Dynamical impacts on marine ecosystem of coastal and marginal seas around Japan

ZHANG, XU

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論文内容の要旨

氏　　名　　　　　ZHANG XU

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論文題目（外国語の場合は，その和訳を併記すること。）

Dynamical impacts on marine ecosystem of coastal and marginal seas around Japan

（日本の沿岸および周辺海域における海洋生態系への力学的影響）

指導教員　　　　　内山雄介

Ocean covers over 70% of the Earth’s surface and is among the most productive ecosystems in the world. Marine ecosystem is an open system that is affected by currents, seasons and other oceanographic processes and provides essential goods and services for human being. Japan is an island country in East Asia situated in the northwest Pacific Ocean, where the local marine ecosystem is broadly influenced by anthropogenic and biological process in coastal and marginal seas.

The Seto Inland Sea (SIS) is the largest semi-enclosed estuary in Japan. The Kuroshio has a considerable impact on the SIS circulation due to sporadic intrusions and meandering of the Kuroshio path. This area is taken out for the current study about anthropogenic impacts on the marine ecosystem, because approximate 24% of Japan's population resides within its watershed basins, leading to heavy nutrient loading of the SIS and thus an increased occurrence of harmful algal bloom. The Tarumi Sewage Treatment Plant (TSTP), one of the largest wastewater treatment plants in Osaka Bay, is located near the narrow Akashi Strait with complex tidal flows, having possible impacts on seaweed farming. On the other hand, the natural biological processes have more extensive and complex impacts on the marine ecosystem. Carbon exchange between the atmosphere and ocean substantially regulates the climate change. The biogeochemistry controls and feedbacks on global ocean primary productivity. Carbon cycling in the coastal waters is a major component of global carbon cycles and budgets. The Kuroshio is one of the most energetic western boundary currents accompanied by vigorous eddy activity at mesoscale and submesoscale, significantly affecting the primary productivity in the Kuroshio Region (KR) and Kuroshio Extension (KE) regions. Historically, there are abundant researches concerning the influences of vertical nitrate transport on the primary productivity. However, studies on the seasonal variability of the primary production in the KR and KE are limited particularly in conjunction with the Kuroshio currents affected by the ridge topography in the KR.

Nutrient transport is one of key influencers in the marine ecosystem. We consider the nutrient source from two major aspects, sewage from treatment plant located in estuary and upward entrainment to surface layer from subsurface in the open sea area. The sewage transport is noticeably affected by the tidal current in estuarine region. By contrast, the vertical eddy-induced nutrient upwelling is an essential source to maintain the primary production, further affecting human being’s life on global scale. Therefore, the researches concerning primary production in the coastal seas are important for marine ecosystem-based management, spatial planning for the future. In the present study, we aim to examine possible driving mechanisms in Osaka Bay, an estuarine area with densely population. We also quantify the impact of the diversion of sewage effluent on the seaweed farm and possible improvement with different discharge operations to examine the anthropogenic effect on marine ecosystem. In addition, to understand the biological processes in the coastal seas, we analyze the seasonal variability of the eddy-driven vertical nutrient fluxes that play essential roles in maintaining the upper-ocean primary production, as well as its driving mechanisms in the KR and KE regions.

In Section 2, we developed a quadruple-nested, high-resolution model with a horizontal of 20 m based on Regional Oceanic Modeling System (ROMS). A Eulerian near-field effluent dilution model was employed to reproduce 3-D advection-dispersion processes of the under-resolved, bottom-released buoyant effluent plume at the TSTP. In addition, in Section 3, we conducted two more alternative scenarios to assess the impacts of wastewater effluents from the standard diversion outfall by reducing the sewage discharge rate and changing the wastewater density. A twin numerical experiment for cases with normal and western diversion outfalls of the TSTP enabled us to quantitatively evaluate the effect of the diversion. The effluent flux budget analysis revealed that the cumulative nondimensional effluent of the seaweed farm is reduced by ~0.81×10^4 m^3 on average compared with that of the normal outfall (~2.83×10^4 m^3), exhibiting a ~28% reduction of the effluent from the TSTP by the diversion, which could lead to favorable influences on the growth of seaweeds. Based on above conclusion, two more operations were set up to analyze the effects of sewage discharge rate and sewage density. We discovered that 16.7% of the wastewater discharge rate decreased from the standard diversion operation resulted in an overall 25.4% reduction in the sewage effluent accumulating on average in the seaweed farm. In turn, the addition of ambient seawater to the freshwater effluent did not substantially alter the effluent accumulation and associated hydrodynamics at the farm.

We have understood the anthropogenic impacts on the marine ecosystem in our research domain. In turn, the natural biological processes are summarized as follows. Carbon cycling in the coastal waters is a major component of global carbon cycles and budgets, further affecting the climate. Therefore, we enlarged our study area to focus on the impacts of upward eddy-induced nitrate transport on the marine ecosystem in the following two sections. Section 4 investigated seasonal variability of eddy fluxes that sustain the upper ocean primary productions and the driving mechanisms behind them in the KR and KE regions. To this end, we conducted a submesoscale eddy-permitting ocean modeling based on ROMS coupled with a nitrogen-based NPZD biogeochemical model, including the KR and KE regions. Furthermore, in Section 5, a synoptic, retrospective downscaling ocean modeling was developed to investigate inter-annual variability of vertical eddy-induced nutrient fluxes, when several large meanders occur in the KR. We found the segmentations of surface chlorophyll-a (Chl-a) on both sides of the Kuroshio with a higher Chl-a concentration on the northern area. Enhanced vertical mixing in winter and subsequent improvement of the light condition in spring results in active primary productions around the Kuroshio both in the KR and KE. The overall upward entrainment from the nutrient-rich subsurface to the nutrient-exhausted surface is substantial for maintaining the near-surface primary productivity. However, a downward eddy nitrate fluxes are found in winter in the upstream (Enshu-nada Sea region) and the downstream regions relative to the ridge in the KR. In winter, the topographic eddy shedding, positive barotropic conversation rate (K_mK_e), and baroclinic conversion rate (P_eK_e) jointly promote eddy-driven downward nitrate fluxes through shear instability and baroclinic instability along the Kuroshio path and its northern side in the KR. In the KE, upward eddy flux due to the combination of positive K_mK_e and P_eK_e enhances the primary production in the upper ocean. By contrast, in summer, the mixed layer depth becomes very shallow and thus makes the upper ocean P_eK_e almost vanish in both KR and KE. Positive K_mK_e and P_eK_e arise mostly at depth beneath the mixed layer, which considerably interact with the ridge topography in the KR to increase in the upstream while decrease in the downstream regions. In the KE, as P_eK_e is prominently reduced in summer, eddy nitrate flux is decreased significantly in particular on the north of the Kuroshio. Therefore, baroclinic instability is the key influencer on seasonal variability in eddy generation near the surface, where vertical eddy mixing is inevitably important to promote the subsurface nutrient supply to the upper ocean. In addition, impacts of the oceanic ridge (Izu-Ogasawara Ridge) are examined in the KR. Turbulence associated with the Kuroshio trends to be less energetic in the upstream, while the ridge generates intensive eddy mixing more broadly and deeply in the downstream mainly due to the interaction between the Kuroshio front and ridge topography that results in mesoscale eddy-generating baroclinic instability. We detected three obvious meanders during our analysis period with the synoptic configuration. When the meander happens in summer, more significant nitrate depletion occurs in the surface layer, resulting in relative weak primary productivity but larger distribution. In the offshore region, mean and transient nitrate flux decreases during the meander, while diffusive flux plays important role in maintaining nutrient upwelling near surface. In the coastal part, mean component is essential for the active primary production during the meandering.