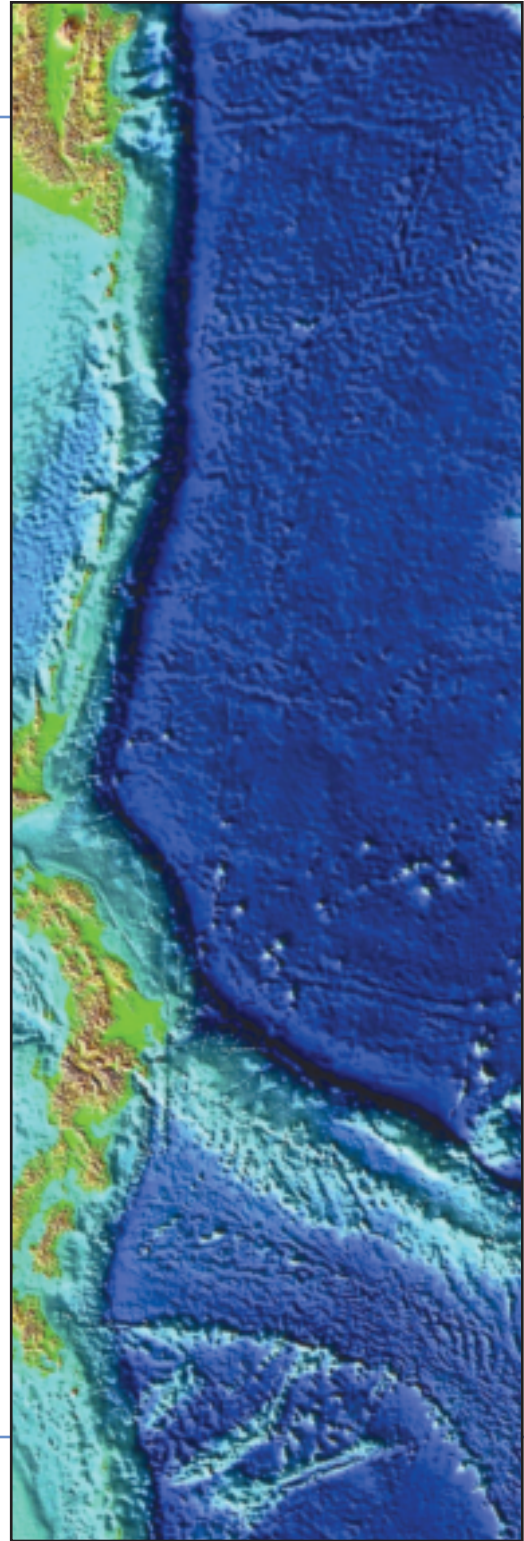


Oyashio & Kuroshio

highlights

- The Kuroshio and Oyashio, both of which are the western boundary currents in the North Pacific, have great influence on fisheries and climate in the western North Pacific. Long-term variation of them is focused with respect to the path of the Kuroshio south of Japan and intrusion of the Oyashio east of Japan.
- Time series of sea surface temperature (SST) anomaly in the Kuroshio south of Japan indicates a remarkable warming trend is found from 1982 to 1999, which is particularly clear in winter and autumn. The SST anomaly in the Oyashio indicates a cooling around the mid-1970s corresponding to a regime shift of the climate system in the North Pacific.
- The biomass level of large copepods in the Kuroshio were higher in the period before 1977 and in 1999 to 2000 than from 1977-88, which could be related to the climatic regime shift in the North Pacific. In the Oyashio, mesozooplankton biomass was low from the early 1950s to the mid-1960s and increased in the late 1960s and sustained a high value until the late 1970s, and decreased in the early 1980s and sustained low values through that decade.
- Biomass and Japanese commercial catches of these small pelagics indicated decadal changes or alternations of dominant species called “species replacements”. Although mechanisms of the species replacements have not been fully resolved, ocean-climate regime shifts have profound impacts on their dynamics together with species interactions.
- The change of prey species of minke whales from chub mackerel to Japanese sardine (pilchard) in 1977, from Japanese sardine to Pacific saury in 1996 corresponded with a change of the dominant species taken by commercial fisheries in the same area in 1976, 1996, respectively.



background

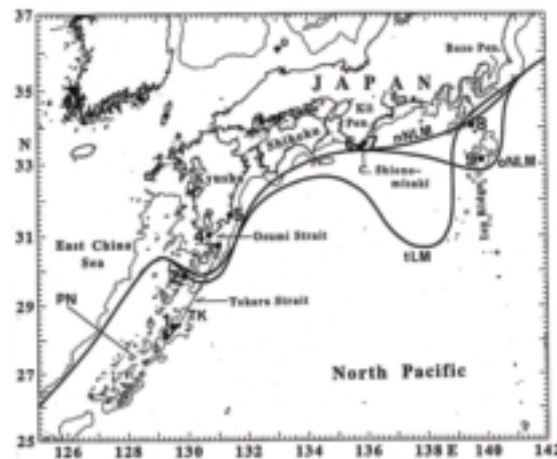
The Kuroshio: (1) flows across three shallow ridges – one east of Taiwan, through the Tokara Strait, and across the Izu-Ogasawara ridges; (2) exchanges large amounts of water with several stable eddies, such as the large warm water eddy to the south of Shikoku; (3) forms a broad Mixed Water Region to the north of the Kuroshio Extension which usually has a large meander just east of Honshu and frequently ejects large warm-core rings into the Mixed Water Region, and (4) interacts with its marginal seas.¹⁴³

The Oyashio has several definitions in the Mixed Water Region. One definition of Oyashio Water is the water found off the Etorofu Islands and Hokkaido where salinity increases monotonically to the bottom. Its southern boundary can be called the Oyashio Front, which is also the western part of the Subarctic Front if the Oyashio Front is defined as a boundary. Next to the Hokkaido coast, the Oyashio (current) is defined as a boundary current with recognizable baroclinic shear, which may be reduced as the Oyashio separates from the coast and turns eastward as the Oyashio Front. The Oyashio influence in the Mixed Water Region is often defined by the location of the 5°C isotherm at 100 m; this location might be farther south than the Oyashio Front defined as the main water mass boundary.¹⁴⁴

Status and Trends

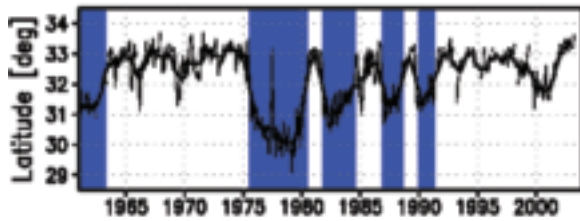
Hydrography

Kuroshio The Kuroshio assumes three major paths south of Japan: typical Large-Meander (tLM) path; nearshore and offshore non-Large-Meander (nNLM and oNLM) paths as shown in Figure 66.¹⁴⁵ When it takes the tLM path, the Kuroshio makes a detour around Enshu-nada and its southernmost position is located south of 32°N, while the two NLM paths, which are distinguished by their position over the Izu Ridge, are close to the coast of Japan. Recent numerical experiments with an inflow-outflow model suggest that the Kuroshio Current system has a multiple equilibrium regime and a three regime path can be steady.^{146,147}

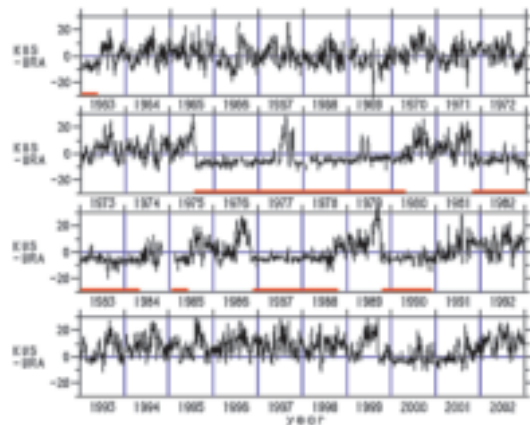


[Figure 66] Typical paths of the Kuroshio south of Japan: nearshore Non-Large-Meander path (nNLM), offshore Non-Large-Meander (oNLM), typical Large-Meander (tLM).¹⁴⁵

A time series of southernmost position of the Kuroshio off Enshu-nada (Figure 67) shows that the Kuroshio took the LM path five times after 1961. The Kuroshio often took the LM path in 1975-1991, and kept the NLM path from 1964-1974 and 1991-2002. In the period of 1975-1991, the Kuroshio alternated between the LM and NLM paths. The Kuroshio has been taking NLM path for the last 12 years, except for the period from 1999-2001. At this period, the Kuroshio takes a quasi-LM path, one that is similar to the LM but is not steady and has large variations in position off Enshu-nada and over the Izu Ridge. A time series of sea level difference at Cape Shionomisaki also indicates the quasi-LM path in 1999-2001 (Figure 68).



[Figure 67] Southernmost latitude of Kuroshio off Enshunada from 1961 to 2002.¹⁴⁸ Areas shaded in blue are the periods of LM path.

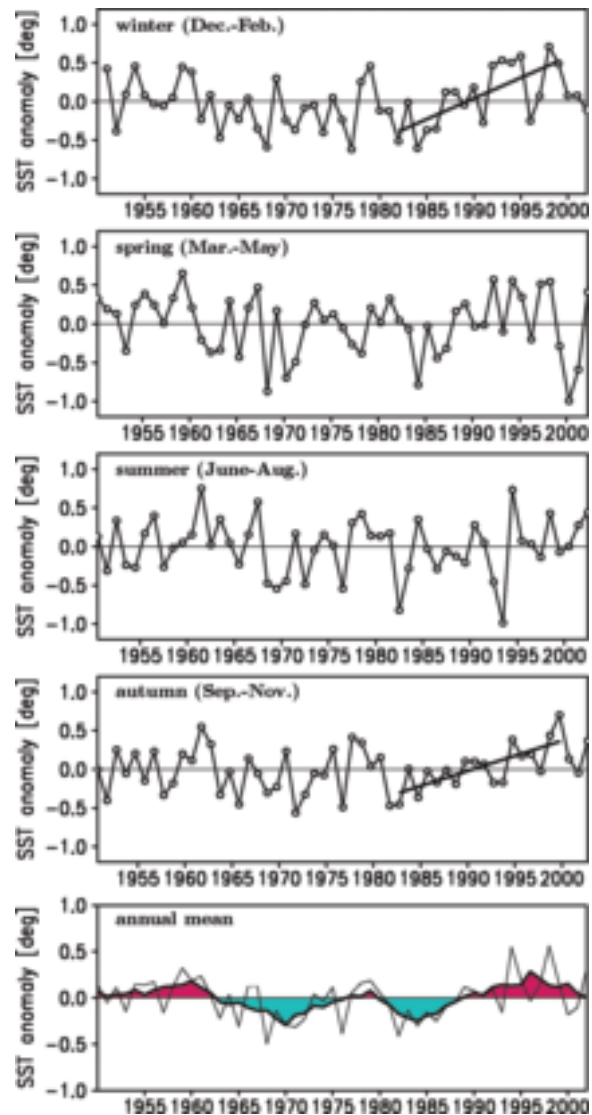


[Figure 68] Sea level difference between Kushimoto and Uragami at Cape Shionomisaki, from 1963 to 2002.¹⁴⁹ This is an index which is classified types of the Kuroshio path. Red lines denote the period of LM path.

Some fisheries in the Kuroshio region are severely dependent on its path. The northern part of the Izu Ridge is an important fishing and nursery ground for pelagic fishes. The Kuroshio passes over the northern part of the ridge on the LM and nearshore NLM paths, while it moves over the southern part of the ridge on the offshore NLM path (Figure 66). The former is good for the fishing and spawning grounds because of the Kuroshio warm water, while the latter is not so good due to the influence of cold coastal water.

Time series of sea surface temperature (SST) anomalies in the Kuroshio region south of Japan indicate a remarkable warming trend from 1982 to 1999 (Figure 69), particularly in autumn and winter. A warming trend of SST is also found along the Kuroshio path in the East China Sea, suggesting that wintertime SST cooling had decreased over the western part of the North Pacific subtropical gyre.¹⁵⁰

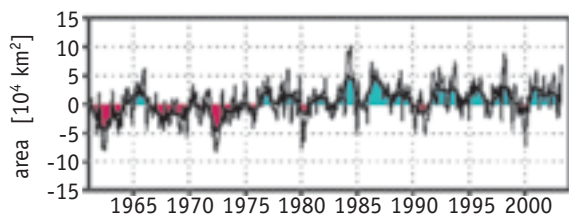
Another function of a variable Kuroshio is its role in varying heat transport, which subsequently affects the atmosphere-ocean climate system. Recent studies on interdecadal time scales suggest that strengthening of the North Pacific subtropical gyre and increased Kuroshio transport are associated with increasing midlatitude wind speeds that occurred after the mid-1970s.^{151,152}



[Figure 69] Seasonally and annually averaged SST anomalies (°C) at 32-35°N, 132-140°E. Linear warming trends from 1982 to 1999 in winter and autumn are indicated. Bottom Panel: Thin line denotes annual mean anomaly and thick line its 5-year running mean. Anomaly is a departure from the averaged temperature from 1950-2002.

In recent years, it has been possible to estimate Kuroshio transport from hydrographic surveys and moored current meters combined with the TOPEX/Poseidon satellite altimeter.¹⁵³ The combination of the observations with ocean model assimilation in the Kuroshio region¹⁵⁴ will help advance understanding of the variation of the Kuroshio transport.

Oyashio The Oyashio is a western boundary current of the Subarctic gyre in the North Pacific. Oyashio water has low temperature, low salinity and is rich in nutrients compared with subtropical water. Seasonal and interannual dynamics of the Oyashio, which are closely linked to climate change, influence the migrations and fluctuations of pelagic and demersal fishes in the northwestern Pacific.

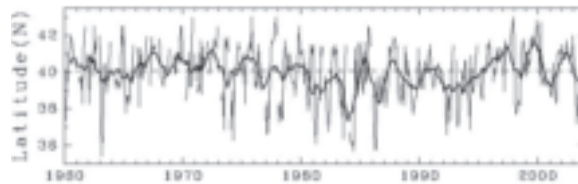


[Figure 70] Monthly anomaly of the extent of Oyashio water from 1961 to 2002. Thin line denotes the monthly change and thick line its 13-month running mean. Anomalies are departures from 1971-2000 monthly means.¹⁵⁵

A time series of the spatial extent of the Oyashio water shows large interannual variation over the whole period and an increase of about 26,000 km² around the mid-1970s (Figure 70).¹⁵⁵ It is well known that a climate regime shift the North Pacific occurred in the mid-1970s when the mid-latitude westerlies strengthened, however, the Oyashio extent anomaly does not have a sign reversal at times when other regime shifts occurred in 1970/71 and 1988/89.¹⁵⁶ Further investigation is needed to understand the long-term variation of the Oyashio intrusions.

The Tohoku National Fisheries Research Institute defines the Oyashio region as one with temperature lower than 5°C at 100m depth. The Oyashio forms a couple of southward tongue-shape intrusions off Honshu, which are called the First Oyashio Intrusion (SL01: coastal intrusion) and the Second Oyashio Intrusion (SL02: offshore intrusion), respectively.

The decadal cycle in the SL01 was observed as well as a multi-year cycle (Figure 71). The SL01 moved north from mid-1960s and shifted south from late 1970s to 1980s, and north again from the mid-1990s.

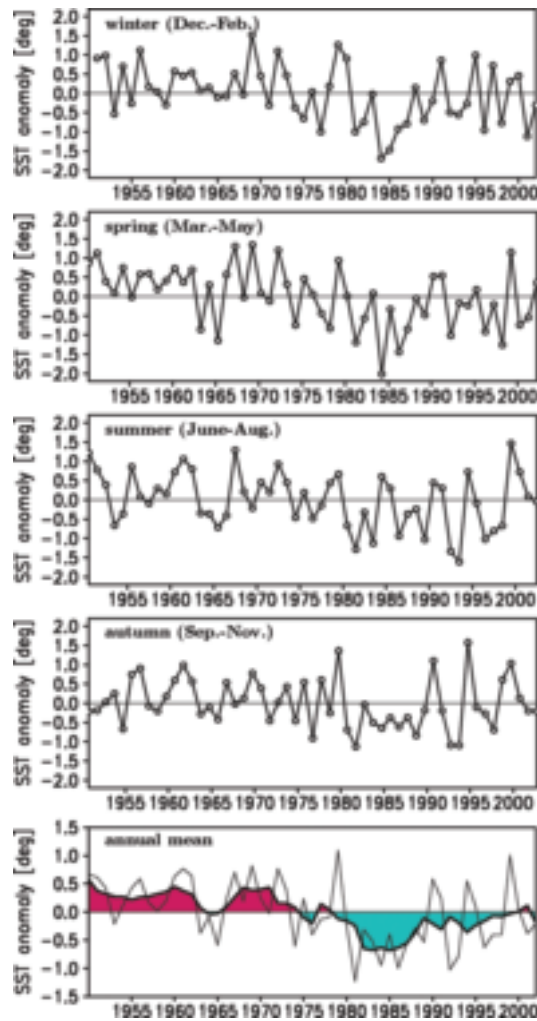


[Figure 71] Changes in monthly mean latitude of South Limit of First Oyashio Intrusion (SL01) from 1960 to 2003. Thick line indicates 13 month running mean.

SST anomalies in the Oyashio coastal intrusion region (Figure 72) show large interannual variation over the whole period. Previous studies have suggested that interannual variability of Oyashio intrusions is due to changes in the wind stress field over the North Pacific. Anomalous southward intrusions of the Oyashio are due to the barotropic response of the ocean to a change in the wind stress by the southward development of an enhanced Aleutian low pressure system.^{157,158} The negative SST anomalies in spring (Figure 72) correspond well with the anomalous southward intrusion of Oyashio water.

Another characteristic of SST fluctuations (Figure 72) is a cooling around the mid-1970s. It is well known that a climate regime shift in the North Pacific occurred in the mid-1970s and the mid-latitude westerlies strengthened. The annual mean SST anomaly has been about zero after the late 1990s.

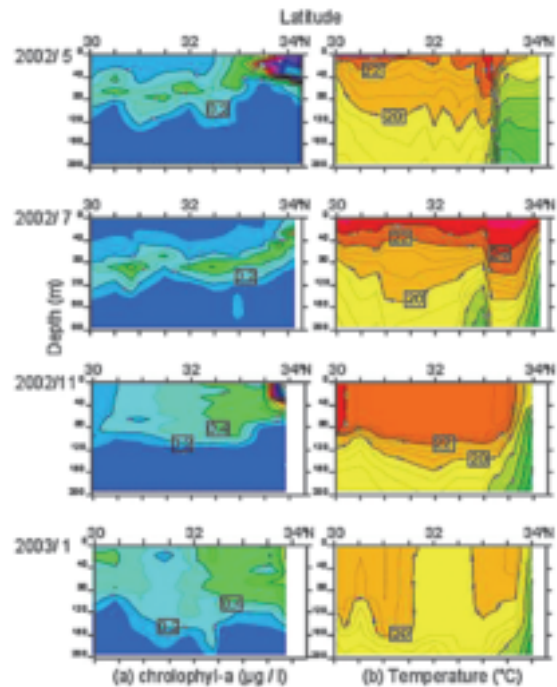
Monitoring - Kuroshio In the area around the Kuroshio, the Japan Meteorological Agency has conducted oceanographic observations since 1965. The data have been published in print or electric format and utilized by researchers. The Fisheries Research Agency of Japan has two monitoring programs: (1) egg census for pelagic fishes (e.g. sardine, saury) that have been conducted since 1947. Several important analyses have resulted from re-analysis of archived samples.^{159,160} The survey data is not yet available, but an online database is under construction. (2) To reveal seasonal changes in the plankton community and its production, a 5-year monitoring program was launched in the area beginning in April 2002. The ecosystem status described in this report would be based on that program.



[Figure 72] Seasonal and annual average SST anomalies (°C) at 37-42°N, 141-144°E. Bottom panel: Thin line denotes annual mean anomaly and thick line its 5-year running mean. Anomalies are departures from the mean temperature from 1950-2002.

Plankton

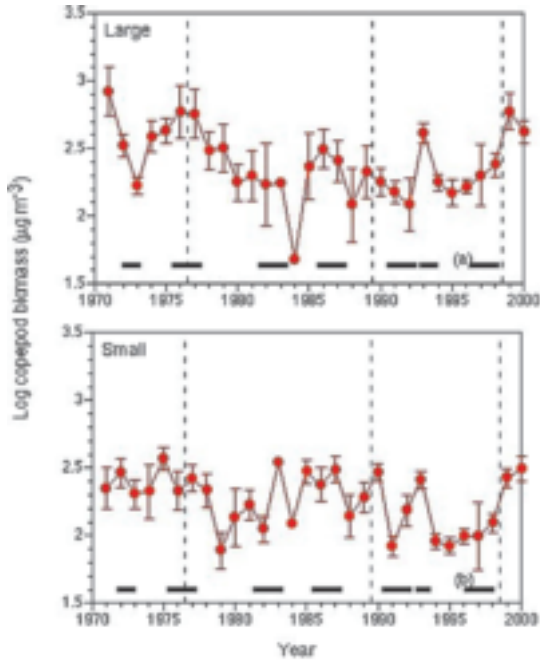
Phytoplankton - Kuroshio The Kuroshio area could be divided into three regions: slope water (coastal side of Kuroshio), Kuroshio water, and offshore water (northern part of the North Pacific Subtropical Gyre). Each region shows seasonal chlorophyll change, characterized by blooms in winter-spring and fall that are induced by changes in the physical environment.¹⁶¹ In late spring and summer, water column stratification develops and a subsurface chlorophyll maximum appears in each region (Figure 73). Analyses of seasonal and regional changes in taxonomic composition of the phytoplankton are currently underway as part of the monitoring program of the Fisheries Research Agency.



[Figure 73] Vertical profiles of chlorophyll-a concentration (a) and temperature (b) in upper 200 m along 138°E in 2002-2003.¹⁶²

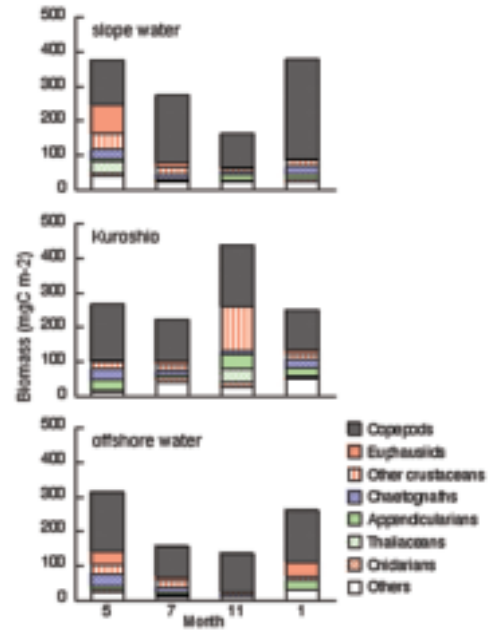
Zooplankton - Kuroshio The zooplankton fauna of the region is well known biogeographically, but knowledge of species composition or distribution is limited. Copepod nauplii are abundant around the Kuroshio Front.¹⁶³ Mesoscale eddies caused by the Kuroshio current have been highlighted, in terms of enhanced biological production¹⁶⁴ and larval transport.¹⁶⁵

Trends in long-term changes of biomass and size composition of copepods from winter to early spring are well known from the egg census survey (Figure 74). In a recent study, the biomass of large copepods in the Kuroshio was shown to be higher in the period before 1977 and in 1999 to 2000 than that in 1977-88, which could be related to the climatic regime shift in the North Pacific.¹⁶⁶



[Figure 74] Interannual variations in the log-transformed biomass of large (>1mmPL) and small (<1mmPL) copepods in the Kuroshio in winter. Vertical line and solid bars denotes the climate regime shifts and the periods of El Niño, respectively.

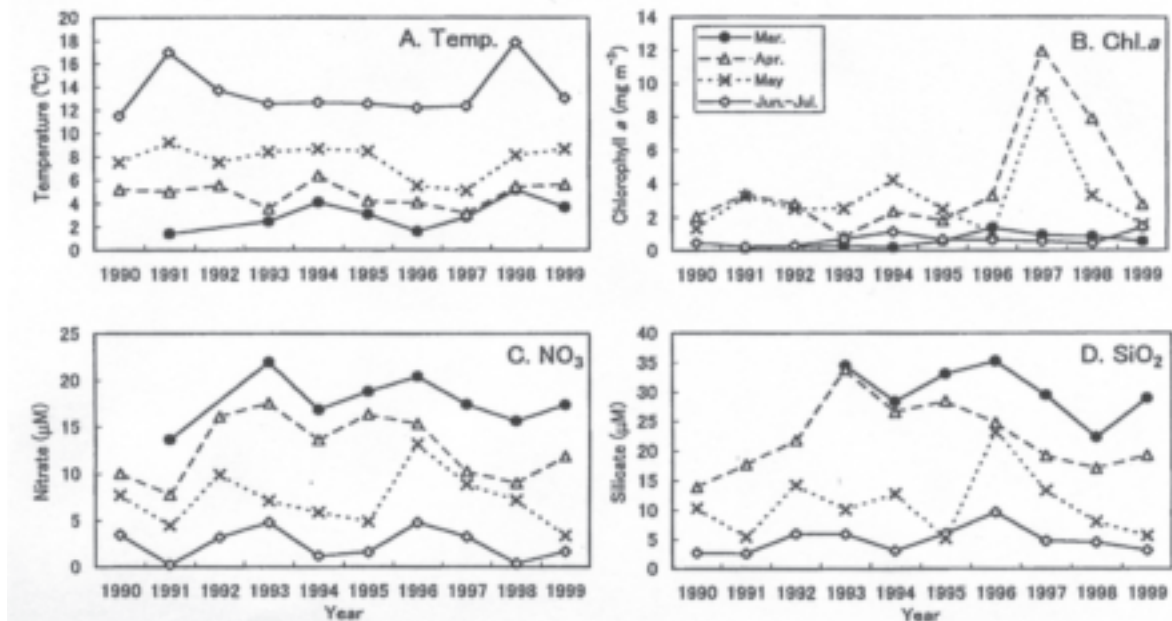
Information about seasonal changes of zooplankton biomass and/or composition are scarce and the results of the 2002-03 survey (Figure 75) suggest that the general pattern will require further observations.¹⁶⁷



[Figure 75] Zooplankton composition along 138°E in 2002-2003

Monitoring – Oyashio Seasonal and interannual variability in temperature, chlorophyll-a and nutrient concentrations at the surface, and netplankton biomass was monitored along the A-line, located in the Oyashio region, from 1990.¹⁶⁸



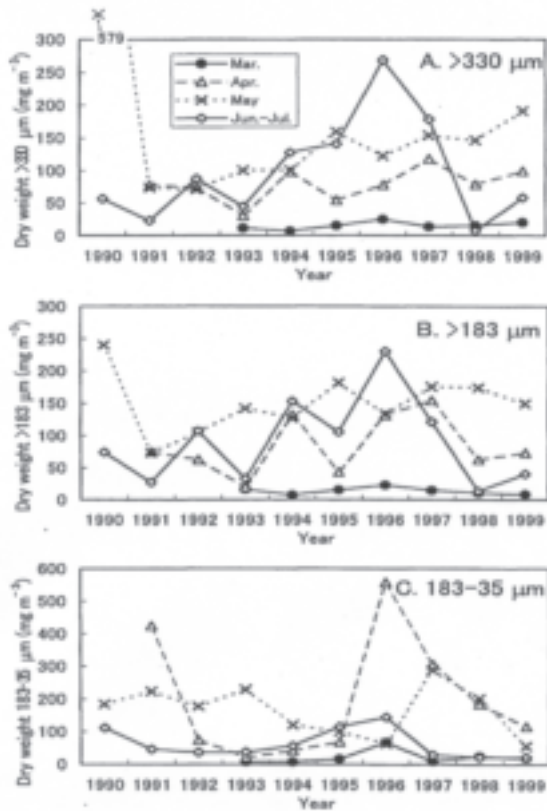


[Figure 76] Temperature, chlorophyll a concentration, nitrate and silicate at the surface water in March, April, May and June-July. Each value was the mean from observations at same seasons in 1990-1999. March 1991 values were determined from only 2 stations.¹⁶⁸

Phytoplankton – Oyashio Interannual variations of mean temperature, chlorophyll-a concentration, concentrations of nitrate and silicate at the sea surface in March, April, May, and June-July were selected because they were representative to the period before spring bloom (March), during spring bloom (April and May), and after spring bloom (June-July). The surface temperature in May was lower in 1996 and 1997 than other years, showing less increase of temperature from April to May (Figure 76A). The surface temperature in June-July was higher in 1991 and 1998 than other years. Interannual variation in surface chlorophyll a concentration was characterized by high values in April of 1997 and 1998, and in May of 1997 (Figure 76B). These chlorophyll-a concentrations exceeded 8 mg m^{-3} . On the other hand, lower concentrations than other years were observed in April of 1993 and in May 1996. From 1990 to 1999, chlorophyll-a concentrations were either similar in April and May, or higher in May than April. From 1996, however, concentrations in April were higher than in May, which might indicate that spring bloom occurred earlier in the late 1990s than in early 1990s.

Decreases in nitrate and silicate occurred mainly between April and May from 1993 to 1995; however, from 1996 to 1998 decrease of nitrate was small between April and May and sharply decreased between March and April and between May and June-July (Figure 76).¹⁶⁸

Zooplankton-Oyashio Along the A-line, interannual variability of the mean standing stock of meso-zooplankton (size-classes of $>330 \mu\text{m}$ and $>183 \mu\text{m}$) was characterized firstly by a remarkably high biomass in May 1990 (Figure 77 A/B). In particular, the mean biomass of size-class $>330 \mu\text{m}$ ($579 \text{ mg m}^{-3} \text{ DW}$) was about twice that of the maximum among other values ($268 \text{ mg m}^{-3} \text{ DW}$ in June-July 1996). Since 1991, there were increasing trends in mean biomass in May and June-July in both size-classes. These trends continued until 1997 in June-July and until 1999 in May. The trend was not observed in micro-zooplankton. The $35\text{-}183 \mu\text{m}$ size-class had high biomass in April of 1991 and 1996 (Figure 77C) and low biomass in May 1994-1996 and 1999.¹⁶⁸



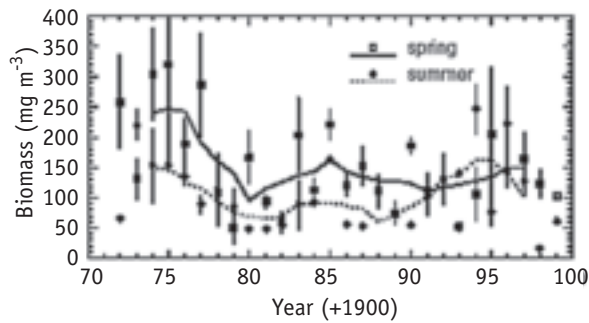
[Figure 77] Interannual variability of netplankton biomass in each size-class (A, >330 μm ; B, >183 μm ; and C, 35-183 μm) in March, April, May and June-July. Each value was the mean of observations in the same seasons from 1990-1999.¹⁶⁸

Meso-zooplankton biomass in the Oyashio is at the same level as in the western Subarctic Pacific, and slightly higher than in the eastern Subarctic Pacific, and lower than in the Bering Sea and Okhotsk Sea. The species composition of meso-zooplankton is similar to other areas of the Subarctic Pacific. Copepods of the genus *Neocalanus* are the main composition in the mesozooplankton community in biomass.¹⁶⁹ In the Oyashio, meso-zooplankton biomass was low from the early 1950s to the mid-1960s, increased in the late 1960s and sustained high values until the late 1970s, decreasing in the early 1980s and thereafter sustained low values through the decade.¹⁷⁰ The variation is similar to that observed in the eastern Bering Sea, and the western and central Subarctic Pacific.¹⁷¹

A recent study looked at the interannual variation of meso-zooplankton biomass in Oyashio water using data and samples collected along a transect PH from 1972 to 1999.¹⁷² In spring, meso-zooplankton biomass, presumably composed mainly of *N. flemingeri*, was high in the mid-1970s and decreased considerably in the late 1970s and sustained low values until the late 1990s (Figure 78). The abundance of diatoms, which are important food for *N. flemingeri* in Oyashio water in spring, also decreased in the late 1970s. The biomass of mesozooplankton in any year was positively related ($r=0.486$, $p<0.05$) to the abundance of diatom cells the previous year. *N. flemingeri* normally has a one year life cycle except for some populations in the western Subarctic Pacific. It has been suggested that copepod egg production is affected by diatom availability the preceding year, such that it affects the number of nauplii surviving the following year. A decrease of diatom cell numbers is consistent with a decrease of primary production during spring.¹⁷³ One possible explanation for decreased primary production was that phytoplankton growth was limited by the availability of iron supplied from depth. An increase in the vertical density gradient throughout the study period reduced vertical mixing in winter, resulting in diminishing resupply of iron in winter. In summer, meso-zooplankton biomass presumably was dominated by *N. plumchrus*. Its biomass was high in the mid 1970s and decreased in the late 1970s, sustaining low values until the late 1980s, whereupon, it increased during the 1990s (Figure 78).

Interannual variability of meso-zooplankton biomass had a significant positive correlation with chlorophyll-a concentration ($r=0.611$, $p<0.01$) but not with diatom cell number. Meso-zooplankton biomass could be affected by the availability of non-diatom (smaller) phytoplankton. *N. plumchrus* cannot utilize smaller phytoplankton efficiently, so an even smaller size-class of zooplankton, the microzooplankton, fill the niche between small phytoplankton and *N. plumchrus*.

The standing stock of Japanese sardine (*Sardinops melanostictus*), as an important predator of *N. plumchrus*, had a significant negative correlation with total meso-zooplankton biomass (-0.601 , $p<0.01$) implying that feeding pressure by the Japanese sardine might influence the interannual variation of *N. plumchrus*.



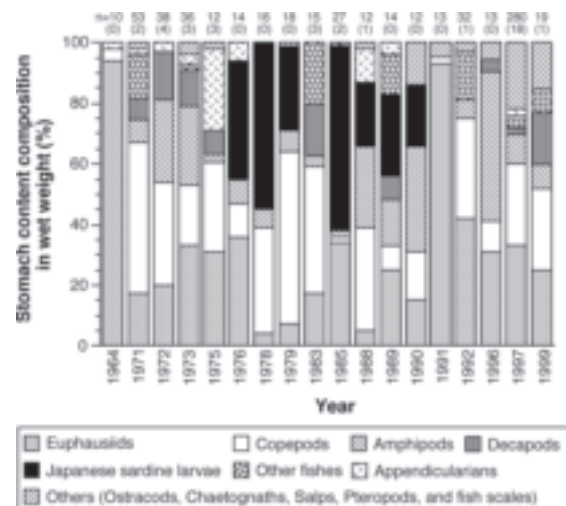
[Figure 78] Interannual variation in total zooplankton biomass (mg m^{-3}) in spring (squares) and in summer (diamonds) from 1972 to 1999. Lines show five-year running mean in spring (solid) and summer (broken). Bars denote ± 1 standard deviation.

Micronekton Micronekton is a group of organisms mainly composed of large-sized euphausiids, shrimps, and small-sized fishes and squids. It also includes all larger sized fishes and squids such as anchovy, sardine, mackerel, albacore tuna, skipjack tuna, Japanese common squid, and neon flying squid during the period of growth through the micronektonic stage during their early life.

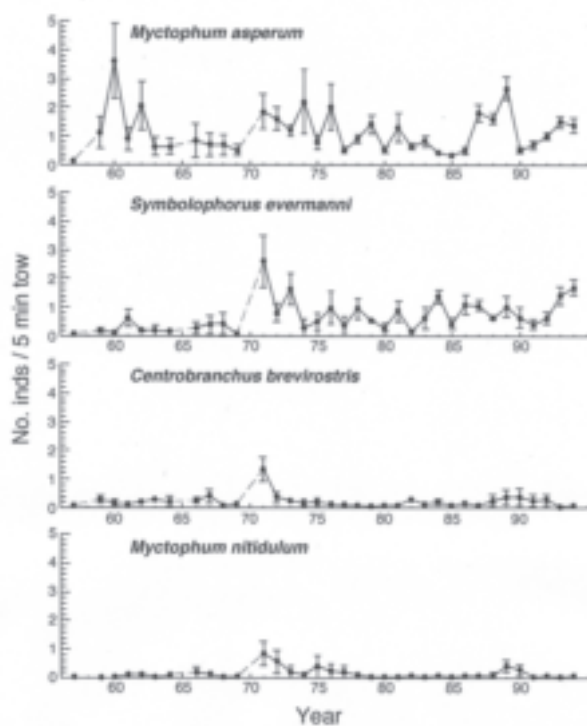
In oceanic ecosystems, myctophid fishes (members of the family Myctophidae) are one of the main components in the micronekton community.^{174,175} Recently, knowledge of their life history strategies has accumulated in the Kuroshio, Oyashio and Kuroshio/Oyashio transition regions of the western North Pacific. In the Kuroshio/Oyashio transition region, most of myctophids migrate vertically at night from the mesopelagic layer up to the epipelagic, and their diel vertical migration patterns were categorized into the 4 types, i.e. migrants, semi-migrant, passive-migrants, and nonmigrants.¹⁷⁶ Myctophids start their vertical migratory behaviour after transformation from larvae to juveniles. Their larvae are distributed in the upper 200 m layer both day and night.¹⁷⁷ In the Kuroshio region, 18 species or types of larval myctophids have been found and they account for 72 % of the total abundance of fish larvae in the 0-200 m layer. These larvae are categorized into three groups by their horizontal distribution patterns, i.e. Kuroshio-axis group, Kuroshio east group, and Pan-Kuroshio group.

Larvae of the subfamily Lampanyctinae are distributed in shallower (0-30 m) waters than those of the subfamily Myctophinae (50-150 m) and this relationship between subfamilies is opposite to the nighttime vertical distribution of their adults of the two subfamilies.¹⁷⁷

Juvenile and adult myctophids mainly feed on crustacean zooplankton such as copepods, euphausiids and amphipods^{178,179,180,181} suggesting that they compete for prey with small pelagic fishes like anchovy and saury, since they actively feed in the productive epipelagic layer.¹⁷⁸ In the Kuroshio region, the four myctophids that migrate to the surface exhibited resource partitioning by having different main prey items and peak feeding hours at night in the top 1-m layer.¹⁷⁹ Furthermore, in the Kuroshio region, the common myctophid, *Myctophum nitidulum* (50-79 mm standard length), was reported to feed mainly on Japanese sardine larvae in winter and early spring between 1976 and 1990 during the period the sardine population exploded. They fed mainly on crustaceans from 1964 to 1975 and from 1991 to 1999 (Figure 79).



[Figure 79] Composition of prey found in *Myctophum nitidulum* (50-79 mm standard length) in the Kuroshio region from 1964 to 1999. n, number of stomachs examined (number of empty stomachs in parentheses).¹⁸¹



[Figure 80] Annual fluctuation in the average catches of juveniles (Standard length ≤ 40 mm) of the surface migratory myctophid species over 35 years, from 1957 to 1994. The bars indicate the standard error.¹⁸¹

Seasonal north-south migrations for feeding and spawning are also recognized for some myctophids like *Diaphus theta*, which is also one of the most common vertical migratory myctophids in the Subarctic and northern transition regions.¹⁸² They undertake southward spawning migrations from the Subarctic to the transition regions and spawn mainly from May to July. Their larvae and early juveniles are distributed in the transition region. On reaching about 40 mm standard length, juveniles start a northward migration to the Subarctic region.

Growth of the tropical-subtropical species *Myctophum asperum* was examined based on daily otolith increment in the Kuroshio and transition regions.^{183,184} The growth rate was 0.24 mm d^{-1} at a size of 12.9 mm, reaching a maximum of 0.30 mm d^{-1} at 26.0 mm, 48 days after metamorphosis. This species is estimated to reach near-adult size, 75 mm, at 9 months after metamorphosis. On the other hand, growth rates of the Subarctic species *Diaphus theta* were 0.14 mm d^{-1} in larvae and 0.13 mm d^{-1} in juveniles; this is slow compared with tropical or subtropical species like *M. asperum*.¹⁸⁵

In the Kuroshio region, the decadal change in abundance of surface migratory myctophid fishes was examined for a period of 35 years from 1957 to 1994.¹⁸⁶ The abundance of juvenile *Symbolophorus evermanni*, *Centrobranchus brevirostris*, and *Myctophum nitidulum* showed prominent peaks in 1971 (Figure 80), as did adult *M. nitidulum*. These peaks corresponded to an extraordinarily high zooplankton abundance in the Kuroshio region in 1971, suggesting high recruitment success and low adult mortality in surface migratory myctophids. Smaller changes in abundance in other years were species-specific, and the fluctuation patterns were mainly explained by year-to-year fluctuations in the strength of the Kuroshio and the geographical distribution of each species, i.e., an increased Kuroshio flow volume resulted in an increase in tropical species and a decrease in temperate species, but no change in the pan-Kuroshio species.

Scientific interests have been stimulated by the possible competition for prey between micronekton and juveniles of commercially important fishes. The Fisheries Research Agency of Japan started a project DEEP (Deep-Sea Ecosystem and Exploitation Programme) in 2002. One of the main objectives of this project is to elucidate the influence of mesopelagic micronekton upon fisheries resources in the regions from the Kuroshio Extension to the Oyashio regions.

Fish and Invertebrates

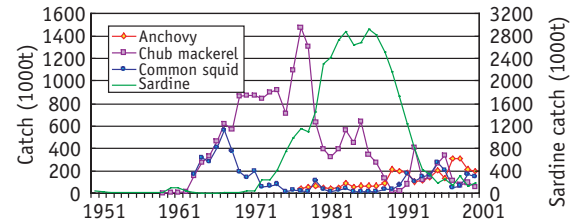
Japanese fishers have been harvesting various marine organisms in the Kuroshio and its adjacent regions for a very long time. Among them, Japanese sardine (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonicus*), chub mackerel (*Scomber japonicus*) and Japanese common squid (*Todarodes pacificus*) have constituted the major fraction of commercial landings since the early 20th century but the landings are vary considerably (Figure 81).^{187,188} These species undergo seasonal north-south migrations between spawning grounds during autumn-winter-spring and feeding grounds in the Oyashio region mainly in summer.¹⁸⁹ The spawning grounds of these species usually extend from Kyushu Island (southern Japan) to Cape Inubo (36°N), except for the common squid (major putative spawning grounds in the East China Sea) and for anchovy 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 is high.

Biomass and Japanese commercial catches of these small pelagics indicate decadal changes or alternations of dominant species called “species replacements” (Figure 81 and Figure 82). Although mechanisms of the species replacements have not been fully resolved, ocean-climate regime shifts have profound impacts on their dynamics together with species interactions.^{190,191}

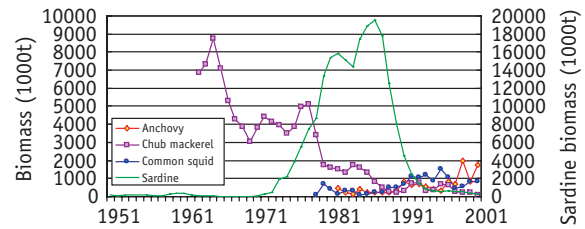
Sardine biomass and catch were high during the 1980s and decreased in the 1990s. The onset of increase and decrease of the biomass occurred in the early 1970s and 1989, respectively, which coincided with regime shifts found in the sea surface temperature (SST) around Japan.¹⁵⁶ The observed recruitment of sardine was above the Ricker curve during 1971-87 and below the curve during 1951-70 and after 1988, suggesting unfavorable environmental conditions after 1988.¹⁹² 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 Oyashio intrusion.^{191,192} Spawning stock biomass (SSB) was around 0.5 million t in the late 1990s, and decreased to less than 0.3 million t in recent years.¹⁸⁹ Therefore, recruitment in recent years is extremely low.

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 1970-77, 1991-92, and 1995-96, and below the curve during 1978-80 and 1986-90.¹⁹² Despite the occurrences of strong year-classes in 1992 and 1996, intensive fishing on immature fishes prevented stock recovery.¹⁸⁹ Thus, recruitment in recent years has been low and variable.

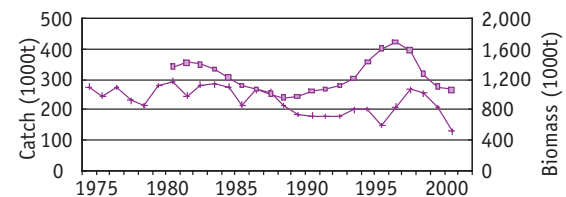
Anchovy and common squid biomass and catch have been relatively high in recent years, but with considerable year-to-year fluctuations (e.g. drastic decline of squid catch in 1998 and 1999), which reflects their relatively short life spans (anchovy -2 or 3 years and squid -1 year). Catch and biomass of sardine seem to be negatively related with those of anchovy and common squid.



[Figure 81] Japanese catch of sardine, anchovy, chub mackerel and common squid along the Pacific coast of Japan.



[Figure 82] Biomass of sardine, anchovy, chub mackerel and common squid along the Pacific coast of Japan. NB: anchovy biomass represents only Japanese coastal and offshore waters.



[Figure 83] Biomass and Japanese catch of walleye pollock (Pacific stock).

On the Pacific coast of Japan, the Pacific stock of walleye pollock (*Theragra chalcogramma*) is distributed from Cape Inubo (36°N) to Etorofu Island. The biomass of this stock has decadal-scale fluctuations with a minimum (0.9 million t) in 1989 and a peak (1.7 million t) in 1997, declining in recent years (Figure 72). The Japanese annual commercial catch of this stock fluctuated between 0.2 and 0.3 million t from the 1970s until 1988, however, it gradually decreased to 148,000 t in 1996. In 1995, a strong year-class appeared and catches recovered to 265,000 t in 1998, but have decreased again to 129,000 t in 2001.¹⁸⁹

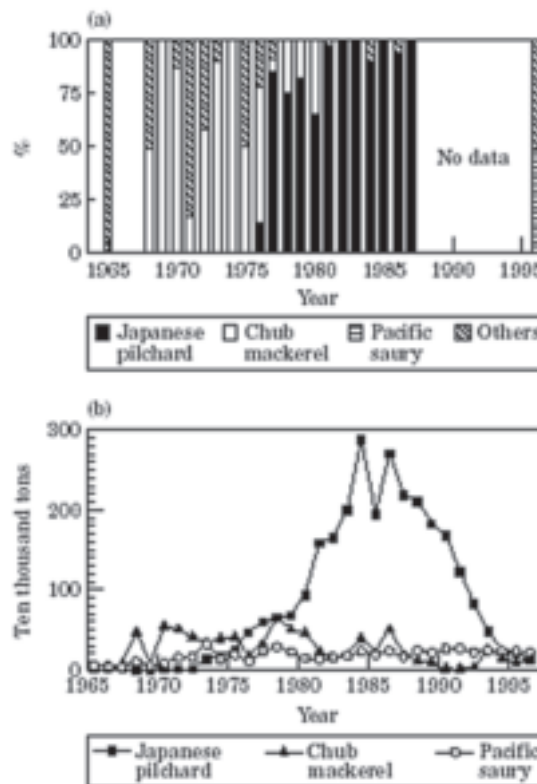
Marine Birds and Mammals

Seabirds No data.

Cetaceans Chub mackerel was the most important prey species of minke whales in the western Pacific in August, and walleye pollock was the most important one for minke whales in east Sakhalin between June and August based on test whaling from 1973-1975.¹⁹³ Annual changes of prey species were determined from the catch records of small-type whaling in the seven whaling grounds off Japan from 1948 to 1987. On the Pacific coast of Hokkaido (a part of sub-area 7W) from April to October, prey species recorded were krill, squid, Japanese pilchard, Japanese anchovy, chub mackerel, walleye pollock, cod, sand lance, Pacific saury and so on.¹⁹⁴ The change of prey of minke whales from chub mackerel to Japanese pilchard in 1977 corresponded with a change of the dominant species taken by commercial fisheries in the same area in 1976. Krill was the dominant prey species from 1964 to 1987 in the Okhotsk Sea.

Annual sampling of the relative frequency of occurrence of each major prey species consumed by minke whales on the Pacific coast of Hokkaido (Figure 84A) and the commercial catches of Japanese sardine, chub mackerel and Pacific saury on the Pacific side of Hokkaido (Figure 84B) indicate a change of prey species from chub mackerel to Japanese sardine in 1977, and from Japanese sardine to Pacific saury in 1996, corresponding to a change in the dominant species taken by commercial fisheries in the same area in 1976, 1996, respectively.¹⁹⁵

In the Kuroshio/Oyashio region, 33 marine mammal species have been reported, and the abundance of six species was estimated as 114,513 in number and $8,978 \times 10^3$ t in biomass during summer. Total prey consumption by these species during summer was estimated at 533×10^3 t.³⁰⁵

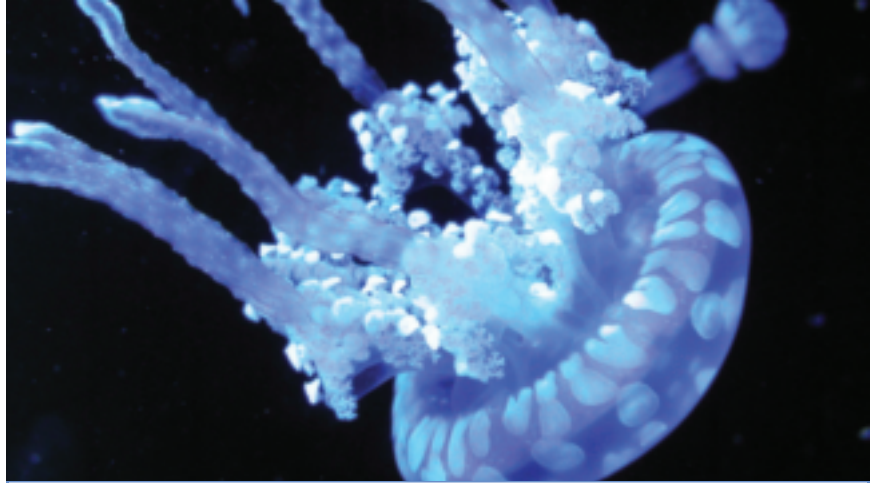


[Figure 84] The annual changes of relative frequency of occurrence of each dominant prey species consumed by minke whale in subarea 7W (a) and the commercial catch on the Pacific side (b). **pilchard=sardine.

issues

Although statistical evidence is accumulating about linkages between the physical environmental and stock abundance or biological productivities of small pelagics, studies on how it occurs are currently at the initial stage. Mechanistic studies are indispensable for reliable fisheries management and are one of the central themes of the PICES-GLOBEC CCCC program.

The literature suggests that the Kuroshio/Oyashio transition zone is the key area for recruitment successes or failures of sardine and possibly other pelagic nekton and micronekton. Continuation and expansion of both modeling and ecosystem monitoring activities are needed particularly for this area.



Authorship

Preparation of this chapter was coordinated by Dr. Yukimasa Ishida of the National Research Institute of Fisheries Science, Kochi, Japan.

Contributors

Hideki Akiyama

National Research Institute of Fisheries Science, Yohohama, Japan

Kiyotaka Hidaka

National Research Institute of Fisheries Science, Yokohama, Japan

Mitsuyuki Hirai

Tohoku National Fisheries Research Institute, Sendai, Japan

Yukimasa Ishida

National Research Institute of Fisheries Science, Kochi, Japan

Masatoshi Moku

Tohoku National Fisheries Research Institute, Sendai, Japan

Satoshi Sugimoto

Japan Meteorological Agency, Tokyo, Japan

Kazuaki Tadokoro

Frontier Research System for Global Change, Tokyo, Japan

Tsutomu Tamura

The Institute of Cetacean Research, Tokyo, Japan

Hikaru Watanabe

National Research Institute of Far Seas Fisheries, Shimizu, Japan

Akihiko Yatsu

National Research Institute of Fisheries Science, Yokohama, Japan