The impacts of fishing and nutrient influx from Yangtze River on the ecosystem in East China Sea

Yiming Xia¹ · Shigeru Tabeta¹ · Shinji Komatsuda¹ · Fengjun Duan²

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Abstract As the main nutrient inputs of East China Sea (ECS), nutrient concentrations of the Yangtze River increase significantly due to high-speed economy development, which play a very important impact on the East China Sea ecosystem. In this study, by integrating MEC and EwE model, we analyzed the impact of Yangtze nutrient fluxes change and fishery on the ecosystem of ECS from 1960 to 2000. Our research shows that under high fishing pressure, the main fish production decrease significantly, average trophic level recession and small fish take the main position of ecosystem. But the increasing nutrition influxes from Yangtze River have a certain influence for the ecosystem to slow the decline tendency of fish because it can stimulate the plankton growth. This research provides a method to study the entire ecosystem from the prospective of both environmental and fishery factors, extending from physical conditions to higher ecosystem, to achieve a top-down and bottom-up management.

Keywords Nutrient influx · Fishing · Ecosystem model · MEC model · JCOPE2 · EwE

Introduction

It is obvious that overfishing should have an adverse impact on ecosystems but evaluating the impact cannot consist only of demonstrating fisheries (Pauly 2000). The depletion of low trophic level species will have greater

impact on another part of ecosystem (Simth and Bulman 2011). Physical conditions change like global warming, climate change, eutrophication, and pollution can also affect the ecosystem which is usually composed of low trophic level (LTL) and high trophic level (HTL) species. Previous researches usually employed a hydrodynamic model coupled with LTL model to simulate the environmental change of physical conditions and LTL ecosystem. However, few researches mentioned about how physical condition will affect the high trophic level (HTL) organisms. Meanwhile, one of the challenges of fishing management is the identification of the major trophic controls operating on marine ecosystems and how exploitation combined with physical conditions change can affect their dynamics (Rose et al. 2010). In conclusion, for marine environmental evaluation and fishing management, very few existing models explicitly incorporate the dynamics from one end of the ecosystem to the other and thus allowing the exploration of interplay between exploitation and physical condition change. So there is a demand for the quantitative tools for ecosystem-based management, particularly models that can deal with both bottom-up and top-down controls that operates simultaneously and varies in time and space and that are capable of handling the multiple impacts (Shin et al. 2010).

Due to the complex of impact factors, the physical condition (bottom-up driving force) in this study was simplified into the nutrient concentration change in the research area caused by the river influx change. And the fishing (top-down driving force) was the removal of the biomass of some specific species. The purpose of this study is to provide a holistic framework which can combine the effect of fishing and physical conditions change and reveal the relationship between LTL and HTL ecosystems. Furthermore, we can evaluate what kind of roles that Yangtze

✉ Yiming Xia
yiming.xia.chn@gmail.com

¹ Department of Environment Systems, The University of Tokyo Kashiwa, Kashiwa, Japan

² The Canon Institute for Global Studies Tokyo, Tokyo, Japan

River and overfishing played during the degeneration of ecosystem in ECS.

Data and methods

Research area

The East China Sea (ECS) is situated in the eastern Pacific between the sub-tropical and temperate zones. The large fishing pressure and the resulted large annual catch have likely changed the structure of the ECS ecosystem. Several decades ago, the ecosystem was dominated by high-valued commercial species. Now the ECS is characterized by having a simple trophic structure, fast growth rate, low trophic level and high turnover rate. These have large implications in fishery management and biodiversity conservation. In addition to that, the change of environmental conditions such like climate change and pollution in ECS also has a significant adverse effect on the ecosystem.

Simulation method

A LTL ecosystem model embedded in MEC Ocean Model with JCOPE2 and EwE (Ecopath with Ecosim) are two models selected to build the basic framework for this research. Linking the two models will provide a mean of going up the food chain by trophic levels. Through adjustment and integration of these two models, these two models can be put into one single framework which could be applied to marine environmental evaluation and fishing management from the perspective of physical conditions and anthropogenic activity. Since our future goal is to analyze total ecosystem from LTL to HTL with spatial information, we employed a 3D model for hydrodynamic and LTL part. As the first step of developing an end-to-end model, a 3D hydrodynamic with LTL model and a 0D HTL model are connected in the present study.

LTL model

A three dimensional LTL ecosystem model is embedded in MEC model (developed by *Marin Environmental Committee, Society of Naval Architects of Japan*) (ASME 2005), which is a time- and spatial-varying 3D hydrodynamic model with a z-coordinate system based on a finite difference scheme. A simplified method was adopted for simulating the current field to address both ocean currents and tidal currents. Incorporation of JCOPE2 (Miyazawa et al. 2009) data into MEC model allowed simultaneous reproduction of them. The total current at each grid point was assumed to be a linear combination of the tidal current and other flow components such as Kuroshio Current. For

the boundary condition to calculate tidal current, amplitude and phase data of the major tidal constituents obtained from the tide model of the National Astronomical Observatory of Japan (Matsumoto et al. 2000) were used. JCOPE2 datasets were used for the current components other than tidal current as well as water temperature and salinity. As JCOPE2 datasets are provided once a day, linear interpolation in time was used to obtain the values for each computational time step in MEC model.

The computational area of MEC model (Fig. 1) is E117–E132 of latitude and N24–E41 of longitude. The horizontal resolution of the grid was set to $1/12^\circ$ and the total grid number is 180×204 . There are 22 vertical layers whose thickness was arranged to increase from the top to bottom layer. The NOAA ERDDAP (Environmental Research Division's Data Access Program) data were used to set the initial conditions and open boundary conditions of water qualities such as temperature, salinity, nutrients, and so on. Solar radiation was inferred from the JRA25 (Japanese Re-Analysis 25 years) data. A lower trophic model (Fig. 2) (Hakuta and Tabeta 2013) embedded in MEC model calculates the temporal and spatial variation of planktons, nutrients and detritus under the condition of Yangtze nutrient fluxes in 1960, 70, 80, 90, and 2000 in Fig. 3. The organic matters from the river are not considered because we didn't find reference data about the POC and DOC in Yangtze River before 1990. However, when we included the POC and DOC from the river into the calculation in 2000, we found that there was no significant change. Parameters for the LTL model were set based on previous researches (Zhao and Guo 2011). For each year, the computational time span is 18 months and the

Fig. 1 The computational area of East China Sea

Fig. 2 Lower trophic ecosystem model (Hakuta and Tabeta 2013)

concentrations of nutrients in Yangtze River were given based on the data of reference (Li et al. 2007).

EwE model (Ecopath with Ecosim)

EwE combines algorithm for ecosystem trophic mass balance (biomass and flow) analysis (Ecopath) with a dynamic modeling capability (Ecosim) for exploring past and future impacts of fishing and environmental disturbances (Christensen and Walters 2004). In Fig. 4, fishing data of 4 groups as the main product in ECS (JZ et al. 2006), and a typical tendency of fishing effort which are used to set the fish catch of other species are shown (Li and Zhang 2011).

The modelling area covers E119–E126 of latitude and N30–E36 longitude (Fig. 1) where the nutrient fluctuation was mainly controlled by the input from Yangtze River. The Ecopath mass-balance model with 22 groups in East China Sea was based on fishery resource surveys of ECS and previous research (Cheng et al. 2009). This Ecopath model was built to set as the initial condition of Ecosim model. Then Ecosim was used to simulate the marine ecosystem dynamics through taking the time-series fluctuation of planktons calculated by LTL model and fishing data as the forcing functions.

Connection of MEC and EwE model

The calculated results of LTL model were transferred to a spatially and temporally averaged data which could be used in EwE model. The data from LTL model was aggregated by the following equations (Tillman 2008).

$$C_{ave} = \frac{1}{T} \times \sum C_i \times \Delta t \quad (1)$$

$$C_{areal} = \sum C_{ave} \times \Delta Z \quad (2)$$

$$C_{reg} = \frac{1}{A_{reg}} \times \sum C_{areal} \times A_j \quad (3)$$

In the equations, C_i is concentration of each group at time step i , C_{ave} is temporal average of C_i , Δt is the model time interval, T is the duration of the averaging interval,

Fig. 3 Nutrient concentration change of influx water in Yangtze River (Li et al. 2007)

Fig. 4 Left capture yield of six species from East China Sea (JZ et al. 2006); Right relative fishing effort for other species (Li and Zhang 2011)

C_{areal} is the vertical integration of C_{ave} , Δz is the cell layer thickness, C_{reg} is the regional and temporally averaged quantity used in comparison with to equivalent Ecopath value, A_{reg} is the regional area and A_i is the surface area of the water column for cell j . The unit here was transformed from g L^{-1} to $\text{ton km}^{-2} \text{year}^{-1}$ or $\text{ton km}^{-2} \text{month}^{-1}$. Through using this method, we applied the data of the inter-annual biomass variations of zooplankton, phytoplankton, and detritus achieved from LTL model into EwE model. During this conversion, the spatial information such as the stratification and the spatial distribution of hypoxia is lost during these conversion. The influences of the simplification should be examined in the future, e.g., by using a 3D coupled model.

In traditional EwE model, the zooplankton should belong to consumer and trophic level should be 2. However, in the previous part, the fluctuations of phytoplankton, zooplankton and detritus were calculated by low trophic ecosystem model in LTL model. During this calculation, the relationships like predation and excretion among phytoplankton, zooplankton and detritus were involved. So in the EwE model, we treated the zooplankton as the producer and trophic level was 1 in order to avoid repeat calculation.

Results and discussion

Water quality and LTL conditions change

The East China Sea (ECS) is one of the major marginal seas of the northwestern Pacific. Many rivers, including the Changjiang River (Yangtze River), provide a substantial input of freshwater and nutrients into adjacent seas (Zhao and Guo 2011). On the other hand, the ECS also receives water and associated nutrients from the South China Sea through the Taiwan Strait, for which the volume transport is greater than river discharge into the ECS by as much as two orders of magnitude (Isobe 2008). In addition to the Taiwan Strait, Chen (2008) suggested that the upwelling of the South China Sea water on the western side of the Kuroshio in the ECS is also a possible pathway for the nutrients transported from the South China Sea to the ECS. In our research, we involved all the parameters including 10 rivers, Taiwan Strait water and Kuroshio Current and open boundaries. As there are a lot of parameters which can affect the ecosystem, we only took the nutrition influx from Yangtze River change as one key variables into consideration and kept others fixed for simplification. Therefore, the distribution area of Yangtze River diluted water should be identified to confirm

Fig. 5 Simulation result of surface distribution of Yangtze River water in different season

Fig. 6 Simulation result of surface distribution of Zooplankton in ECS in different months

the study area for the ecosystem where was affected by Yangtze River mostly. In Fig. 5, we traced the surface distribution of Yangtze River water in different season by MEC model. Based on this, the study area of EwE model was determined as the red box area in Fig. 1.

There are strong seasonal variations in the spatial distribution of nutrients in the ECS. The concentration of

surface nutrients in the ECS is high in winter, is depleted in spring and summer, and reverts smoothly in autumn to the winter concentration (Chen 2009). Such seasonal variations are tightly coupled to biological processes such as plankton blooms in spring and summer and the remineralization of detritus in autumn as well as to physical processes such as summer stratification and winter mixing in Fig. 6. Then by dealing with the spatial 3D data of zooplankton concentration, the seasonal variation of relative biomass change of zooplankton which would be used as production rate of forcing function was obtained in Fig. 7.

Nutrients concentrations of the Yangtze River increased 260, 67 and 914 % from 1970 to 2000 as shown in Fig. 3. Then we employed MEC model to calculate the concentration change of nutrient and low trophic species from 1970 to 2000. Five calculations were employed in 1960, 70, 80, 90, and 2000. All calculations were assumed that the boundary conditions kept the same and the only variable parameter was the nutrition influx concentration change of Yangtze River. The long-term changes of

Fig. 7 Seasonal variation of relative biomass of zooplankton

Fig. 8 Comparison of climatology and simulation for annual-mean nutrient concentration and DO (bottom)

Fig. 9 Surface distribution of chlorophyll-a (left) simulation; (right) satellite image (MODIS)

calculated annual-mean concentrations of nutrient and dissolved oxygen are compared to observation data in the estuary area of Yangtze River from 1975 to 1995 in Fig. 8. The relative relationships of DIN in values are in good agreement and the tendency of DO also keep the same. The spatial distribution trends for the summer season surface layer chlorophyll a (Fig. 9) was also well reproduced.

The average concentrations of PO_4 , NH_4 , and NO_3 in ECS will increase 3, 27, and 190 %, respectively, in the

Fig. 11 Simulation result of relative biomass change of high trophic level species under different scenarios. Scenario **a** inter-annual variation of nutrient influx change from Yangtze River is considered, **b** only fishery influence is considered, and **c** both of nutrient influx change and fishery influence are considered

Target area for EwE model. At the same time, the annual biomass of zooplankton, phytoplankton and detritus will increase 10.5, 8.6 and 11.6 % (Fig. 10).

Fig. 10 Nutrient concentration change in the target area for EwE model (*up*); plankton and detritus concentration change in Target area for EwE model (*below*)

Table 1 Overall ecosystem data of ECS

	Group name	Trophic level	Biomass (ton/km ²)	P/B (year ⁻¹)	C/B (year ⁻¹)	Ecotrophic efficiency	Landings
1	Marine mammals	3.32	0.00404	0.05	30.0	0.00	
2	Sharks	3.70	0.00820	0.50	3.20	0.107	0.000440
3	Hairtail	3.19	1.65	2.58	9.00	0.0770	
4	Yellow croaker	3.08	0.460	2.39	8.00	0.0563	
5	Congers	3.38	0.722	2.30	8.00	0.0814	0.103
6	Filefish	2.74	0.475	2.50	15.5	0.0567	0.0500
7	Mackerels	2.30	0.460	2.30	9.40	0.287	
8	Scads	2.30	0.593	2.30	14.9	0.139	
9	Pomfrets	2.25	0.470	2.32	12.5	0.266	0.195
10	Spanish mackerels	2.45	0.543	2.50	9.10	0.167	0.129
11	Anchovy	2.10	0.672	3.00	18.0	0.620	0.144
12	Cephalopods	2.41	0.492	3.00	10.0	0.294	0.0990
13	Other commercial fishes	3.17	1.73	2.30	10.0	0.391	0.505
14	Small fishes	2.50	4.02	2.30	24.0	0.778	0.252
15	Shrimps and crabs	2.66	5.10	3.90	15.0	0.936	
16	Acetes	2.00	7.24	7.00	27.0	0.943	0.203
17	Jellyfish	2.00	0.849	5.00	20.0	0.873	0.0890
18	Benthos	2.00	14.2	5.00	20.0	0.949	
19	Zooplankton	1.00	7.4	45.0	160	0.950	
20	Phytoplankton	1.00	25.6	200	0.00	0.217	
21	Detritus	1.00	193			0.0871

The influence on the HTL of ecosystem

The whole ecosystem was divided into 22 function groups in Table 1. The ECS ecosystem is dominated by low trophic level groups which represents more than 90 % of total biomass. The landings data was based on references and was changed in accordance with fishing effort showed in Fig. 4 (right). For the *Yellow croaker*, *Hairtail*, *scads*, *Mackerels*, shrimps and crabs, the fishing data came from capture yield in Fig. 4 (left) because of the drastic changing and inconsistent with fishing effort.

Three scenarios were engaged into discussion: (a) inter-annual variation of nutrient influx change from Yangtze River is considered and fishing influence is ignored (b) fishing influence is considered and fixed nutrient influx of year is used, and (c) both of nutrient influx change and fishing influence are considered. The simulated results for each scenario are shown in Fig. 8. In case (a), the biomass of high trophic level will increase varying from 5 to 10 %, especially in which most of trophic level 2–3 creatures will raise about 10 % on account of the increase of primary production. Compared with the rapid increase of nutrient concentration, the increase range of plankton was not so obvious because of the limit of space and other physical condition such like DO. If only concerning the fishing (b), the result suggested that *Yellow croaker* was under serious overfishing and almost extinct after 1975 and *Hairtail* as the main fishing product of ECS was also under drastic pressure and close to extinct, particularly from 1990 to 2000 due to a linear increase of capture yield. On the contrary, small fish and anchovy increased about 30–40 % rapidly due to the decline of predators. The main fish production decrease significantly, average trophic level degrade and small fish take the main position of the ecosystem. In case (c), yellow croaker has the same fate with case (b). But compared with almost extinct under the scenario of only fishery, the biomass of *Hairtail* reduced about 40 % and *scads* reduced 30 % in this scenario which is closer to the true circumstance (Cheng and Yu 2004). The shrimp and crabs still were under sustainable exploration and had more potential in spite of rapid increase of fishing. All indicated that the nutrition input increase from Yangtze River has a certain influence for the ecosystem to slow the declining tendency. The increase of nutrient influx provided larger primary production and improved the tolerance of the ecosystems.

The seasonal variation showed that peak value of most pieces occurred in summer and autumn because of the zooplankton boom. But the fluctuation range of LTL species (*Jellyfish*, *Acetes*, *Anchovy*, etc.) was greater than HTL species (*Yellow croaker*, *Hairtail*, *Congers*, etc.) because the LTL species preyed on plankton directly. It meant that the seasonal variation of plankton has a

greater impact on the LTL species rather than HTL species (Fig. 11).

Conclusion

In this study, by integrating LTL and EwE models, we analyzed the impact of nutrient fluxes change from Yangtze River and fishing influence on the ecosystem of ECS. MEC model embedded with LTL-model was used to calculate the temporary and spatial distribution of plankton, nutrient and detritus under the condition of Yangtze nutrient fluxes in 1960, 70, 80, 90, and 2000. On the basis of this, we transfer the temporal varying 3D data obtained by MEC model to spatially and temporally integrated data, and fit out the long-time fluctuation of low-trophic level ecosystem during 40 years. EwE model was used to simulate the marine ecosystem dynamics through taking the fluctuation of low-trophic level variables and fishing data as the forcing functions. The results show that the main fish production decrease significantly, average trophic level recession and small fish take the main position of ecosystem. But the increase of nutrition input has a certain influence for the ecosystem to slow the decline tendency. The seasonal variation shows that peak value of most pieces occurs in summer and autumn because of the zooplankton boom.

In this study, we only take the river flux in consideration as the environmental factor but it is possible to involve more factors such as climate change. In conclusion, the integrated model provides a prospect that we can study the entire ecosystem from the prospective of both environmental and fishery factors, extending from lower to higher ecosystem, to achieve a top-down and bottom-up management.

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