論文内容の要旨

論文題目 Larval transport of anguillid eels in the Pacific and Atlantic in relation to oceanic environmental fluctuations

（海洋環境変動に関連した太平洋・大西洋に生息するウナギ属魚類の幼生輸送）

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The European and Japanese eel are catadromous fish that migrate back and force between ocean and river. The eel larvae hatched in open ocean are transported by ocean currents from spawning area to the continental shelf during larval phase and recruit to estuaries and coastal waters as glass eel. Glass eel recruitment of both eel species has decreased dramatically during recent decades. It is believed that influence of oceanic environmental fluctuations on larval transport is one of the most important causes of their decline. However, it is not known what is the main cause of their recruitment decline and relation between recruitment decline and oceanic environmental fluctuations.

In this study, we set revealing effects of oceanic environmental fluctuations on larvae during early life stage and subsequent recruitment for the Japanese eel in the Pacific and the European eel in the Atlantic as goals. First, larval duration of both species were estimated using Lagrangian simulations. Larval duration for the European eel especially is controversial because the estimation of it can vary between 6 months and more than 2 years depending on the method of analysis. Additionally, for the European eel, whether low ambient temperature of larvae can explain the underestimation of larval duration using otolith microstructure analysis were tested. This information is a prerequisite to a

better understanding of the effects of the oceanic environment on those eel larvae and subsequent recruitment. Second, it was investigated that whether oceanographic conditions encountered by the Japanese eel larvae during their early life stages may explain the patterns of variability and the decline in glass eel recruitment. Third, we analysed the effects of the oceanic environmental fluctuations in the North Atlantic on the European eel recruitment. Finally, a general conclusion is made from the findings of these studies.

Estimation of larval duration

Mean duration of larval stages in certain species has been estimated by cohort analysis, otolith microstructure analysis and Lagrangian simulations. Some previous studies indicated that the age of otoliths appears to be underestimated in anguillid species because of the decrease in the number of increments caused by low ambient temperature. Using Lagrangian simulations, we estimated the mean larval duration and the number of otolith increments during the larval stage dependent on ambient temperature of the European eel (*Anguilla anguilla*) and the Japanese eel (*A. japonica*). Lagrangian simulations were performed using an Ocean General Circulation Model for the Earth Simulator (OFES) developed by the Frontier Research System for Global Change in the Japan Agency for Marine–Earth Science and Technology. The mean larval durations were estimated as approximately 2 years in the European eel and 7 months in the Japanese eel. Larvae are transported from the spawning to recruitment areas where temperature are within a range of 13.0ºC-22.5ºC in the European eel and 20.0ºC-27.0ºC in the Japanese eel. The number of increments dependent on ambient temperature was estimated to be 313 in the European eel and 208 in the Japanese eel. These estimated values corresponded with otolith microstructure analyses in both species. We suggested that, larval duration only based on otolith microstructure analysis can be underestimated, and that durations of the larval stage confirmed by otolith increment depend on ambient temperature are approximately 2 years in the European eel and 7 months in the Japanese eel.

The effects of oceanic environmental fluctuations in North Pacific on the Japanese eel (*Anguilla japonica*) recruitment

The spawning area of the Japanese eel is situated in the North Equatorial Current (NEC) west of the Mariana Islands. After hatching, larvae are transported westwards by the NEC which bifurcates off the east coast of the Philippines into the north flowing

Kuroshio and the south flowing Mindanao Currents. Only larvae that enter the Kuroshio can migrate successfully to the normal yellow eel growth habitats. Thus, the bifurcation could be an important oceanic structure related to larval transport and ultimately, recruitment of the Japanese eel. Its precise structure and its effects on larval transport, however, have not yet been clarified. The purposes of the study in this chapter, therefore, were to investigate interannual variability of the NEC-bifurcation and to estimate the proportion of larvae transported from the spawning area into the Kuroshio by a Lagrangian numerical simulation of particle transport. Moreover, by investigation relationship between interannual variations of the NEC-bifurcation latitude and glass eel recruitment index, important factors that might control recruitment success of the Japanese eel can be clarified, such as the El Niño-Southern Oscillation (ENSO). To clarify latitudinal fluctuation of the NEC bifurcation, the NEC-bifurcation latitude was defined as the position where the averaged meridional velocity in the 2º longitude band along the eastern coast of the Philippines is equal to zero, the Kuroshio as northward flow and the Mindanao Current as southward flow. The movement of the NEC-bifurcation latitude was significantly correlated with the Southern Oscillation Index (SOI) ($r = –0{\cdot}40$, $p < 0{\cdot}01$). Simulation showed that the number of particles transported from the NEC to the Kuroshio tended to be lowest during El Niño years, and differences between La Niña and regular years were small. Testing for synchrony showed a significant negative correlation between recruitment index in Tanegashima island and time series of the NEC bifurcation latitude ($r = 0.61$, $p < 0.05$). These results suggested that the bifurcation could be related to larval transport and northward change of the NEC bifurcation latitude during El Niño in negative SOI negatively affect the Japanese eel recruitment. Because NEC bifurcation latitude is on a northward trend over the 50 years ($\tau = -0.40$, $p < 0.01$), downward trend in glass eel catch appears to be correlated with the NEC bifurcation latitude.

The effects of oceanic environmental fluctuations in North Atlantic on the European eel (*Anguilla anguilla*) recruitment

The decline in the European glass eel recruitment is alarming. This species has been listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora regarding its current level of abundance. Thermal fronts in the Sargasso Sea act as cues that help adult eels locate the spawning area. In addition to, temperature at surface can be a useful indicator of nutrient availability in this area. Hence, temperature fluctuation in this area affected the European eel recruitment though larval survival caused by starvation and by unfavorable currents that prolong the duration of oceanic migration. In the present analysis, horizontal and vertical thermal structure and

its temporal fluctuations in all of the Sargasso Sea were investigated based on CTD data over 45 years. Secondly, the relationship between the recruitment of the European glass eel and temperature descriptors related to transport and food availability. In order to investigate relationship between recruitment and oceanic environment, the four time series of glass eel recruitment were used from ICES, Ems in Germany, Den Oever in the Netherlands, Loire in France and Nalon in Spain. Temperature data in the Sargasso Sea (10ºN-40ºN, 40ºW-80ºW) were obtained from World Ocean Database 2001 (WOD01) web site in National Oceanographic Data Center. Above 100m depth, three water mass in the Sargasso Sea, that is area of the thermal front and its north-south, were horizontally defined by thermal structure. Temperature of three areas has increase since 1960, with interannual fluctuations. A negative relationship was found between fluctuations in sea temperature (2-4years lagged) and in recruitment indices over the period 1961–2004. Especially, significant negative relationships were confirmed area of the thermal front and its southern area where the European eel spawn. The results of the regime shift detection show that positive regime shift occurred from 1976 to 1980 in the Sargasso Sea temperature. The sequential regime shift detection showed a negative shift in all glass eel recruitment indices in 1980-1982. These results suggested that linkages between recruitment decline with fluctuation of the European eel and change of Sargasso Sea temperature though early larval development. Significant negative correlations were found using a 2 or 3-yr delay between recruitment and temperature time-series. In our analysis, this time lag accounts for transatlantic migration, metamorphosis, and estuarine arrival as glass eel. This is consistent with estimates of larval duration in this study.

On the whole, this study revealed that recruitment of the European and Japanese eel are affected by oceanic environmental fluctuations. The findings provided through these studies can be utilized for the resource management and recovery of eel populations.

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