論 文 の 内 容 の 要 旨

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論文題目

Studies on larval dispersal processes of large abalone in relation to establishment of harvest refugia

（保護区設定に係わる大型アワビ類の幼生分散過程に関する研究）

Abalone is one of the most valuable fishery resources in Japan, particularly large abalone species. There are three large species in warm current regions (*Haliotis discus discus*, *H. gigantea* and *H. madaka*) and one large species in cold current regions (*H. discus hannai*). The total catch of these species has drastically decreased since 1970. Although artificially produced abalone seeds are released in fishery grounds, the total catch has not recovered. Thus, effective management is needed for the recovery of large abalone populations. Abalone can disperse during their planktonic larval stages. The recolonization through their dispersal is important for the replenishment of depleted populations. One of the restoration measures is the establishment of harvest refugia, which provide recruits to the surrounding area. For the recovery of populations, the refugia should be established or assessed with quantitative methods. Modeling approaches allow simulations of larval dispersal and quantitative assessments of the refugia. In the present studies, larval dispersal processes and establishment of effective harvest refugia were investigated for fishery grounds on three coastal regions characterized by different topographic features, using hydrodynamic and particle-tracking models.

Larval dispersal and establishment of effective harvest refugia of large abalone in a large bay

Suitable locations for harvest refugia of three species (*Haliotis discus discus, H. gigantea* and *H. madaka*) in a large bay (Sagami Bay) were investigated. In the larval dispersal simulations, observed current data were assimilated into the hydrodynamic model, and particles were released at the time of hatching, which was calculated from the estimated time of fertilization/potential spawning and based upon the water temperature. The aims of the study in this chapter were to (1) clarify larval dispersal processes and settlement sites, and (2) evaluate the existing harvest refugium and estimate the suitability of other areas for larval sources in the large bay. The model results for two periods were considered. The results of larval dispersal simulations indicate two different dispersal patterns: (i) transport toward the coast after dispersal offshore, and (ii) gradual dispersal offshore. The estimated settlement sites were the area along the southern coast of Miura Peninsula in the dispersal pattern (i), the area from Otawa Bay westward in both patterns (i) and (ii), and the area located southwest of the existing refugium in the pattern (ii). The refugium was compared with three hypothetical reproductive sources located 1 km north, west, and south of the refugium. During settlement competency, transport success (transport to the area at the depth of adult habitat: 30 m or shallower) of particles released at the refugium was highest (27 to 75%), and suggested that the current location of the refugium is more suitable for a larval source than those of the hypothetical reproductive sources.

Larval supply and establishment of effective harvest refugia of large abalone in a small bay

Larval supply in a small bay (Oshoro Bay) was estimated by simulating larval dispersal inside and in the vicinity of the bay. Inside the refugium, located near the head of the bay, most juveniles of *Haliotis discus hannai* originated from wild individuals, although most adults were artificially produced individuals that had been released in this area. The objectives of the study in this chapter were to (1) estimate the larval supply from both artificially produced and wild individuals into the refugium, and (2) compare suitability of locations for larval sources in a small bay. The larval dispersal simulations were carried out for two periods in the spawning season. In the larval dispersal simulations, observed oceanographic and climatological data were incorporated into the hydrodynamic model, and the abundance of adult abalone was taken into account when estimating the larval supply. The simulation results indicate that the larval supply from the wild adults to the refugium was higher than that from the artificially produced adults. These results were consistent with the high abundance of wild juveniles in the refugium. The majority of larvae from

the refugium were predicted to disperse out of the bay. The larval retention in the bay was estimated to be at least one order higher than that in the refugium. This indicates that the self-replenishment increases if the refugium is expanded to the scale of the bay. The suitability of locations in the head of the bay for larval sources showed little differences among compared sites, and thus the effectiveness of establishing new refugia in this area was expected to be at the same level as the current refugium.

Larval connectivity and establishment of effective harvest refugia of large abalone on an open ocean coast

Larval connectivity among fishery grounds of *Haliotis discus hannai* on an open ocean coast (Sanriku coast) was investigated. In the hydrodynamic model, oceanographic reanalysis data from JCOPE2 was used for forcing. In the particle-tracking model, particles were released at the timings determined on the basis of the spawning dates, which were estimated from the biological field data (i.e. shell lengths of newly settled abalone). The larval dispersal was simulated for two periods during the spawning season. The objectives of the study in this chapter were to (1) clarify the larval dispersal processes, (2) quantify the dispersal distance of larvae, and (3) estimate the larval connectivity among seven fishery grounds on the open ocean coast. The modeled hydrodynamics in the first period showed stormy conditions in which strong southward coastal currents due to the passage of low pressure were followed by a clockwise eddy causing northward coastal currents; the second simulation showed calm conditions in which relatively weak coastal currents ran northward. In the first period, the spawning of *H. discus hannai* appeared to be triggered by the low pressure, and the larval dispersal was estimated to be generally greater than the second period. The larval dispersal pattern in the first period can be expected to occur at times since the route of the low pressure was common for the cyclones that form and develop in the northwestern Pacific Ocean. The mean dispersal distances during settlement competency were less than 40 km in both simulation periods. The model results indicate that abalone in the fishery grounds on the mid- and southern coast exhibit two distinct larval dispersal patterns. The number of connected sites was 3-7 and 2-4 in the first and second periods, respectively. The extent of self-recruitment was generally higher in the second period. This indicates that calm hydrodynamic conditions were favorable for self-replenishment. The extent of self-recruitment was usually higher than that of connectivity with the other fishery grounds. However, poor self-recruitment occurred in some fishery grounds. This implies that the restocking and protection of local resource in a fishery ground does not always lead

to an increase in local recruitment. Two fishery grounds on the northern coast were considered the most suitable locations for harvest refugia.

Previous modeling studies on larval dispersal of abalone were conducted without considering detailed physical and biological field data. Based on the detailed field data, the present studies revealed that large abalone species have two potential patterns in the larval dispersal processes in the large bay and open ocean coast. The extent of larval dispersal was estimated to be greater on the open ocean coast than in the large bay. The simulated larval dispersal processes varied depending on hydrodynamic conditions and local topographic features. Even in the small bay, most larvae could disperse out before reaching competency for settlement. The present studies showed that larvae could be dispersed in kilometers to tens of kilometers. The results imply that local restocking can raise the self-replenishment but does not always result in improvement of the local stock. In the present studies, methods to simulate the larval dispersal processes of large abalone were developed, and the quantitative investigations for the establishment of effective harvest refugia were demonstrated. The findings provided through these studies can be utilized for the improvement of fishery management of depleted large abalone populations.