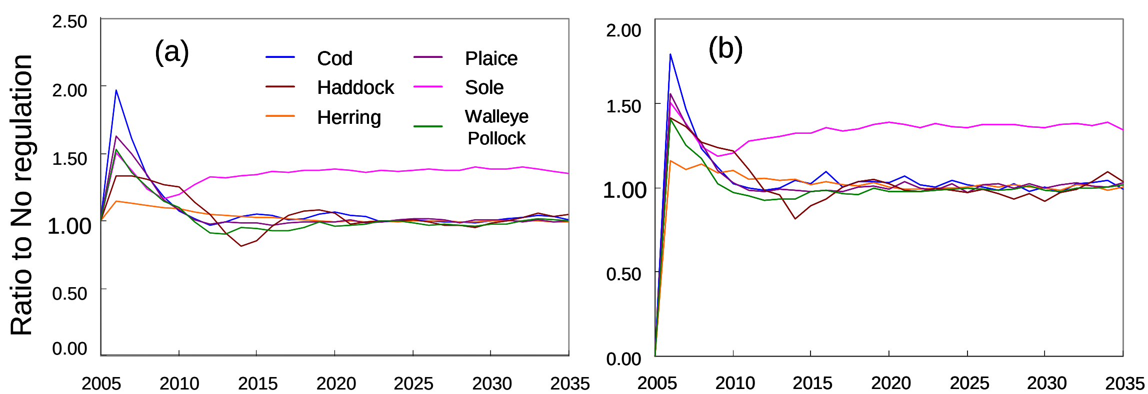

Figure 1. The predicted future (a) spawning stock biomass and (b) yield from 2005 to 2035 for 6 stocks with Belief 1-a.

Figure 2. The probability of the cumulative yields for 6 stocks compared Belief 1-a with no regulation, ■ above or □below no regulation.

For 3 years ban in figure 3 and 4, the trends of dynamics did not change with 1 year ban on both spawning stock biomass and yield, and were much fluctuated. The effect lasts for longer years than 1 year ban, but in the 5 of 6 stocks, the spawning stock biomass and yield went decreasing to the same level with no regulation, or sometimes dropped below no regulation. The cumulative yields of the two stocks were above that of no regulation with high probability.

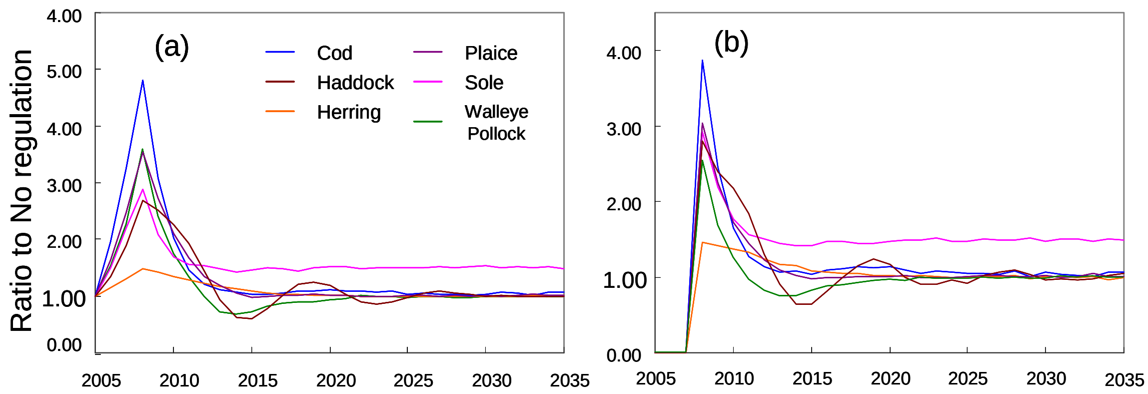

Figure 3. The predicted future (a) spawning stock biomass and (b) yield from 2005 to 2035 for 6 stocks with Belief 1-b.

Figure 4. The probability of the cumulative yields for 6 stocks compared Belief 1-b with no regulation, ■ above or □below no regulation.

From these results, the effects of ban last only 5 or 10 years, so ban were not effective for 5 of 6 stocks. Longer ban made a huge yield just after opening fishery, but for some stocks it sometimes went worse than no regulation.

Only one stock succeeded as far as we examined. It was thought that the effect of ban does not last because of the non linearity of the stock recruitment relationship and the harvest strategy after opening fishery. To make use of the effects of ban effectively, conducting additional management policies to sustain the high stock level were necessary. It is helpful to consider these policies with the population dynamics simulation model which we used in this study. For most stocks, only ban strategy would not make a good prospect for future, so management policies should be considered carefully before adapting them to the fishery.

The figure 5 and 6 shows the result of Belief 2. For Belief 2, both spawning stock biomass and yield were increased compared with no regulation in the 3 stocks. The cumulative yields were higher than no regulation with high probability. On the other hand, the rest 3 stocks had no significant change than that under the no regulation policy. This is often the case that younger fish has low price. For that case, this management policy will be effective in economic view. On the other hand for some stock, younger fish has high value. If the fishery for juvenile is important, it is difficult to make consensus with the fishermen and stock manager on the large mesh size.

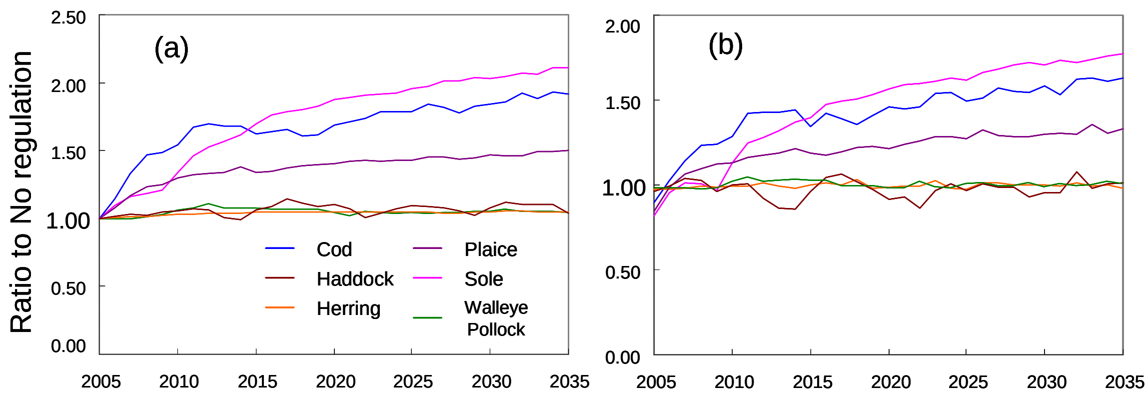

Figure 5. The predicted future (a) spawning stock biomass and (b) yield from 2005 to 2035 for 6 stocks with Belief 2.

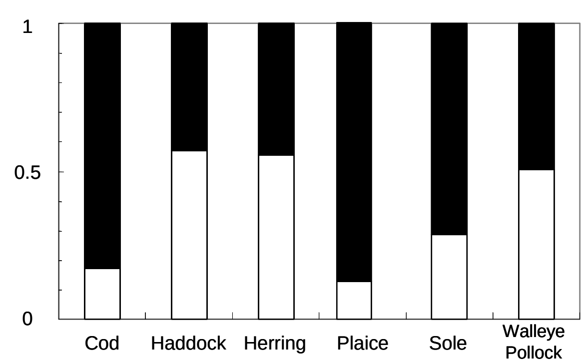

Figure 6. The probability of the cumulative yields for 6 stocks compared Belief 2 with no regulation, ■ above or □below no regulation.

In conclusion, the 2 Beliefs were confirmed using population dynamics model in this study. Many cases were reported on the result of confirming the management policies to rebuild stocks, and some found good performances. However, in general, they are rare cases and stock managers often proceed the stock management without confirming. Therefore the management strategies should be reconsidered well before you practice even if they are widely believed.

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