Plan for ecosystem modelling for species in Area IV in the Antarctic Ocean using JARPA and JARPA II data

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ABSTRACT

This is brief information on the authors' plan for ecosystem modelling for species in Area IV which is a part of the research area of JARPA and JARPA II. Two types of modelling approaches will be employed; one is the EwE, a comprehensive (whole-of-ecosystem) model, and the other is a multi-species production model. There are differences in the component species between them, but the baleen whales and krill play key roles in both. For the EwE approach, the authors are nearing completion of mass-balancing for Ecopath for 27 functional groups, and will then be moving on to projection forward (and backward if possible) by using the Ecosim framework. Statistical estimation will be conducted for tuning the parameters of the dynamics based on the time series of biomass trends for some species including the toothed and baleen whales. For statistical estimation in the multi-species production model, the observation (sampling CV and additional model error) and process errors will be accounted for fitting the time series of population sizes with consideration given to reducing the parameters to be estimated using random-effects. The model will be applied to the data of time series of baleen whales, seals and krill. Results from these two approaches will be reported at the JARPA II review.

According to the stated research objectives of JARPAII, the two aims relevant to the ecosystem modelling were listed: a) to monitor the Antarctic ecosystem (whale abundance trends and biological parameters; krill abundance and the feeding ecology of whales; effects of contaminants on cetaceans; cetacean habitat); and b) to model competition among whale species and future management objectives (constructing a model of competition among whale species; new management objectives including the restoration of the cetacean ecosystem). In this sense, the modeling is a way of expressing competition among predators like whale species for the main prey species, krill, and accounting for its dynamics of interactions/predation, and these works are necessary steps to understand what happened and what is going to happen in the Antarctic.

When it comes to ecosystem modeling, which is usually a substantial exercise, a broad range of approaches has been proposed (e.g. Plagányi 2007). One of the most comprehensive approaches (or so-called the "whole-of-ecosystem" modelling, e.g. Plagányi *et al*. 2012) is the one developed by the group led by Pauly, Ecopath-with-Ecosim (EwE, e.g. Pauly *et al*. 2000), in which a complicated system is represented by a multi-directional linkage among component species with consideration of an initial mass-balancing of the system and its subsequent dynamics afterward. This approach has been widely used for constructing marine ecosystem models, but it also requires various types of information such as the biomass levels, the diet compositions, per capita growth rates and the extent of necessary consumption with consideration of required energy, and these pieces of information are often influential as regards models' results. Also, predicting future dynamics demands further information and assumptions. Nevertheless, it is beneficial to try to draw a bigger picture of the ecosystem.

The dynamics of the population size of wildlife species has traditionally been expressed as a form of production models. This contains, of course, the effect of density dependence, which is usually linked with the relative

depletion compared to its carrying capacity. The model is then extended to consider prey availability including competition in utilising them and the impact of predators on prey species. This can be regarded as a model of intermediate complexity of ecosystem (e.g. Plagányi *et al*. 2012). Primitive but fadeless pieces of work were developed by Lotka and Volterra. Each of them derived different sets of equations, which are now called "predator-prey interactions" and "competition for food and space". Since then, the models have been further developed to take into account multiple prey and predator species simultaneously although the models have to face "the curse of dimension", especially in the presence of the many species to be considered in, for example, a region of the Antarctic. Although the multiple-predators and multiple-preys system potentially possesses a large number of parameters, this could be one of simplest ecosystem models if it is possible to confine the component species and their hierarchy.

In the Antarctic Ocean, it is not in doubt that the Antarctic krill (*Euphausia superba*) are main prey species and play a crucial role for influencing the ecosystem surrounding large predators of baleen whales like the blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*) and Antarctic minke whales (*B. bonaerensis*) and other krill predators like seals and sea birds. When considering that sort of simple hierarchical structure, the extended production model might work well without encountering the difficulty of over-parameterization. Hence we will re-visit a modeling approach in a preceding study conducted by Mori and Butterworth (2006), in which the whole Antarctic was considered, and also statistically refine the model by considering a random-effects approach to facilitate the estimation of parameters.

We are therefore planning to work on ecosystem modelling in the Indian Ocean sector of the Antarctic Ocean (IWC management area: Area IV) based on the following two different approaches, and we will show some results in the JARPA II review workshop which is to be held in February 2014.

1) Comprehensive (whole-of-ecosystem) modelling via EwE

An initial step of the EwE approach is to take a mass-balance of component species (Ecopath), which also includes some key processes of 1) selection of the component functional groups, 2) collection and estimation of basic parameters such as biomass and production and consumption per unit biomass of each species, and 3) adjustment of input parameters by monitoring some indices so that the system can achieve a mass-balance. For our exercise of ecosystem modelling, we have chosen 27 functional groups, which consist of species from toothed and baleen whales to zoo- and phyto-plankton. A question usually raised in the Ecopath modeling is how sensitive is the model to changes in input parameters (Essington 2007). Currently, the mass-balance is proving difficult to achieve if the perturbation of the parameters of the killer whale is considered. We have not assessed this sort of sensitivity systematically yet, but we are going to continue the examination. We are now nearing completion of mass-balancing and moving on to projection forward (and backward if possible) by using the framework of Ecosim. Statistical estimation will be conducted for tuning the parameters of the dynamics based on the time series of biomass for some species including the toothed and baleen whales. These results will be reported at the JARPA II review.

2) Multi-species production modelling

This will be a refinement of the earlier approach by Mori and Butterworth (2006), but some twists will be added into their basic system of equations for multiple predators (some baleen whales and seals) and single prey species (krill). Although the multi-species production model is simpler than the approach of whole-of-ecosystem modelling, it still has many unknown parameters. To reduce the number of parameters to be estimated, some bioenergetic and allometric reasoning by Yodzis and Innes (1992) will be incorporated for the predator species. A random effects estimation approach has been developed to make the model more flexible. The maximum consumption will possibly be linked to the body weight of the predators. For statistical estimation, the observation (sampling CV and additional model error) and process errors are accounted for when fitting the time series of

population sizes. However, it might be difficult to separate these two parameters with limited information of data, so the process error will be dealt with as a sensitivity test. ADMB-RE coding has been completed but a simulation study to examine the estimation performance and robustness to model misspecification is still in progress.

This sort of model has the potential to estimate the extent of competition between the baleen whales. For example, since the population sizes of other larger baleen whales such as blue, fin and humpback declined through commercial harvesting, there might have been a state of krill surplus in the Antarctic. This surplus could be utilized by the Antarctic minke whales, and since that time the minke whales might be still above their pre-exploitation level. This is not explicitly taken into account in the existing RMP implementation, but some multispecies adjustment would contribute to improvement of operating models and harvest controls to make more effective use of this resource, which is a reason for the further development of multi-species production models.

Some updated abundance estimates of the whales (baleen and toothed) and krill together with other information from JARPA and JARPA II surveys will become available for the coming JARPA II review meeting, and these will be used to fit these models, which will include baleen whales, some seals and krill, which will be reported at the review workshop.

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