ECOLOGICAL MODELLING 202 (2007) 132–143

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Application of a lower trophic level model to a coastal sea ecosystem

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ARTICLE INFO

Article history:
Published on line 13 November 2006

Keywords:
Ecosystem modelling
NEMURO
Japan Sea
Nutrients
Peter the Great Bay
Phytoplankton
Zooplankton

ABSTRACT

Two years of environmental and plankton monitoring data observed at a station located in the coastal zone of Peter the Great Bay (Japan Sea) are used to study the seasonal development of a pelagic ecosystem. The functioning of the lower trophic levels was approximated with a semi-empirical ecosystem model based on the set of differential equations of NEMURO LTL model including nutrients, phytoplankton, and zooplankton. Advective fluxes were parameterised because of the strong cross-shelf circulation in the area driven by monsoon winds. Realistic results were obtained with variable coefficients of growth, grazing and mortality instead of constant coefficients. The coefficients' variability takes into account seasonal fluctuations of species composition and plankton ontogenic changes. Lack of a bacterial component in the NEMURO-based model was compensated by very high production of phytoplankton. Horizontal advection was important for nutrients export from the coastal zone in summer, for herbivorous zooplankton transport into the area in spring and autumn, and controlled predatory zooplankton abundance throughout the period of investigation.

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1. Introduction

NEMURO, the North-Pacific Ecosystem Model for Understanding Regional Oceanography, is a set of differential equations quantitatively describing interrelations between components of low trophic levels of marine pelagic community and their exchange with hydrochemical environments (Kishi et al., 2007). Concentrations of biological and mineral components are variable in the model, some changeable external parameters as light intensity and water temperature represent a physical forcing, but over 70 ecological parameters are considered as constants. Their values are based on a wide background of experimental data and theoretical estimates, and are slightly different for certain regions of the North Pacific but have no time-dependent fluctuations.

The coastal zone is characterized by strong spatial and temporal inhomogeneities caused by terrestrial influences. The functioning of coastal sea ecosystems changes dramatically from season to season in moderate latitudes. Some components, such as phytoplankton, completely change their species composition several times in a year, and zooplankton populations change their age composition. Additionally, the coastal zone is a region of active exchange between the shallow and deep-water sea and its circulation is strongly wind-driven. Under these circumstances, it is reasonable to explore the approximations implicit in NEMURO and its implementation as a box model. Can constant values of the coefficients for photosynthetic rate, mortality, grazing and others be used? Are the horizontal exchange processes important for the coastal pelagic ecosystem functioning? These questions are addressed in the study.

The approach taken is to solve for the main ecological parameters by testing NEMURO against a set of observation data and by considering the balances of the main components

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0304-3800/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolmodel.2006.07.044

of the ecosystem. For this purpose, NEMURO was partially reformulated and a semi-empirical modelling of the marine pelagic ecosystem in a coastal area of the Japan Sea was carried out with the following objectives:

- describe its structure and function on the base of observed data;
- estimate departures of the main empirical ecological coefficients from their standard NEMURO values and analyze the reasons;
- analyze the applicability of NEMURO-like models for coastal ecosystem modeling.

2. Materials and methods

2.1. Area description

The northern Japan Sea has many characteristics of subarctic waters, with large seasonal variability reinforced by a monsoon climate. There is active convective mixing in winter when sub-0 °C waters occur in the mixed layer and sea ice forms. During summer stratification, the surface layer temperature can exceed 20 °C while the subsurface layer is about 1 °C. The spring bloom of phytoplankton is an important feature of the ecosystem in the northern Japan Sea. It develops in April with the onset of seasonal summer stratification, but ceases abruptly as stratification strengthens and the supply of nutrients is exhausted. However, blooms continue in the coastal zone in summer, sometimes with short breaks (Stonik and Orlova, 1998). The coastal zone is interpreted here as an area strongly influenced by terrestrial processes, particularly fresh water and nutrient inputs. Eutrophication is a common feature in coastal areas, and the cause is often explained by nutrients of terrestrial origin. These areas are located in the large bays of Asian coast, such as Chosonman, Peter the Great Bay, and in the Tatar Strait. Waters along the Primorye coast have a specific "shelf" regime without significant terrestrial influence (Zuenko and Yurasov, 1995).

A monitoring point was located in the central part of Peter the Great Bay (Fig. 1), where the physical and chemical conditions and plankton composition are quasi-homogeneous spatially. However, this area has a significant exchange of both inorganic and organic substances with the open sea. This exchange is supported mainly by wind-driven circulation caused by monsoon winds. South and southeast winds prevail in summer when their frequency of occurrence is 74% on average. During winter, north and northwest winds dominate (73%). As a result, a cross-shelf water circulation pattern is established in summer with on-shore transport in the surface layer and compensatory off-shore transport in the subsurface layer. The opposite circulation pattern develops in winter. The transport volume depends on the strength and duration of wind.

The species composition of plankton and its environment are uniform over the whole coastal zone, so the general features of the ecosystem's function are similar throughout this zone. On the other hand, the advective contributions to the ecosystem should be considered by taking 3D wind-driven circulation into account. Thus, the quantitative results of the study of one station may not perfectly represent any large region, but the main principles could be understood based on these results.

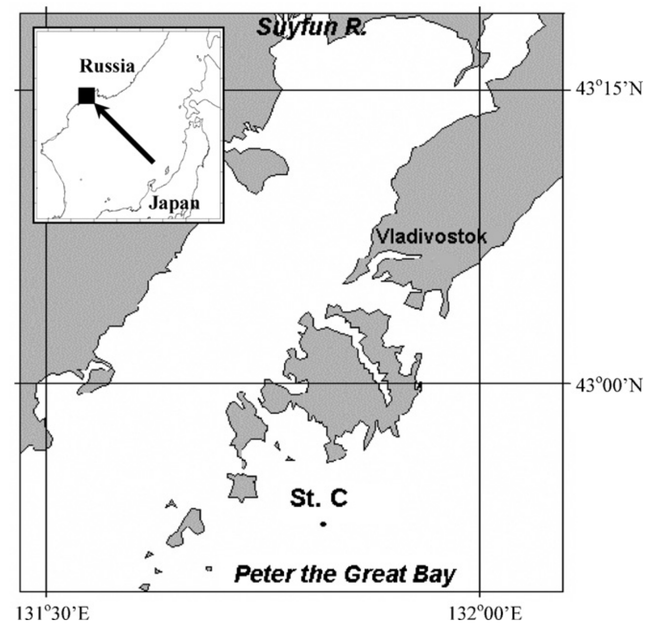

Fig. 1 – Station location in the coastal zone (Station C).

2.2. Model description

The one-dimensional NEMURO lower trophic level (LTL) model (Kishi et al., 2007) includes 11 components: two mineral nitrogen forms, two phytoplankton forms, three zooplankton forms, two organic nitrogen forms, and organic and mineral silicate. Nitrogen and silicate are not limiting in the coastal zone. So, phosphorus fluxes are considered in this study instead of nitrogen and silicon. Besides, large zooplankton biomass is insignificant in the coastal waters of Peter the Great Bay, so the whole herbivorous zooplankton community could be considered as one component, Z. If phosphorous is considered as the model unit of currency then NEMURO could be simplified to seven components: large phytoplankton (PL), small phytoplankton (PS), herbivorous zooplankton (Z), predatory zooplankton (ZP), dissolved organic matter (DON), particle organic matter (PON), and dissolved phosphates (Fig. 2). Five of them were measured: PL, PS, Z, ZP, and phosphates. Note that NEMURO does not include bacteria and phytoplankton is regarded as the only food for herbivores.

NEMURO, in its 1D variant, is represented as a closed ecosystem, with exception of vertical migration of large zooplankton and vertical nutrients exchange between the modelled euphotic layer and the deeper layer. These vertical fluxes are not required to represent the coastal zone because the whole water layer is considered as the modelled volume. On the other hand, the high spatial inhomogeneity of the coastal zone should be taken into account. That is why terms for cross-shelf advection are added to the equations of the

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