Shingo Kimura, Takashi Inoue and Takashige Sugimoto
Ocean Research Institute, University of Tokyo, 1-15-1,
Minamidai, Nakano, Tokyo, 164-8639, Japan.

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Fluctuation in Larval Transport of the Japanese Eel Associated with Global Oceanic – Climatic Changes

Abstact

Surface water in the North Equatorial Current (NEC) is composed of southern low-salinity water diluted by precipitation less than 34.2 psu and northern high-salinity tropical water greater than 34.8 psu. Obvious salinity front (34.5 psu) generated by the two water masses was usually located around 15°N. Effect of El Niño / Southern Oscillation (ENSO) on salinity distribution was confined in the surface layer, while that on temperature appeared in the middle layer. Location of the salinity front sometimes moved southward largely south of 5°N and the southern oscillation index (SOI) was well correlated with the movement. Since precipitation fluctuated with SOI, this spike-like southward movement of the salinity front was probably affected by reduction of low-salinity water area during El Niño in the northwestern Pacific Ocean. This salinity front is quite important for long-distance migrating fish such as the Japanese eel because the eels spawn eggs at just south of the salinity front in the NEC. This behavior suggests a possibility that the movement of the salinity front associated with ENSO controls abundance of larval transport from the spawning ground in the NEC to the nursery ground in East Asia. In fact, catch of the Japanese eel larvae in Japan well corresponded to the fluctuation of SOI and location of the salinity front, and lower catch occurred during El Niño. The salinity front has moved from 13°N to 17°N during the last three decades. Considering worse condition of larval transport north of 15°N, it is suggested that the decadal scale linear decreasing of glass eel catch during the last three decades can be explained by the displacement of the salinity front.

Key words: Larval transport, Japanese eel, Salinity front

In the western equatorial Pacific, fresher water less than 35.0 psu distributes to north and south of the equator and it is termed "fresh pool", while the fresher water distributes to only north of the equator in east of the dateline[1-5]. Salinity minima less than 34.3 psu in the fresh pool in the northern hemisphere are located at 6-8°N[6,1] and spreading into the North Equatorial Current (NEC) region[7]. This southern low-salinity water less than 34.2 psu diluted by precipitation composes the surface NEC water with high-salinity water greater than 34.8 psu caused by excessive evaporation (North Pacific Tropical Water; NPTW). In the far western tropical Pacific, obvious salinity front (34.5 psu) generated by the two water masses was usually located around 16°N[7]. The NEC is well known as a broad westward current flowing between 8-18°N and bifurcating into the northward stream "the Kuroshio" and the southward stream "the

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Mindanao Current" off the east of the Philippine Islands with an approximately same ratio of volume transport(8,9).

The western region of the NEC is the most important area for fish where spawning ground is located around upstream of the NEC because their eggs and larvae receive passive transport effect of the current. A mysterious long-distance migrating fish, the Japanese eel *Anguilla japonica*, spawns their eggs just south of the salinity front in the NEC (Figure 1) and its larval transport in the NEC seems to control abundance of the eel distributed to the eastern Asian countries, as shown in Figure 2, which is a result of numerical simulation of the larval transport(10). In a word, they can recognize the spawning ground when they reach the salinity front. Therefore, year – to - year fluctuation of the salinity front may be a significant factor to understand fluctuation of their stock abundance. In this paper, we discussed physical oceanographic structure in the western NEC focusing to relationship with El Niño / Southern Oscillation (ENSO) events and clarified their effects on the larval migration of the Japanese eel, particularly recruitment success for the stock.

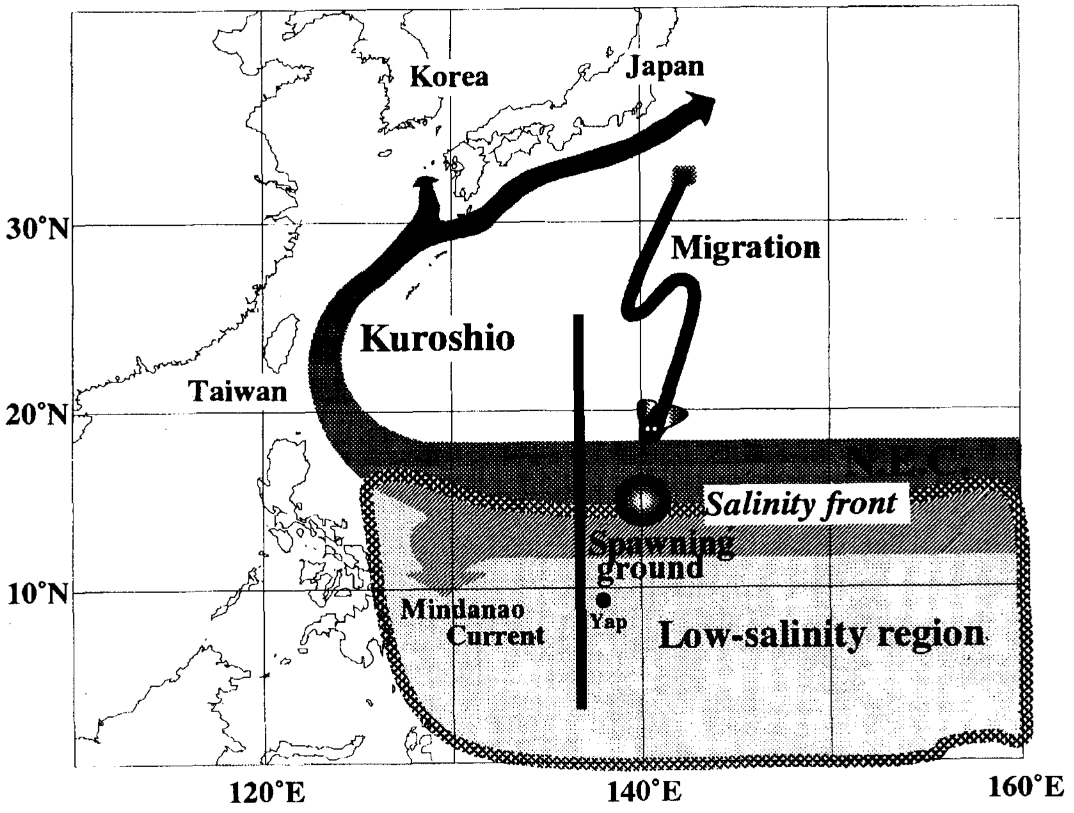


Fig. 1. Observational location and schematic view of ocean circulation in the western North Pacific.

Data and method

Hydrographic surveys observing temperature and salinity have been conducted along 137°E from the coast of Japan (34°N) to Papua New Guinea (1°S) by the Japan Meteorological Agency (JMA). Data in winter and summer cruises during 1972-1998 upper 300m depth were used for most of analyses in this study to describe meridional distribution of low-salinity water in the upper ocean. Observational locations used in this paper and schematic view of ocean circulation in the western North Pacific are shown in Figure 1. Catch of the Japanese eel larvae in the Kagoshima Prefecture was used as data representing relative stock abundance of the glass eel in the East Asia. The Kagoshima Prefecture is located southern part of the Japanese island and the catch data seems to be much more reliable than other downstream regions. In addition, total catch of the larvae at most of Japanese rivers and river mouths was also used to estimate general tendency of the larval eel population. This data is summarized in Annual Statistical Report on Fisheries and Aquaculture Production published by the Ministry of Agriculture, Forestry and Fisheries of Japan.

Mean vertical structures of temperature and salinity along 137°E

Sections of 27-year averaged temperature and salinity with their standard deviation in upper 300m depth along 137 °E crossing the NEC (8-18 °N) and North Equatorial Countercurrent (NECC, 2-8 °N) are shown in Figure 3[11].

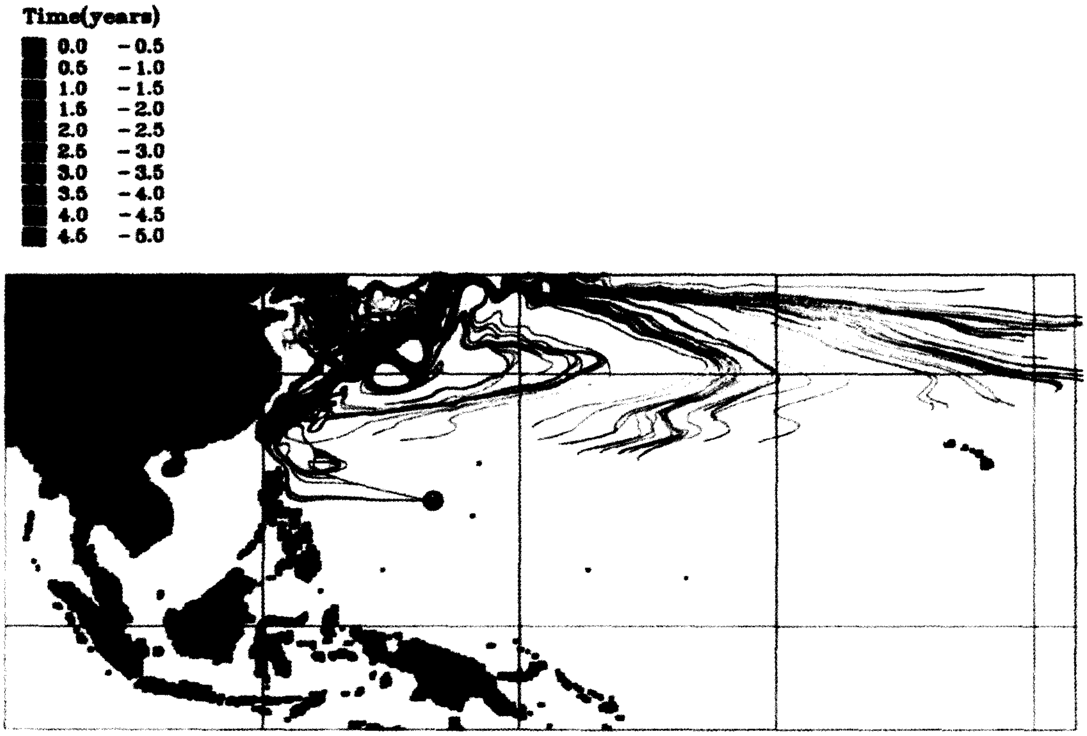
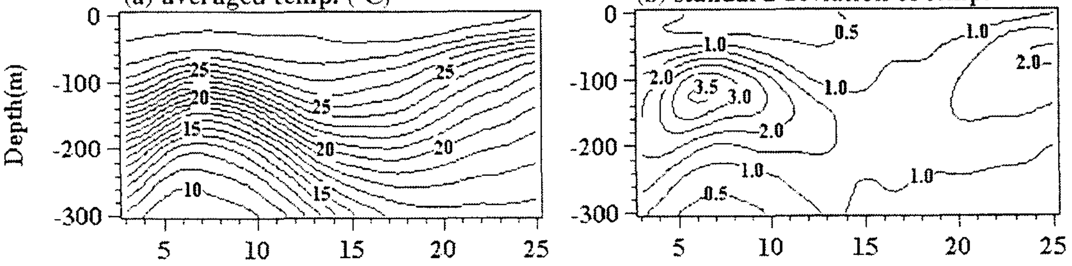


Fig. 2. Larval trajectories released at the spawning ground with time change.

In temperature section (Figure 3(a)), obvious thermocline was recognized in shallower layer south of the NEC. The largest standard deviation (Figure 3(b)) occurred at a depth of 125m and 6°N in the thermocline and the location almost corresponded to a boundary between the NEC and NECC. According to EOF analyses, this large fluctuation in temperature appearing at the depth of 125m and 6°N was explained by the ENSO.

Water in the upper layer of the NEC (Figure 3(c)) is characterized by three water masses southern low-salinity surface water less than 34.2 psu diluted by precipitation, high-salinity NPTW greater than 34.8 psu caused by excessive evaporation situated at depths between 100-200 m and the low-salinity water deeper than 150 m originated from the North Pacific Intermediate Water[11]. The shape of 34.7 psu contour was the same as that in temperature. However, the largest standard deviation of salinity (Figure 3(d)) similar to temperature did not appear in the middle layer but in the surface layer and extended over the NEC region. EOF analyses indicated that ENSO effect was confined only in the surface layer. These results suggest the salinity variation is quite different from the temperature, and salinity fluctuation is much larger than temperature in the spawning ground of the Japanese eel.


(a) averaged temp. (°C) (b) standard deviation of temp.

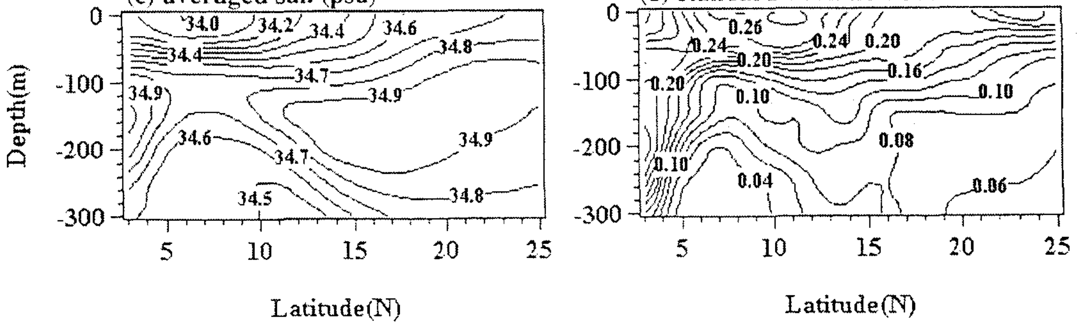

(c) averaged sal. (psu) (d) standard deviation of sal.

Fig. 3. Sections of 27-year (1972-1998) averaged temperature (a), standard deviation of temperature (b), averaged salinity (c) and standard deviation of salinity (d).

Movement of salinity front

Figure 4 shows time series of latitude of the salinity front. Locations of the salinity front were determined by 34.5 psu in the sea surface. Precipitation at Yap in the NEC fluctuated with the SOI quite significantly with 4-month time lag, and the fluctuation of precipitation was highly correlated with fluctuation of the salinity front without time lag. Therefore, the southward movement of the salinity front is explained by reduction of low salinity water area during El Niño in the western North Pacific. Weaker trade winds during El Niño had a possibility to reduce northward movement of the salinity front associated with the weakened Ekman transport. However, according to multiple regression analysis, this indirect wind effect was not so large, while precipitation contributed to 60% of the movement of the salinity front.

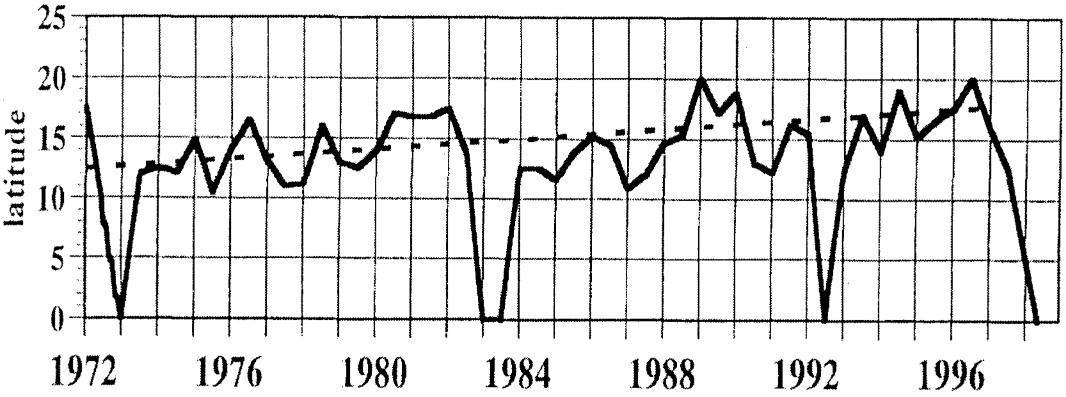


Fig. 4. Time series of latitude of the salinity front. Broken line is a linear trend of the salinity front.

Physical factors controlling larval transport

Averaged spawning season of the Japanese eel is estimated to be July(12). Before reaching the Taiwan and Japanese coasts, they have to metamorphose from leptocephali to glass eel (approximately 4 to 5 months after birth) and spend a further 1 to 2 months at sea(13,14). According to a back calculation based on these studies, larvae should be transported to East Asia by current velocity of about 20 cm/s (2600 km/5 months for Taiwan, 3800 km/7 months for Japan). Current velocity satisfying this larval transport velocity was recognized at depths shallower than 150 m south of 15 °N. Larval eel caught around the Japanese coast are usually aquacultured in ponds where water temperature is higher than 19°C. The depth of 19°C contour corresponded to 150 m depth. Therefore, layer shallower than 150 m depth is quite appropriate to survive and grow for larvae from physiological point of view. Current velocity in southern half (10-15 °N) of the NEC, 18cm/s, is four times larger than that in northern half (15-20 °N), 5 cm/s. If larvae are transported by the current velocity in the northern half of the NEC, they cannot reach rivers in the East Asia when they have to migrate upstream of the rivers. It means that they would lose timing for the migration. However, remaining in the southern half results in entrainment into the Mindanao Current and it also means that the larvae are carried southward far from their growth habitats. To avoid this effect, northward Ekman transport by the trade wind is important factor associated with large vertical larval migration, particularly bifurcation region east of the Philippine Islands(7). If the Japanese eel spawns eggs at 143 °E, larvae are transported in ranges 138-143, 133-138 and 128-133 °E in July, August and September, respectively. According the statistical data, averaged velocity of the northward Ekman transport in September was estimated to be 1-2 cm/s. However, the velocity averaged in El Niño years was negative 1-3 cm/s meaning southward transport. This difference causes meridional 100-200 km spatial difference of larval transport location and it indicates that effect of the northward Ekman transport does not work on the northward larval migration during El Niño at all.

Effect on larval transport

Larval catch in the Kagoshima Prefecture (Figure 5) (11) indicates a linear decreasing trend in recent decades. However, year-to-year short term fluctuation was also dominated and its anomaly from the linear trend probably can be explained by ENSO. After elimination of the linear decreasing, the larval catch and SOI were ompared (Figure 5(b)). Low-catch years were well corresponded to El Niño years except for only one year (1987). ENSO causes large southward movement of the salinity front most of the time, meaning southward movement of spawning ground. Current velocity in 5-10°N where flow is directly connecting to the Mindanao Current is considerably smaller than that in 10-15°N where the spawning ground is usually located. It indicates that spawning south of 10°N does not contribute to recruitment of the fish stock. Therefore, this correspondence between larval catch and SOI is one of the evidence to explain movement of the salinity front influences long-distance migrating fish, particularly Japanese eel larvae. In case of 1987, large southward movement of the salinity front did not occur despite negative SIO. This inconsistency probably caused the exception in the year.

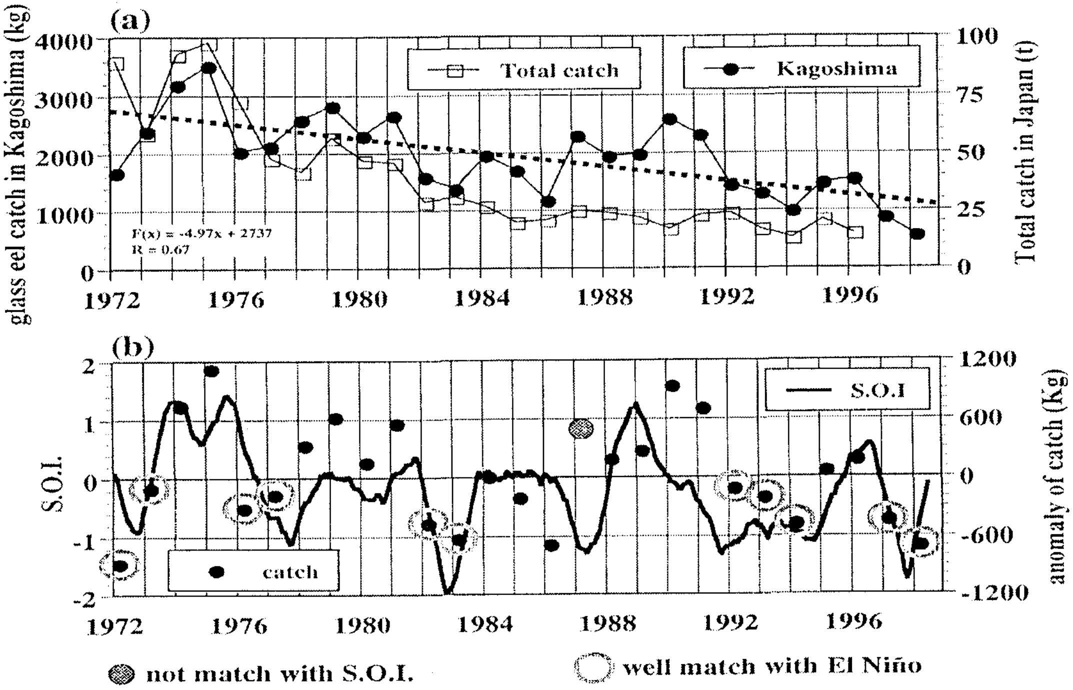


Fig. 5. Catch of the glass eel in Japan. (a): total catch in Japan and in the Kagoshima Prefecture, (b): SOI and anomaly of the catch in the Kagoshima Prefecture.

Concerning the decadal scale linear decrease, following three factors have been well considered; 1) effect of larval transport change, 2) over fishing and 3) environmental change in nursery ground. Although it is still quite difficult to explain this long term decline, there is a possibility that the cause would be explained by the effect of larval transport change in the NEC region. Recruitment of American and European eel in the Atlantic Ocean has declined dramatically in the 1980s. Castonguay et al.(15) suggests Atlantic-wide ocean climate change caused the recruitment failure. The decreasing circumstance is quite similar to the

Japanese eel case, while decreasing in the Pacific case started in the late 1970s, approximately five years earlier than the Atlantic case. This coincidence suggests that world-wide ocean climate change caused the recruitment failure for the closely related species. As an indirect evidence, they pointed out weakness of the Gulf Stream. In the Pacific case, although dominant slower current velocity was not observed in the NEC, the salinity front has moved northward gradually in last thirty years as shown in Figure 4. The salinity front was located at about 17°N in the 1990s, but at 13°N in the 1970s. It means that adult eels spawn eggs before reaching appropriate current velocity region for their larval transport south of 15°N. In this case, since larvae have to be transported by a slower current, they can not reach the nursery ground by good timing for upstream migration into the rivers. The bifurcation latitude of the NEC during July-September did not change largely and its gradient was considerably smaller than that of the salinity front. Therefore, this 4° northward movement of the salinity front should be considered as a cause of recruitment failure. In fact, total catch of the glass eel in Japan has hovered around 25 t/year since 1981.

Conclusion

Decadal scale regime shift of marine ecosystems related to atmospheric and oceanic climate in the North Pacific has been well discussed(16,17). In particular, climate change in the 1970s is dominant and ENSO activity has been enhanced since then. Therefore, long term decline of the recruitment would be attributed to the interdecadal climate change similar to these studies.

It is still necessary to further observe and sample around the NEC region to reconfirm that the salinity front plays an important role as a landmark for spawning and ENSO affects recruitment success. In this study, effect of the northward Ekman transport on the larvae in the NEC was not decomposed from a process between SOI change and glass eel catch change whereas the effect was estimated to be important. The detailed process including ENSO related another effects should be clarified in near future.

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