Modeling mussel cultivation at Gouqi Island

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Goal

To quantify an economically optimal strategy for mussel cultivation and evaluate its ecological impacts on other parts of the ecosystem.

Background and motivation

The coastal zone of Gouqi Island in the East China Sea is one of the important mussel-cultivation areas in China. The mussel-cultivation catamarans are located close to the island, and a third of the about 2300 local fishermen derive their livelihood from mussel cultivation. It is therefore important to ensure sustainable and stable cultivation. Furthermore, an assessment of the maximum economic yield of cultivated mussels should also take into account the capacity of the ecosystem to support mariculture activities.

Two species of mussels are farmed in this area: an introduced species *Mytilus edilus* is harvest after one year, whereas the less common native mussel species *Mytilus coruscus* grows to larger size while typically being cultivated for two years before harvesting. Fishermen can choose how many juvenile mussels of each species to plant at sea. The commercial value of the annual yield depends on the number and weight of harvested mussels. Their growth is limited by environmental conditions and food concentration. The latter includes particulate organic matter and phytoplankton. Modeling the impact of mussel cultivation on these factors allows predicting mussel growth in dependence on other environmental factors (Cédric et al. 2003). On this basis, optimal stocking densities for mussel cultivation can be determined (Mazouni et al. 1998).

Mussels are mainly phytoplankton grazers (Rouillon et al. 2005). According to an experiment conducted by Chang and Wu (2007), for water depths of 20-30 m and cultivation densities of 3.0-4.5 kg m^{-2}, *M. coruscus* larva can graze 7.75×10^7 phytoplankton cells per liter and day. The weight at age of *M. coruscus* is about 1.5 times as large as that of *M. edulis*. The quantity of food that mussels graze is mainly dependent on their size, and amounts to roughly 5% of their weight per day (Li et al. 1999). Larger mussels will earn more money for the fishermen than smaller ones: sometimes *M. coruscus* can be sold at a price that is four times higher than that of *M. edilus*.

While mussels need enough phytoplankton intake to grow, other species in the ecosystem also feed on this food source: these include zooplankton, some crustaceans, and most juvenile fishes. Other species, in turn, live on zooplankton: these include benthos, some plankton-eating fish, and some polyphagia fish that are predated upon by other fish. Hence, if mussel cultivation reduces phytoplankton density too much, this can cause modifications in food-web structure and functioning. The impact of mussel cultivation on the ecosystem therefore depends not only on the stocking density of cultivated mussels, but also on the ecological interactions within the ecosystem. To assess how the ecosystem is affected by mussel cultivation, it is therefore important to understand and quantify these ecological interactions. If species at higher trophic levels of the ecosystem – such as fishes, crabs, or cephalopods – lose their ecological positions in the ecosystem, this causes damages not only to the ecosystem, but also to the economic interests of fishermen who live on fishery catches from this ecosystem.

Research questions

In this project, I will try to find the economically optimal strategy for mussel cultivation around Gouqi Island. In addition, as a guide for fishermen and policy makers, I will try to predict the environmental and ecological impacts of mussel cultivation around Gouqi Island. I will focus on the following research questions:

- What is the optimal strategy for mussel cultivation?
- What are the impacts of mussel cultivation on other species in the ecosystem?
- What models and methods should be used to quantify the ecological and production carrying capacity for mussel cultivation?

Methods and work plan

I will address the above questions using two complementary approaches. First, a size-structured model of commercial mussel cultivation will be used to explore the profitability of different mussel-cultivation strategies. This model will help to evaluate which of the two mussel species should be chosen for cultivation and to predict the resultant economic benefits. Second, a model based on the 'Ecopath with Ecosim' (EwE) framework will be used to determine the ecological impacts of mussel cultivation.

Size-structured model of mussel cultivation

Assuming that fishermen plant all spat at roughly the same time of the year, we can represent the planted mussels as a cohort and describe changes in the size s_i and abundance n_i of mussel species i by two ordinary differential equations,

$$\frac{ds_i}{dt} = g_i(s_i, z, T) \text{ and } \frac{dn_i}{dt} = -d_i(s_i, z, T),$$

with $s_i(0) = s_{i,0}$ and $n_i(0) = n_{i,0}$, where $g_i = g_i(s_i, z, T)$ and $d_i = d_i(s_i, z, T)$ are the growth rate and mortality rate, respectively, of a mussel of species i with size s_i when the water temperature is T and the density of phytoplankton is z. The mussels interact through filter-feeding on phytoplankton. I will model the dynamics of the phytoplankton density under the assumption of an inflow from the kelp beds in the coastal area and a constant outflow of water from the area under consideration. Using this model, we will first identify the economically optimal amount of spat $n_{1,0}$ and $n_{2,0}$ of the two mussel species to plant each year. Second, we will consider different harvesting strategies. In particular, we will explore whether partial harvesting can be profitable.

A major challenge will be to choose suitable functions for describing the mortality rate and the growth rate. We will attempt this based on a simple energy-budget model, which will be parameterized from available data on mortality and growth trajectories under different water temperatures and phytoplankton concentrations. If the data proves insufficient to quantify both dependences, we will either leave out the former dependence or attempt to include it based on general knowledge about the scaling of metabolic rates with an organism's body size and ambient temperature.

Ecopath model of ecosystem impacts

'Ecopath with Ecosim' (EwE) is a software tool for representing the trophic structure of an ecosystem and for providing basic information for the management of fishery resources involving multiple trophic levels (Pauly et al. 2000; Jiang et al. 2005). It can be used to model the trophic relationships among functional groups, to assess flows of biomass among several trophic levels, and to identify other salient ecosystem properties. Using the EwE framework, I will integrate recent survey data and information from published literature (Zuozhi et al. 2008; Hong et al. 2008) to build a food-web model describing the trophic structure and energy flows of the Gouqi Island ecosystem.

We divide the aquatic organisms of the Gouqi Island ecosystem into 17 functional groups. Each such functional group can represent a single species or a group of species. Several species can be grouped if they occur in a common physical habitat and if they have similar food preferences and life-history characteristics. A particular species can be represented separately based on its ecological and economic importance in the ecosystem.

Considering the features of, and interactions among, all functional groups, a balanced model of trophic flows can be constructed (Christensen et al. 2005),

$$B_i (P/B)_i EE_i - \sum_j B_j (Q/B)_j DC_{ij} - Y_i - E_i = 0,$$

where B_i is the biomass of species i, $(P/B)_i$ is the production rate of species i, EE_i is the ecotrophic efficiency of species i, $(Q/B)_i$ is the consumption rate of species i, DC_{ij} is the proportion of species i in the average diet of species j, Y_i is the annual catch of species i, and E_i is the net export of species i through the boundaries of the modeled ecosystem. We intend to integrate into this EwE model as much as possible empirical knowledge on biomasses, production rates, consumption rates, diet compositions, and, if applicable, catch. The data required for calibrating the model originates from survey data, stomach-content analyses, and published literature. The calibration will allow the EwE software to compute the ecotrophic efficiencies (Blanchard et al. 2002). A successful calibration will ensure that all values of ecotrophic efficiency – defined as the fraction of the production of a functional group that is trophically used by the ecosystem – are smaller than 1. Once this is achieved by manual tuning, the automatic balancing routine of the EwE software will be used to complete model calibration through balancing biomass fluxes. This will be followed by a consistency check using physiological criteria, to verify that the respiration/assimilation ratio and the production/respiration ratio are smaller than 1 and that the production/consumption ratio is smaller than about 0.2 for all functional groups.

After balancing the EwE model, we can evaluate the ecological and production carrying capacities for mussel cultivation, based on considering ecosystem responses (in terms of biomass changes, transfer efficiencies between groups and trophic levels, competition, detritus recycling, etc.) to changes in the biomasses and harvest rates of the cultivated mussels. We will also try to determine under which conditions the trophic resources used by the cultivated mussels are available to the extended needed for obtaining good economic benefits.

Relevance and link to EEP's research plan

This project aims to evaluate the ecological and production carrying capacities for mussel cultivation at Gouqi Island, while considering how to minimize the associated environmental degradation. This work not only allows us to develop ideas pertinent to other instances of this unique kind of aquatic ecosystem, but also provide managers with sustainable options for mariculture exploitation. It is therefore linked to EEP's research project on *Evolutionary Fisheries Management*.

Expected output and publications

This work will be a part of my PhD thesis and is intended for publication as a co-authored article in an international scientific journal.

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