Ecological Modelling 313 (2015) 266–275

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Combined modeling of fish behavior and fishing operations for conger eel fishery in Ise Bay

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ARTICLE INFO

Article history:
Received 2 March 2015
Received in revised form 15 June 2015
Accepted 30 June 2015

Keywords:
Fish migration
Fishing operation
Conger myriaster
Ise Bay
Bottom otter trawling

ABSTRACT

In order to simulate the conger eel (*Conger myriaster*) fishery in Ise Bay, a typical semi-enclosed bay in Japan, we developed a fishery simulator that consists of a fish behavioral model and a fishing operations model. The fish behavioral model considers the migration effect as well as the growth rate of individuals and changes in population size. In the behavioral model with migration, the direction of fish movement is determined by the preference intensities for the environmental factors of water temperature and dissolved oxygen. The change in population size is calculated by using a general population dynamics model considering natural and fishing mortalities. In the first step, the fishing mortality was estimated by the actual fish catch data. Studies have clarified that environmental conditions such as oxygen-deficient water in summer have a large influence on the migration and distribution of *C. myriaster*. Although the simulated catch per unit effort (CPUE) based on actual fishing operations data was able to describe general features of the annual variability, some improvement of the model will be necessary for more accurate prediction. In the next step, the fish behavioral model was combined with a fishing operations model, which predicts the behavior of trawling boats based on economic conditions and resource distribution. The combined model reproduced the boats' fishing locations and their fish catch amounts well. The model was applied to evaluate the effects of fishery management and clarified that the control of fine-net use is an effective means to increase the fishery profit.

1. Introduction

When considering the environmental management and sustainable use of a coastal zone, revitalization of coastal fisheries is an important issue that is deeply connected to ecosystem services and the local economy. With regard to fishery production in the Japanese coastal zone, its relationship with water quality and/or terrestrial load has often been discussed, as well as the effects of environmental regeneration projects such as the development of seagrass beds and tidal flats (e.g., Kodama and Tabeta, 2012). However, coastal fisheries in Japan are facing serious situations due not only to the decline of fishery resources caused by environmental degradation and other reasons, but also to economic problems including price setting and distribution infrastructure, decreased consumption, and unstable income of fishermen. In order to revitalize coastal fisheries and distressed local communities, appropriate fisheries management considering both environmental and economic factors is necessary, as well as a system for assessing these factors. For example, more efficient and sustainable fishing operations should be investigated based on the resource conditions and business profitability.

Recently, a number of models considering both ecological and economic conditions have been developed and applied to assessing fishery management (e.g., Bastardie et al., 2014; Blenckner et al., 2011; Fulton et al., 2011; Kaplan and Leonard, 2012; Romagnoni et al., 2015; Russo et al., 2015). However, there have been very few applications of bio-economic models to Japanese coastal fisheries. Additionally, modeling and implementing of fish migration in coastal area where complex environmental factors affect the fish behavior is still a challenging issue.

Ise Bay (Fig. 1) is a typical semi-enclosed bay located in south-central Honshu, Japan, with a large urban area along its shore. Coastal development and terrestrial loads have caused environmental degradation and affected the marine ecosystem and fisheries in the bay. In particular, oxygen-deficient water in the bottom layer during summer has caused serious impacts on the bay's benthic ecosystem (Fujiwara et al., 2002; Suzuki, 2001). It is reported that oxygen-deficient water appears from June to October almost every year in Ise Bay, whose area has been increasing and the duration has become longer (Kuroda and Fujita, 2006).

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http://dx.doi.org/10.1016/j.ecolmodel.2015.06.043
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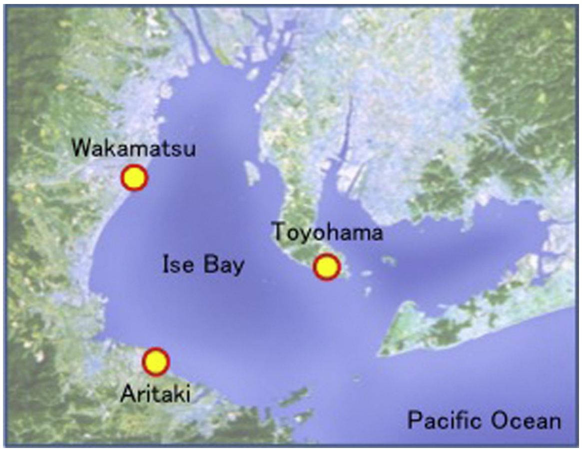

Fig. 1. Ise Bay and the three major fishing ports for bottom otter trawling.

However, various fisheries activities are still continuing under these harsh social conditions (Funakoshi, 2008; General, 2008). Bottom otter trawling is one of the major fisheries activities in Ise Bay, and the success of such trawling is sensitive to marine environmental conditions such as the dissolved oxygen level. The fish catch of bottom otter trawling in Ise Bay was about 7200 t in 2000, but it declined to about 4600 t in 2009. The number of fishery management entities, which was about 3000 in 1998, also declined to about 1900 in 2013. The main target species are conger eel (*Conger myriaster*), mantis shrimp (*Oratosquilla oratoria*), Japanese pufferfish (*Takifugu rubripes*), prawn (*Trachysalambria curvirostris*), and Japanese sea bass (*Lateolabrax japonicus*) (Japan Fisheries Agency, 2007, 2012).

In the present study, we developed a fishery simulator for *C. myriaster*, which is one of the representative target species for trawl fishing in Ise Bay. The fish catch of *C. myriaster* in the bay has been declining in recent years, with more than 1000 t caught annually in the 1990s but less than 500 t caught in 2012 (Kurogi et al., 2013). The simulator consists of a fish behavioral model that predicts spatiotemporal variability of fish biomass and population size and a fishing operations model that predicts the fishing activities of trawling boats.

In the fish behavioral model, the migration, growth rate, and changes in population size of the fish are calculated. We previously developed a similar model for *Pagrus major* in the Seto Inland Sea (Hakuta and Tabeta, 2013), but the model validation was difficult because there are limited quantitative data about the behavior of the target fish. In the present study, we were able to obtain better quantitative data by using fishery information such as fish catch and catch per unit effort (CPUE).

In the first step, the fishing coefficient was estimated by using actual fish catch data to validate the fish behavioral model. In the next step, the fish behavioral model was combined with a fishing operations model, which predicts the activities of trawling boats based on economic conditions and resource distribution. The combined model was then applied to evaluate the effects of trawl fishing management on the conger eel fishery in Ise Bay.

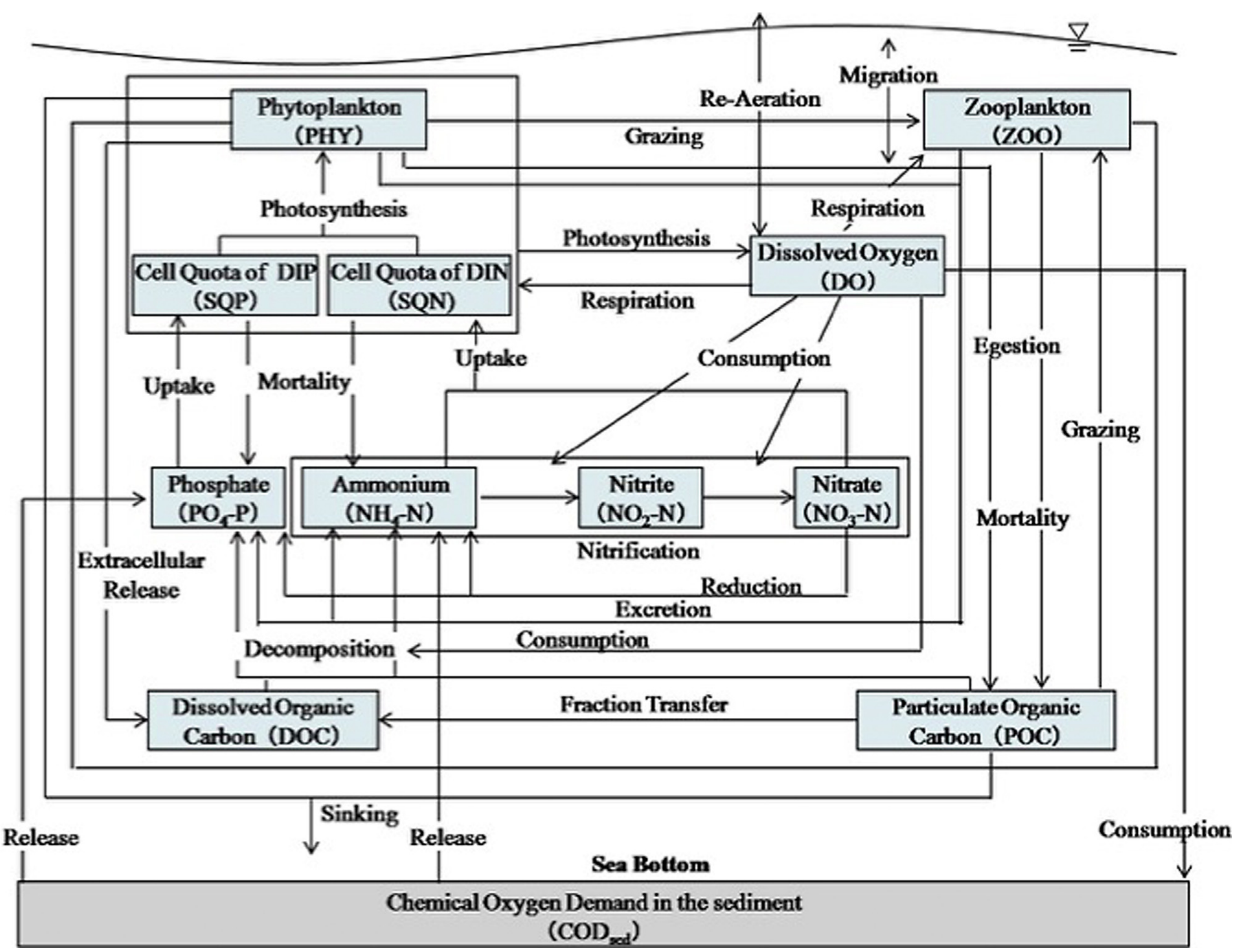

Fig. 2. The lower-trophic ecosystem model used for calculating environmental conditions (from Hakuta and Tabeta, 2013).