Marine Ecosystems of the North Pacific Ocean 2003-2008

McKinnell, S.M. and Dagg, M.J. [Eds.] 2010.
Marine Ecosystems of the North Pacific Ocean, 2003-2008.
PICES Special Publication 4, 393 p.

PICES Special Publication Number 4

© G. Ruggerone

Oyashio

lead author

Sanae Chiba

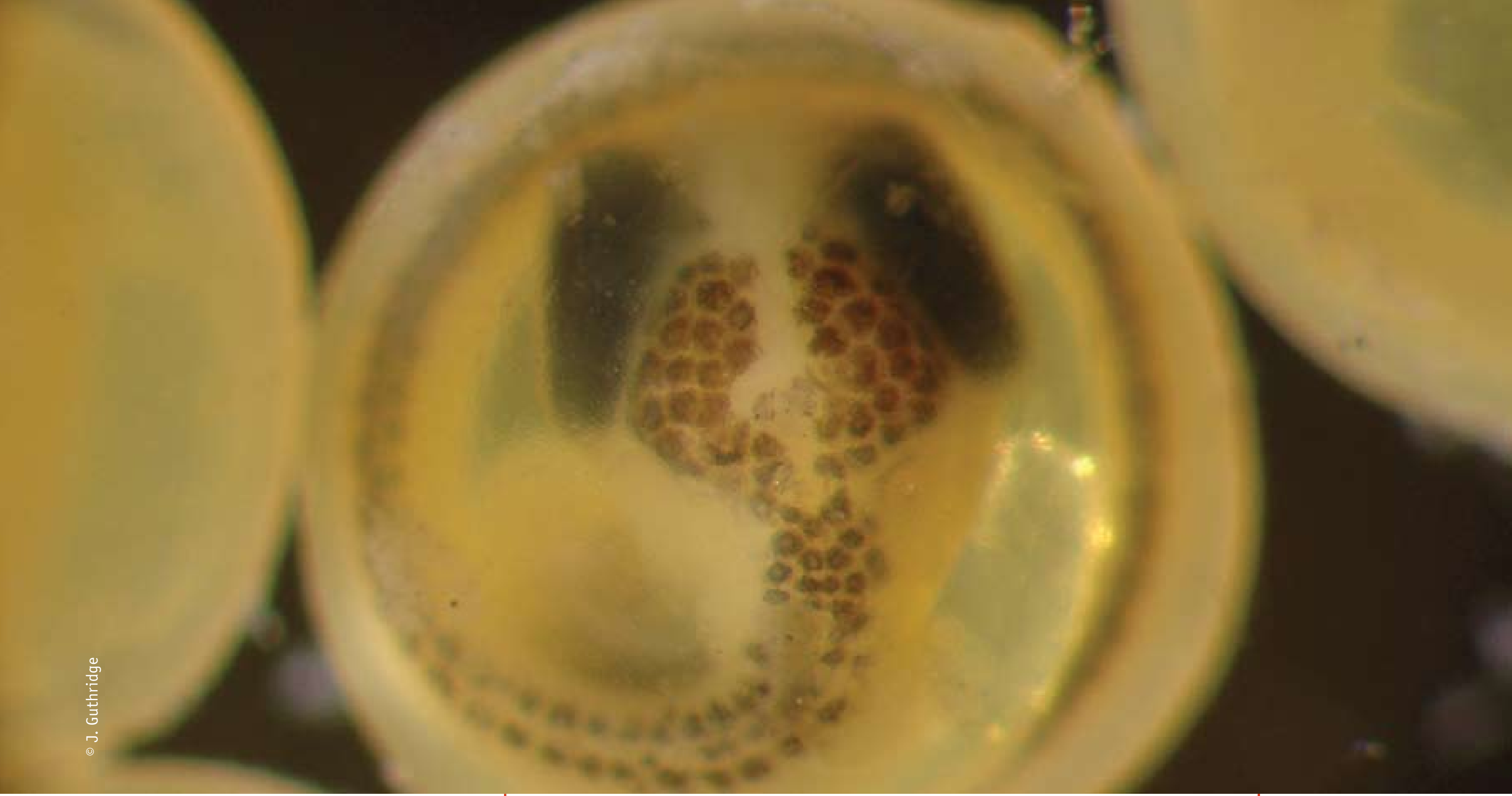
Environmental Biogeochemical Cycle Research Program
JAMSTEC
Yokohama, Japan

Citation:

Chiba, S., Hirawake, T., Ishizaki, S., Ito, S., Kamiya, H., Kaeriyama, M., Kuwata, A., Midorikawa, T., Minobe, S., Okamoto, S., Okazaki, Y., Ono, T., Saito, H., Saitoh, S., Sasano, D., Tadokoro, K., Takahashi, K., Takatani, Y., Watanabe, Y., Watanabe, Y.W., Watanuki, Y., Yamamura, O., Yamashita, N., Yatsu, A. 2010. Status and trends of the Oyashio region, 2003-2008, pp. 300-329 In S.M. McKinnell & M.J. Dagg [Eds.] Marine Ecosystems of the North Pacific Ocean, 2003-2008. PICES Special Publication No. 4. 393 p.

highlights

- The West Pacific atmospheric pattern was conspicuous after 2003. It was associated with windy, lower sea surface temperature conditions during winter compared to the preceding warm period.
- Unlike the previous cool period (mid 1970s to mid 1980s), a southward shift of the Oyashio coastal branch was less extensive after 2003.
- There is no long-term trend in SST after the mid 1980s.
- Subsurface dissolved oxygen and mixed layer phosphate concentrations had decadal variation superimposed on a long-term declining trend. The decadal-scale variation is likely related to the North Pacific index and extent of mixing with Okhotsk Sea water. The long-term decline after the 1970s might indicate a gradual increase in water column stratification. Both dissolved oxygen and phosphate increased from the late 1990s and remained relatively constant after 2003.
- Contaminant levels remained low through 2008 compared to previous years.
- The geographical distribution and seasonality of phytoplankton in Oyashio water adjacent to Japan were similar before 2002 with a peak in May. In the wide range of the northern offshore areas however, $chlorophyll_a$ peaked in June after 2003, possibly related to cool winter conditions.
- Zooplankton seasonality was similar from the 1960s to 2007 although a comparison of zooplankton biomass before and after 2002 was difficult due to incompatible data.
- After 2003, zooplankton biomass in July was significantly lower in 2005 than in other years.

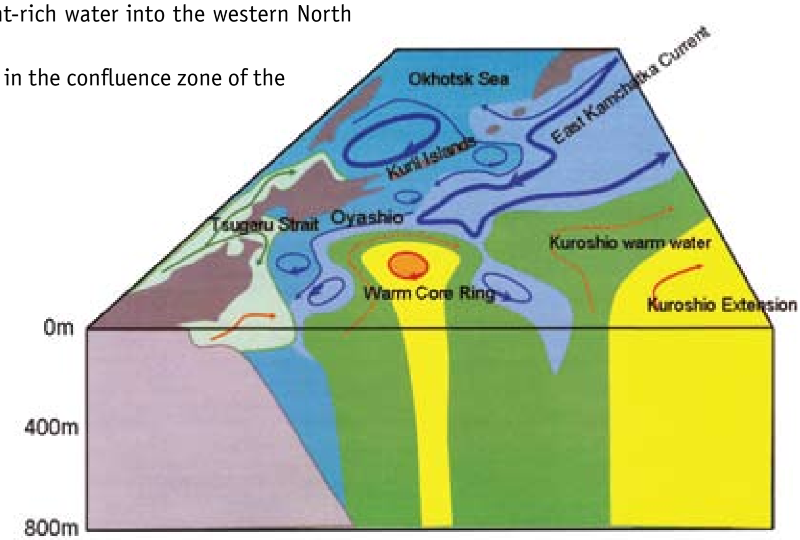


- No clear relation was detected between sea surface temperature and lower trophic levels at the interannual time-scale.
- The anchovy regime (high anchovy and common squid biomass and low sardine and chum mackerel biomass), which started in the mid 1990s (at the end of the sardine regime), continued until 2007. Anchovy biomass peaked in 2003 and decreased toward 2007.
- Catch and biomass of salmon (pink, chum, sockeye) increased markedly after the mid 1970s, peaked in the mid 1990s, and has remained at a relatively high level after 2000. The increase in chum salmon catch and biomass was mainly from hatchery fish.
- Catch of threadfin hakeling increased after the late 1990s and remained at a high level after 2000.
- Catch and biomass of walleye pollock showed a decreasing trend from the mid 1970s and remained at a low level after 2003.
- No clear link was detected between interannual variation in phytoplankton and zooplankton or between lower and higher trophic levels after 2003. Low summertime zooplankton biomass in 2005 might have had a negative influence on seabird density in the Oyashio shelf area and pink salmon return.

Introduction *(Ito)*

The Oyashio is the western boundary current of the Subartic North Pacific.

It is characterized by low temperature, low salinity, and high nutrient concentrations (Stommel and Yoshida 1972). The Oyashio is a continuation of the East Kamchatka Current (Fig. OY-1) and is fed by waters from the Western Subarctic Gyre and the Sea of Okhotsk (Shimizu et al. 2001). Strong tidal mixing along the Kuril Islands inputs the low salinity characteristic of the intermediate Oyashio. The Oyashio is a possible source of North Pacific Intermediate Water (NPIW) (Yasuda 1997) and its contribution to the North Pacific overturn cannot be ignored. The Oyashio flows southward along Hokkaido Island and Honshu Island, then changes direction and flows to the east, with meanders. The meander crests are called the First and Second Branches of the Oyashio according to their sequence from land. The eastward flowing Oyashio forms the Subarctic Front (Oyashio Front), which is a distinctive temperature front. Between the Subarctic Front and the Kuroshio Extension Front, cold and warm waters mix in a complex manner and many mesoscale features are formed. Therefore, this region is called the Kuroshio-Oyashio-Transition Zone (KOTZ) or mixed water region. The outflow of the Kuroshio, the Kuroshio Extension, feeds into the North Pacific Current, while the outflow from Oyashio feeds into the Subarctic Current. Between these two eastward flows, the Transition Domain is formed (Favorite et al. 1976). The Oyashio brings nutrient-rich water into the western North Pacific, resulting in high productivity in the confluence zone of the two currents, the KOTZ.



[Figure OY-1] Schematic picture of the Oyashio and mixed water region (modified from Shimizu et al. 2001).

The Oyashio transport and its southward extent show large seasonal variation and comparable interannual variations (e.g. Qiu 2002). The response to large-scale atmospheric circulation is a combination of barotropic (less than one year lag) and baroclinic (several year lag) responses (Ito et al. 2004a). The dominant climate variability in the western North Pacific is decadal although there are also high-frequency variations associated with ENSO events. Much of the variability in the Oyashio System is via remotely generated ocean Rossby waves that may create a lag in the response to the Aleutian Low. Variations in the strength of the Aleutian Low can be decomposed to bi-decadal and penta-decadal oscillations (Minobe 1999), but only the penta-decadal signal reaches the western boundary region (Tatebe and Yasuda 2005). Moreover, many local factors contribute to environmental variability in the Oyashio, making it quite unlikely that these systems respond to climate forcing on the same time frame as the rest of the North Pacific. The physical condition of Oyashio water varies primarily due to: i) wind stress changes associated with the Aleutian Low; ii) Rossby wave propagation; iii) upstream conditions in Western Subarctic Gyre and Sea of Okhotsk; and iv) tidal mixing along the Kuril Islands.

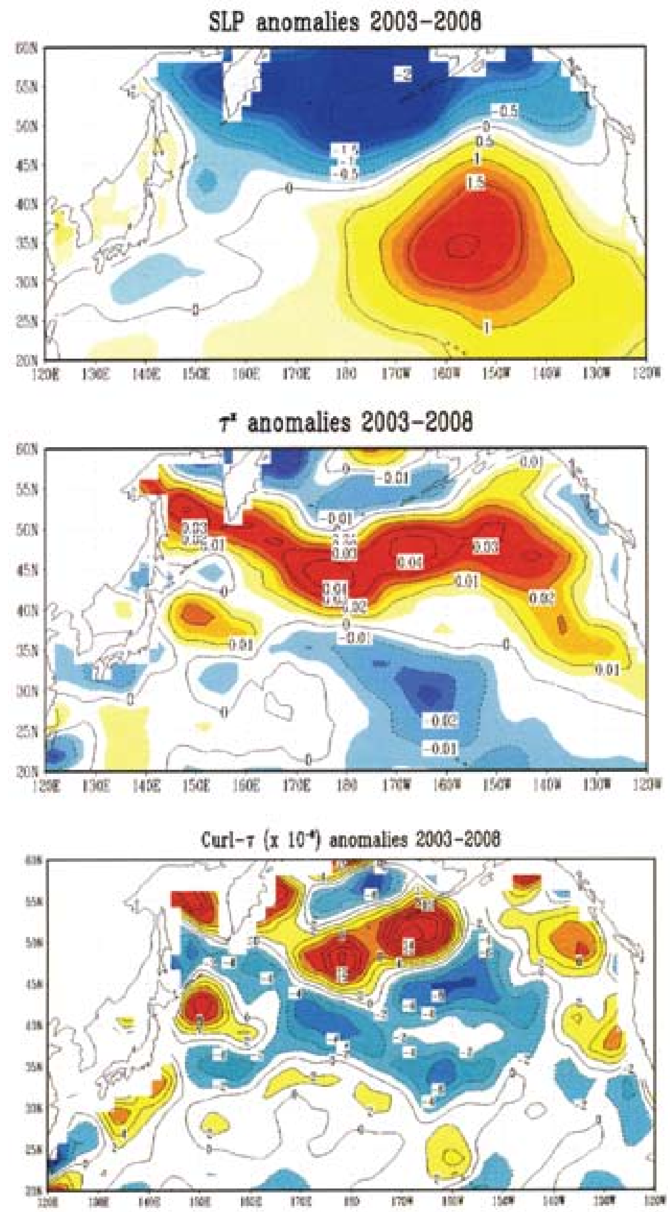
This chapter is a review of the status and trends of the Oyashio region from 2003-2008, hereafter the *focus period*.

2.0 Atmosphere *(Minobe)*

2.1 Wind and pressure

Major components of atmospheric circulation anomalies are associated with large scale structures. Thus regional atmospheric changes in the Oyashio region can often be best understood in the context of basin- or hemispheric-scale changes. Winter conditions receive special attention because winter is when the most prominent atmosphere-to-ocean influences generally occur.

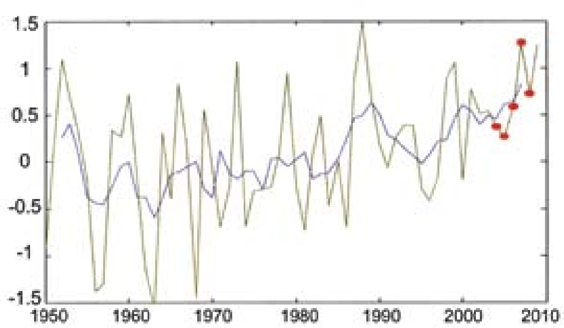
Wintertime sea-level pressure (SLP) anomalies during the focus period were characterized by negative anomalies to the north and positive anomalies to the south in the North Pacific (Fig. OY-2). This pattern is reminiscent of the North Pacific Oscillation (NPO) (Walker and Bliss 1932), though the southern pole is shifted eastward from the typical NPO pattern. Zonal (east-west) wind stress anomalies were positive from the Okhotsk Sea to the central and eastern



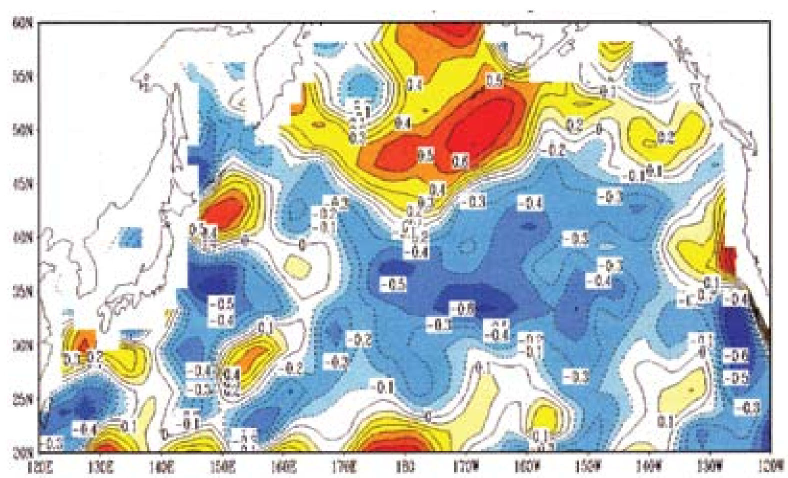
[Figure OY-2] Anomalies of (top) SLP, (middle) zonal wind stress and (bottom) wind stress curl averaged for a period from 2003 to 2008 in the winter season (December-February) based on NCEP-NCAR reanalysis. Contour interval is 0.5 hPa for SLPs, 0.01 $N \cdot m^{-2}$ for wind stress, and $2 \times 10^{-8} N \cdot m^{-3}$ for wind stress curl. Base period for the anomalies is 1970-2000.

North Pacific, with isolated weaker positive anomalies around 40°N 150°E. The extending positive wind stresses occur roughly along the perimeter of the negative SLP anomalies. Zonal wind stress contributes to zonal wind stress curl anomalies that were characterized by strong positive anomalies centered at 43°N 150°E surrounded by negative anomalies in the western North Pacific.

Figure OY-3 shows that the winter West Pacific (WP) index exhibited a prominent increasing trend during the focus period. Therefore, the anomalous meridional dipole in SLP shown in Figure OY-2 and the related wind stress and wind stress curl are most likely expressions of the trend component of the WP pattern. Actually, a correlation map between the WP index and wind stress curl in winter shows a striking similarity with the wind-stress curl anomalies in the western North Pacific (Fig. OY-4). Therefore, it can be concluded that anomalous conditions of the wind stress and wind stress curl in winter during the focus period are aspects of the trend-like increase of WP pattern.



[Figure OY-3] Winter WP index from 1950 to 2009. Raw data are shown by the green line, data smoothed by a 5-year running mean are shown by the solid blue line, and raw data from 2003 to 2008 are also shown by red circles. The monthly WP pattern index was obtained from the Climate Prediction Center. Base period of anomalies is 1950-2000. Five year running means are calculated from 1952 to 2007.

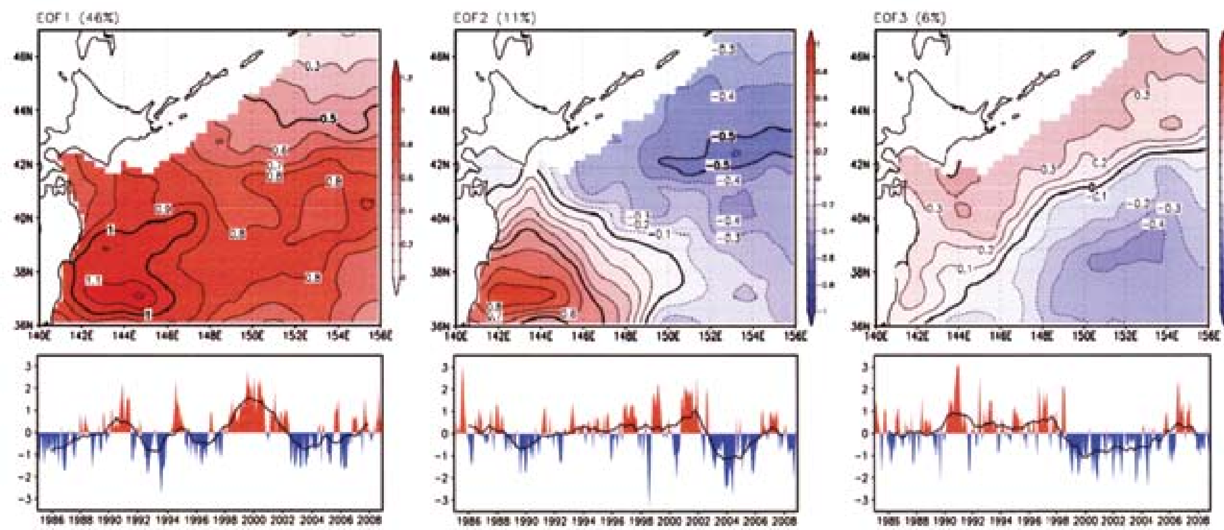


[Figure OY- 4] Correlation coefficient between the WP index and wind stress curl in winter. Data are smoothed by a 5-year running mean before calculating correlations. Correlation coefficients corresponding to the 90% and 95% confidence levels are 0.50 and 0.57, respectively, with the assumption that one datum in five years is independent.

3.0 Physical Ocean *(Ishizaki)*

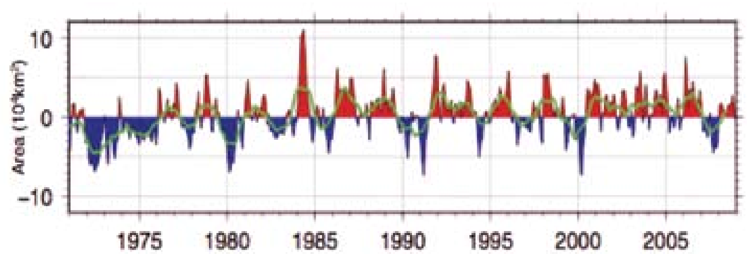
The main feature of sea surface temperature (SST) variation in the Oyashio region is a single EOF pattern covering the entire area (Fig. OY-5). The time sequence of the first mode of the EOF shows both interannual and decadal variations. Sea surface temperatures in the Oyashio region were warmer than average from 1998 to 2002, but turned cooler in 2003. The spatial pattern of the second EOF mode has two centers of action, located east of Japan (around 37°N, 143°E) and southeast of the Kuril Islands. Both the first and second EOF modes indicate that sea surface temperature east of Japan were cooler than average from 2003 to 2006. This cold surface temperature is consistent with the nature of variation of Oyashio water described below.

The Tohoku National Fisheries Research Institute defines the Oyashio region as that having a temperature <5°C at 100 m. A time series of the spatial extent of Oyashio water shows that the Oyashio area has been generally above average since 1984 (Fig. OY-6). The southernmost position of the Oyashio First Branch varies from year to year (Fig. OY-7). It was located south of average from 2003 to 2006. The southward shift of the Oyashio First Branch from 2003 to 2006 corresponds with the negative SST anomalies observed east of Japan.

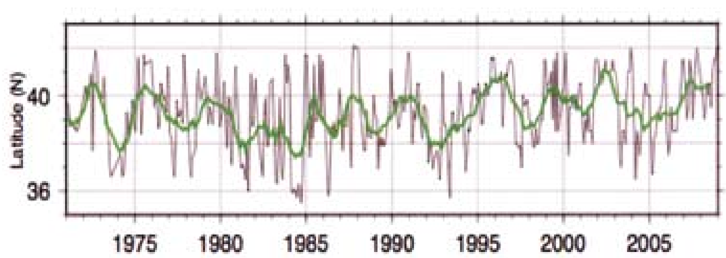


[Figure OY-5] Time sequences (bottom panels) and corresponding spatial patterns (top panels) for the three dominant modes of the EOF for monthly mean SST anomalies. Black line in the bottom panels shows the 13-month running mean value.

[Figure OY-6] Time series of monthly mean of the extent of Oyashio water (104 km^2) from 1971 to 2008. Thick line denotes the 13-month running mean value. Anomalies are deviations from the 1971-2000 climatology.



[Figure OY-7] The monthly southernmost position of the coastal branch of the Oyashio cold water from 1971 to 2008. The thin line denotes the monthly change and the thick line shows the 13-month running mean value.



4.0 Chemical Ocean

4.1 Oxygen *(Sasano, Takatani)*

Recent studies of dissolved oxygen (DO) in the North Pacific report a significant decreasing trend over the past several decades (Emerson et al. 2004; Mecking et al. 2008). For example, at Station Papa (50°N 145°W), oxygen levels declined by 23% between 1956 and 2008 (updated from Whitney et al. 2007), with the strongest declines occurring between 150 and 400 m. The largest decrease in DO occurs at around $26.6\sigma_\theta$, the densest isopycnal surface that outcrops in the northern North Pacific. The modeling work of Deutsch et al. (2005) shows that the primary explanation for this oxygen loss is reduced ventilation of the ocean but other factors also contribute to variability.

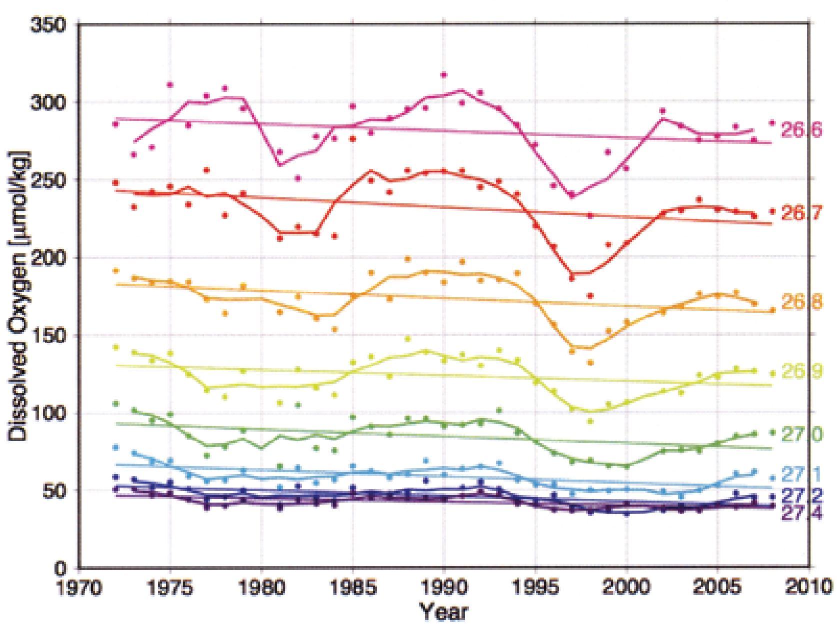
The Oyashio region is a subarctic western boundary current that originates from the mixing of Okhotsk Sea Water (OSW: low temperature and high oxygen) with Western Subarctic Gyre Water (WSAGW: high temperature and low oxygen). Here, a decreasing trend in DO superimposed on a decadal oscillation in DO has been observed (Ono et al. 2001; Watanabe et al. 2008). The decadal variations over the North Pacific could be related to the 18.6-year nodal tidal cycle (Yasuda et al. 2006; Osafune and Yasuda 2006). This cycle is apparently similar to the variation of the North Pacific index (NPI) but their relationship is yet to be clarified. Takatani et al. (2007) suggested that the decadal oscillation of DO is caused by oscillation in the mixing ratio of the source waters rather than DO changes in the source waters and correlates well with the NPI.

Following Takatani et al. (2007), we reanalyzed the long-term variation of DO on various isopycnal surfaces in the Oyashio region at 41° 30'N, 146-147°E up to the year 2008. The extended time series of DO showed a decadal oscillation that is consistent with the former period; the higher DO condition is continuing after 2002 (Fig. OY-8).

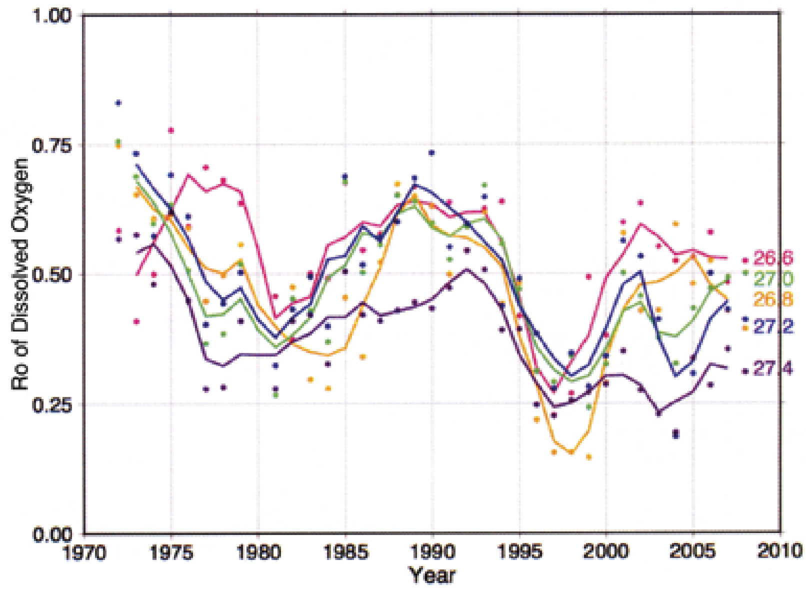
We define the mixing ratio of OSW in Oyashio water, Ro, as Eq (1):

$$Ro = (DO_{obs} - DOW_{SAGW}) / (DO_{OSW} - DOW_{SAGW}) \qquad (1)$$

where DO_{obs}, DOW_{SAGW}, DO_{OSW} represent observed DO concentration, and climatological DO in the WSAGW and the OSW, respectively. Phases of lower DO in the early 1980s and late 1990s correspond with phases of a lower mixing ratio of OSW, and phases of higher DO periods, including the most recent condition, correspond with a higher mixing ratio of OSW (Fig. OY-9). These correspondences between DO, mixing ratio and the NPI indicate the linkage of DO variation in the Oyashio with variation in the atmospheric circulation over the North Pacific and mixing processes of OSW and WSAGW forming the Oyashio water.



[Figure OY-8] Time series of DO on isopycnals from 26.6 to $27.4\sigma_\theta$ in the Oyashio region at 41°30'N, 146-147°E. The solid line denotes the 3-year running average.



[Figure OY-9] Time series of Ro estimated from DO on isopycnals from 26.6 to 27.4σ_θ in the Oyashio region at 41°30'N 146-147°E. Original WSAGW is defined at 0, and original OSW is defined at 1. The solid lines denote the 3-year running averages of DO on isopycnals from 26.6 to 27.2σ_θ.

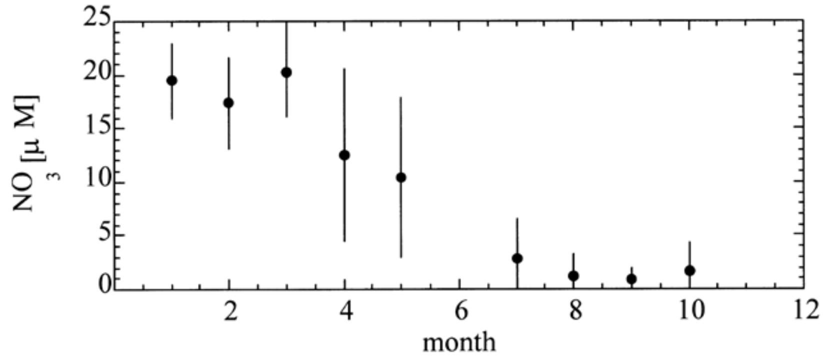
In the long-term, the decreasing DO trend has been observed over isopycnals ranging from 26.6 to 27.4σ_θ. The largest decreasing rate (-0.55 ± 0.18 μmol·kg^{-1}·y^{-1}) was seen on 26.7σ_θ (Fig. OY-8), nearly identical to 26.6σ_θ where the largest decrease in DO has been observed in the North Pacific. Decreases in DO have been reported in the source water of WSAGW (Andreev and Watanabe 2002) and OSW (Nakanowatari et al. 2007). However, this long-term DO decrease in the Oyashio is also attributable to the change in the mixing ratio of OSW and WSAGW, i.e., the trend of a smaller contribution of OSW (Fig. OY-9). The increasing trend of potential vorticity in 26.7-27.0σ_θ (data not shown) indicates a larger contribution of WSAGW with high potential vorticity (Takatani et al. 2007).

Monitoring DO and hydrographic parameters for an extended period is key to understanding the linkages among decadal to longer-term variations in atmospheric circulation, ocean circulation and DO. Clarifying the changes in DO in the Okhotsk Sea and in the Western Subarctic Gyre and changes caused by biological activities are also very important to better understanding the causes of long-term DO decrease in the Oyashio region and across the North Pacific.

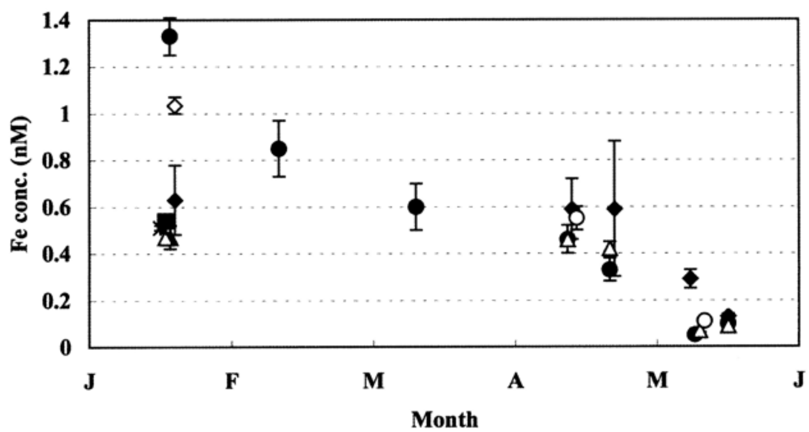
4.2 Nutrients *(Ono)*

Nutrient dynamics in the Oyashio mixed layer are characterized by a larger seasonal amplitude compared to other regions of the Subarctic North Pacific. While the annual maximum concentration in winter differs only slightly from other Subarctic North Pacific regions, the large seasonal amplitude results from nutrients being almost completely exhausted from the mixed layer at the end of the summer season (Fig. OY-10).

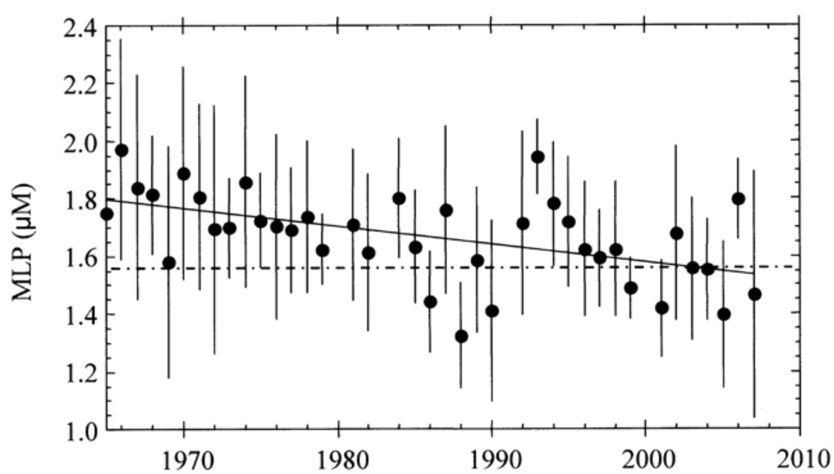
Although this non-HNLC (high nitrogen, low chlorophyll) characteristic indicates that nitrate is the ultimate limiting factor for annual primary production in this region, iron limitation in the Oyashio ecosystem at the end of the spring bloom was hypothesized by Saito et al. (2002) and later demonstrated by Nishioka et al. (2007) through seasonal observations of surface iron concentration (Fig. OY-11). A high concentration of dissolved iron occurs in the Oyashio surface water in winter. It is caused by vertical mixing with the iron-rich Oyashio subsurface waters that originated from Okhotsk Intermediate Water (Nishioka et al. 2007). This iron sustains an enormous phytoplankton bloom in the Oyashio region in spring but it is exhausted by the end of the bloom and thereafter limits the amount of primary production (Fig. OY-11). At this time, significant amounts of major nutrients remain in the Oyashio surface water, as in other Subarctic North Pacific regions (Fig. OY-10). In the Oyashio however, primary production is reactivated by small phytoplankton, and nutrient levels are decreased further until complete exhaustion in late August (Saito et al. 2002). This unique summer production in the Oyashio may be maintained by iron originating from dust input after the spring bloom.



[Figure OY-10] 40-year climatology of surface nitrate in the Oyashio region. Data are calculated from the Japan Meteorological Agency (JMA) and Japanese Fisheries Research Agency (FRA) hydrographic database from 1965 to 2008. The amplitude of seasonal variation (March - September) is 19±5 μM, which is about 3 and 1.4 times larger than that of Stn. P (Whitney and Freeland 1999) and Stn. KNOT (Tsurushima et al. 2002), respectively.



[Figure OY-11] Seasonal variation of surface dissolved iron concentration in the Oyashio region observed in 2003, January - June. Symbols indicate individual stations. After Nishioka et al. (2007).



[Figure OY-12] Time series of phosphate concentration in the winter (January-March) mixed layer in the Oyashio region. Dash-dotted line indicates the 2003-2007 average while the thin line indicates a linear regression of the whole time series. The slope of the linear regression is -0.0060 ± 002 μM y^{-1} (Updated from Ono et al. 2002).

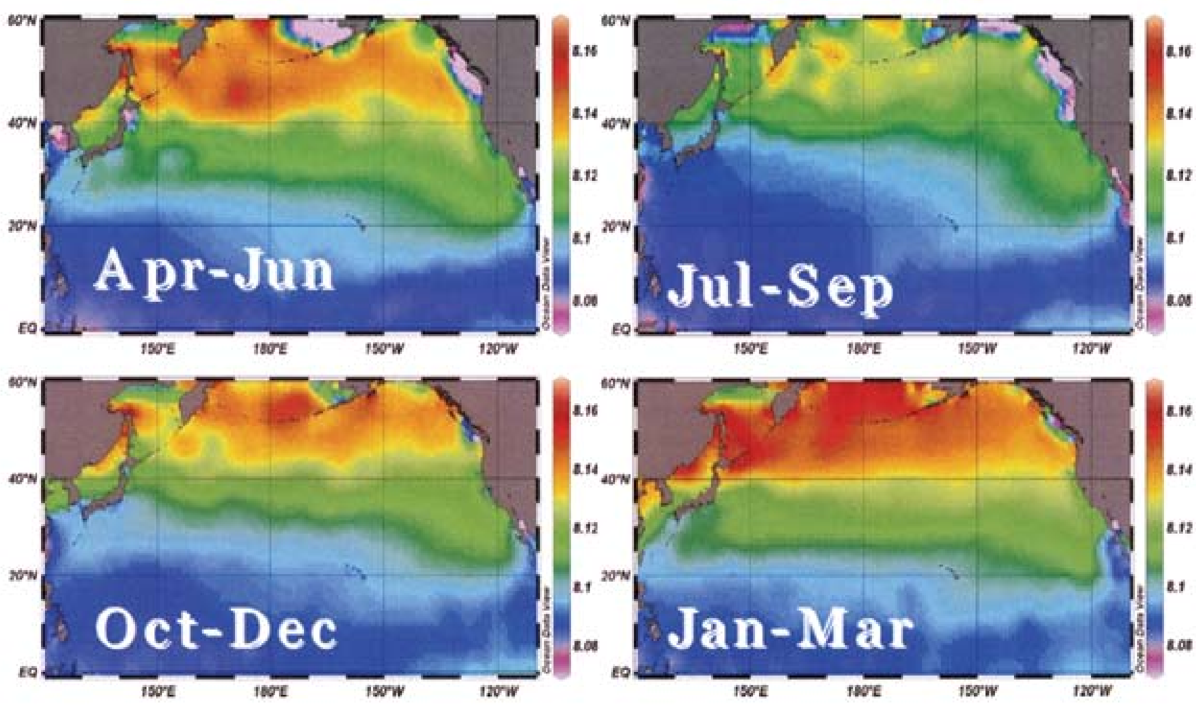
From at least the late 1960s until the present, the nutrient content of the winter mixed layer in the Oyashio region has gradually diminished (Ono et al. 2002)(Fig. OY-12). The average concentration of winter mixed-layer phosphate for the five years since 2003 has dropped to 1.55 ±0.11 μM, the lowest level in the past 40 years except for the latter half of the 1980s. This decline is thought to be caused by diminished winter vertical mixing attributed to increased upper-water stratification in the Subarctic North Pacific (e.g. Ono et al. 2001). Because the winter vertical mixing supplies a significant part of the iron observed in the winter mixed layer (Nishioka et al. 2007), it is believed that winter iron concentration has also diminished in parallel with the major nutrient decrease. Consistent with this, several reports show a multi-decadal decrease of primary production in the spring Oyashio region (e.g. Chiba et al. 2008).

4.3 Ocean acidification *(Watanabe)*

Model results predict that a decrease of pH in the ocean surface water will result from an increase of atmospheric CO_2 in the future (Orr et al. 2005). Based on a time series of oceanic carbonate species, Feely et al. (2008) reported a decreasing trend in pH of 0.0019 ± 0.0003 y^{-1} during recent decades in the central North Pacific, although there were assumptions of no land-ocean interactions with increasing temperature. Unfortunately, there are few reports for the region west of 155°E. However, some efforts have been made to clarify the spatiotemporal changes of pH and its related hydrographic parameters. Wakita et al. (2003) found that dissolved inorganic carbon (DIC) had an increasing trend of 1.3 - 2.3 $\mu mol \cdot kg^{-1} \cdot y^{-1}$ at 44°N 155°E (Station KNOT) during the past decade, suggesting that oceanic acidification may be affecting the western North Pacific. Nakano and Watanabe (2005) described the seasonal spatial distributions of pH over the North Pacific surface water by using a simple algorithm relating pH to subsurface temperature and chlorophyll$_a$. They showed that pH in the western North Pacific is generally higher than in the eastern region, and increases westward (Fig. OY-13). Therefore, the western North Pacific has the potential to absorb large amounts of CO_2, suggesting that the marginal seas may affect the spatiotemporal distributions of seawater pH in the western North Pacific. To elucidate whether oceanic pH decreases with increasing atmospheric CO_2 over the western North Pacific, further study on the carbonate system in this region, including its marginal seas, is needed.

4.4 Contaminants *(Midorikawa, Kamiya)*

Time series data of contaminants are limited in the Oyashio region but the Japan Meteorological Agency (JMA) and Hakodate Marine Observatory have been conducting seasonal monitoring of cadmium (Cd), floating tar balls, and petroleum hydrocarbons (JMA 2008). Time series of Cd in surface waters at an inshore monitoring site at 41.5°N 142°E (PH-1) and an offshore monitoring site at 41.5°N 147°E (PH-6), south of Hokkaido, from 1990 to 2008 are shown in Fig OY-14. Cd concentrations at these two monitoring sites showed large seasonal variations: high in winter and low in summer and autumn. These variations are highly correlated with nutrients, especially

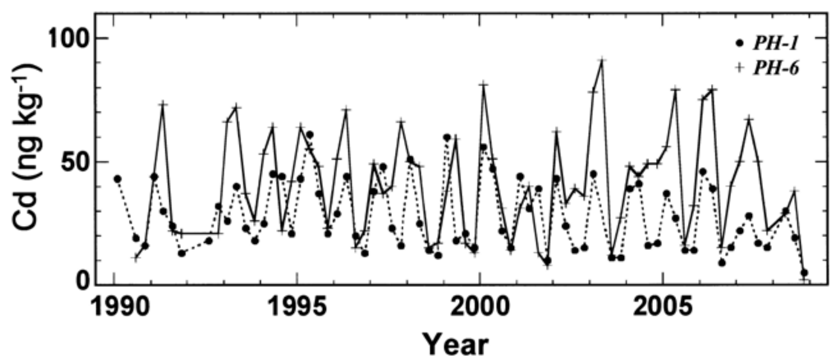


[Figure OY-13] Seasonal distribution of *in situ* pH in the North Pacific (redrafted from Nakano and Watanabe 2005). This scale is shown as pH *in situ* temperature. To describe the distribution of pH over the North Pacific with their algorithms, Nakano and Watanabe (2005) used the data for each of the four seasons (Apr–Jun, Jul–Sep, Oct–Dec and Jan–Mar) from the World Ocean Atlas (WOA) 2001 (Ocean Climate Laboratory National Oceanographic Data Center, 2002).

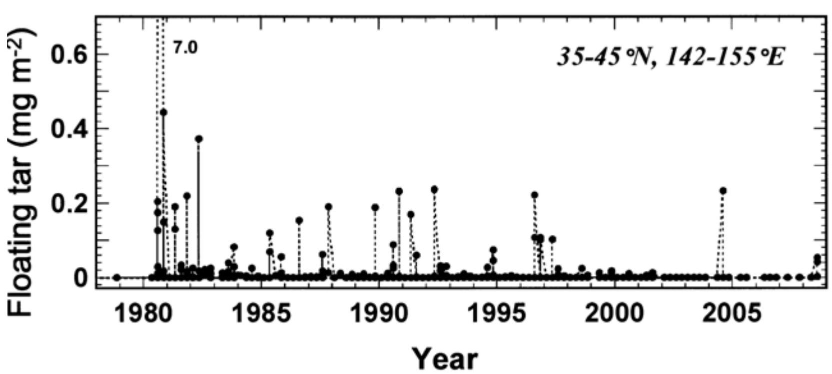
phosphate (r^2 = 0.57, n= 69 at PH-1; r^2 = 0.72, n= 68 at PH-6), suggesting these variations are due to Cd supply through entrainment and removal by active biological consumption, but not to anthropogenic contamination. Relatively high Cd concentrations at PH-6 in winter and spring were attributable to larger entrainment due to deeper convection, as evidenced by temperature at 100 m, which is the index of the Oyashio region (where a temperature-minimum layer is formed, corresponding to the bottom of the winter mixed layer). Temperature at PH-6 (2.0 ± 1.2°C) was lower than that at PH-1 (4.9 ± 1.3°C). Temperature at 100 m at PH-6 was low especially in 2000 (0.93°C) and 2003 (0.97°C), when the Cd concentration was high. At PH-1, the average annual mean and maximum for Cd concentration decreased from 29±5 ng·kg^{-1} and 48±7 ng·kg^{-1} in the 1990s to 24±3 ng·kg^{-1} and 40±7 ng·kg^{-1} after 2002, respectively, corresponding to an increased annual temperature minimum at 100 m from 9.2±0.9°C to 10.4±0.5°C. At PH-6, the decadal mean Cd concentration increased from 41±10 ng·kg^{-1} in the 1990s to 48±4 ng·kg^{-1} after 2002, corresponding to an increased annual minimum of temperature at 100 m from 3.3±1.2°C to 4.3±1.4°C. The difference between the two sites can be attributed to the occasional displacement by Tsugaru Warm Water at PH-1.

A time series of floating tar balls was created by horizontal tows of a 0.35 mm mesh net in the region of 35-45°N 142-155°E (Fig OY-15). In this region, 3 to 22 (average, 14) samples a year were obtained during the period of 1980-2008. Before 1983, the concentration of tar balls was high (average, 0.14 mg·m^{-2}) and a large tar ball concentration exceeding 0.4 mg·m^{-2} was found. After 2000, the tar ball concentration was low (average, 0.0048 mg·m^{-2}) and few tar balls were collected throughout the year, although a high tar ball concentration was occasionally observed as in 2004 (0.23 mg·m^{-2}).

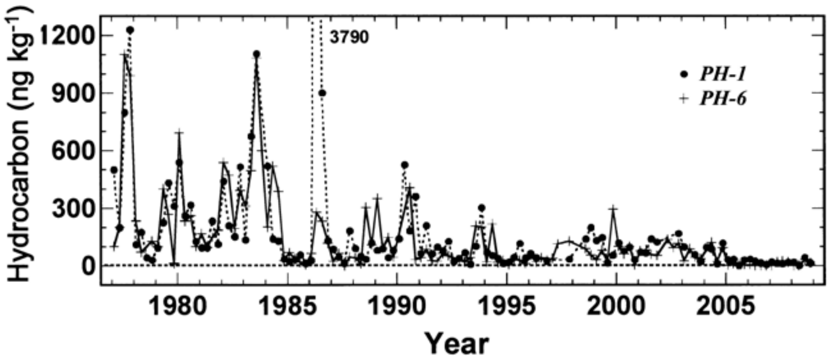
The concentrations of petroleum hydrocarbons in surface waters at two monitoring sites were high (averages, 383 ng·kg^{-1} at PH-1 and 295 ng·kg^{-1} at PH-6) before 1987 (Fig. OY-16). After 2002, the hydrocarbon concentrations (averages, 34 ng·kg^{-1} at PH-1 and 24 ng·kg^{-1} at PH-6) were low compared with the levels for 1995 to 2002 (averages, 85 ng·kg^{-1} at PH-1 and 70 ng·kg^{-1} at PH-6).



[Figure OY-14] Temporal variations of cadmium concentration in surface waters at the two monitoring sites : PH-1 (41.5°N, 142°E) and PH-6 (41.5°N, 147°E), in the western North Pacific for 1990-2008.



[Figure OY-15] Temporal variations of floating tar balls collected in the region of 35-45°N, 142-155°E for 1978-2008.



[Figure OY-16] Temporal variations of petroleum hydrocarbon concentration in surface waters at PH-1 and PH-6 for 1977-2008. The hydrocarbon concentration is expressed as the chrysene equivalent in the fluorescence measurements.

5.0 Biological Ocean

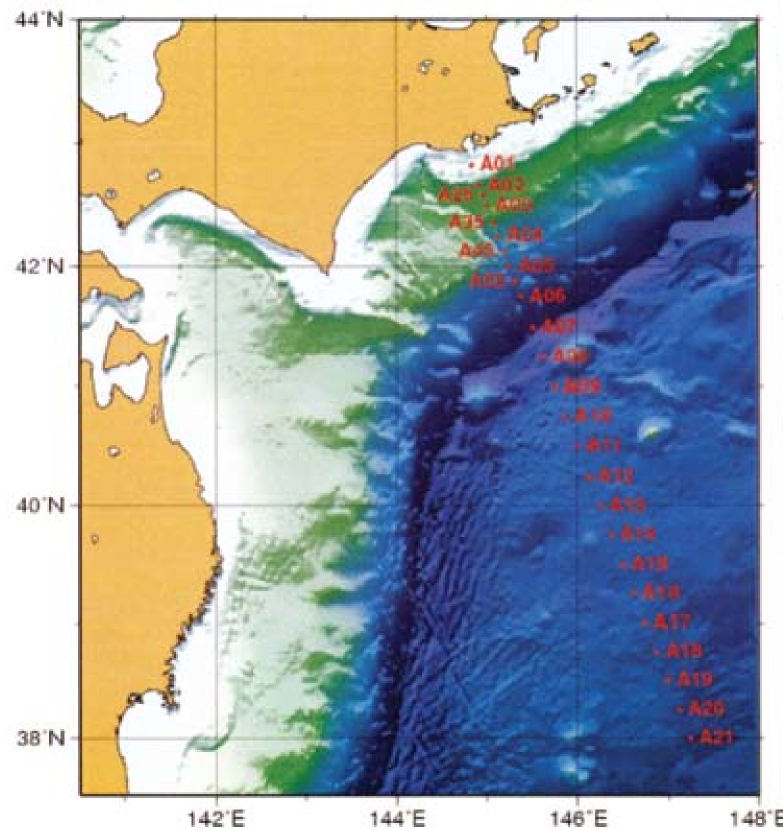
5.1 Phytoplankton

5.1.1 Chlorophyll measurements *(Saitoh, Kuwata)*

Shipboard measurements of chlorophyll$_a$ concentration were carried out at near bimonthly intervals at 12 stations along the A-line, off Hokkaido, Japan (38-42°50'N 147°25' - 144°50'E) (Fig. OY-17). Spring and fall phytoplankton blooms were observed during April through June and during September through November, respectively, although the fall bloom was indistinct in the southern region (Fig. OY-18). In general, the chlorophyll$_a$ concentration was higher on the continental shelf and in the Oyashio First Branch (>41°30'N) compared with the southern region. Lowest chlorophyll$_a$ concentrations were observed in regions with SST>20°C where nutrients were depleted. SST was cooler after 2006 than in 2003-2005, particularly north of 40°N, and chlorophyll$_a$ concentration was low during early spring but its peak was high.

In the Oyashio region, mean chlorophyll$_a$ concentration peaked in May and the lowest values were observed in January and July (Fig. OY-19). The median value in April was only 0.48 mg·m^{-3}, which indicates that the spring bloom begins in May at most stations. The seasonal pattern and the concentration in each month were similar to previous reports (Saito et al. 2002; Yokouchi et al. 2006).

On the continental shelf, the spring bloom began in March and continued until July (Fig. OY-20). High concentrations were observed throughout the water column (100 m) during the spring bloom, which indicated a high sinking flux of phytoplankton from the euphotic zone. The initiation of the phytoplankton bloom in the Oyashio First Branch was late compared with that in the Second Branch, due to the late development of the thermocline. A subsurface chlorophyll maximum (SCM) due to nutrient depletion in the warm surface layer was observed in summer in the Oyashio Second Branch. A weak phytoplankton bloom was observed in the Oyashio-Kuroshio Inter-frontal Zone south of the Subarctic Front. Chlorophyll$_a$ concentration in the sea surface was low in summer, and the SCM developed in the 40-60 m layer. These latitudinal differences in the seasonal pattern and vertical profiles of chlorophyll$_a$ concentration observed during 2003-2008 were similar to those reported in previous studies (Kasai et al. 1998; Taguchi et al. 1992).

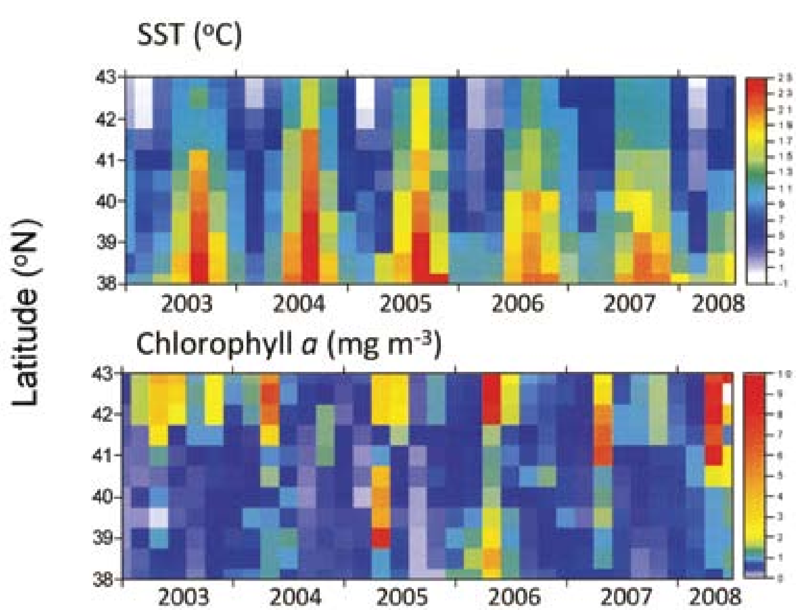


A-Line Stations

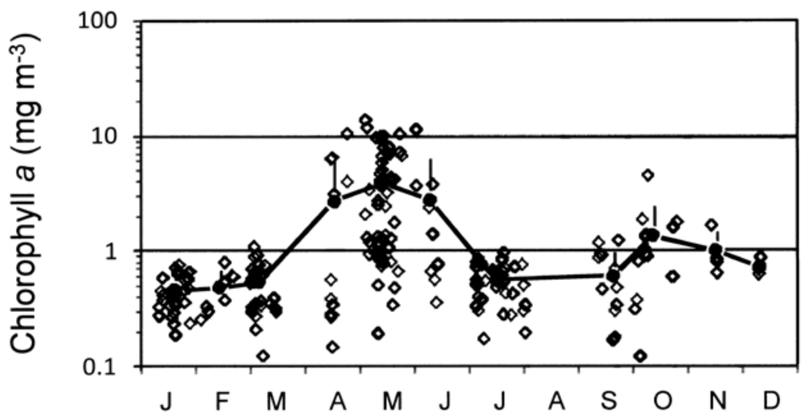
St #	Latitude	Longitude	Depth (m)
A1	42°50'N	144°50'E	99
A2	42°40'N	144°55'E	400
A25*	42°35'N	144°57.5'E	1200
A3	42°30'N	145°00'E	1780
A35*	42°21'N	145°04.5'E	2574
A4	42°15'N	145°07.5'E	2950
A45*	42°07.5'N	145°11.3'E	3200
A5	42°00'N	145°15'E	4000
A55*	41°52.5'N	145°18.8'E	4500
A6	41°45'N	145°23'E	5280
A7	41°30'N	145°30'E	7150
A8	41°15'N	145°38'E	6320
A9	41°00'N	145°45'E	5580
A10	40°45'N	145°53'E	5280
A11	40°30'N	146°00'E	5160
A12	40°15'N	146°08'E	5150
A13	40°00'N	146°15'E	4900
A14	39°45'N	146°23'E	5170
A15	39°30'N	146°30'E	5200
A16	39°15'N	146°38'E	5220
A17	39°00'N	146°45'E	5210
A18*	38°45'N	146°52.5'E	5200
A19*	38°30'N	147°00'E	5200
A20*	38°15'N	147°7.5'E	5200
A21*	38°00'N	147°15'E	5200

*: operated from Jan 2003

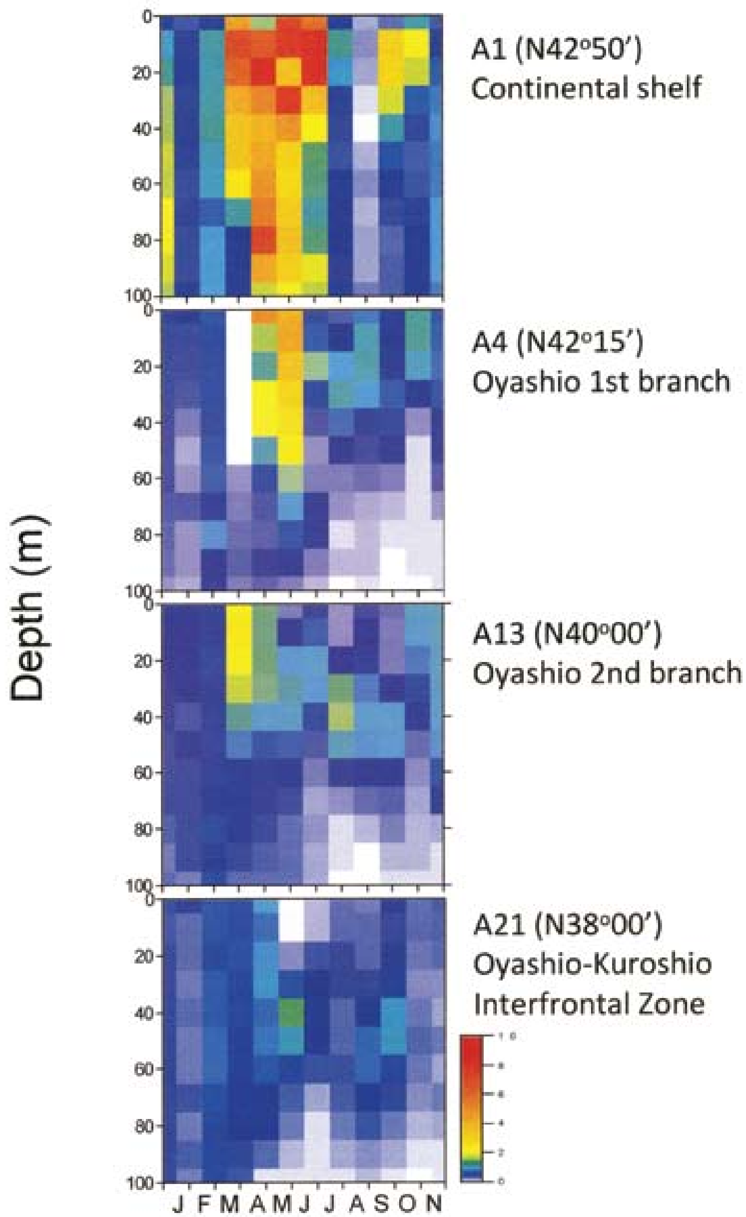
[Figure OY-17] Map of the A-line stations occupied by the Hokkaido National Fisheries Research Institute / Tohoku National Fisheries Research Institute (http://hnf.fra.affrc.go.jp/a-line/intro/index_e.html)



[Figure OY-18] Temporal variations in temperature (top) and chlorophyll$_a$ concentration (bottom) at the sea surface along the A-line during 2003-2008.



[Figure OY-19] Seasonal variation in the chlorophyll$_a$ concentration at the sea surface during 2003-2008. Circles connected with the thick line and the vertical bars indicate the mean and standard error in each month, respectively.



[Figure OY-20] Temporal variations in the vertical profile of chlorophyll$_a$ concentration at Stns A1 (continental shelf), A4 (Oyashio 1st branch), A13 (Oyashio 2nd branch) and A21 (Oyashio-Kuroshio interfrontal zone) during 2003-2008.

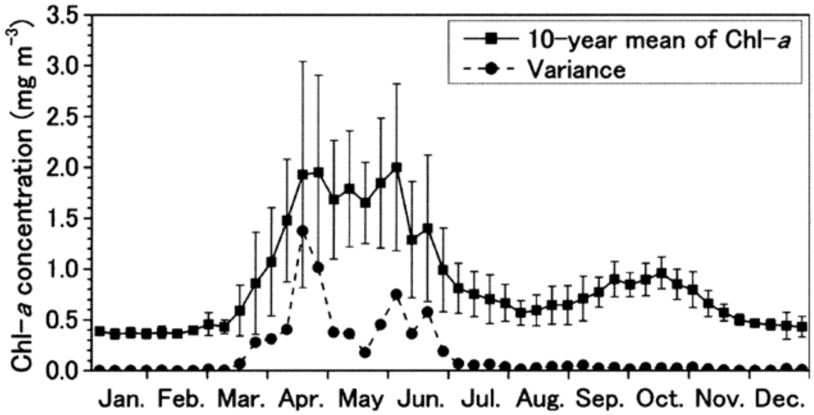
5.1.2 Chlorophyll from satellite

(Okamoto, Saitoh, Hirawake)

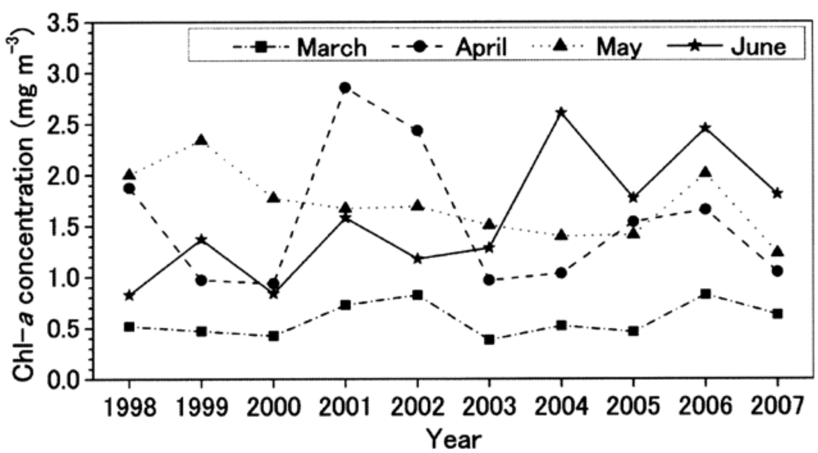
From 1998 to 2007, sea surface chlorophyll$_a$ concentration was generally high (>1 mg·m⁻³) from April to June, followed by a summer low from July to August, and the interannual variability was substantial from late March to June (Fig. OY-21). Fall blooms were observed from September to October, but the interannual variability in chlorophyll$_a$ concentration was low during these months.

In April, chlorophyll$_a$ concentration was comparatively high in 2001 and 2002, and low in 1999, 2000, 2003, 2004 and 2007 (Fig. OY-22). No distinctive trend was observed in April during the 10 years from 1998 to 2007. On the other hand, chlorophyll$_a$ concentration tended to decrease in May and to increase in June. Until 2003, it was lower in June than in May but from 2004 on, it was higher in June. From 2003 on, chlorophyll$_a$ concentration was also higher in June than in April. These patterns indicate changes in the timing and duration of the spring bloom.

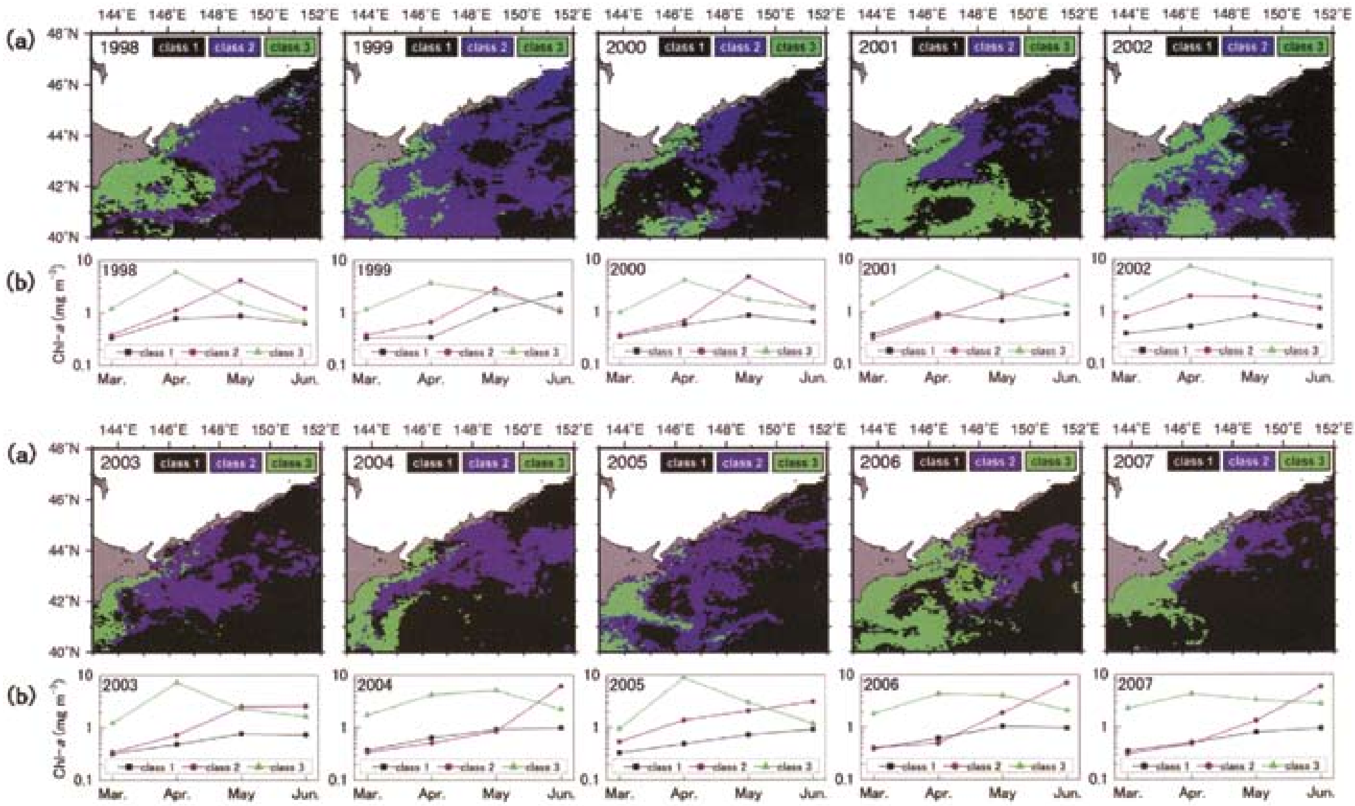
The seasonal and spatial variability in chlorophyll$_a$ concentration from March to June were examined by cluster analysis. Each grid was classified into one of the 3 cluster groups based on the peak timing and extent of chlorophyll$_a$ concentration: class 1 had low chlorophyll$_a$ with its peak in May-June; class 2 had moderate chlorophyll$_a$ with its peak in May-June; and class 3 had high chlorophyll$_a$ with its peak in April-May. The results show that chlorophyll$_a$ concentration during spring was greatly different between areas and years (Fig. OY-23). In 2001, 2002 and 2006, the area where chlorophyll$_a$ concentration was highest in April was more extensive than usual, whereas it was very narrowly distributed in 2003. In 1999, the area where chlorophyll$_a$ concentration was highest in May was the widest among the 10 years, due to the bloom in May of that year (Fig. OY-23). The areas which had peak chlorophyll$_a$ concentration in April or May were extensively distributed until 2002 (Fig. OY-23). From 2003 on, increasing temporal variation in chlorophyll$_a$ concentration from March to June was observed over a broad area. From 1998-2002 to 2003-2007, the season of high chlorophyll$_a$ concentration shifted to June in this broad area.



[Figure OY-21] The seasonal variability in sea surface chlorophyll$_a$ concentration (from a satellite ocean color sensor, SeaWiFS) averaged for 10 years (solid line) and its variance from 1998 to 2007 (dashed line) in the Oyashio region.



[Figure OY-22] Interannual variability in chlorophyll$_a$ concentration from March to June.



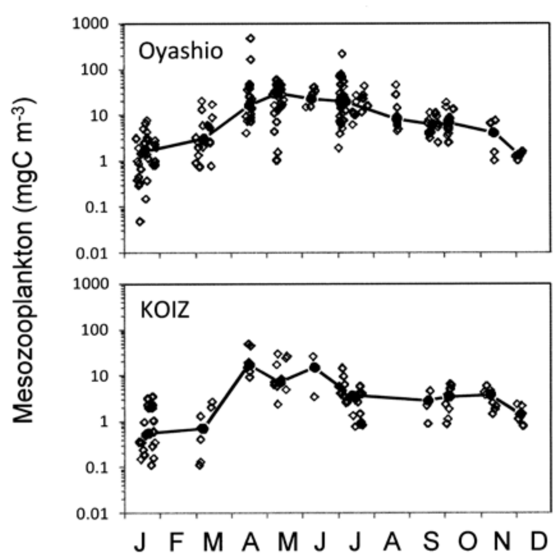
[Figure OY-23] (a) Spatial distribution of seasonal variation pattern of chlorophyll$_a$ concentration from 1998 to 2007 for each class specified by cluster analysis based on the timing and extent of peak chlorophyll$_a$. (b) Seasonal variability of chlorophyll$_a$ concentration in the region of each class. Class 1: low chlorophyll$_a$ with its peak in May-June, Class 2: moderate chlorophyll$_a$ with its peak in May-June, Class 3: high chlorophyll$_a$ with its peak in April-May.

5.2 Zooplankton

(Saito, Okazaki, Tadokoro, Takahashi)

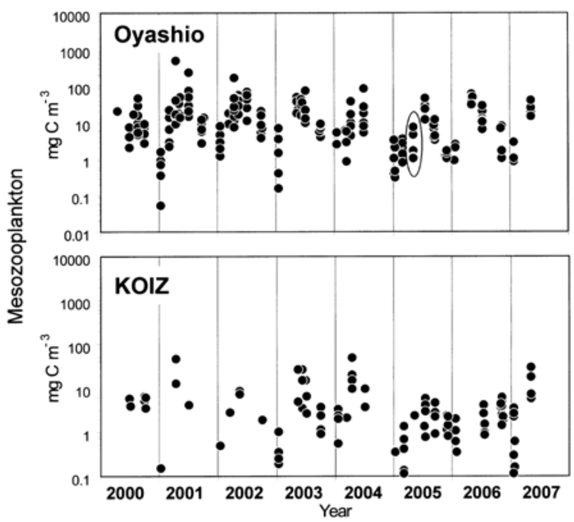
5.2.1 Biomass and seasonal cycle

Along the A-line, the mesozooplankton biomass in the upper 150 m showed clear seasonal variation both in the Oyashio region and the Kuroshio-Oyashio Inter-frontal Zone (KOIZ) (Fig. OY-24). The highest values were observed during April to July, and the lowest in December and January. The magnitude of the seasonal variation (max - min of median in each month during 2001-2007) was 28.2 mgC·m^{-3} and 16.7 mgC·m^{-3} in the Oyashio and KOIZ, respectively, and the ratio of the maximum to minimum was 22 and 31, respectively. In the Oyashio region, the mean biomass in each month was higher than in the KOIZ except for December, and the mean ratio of the Oyashio to KOIZ was 2.8. The highest ratio was observed in July (7.58), at which time the mesozooplankton biomass in the KOIZ declined from June, probably due to the decreasing chlorophyll$_a$ and/or increasing sea surface temperature.



[Figure OY-24] Seasonal change in the mesozooplankton biomass in the top 150 m of the water column in the Oyashio region (top) and Kuroshio-Oyashio Interfrontal Zone (KOIZ, bottom). Data were obtained at stations along *A-line* during 2001-2007. Circles connected with thick line indicate the median in each month.

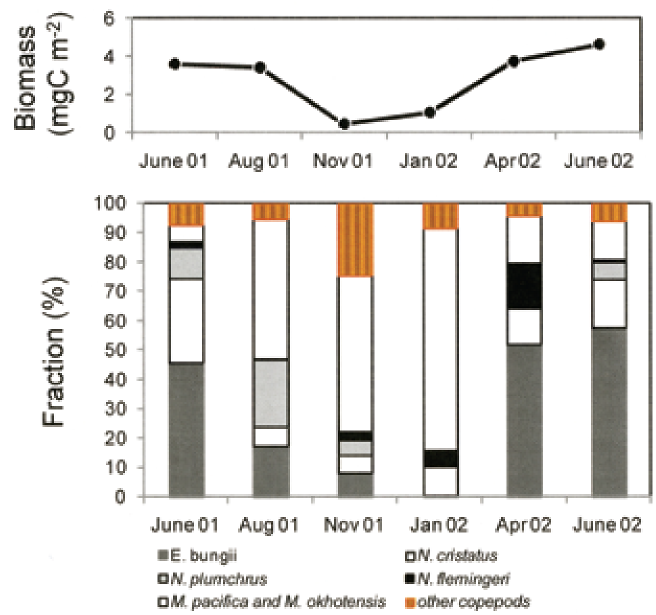
The mean and median biomass in July in the Oyashio region (29.3 mgC·m^{-3} and 19.8 mgC·m^{-3}) were comparable to those in April, May and June. No statistical difference in the mean biomass in January and July was observed among years. On the other hand, the mean biomass in July 2005 was significantly lower than other years (Fig. OY-25). In the KOIZ, the peak biomass was relatively low also in 2005 and in 2006 (Fig. OY-25).



[Figure OY-25] Interannual change in the mesozooplankton biomass in the top 150 m of the water column in the Oyashio region (top) and Kuroshio-Oyashio Interfrontal Zone (KOIZ, bottom). Data were obtained at the stations along *A-line* during 2000-2007. July biomass in 2005 in Oyashio is indicated by the circle.

5.2.2 Copepods

During the period of June 2001 and June 2002, the seasonal dynamics and annual ingestion rate of copepod populations were investigated in the Oyashio region, off Hokkaido (Takahashi et al. 2008). Total copepod biomass in the upper 150 m ranged between 0.47 - 4.6 gC·m^{-2} (converted from wet weight using a C:WW ratio of 0.08). The dominant species in spring to early summer was *Eucalanus bungii* (Fig. OY-26). Adult females and copepodid stage 5 (C5) were most abundant in April, and C1 and C2 were numerically dominant in June. *Neocalanus* spp. were abundant in spring and summer. *N. flemingeri* was most abundant in April and *N. plumchrus* in June and August. *N. cristatus* occurred throughout the year, and was most



[Figure OY-26] Seasonal change in mesozooplankton biomass (0-150 m) at a fixed station in the Oyashio region (top) and species composition (bottom) from June 2001 to June 2002.

abundant from spring to early summer. *Metridia* spp. also occurred throughout the year and was most abundant in summer. The contribution of *Metridia* spp. to the copepod assemblage was high in late summer and winter when most *E. bungii* and *Neocalanus* spp. were dormant in the mesopelagic zone. The seasonal succession of copepods was consistent with previous studies (Tsuda et al. 1999, 2004; Padmavati et al. 2004).

The annual ingestion rate of phytoplankton and particulate organic matter (POM) by the copepod assemblage was 37.7 gC·m^{-2}·y^{-1} and 137.9 gC·m^{-2}·y^{-1}, respectively, which was equivalent to 13% and 46% of the annual primary production (Takahashi et al. 2008). *E. bungii* contributed 33.1% and 46.5% of the ingestion rate on phytoplankton and POC, respectively. The biomass of *E. bungii* was comparable to that of the Bering Sea and 1-2 orders of magnitude higher than that of the western and eastern Subarctic gyres. The high biomass of *E. bungii* in the Oyashio region probably reflects the high food availability during the spring bloom. *Neocalanus* spp. and *Metridia* spp. annually contributed 26.5% and 19.9% respectively to the total copepod ingestion of POC.

Copepods are important drivers of the biological carbon pump to the ocean interior because they package small prey particles into fast sinking fecal pellets and because of their diel or ontogenetic vertical migrations. Based on the observation from September 1996 to October 1997 in the Oyashio region, *Neocalanus* spp. transported 6.5 $gC \cdot m^{-2} \cdot y^{-1}$ to 200 m by ontogenetic vertical migration and fecal pellet production, and 4.3 $gC \cdot m^{-2} \cdot y^{-1}$ to 1000m (Kobari et al. 2003). *Metridia* spp. are the dominant diel vertical migrators in the Oyashio region and their annual carbon transport to 150 m was estimated to be 3.0 $gC \cdot m^{-2} \cdot y^{-1}$ based on observations from June 2001 to June 2002 (Takahashi et al. 2009). The *Metridia* spp. contribution to the active biological pump was high from late summer to winter when both sinking particle flux and the *Neocalanus* and *Eucalanus* contributions to the active biological pump were low.

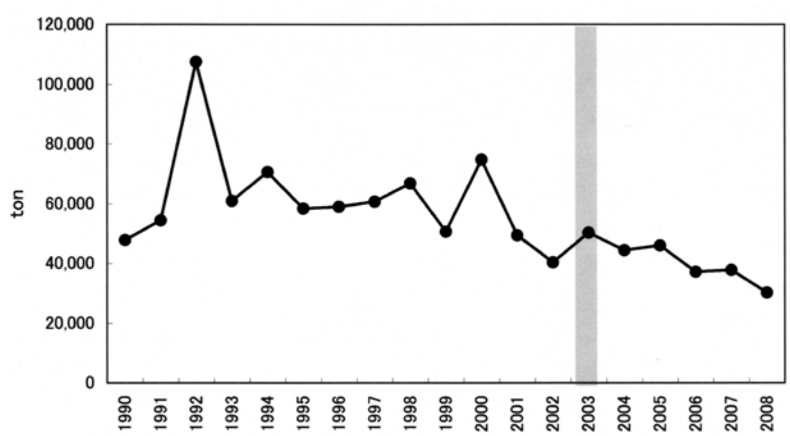
5.2.3 Euphausiids

Twenty-six euphausiid species are recorded in the coastal area of northeastern Japan (Taki 2007a). *Euphausia pacifica* is the most abundant species in this region, and *Thysanoessa inspinata* is the second most abundant. Along the A-line, 21 species of euphausiids were collected in the Oyashio and mixed water region (Okazaki, unpublished data). *E. pacifica* and *Thysanoessa* spp. were the two most abundant taxa in the Oyashio region. *Euphausia recurva*, *E. mutica* and *Nematoscelis microps* occurred year round in the mixed water region (temperature at 100 m ≥5°C). *Stylocheiron* spp., *Thysanopoda* spp. and *E. brevis* occurred from summer to autumn in the mixed water region.

The diet of *E. pacifica* off northeastern Japan depends on both heterotrophic (microzooplankton) and autotrophic (phytoplankton) prey. Based on a study during 1997-1998 (Nakagawa et al. 2001), seasonal change in the number of prey items consumed by *E. pacifica* showed diatoms (88.0%) were the most abundant prey items in April, whereas the most abundant prey items in other seasons (June, August, October, December and February) were dinoflagellates, tintinnids and copepods. On the other hand, seasonal change in carbon composition of prey items showed that the most important prey items throughout the survey period were copepods (more than 98.5%).

E. pacifica is an important prey item for many fish, marine mammals and seabirds. In the Oyashio and mixed water region, Pacific saury (*Cololabis saira*) was reported to feed mainly on *E. pacifica* during 1999-2001 (Sugisaki and Kurita 2004). In demersal environments, Pacific cod (*Gadus macrocephalus*) and walleye pollock (*Theragra chalcogramma*) were reported to have a high proportion of *E. pacifica* in their diets during 1989-1992 (Yamamura et al. 1998). *E. pacifica* is not only an important prey item for commercial fishes, but also for non-commercial fishes. For example, it was reported that many Myctophidae fishes (*Diaphus theta, Stenobrachius leucopsarus, Notoscopelus japonicas* and *Lampanyctus jordani*) fed on *E. pacifica* in the mid to late 1990s (Moku et al. 2000; Uchikawa et al. 2002, 2008) in the western North Pacific.

In Japanese waters, euphausiids are not only important to higher trophic organisms as prey but are also a direct fishery resource. A euphausiid (mostly *E. pacifica*) fishery is conducted in Sanriku and Joban waters off northeastern Japan in late winter to spring. In recent years, euphausiids have been caught by boat seines. In the last 10 years, total landings were from 30,000 to 50,000 t annually (Fig. OY-27). The annual landings are regulated by prefectural governors to keep stable prices, therefore we should note that landing data do not represent euphausiid biomass or stock status.



[Figure OY-27] Catch (t) of *Euphausia pacifica* off northeastern Japan. Note that the total catch is regulated by prefectural governors and does not represent its biomass.

Long-term changes of euphausiid biomass have not been reported in the western North Pacific because the data are limited. Taki (2007b) showed interannual variation in abundance of *E. pacifica* collected from 1993-2000. The abundance of adult *E. pacifica* in summer-autumn was higher in 1993, 1994 and 1999 than other years during the study period. He also reported that the abundance of eggs and larvae in spring were highly correlated with adult abundance in the subsequent summer-autumn. This implies that interannual variation in abundance of euphausiid eggs and larvae could be a good indicator of euphausiid population changes. Eggs and larvae can be estimated by a small plankton net such as a NORPAC net. Thus, eggs and larvae collections are a possible way for long term analysis because sampling by NORPAC net in the western North Pacific has been conducted since the 1950s.

6.0 Fishes and Invertebrates

6.1 Pelagic fish and squid

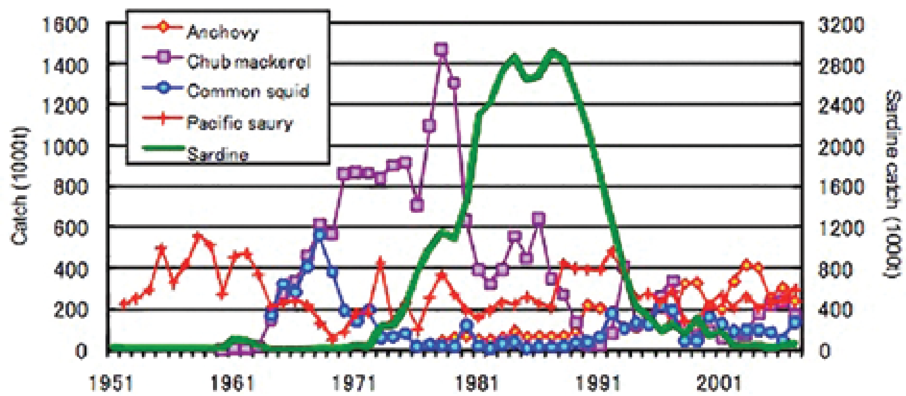
(Yatsu, Yamashita, Watanabe)

Japanese fishers have been harvesting various marine organisms in the Oyashio, Kuroshio and its adjacent regions for a very long time. Small pelagic fish such as Japanese sardine (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonicus*), chub mackerel (*Scomber japonicus*), Pacific saury (*Cololabis saira*) and Japanese common squid (*Todarodes pacificus*) have constituted most of the commercial landings since the early 20th century, but the landings have varied considerably (Fig. OY-28).

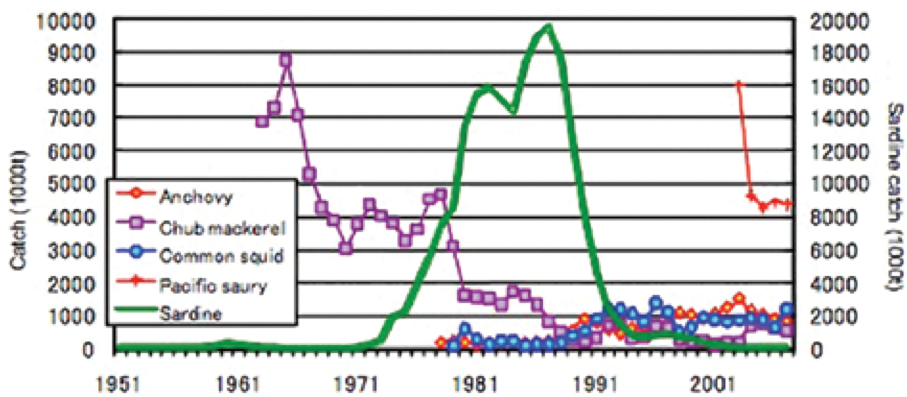
These species undergo seasonal north-south migrations between spawning grounds in the subtropical, Kuroshio region (see Sugisaki et al. 2010) during autumn-winter-spring and feeding grounds in the subarctic, Oyashio water in summer. One of the distinctive features of the Kuroshio-Oyashio system is the large latitudinal contrast of environments. The dominant zooplankton size increases with latitude, and the start of active plankton production is earlier in the year in the south than in the north. Therefore, ontogenetic migration in the Kuroshio-Oyashio system favors small pelagic fish (Ito et al. 2004b). Consistent with the "surf riding theory", reproduction occurs on time and space scales that take advantage of the “wave” of food supply that propagates from south to north (Pope et al. 1994). The spawning grounds of these species usually extend from Kyushu Island (southern Japan) to Cape Inubo (36ºN), except for the common squid, which has its major spawning grounds in the East China Sea in winter, and for anchovy and Pacific saury, whose spawning grounds extend from southern Japan to the extensive area of the Transition Zone, presumably beyond the International Date Line in recent years when stock level has been high (anchovy) or to the California Current (Pacific saury).

Biomass patterns and Japanese commercial catches of these small pelagic fishes indicate decadal changes or alternations of dominant species called “species replacements” (Figs. OY-28 and OY-29). Although mechanisms of species replacements have not been fully resolved, ocean-climate regime shifts together with species interactions have profound impacts on dynamics of small pelagic fishes. Sardine biomass and catch were high during the 1980s and decreased in the 1990s. The onset of increase and decrease of the biomass occurred in the early 1970s and 1989, respectively, which coincided with regime shifts found in SST and mixed layer depth (Nishikawa and Yasuda 2008) around the Kuroshio Extension. The observed recruitment of sardine was above the Ricker curve, which indicates a relationship between net reproduction and stock density during 1971-1987, and below the curve during 1951-1970 and after 1988, suggesting unfavorable environmental conditions after 1988. Reproductive success, which is determined by interannual changes in survival rates of larvae and juveniles, is affected by the SST of the Kuroshio Extension southern area and locations around the southern boundary of the Oyashio intrusion. Spawning stock biomass (SSB) was around 0.5 million t in the late 1990s, and has decreased to less than 0.3 million t since 2002. Therefore, recruitment in recent years has been extremely low and catch has been less than 60,000 t since 2002. Mean body weight of age 0-2 sardines was low during the 1980s when sardine biomass was high, and then suddenly increased in the early 1990s (Fig. OY-30).

Chub mackerel biomass and catch were high during the 1970s and decreased in the early 1990s, thereafter increasing slightly. The observed recruitment of chub mackerel was above the Ricker curve during 1970-1977, 1991-1992, and 1995-1996, and below the curve during 1978-1980 and 1986-1990. Despite the occurrences of strong year-classes in 1992 and 1996, intensive fishing



[Figure OY-28] Japanese catch of sardine, anchovy, chub mackerel, Pacific saury and common squid (winter spawning stock) along the Pacific coast of Japan.

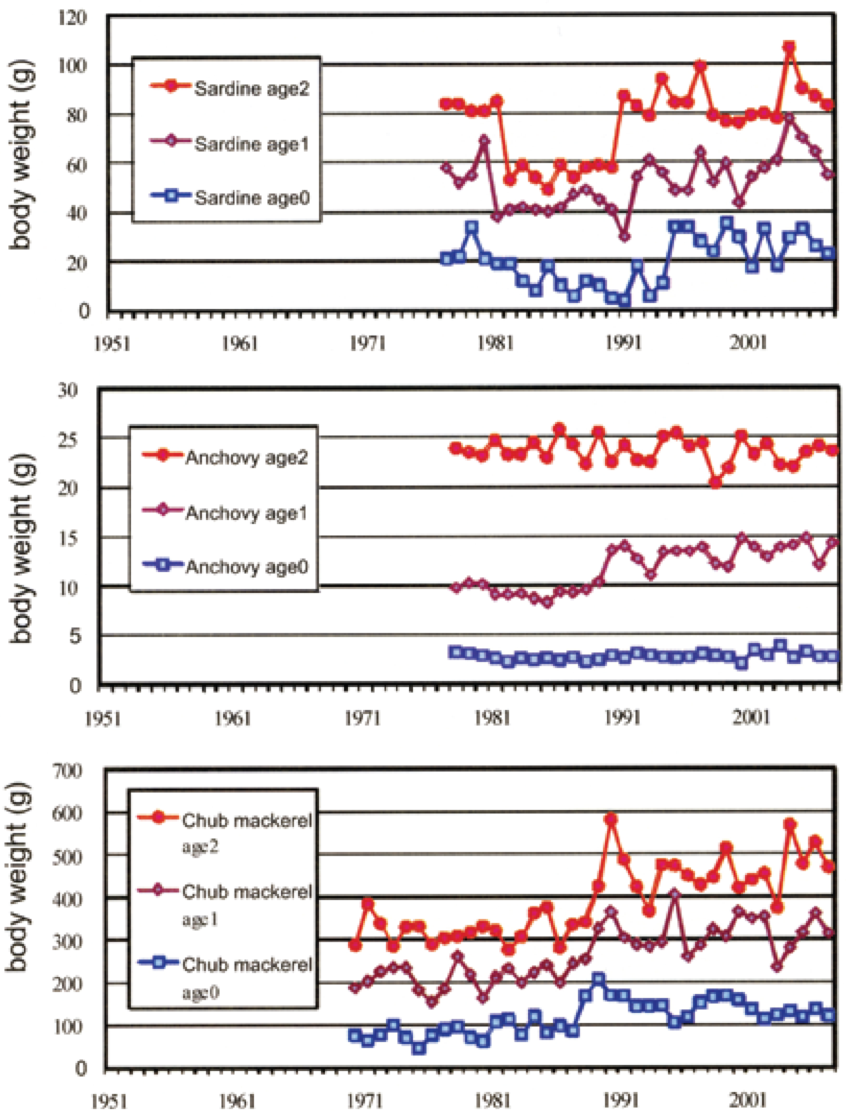


[Figure OY-29] Biomass of sardine, anchovy, chub mackerel, Pacific saury and common squid (winter spawning stock) along the Pacific coast of Japan. NB: anchovy biomass represents only Japanese coastal and offshore waters. Biomass of Pacific saury was estimated for western and central North Pacific west of 177°W.

on immature fishes prevented stock recovery. In 2004, an occurrence of a strong year-class together with a “stock recovery plan” slightly improved stock biomass and catch in subsequent years. Thus, recruitment and catch since the 1990s have been variable. The biomass of chub mackerel fluctuated between 0.15 million t (2001) and 0.78 million t (2005) during the 2000s. Mean body weight of age 0-2 chub mackerel was low until the mid 1980s, when chub mackerel biomass was high, and gradually increased in the late 1980s (Fig. OY-30).

Anchovy and common squid biomass and catch have been relatively high since the 1990s, but with considerable year-to-year fluctuations (e.g. a drastic decline of squid catch in 1998 and 1999 when an extremely strong El Niño occurred), which reflects their relatively short life spans (anchovy - 2 or 3 years and squid - 1 year). The biomass of anchovy gradually decreased from 2003 (1.5 million t) to 2007 (0.8 million t). The biomass of common squid fluctuated between 0.8 and 0.9 million t between 2000 and 2005, and decreased to 0.7 million t in 2006. However, a strong year-class appeared and biomass increased to 1.2 million t in 2007. Fluctuations of biomass in recent years, as well as during the 1990s, have been large. Catch and biomass of sardine seem to be negatively related with those of anchovy and common squid. Mean body weight of age 0-2 anchovy has been relatively stable since the late 1970s, except for a slight increase in body weight of age-1 fish in the late 1980s, which coincided with the increase in body weight of chub mackerel (Fig. OY-30).

Catch of Pacific saury, which has a 2-year life span, showed a decadal fluctuation before the 1990s but has stabilized at 0.2-0.3 million t per year since the late 1990s when the Japanese Total Allowable Catch system took effect to prevent overexploitation. Exceptions were the considerable declines of catch and biomass in 1998 and 1999. Biomass data directly estimated with a pelagic trawl are available only since 2003, and indicate biomass was stable during 2004-2007.

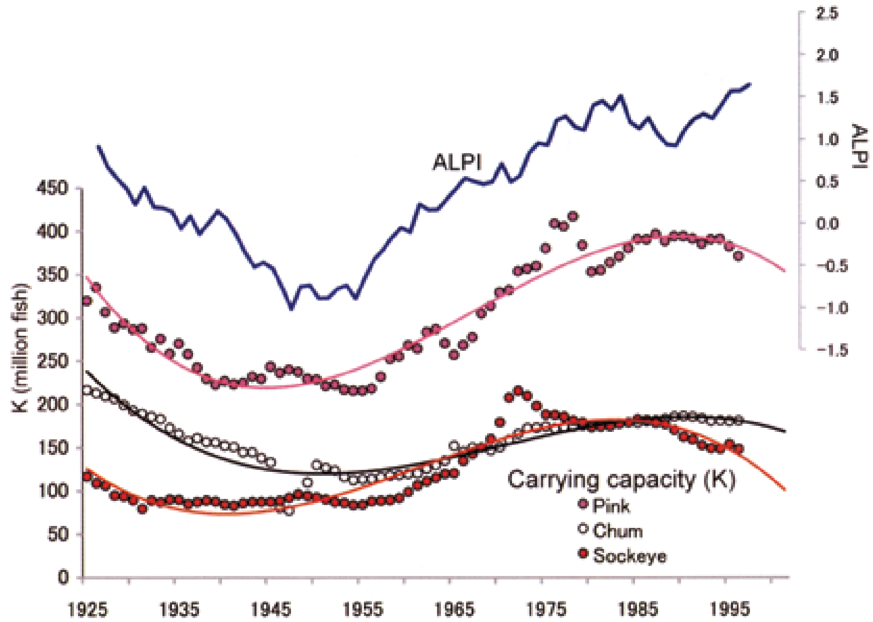


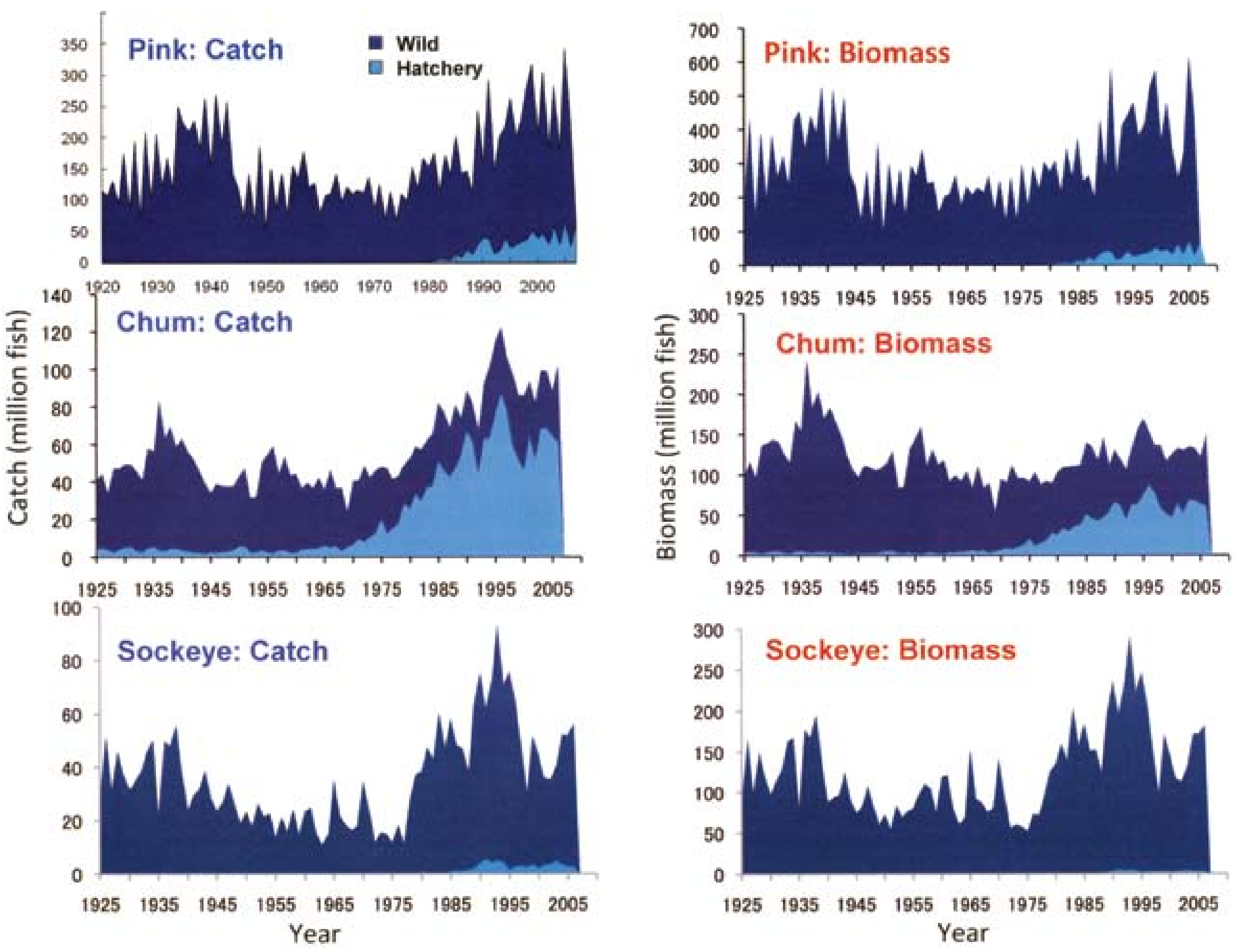
[Figure OY-30] Mean body weight by age of sardine, anchovy and chub mackerel along the Pacific coast of Japan.

6.1.2. Pacific salmon *(Kaeriyama)*

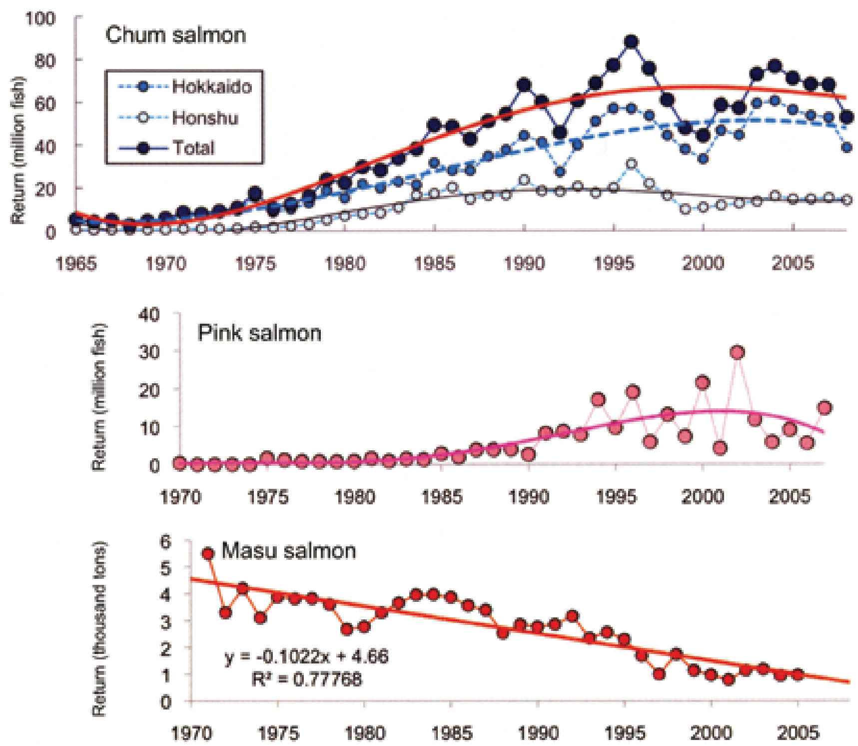
Pacific salmon occupy the fourth and fifth trophic levels in the Subarctic ocean ecosystem and can be considered as key species. Because they are anadromous, they sustain biodiversity and productivity in riparian ecosystems by bringing marine-derived materials to the rivers. Salmon carrying capacity (K) in the North Pacific Ocean has been synchronized with long-term climate change (Kaeriyama and Edpalina 2004). Interannual variation of average K of three species [sockeye (*Oncorhynchus nerka*), chum (*O. keta*), and pink (*O. gorbuscha*) salmon] was significantly correlated with Aleutian Low Pressure index (Beamish and Bouillion 1993) for the 1920s to present ($R^2 = 0.87$, $P < 0.001$) (Fig. OY-31). There have been gradual downward trends in K since the early 2000s (Fig. OY-31) suggesting a declining trend in biomass despite an increase in total catch during the focus period. Catches of pink and chum salmon since the 1990s have increased but catches of sockeye, coho, and masu salmon have decreased. Chinook salmon catches have been relatively stable Since the late 1970s, releases of hatchery chum and pink salmon have increased exponentially in Japan and Alaska. Hatchery chum salmon recently accounted for >80% of chum salmon catch, and >50% of chum salmon biomass. There has been no increase in wild chum salmon (Fig. OY-32). Pacific chum salmon returning to Japan (Fig. OY-33) peaked in the late 1990s, and shifted to a decreasing trend in the 2000s. Pink salmon increased until 2002 but has decreased since then. Masu salmon which live in freshwater over one year before going to sea have declined sharply since the 1970s.

[Figure OY-31] Aleutian Low Pressure index (ALPI) from Beamish and Bouillion (1993) and temporal changes in carrying capacity (K) of sockeye, chum, and pink salmon. The time span of data used to estimate the parameters (a, b, K) for year class, *t*, was 10 generations of odd- and even-year groups for pink salmon, and 10-20 brood years for sockeye and chum salmon from *t* to *t* +10/20. K of the year class *t* was estimated based on the salmon recruited during the year of *t* + 20.





[Figure OY-32] Temporal changes in catch and biomass of hatchery and wild pink, chum and sockeye salmon.

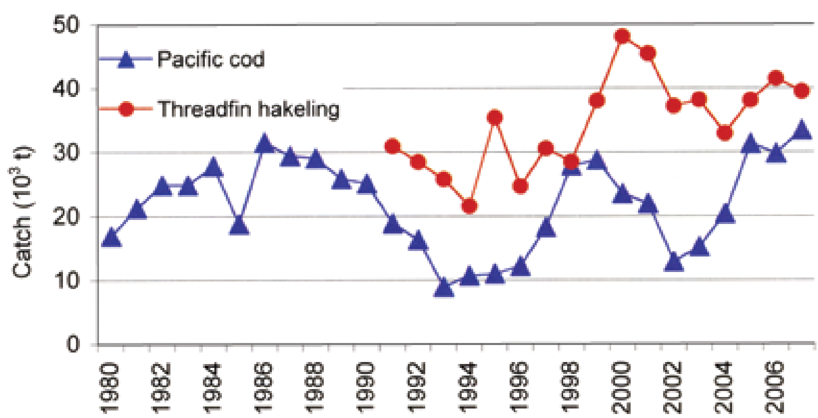


[Figure OY-33] Recent trends on returns of chum, pink, and masu salmon in Japan.

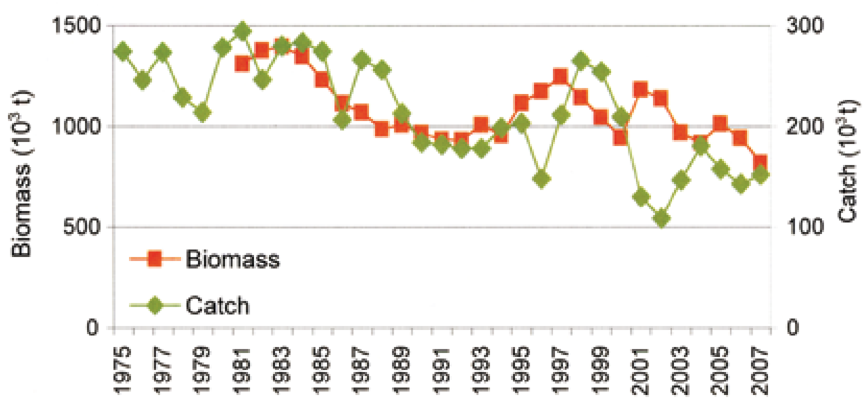
6.1.3. Demersal fish *(Yamamura)*

Three gadiform species, threadfin hakeling (*Laemonema longipes*), Pacific cod, and walleye pollock are abundant along the Pacific coast of northern Japan. For threadfin hakeling and Pacific cod, only catch statistics are available (FAJ and FRA 2009). The catch of Pacific cod has fluctuated between 9-34 thousand t with a decadal-scale oscillation (Fig. OY-34). Since 2004, >70% of the total catch is from the Tohoku area (northeastern coast of the mainland). Threadfin hakeling are distributed over the upper continental slope and are caught by Japanese and Russian trawlers. The catch has fluctuated between 21 – 48 thousand t since 1991 (Fig. OY-34).

The Japan Pacific Stock of walleye pollock is distributed along the Pacific coast of northern Japan. Its biomass is estimated by cohort analysis (Fig. OY-35) (FAJ and FRA, 2009) which shows a decreasing trend from the late 1970s (1.3 million t) to the most recent 5 year period (0.9 million t). This decrease reflects decadal variation in recruitment of the stock (Hamatsu et al. 2004). Whereas substantial numbers of walleye pollock recruited successfully and were caught in the Tohoku area in the early years, only a limited portion of this stock has been distributed in the Tohoku area since the 1990s. The decreasing trend in the catch of walleye pollock also reflects an abrupt decrease of the catch quota in the area of the northern four islands during the late 1980s (Fig. OY-35) (FAJ and FRA 2009).



[Figure OY-34] Catch of Pacific cod and threadfin hakeling.



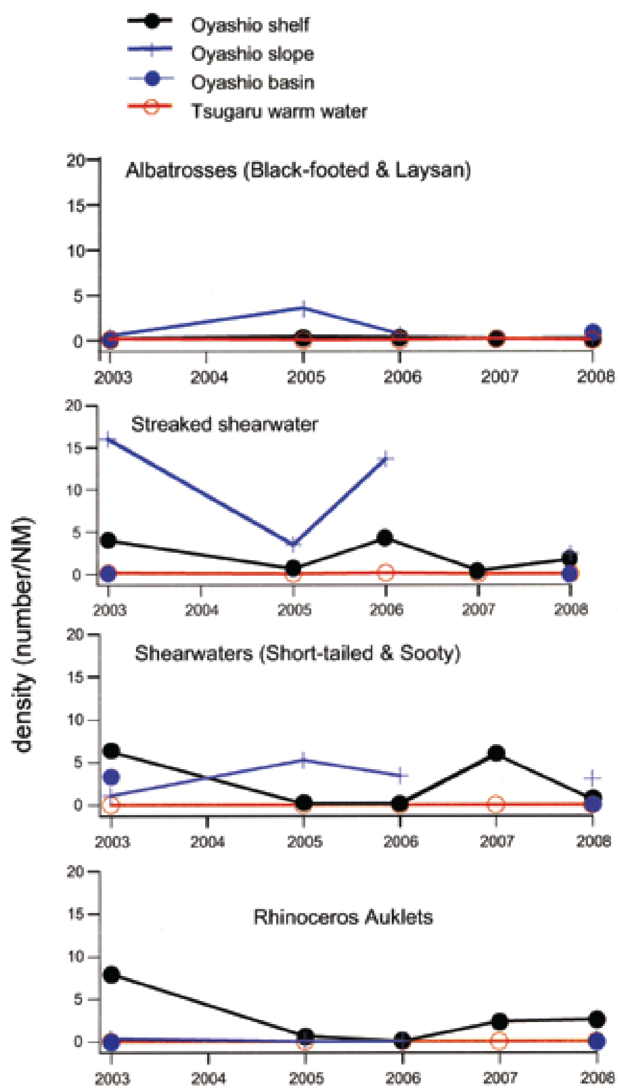
[Figure OY-35] Biomass and catch of the Japan Pacific Stock of walleye pollock.

7.0 Marine Birds *(Watanuki)*

The coastal area off eastern Hokkaido, Japan is an important foraging area for many seabird species in autumn. To understand the distribution and inter-annual variation of seabirds in shelf, slope and basin regions in this coastal area, ship-based censuses have been conducted in late September and early October from the T/S *Oshoro maru* (Department of Fisheries Sciences, Hokkaido University) since 2003. Seabirds sitting on the water and flying across a 300 m fan area of either the port or starboard side were counted. In every year, the warm (>19°C SST) Tsugaru water affected the eastern area of Cape Erimo, while cold (< 14°C SST) Oyashio water affected the western area. Coastal upwelling was observed along the slope. The density of seabirds was higher on the Oyashio shelf and slope area than in the Oyashio basin, and lower in the warm Tsugaru water (Table OY-1). Densities of rhinoceros auklet (*Cerorhinca monocerata*), a diving bird, were high on the shelf, and densities of other diving birds, short-tailed and sooty shearwater (*Puffinus* spp.) were high in some years in the shelf, too. Densities of surface feeders, streaked shearwater (*Calonectris leucomelas*), black-footed albatross (*Diomedia nigripes*) and Laysan albatross (*D. immutabilis*) were higher in the slope region. Within the 5 year observation period, no trends were apparent (Fig. OY-36).

[Table OY-1] Mean density (numbers per nautical mile) of albatrosses (black-footed and Laysan), shearwaters (short-tailed and sooty), streaked shearwaters and rhinoceros auklets sitting in Tsugaru warm water, Oyashio shelf, Oyashio slope and Oyashio basin areas in the coastal area of eastern Hokkaido.

	Tsugaru water	Oyashio shelf	Oyashio slope	Oyashio basin
Albatrosses	0.03	0.15	1.20	0.53
Shearwaters	0.00	2.61	3.21	1.65
Streaked Shearwaters	0.06	2.22	8.90	0.04
Rhinoceros Auklet	0.00	2.68	0.14	0.00



[Figure OY-36] Density of seabirds in numbers per nautical mile (NM) sitting on the sea surface in each water type in the coastal area of eastern Hokkaido.

References

Andreev, A., Watanabe, S. 2002. Temporal changes in dissolved oxygen of the intermediate water in the subarctic North Pacific. *Geophysical Research. Letters 29*(14): 1680, 10.1029/2002GL015021.

Beamish, R.J., Bouillion, D. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fishery and Aquatic Science 50: 1002-1016.

Chiba, S., Aita, N.M., Tadokoro, K., Saino, T., Sugisaki, H., Nakata K. 2008. From climate regime shifts to lower-trophic level phenology: Synthesis of recent progress in retrospective studies of the western North Pacific. Progress in Oceanography 77: 112-126.

Deutsch, C., Emerson, S., Thompson, L. 2005. Fingerprints of climate change in North Pacific oxygen. Geophysical Research Letters 32: L16604, doi:10.1029/2005GL023190.

Emerson, S., Watanabe, W.Y., Ono, T., Mecking, S. 2004. Temporal trends in apparent oxygen utilization in the upper pycnocline of the North Pacific: 1980–2000. Journal of Oceanography 60: 139-147.

FAJ (Fisheries Agency of Japan) and FRA (Fisheries Research Agency of Japan) .2009. Marine fishery stock assessment and evaluation for Japanese waters (fiscal year 2001/2002). Fisheries Agency of Japan, Tokyo. (In Japanese)

Favorite, F., Dodimead, A.J., Nasu, K. 1976. Oceanography of the subarctic Pacific region 1960-71. Bulletin of the International North Pacific Fish Commission 33: 1-187.

Feely, R.A., Fabry, V.J., Guinotte, J.M. 2008. Ocean acidification of the North Pacific Ocean. PICES Press 16(1): 22-26.

Hamatsu, T., Yabuki, K., Watanabe, K. 2004. Decadal changes in reproduction of walleye pollock (*Theragra chalcogramma*) off the Pacific coast of northern Japan. Fisheries Oceanography 13 (Suppl. 1): 74-83.

Ito, S., Uehara, K., Miyao, T., Miyake, H., Yasuda, I., Watanabe, T., Shimizu, Y. 2004a. Characteristics of SSH anomaly based on TOPEX/POSEIDON altimetry and in situ measured velocity and transport of Oyashio on OICE. Journal of Oceanography 60: 425-438.

Ito, S., Sugisaki, H., Tsuda, A., Yamamura, O., Okuda, K. 2004b. Contributions of the VENFISH program: meso-zooplankton, Pacific saury (*Cololabis saira*) and walleye pollock (*Theragra chalcogramma*) in the northwestern Pacific. Fisheries Oceanography 13. Suppl. 1: 1-9.

JMA (Japan Meteorological Agency). 2008. Annual Report on Atmospheric and Marine Environment Monitoring No. 8, Observation Results for 2006 [CD-ROM], Tokyo.

Kaeriyama M., Edpalina R.R. 2004. Evaluation of the biological interaction between wild and hatchery population for sustainable fisheries management of Pacific salmon, pp. 247-259 In Leber, K.M., Kitada, S., Blankenship, H.L., Svasand, T. [eds.] Stock Enhancement and Sea Ranching, Second Edition: Developments, pitfalls and opportunities. Blackwell Publishing Ltd, Oxford.

Kasai, H., Saito, H., Tsuda, A. 1998. Consideration for estimation of standing stock of chlorophyll a and primary production from remote-sensed ocean color in the Oyashio region, the western subarctic Pacific, during the spring bloom in 1997. Journal of Oceanography 54: 527-537.

Kobari, T., Shinada, A., Tsuda, A. 2003. Functional roles of interzonal migrating mesozooplankton in the western subarctic Pacific. Progress in Oceanography 57: 279-298.

Mecking, S., Langdon, C., Feely, A., Sabine, C., Deutsch, C., Min, D.-H. 2008. Climate variability in the North Pacific thermocline diagnosed from oxygen measurements: An update based on the U.S. CLIVAR/CO2 Repeat Hydrography cruises, Global Biogeochemical Cycles 22: GB3015, doi:10.1029/2007GB003101.

Moku, M., Kawaguchi, K., Watanabe, H., Ohno, A. 2000. Feeding habits of three dominant myctophid fishes, *Diaphus theta, Stenobrachius leucopsarus and S. nannochir,* in the subarctic and transitional waters of western North Pacific. Marine Ecology Progress Series 207: 129-140.

Minobe, S. 1999. Resonance in bidecadal and pentadecadal climate oscillations over the North Pacific: Role in climatic regime shifts. Geophysical Research Letters 26: 855-858.

Nakagawa, Y., Endo, Y., Taki, K. 2001. Diet of *Euphausia pacifica* Hansen in Sanriku waters off northeastern Japan. Plankton Biology and Ecology 48: 68-77.

Nakano, Y., Watanabe, Y.W. 2005. Reconstruction of pH in the surface seawater over the North Pacific basin for all seasons using temperature and chlorophyll-a. Journal of Oceanography 61: 673-680.

Nakanowatari, T., Ohshima, K., Wakatsuchi, M. 2007. Warming and oxygen decrease of intermediate water in the northwestern North Pacific, originating from the Sea of Okhotsk, 1955–2004. Geophysical Research Letters 34: L04602, doi:10.1029/2006GL028243.

Nishikawa, H., Yasuda, I. 2008. Variation of Japanese sardine (*Sardinops melanostictus*) mortality in relation to the winter mixed layer in the Kuroshio Extension. Fisheries Oceanography 17: 411-420.

Nishioka, J., Ono, T., Saito, H., Nakatsuka, T. and Takeda, S., Yoshimura, T., Suzuki, K., Kuma, K., Nakabayashi, S., Tsumune, D., Mitsudera, H., Johnson, W.K., Tsuda, A. 2007. Iron supply to the western subarctic Pacific: Importance of iron export from the Sea of Okhotsk. Journal of Geophysical Research 112: C10012, doi: 10.1029/2006JC004055.

Ono, T., Midorikawa, T., Watanabe, W. Y., Tadokoro, K., Saino, T. 2001. Temporal increases of phosphate and apparent oxygen utilization in the subsurface waters of western subarctic Pacific from 1968 to 1998. Geophysical Research Letters 28: 3285-3288.

Ono, T., Tadokoro, K., Midorikawa, T., Nishioka, J., Saino, T. 2002. Multi-decadal decrease of net community production in western subarctic North Pacific. Geophysical Research Letters 29: 10.1029/2001GL014332.

Orr, J. C., et al. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature. 437: 681-686, DOI: 10.1038/nature04095.

Osafune, S., Yasuda, I. 2006. Bidecadal variability in the intermediate waters of the northwestern subarctic Pacific and the Okhotsk Sea in relation to 18.6-year period nodal tidal cycle. Journal of Geophysical Research 111: C05007, doi:10.1029/2005JC003277.

Padmavati, G., Ikeda T., Yamaguchi, A. 2004. Life cycle, population structure and vertical distribution of *Metridia* spp. (Copepoda: Calanoida) in the Oyashio region (NW Pacific Ocean). Marine Ecology Progress Series 270: 181-198.

Pope, J.G., Shepherd, J.G., Webb, J. 1994. Successful surf-riding on size spectra: the secret of survival in the sea. Philisophical Transactions of the Royal Society of London, B 343: 41-49.

Qiu, B. 2002. Large-scale variability in the midlatitude subtropical and subpolar North Pacific Ocean: Observations and causes. Journal of Physical Oceanography 32: 353-375.

Saito, H., Tsuda, A., Kasai, H. 2002. Nutrient and plankton dynamics in the Oyashio region of the western subarctic Pacific Ocean. Deep-Sea Research II 49: 5463-5486.

Shimizu, Y., Yasuda, I., Ito, S. 2001. Distribution and circulation of the coastal Oyashio intrusion. Journal of Physical Oceanography 31: 1561-1578.

Stommel, H., Yoshida, K. 1972. Kuroshio: Its Physical Aspects. University of Washington Press, Seattle.

Sugisaki, H., Kurita, Y. 2004. Daily rhythm and seasonal variation of feeding habit of Pacific saury (*Cololabis saira*) in relation to their migration and oceanographic conditions off Japan. Fisheries Oceanography (suppl.): 63-73.

Sugisaki, H., Nonaka, M., Ishizaki, S., Hidaka, K Kameda, T., Hirota, Y., Oozeki, Y., Kubota, H., Takasuka, A. 2010. Status and trends of the Kuroshio Current region, 2003-2008, pp 330-359 In, S.M. McKinnell and M.J. Dagg [Eds.] Marine Ecosystems of the North Pacific Ocean, 2003-2008. PICES Special Publication 4, 393 p.

Taguchi, S., Saito, H., Kasai, H., Kono, T., Kawasaki, Y. 1992. Hydrography and spatial variability in the size distribution of phytoplankton along the Kurile Islands in the western subarctic Pacific Ocean. Fisheries Oceanography 1: 227-237.

Takahashi, K., Kuwata, A., Saito, H., Ide, K. 2008. Grazing impact of the copepod community in the Oyashio region of the western subarctic Pacific Ocean. Progress in Oceanography 78: 222-240.

Takahashi, K., Kuwata, A., Sugisaki, H., Uchikawa, K., Saito, H. 2009. Downward carbon transport by diel vertical migration of the copepods *Metridia pacifica* and *Metridia okhotensis* in the Oyashio region of the western subarctic Pacific Ocean. Deep-Sea Research Part I: 56: 1777-1791.

Takatani, Y., Iwao, T., Miyao, T., Midorikawa, T., Saito, K. 2007. Oyashio water quality: Decadal changes and controlling factors. Oceanography in Japan 16: 23-27.

Taki, K. 2007a. Seasonal changes in distribution and abundance of euphausiids in the coastal area of north-eastern Japan. Fisheries Science 73: 522-533.

Taki, K. 2007b. Seasonal and interannual variation in abundance of *Euphausia pacifica* off north-eastern Japan. Fisheries Science 73: 1094-1103.

Tatebe, H., Yasuda, I. 2005. Interdecadal variations of the coastal Oyashio from the 1970s to the early 1990s. Geophysical Research Letters 32:L10613, doi:10.1029/2005GL022605.

Tsuda, A., Saito, H., Kasai, H. 1999. Life histories of *Neocalanus flemingeri* and *Neocalanus plumchrus* (Calanoida: Copepoda) in the western subarctic Pacific. Marine Biology 135: 533-544.

Tsuda, A., Saito, H. and Kasai, H. 2004. Life histories of *Eucalanus bungii* and *Neocalanus cristatus* (Calanoida: Copepoda) in the western subarctic Pacific. Fisheries Oceanography 13: 10-20.

Tsurushima, N., Nojiri, Y., Imai, K., Watanabe, S. 2002. Seasonal variations of carbon dioxide system and nutrients in the surface layer at station KNOT in the sub-arctic western North Pacific. Deep-Sea Research II 49: 5377-5394.

Uchikawa K., Yamamura, O., Hattori, T. 2008. Feeding habits of mesopelagic fish *Lampanyctus jordani* (Family: Myctophidae) over the continental slope off Tohoku area, northern Japan. Fisheries Science 74: 69-76.

Uchikawa K., Yamamura, O., Kitagawa, D., Sakurai, Y. 2002. Diet of the mesopelagic fish *Notoscopelus japonicus* (Family: Myctophidae) associated with the continental slope off the Pacific coast of Honshu, Japan. Fisheries Science 68: 1034–1040.

Wakita, M., Watanabe, Y.W., Watanabe, S., Noriki, M., Wakatsuchi, M. 2003. Oceanic uptake rate of anthropogenic CO2 in a subpolar marginal sea: The Sea of Okhotsk. Geophysical Research Letters 30: 2252, DOI: 10.1029/2003GL018057.

Walker, G.T., Bliss, E.W. 1932. World weather, V. Memorandum of the Royal Meteorological Society 4: 53–84.

Watanabe, W.Y., Shigemitsu M., Tadokoro K. 2008. Evidence of a change in oceanic fixed nitrogen with decadal climate change in the North Pacific subpolar region, Geophysical Research Letters 35: L01602, doi:10.1029/2007GL032188.

Whitney, F.A., Freeland, H. 1999. Variability in upper-ocean water properties in the NE Pacific Ocean. Deep-Sea Research II 46: 2351–2370.

Whitney, F.A., Freeland, H.J., Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. Progress in Oceanography 75: 179-199.

Yasuda, I. 1997. The origin of the North Pacific Intermediate Water. Journal of Geophysical Research 102 C1: 893-909.

Yasuda, I., Osafune, S. and Tatebe, H. 2006. Possible explanation linking 18.6-year period nodal tidal cycle with bi-decadal variations of ocean and climate in the North Pacific. *Geophysical Research Letters 33*: L08606, doi:10.1029/2005GL025237.

Yamamura O., Inada, T., Shimazaki, K. 1998. Predation on *Euphausia pacifica* by demersal fishes: predation impact and influence of physical variability. Marine Biology 132: 195-208.

Yokouchi, K., Tsuda, A., Kuwata, A., Kasai, H., Ichikawa, T., Hirota, Y., Adachi, K., Asanuma, I., Ishida, H. 2006. Simulated in situ measurements of primary production in Japanese waters, pp. 65-83 In Kawahata, H., Awata, Y. [eds.] Global climate change and response of carbon cycle in the equatorial Pacific and Indian Oceans and adjacent landmasses. Elsevier Oceanography Series 73. Elsevier, Oxford.