

## Ecosystem modeling using Ecopath with Ecosim and fishery related data for practical application

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Concepts and methods of ecosystem-based fisheries management have not been fully discussed in Japan, and thus data collection, assessment and conservation planning of marine ecosystems have not yet been established. However, fishery-related surveys and oceanographic monitoring have long been conducted around Japan and the resultant data are accumulated. It will be helpful to evaluate the current status of marine ecosystems and assess fisheries interactions using these existing data. In this respect, Fisheries Research Agency have examined feasibility of ecosystem modeling using fishery-related data and Ecopath with Ecosim (EwE).

EwE is an end-to-end model that expresses an ecosystem as flows of biomass. A simple relationship between consumption ( $Q_i$ ), production ( $P_i$ ), respiration ( $R_i$ ) and unassimilated excretion ( $U_i$ ) of a functional group  $i$  is represented as,

$$Q_i = P_i + R_i + U_i \cdots (1)$$

A mass balance equation is presumed which means input and output of a functional group is balanced as,

$$P_i - Y_i - M2_i - P_i(1 - EE_i) - EX_i - BA_i = 0 \cdots (2)$$

where  $Y_i$  is fishery catch,  $M2_i$  is predation mortality,  $P_i(1 - EE_i)$  is other mortality ( $EE_i$  is a ratio called ecotrophic efficiency),  $EX_i$  is export, and  $BA_i$  is biological assimilation. The predation mortality is divided into consumption of prey  $i$  by predator  $j$ ,

$$M2_i = \sum_j Q_j DC_{ji} \cdots (3)$$

which leads to linear simultaneous equations of predator-prey relationships ( $DC_{ji}$  is the ratio of prey  $i$  in the diet of predator  $j$ ). By solving the equations, Ecopath estimates the flows of biomass and estimates trophic levels, trophic interactions and network properties. However, comparison of network properties between different models is not effective because these values vary depending on the model structure. Ecopath is more suited to summarize flows and biomasses into trophic levels and calculate system productivity or transfer efficiency.

Mean trophic level of catch (MTLc, Pauly et al. 1998), primary production required (PPR) to support catch (Pauly & Christensen 1995), loss of food for higher trophic levels caused by fishery removals (L index, Libralato et al. 2008) and other indices of fishery impacts can be calculated using the outputs. Comparison of Ecopath models of several waters around Japan with world models published in literature revealed that the Japanese commercial fisheries harvested over relatively wide range of trophic levels and had moderate impacts on marine ecosystems.

Ecosim uses the left part of formula (2) as the differential equation of biomass and simulates the temporal dynamics after the mass balance is broken. Dynamic behavior of Ecosim is largely dependent on the vulnerability parameter, which determines the functional response of a predators to prey density change. The vulnerability parameters can be tuned if time series data on relative abundance of functional groups are available.

Many expanded functions are added to recent versions of EwE such as age-structure, spatial heterogeneity (Ecospace), economic evaluation (Value chain) and management strategy evaluation (MSE). Ecospace simulates spatio-temporal dynamics and is used for predicting the effect of spatial management but it also stands on the balanced homogeneous state of Ecopath.

EwE appears to be a good starter of marine ecosystem modeling for understanding foodweb structure and fishery impacts because Ecopath is tailored to take fishery related information as input data in the form of ratios to biomass ( $P/B$ ,  $Q/B$ ) or diet composition ( $DC$ ). The assumption of mass balance does not necessarily mean that the system is in steady balanced state but is rather understood as that the biomass budget is balanced at an average condition over a certain space and period. Preparation of relevant data by appropriate spatio-temporal scale and comparison and/or coupling with other models while exploring data and modeling gaps will be effective steps for the development and practical application of ecosystem modeling to management.

Keywords: ecosystem-based fisheries management, fishery impacts, marine food web, mass balance model, monitoring data