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Recent change in water temperature and its effect on fisheries catch of bottom gillnets in a coastal region of the Tsushima Warm Current

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Abstract: Effect of water temperature change in the recent decade on coastal fisheries in the Tsushima Warm Current region is discussed using monitoring data on the water temperature and fisheries catch of bottom gillnets from 1995–2005 near the Awashima Island, Niigata. Interannual change in water temperature at Awashima showed significant negative correlation with the Pacific Decadal Oscillation (PDO) index, indicating that even coastal water temperature is under the strong influence of climate events. The dominant species in the catch of bottom gillnets has changed in response to water temperature. Turban shell (*Turbo cornutus*) was most dominant in 1995–1998 and then rapidly declined responding to temperature increase, while yellowtail (*Seriola quinqueradiata*) dominated in warm years (1998–2001), followed by cod (*Gadidae* spp.) in 2001–2005. Further, flounder (*Paralichthys olivaceus*) preferred colder years as opposite to the yellowtail. It should be noted that a regime shift accompanied with ENSO in 1997/1998 could have large effect on the catch composition. The recent decline of the turban shell is closely connected with decrease of larger-sized individuals in the regional population. Reduced food availability and intensified wave due to increased winter wind could be the critical causes for this decline.

Keywords: *fisheries catch, Tsushima Warm Current region, turban shell, water temperature*

1. Introduction

Long-term change in water temperature of the Japan Sea has apparently affected the distribution and abundance of fisheries resources, including Pacific saury, chub mackerel and other small pelagic fishes (ZHANG *et al.*, 2000 ; HIYAMA *et al.*, 2002 ; TIAN *et al.*, 2004, for example). Many studies have demonstrated the relationship between climatic change and fluctuations in fisheries catch in recent decades as well ; however its relation to coastal fisheries has not been well understood partly due to high variability and lack of the monitoring data with good quality. During 1990s, it is known that ENSO occurred in 1997/1998 and possibly gave much effect on marine organisms all over the world, even in the Japan Sea (CHIBA *et al.*, 2003), while it is also reported that there could be a regime shift around 1998 in the North Pacific (MINOBE, 2002 ; TIAN *et al.*, 2004). The dynamics of water temperature and fisheries production in the coastal region of Tsushima Warm Current may have been connected with such climate events on both decadal and interdecadal scales. In addition, recent warming in this region may also give a serious effect on the fisheries production in near future (TIAN *et al.*, 2004 ; DRINKWATER, 2005).

In this paper, we discuss the effect of water temperature change, possibly due to the above

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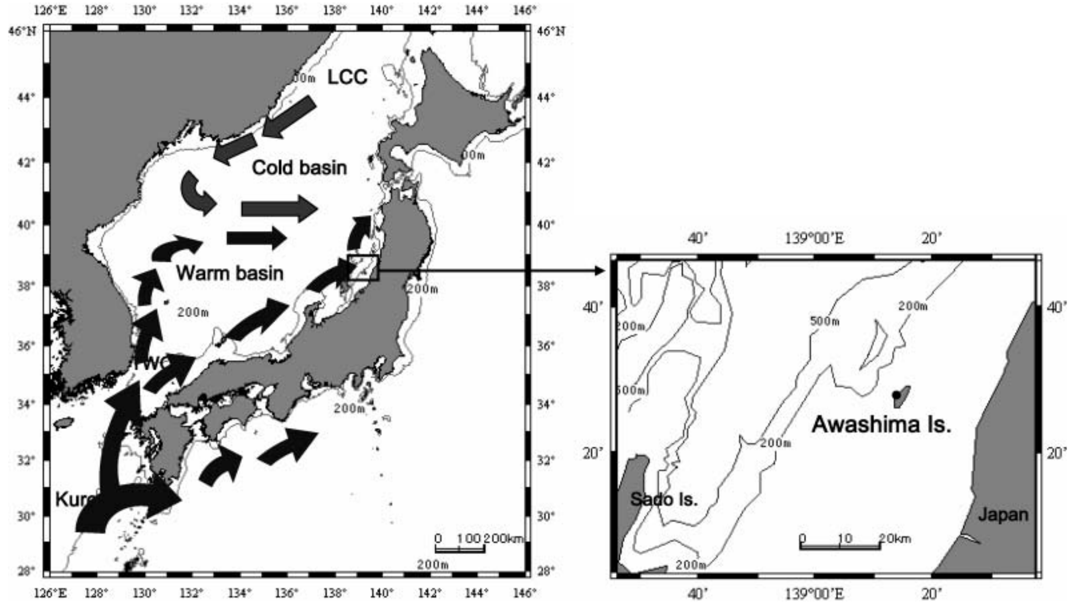

Fig. 1. The study area. Awashima Island (38°28′24.00″N and 139°14′12.23″E) is located in the coastal region of the Tsushima Warm Current (TWC).

climate events in the recent decade, on coastal fisheries in the Tsushima Warm Current region, using the data from continuous monitoring of water temperature and bottom gillnet catches at a coastal region (near Awashima Island, see Fig. 1) from 1995 to 2005. The Tsushima Warm Current (TWC) flows from south-west to north-east along the coast of the Japan Sea, and together with Liman Cold Current (LCC), TWC divides the Japan Sea into warm and cold basins with the boundary around 40° N (Senjyu, 1999). The area of this study, Awashima Island (38° 29'24.00"N and 139° 14'12.23"E), is located along the TWC path and just south of the above boundary (Fig. 1). The main objectives of this study are : (1) to identify water temperature variability in the coastal TWC region and its linkage to climate change on a larger scale ; and (2) to examine the possible effect of water temperature change on coastal gillnet fisheries, focusing on the climate event such as a regime shift in 1997/1998 accompanied by ENSO. The possible reason of recent decline of turban shell (*Turbo cornutus*), one of the dominant species for the bottom gillnet fisheries at the Awashima Island is also discussed in detail.

2. Data and Methods

We installed a set of automatic water temperature recorder, RTM–500 (Rigo Co. Ltd., Japan) on a rocky shore (about 6–7 m deep) near the Awashima Island from June 1995 to June 2005. This recorder is able to store about 65000 water temperature data covering the range between −5 to 45° C with resolution of 0.01° C and accuracy of ±0.05° C. In order to avoid over storage, the recorder was reset in every about 12 months. From the original 10 min interval data, we used ten-day and monthly means of water temperature data in this study. In addition, the Pacific Decadal Oscillation (PDO) index was used for the analysis to clarify the possible response of coastal water temperature in the TWC region to climate change. The PDO index is defined as the time coefficient of the leading EOF created from monthly Sea Surface Temperature (SST) anomalies pole-ward of 20° N in the Pacific bas in ; positive (negative) PDO indices represent the cooling (warming) phase in the central North Pacific (Mantua and Hare, 2002). Monthly value of climatic indices (PDO) was provided by Climatic Prediction Center of NOAA for 1995 to 2005.

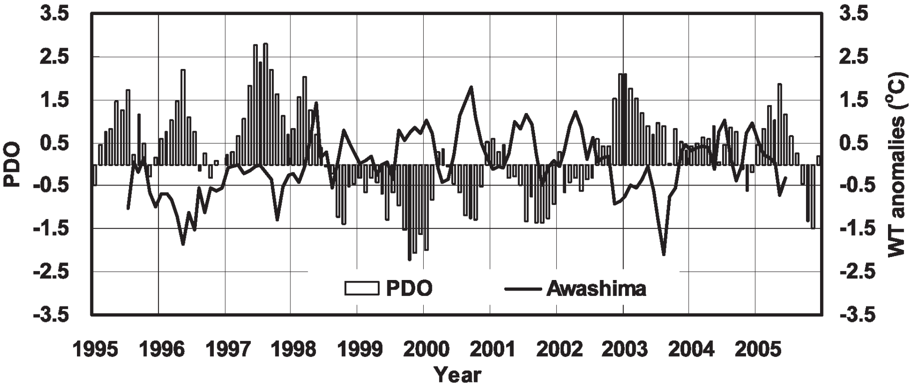

Fig. 2. Time series of water temperature anomalies at the Awashima Island (solid line) and Pacific Decadal Oscillation (PDO) index (bar).

Together with temperature data, catch data from bottom gillnet fisheries (with mesh size of about 120 mm), which has been conducted almost all year around near the Awashima Island, were collected from logbooks of fishermen of the Awashima-ura Fisheries Cooperative within the period of 1995 to 2005. As a biological time-series, these data are believed to be more reliable than other fisheries in terms of rather stable fishing efforts at mostly fixed sites. For our interest, the monthly catch data were used in this study.

Further, in order to investigate the possible factors affecting the catch of turban shell, one of the dominant species of the bottom gillnet fisheries, we analyzed annual monitoring data on the density and shell size of turban shell individuals at a wave-exposed rocky shore at the northwestern side of the Awashima Island (near the location of temperature measurement), based on the routine sampling of the areas of 42–100 m^2 at the beginning of fishing season (every June) from 1993–2006. The catch data of seaweed fisheries (from 1995–2005) at the Awashima Island were also used for the discussion, together with a time-series of winter wind (from 1995–2005) at Awashima collected from the Japan Meteorological Agency.

3. Results

Temperature variation

Figure 2 shows time series of water temperature anomalies at the Awashima Island for eleven-years (1995–2005), together with the Pacific Decadal Oscillation (PDO) index. The increase in water temperature for all the period was about 0.6℃, however prominent warming started from 1998. It is also noticeable that the change in water temperature at the Awashima Island corresponds well with the PDO indices; positive (negative) PDO indicates the cooling (warming) event. From the time series, a regime shift between cooling (1996/1997) and warming (late 1998- early 2002) regime was detected, while another shift possibly occurred in 2002/2003 with a shorter period (one year) of cooling, followed by warming in 2004–2005. However 2004–2005 warming may not be supported by PDO indices. There is negative significant correlation between PDO indices and water temperature anomalies at the Awashima Islands ($r = -0.552$, $p < 0.001$) (Fig. 3).

Fisheries catch and its composition

Year to year change in the total catch of bottom gillnet fisheries near the Awashima Island is shown in Fig. 4 (a). The fisheries yields of about 40 tons were recorded except for 1999, 2001, and 2005 showing about twofold of the other years. The catch composition of bottom gillnet fisheries, as shown in Fig.4 (b), is dominated by migrating pelagic species such as yellowtail (*Seriola quinqueradiata*) and demersal species such as cod (*Gadidae* spp., mainly Pacific cod), coastal water species such as flounder (*Paralichthys olivaceus*) and red seabream (*Pagrus major*), and non-migrating shellfishes including turban shell (*Turbo cornutus*).

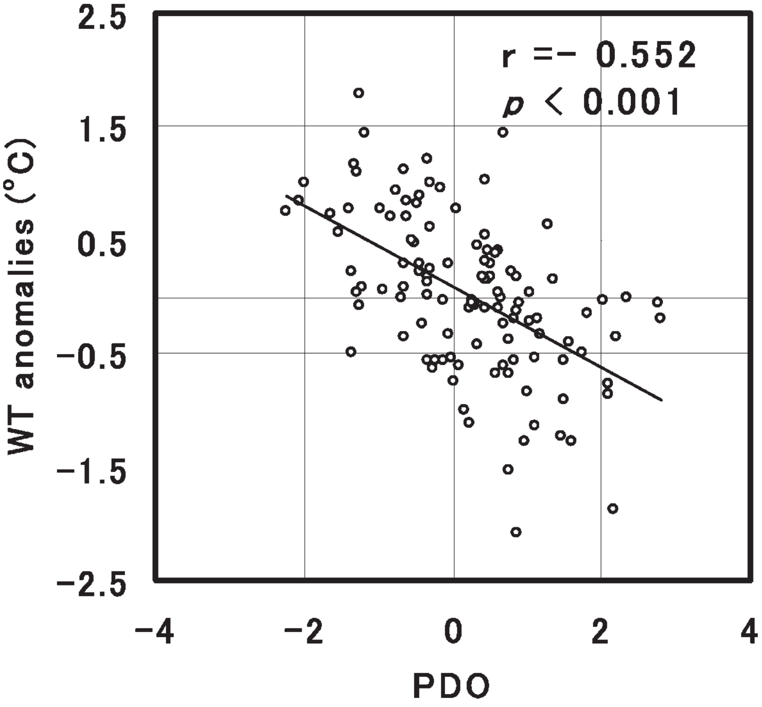

Fig. 3. Correlation between Pacific Decadal Oscillation (PDO) indices and water temperature anomalies at the Awashima Island.

From the time series, turban shell was most dominant in 1995–1998, while yellowtail in 1998–2001, followed by cod in 2001–2005. Furthermore, flounder and red seabream also contributed to the catch amount although the percentage was relatively small.

According to the Awashima-ura Fisheries Cooperative, catch data of turban shell in earlier years actually included catch yields by public diving at the opening of fishing period. However, this ceremonial catch event ceased in recent years due to rapid decline in the amount ; this is an additional evidence of abundance decline in the turban shell.

Relation between temperature variation and fisheries catch

The time changes of water temperature anomalies and fisheries yields of dominant four species (turban shell, cod, yellowtail and flounder) are demonstrated on the monthly basis in Fig. 5a-e. The catch yields of turban shell (*T. cornutus*) and cod (*Gadidae* spp.) show decreasing and increasing trends, respectively, for 11 years (Fig. 5b-c). These trends may be related in some way with warming of water temperature after a regime shift in 1997/1998 (see Fig. 2). In fact, significant negative correlation ($r = -0.706$, $p < 0.05$) between the water temperature anomalies and the catch of turban shell was obtained from cross-correlation analysis with a lag of 6 months.

On the other hand, there are more direct responses of fisheries catch to water temperature for yellowtail (*S. quinqueradiata*) and flounder (*P. olivaceus*) in an opposite way ; warm years seems favorable (unfavorable) for yellowtail (flounder) (Fig. 5d-e).

Monitoring of the density and shell size composition of turban shell

The catch yields of turban shell were high during 1995–1996 with negative anomalies of water temperature, and rapidly decreased to the lowest level in 2004–2005 without any sign of the recovery. Figure 6 demonstrates density (a) and size ratio of large (over 60 mm in shell height) and small (under 60 mm in shell

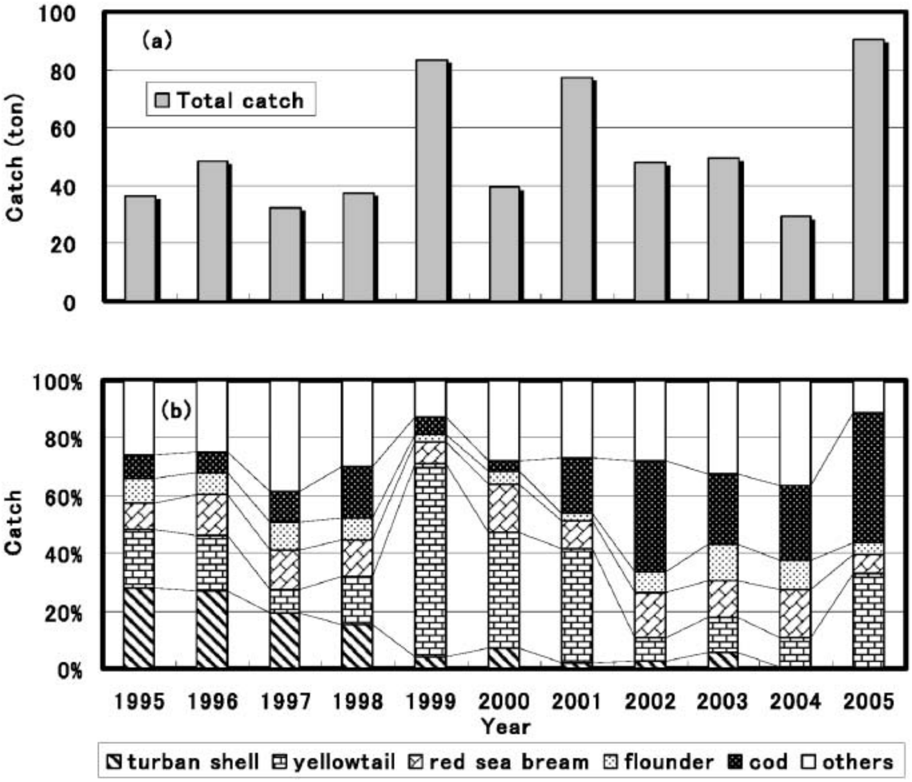

Fig. 4. (a) Interannual change in the total catch of bottom gillnet fisheries near the Awashima Island. (b) Interannual change in the catch composition of the bottom gillnet fisheries, including five dominant species: turban shell, yellowtail, red seabream, flounder, and cod.

height) individuals (b) of the turban shell, based on annual monitoring data from a rocky shore habitat of the Awashima Island in 1993–2006. It should be noted that small-sized turban shell showed remarkable increase in density, with average 3.7 individuals/ m^2 in 1998 to 2006, while large-sized one continuously decreased from about 1 individual/ m^2 in 1993–1995 to lowest levels in recent years (Fig. 6a).

The replacement of the large-sized individuals by the small-sized ones in a regional population is obvious in the time change of size composition (Fig. 6b). Since the target of the gillnet fisheries at the Awashima Island is large-sized individuals, the above change in the size composition is most critical to the fisheries yield as shown by significant negative correlations of turban shell catch with density (Fig. 7a) and size ratio (Fig. 7b) of small-sized individuals.

4. Discussion

Responses of fisheries catch to water temperature change

Figure 8 shows the standardized index of water temperature and fisheries catches of yellowtail, flounder, cod, and turban shell. All data were standardized using the formula, $(x_i - x)/sd$, where x_i denotes the original data for variable (i), and x and sd the mean and standard deviation, respectively. The catch index of turban shell starts to decline from 1997 and shows negative values after 1999. In contrast, cod shows an increasing trend with positive values after 2001. Furthermore, the catch index of yellowtail is positive during warm years (1999–2001), while that of flounder is negative during the same period.

As previously reported, regime shifts of oceanic conditions occurred in 1997/1998 (Beamish *et al.*, 2004; Chiba *et al*, 2003) and 2002/2003

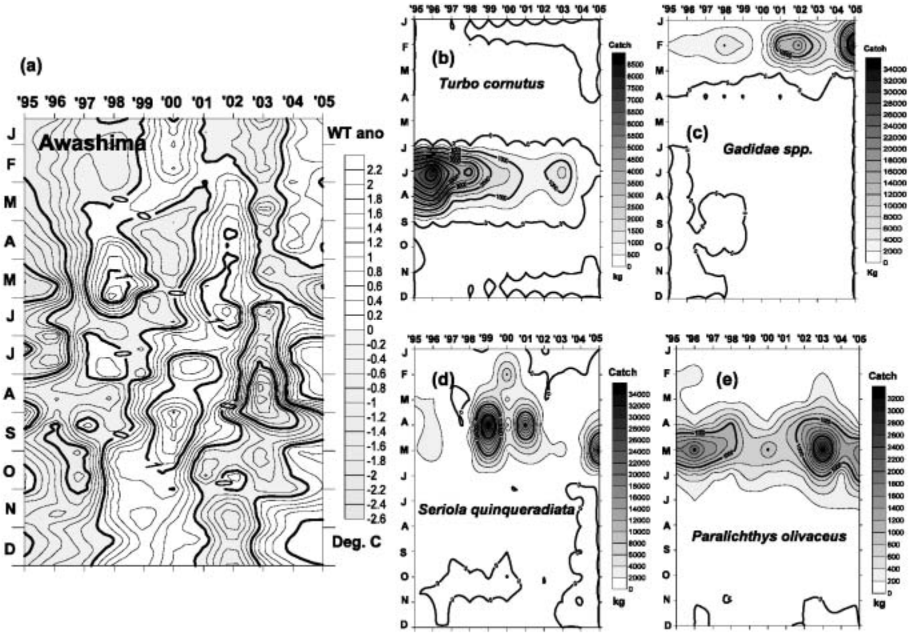

Fig. 5. Time changes of water temperature anomalies (a) and catches of dominant species (b-e) at the Awashima Island on the monthly basis.

(PICES, 2004 ; JMA, 2004). Besides the regime shifts, it is also well known that ENSO occurred in 1997/1998 (CHIBA *et al*, 2003 ; TIAN *et al.*, 2004). At Awashima, the regime shift 1997/1998 could be defined as a major shift of water temperature from cold years with positive PDO to warm years with negative PDO, followed by a great change of fisheries catch as mentioned above.

From Fig. 8, we may conclude that the responses of coastal fisheries catch to water temperature change into two categories : (1) responses to warm-cold temperature change on the inter-annual scale due to El Nino-La Nina cycles, for example ; e.g. temporary shift of yellowtail and flounder catches, and (2) responses to longer-term temperature changes derived from regime shifts and/or warming trends on the inter-decadal scale ; e.g. vanishing of turban shell and increasing cod abundance in recent years.

As warm water species, yellowtail may favor warm water masses and migrate to the north in the Japan Sea. HARA (1990 a, b) reported that residence time and the period of fishery formation of yellowtail increases with warm water masses spreading into the Japan Sea coast. Furthermore during warm El Nino years like 1998, followed by a regime shift to the warm and negative PDO phase from late 1998, there was overall increase in the catch of yellowtail in the Japan Sea (TAMEISHI *et al.* ; 2005). This suggests that increased catch of yellowtail at Awashima may be caused by northward spread of yellowtail to and its prolonged residence time in the Japan Sea, following the water temperature increase due to the regime shift and ENSO in 1997/1998. However, flounder has negative response to the water temperature increase ; there is high and low catches of flounder during warm years (1999 to 2001) and cold years (before 1998 and after 2002), respectively. There has been however very little detailed information concerning temperature effect on this fish.

It is reported that Pacific cod are distributed over a wide range from North Pacific to the Japan Sea, and as a demersal cold water species, it is suggested that cold temperature regime is favorable for productivity and recruitment of Pacific cod (PFMC, 1998 ; BEAMISH *et al.*, 2004). In fact, northward shift of the Pacific

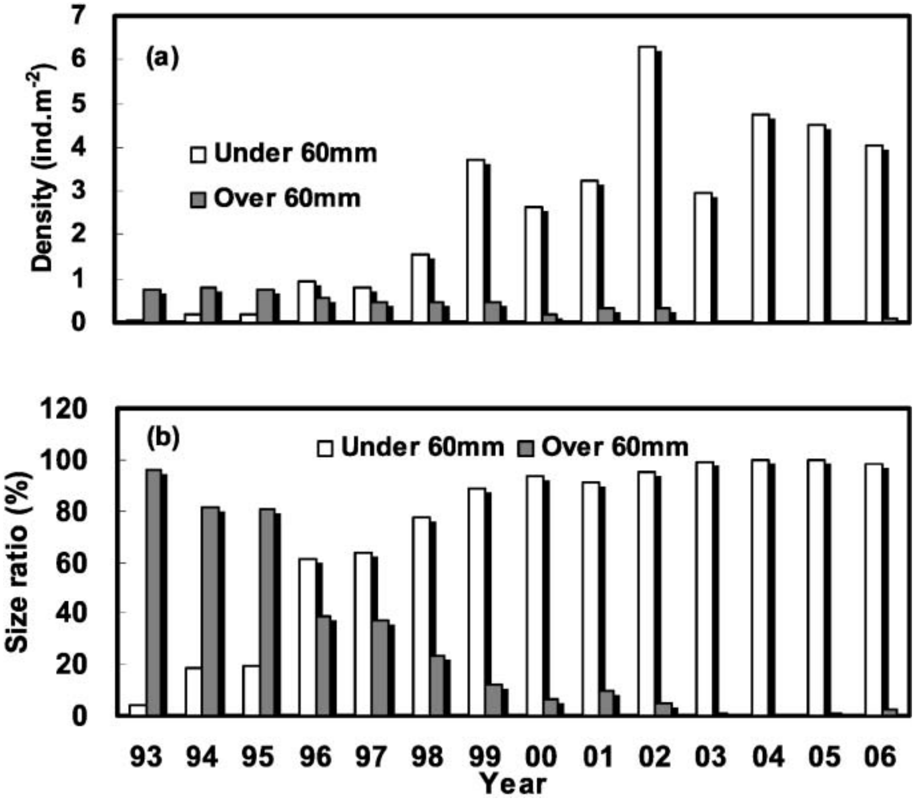

Fig. 6. (a) Interannual change in the density of turban shell (*Turbo cornutus*) at the rocky shore habitat of Awashima Island during 1993–2006. (b) Interannual change in the fraction of small-sized turban shell (under 60 mm in shell height) and large-sized one (over 60 mm in shell height).

cod distribution responding to recent warming was actually suggested in the Japan Sea, from more apparent decreasing catch yields in the southwestern Japan Sea compared to those in the north (Ishiko, unpublished data). Therefore, the reason of increase in cod catch at Awashima during warm years has remained unknown. Though the catch yields of the middle of Japan Sea including Niigata Prefecture have not yet showed any decline, relatively low temperature in the coastal regions (9.7 to 11.1 ℃ at Awashima in the period of cod fishing) could cause a spatial shift of cod distribution toward the coast, resulting in increase of cod abundance near the Awashima Island during recent warm years.

Possible factors affecting recent decline in the fisheries catch of turban shell

Remarkable decreasing of turban shell catches to the lowest level in recent years has insisted us to clarify the causal factors behind it. The first hypothesis for this incidence could be the change in food availability. It has been revealed that diets of turban shell collected from wave-exposed areas of Awashima Island are dominated by small seaweeds such as red algae (*Polysiphonia morrowii*) and brown algae (*Dictyota* spp.) (YAMAKAWA and HAYASHI, 2004). Since there was no available data on those prey biomass; we collected the data for three types of seaweed catch, which could be a proxy of the prey biomass. The time series of seaweed catches, which are standardized in the same way as Fig. 8, is shown in Fig. 9a. It is noticeable that the period of decline of turban shell catch coincides with low seaweed catches at the Awashima Islands. The correlation between the standardized indices of the catch for turban shell and seaweeds (mean of the above

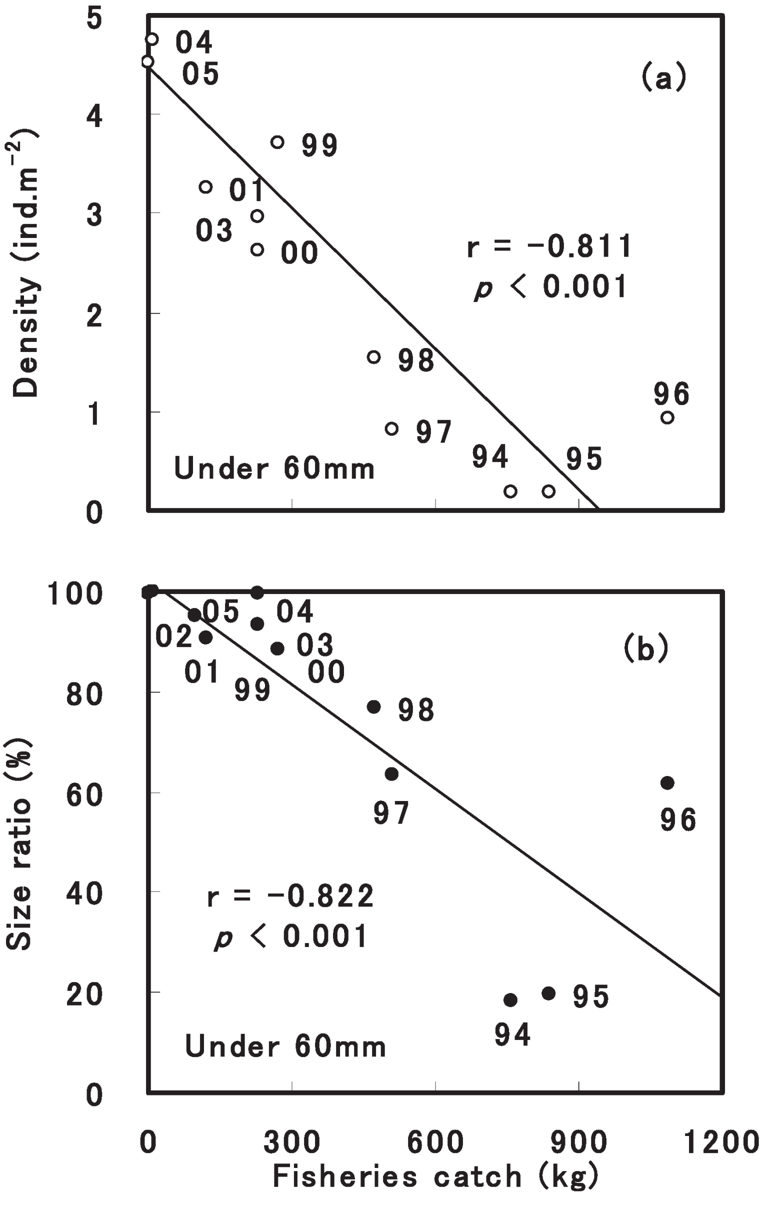

Fig. 7. Correlation of fisheries catches of turban shell with density of small-sized turban shell (a) and small-sized fraction of the turban shell (b) in the neighboring habitat.

three types of seaweed) is significant (r = 0.739, $p < 0.01$) as seen in Fig. 9 (b). However, the above proxies are annual seaweeds and mostly grow in intertidal zones, therefore direct effect of the time change in the prey biomass on the growth of turban shell should be confirmed in another way in the future. In addition, it should be also noted that species composition of dominant seaweeds at the monitoring site has changed in recent years (HAYASHI, unpublished data) ; this suggests possible decline of food availability in the aspect of food quality.

On the other hand, increase in water temperature may lead to enhance the reproduction. In fact, density of small-sized turban shell

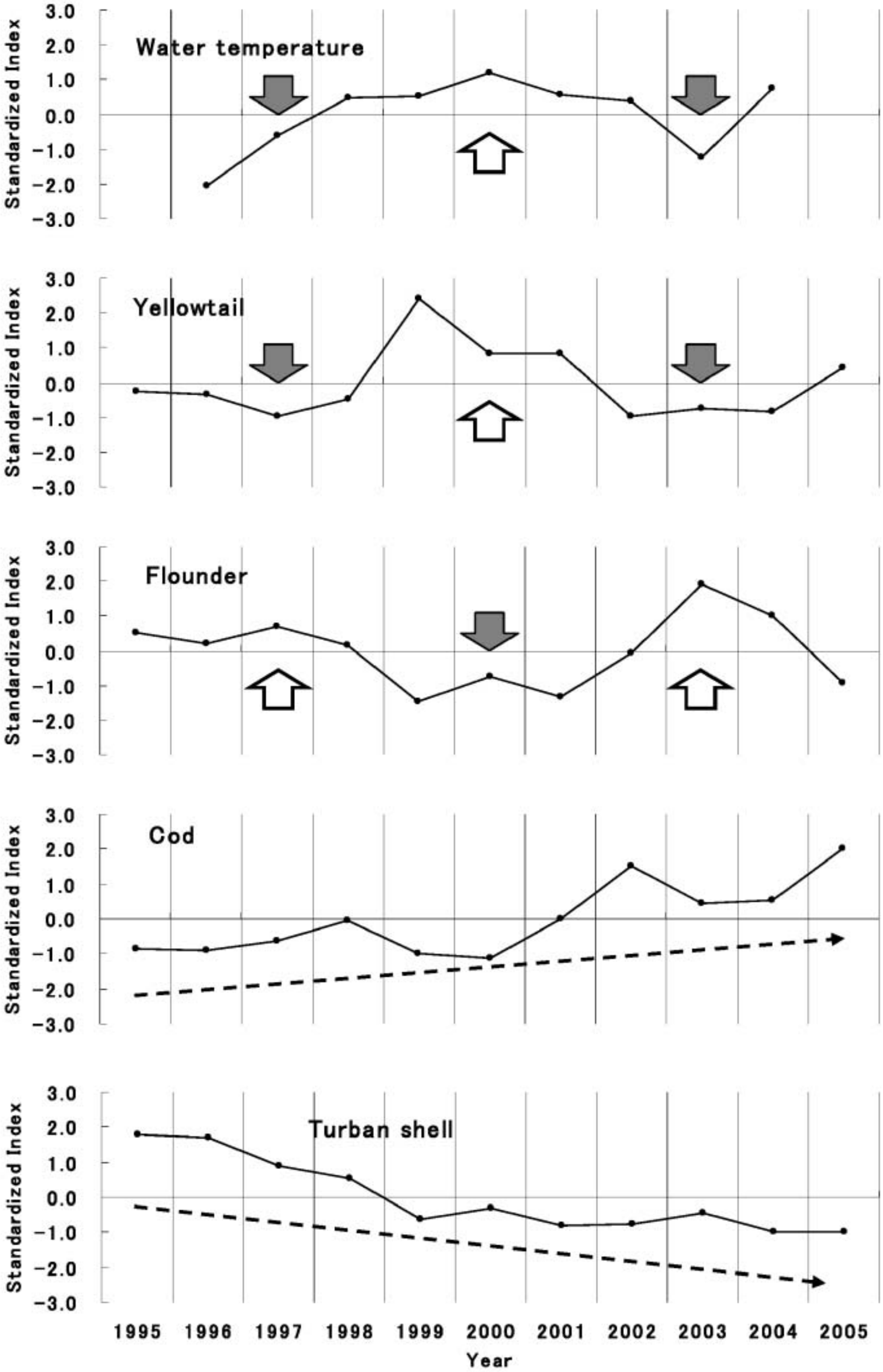

Fig. 8. Interannual change in standardized index of water temperature and fisheries catches of yellowtail, flounder, cod, and turban shell at the Awashima Island during 1995–2005. For the standardized index, see the text.

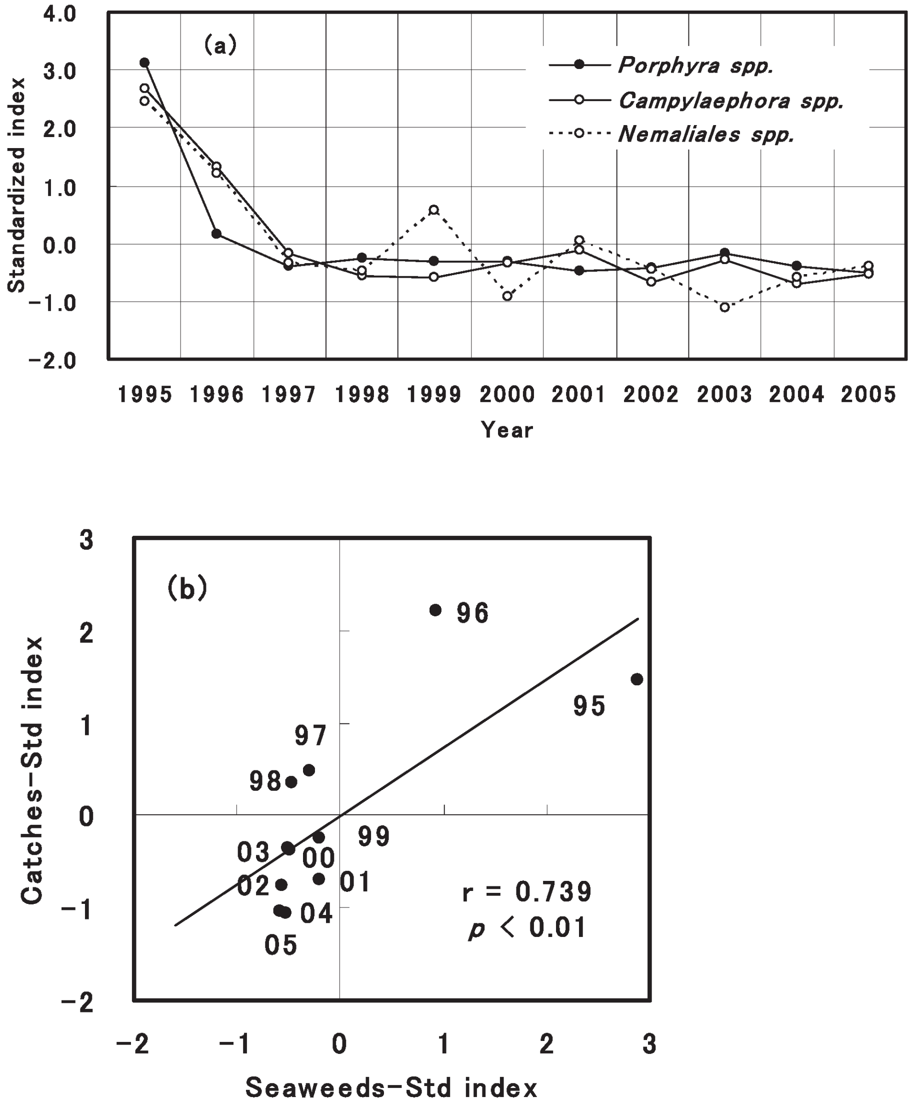

Fig. 9 (a) Interannual change in the fisheries production of seaweeds, represented by iwanori (*Porphyra* spp.), egonori (*Campylaephora* spp.) and umizomen (*Nemaliales* spp.) at the Awashima Island. The amount of production is represented by the standardized index in the same way as Fig. 8. (b) Correlation between seaweed production (mean of the above three types of seaweeds) and catch of turban shell at the Awashima Island during 1995–2005.

individuals increased to over 2 ind./m^2 after 1999 (Fig.6a). Further as seen in Fig. 7, increase in the density and ratio of small-sized turban shell (mostly the age of 2–4 years) well corresponds to the decline in the fisheries catch of commercial size turban shell (over 60 mm in shell height with the age of more than 4 years).

In addition to decline in seaweed production (Fig. 9a), density effect due to the increase in the number of small individuals may also contribute to enhance the competition among this species, resulting in further decrease in the abundance of large-sized individuals. More detailed quantitative investigation on the feeding and growth of the turban shell population in this region is necessary.

Another possible hypothesis could be physical effect of strong wind in winter when

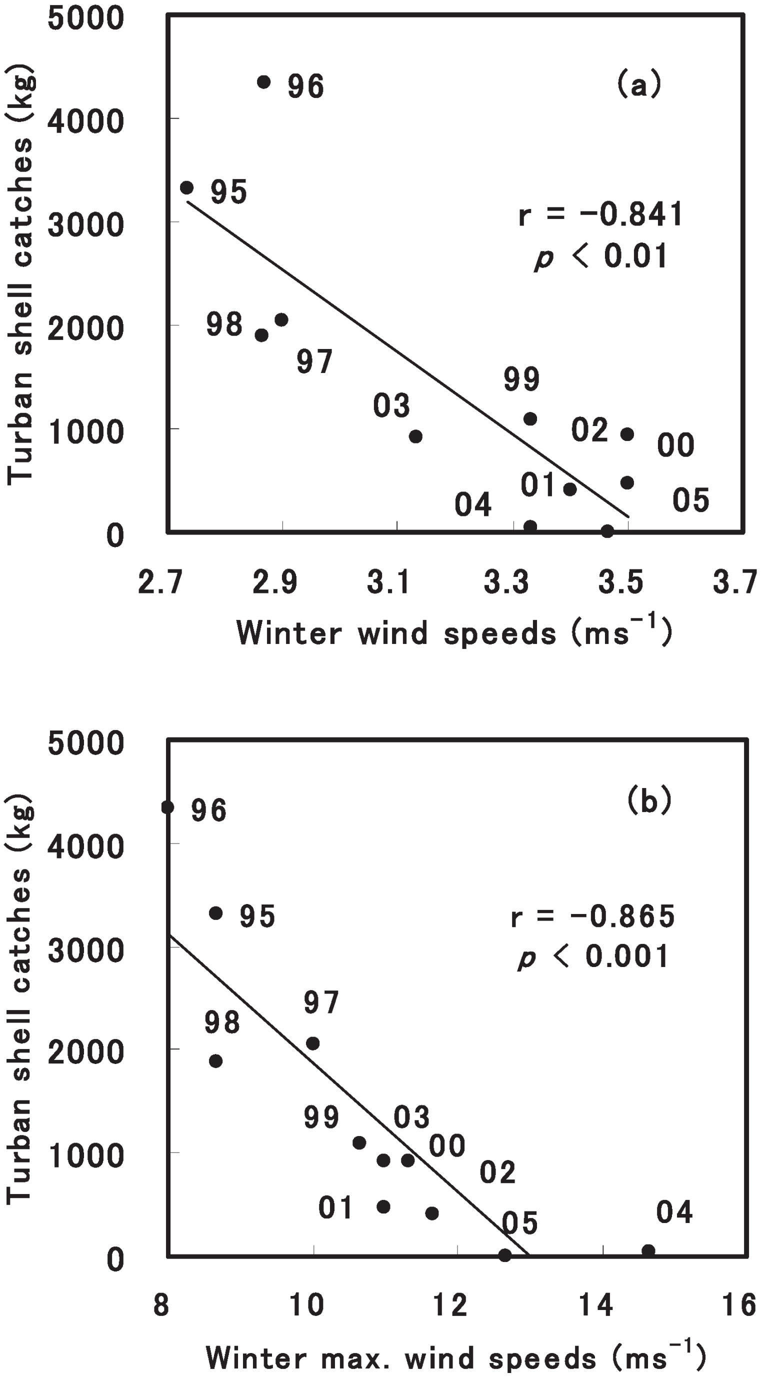

Fig. 10. Correlation of fisheries catches of turban shell with mean wind speed in winter (a) and with maximum wind speed in winter (b) at Awashima during 1995–2005.

adhesion ability of turban shell becomes weaker. Since the monitoring site of the turban shell was a wave-exposed rocky shore under the strong influence of prevailing wind in winter, strong waves generated by the strong wind may intrude the habitat of turban shell and then do damage to large-sized turban shell by washing them away from the suitable habitat, resulting in density decline in large-sized turban shell. The above statement is strengthened by the fact that there is different behavior between small and large-sized turban shell. Most of small-sized individuals tend to be hidden in the small holes and crevices among rocks to avoid from any disturbances, while large ones are on the surface of the rock where there is no place to hide away from wave action (HAYASHI, unpublished data).

Recent warming after the regime shift of 1997/1998 in the Japan Sea could have triggered high atmospheric pressure gradients between the Siberian High and the Aleutian Low, and then followed by the stronger winter wind. This hypothesis is supported by significant negative correlations between average wind speed in winter and turban shell catch ($r = -0.841$, $p < 0.01$) (Fig.10 a), and between winter maximum wind speed and turban shell catch ($r = -0.865$, $p < 0.001$) (Fig. 10 b).

In summary, our analysis suggested that water temperature change modified by climate events such as a regime shift and ENSO in 1997/1998 have remarkable effect on the coastal fisheries catch in the TWC region in the recent decade. Although the geographic location of Awashima Island, the main area of this study, could be unique as described in Fig. 1, the findings of this study strongly suggest that water temperature and associated climate events can be used as an indicator for prediction of coastal fisheries along the Tsushima Warm Current region.

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