10. Numerical Simulations of the Transport Process of Walleye Pollock Eggs into Funka Bay

Manabu SHIMIZU and Yutaka ISODA

Faculty of Fisheries, Hokkaido University, Hakodate, Hokkaido 041-8611, Japan

Introduction

The area south of Hokkaido is well-known as an important spawning and nursery ground for walleye pollock (*Theragra chalcogramma*) in Japan. The spawning season here for walleye pollock commences in December and lasts until late March (Hayashi et al., 1968; Maeda et al., 1976). According to previous work in Funka Bay and its vicinity (cf. Maeda et al., 1979; Nakatani and Maeda, 1981; Nakatani, 1988), adult walleye pollock spawn in the northeastern part of the bay mouth and the pelagic eggs are transported to the inner area of the bay by Coastal Oyashio. However, recent findings showed that walleye pollock eggs and larvae were present there before the Coastal Oyashio Water flows into Funka Bay (Nakatani and Maeda, 1989). This suggests that a different transport process is involved other than transport by inflowing Coastal Oyashio Water. We examined the winter transport of walleye pollock eggs from the spawning grounds to the nursery grounds in winter from the physical point of view, using a barotropic model with the Euler-Lagrange method to track eggs or larvae movements. The specific observations focused on Coastal Oyashio flow structure.

Model and Observation Results

The Period Before Inflowing Coastal Oyashio

An advective model, based on the availability of walleye pollock egg data in February 1987 around Funka Bay (Nakatani and Maeda, 1989), was used to demonstrate the drift of eggs over a twenty day period. At this time, the water in Funka Bay did not have the properties of Coastal Oyashio Water. A model calculation was carried out to assess the physical mechanism which could explain the egg distributions at each stage and to investigate the accumulation of eggs in a specific area within the bay. We used the laboratory results on duration of each embryonic development stage of Nakatani and Maeda (1984) to assign developmental stage periods for the eggs in our model. Current fields generated from a barotropic model driven by winds were used to advect particles seeded every day on the shelf off Funka Bay. Specific features of egg distribution, such as the accumulation of eggs in the central part of Funka Bay in late February, were tracked well by this model. The modeled flow pattern shows that a predominant northwesterly wind in winter is responsible for the formation of the vortex pair within the bay. Their two vortices appear capable of both transporting the early stage eggs from the shelf area and trapping

eggs within the bay (Fig. 1).

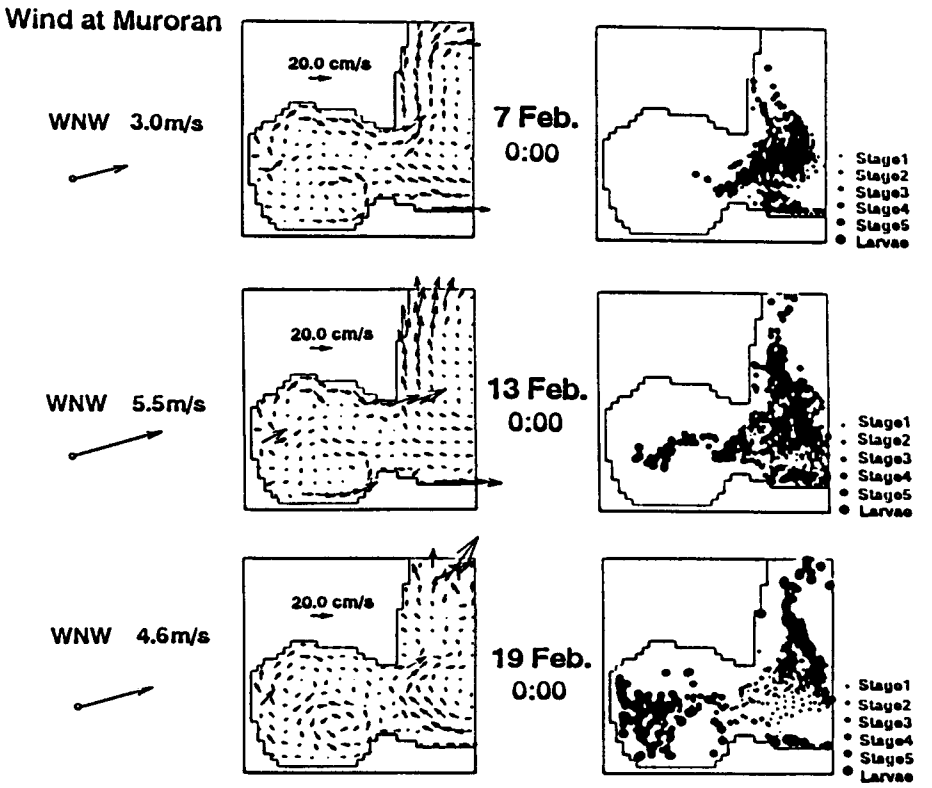

Fig.1. Instantaneous fields of the calculated current vectors(left panel), and the horizontal distributions of modeled walleye pollock eggs/larvae(right panel) at the intervals of six days.

The Period After Inflowing Coastal Oyashio

The water of Coastal Oyashio, composed primarily of cold and low salinity water, flows along the shelf into Hidaka Bay south of Hokkaido from February to March. We carried out CTD and ADCP observations on 5-13 March 1996 to examine its spatial and vertical flow structures. The main axis of Coastal Oyashio lay over the shelf slope along the bottom contour lines and its current structure was almost vertically uniform as in barotropic flow. In addition, the volume transport of about 0.5 sv can be estimated by using a robust diagnostic model calculation. Next, we examined the transport of walleye pollock eggs from the spawning ground to Funka Bay after an inflow event of Coastal Oyashio Water.

A barotropic model can serve as the first approximation because an essential characteristic of Coastal Oyashio has a barotropic flow structure. The results of current and

egg distribution patterns are shown in Fig. 2 (a). The first model case does not include the predominant northwesterly wind in winter, but is only forced by the inflow-outflow condition, i.e., only the Coastal Oyashio flow is represented. The current pattern shows the large anti-clockwise circulation on the shelf/slope in agreement with our observations. In this case, the modeled egg/larvae is only transported from the shelf area to offshore, and is not transported into Funka Bay.

The second model case includes the forcing terms of both wind and inflow-outflow. The results show that a predominant northwesterly wind in winter is necessary for the transport of walleye pollock eggs into Funka Bay. The current and eggs/larvae distribution pattern are shown in Fig. 2 (b). Although the current patterns on the slope show large anti-clockwise circulation similar to the previous case, strong clockwise circulation is formed along the shallower shelf area, and the vortex pair is generated within Funka Bay by wind forcing. Therefore, the modeled eggs/larvae could be intruded into Funka Bay due to such

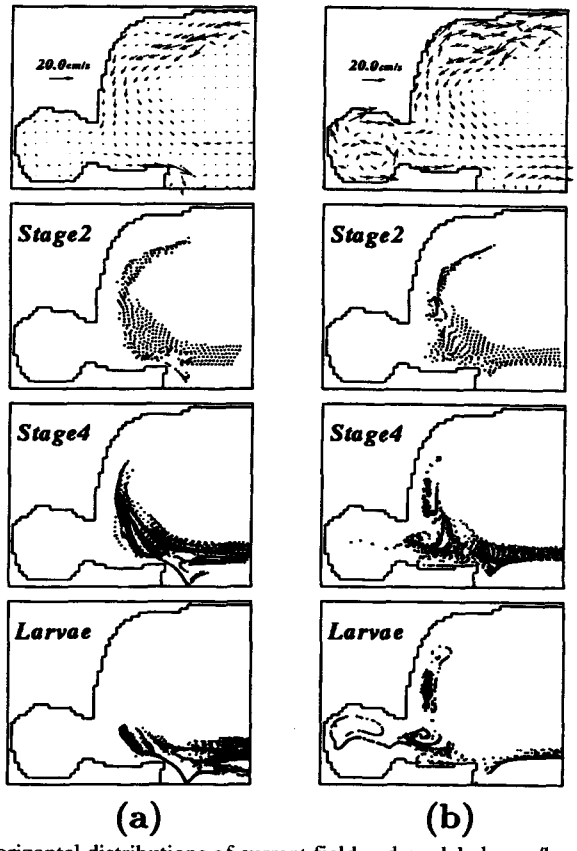

Fig.2. (a) Horizontal distributions of current field and modeled eggs/larvae under the constant inflow-outflow condition calculated by single layer model after 30 days. Model forcing term is only 0.5sv inflow-outflow condition. (b) The same as (a), but model forcing terms of both wind and inflow-outflow conditions. The northwesterly(from left to right in figure) wind, which has constant wind velocity(10m/s), is blowing.

wind-induced currents, and also, the modeled larvae were widely distributed over the shelf area.

Conclusion

We used a barotropic model with the Euler-Lagrange method to examine the transport of walleye pollock (Theragra chalcogramma) eggs from the spawning grounds on the shelf off Funka Bay into the nursery grounds in Funka Bay in winter. The actual features of egg distribution around Funka Bay were compared to those produced by the model before the inflow of Coastal Oyashio Water. Our model and the results of observations showed that Coastal Oyashio Water on the shelf area carries the eggs/larvae into the offshore region rather than into Funka Bay. In spite of the occurrence of inflowing Coastal Oyashio Water, it appears that wind-induced currents generated by a predominant northwesterly wind in winter play an important role in the transport of eggs/larvae into the nursery grounds of Funka Bay. This means that the prerequisite for the transport process is a current generated by predominantly northwesterly winds in winter, rather than an episode of Coastal Oyashio intrusion.

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