The development of an ecosystem model to reproduce green Noctiluca red tide for the upper Gulf of Thailand

Anukul Buranapratheprat[1], Siraporn Tong-u-dom[2] and Akihiko Morimoto[2]
[1]Department of Aquatic Science, Faculty of Science, Burapha University, Thailand
[2]Center for Marine Environmental Studies (CMES), Ehime University, Japan

Introduction

The upper Gulf of Thailand (Figure 1) is a eutrophic area facing red tide problems stimulated by anthropogenic nutrients. The area is influenced by discharge from major rivers, one of which is the Chao Phraya River, the largest river passing through Bangkok, the capital city of Thailand. Among dominant red tide species, green Noctiluca is an important one that frequently blooms during the southwest monsoon when the river discharge is large, and the wind blows landward. Red tide makes adverse impacts on the coastal ecosystem, shellfish aquaculture, and tourism in the surrounding area (Morimoto *et al*., 2021). It got a lot of public attention when the red tide hit the shoreline making dark green watercolor, a bad smell, and mass mortality of marine animals. An attempt has been made to identify the green Noctiluca bloom in the upper Gulf of Thailand by using remote sensing techniques (Luang-on *et al*., 2022). This research is a great effort to investigate the spatiotemporal variation of the red tide in this area. To understand the mechanism of red tide, we need to apply a sophisticated ecosystem model to simulate its dynamics. A lower trophic ecosystem coupled with a hydrodynamic model is applied to investigate the mechanism of the Noctiluca red tide in the upper Gulf of Thailand. This research will help us understand the eutrophication process in this tropical coastal region.

Procedure

The ecosystem model used in this study is coupled from a combination of a box lower trophic ecosystem model eNEMURO (Yoshie *et al.*, 2011) and a 3-dimensional circulation model POM (Princeton Ocean Model) (Mellor, 1988). In our study area, green Noctiluca is the most significant dominant species of the red tide, which is a mixotroph, an organism that grows as an autotroph and a heterotroph. The eNEMURO model, an NPZD (Nutrient-Phytoplankton-Zooplankton-Detritus) model, needs to be modified to include Noctiluca as a mixotroph in the simulation. The eNEMURO model concept after the modification for Noctiluca (Noc) is presented in Equation 1. It is from combining phytoplankton as the symbiont and zooplankton as the host.

$$d(Noc)/dt = [(\text{Primary Production})-(\text{Respiration})-(\text{Mortality})-(\text{Excretion})]_{\text{Symbiont}} + [(\text{Grazing})-(\text{Egestion})-(\text{Mortality})-(\text{Excretion})]_{\text{Host}} \quad (1)$$

For this preliminary experiment, the parameters for phytoplankton and zooplankton from the eNEMURO model are still used.

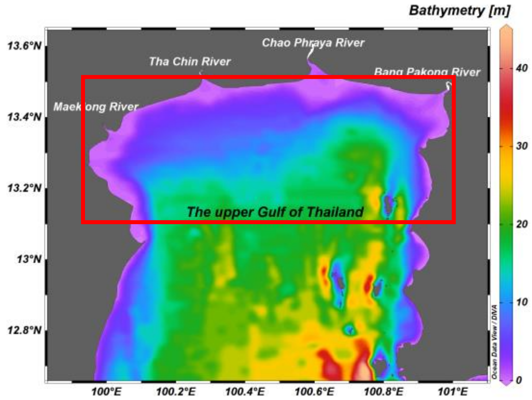

Figure 1 The upper Gulf of Thailand showing water depth in meters, and the eutrophic area in red rectangular used for time series analysis.

Results and discussion

The simulation was operated for two months, in June as the southwest monsoon and in December as the northeast monsoon. Nutrients (dissolved inorganic nitrogen: DIN) from the Chao Phraya River and the Tha Chin River (Figure 2) stimulate the blooming of noctiluca (TNOC) in the north and the northeast of the upper Gulf of Thailand during the southwest monsoon (June). The blooming spread widely in the north with a tendency for accumulation in the northwest of the gulf during the northeast monsoon (December). High DIN at the river mouths changes from the Chao Phraya and the Tha Chin to the Bangpakong and the Maeklong River mouths. This is related to the direction of the current flowing toward the shore or small eddy development that extends the material residence time at each river's mouth (Morimoto *et al*., 2021). Noctiluca can bloom year-round but in different locations following the transport of nutrients from the river mouths depending on monsoonal winds. There are no intense blooms where the nutrient concentration is very high near the river mouth's vicinity. This may be related to other factors inappropriate for the Noctiluca growth such as another limited nutrient, self-shading effect, or the mortality rate of the noctiluca.

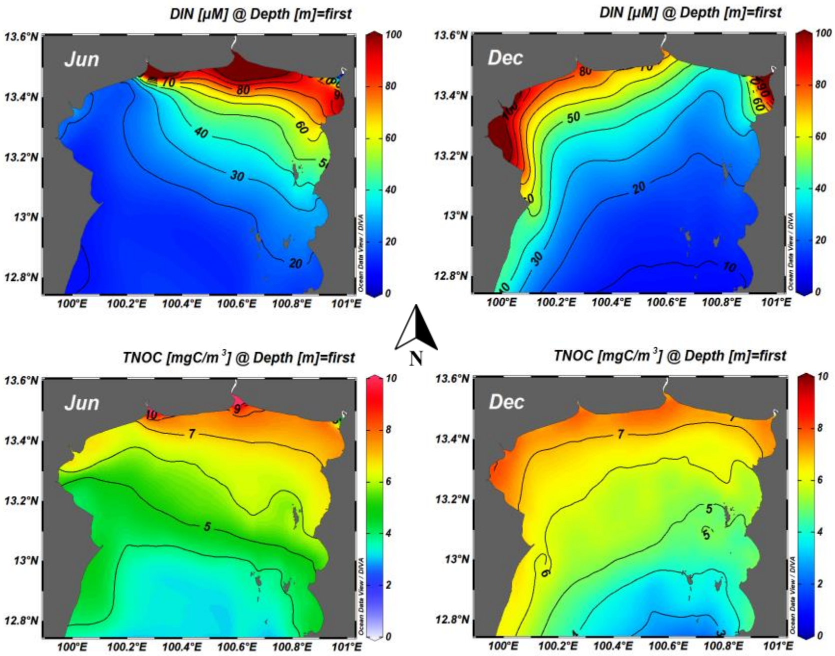

Figure 2 The distributions at the sea surface of DIN and Noctiluca (TNOC) in June (the southwest monsoon) and December (the northeast monsoon).

Time series in an entire year of the standing stocks of small (PS), medium (PM), and large (PL) phytoplankton and Noctiluca symbiont (PNOC) average over the eutrophic area (red rectangle in Figure 1) is investigated (Figure 3). The standing stock of the symbiont is always higher than that of the other phytoplankton combined. The standing stocks are high from July (the rainy season) to November (the early northeast monsoon season) when the river discharge increase. Fluctuation in the standing stock within a month may come from spring and neap tidal effects. This phenomenon is enhanced in the wet season when the river water increases from June to December.

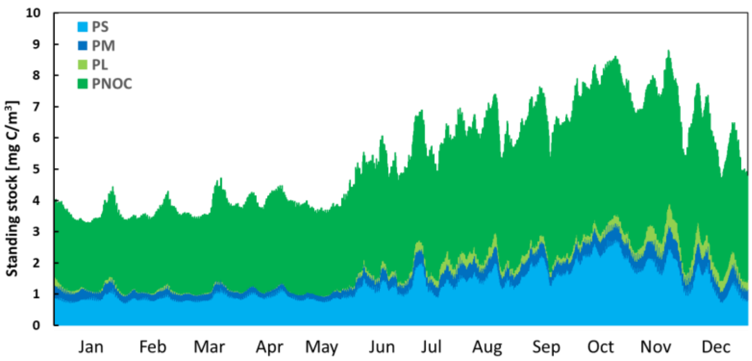

Figure 3 The standing stocks of small (PS), medium (PM), and large (PL) phytoplankton and Noctiluca symbiont (PNOC) average over the eutrophic area of the upper Gulf of Thailand.

Interestingly, the results of the simulation show that the proportion of Noctiluca is greater than that of both phytoplankton and zooplankton combined. No parameter was changed other than the definition of a mixotroph by combining both phytoplankton (PNOC) and zooplankton (ZNOC) into the new component as a variable named TNOC. It is not known exactly what key factors cause simulated Noctiluca to multiply more in an area than other plankton species. This may reflect what happened in nature where a mixotroph can bloom better than other plankton.

This study is just a preliminary experiment on developing an ecological model to incorporate a mixotroph into the calculation. To improve this model to be able to simulate the occurrence of red tide from Noctiluca in the upper Gulf of Thailand, the physiological parameters of Noctiluca and its symbiont, although rare, must be used for more realistic simulation. Noctiluca-specific factors such as cellular buoyancy, salinity, and dissolved oxygen may need to be added to the ecosystem model. The buoyancy of Noctiluca cells is relatively high since the intracellular fluid has a lower density than that of seawater, which may be a significant factor affecting its bloom. Noctiluca prefers relatively high salinity, which can be a limiting factor for blooming in low-salinity areas near the river mouths or during times of unusually high river discharge. This could be an important factor in year-to-year variations. Dissolved oxygen is a factor in the nature of the interaction with plankton bloom that causes hypoxia in the water mass, while hypoxia also limits the bloom of plankton.

Conclusion

Noctiluca as a mixotroph was simulated using a coupled physical-ecosystem model based on the eNEMURO and POM in the upper Gulf of Thailand. The preliminary simulation showed the abundance of Noctiluca was populated in the area greater than other plankton species. The model needs to be improved for a more realistic simulation in the near future.

References

Luang-on, J., Ishizaka, J., Buranapratheprat, A., Phaksopa, J., Goes, J., Kobayashi, H., Hayashi, M., Maúre, E.R., Matsumura, S. (2022.) Seasonal and interannual variations of MODIS Aqua chlorophyll-a (2003–2017) in the Upper Gulf of Thailand influenced by Asian monsoons. *Journal of Oceanog*raphy 78, 209 - 228.

Mellor, G.L. (1998). *User's Guide for a Three-Dimensional, Primitive Equation, Numerical*

Ocean Model. Program in Atmospheric and Oceanographic Sciences Report, Princeton University, Princeton, N.J.

Morimoto, A., Mino, Y., Buranapratheprat, A., Kaneda, A., Tong-U-Dom, S., Sunthawanic, K., Yu, X., Guo, X. (2021). Hypoxia in the Upper Gulf of Thailand: Hydrographic observations and modeling. *Journal of Oceanography* 77, 859 -811. https://doi.org/10.1007/s10872-021-00616-3

Yoshie, N., Guo, X., Fujii, N., Komorita, T. (2011). Ecosystem and nutrient dynamics in the Seto Inland Sea, Japan. Interdisciplinary Studies on Environmental Chemistry—Marine Environmental Modeling and Analysis. TERRAPUB, Tokyo. pp 39–49.

Publication/conference presentation

It was planned to present the preliminary results at a scientific meeting or a conference. The title will be “The development of an ecosystem model to reproduce green Noctiluca distribution in the upper Gulf of Thailand: preliminary results”

Perspectives in the future

We will improve the simulation for Noctiluca by including the physiological parameters of Noctiluca and its symbiont, and other limiting factors namely salinity and dissolved oxygen in the model.