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

Yellow and East China Seas

lead author

Sinjae Yoo

Marine Living Resources Division
Korea Ocean Research and Development Institute (KORDI)
Ansan, Republic of Korea

Citation:

Yoo, S., An, Y.-R., Bae, S., Choi, S., Ishizaka, J., Kang, Y.-S., Kim, Z.G., Lee, C., Lee, J.B., Li, R., Park, J., Wang, Z., Wen, Q., Yang, E. J., Yeh, S.-W., Yeon, I., Yoon, W.-D., Zhang, C.-I., Zhang, X., Zhu, M. 2010. Status and trends in the Yellow Sea and East China Sea region, pp. 360-393 In S.M. McKinnell and M.J. Dagg [Eds.] Marine Ecosystems of the North Pacific Ocean, 2003-2008. PICES Special Publication 4, 393 p.

highlights

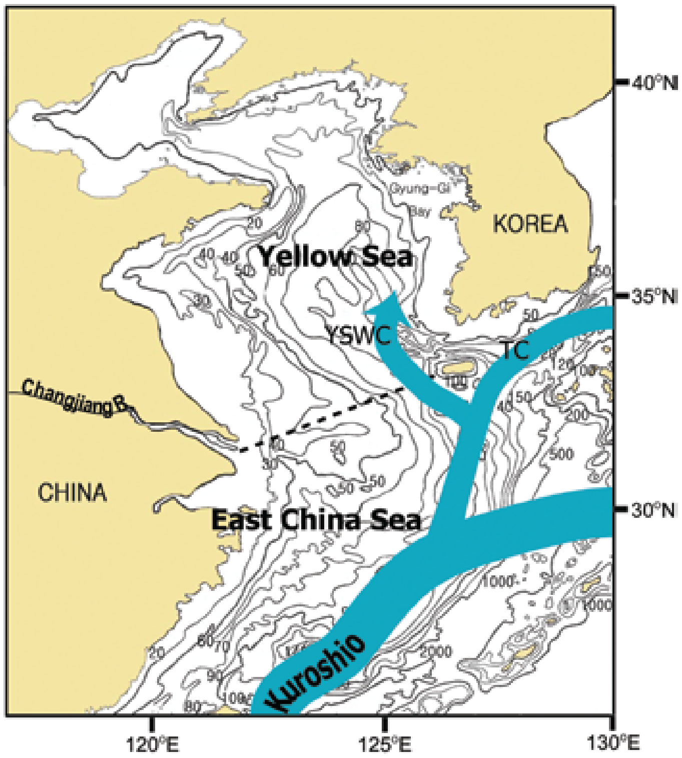
- The Yellow Sea and East China Sea have undergone drastic changes in the past decades as witnessed by species shifts, increasing outbreaks of HABs, and jellyfish blooms. More recently, macroalgal blooms appeared in the western coastal areas of the Yellow Sea and East China Sea (Liu et al. 2009). These and other changes indicate the ecosystem structure is rapidly shifting.
- There is clear evidence of ongoing eutrophication in the Yellow Sea from the record of organic deposition in sediments, increases in biomass and abundance of the benthos during the past decade, and the appearance of an hypoxic area.
- Warming of the ocean surface waters has occurred since the mid- to late 1980s, with a parallel increasing trend in mesozooplankton abundance. The mechanism of this linkage and a possible interaction with eutrophication is unclear.
- Changjiang River discharge has been reduced with an accompanying impact on ecosystem productivity and structure in the vicinity of the river mouth. An impact on a larger scale on the shelf area is not yet evident.
- In the Yellow Sea, nitrogen:phosphorus and nitrogen:silicon ratios have been increasing basin-wide for the past three decades.
- The most prominent pressures to the ecosystem in the past decades were overfishing, eutrophication and disturbances in the freshwater budget.
- A recent survey indicates that the volume of the Yellow Sea Bottom Cold Water is reduced.
- A complicated network of pressures, anthropogenic as well as natural, is at work in these ecosystems with an anticipation of even more changes in near future. These changes are expected to have a significant impact on the resource utilization of the Yellow Sea and East China Sea.

Introduction

The Yellow Sea is a shallow marginal sea in the western North Pacific with a surface area of 380,000 km² and an average depth of 44 m (Fig. YS-1).

It is broadly connected with the East China Sea to the south and contains a semi-enclosed gulf in the north, the Bohai Sea. The region is one of the more densely populated in the world with human populations organized as the Peoples Republic of China, Democratic People's Republic of Korea, and the Republic of Korea, two of which are PICES member nations.

The surface circulation in the region has three main currents: Kuroshio, Tsushima and the Yellow Sea Warm Current (YSWC). The Kuroshio enters the East China Sea through the strait between Taiwan and Yonakunijima Island (the easternmost of the Ryukyu Islands) and flows northeastward along the shelf slope before branching into Tsushima Strait. The YSWC flows into the Yellow Sea after separating from the Tsushima Current west of Jeju Island. There are varying opinions regarding the origins of the Tsushima Current and YSWC (Beardsley et al. 1985; Lie, H.-J. 2002; Ichikawa and Beardsley 2002).



[Figure YS-1] Geography, bathymetry and major currents of the Yellow Sea and East China Sea. YSWC=Yellow Sea Warm Current. TC=Tsushima Current.

The Yellow Sea is characterized by a diversity of marine habitats due to its jagged coastline and the many islands scattered around the shallow sea. Intertidal flats are the most significant type of coastal habitat. Several different types can be found, such mudflats, salt marshes, sand flats with gravel beaches, sand dunes or eelgrass beds, and mixed flats. These habitats support important food resources and an ecological niche for a diversity of organisms. They also provide feeding, wintering and summering grounds for migratory birds. The shallow coastal areas, encompassing more than 1,000 islands, also show high productivity and provide good nursery and fishing grounds.

The Yellow Sea and East China Sea are very productive, supplying a large portion of the protein to human diets in the surrounding nations. The primary productivity of these seas has been estimated to be in the range of 150-200 $gC \cdot m^{-2} \cdot yr^{-1}$. Approximately 1,600 species were reported from marine and coastal habitats in the Korean part of the Yellow Sea, including 400 phytoplankton, 300 marine macroalgae, 50 halophytes, 500 marine invertebrates, and some 389 vertebrate species (Kim and Khang 2000). Among them, 166 zooplankton and 276 fish have been reported as resident species in the Yellow Sea. Approximately 100 commercial species have been identified in the region, comprising demersal fish (66%), pelagic fish (18%), cephalopods (7%), and crustaceans (7%).

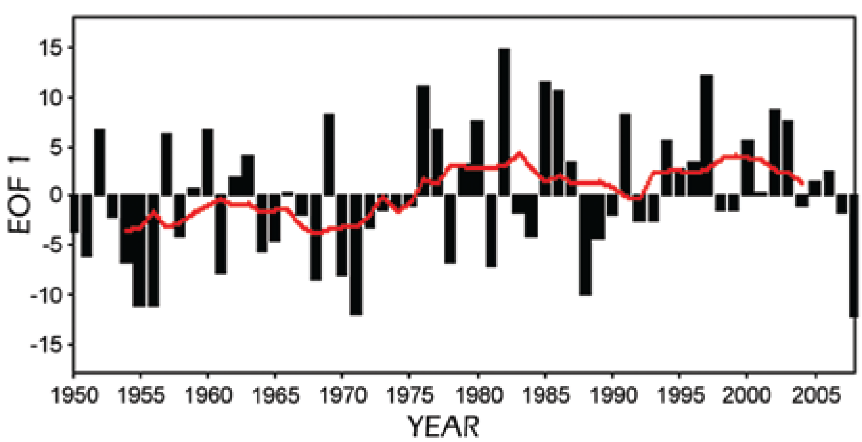
However, various human activities threaten the region. The Yellow Sea and East China Sea are among those facing all conceivable stresses, whether natural or anthropogenic. The coastal regions of the Yellow Sea are densely populated, with approximately 600 million humans living in the region, and most of their by-products drain into the Yellow Sea. There is clear evidence of eutrophication. Artificial jetties and dams have interfered with local circulation and freshwater inputs into the sea. Overfishing has changed the trophic structure which cascades down the food web. Warming is evident. All in all, significant changes in the ecosystem are anticipated and there have been many signs. This chapter provides a review of marine ecosystem variability, with special attention to the period from 2003-2008, hereafter, the *focus period*.

2.0 Atmosphere and hydrology

2.1 Wind and pressure

The Yellow Sea/East China Sea region is located where the Siberian High and the Subtropical Pacific Low collide to produce cold-dry winters and warm-wet summers. North and northwest winds in the autumn and winter are strong, with maximum speeds reaching 10 $m \cdot s^{-1}$. In the spring and summer, monsoon winds reverse the direction and become weaker. Typhoons develop in the western Subtropical Pacific bringing heavy rains in the summer and autumn. On average, about nine typhoons pass the region every year.

Winter sea level pressure (SLP) in the North Pacific from 1950 to 2008 shows that the western North Pacific is in a high pressure state since 1976 (Fig. YS-2). The leading EOF explains 41.8% of the variance with positive loading in western North Pacific. Although in 2007 and 2008, the anomaly shifted to negative, it is too early to tell whether this is a trend.



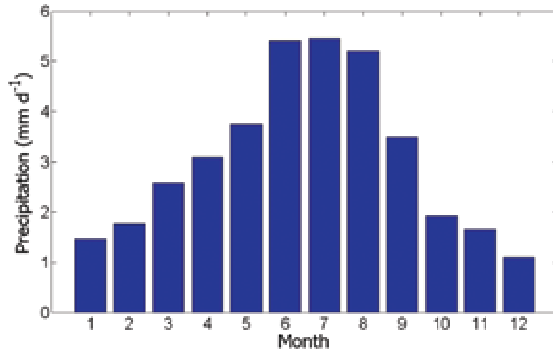
[Figure YS-2] Time series of the 1st EOF (explaining 41.8% of the variance) scores of SLP for Dec-Jan-Feb during 1950-2008 in the North Pacific (bounded by 110°E-120°W and 20°N-70°N). This pattern is positively loaded throughout the western North Pacific.

2.2 Precipitation and hydrology

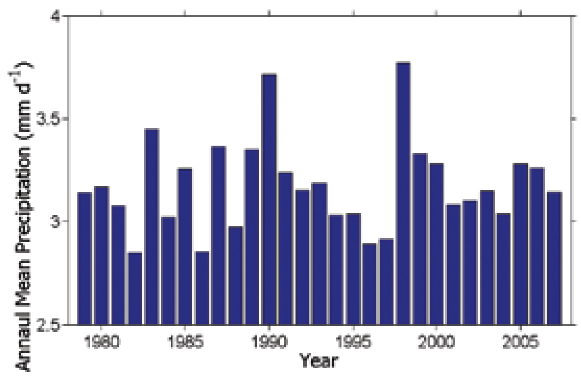
The precipitation pattern over the Yellow Sea and East China Sea shows a typical Northeast Asian monsoon pattern according to the NOAA/Climate Prediction Center Merged Analysis of Precipitation (CMAP) http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.cmap.html. The region has dry winters with the annual precipitation minimum ($1.1\ mm \cdot d^{-1}$) in December and wet summers with the maximum precipitation ($5.5\ mm \cdot d^{-1}$) occurring in July for the period 1979-2007 (Fig. YS-3). During the same period, there was no discernable long-term trend (Fig. YS-4). The maximum rainfall in recent years occurred during the flood year of 1998. There was no difference in annual average rainfall during the focus period (to 2007 only) from the previous period.

Fourteen rivers drain into the Yellow and East China seas, with a total discharge of $>10^{12}\ m^3 \cdot y^{-1}$ (Hong et al. 2003). Of these, the Changjiang River has the largest discharge ($895 \times 10^9 \cdot m^3 \cdot y^{-1}$) onto the shelf of the East China Sea. Interannual variation of satellite chlorophyll$_a$ on the shelf of the East China Sea from 1998 to 2006 was closely related to the Changjiang River discharge (Kim et al. 2009). During the summer monsoon salinity drops by as much as 6 psu. Such abrupt events have devastating effects on aquaculture and on some parts of the adjacent ecosystem.

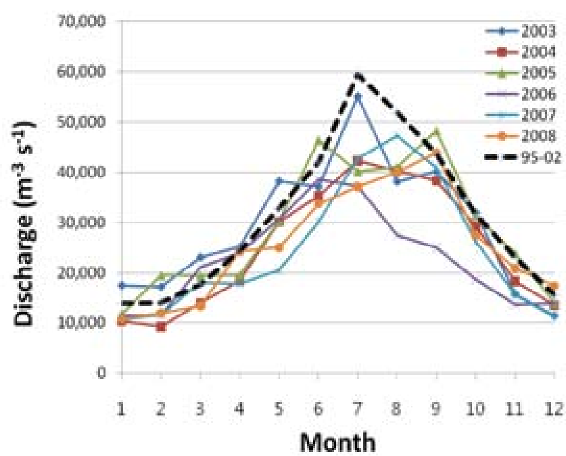
The first phase of Three Gorges Dam (TGD) construction was completed and impoundment began in June 2003, so the focus period of this report corresponds to the first six years of water impoundment. Records show lower discharges compared to the average of 1995-2002 period. Peak discharge occurred in different months (Fig. YS-5): June (2006), July (2003), August (2007) and September (2008). Average annual discharge decreased by 16.9% from 1995-2002 to 2003-2008 (Fig. YS-6). The reduction could influence the adjacent ecosystem by changing the supply of nutrients, sediment, and transparency. In fact, some recent studies showed that such changes occurred immediately after June 2003 when water impoundment started. The sediment loading was reduced by about 55% at the Datong hydrological station after June 2003 and the Si:N ratio in the vicinity of Changjiang River mouth changed from 1.5 in 1998 to 0.4 in 2004 (see Section 3.2.2) (Gong et al. 2006). The microbial community structure and microbial diversity also changed after 2 months of water storage operation (Jiao et al. 2007).



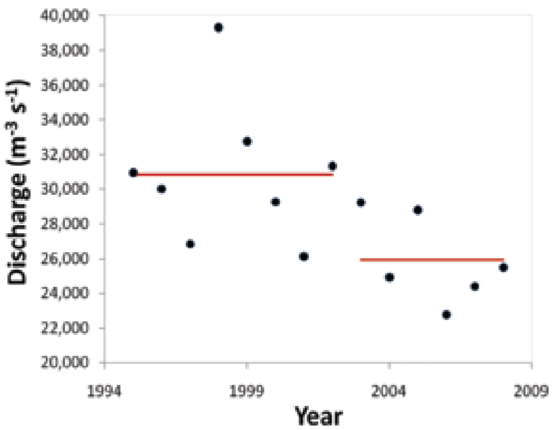
[Figure YS-3] Monthly precipitation over the Yellow Sea and East China Sea area averaged for 1979-2007. The pattern shows a typical northeastern Asian monsoon pattern of dry winters and wet summers. CMAP data are used.



[Figure YS-4] Annual average precipitation over the Yellow Sea and East China Sea area. CMAP data are used.



[Figure YS-5] Monthly discharge of the Changjiang River measured at Datong station (600 km upstream of the East China Sea). Broken line denotes the average for the period from 1995 to 2002.

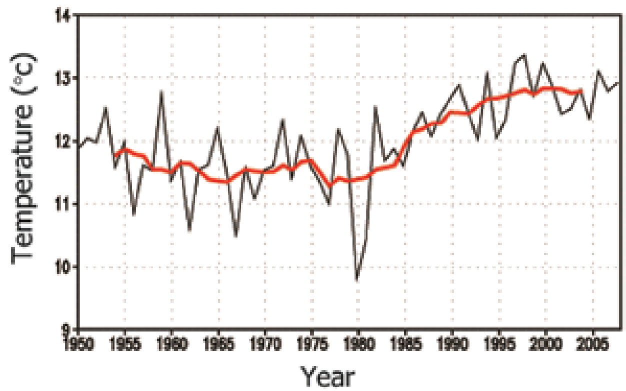


[Figure YS-6] Annual average discharge of the Changjiang River measured at Datong station. The discharge decreased after the impoundment of water began by TGD in June 2003.

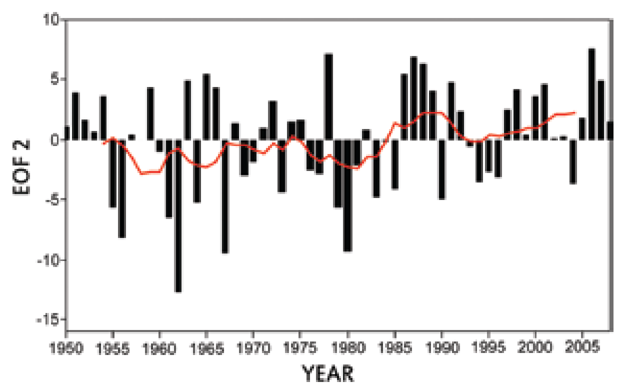
3.0 Physical and Chemical Ocean

3.1 Hydrography

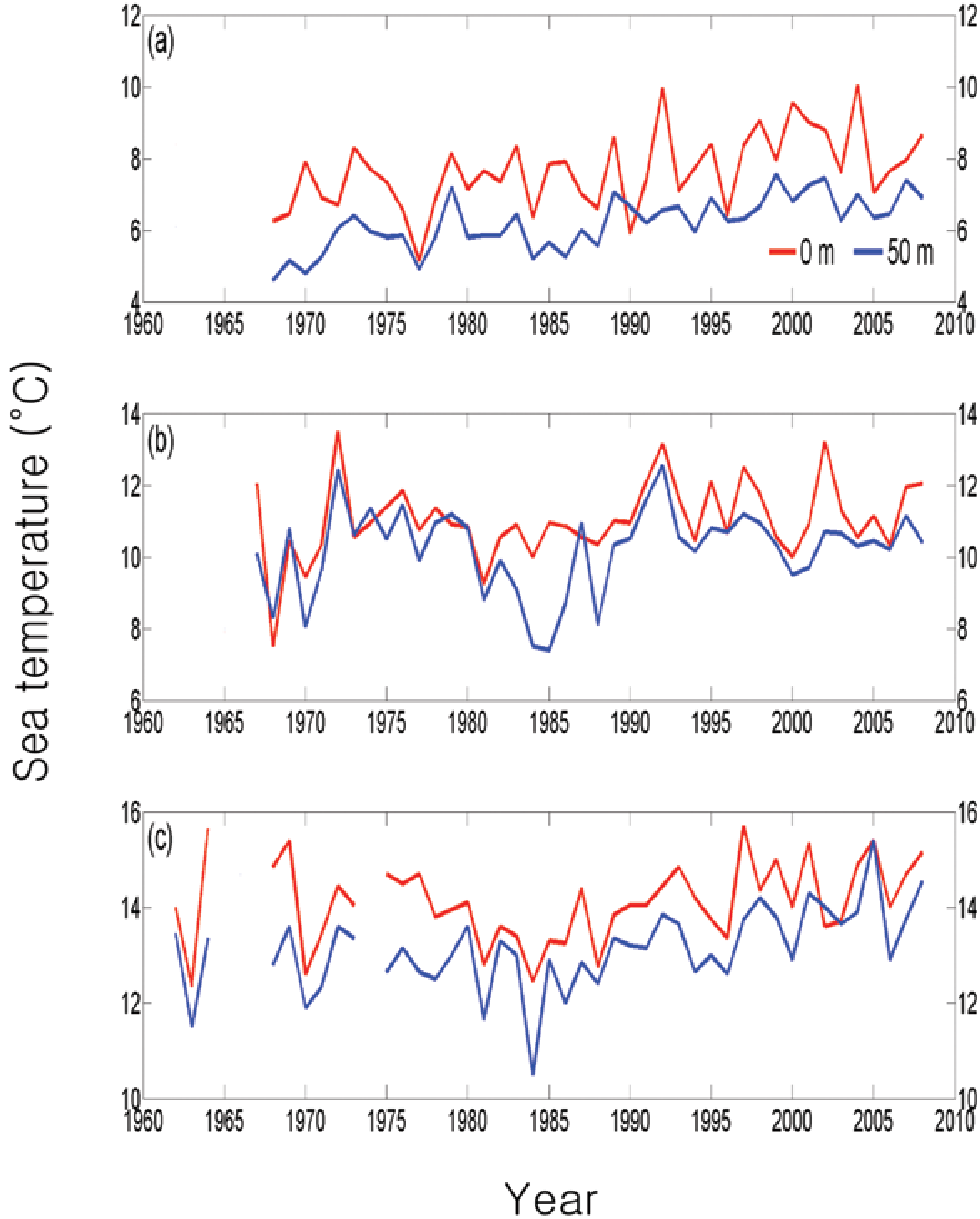
The most striking feature in the region (25°N-40°N, 118°E-127°E) is how its surface waters have warmed during boreal winter since the mid-1980s (Fig. YS-7). The long-term trend of SST in the Yellow Sea and East China Sea shows two distinctive periods from 1950 to 2008 (Yeh 2009). The first was a cooler period up to the middle 1980s, followed by a shift to a warm period (Fig. YS-7). EOF analysis shows the warming trend is most conspicuous on the shelf area of the East China Sea and in the central Yellow Sea. There is a phase shift in the temporal pattern of EOF1 based on SST from negative to positive around 1985. Recent warming in the region seems to be associated with large-scale atmospheric variability over the North Pacific basin. The 2nd EOF (explaining 19.6% of the variance) of sea level pressure (SLP) over the North Pacific, which describes the North Pacific Oscillation (NPO, Rogers 1981), shows a shift from low pressure to higher pressure in the middle of 1980s (Fig. YS-8). The correlation coefficient between the moving-averaged SST in the Yellow and East China seas and the moving-averaged principal component time series of SLP over the North Pacific was 0.79. This suggests that the circulation anomalies and thermal advection associated with NPO-like SLP variability play a role in warming the mean SST in the Yellow and East China seas during recent decades. The water temperature in April at the surface and 50 m shows a warming shift after the mid-1980s in the central Yellow Sea and Tsushima Current region (Fig. YS-9). However, on the shelf of the northern East China Sea, the trend is less clear.



[Figure YS-7] The trend of SST (Hadley Center) in Dec-Jan-Feb from 1950 to 2008 in the Yellow Sea and East China Sea region (25°N-40°N, 118°E-127°E). A warming trend is evident after the mid-1980s. The thick line indicates a nine-year moving average.



[Figure YS-8] Time series of the 2nd EOF scores of SLP for Dec-Jan-Feb from 1950 to 2008 in the North Pacific (bounded by 110°E-120°W and 20°N-70°N). The 2nd EOF explains 19.6% of the variance and the positively loaded in the southern half of the study area. The trend shows a shift from low pressure to high pressure after the mid-1980s. The line indicates a nine-year moving average. The correlation coefficient between this moving average and the SST moving average in Figure YS-7 is 0.79.



[Figure YS-9] The long-term trend of the temperature in April at the surface and 50 m in: (a) central Yellow Sea, (b) shelf of northern East China Sea, and (c) Tsushima Current area. The data were taken bimonthly at the stations of Korea Oceanographic Data Center (http://kodc.nfrdi.re.kr/page?id=eng_index).

3.2 Water properties

3.2.1 Oxygen and pH

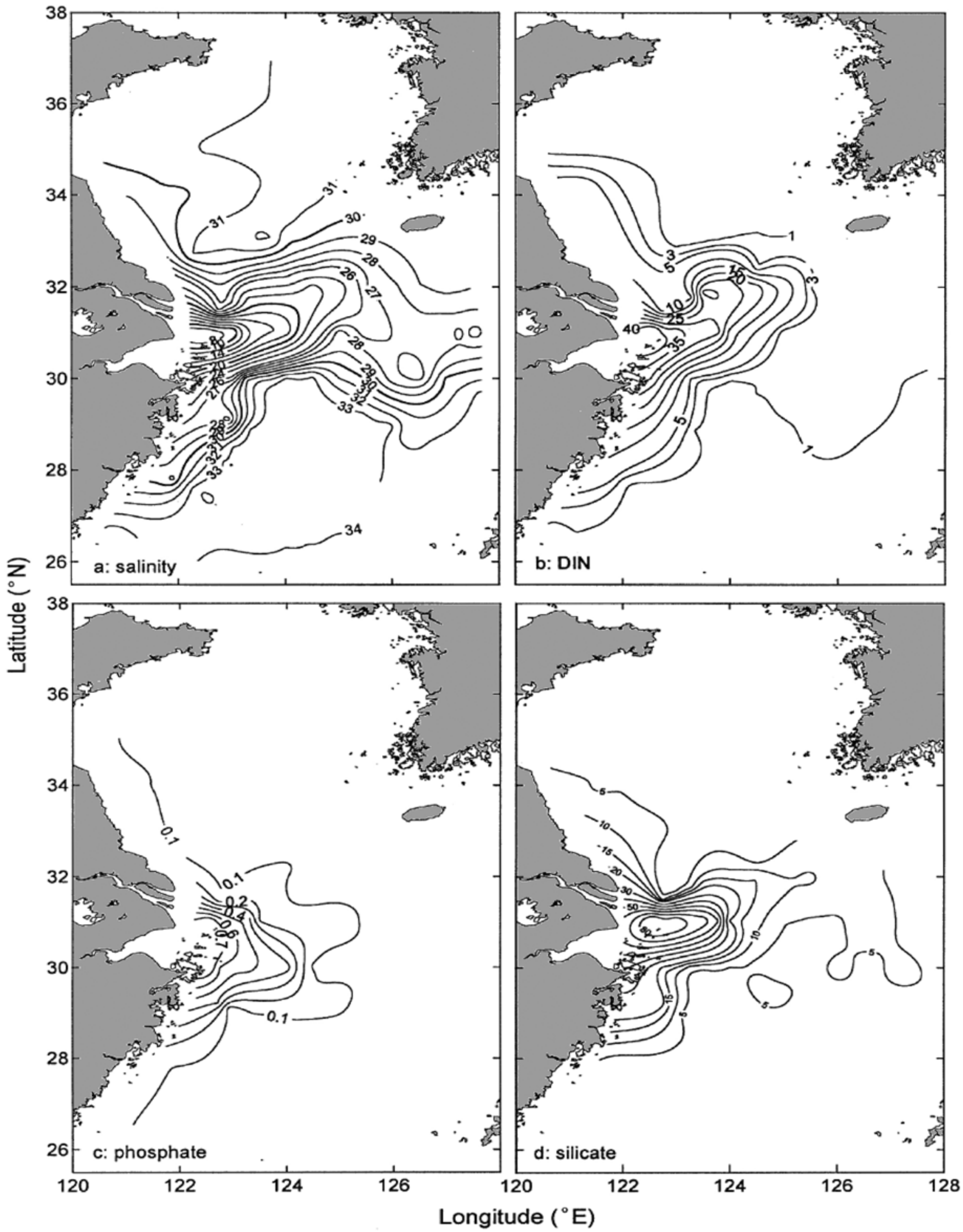
The dissolved oxygen (DO) concentration in the central part of the Yellow Sea was found in the range from 6.40 $mg \cdot l^{-1}$ to 7.81 $mg \cdot l^{-1}$. An average of 9.07 $mg \cdot l^{-1}$ was obtained from a basin-wide cruise carried out in the Yellow Sea in October 2003 (KCJRG 2004). A survey in August 2008 found that oxygen concentrations ranged from < 2.0 $mg \cdot l^{-1}$ to > 5.0 $mg \cdot l^{-1}$ in the bottom layer of the basin (UNDP/GEF 2010). Except for the station in the vicinity of the Changjiang river mouth, the oxygen concentration was >2.0 $mg \cdot l^{-1}$ in most regions. One of the largest coastal low-oxygen areas in the world occurs in the vicinity of the Changjiang River mouth (Chen et al. 2007). In August 2003, the area of DO concentrations <2-3 $mg \cdot l^{-1}$ covered >12,000 km^2. Hypoxia occurs near the Changjiang River mouth due to strong stratification and high primary production (Rabouille et al. 2008). The basin-wide survey in October 2003 also showed that pH values ranged from 7.63 to 8.17 with an average of 8.02 (KCJRG 2004). The pH is slightly higher on the surface than it is at a depth of 50 m.

3.2.2 Nutrients

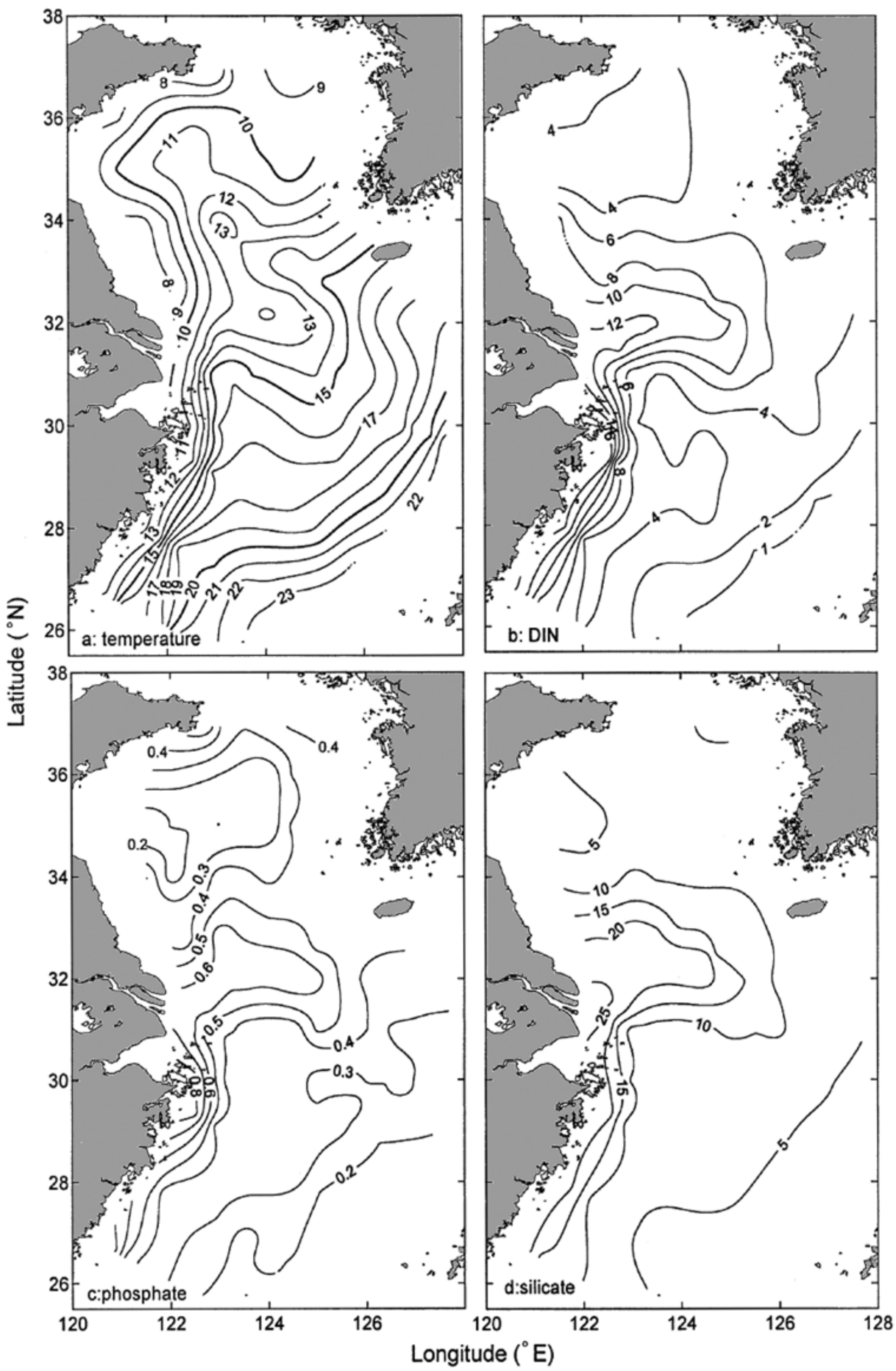
Nutrient concentrations that were measured in the summer of 1998 and the winter of 1999 show some of the characteristics of the Yellow Sea and East China Sea (Wang et al. 2003; Fig. YS-10, YS-11). In summer, most regions of the Yellow Sea were stratified and surface nutrient concentrations were very low. In the southern region, however, discharge from the Changjiang River created a strong south-north nutrient gradient. One of the biggest floods occurred in 1998 when the discharge was 30% greater than the average and the discharge during the summer flood (June 25 to the end of August) accounted for about one-third of the annual total (Wang et al. 2003). Discharge of nitrate in 1998 was 103×10^9 $moles \cdot y^{-1}$ which was more than twice the 1980-1990 average. High nutrient water covered a substantial area of the coastal Yellow Sea and northern East China Sea shelf. In January 1999, nutrients in the central Yellow Sea increased due to vertical mixing (Fig. YS-11). The area encompassed by the Changjiang River discharge was smaller in 1999 than what had occurred during the previous summer flood. A survey of the western Yellow Sea in January-February 2007 found that a similar pattern was observed (Fu et al. 2009). In some shallow coastal areas in the western Yellow Sea, $chlorophyll_a$ concentrations were high and nitrate concentrations were low indicating that biological production was active in these areas. Another basin-wide survey of the Yellow Sea in February 2008 found that nitrate concentration ranged from 4.05-11.8 μM and was higher on the eastern side (UNDP/GEF 2010). Phosphate concentrations were in the range 0.26-1.53 μM with higher values in the southeastern region. Silicate concentrations were in the range 8.16-14.5 μM with higher values in the center of the basin.

Nutrient ratios in the basin are among the best documented examples of change. Nitrate increased continuously from 1984-2000, while phosphate decreased after 1994 and silicate decreased after 1980 (Fig. YS-12). The net effect was an increase in N:P and N:Si ratios (Lin et al. 2005). The basin-scale impact of this change in nutrients on the Yellow Sea ecosystem is not clear yet.

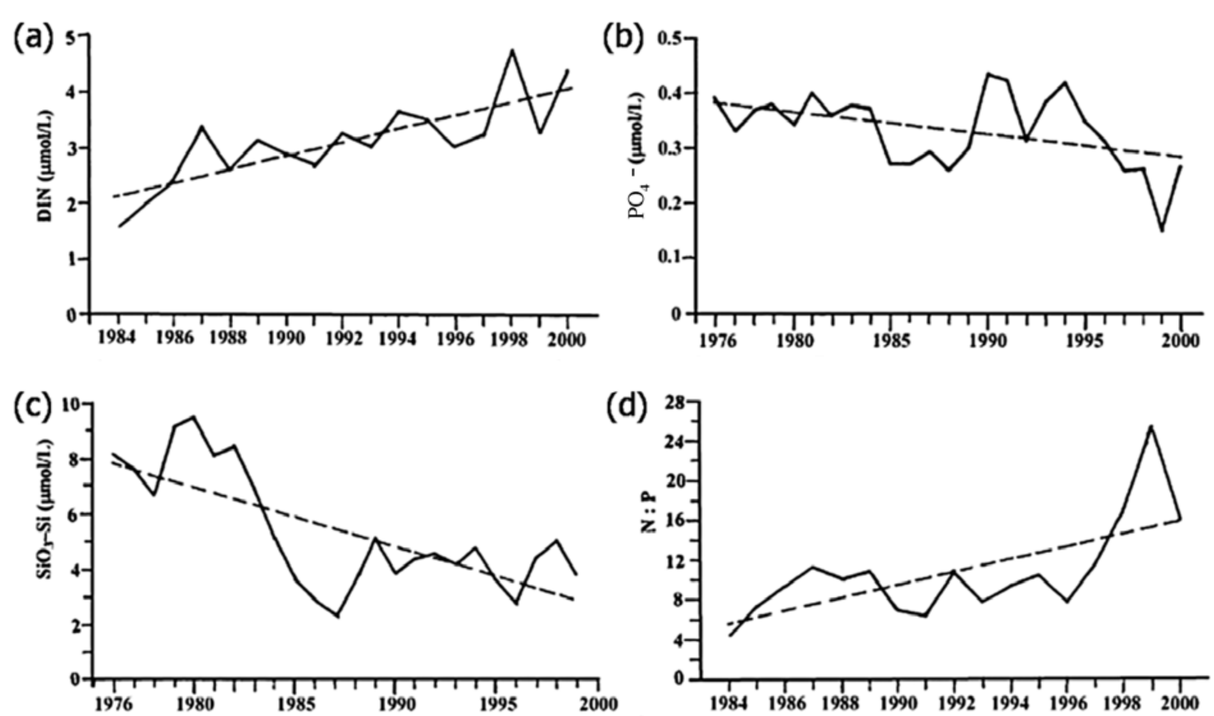
The Changjiang River is a major source of nutrients in the East China Sea. Nitrate loadings from the river have increased about threefold in 40 years (Zhou et al. 2008; Fig. YS-13). At the same time, the dissolved silicate flux has decreased since the 1950s because it is consumed in 162 large reservoirs (48,000 dams in total) in the Changjiang River basin (Li et al. 2007; Gao and Wang 2008). Sediment discharge also plays an important role in supplying nutrients, silicate in particular, to the East China Sea. The amount of sediment discharged depends on precipitation, erosion, sediment trapping by reservoirs, sediment extraction, and other factors (Chen et al. 2008). The amount of sediment discharged has been decreasing continuously since 1986. Therefore even before the construction of the TGD, N:Si and P:Si increased significantly and the result was a shift in the phytoplankton community composition toward non-siliceous species after the 1980s. The area of potential P limitation of phytoplankton growth expanded after 2003 and potential Si limitation appeared in 2005 and 2006 (Chai et al. 2009).



[Figure YS-10] Surface distribution of salinity and horizontal distributions of Dissolved Inorganic Nitrate (DIN), phosphate and silicate (all in μM) in the upper water of the YS and the ECS in August 1998 (adapted from Wang et al. 2003).



[Figure YS-11] Surface distribution of temperature and horizontal distributions of Dissolved Inorganic Nitrate (DIN), phosphate and silicate (all in μM) in the upper water of the YS and the ECS in January 1999 (adapted from Wang et al. 2003).



[Figure YS-12] Long-term trend of the nutrients along a transect across 36°N in the Yellow Sea. (a) Dissolved Inorganic Nitrate (DIN), (b) phosphates, (c) silicates, (d) N:P ratio. Modified from Lin et al. (2005).

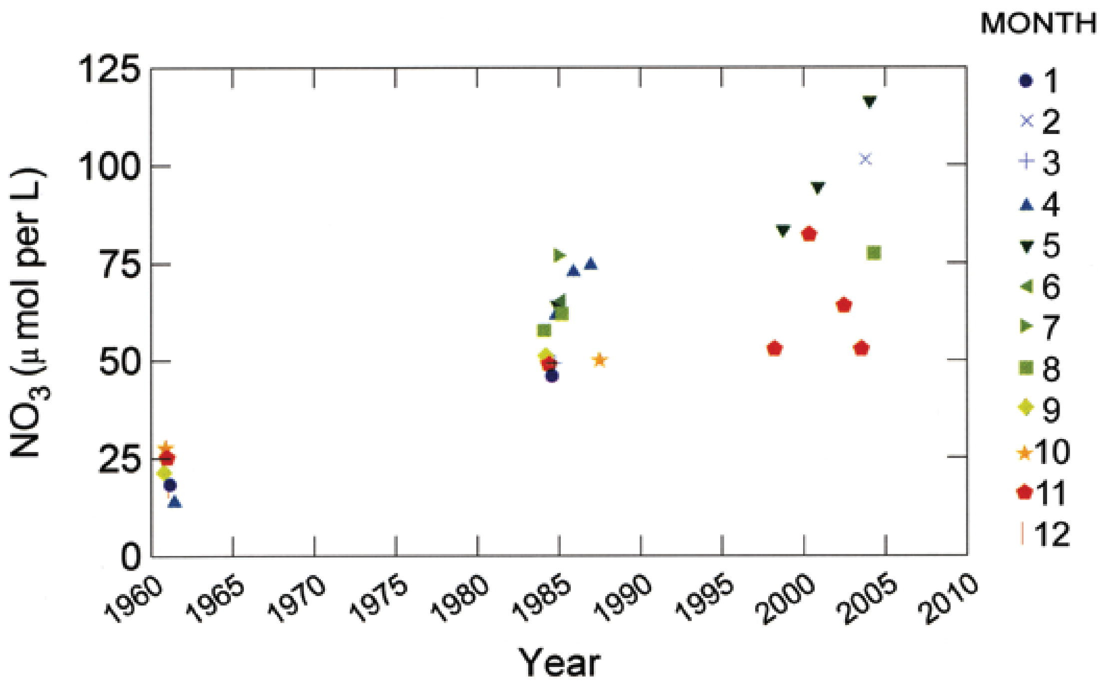
3.2.3 Organic sedimentation

Over the last century, total organic carbon (TOC), total nitrogen (TN) and total phosphorus (TP) have an increasing trend in the Yellow Sea. Likewise, C:N, C:P and N:P molar ratios also have significant increases. This generally coincides with the end of World War II and the beginning of the modern socio-economic developments of the surrounding lands. The decreases of TOC and TN in the sediment during the period from 1960 through the 1970s may be a reflection of a colder climate and overfishing in the region, whereas the stabilization of TP in the last 30 years is possibly associated with restricting the use of P in detergents (Fig. YS-14).

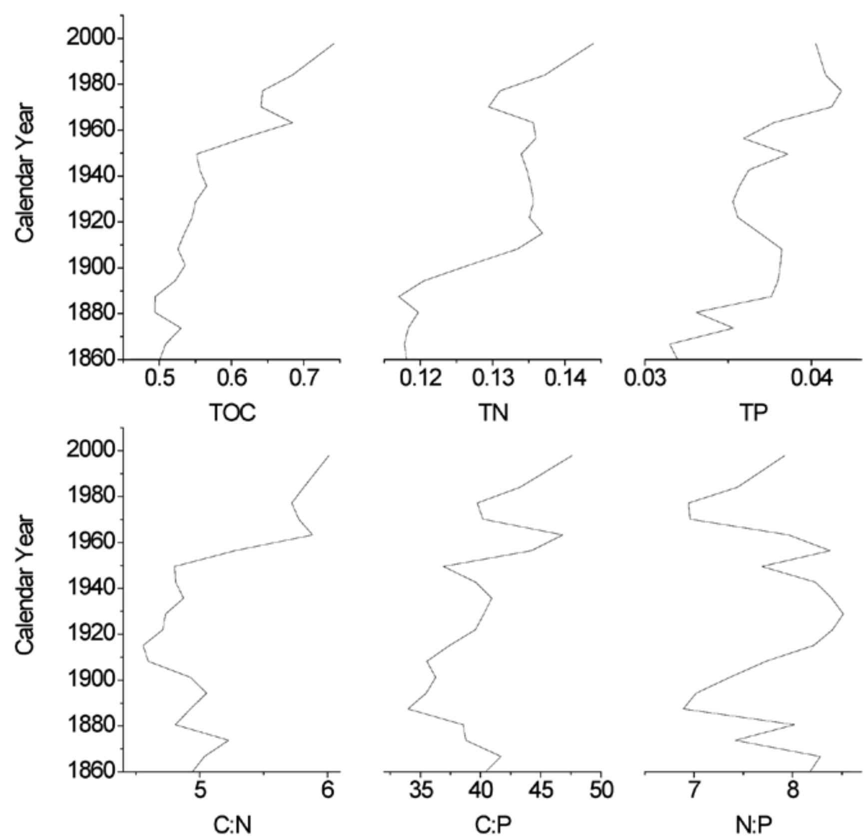
3.2.4 Contaminants

Sixteen polycyclic aromatic hydrocarbons (PAHs) and 28 polychlorinated biphenyls (PCBs) were measured in a core sample from the middle of the southern Yellow Sea in October, 2004 (Zhang et al. 2009). The chronology suggests that usage of PAHs had peaks from 1938-1944 and 1956-1962. The concentrations of these organic pollutants were lower than known ecologically effective values. In another study comparing various nearshore environments in the early 2000s, PCB residues in the sediments of some rivers and estuaries show that China's northeast and southern regions were more seriously polluted (Songhua River and Dalian Bay) than other areas. Jiaozhou Bay and the Pearl Estuary had relatively high PCB levels in organisms (Xing et al. 2005).

Trace metals (Al, Fe, Cu, Mn, Ni, Pb, Zn) in surface sediments of the shelf region near the Changjiang River mouth were generally lower than expected (Fang et al. 2009). Surface sediments of the inner shelf of the East China Sea were mildly contaminated by trace metals whereas higher concentrations of trace metals were found in Hangzhou Bay and along the inner shelf of the East China Sea. Trace metal contamination did not extend to the middle and outer shelves of the East China Sea (Fang et al. 2009).



[Figure YS-13] Long-term variation of nitrate concentration at the mouth of the Changjiang River, by month and year when a sample was collected. Data collected during the 1960s are courtesy of Dr. Hongkan Gu.



[Figure YS-14] Element chronographs of the Yellow Sea sediment (35°N 123.5°E): total organic carbon (TOC), nitrogen (TN), phosphorus (TP) content (w/w%) and their molar ratios.

4.0 Phytoplankton

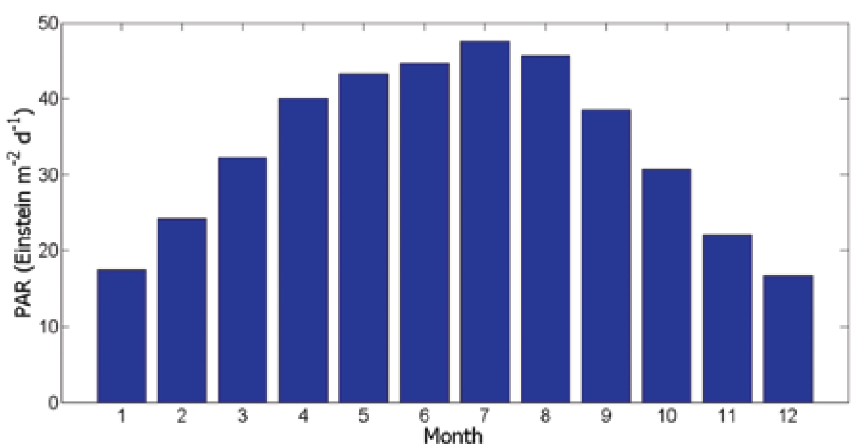
4.1 Light

Photosynthetically Active Radiation (PAR) at the sea surface over the Yellow Sea and East China Sea region was estimated from SeaWiFS data for the period 1998-2007. Monthly averages ranged from 16.8 $E\cdot m^{-2}\cdot d^{-1}$ in December to 47.6 $E\cdot m^{-2}\cdot d^{-1}$ in July (Fig. YS-15) and interannual variation was <5.5%. The minimum annual average PAR was 32.6 $E\cdot m^{-2}\cdot d^{-1}$ in 1998 and the maximum was 34.4 $E\cdot m^{-2}\cdot d^{-1}$ in 2004 (Fig. YS-16).

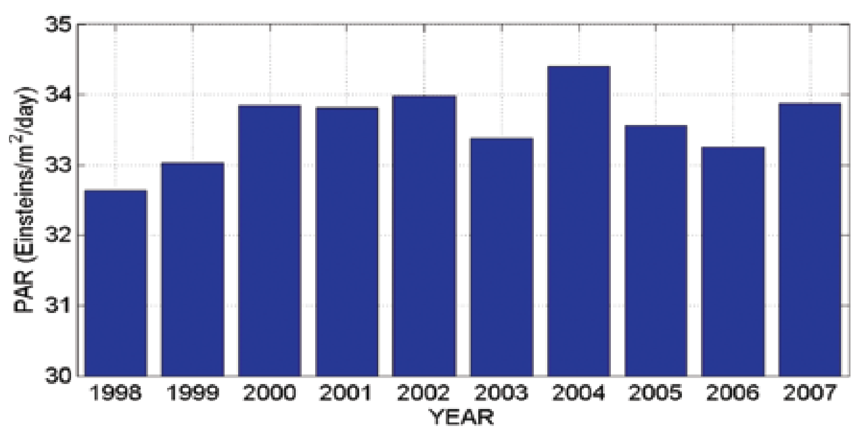
4.2 Phytoplankton

Seasonal phytoplankton blooms are known to occur in the Yellow Sea but there are few time series to show the interannual variation in the timing and intensity of the blooms. The current limitation the ocean colour analysis for accurate retrieval of chlorophyll delays such data availability. Compiled *in situ* records show that there are great variations in the phytoplankton biomass and primary productivity in the Yellow Sea depending on the area and time. For example, the primary productivity ranged from 11.8 to 3175 $mgC\cdot m^{-2}\cdot d^{-1}$ (Yoo and Shin 1995; Cho et al. 1994; Kang et al. 1992; Choi et al. 1988; Park 2000).

In open waters of the Yellow Sea where the water column is seasonally stratified at shallow depths, seasonal blooms develop in spring and autumn. Qualitative analysis of ocean colour data from the Coastal Zone Color Scanner indicates that seasonal blooms occur in April and October. A bi-monthly survey of the eastern half of the Yellow Sea in 1986 showed that mean chlorophyll$_a$ was 1.5 $mg\cdot m^{-3}$ from 12 stations in April (0.4-3.3 $mg\cdot m^{-3}$) while in October, the mean was 0.97 $mg\cdot m^{-3}$ (range: 0.7-1.2 $mg\cdot m^{-3}$) (Choi et al. 1988). The mean values were 0.70, 0.66, and 0.4 $mg\cdot m^{-3}$, in June, August and December, respectively, showing a clear bimodal seasonal pattern. Seasonal cycles were also observed in some of the shallow tidally-mixed areas. There, timing of blooms varied depending on local conditions. In Gyung-Gi Bay (see Fig. YS-1 for location), the spring bloom occurred in March and the autumn bloom



[Figure YS-15] Monthly averages of PAR in the Yellow Sea and East China Sea from 1998 to 2007.



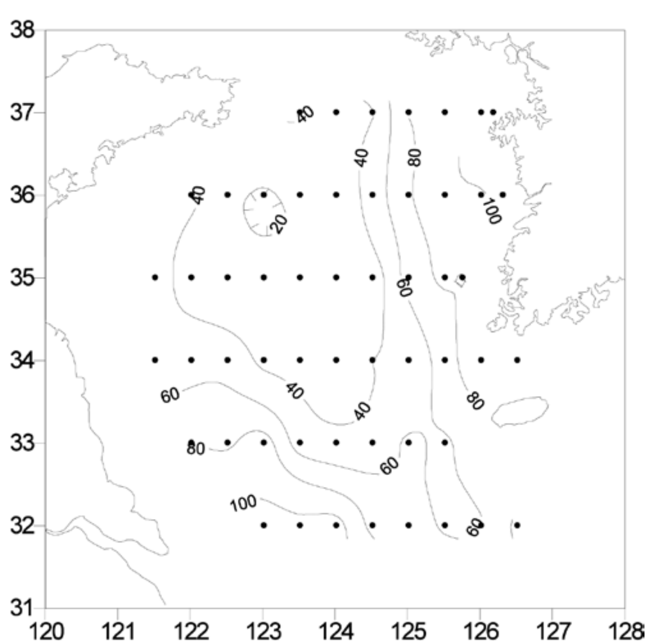
[Figure YS-16] Annual averages of PAR in the Yellow Sea and East China Sea from 1998 to 2007.

early in September. Freshwater discharge probably played an important role in this area (Song 1999). Chlorophyll$_a$ was high throughout the year (1.3-22.6 $mg\cdot m^{-3}$). In the Saemangeum area where jetties were built recently, no particular seasonal cycle can be identified. In these areas, chlorophyll$_a$ was also high throughout the year (0.9-6.9 $mg\cdot m^{-3}$).

A bi-monthly survey in the eastern half of the Yellow Sea in 1987 found 394 species of phytoplankton during the year (Han and Choi 1991). More than 90% of these were diatoms and dinoflagellates and the proportion of dinoflagellates increased in stratified water. Biomass and abundance of phytoplankton were typically high in coastal areas and near the Changjiang River mouth but lower in the central areas (UNDP/GEF 2007). Species diversity also showed a similar pattern (Fig. YS-17). In the summer of 2008, chlorophyll$_a$ concentrations varied from 0.13 $mg\cdot m^{-3}$ to 6.69 $mg\cdot m^{-3}$ with an average of 1.24 $mg\cdot m^{-3}$ (microplankton; 29%, nanoplankton; 12%, picoplankton; 59%) (UNDP/GEF 2010). In the northern part of the Yellow Sea, *Chaetoceros* spp., cryptomonads, *Paralia sulcata*, *Karenia mikimotoi*, and *Navicula* spp. were the dominant species. The total number of species there was 110, among which 73 species were diatoms and 29 were dinoflagellates. In the southern part of the Yellow Sea, nanoflagellates, cryptomonads, and *Prorocentrum* spp. were the dominant species. The daily primary production during this study was in the range 121 $mgC\cdot m^{-2}\cdot d^{-1}$ to 1,204.7 $mgC\cdot m^{-2}\cdot d^{-1}$ with an average of 592.8 $mgC\cdot m^{-2}\cdot d^{-1}$ (UNDP/GEF 2010). Because of the high spatial and temporal variability, it is difficult to compare these results with previous studies.

In the tidally mixed zone, turbidity is very high and light could be a major limiting factor for phytoplankton growth. I_k was as low as 10-12 $\mu E\cdot m^{-2}\cdot s^{-1}$ in a mixed coastal area in the winter (Yoo and Shin 1995). Tyco-pelagic species such as *Paralia sulcata* are dominant and diatoms are abundant. Species diversity is usually high throughout the year with a less conspicuous seasonal pattern.

The 1986 survey found that primary production was highest in June (1,391 $mgC\cdot m^{-2}\cdot d^{-1}$) with an estimate of the annual production at 141 $gC\cdot m^{-2}\cdot yr^{-1}$. A basin-scale estimate of annual production would be higher since the shallow mixed zone has higher production. During late spring and summer, a subsurface chlorophyll maximum (SCM) layer forms near the shallow thermocline (10-30 m) and production at the SCM was substantial, contributing 17.7-30.1% of the depth-integrated production in June 2000 (Park 2000). Continuous measurements by a towed profiler show that the SCM depth tends to increase towards the center of the basin. Daily primary production estimated from satellite data for the period from 1998 to 2003 was 835.6 $mgC\cdot m^{-2}\cdot d^{-1}$ for May and 672.3 $mgC\cdot m^{-2}\cdot d^{-1}$ for September (Son et al. 2005). Chlorophyll$_a$ was higher in coastal waters but primary production was higher in the central region because



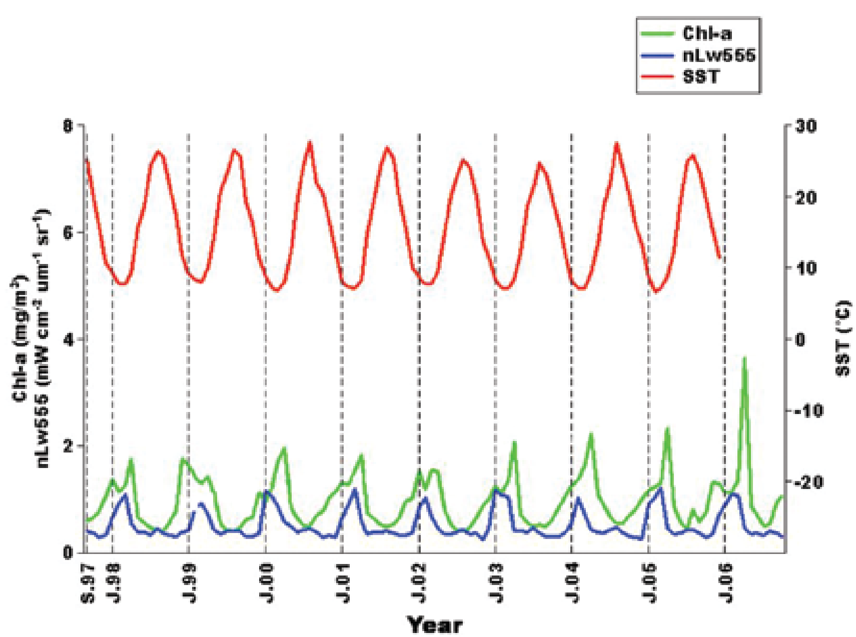
[Figure YS-17] Distribution of phytoplankton species numbers in the Yellow Sea, September 1992 (J.-H. Noh, unpublished data).

of lower turbidity. There are few data to indicate interannual variation or trends. Comparing satellite ocean colour data for 1979-1984 with 1998-2002 showed that chlorophyll$_a$ increased in most of the Yellow Sea and East China Sea. However, as two different satellites were used for the comparison, it is not clear how much of the difference was due to different sensors (Son et al. 2005). From 1997 to 2006, SeaWiFS chlorophyll$_a$ in the central area of the Yellow Sea increased after 2002 (Fig. YS-18) but the cause of this increase is not clear and there was no parallel trend in SST.

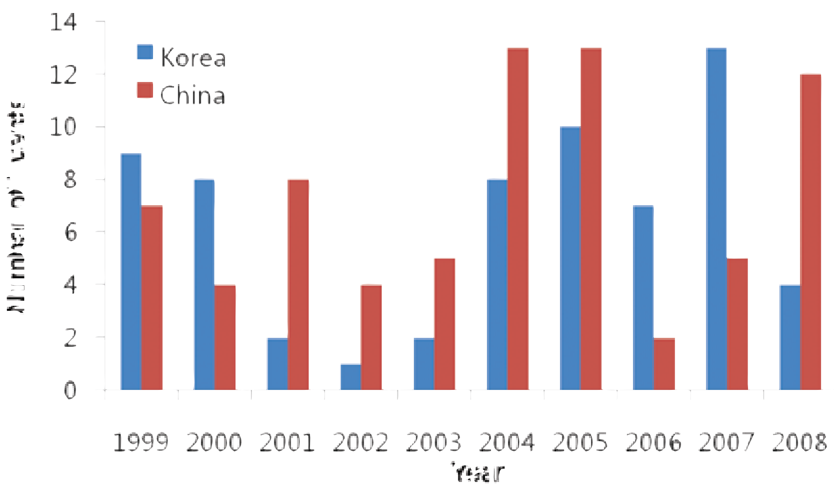
While phytoplankton in the open waters of the Yellow Sea show a typical mid-latitude bimodal seasonal cycle, the phytoplankton on the East China Sea shelf have another peak that is related to fresh water discharge from the Changjiang River in summer. Unlike the shelf waters, the Kuroshio region (Fig. YS-1) on the continental slope of the East China Sea has low chlorophyll$_a$ throughout the year (0.1-0.3 $mg \cdot m^{-3}$) and a damped seasonal cycle with only one peak in early spring. Phosphate and chlorophyll$_a$ in the upper 200 m of Kuroshio area decreased by 0.011 μM and 0.013 $mg \cdot m^{-3}$ per decade, respectively, from 1973 to 2004 and the increase of temperature in this area was faster than the global mean warming (Aoyama et al. 2008).

Red tides are common off the Chinese and Korean coasts and are related to the eutrophication of the Yellow Sea and East China Sea (Zhou et al. 2008; Tang et al. 2006). During the 1980s, algal blooms (defined by cell density) in both Chinese and Korean waters increased and reached a peak in 1990s but since then, the number of algal blooms leveled off (UNDP/GEF 2007). In both the Korean and Chinese coasts of the Yellow Sea, the number of algal blooms did not differ between the period from 1999-2003 versus the period from 2004-2008 (Fig. YS-19). Likewise, the number of algal blooms on the Korean coast of the East China Sea does not have a trend (Fig. YS-20).

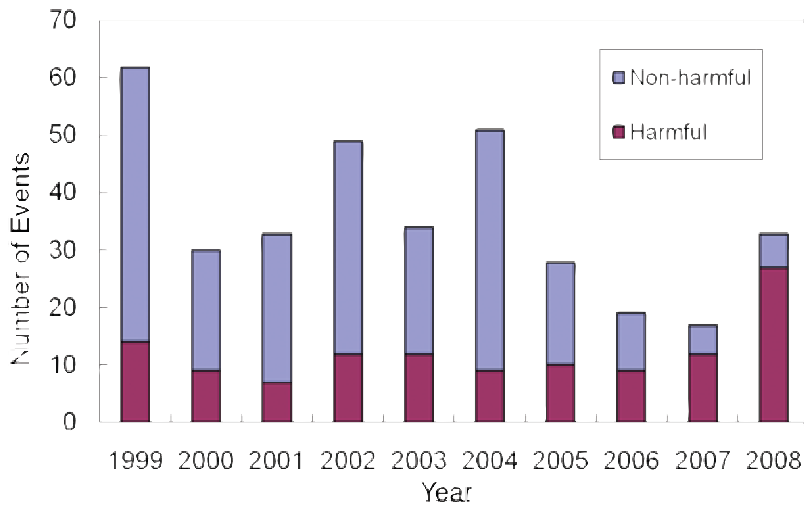
The species of dinoflagellates that cause HABs in Korean waters have changed. From 1999 to 2003, the major species were *Cochlodinium polykrikoides* (26% of blooms), *Prorocentrum minimum* and *P. dentatum* (25%), *Heterocapsa akashiwo* (16%), *Akashiwo saguinea* (7%), *Noctiluca scintillans* (5%), and *Ceratium* spp. (5%). From 2004 to 2008, the major species were *C. polykrikoides* (34%), *Prorocentrum minimum* and *P. dentatum* (13%), *N. scintillans* (12%), *H. akashiwo* (8%), *Chattonella* spp. (7%), *A. saguinea* (5%), and *G. polygramma* (5%). While *Prorocentrum* spp., *H. akashiwo*, and *Ceratium* spp. decreased, *N.scintillans*, *Chattonella* spp., and *G. polygramma* increased. In the Yellow Sea, *Chattonella* spp. increased from 0% to 27% and *N. scintillans* from 20% to 31%. *C. polykrikoides* decreased from 10% to 0% and *H. akashiwo* from 15% to 0%. Along the southern coast of Korea (northern East China Sea), *Gonyaulax polygramma* increased from 0% to 6%, *Chattonella* spp. from 0 to 3%, and *C. polykrikoides* 28% to 43%. However, *Prorocentrum* spp. decreased from 26 to 16%, and *Ceratium* spp. 5% to 0%.



[Figure YS-18] Changes in the satellite chlorophyll$_a$ in the central region of the Yellow Sea. nLw555 indicates the influence of suspended sediments. Chlorophyll$_a$ increased after 2002 while there was no change in SST and nLw555.



[Figure YS-19] Frequency of algal blooms along the Chinese and Korean coasts in the Yellow Sea during 1999-2008.

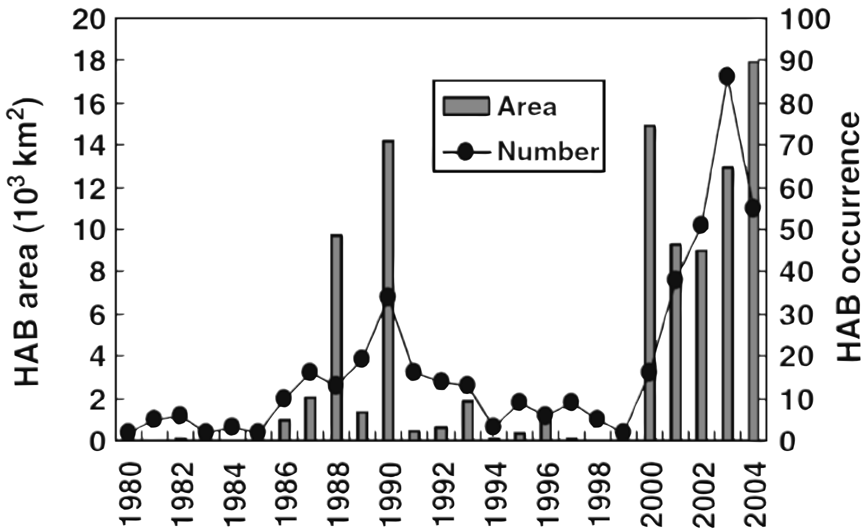


[Figure YS-20] Number of algal bloom events in the southern coast of Korea (East China Sea) during 1999-2008.

To summarize, *C. polykrikoides*, *P. minimum*, *P. dentatum*, *H. akashiwo*, *A. saguinea*, *N. scintillans*, *Ceratium* spp. and *S. costatum* were major HAB causative species throughout Korean waters from 1999 to 2008. *Chattonella* spp. (Yellow Sea) and *G. polygramma* (East China Sea) have been newly emerging HAB species in the past five years.

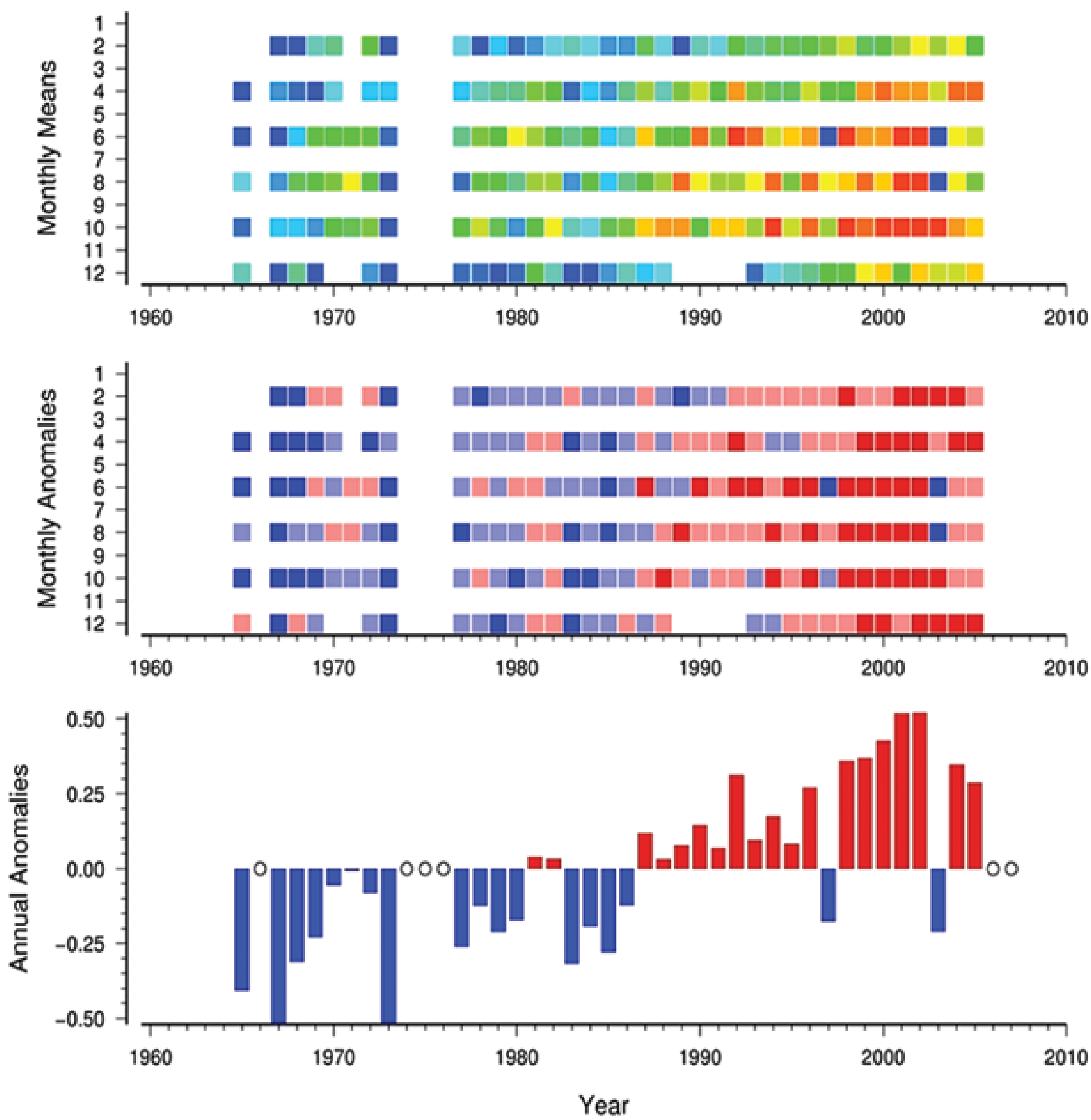
HAB occurrences are more extensive and more frequent in Chinese coastal waters of the East China Sea (Tang et al. 2006; Fig. YS-21). The frequency increased drastically after 2000 reaching almost 90 times a year by 2004. HAB events were most frequent near the Changjiang River mouth, where eutrophication is the most severe in China (http://www.soa.gov.cn/chichao/index.html). In addition to anthropogenic eutrophication, upwelling provides nutrients to the Chinese coastal region in the East China Sea (Tang et al. 2002). During the past decades, there was a shift in seasonal occurrence and causative organisms in the vicinity of the Changjiang River mouth. Before the 1980s, HABs occurred most frequently in autumn. During the 1980s, they were most frequent in July-August. After the 1990s, HAB events occurred most frequently in May. During the 1980s, *Noctiluca scintillans* was the major causative organism, however, since 2000, *Prorocentrum dentatum* became the major HAB species. It was not reported as a causative species before 2000. This shift of dominant species may be a result of increased N:Si or N:P ratio (Chai et al. 2009; Tang et al. 2006).

[Figure YS-21] Number and area of HAB occurrences in the Chinese coastal areas on the southern East China Sea shelf including the Changjiang River vicinity during 1980-2004. Adapted from Tang et al. (2006).



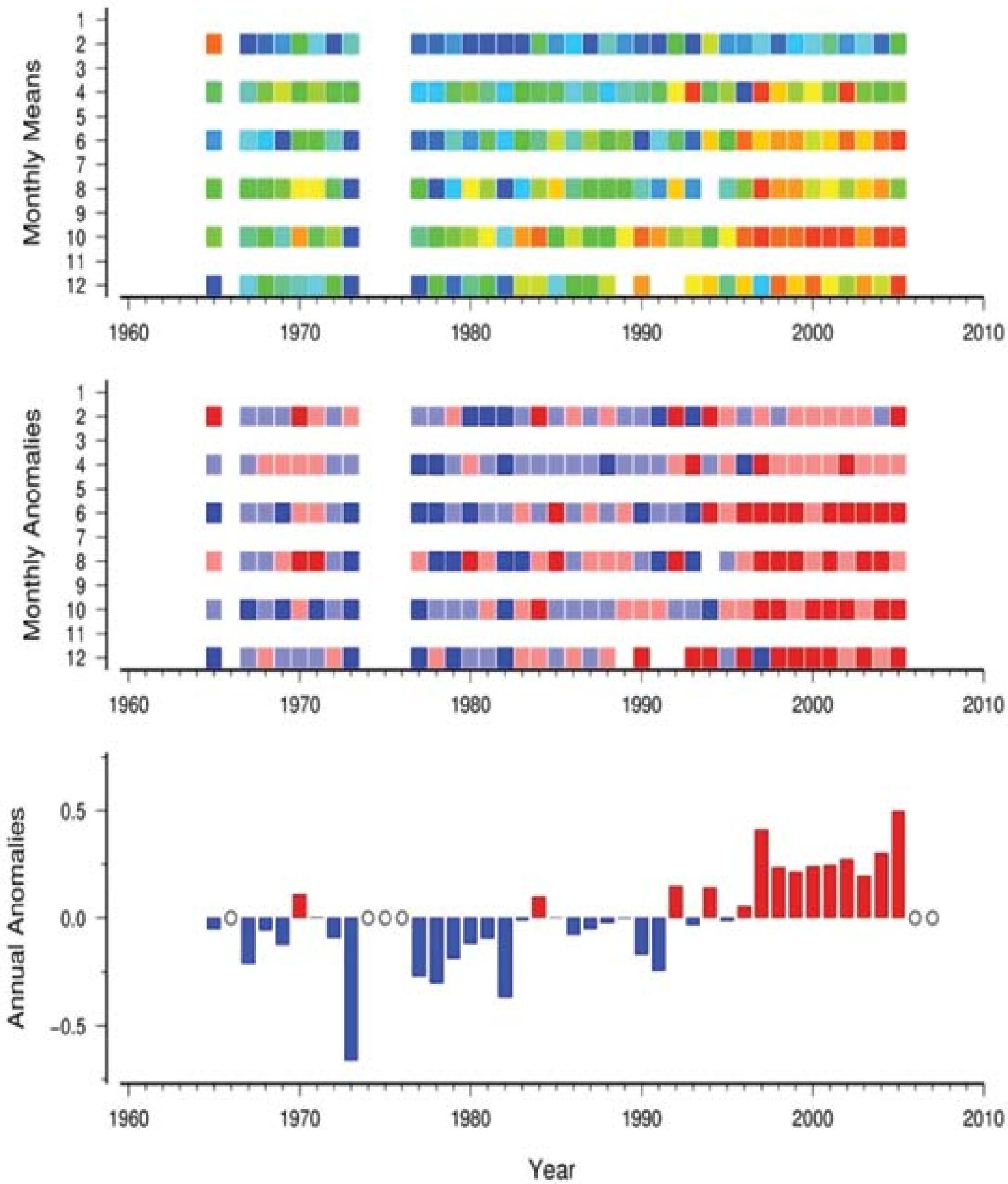
5.0 Zooplankton

Bimonthly mesozooplankton samples have been taken in Korean waters for decades, and there is some evidence of long-term change. Beginning in the late 1980s in the eastern Yellow Sea and in the early 1990s in the northern East China Sea, zooplankton biomass showed an increasing trend which reached its peak in the early 2000s (Figs. YS-22, YS-23). Although the mechanisms responsible for the change are not yet understood, the trends are parallel to changes observed in SST (Fig. YS-8). Annual anomalies of zooplankton biomass in the eastern Yellow Sea shifted generally from negative to positive values in the late 1980s. After 1987, anomalies became positive except for 1998 and 2004. Biomass anomalies were higher from 1999 to 2006 than from 1988-1997 (Kang et al. 2009; Fig. YS-22). Seasonal variation of zooplankton biomass anomalies was generally lowest in winter (February and December) and highest in late spring/autumn (June-October).

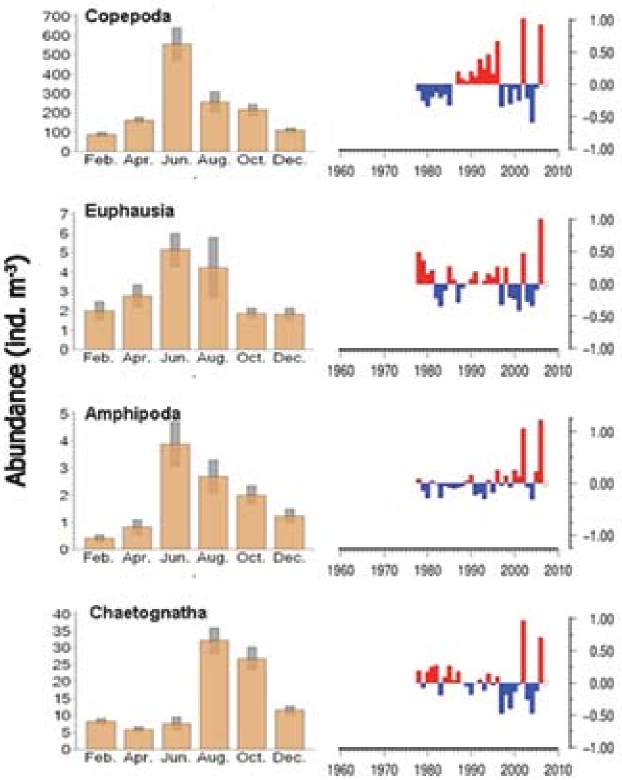


[Figure YS-22] Standardized (SCOR-WG 125) time series of monthly zooplankton biomass (ln[mg·m⁻³]) in the eastern Yellow Sea. Small circles indicate missing data. See Kang et al. (2009) for further details of the analysis.

Annual mean abundance anomalies in the eastern Yellow Sea showed a similar trend among copepods, euphausiids and chaetognaths (Fig. YS-24). Copepods and euphausiids showed a slight upward trend after the late 1980s, but switched to a downward trend after the mid-1990s, especially in 1997. Chaetognaths also showed a downward trend after the mid-1990s but there were high positive values observed in 2002 and 2006. In contrast to the other three groups, anomalies of amphipod abundance increased slightly after the early 1990s with two high values in 2002 and 2006. Bimonthly mean densities of four zooplankton groups, copepods, euphausiids, amphipods and chaetognaths showed seasonal variation (Fig. YS-24). Densities of copepods, euphausiids and amphipods were highest in June, while chaetognath density was highest in August.



[Figure YS-23] Standardized (SCOR-WG 125) time series of monthly zooplankton biomass (ln[mg·m⁻³]) in the northern East China Sea. Small circles indicate missing data. See Kang et al. (2009) for further details of the analysis.

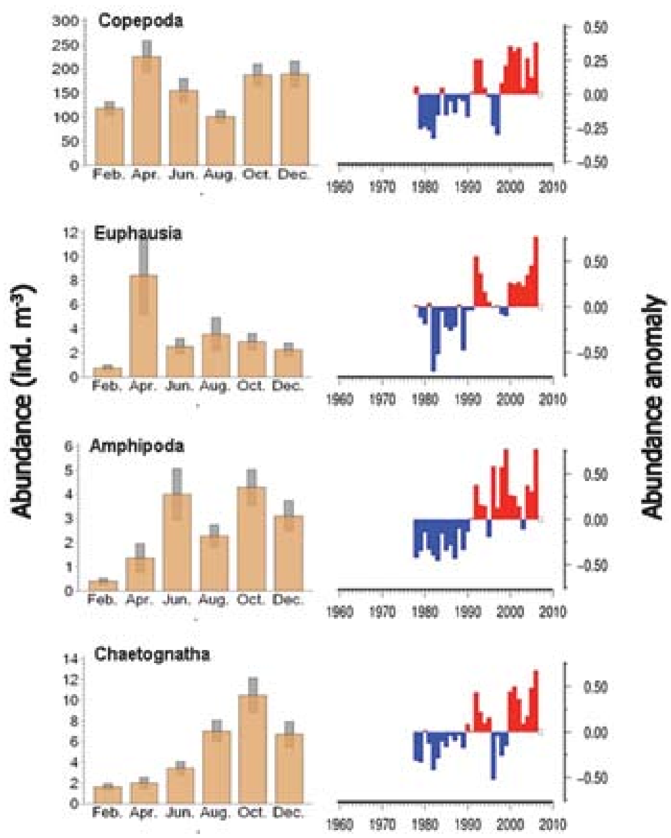


[Figure YS-24] Seasonal and interannual comparison of copepods, euphausiids, amphipods and chaetognaths in the eastern Yellow Sea.

Annual mean anomalies of zooplankton biomass in the northern East China Sea shifted from negative to positive values in the early 1990s, except for 1994 and 1996 (Fig. YS-23). Biomass increased abruptly after 1998 and maintained a high value through 2006. Bimonthly mean biomass of total zooplankton was generally lowest in February and highest in June/October while high values were observed mainly in October and December after the late 1980s. After the mid-1990s, the peak biomass occurred in June and August.

Annual mean abundance anomalies in the northern East China Sea were similar among copepods, euphausiids and chaetognaths, but the amphipod trends were distinctive (Fig. YS-25). The abundance of copepods, euphausiids and chaetognaths increased after the early 1990s, but anomalies were negative during the mid-1990s with a peak around 1997. The abundance of amphipods increased after the early 1990s despite the negative anomalies in 1995 and 2003. In bimonthly mean densities of the four zooplankton groups, copepods and euphausiids had peaks in April, October and December (Fig. YS-25), while amphipods peaked in June and October and chaetognaths in October.

A detailed analysis of bimonthly samples from the Yellow Sea from 1997 to 1999 showed that copepods made up 70.1% of the total zooplankton biomass, on average (Lim et al. 2003). The remainder was comprised of dinoflagellates (5.78%, mostly *Noctiluca*), Cladocera (5.42%), Chordata (5.26%) and Chaetognatha (5.19%). The proportion of copepods was highest from late autumn through early spring because the biomass of other groups increased from late spring and remained high until late autumn. Among the copepods, *Calanus sinicus*, *Paracalanus* sp., *Oithona atlantica*, and *Corycaeus affinis* were dominant through all seasons and occurred in most areas, comprising 75.6% of the total copepod biomass. Total zooplankton biomass was highest in June and October. There was a year to



[Figure YS-25] Seasonal and interannual comparison of copepods, euphausiids, amphipods and chaetognaths in the northern East China Sea.

year variation in the pattern. For example, in 1997 and 1998, the biomass was highest in June, while in 1999, the biomass was highest in October. Seasonal fluctuation was higher in the northern and neritic environments.

In the Yellow Sea copepods account for 70~90% by number of total zooplankton but there are seasonal and areal variations (Kang and Lee 1991; Rebstock and Kang 2003). *Calanus sinicus* is the most important large calanoid species in the Yellow and East China seas (Chen 1964). *Paracalanus* spp. and *Acartia* spp. are small neritic species that are important in the coastal areas of China and Korea. Apart from copepods, *Sagitta crassa*, *Euphausia pacifica* were also dominant (Tang 1989). Oceanic, warm water species were rare but found episodically in the Yellow Sea. Zooplankton biomass was highest in the southern area off the Changjiang River estuary (UNDP/GEF 2010; OSTI & IOCAS 1998). In general, zooplankton biomass was higher in the coastal waters than in central waters. Unlike in the northern East China Sea, where zooplankton abundance showed two peaks annually, the zooplankton abundance has one seasonal peak in the eastern Yellow Sea. For copepods, amphipods, and euphausiids the peak occurs in June, while chaetognaths have a peak in October (Kang 2008).

In the northern East China Sea, copepods account for >90% by number of total zooplankton. In contrast to the Yellow Sea, many oceanic, warm-water copepods are common and important components of the zooplankton biomass (Kang and Hong 1995). Zooplankton biomass has episodic peaks in the northern East China Sea when warm water species are transported by the Tsushima Warm Current. This phenomenon indirectly or directly influences fisheries.

A conspicuous feature of the zooplankton community in recent years is the occurrence of blooms of the large scyphomedusa, *Nemopilema nomurai* (giant jellyfish) in the East China Sea (Anonymous 2004). An unusual bloom was first observed in 2000 with the largest bloom occurring in 2003. Ocean currents carried the jellyfish northward into adjacent seas causing serious problems for fishermen (and beach bathers). Jellyfish observed in Korean waters are the giant *Nemopilema nomurai*, medium-sized *Aurelia aurita*, big and venomous *Cyanea capillata* and *Dactylometra quinquecirrha* (*Chrysaora quinquecirrha*). The highly venomous *Physalia physalis* and *Carybdea rastonii* are also reported occasionally. *N. nomurai* is the biggest jellyfish occurring in Korean waters with bell size of about 2 m and weight of 150 kg. Outbreaks of these were reported by Japanese fishermen in 1920, 1958, 1995, and 2002. The causes of the blooms and their interannual fluctuation are unknown. Several factors such as increasing sea temperature, overfishing, and marine pollution have been suggested as causal factors or at least mediators.

Giant jellyfish have occurred in the region in large numbers since 2003. The average densities off the southern Korean peninsula were 177, 7, 83, and 9 inds.·ha^{-2} in August 2005, 2006, 2007 and 2008, respectively. The cosmopolitan jellyfish species, *A. aurita*, has been superabundant in Korean waters since the late 1990s. Along with giant jellyfish, *A. aurita* causes significant damage to fisheries. In 2006, *C. capillata* began appearing from the end of spring to the end of autumn in the southern offshore areas. Since then, its areal distribution has expanded and the duration of its seasonal appearance is prolonged. *D. quinquecirrha* has appeared mainly in the eastern and southern parts of the Korean peninsula. Its occurrence seems related to the cold water mass in those areas.

6.0 Fishes and Invertebrates

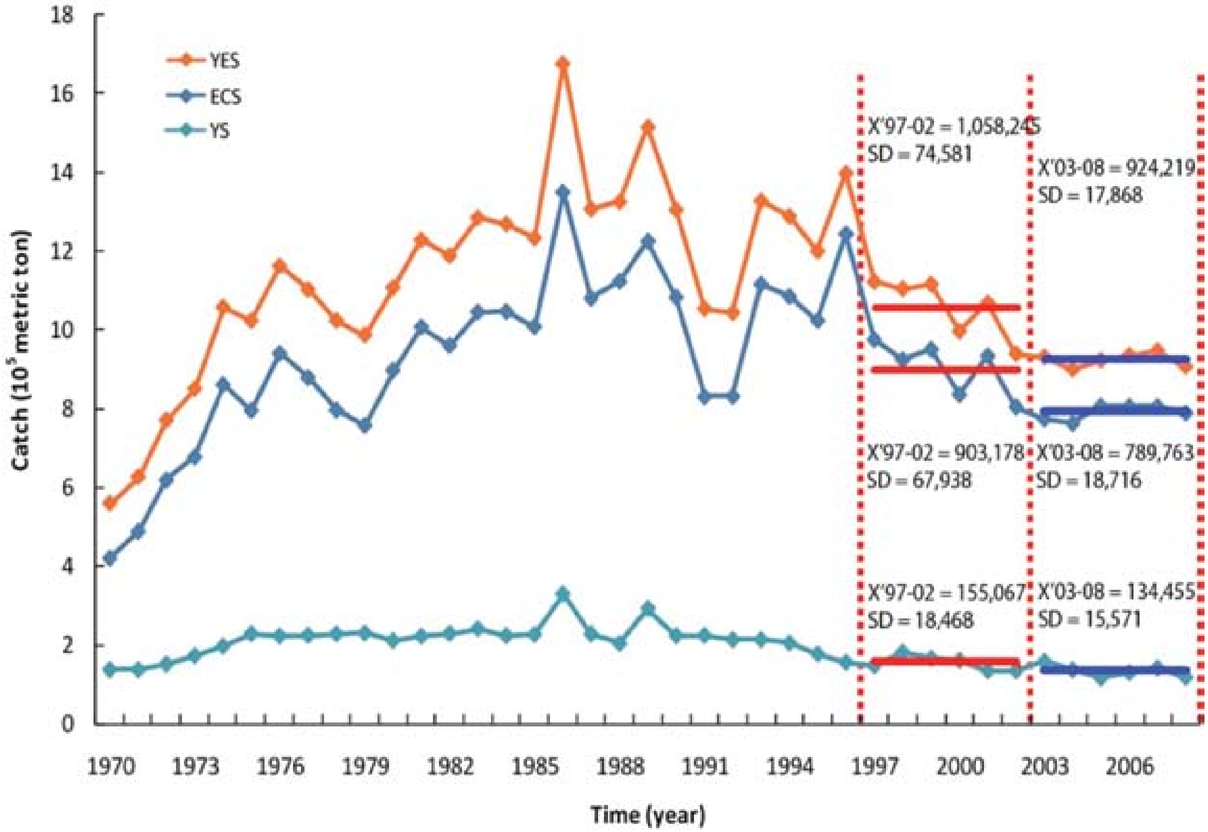
The Yellow Sea is the location of multispecies, multinational fisheries and is one of the most intensively exploited areas in the world. Although many fisheries resources are utilized commonly by neighboring countries, there are few joint scientific and management activities. A total of 276 species have been identified on the Korean side of the Yellow Sea, and approximately 100 species including cephalopods and crustaceans have been utilized as resources. Over 90% of these species are warm or warm-temperate water species. Many share a typical migration pattern with spawning in the coastal areas during the spring, and overwintering in the southern Yellow Sea and the northern East China Sea. Currently, about 30 species are commercially targeted. The abundance of most species is relatively low and only ~20 species exceed 10,000 t in annual catch. A small group of species (Table YS-1) accounts for 40 to 60% of the annual catch in the Yellow Sea and East China Sea. The biomass of demersal species such as small yellow croaker, hairtail, large yellow croaker, flatfish, and Pacific cod declined by more than 40% as the fishing effort increased threefold from the early 1960s to the early 1980s (Zhang and Kim 1999).

Scientific surveys of the Chinese side found 149 and 177 species during bottom surveys in autumn 2000 and spring 2001, respectively. They found that biomass in autumn was higher than in spring. The biomass of pelagic species was higher than that of demersal fish especially in autumn, but the reverse was true in spring. Bottom trawl surveys in Korean waters found 134 demersal species in the summer of 1967 but only 51 species were found in the 1980/81 survey revealing a 62% reduction in the number of species. Of the 15 most abundant species in the 1980/81 survey, 8 were not found in a list of the 20 most abundant species in the 1967 survey (Zhang and Kim 1999).

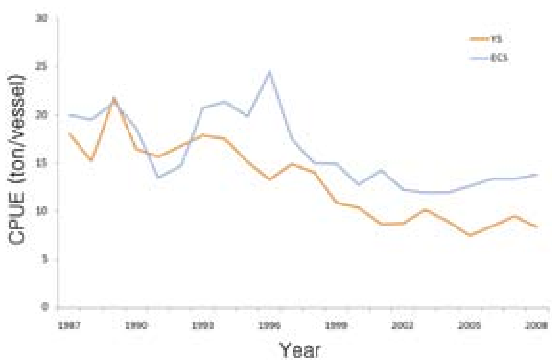
The total catch by Korean fisheries in the Yellow Sea has decreased gradually since its peak in the mid-1980s (Fig. YS-27). Likewise, CPUE has gradually decreased since its peak in the late 1980s (Yellow Sea) and the mid-1990s (East China Sea) (Fig. YS-28). In the long-term, semi-demersal fishes have been replaced by small pelagic fishes and as a consequence, the mean trophic level has been decreasing for the past three decades (Fig. YS-29, YS-30, YS-31 and YS-32). The mean annual catch decreased from 1,058,245 t in 1997-2002 to 924,219 t during the focus period. Fluctuations have decreased and the annual catch became stable during the focus period. The decline in catch from the Yellow Sea was less than from the East China Sea, and fluctuations were proportionately lower in the Yellow Sea than in the East China Sea.

[Table YS-1] Major commercial species in the Yellow Sea and the East China Sea

Common Name	Species
Demersal and semi-demersal fishes	
Small yellow croaker	*Pseudosciaena polyactis*
Hairtail	*Trichiurus lepturus*
Filefish	*Stephanolepis cirrhifer*
Pomfret	*Pampus argenteus*
Corvenias	*Collichthys niveatus*
Large yellow croaker	*Pseudosciaena crocea*
White croaker	*Argyrosomus argentatus*
Brown croaker	*Miichths miiuy*
Roundnose flounder	*Eopsetta grigorjewi*
Bastard halibut	*Paralichthys olivaceus*
Common seabass	*Epinephelus septemfasciatus*
Pacific cod	*Gadus macrocephalus*
Puffers	*Tetraodontidae*
Sharptoothed eel	*Muraenesox cinereus*
Red seabream	*Pagrus major*
Sea-devil	*Lophiomus setigerus*
Bigeyed herring	*Herklotsichthys zunasi*
Rockfish	*Sebastes inermis*
Flathead	*Platycephalus indicus*
Skateray	*Raja kenojei*
Pelagic fishes	
Anchovy	*Engraulis japonica*
Sardine	*Sardinops melanostictus*
Pacific herring	*Clupea pallasii*
Common mackerel	*Scomber japonicus*
Horse mackerel	*Trachurus japonicus*
Spanish mackerel	*Scomberomorus niphonius*
Shellfish	
Cuttlefish	*Sepia esculenta*
Blue crab	*Portunus trituberculatus*
Large shrimp	*Penaeus orientalis*
Common squid	*Todarodes pacificus*



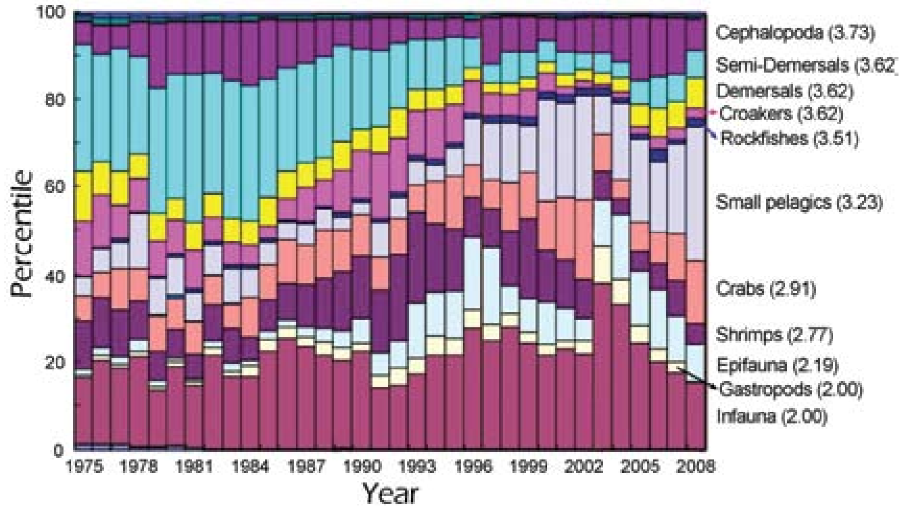
[Figure YS-27] Long-term trend in the catch by Korean fisheries in the Yellow Sea (YS), East China Sea (ECS) and the sum of the two seas (YES).



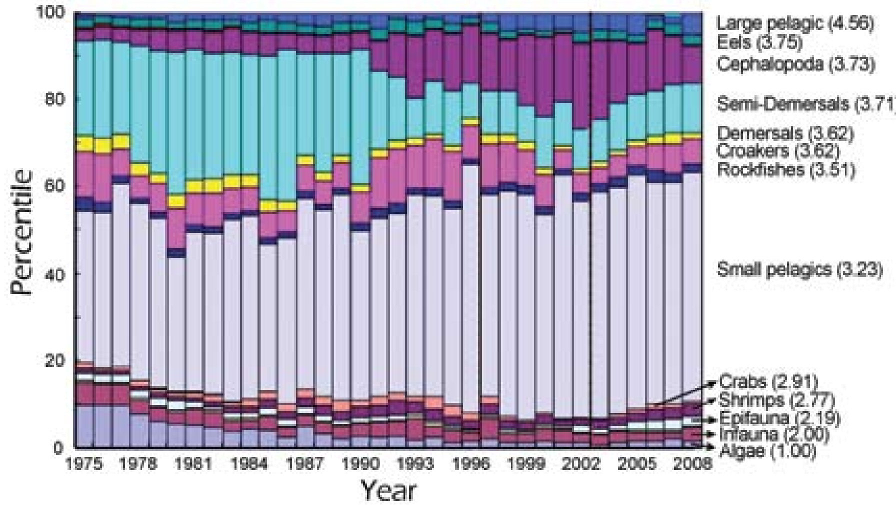
[Figure YS-28] Long-term trend of effort by Korean fisheries in the Yellow Sea (YS) and the East China Sea (ECS).

The catch composition in major fisheries changed during the focus period. In the Yellow Sea, the proportion of anchovy increased from 15.5% to 21.6% while that of common squid increased from 2.8% to 8.3% between 1997-2002 and 2003-2008 (Fig. YS-33). The proportion of flatfishes also increased from 0.8% to 3.2% during the same periods, while the catches of blue crab and shrimps declined. As a result, the mean trophic level in the catch increased from 3.24 to 3.34. In the East China Sea, the proportion of anchovy increased from 25.4% to 28.9% and that of Spanish mackerel increased from 2.5% to 4.3% between the two periods (Fig. YS-34). However, unlike the Yellow Sea, the proportion of common squid decreased from 13.2% to 11.1% while the catches of other species remained more or less the same. Therefore, the mean trophic level was similar between the two periods.

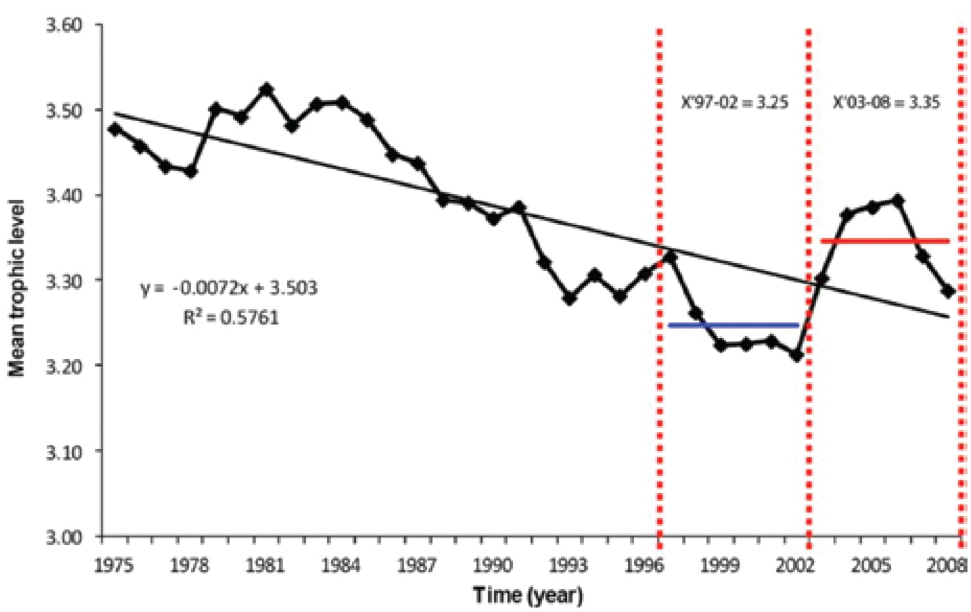
Of the six major species caught in Korean fisheries in the Yellow Sea and the East China Sea, the CPUEs of common mackerel and anchovy were relatively stable during the recent decade, but with some fluctuations (Fig. YS-35). The CPUE of common squid increased until 2003 and then decreased afterward. The CPUE of hairtail has a declining trend while that of small yellow croaker has an increasing trend (Fig. YS-35).



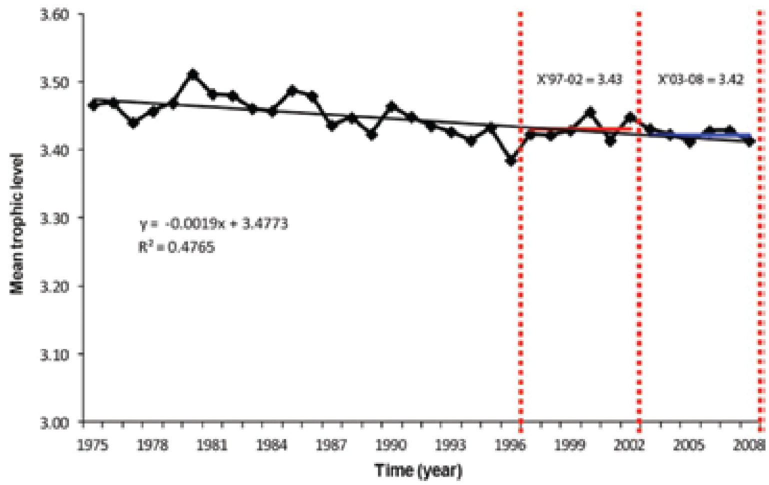
[Figure YS-29] Changes in the major Korean fisheries species in the Yellow Sea. The numbers in the parentheses are estimated trophic level.



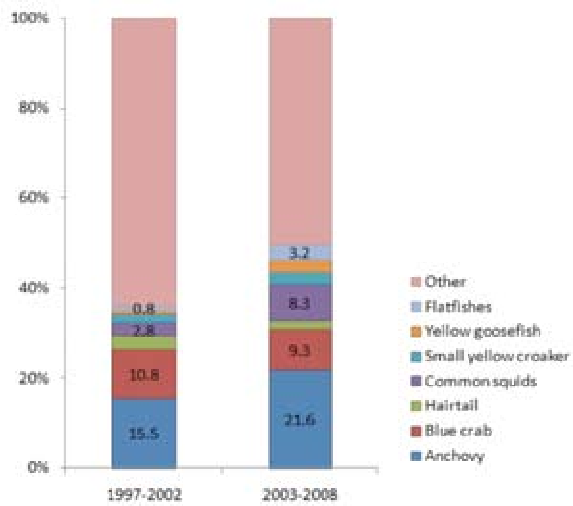
[Figure YS-30] Changes in the major fisheries species in the East China Sea. The numbers in the parentheses are estimated trophic level.



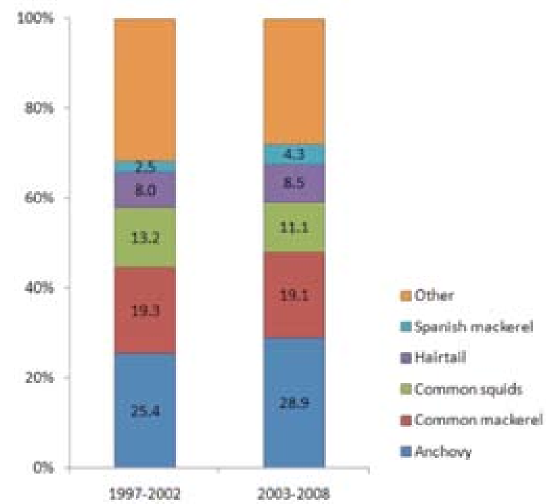
[Figure YS-31] Mean trophic level of the fisheries catch in the Yellow Sea. It increased in 2003-2008 period due to increased catch of demersals and cephalopods.



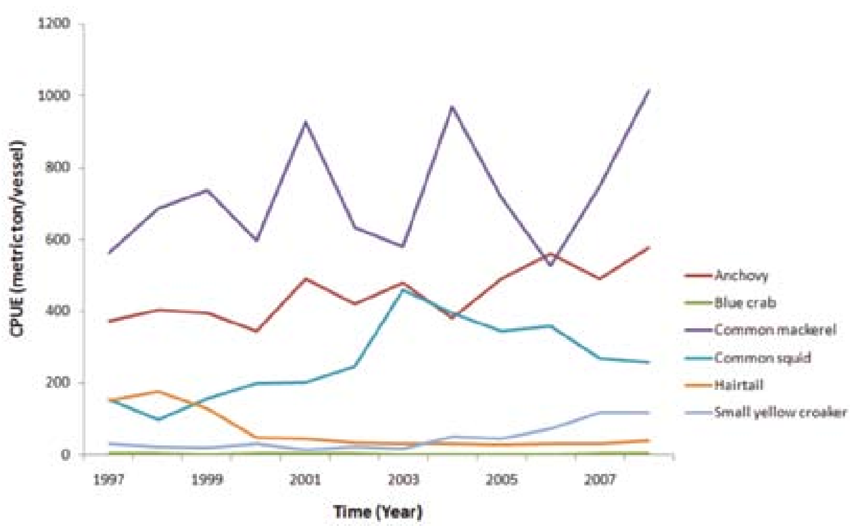
[Figure YS-32] Mean trophic level of the fisheries catch in the East China Sea. Although it has decreased in the long term, it is similar in 1997-2002 and 2003-2008.



[Figure YS-33] Proportion of species in Korean fisheries in the Yellow Sea. Anchovy and common squid increased in large proportions.



[Figure YS-34] Proportion of species in Korean fisheries in the East China Sea. The proportions largely did not change.



[Figure YS-35] CPUE (catch/vessel) of species in Korean fisheries in the Yellow Sea and the East China Sea.

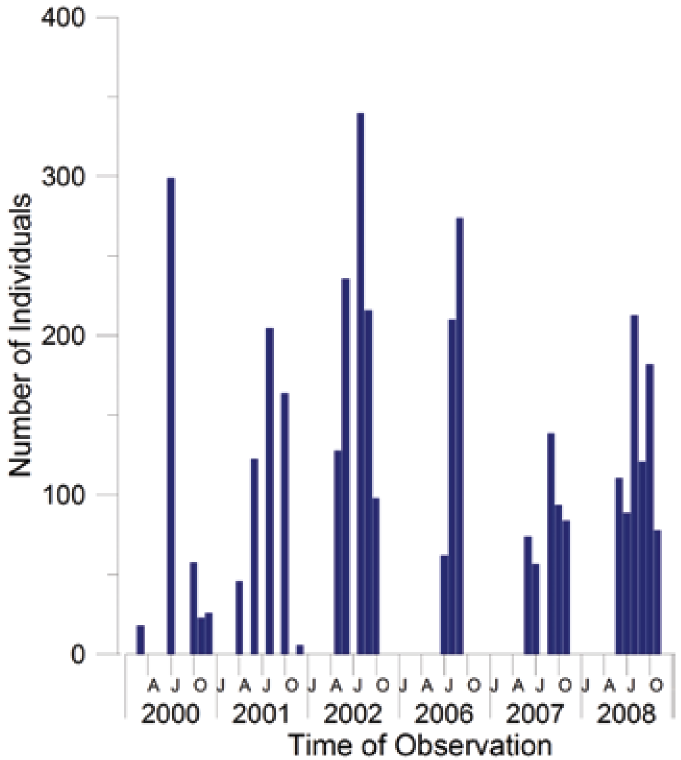
7.0 Marine Birds and Mammals

7.1 Pinnipeds

Larga seals, *Phoca larga*, inhabit many coastal areas of the Yellow Sea. Since the 1960s, populations have been decreasing due to heavy catch and habitat destruction and only small groups can now be found. Larga seals are designated as protected animals in both Korea and China. For the past nine years, surveys of larga seals have occurred on Bakryoung-Do, an island in the northern Yellow Sea that is a major habitat for the larga seals. A maximum of 343 individuals was observed in 2002 (Fig. YS-36). The number of individuals was 139 in 2007 and 210 in 2008. Whether this indicates a reduction in the population size is not clear and further monitoring is necessary.

7.2 Cetaceans

A total of 16 cetacean species have been recorded. Amongst them, fin whale (*Balaenoptera physalus*), Minke whale (*B. acutrostrata*), killer whale (*Orcinus orca*), Blainville's beaked whale (*Mesoplodon densirostris*), and finless porpoise (*Neophocaena phocaenoides*) have commonly been observed. Catching whales was banned in Korea in 1986 and some of the whale populations have increased. In the Changjiang River estuary, two endangered migratory freshwater cetaceans can be found, baiji (*Lipotes vexillifer*) and finless porpoise. The former, listed as a critically endangered species in IUCN Red Book, lives only in China (The Yellow Sea Ecoregion Initiative 2001). In Korean waters, finless porpoises are typically observed in nearshore areas while Minke whales are observed in offshore areas. Surveys in Korean coastal waters of the Yellow Sea show that the number of Minke whales was reduced from 1,685 in 2001 to 733 in 2008, although this may not be statistically significant (Table YS-2).



[Figure YS-36] Census of spotted seal (*Phoca larga*) around Bak-ryoung island in 2000 to 2002 and 2006 to 2008.

[Table YS-2] Abundance of Minke whale in Yellow Sea in 2001-2008.

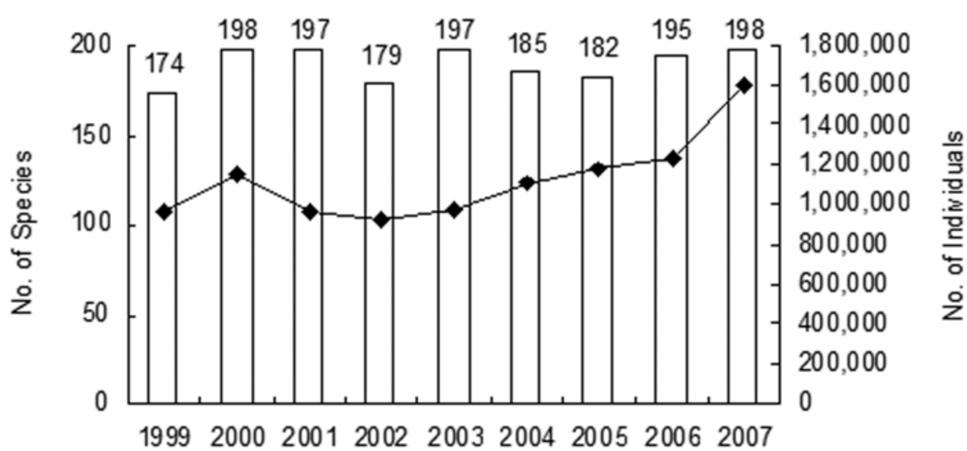
Year	Survey effort (n. mile)	Number of Observation (No.)	Abundance (No.)	95% CI	
				Lower	Upper
2001	811	28	1,685	1,042	2,726
2004	1,787	18	1,287	385	4,303
2008	1,407	18	733	327	1,646

7.3 Seabirds

The intertidal areas and coastal wetlands of the Yellow Sea support >2 million shorebirds during their northward migration; about 40% of the all migratory shorebirds in the East Asian-Australasian Flyway (Barter 2002). A total of 36 shorebird species have been found to occur in internationally important numbers at one or more sites in the Yellow Sea, representing 60% of the migratory shorebird species occurring in the flyway. Two of the species are classified as globally threatened, the spotted greenshank, *Tringa guttifer*, and the spoon-billed sandpiper, *Eurynorhynchus pygmeus*, whilst two are near-threatened, the eastern curlew *Numenius madagascariensis* and Asian dowitcher *Limnodromus semipalmatus*. While the South Korean coastline has been well surveyed, only about one-third of the Chinese coasts have been surveyed and little is known from North Korea.

In Korea, water birds of islands/islets, coastal wetlands/tidal flats, and the seas include 167 species in 16 families: the Anatidae, Gruida, Rallida, Scolopacida, Rostratulidae, Jacanidae, Charadriidae, Glareolidae, Laridae, Podicipedidae, Phalacrocoracidae, Ardeidae, Threskiornithidae, Pelecanidae, Ciconiidae, and Gaviidae. In addition, some of the marine birds that inhabit the shorelines include the Procellaridae, Diomedeidae, Hydrobatidae, Fregatidae and Laridae (Stercorariini and Alcinae). The number of species of waterbirds for the entire Korean peninsula is approximately 176 (the total number of species counts is 430), including those mentioned above (167 species) and several other observed waterbirds, representing approximately 40.9% of all bird species in Korea. The Korean peninsula is an attractive area for waterbirds, as reflected by the relatively high percentage of waterbirds compared to the global percentage of waterbird species (8.6% of total bird species of the world).

Since 1999, an annual national census of wintering birds has occurred at 128 inland and coastal wetlands/tidal flat sites. These reports include the abundance of wintering birds in river watersheds, artificial lakes formed after reclamation, coastal wetlands/tidal flats (excluding inland wetlands), and freshwater lakes. The number of species from 1999-2007 was rather stable, varying between 174-198 (Fig. YS-37). The number of individuals increased steadily after 2003.



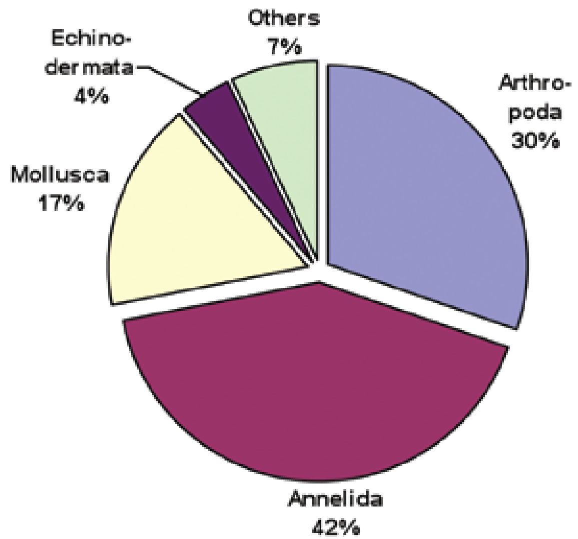
[Figure YS-37] Annual fluctuation in the number of species and individuals of wintering populations of water birds in South Korea.

8.0 Benthos

8.1 Zoobenthos

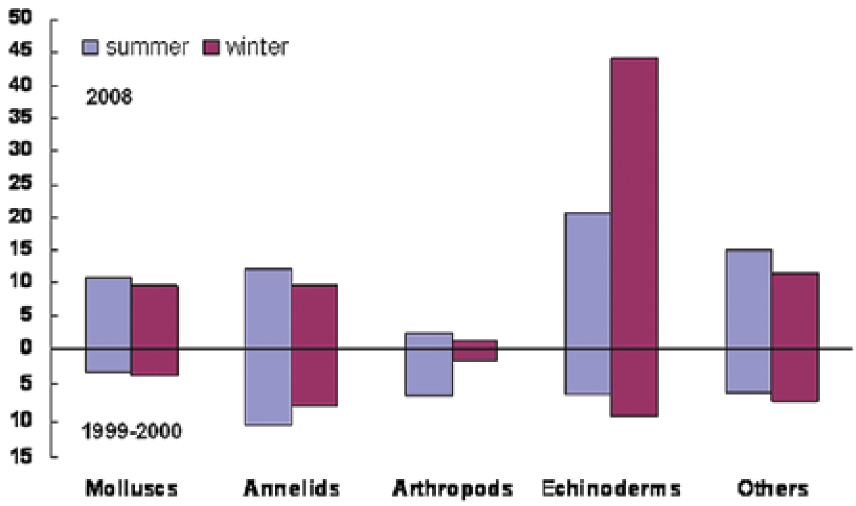
Approximately 50 years ago, the biomass of zoobenthos was higher in the northern Yellow Sea than in the central and southern regions (Liu 1963). The seasonal maximum of 49.68 $g \cdot m^{-2}$ occurred in the spring, and seasonal means were 39.14 $g \cdot m^{-2}$ in winter, 38.05 $g \cdot m^{-2}$ in autumn, and 37.85 $g \cdot m^{-2}$ in summer. In the central and southern Yellow Sea, the mean biomass was 19.71 $g \cdot m^{-2}$ where the maximum value 27.36 $g \cdot m^{-2}$, also occurred in the spring. In other seasons, mean biomass did not vary significantly, ranging from 17.29 $g \cdot m^{-2}$ in summer, 16.39 $g \cdot m^{-2}$ in autumn and 16.38 $g \cdot m^{-2}$ in winter. Mollusks accounted for >55% of the total biomass while the remainder was made up of echinoderms (20%), polychaetes (15%), and crustaceans (10%). The remaining taxa accounted for about 5% of total biomass. Along the Korean coast, benthic biomass was higher, in the range from 79.44 to 171.6 $g \cdot m^{-2}$ (UNDP/GEF 2007). Abundance ranged from 769 - 1,939 ind.$\cdot m^{-2}$. A total of about 500 species has been reported comprising 135 mollusks, 148 arthropods, 87 annelids, 24 echinoderms, 34 cnidarians, and 7 poriferan species (UNDP/GEF 2007). Such differences are at least partly related to different sampling methods and strategies.

Recent surveys of the central Yellow Sea in winter and summer of 2008 (UNDP/GEF 2010) found ~360 species of macrobenthos with the following taxonomic composition: Annelida (42%), Arthropoda (30%), Mollusca (17%), Echinodermata (4%) and 7% distributed among the Coelenterata, Urochordata, Plathyhelminthes, Nemertinea, Nematoda, Echiura, Sipuncula, Ectoprocta (Bryozoa), Branchiopoda and Osteichthyes (Fig. YS-38). The benthic environment in the central region of the Yellow Sea maintains stable low temperature throughout the year due to Yellow Sea Cold Water Mass. This makes the benthic fauna relatively consistent through the seasons: ca. 38% of all identified species occurred both in winter and summer. *Ophiura sarsii* and *Eudorella pacifica* were the most dominant ones throughout the seasons.

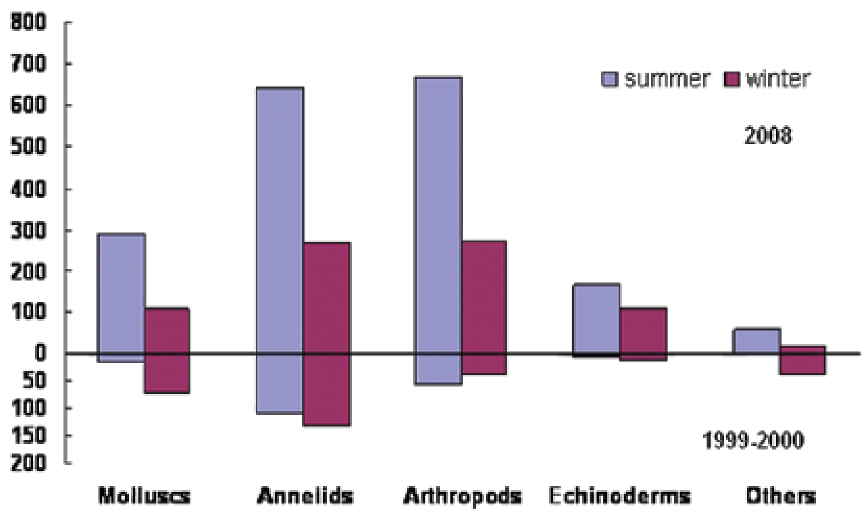


[Figure YS-38] Macrobenthos in the central Yellow Sea: total species composition in winter and summer 2008.

Average seasonal biomass was higher than what was found ten years ago (Li 2003), and this was due mainly to increases of echinoderm and mollusk biomasses (Fig. YS-39). This suggests increased food availability possibly associated with eutrophication (bottom-up effect) and/or a decline in fish abundance (top-down effect). In 2008, the average biomass in summer (60.65 $g \cdot m^{-2}$) was lower than that in winter (76.06 $g \cdot m^{-2}$), although by taxonomic group the averages were generally higher in summer except for the larger sea urchins whose biomass was higher in winter. Echinoderms accounted for the highest proportion (~47%) of the total biomass, followed by annelids (16%), mollusks (15%), arthropods (3%) and the remaining species (19%). Arthropods had higher biomass in the area south of 34°N than in the north, whereas echinoderm biomass is higher north of 34°N. Annelid biomass is more evenly distributed, mollusks present higher biomass between 122.5°E and 124°E, other remaining species occurs with higher biomass along two transects 124°E and 34°N.



[Figure YS-39] Comparison of macrobenthos biomass (g·m⁻²) in the central Yellow Sea in 1999-2000 and 2008.



[Figure YS-40] Comparison of macrobenthos abundance (ind.·m⁻²) in the central Yellow Sea in 1999-2000 and 2008.

Seasonal mean abundance was higher than what was measured 10 years ago (UNDP/GEF 2010), especially for arthropods, annelids, mollusks and echinoderms (Fig. YS-40). In 2008, abundance in summer (1824 ind.·m^{-2}) was higher than what was found in winter (774 ind.·m^{-2}). Arthropods accounted for the highest proportion of the total abundance (~36%), followed by annelids (35%), mollusks (15%), echinoderms (11%) and the remaining species (3%). Total abundance generally increases from lower levels in the northwest to higher levels in the southeast parts of the Yellow Sea. Both annelids and mollusks were more abundant in the area south of 34°N, whereas echinoderms are more abundant north of 34°N. Arthropods had the highest abundance south of 33.5°N, lower between 36°N and 36.5°N and lowest 33.5-36°N. Other remaining species are abundant in the south, southwest and northwest margins.

References

Anonymous. 2004. Proceedings of "International Workshop on Jellyfish Bloom: China, Japan and Korea", Yokohama, Japan, February 24, 2004.

Aoyama, M., Goto, H., Kamiya, H., Kaneko, I., Kawae, S., Kodama, H., Konishi, Y., Kusumoto, K.-I., Miura, H., Moriyama, E., Murakami, K., Nakano, T., Nozaki, F., Sasano, D., Shimizu, T., Suzuki, H., Takatsuki, Y., Toriyama, A. 2008. Marine Biogeochemical response to a rapid warming in the main stream of the Kuroshio in the western North Pacific. Fisheries Oceanography 17: 206-218.

Barter, M.A. 2002. Shorebirds of the Yellow Sea: Importance, threats, and conservation status. Wetlands International Global Series 9, International Wader Studies 12, Canberra, Australia.

Beardsley, R.C., Limeburner, R., Yu, H., Cannon, G.A. 1985. Discharge of the Changjiang (Yangtze) River into the East China Sea. Continental Shelf Research 4: 57-76.

Chai, C., Yu, Z., Shen, Z., Song, X., Cao, X., Yao, Y. 2009. Nutrient characteristics in the Yangtze River Estuary and the adjacent East China Sea before and after impoundment of the Three Gorges Dam. Science of the Total Environment 407: 4687-4695.

Chen, Q.C. 1964. Study on the reproduction, sex ratio and body size of *Calanus sinicus*. Chinese Journal of Oceanology and Limnology 6: 272-287.

Chen, C.-C., Gong, G.-C., Shiah, F.-K. 2007. Hypoxia in the East China Sea: One of the largest coastal low-oxygen areas in the world. Marine Environmental Research 64: 399-408.

Chen, X., Yan, Y., Fu, R., Douy, X., Zhang, E. 2008. Sediment transport from the Yangtze River, China, into the sea over the post-Three Gorges Dam period: A discussion. Quaternary Internaitonal 186: 55-64.

Cho, B. C., Choi, J.-K., Chung, C.-S., Hong, G. H. 1994. Uncoupling of bacteria and phytoplankton during a spring diatom bloom in the mouth of the Yellow Sea. Marine Ecology Progress Series 115: 181-190.

Choi, J.K., Park, Y.C., Kim, Y.C., Lee, Y.C., Son, S.K., Hwang, H.J., Han, B.S., Jung, C.S. 1988. The study on the biological productivity of the fishing ground in the western coastal area of Korea, Yellow Sea. Bulletin of the National Fisheries Research Development Agency 42: 143-168.

Fang, T.-H., Li, J.-Y., Feng, H.-M., Chen, H.-Y. 2009. Distribution and contamination of trace metals in surface sediments of the East China Sea. Marine Environmental Research 68: 178-187.

Fu, M., Wang, Z., Li, Y., Li, R., Sun, P., Wei, X., Lin, X., Guo, J. 2009. Phytoplankton biomass size structure and its regulation in the Southern Yellow Sea (China): Seasonal variability. Continental Shelf Research 29: 2178-2194.

Gong, G.-C., Chang, J., Chiang, K.-P., Hsiung, T.-M., Hung, C.-C. Duan, S.-W., Codispoti, L. A. 2006. Reduction of primary production and changing of nutrient ratio in the East China Sea: Effect of the Three Gorges Dam? Geophysical Research Letters 33: L07610, doi:10.1029/2006GL025800.

Han, B.S., Choi, J.K. 1991. A study on the environmental conditions and phytoplankton ecology in the tidal front area of the Yellow Sea. Yellow Sea Research 4: 39-55.

Hong, G.H., Chang, J., Kim, S.-H., Chung, C.S., Yang, S.R., Lee, J.H., Kim, Y.I. 2003. East Asian marginal seas: river-dominated ocean margin. Proceedings of the International Symposium on Oceanographic Environmental Change after Completion of the Changjiang Three-Gorges Dam, May 15, 2003, Jeju, Korea.

Ichikawa, H., Beardsley, R.C. 2002. The current system in the Yellow and East China seas. Journal of Oceanography 58: 77-92.

Jiao, N., Zhang, Y., Zeng, Y., Gardner, W.D., Mishonov, A.V., Richardson, M.J., Hong, N. Pan, D., Yan, X.-H., Jo, Y.-H., Chen, C.-T.A., Wang, P., Chen, Y., Hong, H., Bai, Y., Chen, X. Huang, B., Deng, H., Shi, Y. Yang, D. 2007. Ecological anomalies in the East China Sea: Impacts of the Three Gorges Dam? Water Research 41: 1287-1293.

Kang, Y.S. 2008. Seasonal variation in zooplankton related to North Pacific Regime Shift in Korea Sea. Journal of the Korean Fisheries Society 41: 493-504.

Kang, Y.S., Hong, S.Y. 1995. Occurrences of oceanic warm-water calanoid copepods and their relationship to hydrographic conditions in Korean waters. Bulletin of the Plankton Society of Japan 42: 29-41.

Kang, Y.S., Lee, S.S. 1991. Seasonal fluctuations of zooplankton biomass in the adjacent sea of Korea. Bulletin of the National Fisheries Research and Development Agency 45: 13-21.

Kang, Y. S., Choi, J.-K., Chung, K. H., Park, Y.-C. 1992. Primary productivity and assimilation number in the Kyonggi Bay and the mid-eastern coast of Yellow Sea. Journal Oceanology of Korea 27: 237-246.

Kang, Y.S., Jung, S., Zuenko, Y., Choi, I., Dolganova, N. 2009. Regional differences in response of mesozooplankton to long-term oceanographic changes (regime shifts) in the northeastern Asian marginal seas. Submitted to Progress in Oceanography.

KCJRG (Korea-China Joint Research Group). 2004. Report of the Yellow Sea environment cooperative research between Korea and China, 2003.

Kim, H.-C., Yamaguchi, H., Yoo, S., Zhu, J., Okamura, K., Kiyomoto, Y., Tanaka, K., Kim, S.-W., Park, T., Oh, I. S., Ishizaka, J. 2009. Distribution of Changjiang Diluted Water detected by satellite chlorophyll-a and interannual variation during 1998-2007. Journal of Oceanography 65: 129-135.

Kim, S., Khang, S.H. 2000. The Yellow Sea, pp. 487-498, *In* Sheppard, C. (ed.), Seas at the Millenium: An Environmental Evaluation, Elsevier Science.

Li, R.G. 2003. Macrobenthos on the Continental Shelves and Adjacent Waters, China Sea. China Ocean Press, Beijing, 164 p.

Li, M., Xu, K., Watanabe, M., Chen, Z. 2007. Long-term variations in dissolved silicate, nitrogen, and phosphorus flux from the Yangtze River into the East China Sea and impacts on estuarine ecosystem. Estuarine, Coastal and Shelf Science 71: 3-12.

Lie, H.-J., Cho, C.-H. 2002. Recent advances in understanding the circulation and hydrography of the East China Sea. Fisheries Oceanography 11: 318-328.

Lim, D.H., Yoon, W.D., Cho, S.H., Lee, Y. 2003. The spatio-temporal distribution of zooplankton in the Yellow Sea, pp. 159-169, *In* Choi, J.K. (ed.), Biological Oceanography in Korea, Dongwha Press, Seoul, (in Korean).

Lin, C., Ning, X. Su, J., Lin, Y., Xu, B. 2005. Environmental changes and the responses of the ecosystems of the Yellow Sea during 1976–2000. Journal of Marine Systems 55: 223-234.

Liu, D., Keesing, J.K., Xing, Q., Shi, P. 2009. World's largest macroalgal bloom caused by expansion of seaweed aquaculture in China. Marine Pollution Bulletin 58: 888-895.

Liu, T.Y. 1963. Preliminary studies on the benthic fauna of the Yellow Sea and East China Sea. Chinese Journal of Oceanology and Limnology 5: 306-319 (in Chinese).

OSTI (Ocean Science and Technology Institute) and IOCAS (Institute of Oceanology, Chinese Academy of Sciences). 1998. Yellow Sea Atlas. Ho Yong Publishing Co., Seoul, 524 p.

Park, J. 2000. Vertical distribution and primary productivity of phytoplankton in the Yellow Sea in spring time, M.S. thesis, Inha University, Korea.

Rabouille, C., Conley, D. J., Dai, M. H., Cai, W. J., Chen, C. T. A., Lansard, B., Green, R., Yin, K., Harrison, P. J., Dagg, M., McKee, B. 2008. Comparison of hypoxia among four river-dominated ocean margins: The Changjiang (Yangtze), Mississippi, Pearl, and Rhône rivers. Continental Shelf Research 2812: 1527-1537.

Rebstock, G., Kang, Y.S. 2003. A comparison of three marine ecosystems surrounding the Korean peninsula: Responses to climate change. Progress in Oceanography 59: 357-379.

Rogers, J.C. 1981. The North Pacific Oscillation. Journal of Climate 1: 39-57.

Son, S., Campbell, J., Dowell, M., Yoo, S. 2005. Decadal variability in the Yellow and East China Sea as revealed by satellite ocean color data (1979-2003). Indian Journal of Marine Science 34: 418-429.

Son, S., Campbell, J.W., Dowell, M, Yoo, S., No, J.H. 2005. Primary production in the Yellow Sea determined by ocean color remote sensing. Marine Ecology Progress Series 303: 91-103.

Song, T.Y. 1999. Monthly variation of phytoplankton community structure and pigment in the Kyeonggi Bay, Korea. M.S. thesis, Inha University. 106 p.

Tang, D., Di, B., Wei, G., Ni, H., Oh, I.S., Wang, S. 2006. Spatial, seasonal and species variations of harmful algal blooms in the South Yellow Sea and East China Sea. Hydrobiologia 568: 245-253.

Tang, D.L., Kester, D. R., Ni, I. -H., Kawamura, H., Hong, H.S. 2002. Upwelling in the Taiwan Strait during the summer monsoon detected by satellite and shipboard measurements. Remote Sensing of Environment 83: 457–471.

Tang, Q. 1989. Changes in the biomass of the Yellow Sea ecosystem. pp. 7-35 Sherman, K. and Alexander, L.M. (eds.), *In* Biomass Yields and Geography of Large Marine Ecosystems, AAAS Selected Symposium 111, Westview Press, Boulder, CO, USA

The Yellow Sea Ecoregion Initiative. 2001. Yellow Sea Ecoregion: Reconnaissance Report on Identification of Important Wetland and Marine Areas for Biodiversity Conservation. Volume 2: South Korea. The Yellow Sea Ecoregion Initiative: a joint project of WWF-Japan, Wetlands & Birds Korea and Wetlands International-China Programme.

UNDP/GEF (United Nations Development Programme/Global Environment Facility). 2007. The Yellow Sea: Analysis of Environmental Status and Trends, Volume 3: Regional Synthesis Reports. UNDP/GEF Yellow Sea Project, Ansan, Republic of Korea.

UNDP/GEF (United Nations Development Programme/Global Environment Facility). 2010. Co-operative Cruise Report. In preparation.

Wang, B.-D., Wang,X.-L., Zhan, R.2003.Nutrient conditions in the Yellow Sea and the East China Sea. Estuarine, Coastal and Shelf Science 58: 127–136.

Xing, Y., Lu, Y., Dawson, R. W., Shi, Y., Zhang, H., Wang, T., Liu, W., Ren, H. 2005. A spatial temporal assessment of pollution from PCBs in China. Chemosphere. 60: 731-739.

Yeh, S.-W. Recent warming in the Yellow and East China Sea. Continental Shelf Research (accepted).

Yoo, S., Shin, K. 1995. The primary productivity off the coast of Taeahn. Ocean Research 17: 91-99.

Zhang, C.I., Kim, S. 1999. Living marine resources of the Yellow Sea ecosystem in Korean waters: Status and perspectives. pp. 163-178, *In* Sherman, K. and Q. Tang, Q. (eds.), Large Marine Ecosystems of the Pacific Rim. Assessment, Sustainability, and Management. Blackwell Science.

Zhang, P., Song, J., Fang, J., Liu, Z., Li, X., Yuan H. 2009. One century record of contamination by polycyclic aromatic hydrocarbons and polychlorinated biphenyls in core sediments from the southern Yellow Sea. Journal of Environmental Sciences 21: 1080–1088.

Zhou, M.-J., Shen, Z.-L., Yu, R.-C. 2008. Responses of a coastal phytoplankton community to increased nutrient input from the Changjiang (Yangtze) River. Continental Shelf Research 28: 1483-1489.