Fisheries management based on ecosystem models

- A case study using Ecopath and Ecosim -

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SUMMARY: The Ecopath model for the western North Pacific was constructed and some preliminary analyses were carried out in order to examine the usefulness of the model for multi-species management. Our Ecopath model consisted of 30 species groups based on the information that is mainly collected from published literature. Some Ecosim simulations showed non-trivial interaction between cetaceans and fishes and relative biomass of some cetaceans and fishes changed dramatically when their present harvest rates were changed in future. Fitting our model to the available abundance indices of some fishes indicated that the vulnerability parameter in the model was likely to be high. Further, additional simple simulation suggested that we could achieve targeted biomass of mackerel by adjusting the future harvest rate of cetaceans in place of that of mackerel. This indicates that multi-species management in the western North Pacific area might bring efficient fishing strategy. However, the results were very sensitive to setting of the vulnerability parameter. Therefore, Ecopath and Ecosim should not be considered as tools for multi-species management until uncertainty of important parameters is properly incorporated into Ecopath/Ecosim and the difference between them and a single-species model becomes clear. Nevertheless, those results from ecosystem models such as Ecopath and Ecosim are suggestive and valuable when they are brought up along with the result of single-species assessment.

KEY WORDS: multi-species management, ecosystem model, Ecopath, Ecosim, vulnerability, uncertainty

INTRODUCTION

The importance of the ecosystem modeling approach for fisheries management is mounting up these days. The Government of Japan disclosed the second phase of the Japanese Whale Research Program under Special Permit in the Western North Pacific (JARPEN II) research plan in the Scientific Committee of International Whaling Commission (IWC/SC) meeting held in 2000.¹⁾ The objective of JARPEN II research is to study the feeding ecology based on the research on prey consumption and preference of cetaceans. It is expected that these information will contribute to future multi-species management in Japan, especially the control of multiple harvest rates through the interaction between cetaceans and fisheries over marine resources. On the one hand, the development of Ecopath with Ecosim program^{2,3,4,5)} and the homepage on the Internet web (<http://www.ecopath.org/>) facilitated us to model the complicated ecosystem and examine the characteristics. Things being what they were, the western North Pacific Ecopath model^{6,7)} was developed as part of JARPEN II project. Some analyses that were obtained from the model indicated that the competition between cetaceans and fisheries over marine resources could occur in the western North Pacific, although the results are very sensitive to the diet composition and the vulnerability parameter that is the transfer rate between vulnerable and invulnerable components to predators.

In this paper, the characteristics of Ecopath and Ecosim are described briefly and the results that were obtained up to the present are introduced. Moreover, we think over the possibility of multi-species management based on the western North Pacific Ecopath/Ecosim model.

MATERIALS AND METHODS

The western North Pacific Ecopath model was constructed off the eastern coast of northern Japan called the Sanriku area. The model consisted of 30 groups that are representative species in Sanriku area. Because we mainly have an interest in cetaceans, the constructed model included many species of cetaceans separately. For example, we divided toothed whales into sperm whale, Baird's beaked whale, Dall's porpoise, short-finned pilot whale, and other toothed whales. In view of the future multi-species management, our model also treated many fishes that Japanese fisheries targeted as separate groups. For example, although saury, sardine and anchovy are small pelagic fishes with similar trophic level and traits, they were treated separately in our model because they are very important in Japanese fishery.

Ecopath and Ecosim

Ecopath is a simple ecosystem modeling approach. It is a static mass-balance trophic model that can easily handle

very complicated ecosystem. The master equation is given by

$$\text{Production utilized} = \text{Consumption by predator}^{35} + \text{Catch}.$$

Based upon the above equations, n linear equations can be given for an ecosystem with n groups. One equation basically has one unknown parameter. The simultaneous linear equations can be solved using standard matrix algebra in the program. Ecopath basically requires biomass (B), production/biomass (P/B), consumption/biomass (Q/B), diet composition, and fished biomass (= catches) for each group.

Most of input parameters and critical assumptions for the western North Pacific Ecopath model were made up from published sources. The information of biomass for whales was taken from data of Area 7 in Table 1 of Appendix 1 of the Government of Japan,¹⁾ and the information of diet composition was taken from Appendix Table 10.11 and 10.12 of Hunt Jr. and Kato.⁸⁾ The information of fishes was collected from a great variety of literature.⁷⁾ When there was no appropriate literature, we used the parameters of Trites et al.⁹⁾ or FishBase on the web (<http://www.fishbase.org/search.cfm>).

Ecosim is a temporal dynamic mass-balance approach for ecosystem simulation based on initial parameters inherited from the Ecopath model. It enables us to explore past and future impacts of fishing and environmental disturbances. The basic equation is derived from the Ecopath master equation with some alterations. Ecosim has two key features that have not previously been incorporated into multispecies biomass models. The first is the notion of vulnerability.³⁾ This indicates that the prey is not always available to encounters with predators. The prey biomass is divided into two parts, available and unavailable. It is known that the results of Ecosim are very sensitive to the setting of the degree of vulnerability. The second is the introduction of the delay-difference equations to deal with trophic ontogeny, especially for top predators. The simple solution to deal with top predator's life history is to divide the biomass into two parts, juveniles and adults. The linkage between juveniles and adults is described by the delay-difference model.⁴⁾

Simulations

The influence of the change of harvest rates of whales and fishes on the western North Pacific is examined using Ecosim. The result of future 50-year simulation is shown in the form of relative biomass trajectory of each group. The simulation is done under the following 4 scenarios:

Scenario 1: Harvest rate of cetaceans = 0

Scenario 2: Harvest rate of fishes = 0

Scenario 3: Doubling the harvest rate of cetaceans

Scenario 4: Doubling the harvest rate of fishes.

Because Ecosim is very sensitive to the vulnerability parameter, each simulation is carried out under two settings of the vulnerability parameters (v) of 0.3 and 0.6. The vulnerability of 0.3 is the default value in Ecosim and 0.6 is double the default value. When the vulnerability parameter is large, the ecosystem approaches top-down control such as Lotka-Volterra dynamics. Because we assume no "biomass accumulation" that is the difference between the biomasses of a group at the beginning of the year and at the beginning of the next year, biomass trajectories are eternally constant in the model if future fisheries are not changed at all.

The vulnerability parameter is estimated from fitting our Ecosim model to available time series data. For analytical simplicity, we estimate only the overall vulnerability parameter, i.e. a single parameter under the assumption that all the groups have the same value. The employed time series data are taken from harvest rates and biomass estimates of sardine, chub mackerel and common squid from 1987 to 1999. To supplement the result of estimation of the vulnerability parameter, an evolutionary criterion to search for an optimum estimate is used.

Additionally, a optimal harvest rate that increases relative biomass of mackerel by 2 times after 10 years is searched to throw light on multi-species management by Ecosim. Simulations are carried out under two scenarios, one is with the alteration of future harvest rate of mackerel itself and the other is with the adjustment of harvest rate of cetaceans and no change of that of mackerel. Three vulnerability parameters, 0.5, 0.6 and 0.7, were chosen to investigate its sensitivity. The results are shown in the form of the ratio of the harvest rate after 10 years to the present harvest rate. This example is unrealistic because biomass of cetaceans is not controlled. Nevertheless, the reason that we give this example is just the introduction of the ability of Ecosim.

RESULTS

The results of the first simulations showed a clear change of biomasses, especially when the vulnerability parameter is high. When there was no catch of cetaceans in future 50 years (Scenario 1), relative biomass of some fishes decreased in the order of several ten percent, and some whales increased in the similar order. Without fisheries except whaling in future 50 years (Scenario 2), relative biomass of some fishes increased in the order of several hundred percent and some whales increased in the order of several ten percent. With double harvest rate for cetaceans in future 50 years (Scenario 3), some fishes increased in the order of several ten percent. Some squids showed different dynamics from those fishes, probably because of indirect

effects. With double harvest rate for fishes in future 50 years (Scenario 4), many fishes became extinct. Some cetaceans decreased in the order of a few ten percent, probably because of lack of prey. One of the results is shown in Fig. 1.

Fitting the model to the available time series data of some fishes showed that the vulnerability parameter in the model was likely to be high. The vulnerability parameter estimated through fitting time series data was about 0.6 and the value obtained through searching for the evolutionarily stable strategy was some 0.5. Among three species employed in time series fitting, the relative biomass trend of sardine was not successfully fitted.

The results of the simulations for harvest rates of mackerel and cetaceans suggested that we could achieve targeted biomass of mackerel by adjusting the future harvest rate of cetaceans in place of that of mackerel. However, it is easily observable that the difference of the vulnerability parameter can have big impacts on the optimum fishing strategy. This result is shown in Table 1.

Figure 1. The result of Ecosim dynamic simulation. The change of relative biomass of some fishes under Scenario 1 ($v = 0.6$).

Table 1. The relative value of the fishing rates of mackerel or cetaceans after 10 years to the present fishing rates needed to increase the biomass of mackerel by two times. When one fishing rate was changed in the simulation, the other was set to be constant.

v	F_{mackerel}	F_{cetacean}
0.5	Non achievable	3.29
0.6	0.067	2.17
0.7	0.67	1.45

DISCUSSION

The results of the simulations indicated that there is a possibility that cetaceans and fisheries are competing each other in the western North Pacific because the search of the vulnerability parameter in our model resulted in relatively high value. Therefore, the ecosystem of the western North Pacific may be affected on a large scale by trophic interactions and changes of fishing.

However, Ecopath with Ecosim has not yet had the function to include uncertainty of many parameters. Our model in this paper is the first trial of the development of an Ecopath-type ecosystem model in this area. The parameters can stand further improvement. Okamura⁹⁾ showed that the relations between whales and fishes could be strongly influenced by the diet composition of whales. In the future, accuracy and precision of parameters should be improved and uncertainty of parameters should be reasonably incorporated into our Ecopath/Ecosim model.

It is well known that the vulnerability parameter is very sensitive to the results of Ecosim. The vulnerability parameter is in general not subject to direct measurement. One method is to search the parameter(s) through fitting Ecosim to time series data. However, fitting of sardine time series data was not reasonably achieved in our example. This probably means that the change of biomasses in the western North Pacific cannot be explained by only the trophic interactions. The inclusion of non-exploitative competition¹⁰⁾ and environmental factors into our model may be important.

The biomass of mackerel was improved by the adjustment of biomass of cetaceans that are predators of mackerel without the alteration of harvest rate of mackerel. This means that multi-species management could provide efficient fishing strategy. However, our simulations were too simple. If we think over more parameters and conditions, the results may show more complicated situations and they make it difficult that we interpret them. Aydin and Friday¹¹⁾ examined the difference of multi-species model and single-species model under uncertainty of parameters using

simple Ecosim model. They pointed out from their results that multi-species management was very sensitive to the difference of parameters and a complicated model might put this behavior out of sight. Putting our and their results together, it is plausible that multi-species management by Ecopath and Ecosim is still too early. We need the development of the method to incorporate the uncertainty of parameters into the Ecosim model sufficiently. Further, thorough examination of the difference between single-species and multi-species models is also needed. Especially, estimation of the vulnerability parameters is important because the results from Ecosim runs is very sensitive to it and the method to estimate it has not well established yet. If uncertainty of parameters is properly included, Ecopath and Ecosim will be useful as a tool for the multi-species management without doubt.

There are some problems to be solved in the future for the western North Pacific Ecopath model. First of all, basic parameters of the model should be improved, especially for groups with a lower trophic level. Then, we are going to try to develop the method to estimate the vulnerability parameter statistically, to carry out sensitivity analyses thoroughly, and to compare our Ecopath and Ecosim model with other ecosystem models. Ecospace¹²⁾ and Multispec¹³⁾ are supposed as candidates of other ecosystem models for the time being.

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