Spatial distributions of anchovy larvae and naupliar copepods in relation to frontal eddies

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INTRODUCTION

Cyclonic frontal eddies are often recognized along the frontal area of the Kuroshio and Kuroshio Extension. These eddies may contribute to both upwelling of nutrient-rich deep water and horizontal entrainment of fish larvae into the eddy region.^{1, 2)} The main objective of our study is to look at the effects of frontal eddy on the distribution of anchovy (*Engraulis japonicus*) larvae and their prey organisms.

MATERIAL AND METHODS

Observations of a frontal region of the Kuroshio and the Kuroshio Extension were conducted during May 1997 and May 1999 (Fig. 1). In each observation, temperature and salinity observations were measured with a CTD cast. Larvae were collected using the Ocean Research Institute (ORI) net³⁾ with 1.6 m diameter and 0.33 mm mesh size. The ORI net was towed at the surface for 3-5 min at a speed of 1m/s. Larval samples were fixed in 2.5% seawater glutaraldehyde. Larval prey (mainly naupliar copepods) was collected from the surface water (1-liter) using a bucket simultaneously with the surface net towing. The larval prey samples were fixed in 5% seawater formalin after concentrated by a plankton net with 0.020 mm mesh. In the Kuroshio Extension, observation was conducted along a drifting route of a surface buoy released from the eddy center to trace the time change in the physical

and biological characteristics. Surface water samples (200ml) for determining chlorophyll-*a* concentration were filtered through a Whatman GF/F filter. Chlorophyll-*a* on the filter was extracted in dimethylformamide and then measured using the fluorometric method.

RESULTS

It was inferred from dome shape isotherm distribution along the Enshu-nada Line (St.1-5) that upwelling was induced by a frontal eddy (Fig. 2). Peak of larval anchovy abundance at St. 4 apparently coincided with the periphery of the eddy. However, naupliar copepod densities were low in and around the frontal eddy compared to the most coastal station (St.1, Fig. 2).

On the other hand, Figure 3 demonstrates time changes in the distribution of chlorophyll-*a* concentration and naupliar copepod densities in the surface water of the eddy in the Kuroshio Extension.

Fig. 1 Map of stations during May 1997 and May 1999.

Fig. 2 Surface distributions of anchovy larvae and naupliar copepods (upper panel) and vertical profile of sea temperature (lower panel) in Enshu-nada Sea in May 1997.

During one day tracking of a drifting buoy, we detected a marked upwelling induced by a frontal eddy. Corresponding to the upwelling, concentrations of chlorophyll-*a* were high at first day (Day 0 in Fig. 3), however they gradually decreased with time. On the contrary, naupliar copepod densities on the same stations evidently increased (Fig. 3).

DISCUSSION

Entrainment of fish larvae into the cyclonic eddy as seen in the present study was also reported off Hawaii Island,⁴⁾ off Northern Africa⁵⁾ and in a Kuroshio frontal eddy.²⁾ It should be noted in our results that anchovy larvae were most abundant in the periphery of the eddy in the Enshu-nada Sea. Although detail of the physical mechanism has not yet clarified, divergence of the surface water due to the upwelling at the eddy center may have implication for this larval aggregation.

It has been reported that due to upwelling of nutrient-rich deep water to the surface euphotic zone, primary production tends to be enhanced in the frontal eddy regions.^{1,6)} Further, marked increase of copepod production in the upwelling region has been reported in the coastal area of Izu Islands⁷⁾ and in the Kuroshio frontal eddy.²⁾ Our results in the Kuroshio Extension also show that naupliar copepod abundance in the frontal eddy became about 2-fold during one day. Egg production of smaller copepods such as *Paracalanus* sp. would be enhanced within a few days responding to the increase in food concentration.^{8,9)} This suggests that marked increase in the abundance of naupliar copepods in the frontal eddy could occur within a few days responding to the increase in food concentration.

The survival of larval fish in oligotrophic oceanic water such as the Kuroshio and Kuroshio Extension region could therefore greatly depend on whether and how frequent they encounter with the frontal eddy. Namely, the frontal eddy could prevent the larvae from dispersing to unproductive offshore water by its function of entrainment and entrapment, and provide a favorable feeding ground due to high production induced by upwelling. These functions of the frontal eddy possibly benefit the growth and survival of fish larvae in the offshore open ocean.

Fig. 3 Time changes in the chlorophyll-*a* concentration and abundance of naupliar copepods in the surface water of the eddy center in the Kuroshio Extension in May 1999.

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