Republic of Korea

Suam Kim[1], Chang-Ik Zhang[1], Jin Yeong Kim[2], Sukyung Kang[2] and Jae Bong Lee[2]

[1] Pukyong National University, 559-1 Daeyeon-3-dong, Nam-gu, Busan 608-737, Republic of Korea. E-mail: suamkim@pknu.ac.kr
[2] National Fisheries Research and Development Institute, 408-1 Sirang-ri, Gijang-eup, Gijang-gun, Busan 619-905, Republic of Korea

The Fishery

There are 300 to 400 fish species in the marine waters around Korea of which over 100 species are of commercial value. Korean fisheries yield over 1 million t of marine fish from the waters annually. In general, the increase in fishing activities since the 1970s has reduced fish populations. UN Food and Agriculture Organization records (FAO, 2000) indicate that total catches of marine fish and invertebrates averaged 1,565,973 t from 1980 to 2000. The largest catch of 2,056,521 t occurred in 1986 (Fig. 37). Catches were relatively stable from 1987 to about 1996, and have decreased slightly in recent years.

Catches in the Yellow Sea and the East China Sea were 210,000 t in the early 1960s. However, they grew rapidly and have exceeded 1 million t since the mid-1970s. Total catches started to decrease after 1986 when they reached around 1.5 million t. Recently catches have been about 1 million t (Fig. 38).

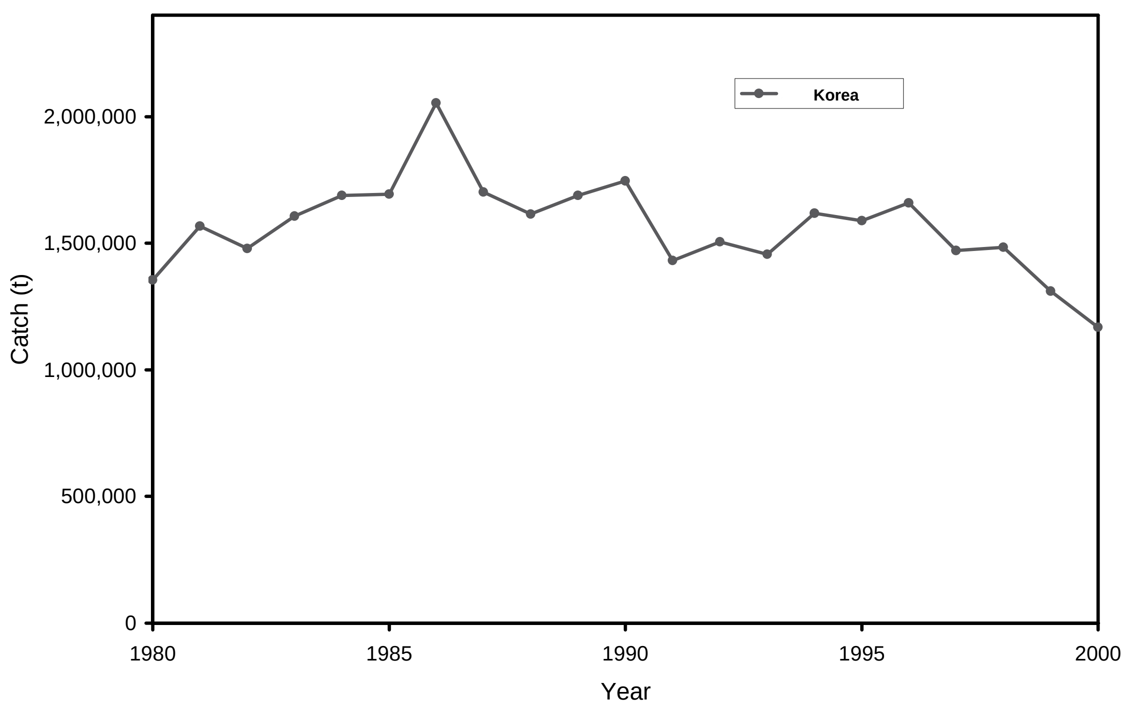

Fig. 37 Total commercial catches of marine fish and invertebrates by Korea since 1980 (FAO, 2000).

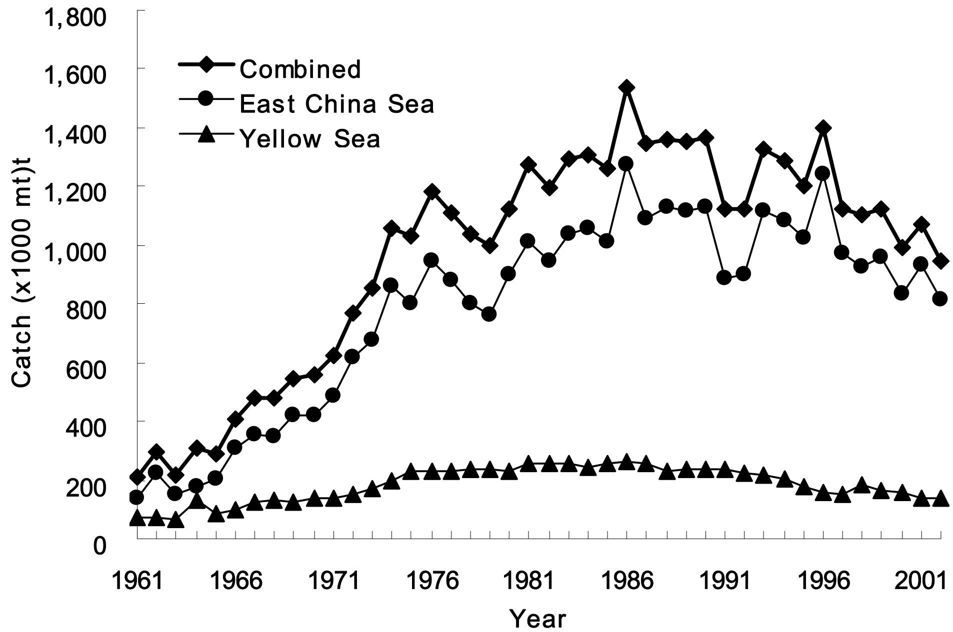

Fig. 38 Annual catch of fish and invertebrates in Korean waters of the Yellow Sea and the East China Sea.

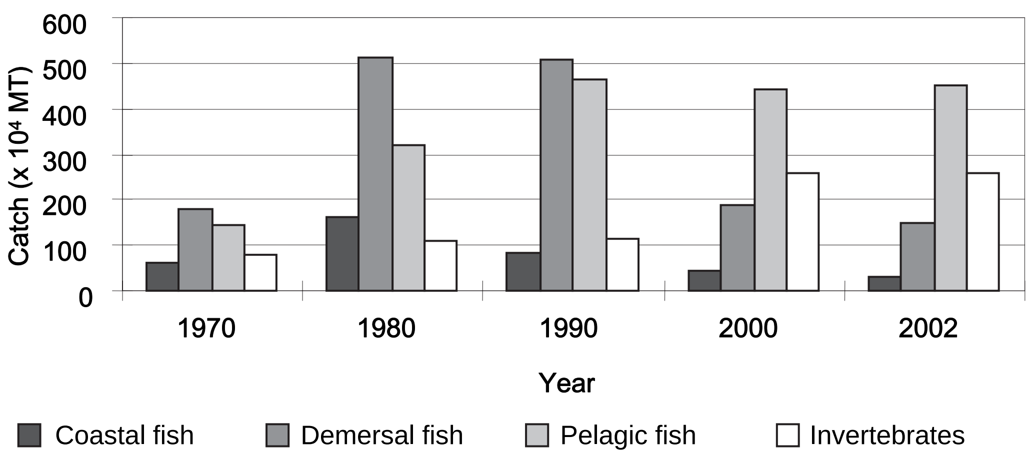

Fig. 39 Catch composition, by group, of Korean fisheries from Korean waters.

From 1980 to 2000, catches in demersal fishes decreased, and increased in pelagic fishes and invertebrates (Fig. 39). Demersal fish used to be abundant in Korean waters and were especially predominant on the Korean side of the Yellow Sea and the East China Sea in the 1960s (Zhang and Kim, 1999). In addition to the decrease in abundance, the size of spawning demersal fish has continuously decreased. The abundance of small pelagic fish has increased in the Tsushima Warm Current system. For example, Japanese anchovy (anchovy hereafter) are widely distributed in the northwestern Pacific Ocean as demersal fish abundance decreased, and are one of the most abundant pelagic species in the Yellow Sea and the East China Sea. Chinese research surveys in the winters between 1986 and 1995 indicated that anchovy biomass fluctuated between 2.5 to 4.3 million t in the Yellow Sea and the East China Sea. However, recent overexploitation and natural decreases appear to have caused the depletion of anchovy stocks on the Chinese side of the Yellow Sea. Other small pelagic fish, including the common squid, have tended to increase, occupying about 70% of the total catch of Korean marine fisheries.

The seven major target species in the Yellow Sea during the last 40 years are: (1) largehead hairtail (hairtail hereafter), (2) corvenia, (3) anchovy, (4) small yellow croaker, (5) blenny, (6) pomfret, and (7) flounder. Species composition in the catch has changed remarkably during the 1960s to 1990s. Hairtail were most dominant, followed by small yellow croaker in the 1960s and 1970s. Thereafter, the catch of small yellow croaker decreased while corvenia, flounder, and anchovy increased in the 1980s and 1990s (Fig. 40).

The seven major target species in the East China Sea during the last 40 years are: (1) anchovy, (2) chub mackerel, (3) threadsail filefish (filefish hereafter), (4) hairtail, (5) Japanese sardine, (6) corvenia, and (7) common squid. Anchovy, hairtail, and small yellow croaker dominated in the 1960s, but the catch of small yellow croaker almost disappeared from the composition after the 1960s. The relative

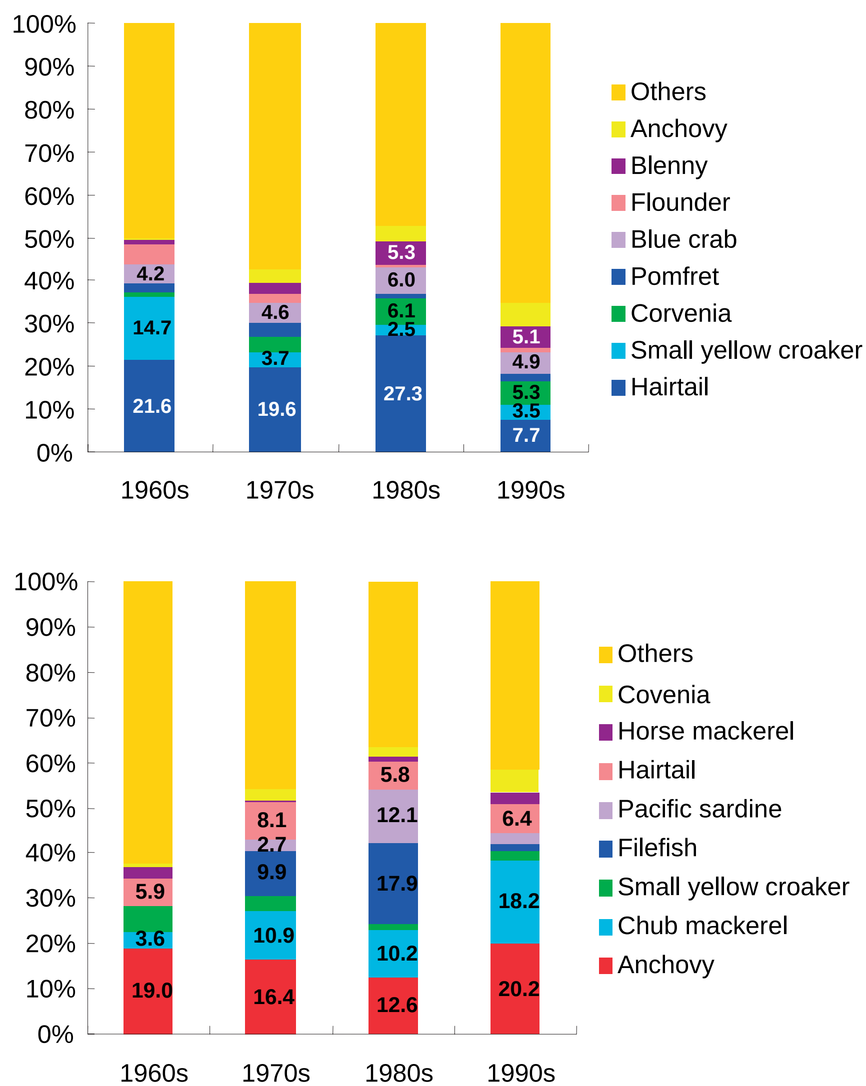

Fig. 40 Catch proportions by species from 1961 to 2000. Yellow Sea (upper panel) and East China Sea (lower panel).

compositions of chub mackerel, filefish, and sardine increased in the 1970s and the 1980s. In the 1990s, filefish and sardine disappeared and anchovy, chub mackerel, and common squid dominated the composition (Fig. 40).

Around 350 to 400 fish species reside in the East/Japan Sea (which also is called the Japan/East Sea, the East Sea, the Sea of Japan, or the Japan Sea). In the waters of the northern Korean Peninsula, demersal species represent 75% of all species and the ratio of demersal species decrease to 45% in the waters of the southern Korean Peninsula. Pelagic fish are greater in the south than in the north. Total commercial catch by neighboring nations in the East/Japan Sea peaked in 1983, reaching 3.3 million t. Korean catches, however, ranged from 132,000 t in 1967 to 275,000 t in 1982. The major species were common squid, walleye pollock (also called Alaska pollock, pollock hereafter), and saury, though large fluctuations on the decadal scale have appeared during the last four decades.

Commercial catches in the East/Japan Sea indicate changes in species composition (Fig. 41). The ecological shift between small pelagic fish and demersal fish is especially evident in accordance with the climate regime shift. In the 1960s, common squid catch occupied 43% of the catch in the East/Japan Sea, followed by Pacific saury (15%) and pollock (13%). Pollock increased, accounting for 33% from the 1970s to the 1980s. Concurrently, the proportions of common squid and saury greatly decreased in the 1970s and the 1980s. The dominant fisheries catch also shifted from saury, cod, and pollock in the 1980s to squid in the 1990s (Park *et al.*, 1998). Common squid became the dominant species (45%), and pollock and saury occupied less than 5%. However, knowledge concerning the East/Japan Sea and its relationship to the regime shift has been very limited. Thus there is a strong possibility that an increase in the squid catch is closely associated with changes in the lower trophic levels, such as zooplankton biomass and community structure.

The trophic levels of fishery resources in the catches from Korean waters showed a significant decreasing trend from 1967 to 2000 (Fig. 42). Mean trophic levels were 3.43 and 3.46 in the Yellow Sea and the East China Sea, respectively, during the 1967 –2000 period. Figure comparison shows that the slope of the declining line was steeper in the Yellow Sea than in the East China Sea. Because of the decrease of demersal fish such as small yellow croaker, which are at higher trophic levels, small pelagic fish such as anchovy, common squid, and blenny, which were at relatively lower trophic levels, increased during the four decades.

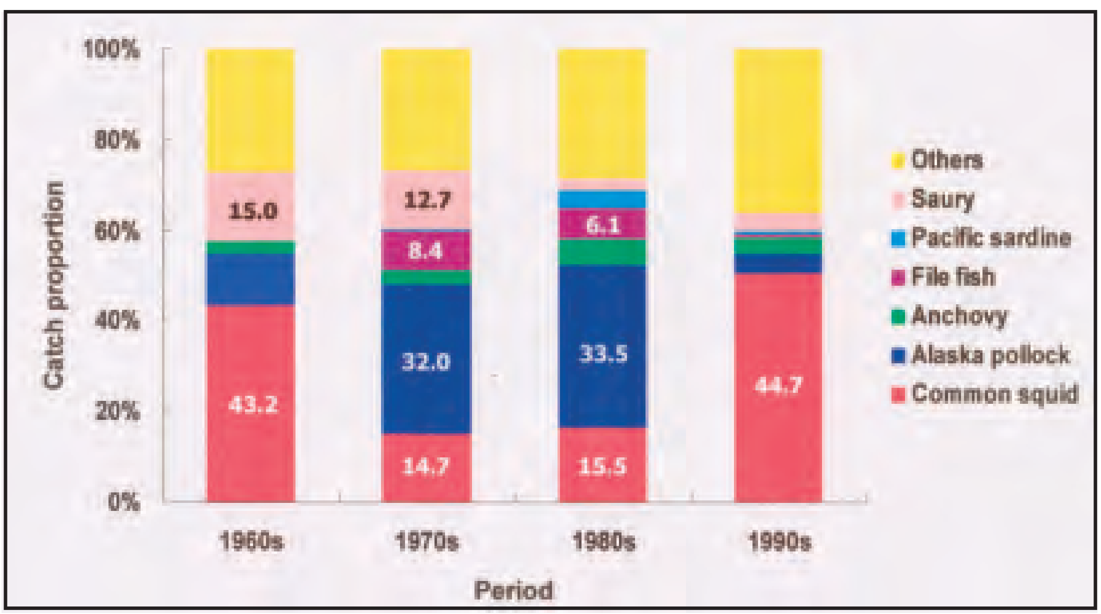

Fig. 41 Catch proportions of major species in the East/Japan Sea from 1961 to 2000.

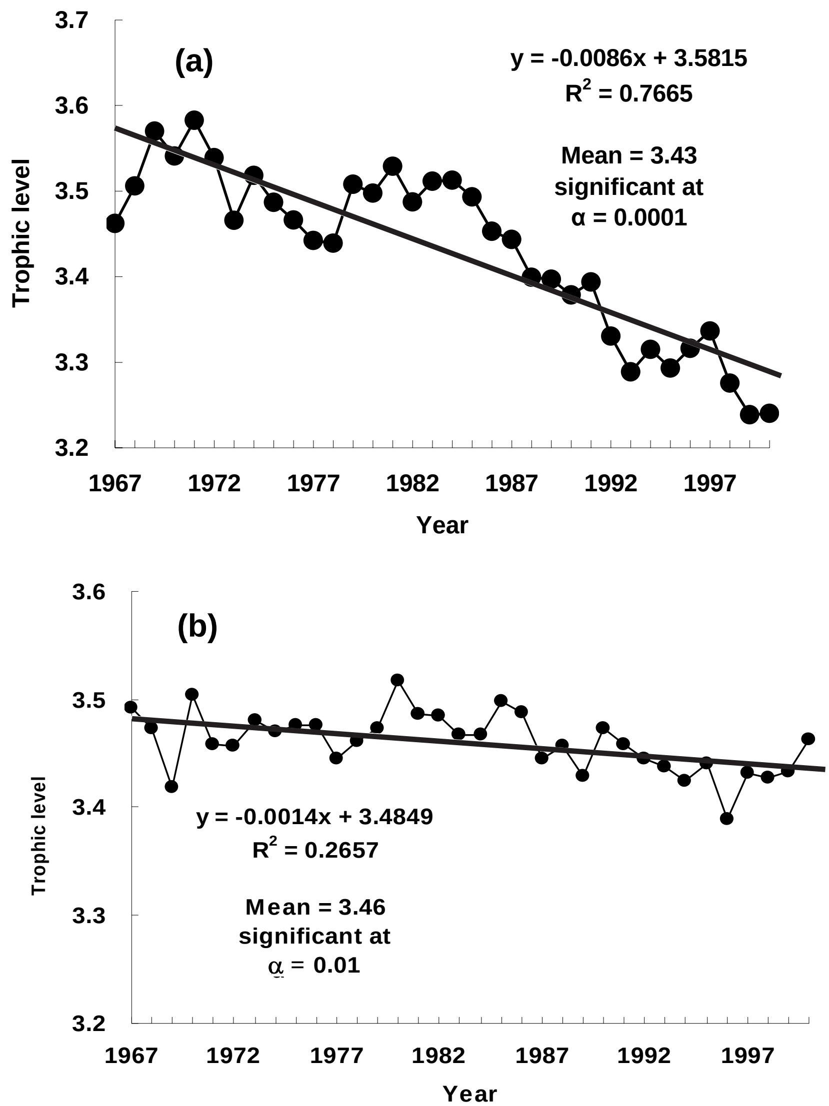

Fig. 42 Catch for mean trophic levels of fishery resources in (a) the Yellow Sea and (b) the East China Sea.

Regime shifts particularly affect the production of major small pelagic fish. Different fishing grounds of common mackerel, horse mackerel, and sardine were found between pre- and post-climatic regime shifts. There were many changes in the East/Japan Sea ecosystem after the 1976/77 regime shift, as seen through changes in the marine environment. In the East/Japan Sea, the mean trophic level increased from 3.09 to 3.28 during the 1976/77 regime shift period (Zhang *et al.*, 2004).

Climate and Ocean Influences

The Korean Peninsula is surrounded by the Yellow Sea to the west, the East China Sea to the south, and the East/Japan Sea to the east. Large-scale air–sea interaction in the Pacific Ocean is the main driving force controlling the climate over the Korean Peninsula. Some effects of climatic events, such as global warming, atmospheric circulation patterns, climate regime shifts in the North Pacific, and El Niños in tropical Pacific waters occasionally appear in this region (Kang *et al.*, 2000; Kim and Kang, 2000; Zhang *et al.*, 2000; Zhang and Lee, 2001).

The Korean Peninsula is located where the Siberian High and the subtropical Pacific Low collide, producing cold, dry winters and warm, wet summers. North and northwest winds in the autumn and winter are strong, and wind speeds easily reach 10 m s^{-1}.

Winds reverse direction and become weaker in the spring and summer. Typhoons developed in the western subtropical Pacific bring heavy rains in the summer and autumn. On the average, about nine typhoons pass through the region every year (Kim and Khang, 2000).

The coastal zone serves as spawning and nursery grounds for fish species, and the survival of some migratory species are threatened by coastal development. The main threat to the coastal habitats is land reclamation, especially in estuaries and shallow bays. During the 1987–1997 period, approximately 25% of the total tidal flats were lost to reclamation in Korea (Cho, 2001). The loss of spawning grounds, and habitat degradation due to pollutants, are also reducing the productivity of the coastal area.

Changes in the sea surface layer in the spring have a profound effect on productivity. There has been a 1.8°C increase in sea surface temperature (SST) in February in the Korean seas during the past 100 years (Hahn, 1994). The rate of change has become greater during the past decade. Hahn (1994) also showed that there was a northward movement of isothermals during the same period (Fig. 43). Aside from the long-term view of global warming, SST is closely related to the variation of the Asian monsoon. The SST change over Korean waters is also connected to the El Niño–Southern Oscillation (ENSO), with phase lags of 5 to 9 months (Park and Oh, 2000) which results in a cold summer in the East/Japan Sea after an El Niño winter.

In the surface layer of the East/Japan Sea, warm water masses were prevalent during the 1960s to 1975, cold ones from 1976 to 1986, and warm ones again since 1987 (Fig. 44). This phenomenon was typical in the spring and the autumn and showed a similar trend, with an exception from 100 to 200 m depth during the late 1970s. It is also anticipated that changes of SST due to climate variability could change the pattern of frontal and current systems in the East/Japan Sea.

Since the early 1990s, high SSTs have prevailed in the East/Japan Sea. Concurrently, zooplankton biomass and catch of warm-water pelagic species (*e.g.*, squids, jellyfish, mackerels) have increased. Recently, the occurrence of warm-water species has been frequently reported, while cold-water species (*e.g.*, pollock) have decreased. The returning rate of chum salmon, which were released from the east coast of the Korean Peninsula, has been depressed. As long as the warming trend of SST continues, more warm-water species (also less cold-water species) are expected to be found in Korean waters.

The spatial distribution of seawater temperature indicated that the isotherms were perpendicular to the coastline at the surface. Those lines, however, became parallel at 50–100 m depth. Especially, during the spring from 1976 to 1986, cold temperatures were prevalent near coastal areas. Warming of seawater was frequently observed from the late 1980s. The vertical structure of temperature represented the cold regime lower than 11°C in the 0 to 100 m layer during the 1977–1983 period. Temperatures warmer than 11°C were common after 1989.

General Description of Ecosystem Status and Fisheries Trends

Changes in Ecosystem Components

In the East/Japan Sea, there was a major change in the ecosystem structure and productivity from 1960 to 1990. The mixed layer depth increased from 1977 and fluctuated around depths about 40% deeper than prior to 1976 (Zhang *et al.*, 2000). The mean transparency depth from Secchi disk observations showed 11.9 m during the 1960–1975 period, but increased to 14.2 m during the 1976–1990 period. This resulted in higher primary productivity (and consequently the zooplankton biomass) appearing in the earlier period (Kang *et al.*, 2000). Correlation studies indicate that some fish (saury and sandfish) predominated the catches when the Southern Oscillation Index (SOI) was positive (*i.e.*, la Niña period), when spring chlorophyll was high, when air temperatures were cooler in coastal cities, and when catches were low for other fish species (sardine and pollock) (Kang *et al.*, 2000; unpublished ms).

Some resident fish species are found near the coast, while others show a long-range migration behavior during the course of spawning. Kim (2003) identified three important ecosystems in Korean waters based on marine commercial fish catches (Fig. 45): the demersal ecosystem in the Yellow Sea and the East China Sea, the pelagic ecosystem in the Tsushima Warm Current (*i.e.*, a branch of the Kuroshio) from the East China Sea to the East/Japan Sea, and the demersal ecosystem in the northern part of the East/Japan Sea. Most species in these categories generally showed a typical migration

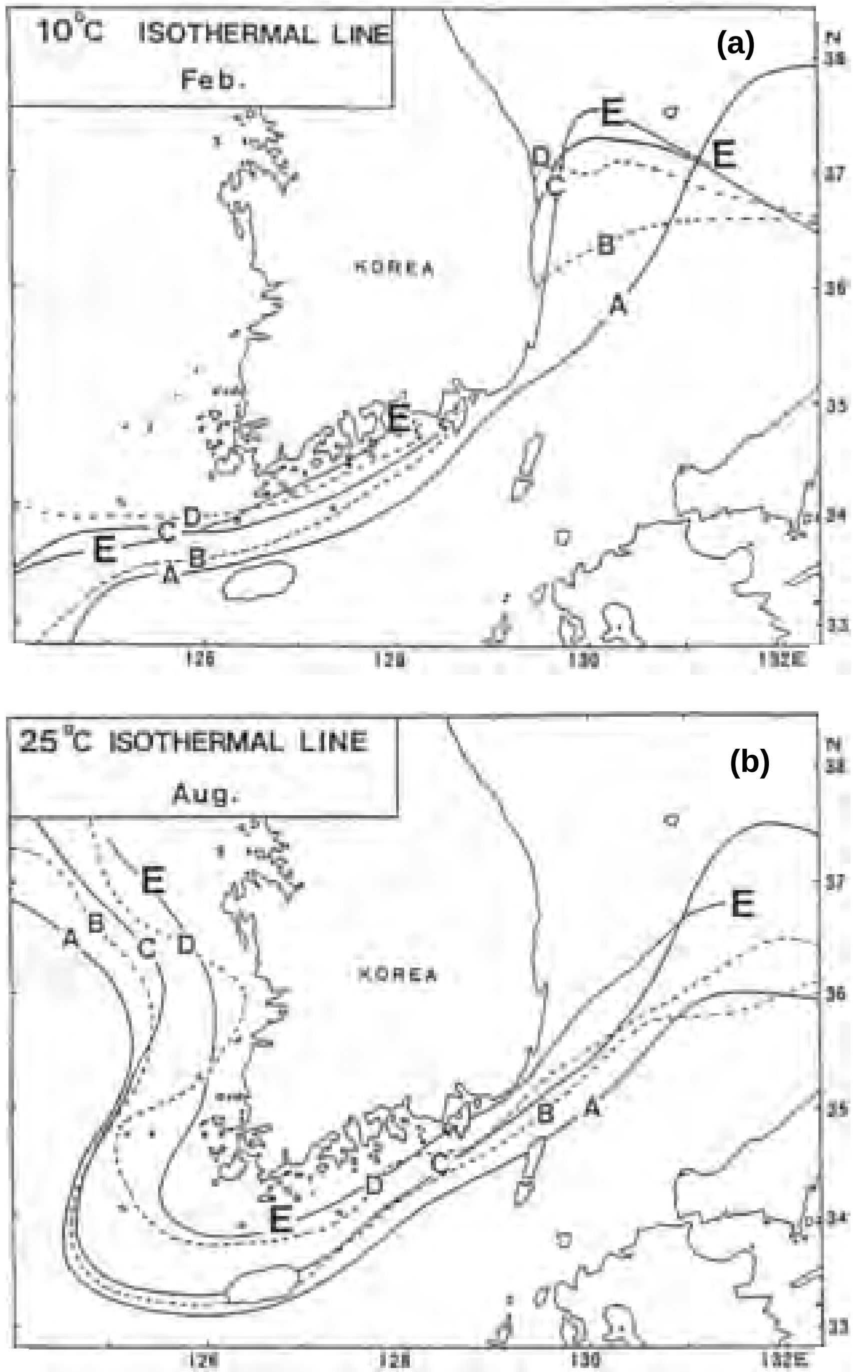

Fig. 43 Northward movement of the isothermals from 1891 to 1990. (a) refers to February and (b) refers to August. A: 1891–1910; B: 1911–1925; C: 1926–1940; D: 1961–1975; E: 1976–1990 (source: Hahn, 1994).

pattern: spawning in the coastal areas during the spring, feeding to the north during the summer, and overwintering after southward movement to the East China Sea.

Key Species in the Fishery

The fish species selected in this report are pollock, chum salmon, small yellow croaker, hairtail, anchovy, Japanese sardine, chub mackerel, jack mackerel, filefish, Pacific saury, skipjack tuna, and common squid. These are the key species in catch, accounting for more than 75% of the total catch since 1980 (Table 25). Most species have a wide range of distribution/migration around the Korean Peninsula. Unfortunately, the biology of these species has not been studied extensively.

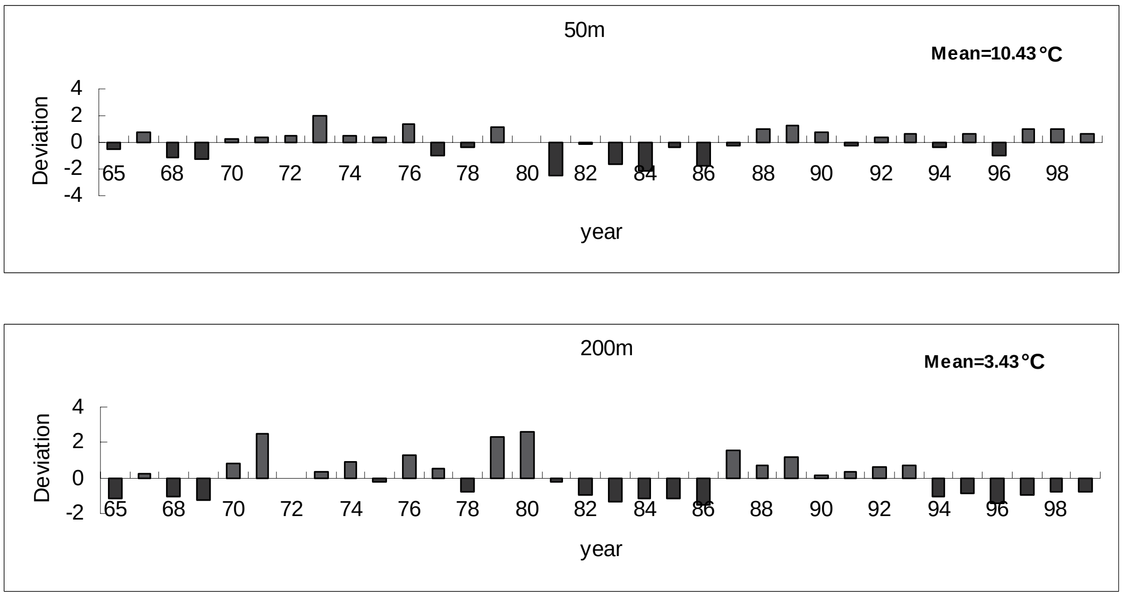

Fig. 44 Change in seawater temperature in April at 50 and 200 m depth in the East/Japan Sea.

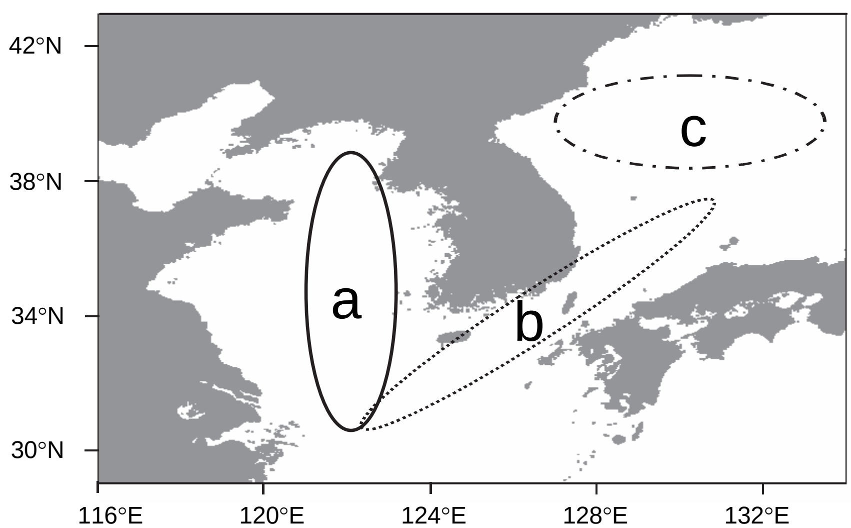

Fig. 45 Three categories of fish communities in Korean waters. (a) Demersal ecosystem in the Yellow Sea: small yellow croaker, and hairtail, (b) pelagic ecosystem in the East China Sea through the southern East/Japan Sea: mackerel, squid, and anchovy, and (c) demersal ecosystem in the East/Japan Sea: Pollock and Pacific cod.

Table 25 Catches (t) of major species in the Korean fisheries (FAO data).

	1980	1985	1990	1995	2000
Pollock	286,158	451,305	321,496	345,888	86,143
Chum salmon	128	2,353	666	1,455	28
Small yellow croaker	48,843	6,872	27,890	25,719	19,630
Hairtail	119,980	127,608	103,970	94,596	81,050
Japanese anchovy	169,657	143,512	168,101	230,679	201,192
Japanese sardine	38,282	107,776	132,924	13,539	2,207
Chub mackerel	62,690	68,479	97,227	200,481	145,908
Jack mackerel	565	16,343	17,429	12,269	19,510
Filefish	229,230	256,529	230,252	1,755	9
Pacific saury	12,395	4,393	23,103	37,865	44,340
Skipjack tuna	2,526	14,132	138,491	137,848	137,008
Common squid	48,490	42,879	75,293	200,897	226,309
Total	1,018,944	1,242,181	1,336,842	1,302,991	963,334

Walleye pollock (*Theragra chalcogramma*)

Biology

Walleye pollock mature at age 3 when their size reaches about 25 to 30 cm. They spawn in shallow water near the coast, and Won-San Bay in the Democratic People's Republic of Korea is as the largest spawning ground in the East/Japan Sea. The older and larger fish spawn first. The optimum water temperature of spawning pollock ranges from 2° to 5°C. The peak spawning season varies with regions: November to December in southern Korean Peninsula waters, December near Won-San Bay, and January to February off the northeastern Korean Peninsula (Gong and Zhang, 1983). Pollock are distributed along the coastal areas of the northern East/Japan Sea, from the southern to northern regions of the Korean Peninsula, Russia, and Japan. They reside in offshore areas, but move to the coastal areas for spawning. In general, pollock tend to move to the upper layer in the winter and to the deep layer in the summer when warm water masses are strong in the surface layer. Fecundity ranges from 250,000 to 400,000 eggs (Chyung, 1974). Pollock move southward from the Russian coast to the southern coastal areas of Korea in the spawning season.

Fishery

Korea has a long history of participation in pollock fisheries (Park, 1978). Modern fishing and catch statistics on pollock started in the early 20th century. Because pollock are a cold-water species, fishing activities were common traditionally in northern Korean Peninsula waters (*i.e.*, Democratic People's Republic of Korea), and this fishery was not popular in the southern part of the Korean Peninsula before the Korean War. However, catch statistics from the Democratic People's Republic of Korea have not been correctly reported since the 1940s. In the northern Korean Peninsula waters, pollock catches were high in the middle of 1980s, with a peak around 1.8 million t in 1983 (Kim and Kang, 1998). They decreased to 400,000–500,000 t in the 1990s, and unofficial records have recently indicated a very low catch in these waters.

Parts of the pollock population moved to the south along the coast, though the main group remained in northern Korean Peninsula waters. Annual catches increased from the early 1970s and peaked in 1981 at 165,000 t in the waters of the southern Korean Peninsula (Fig. 46). Since then, catches have declined continuously. One typical characteristic of the Korean pollock catch is the inclusion of immature juvenile pollock (called small pollock of ages 1 to 2 in Korean statistics). The proportion of immature pollock was higher than 90% in the late 1970s, decreasing continuously to 40% in 1987, and to 18% in 1988. In 1990, it increased to 63%, but decreased to 12% in 1997. For this species, there was no legal measure to protect juveniles, so that overfishing of juveniles might have influenced recruitment.

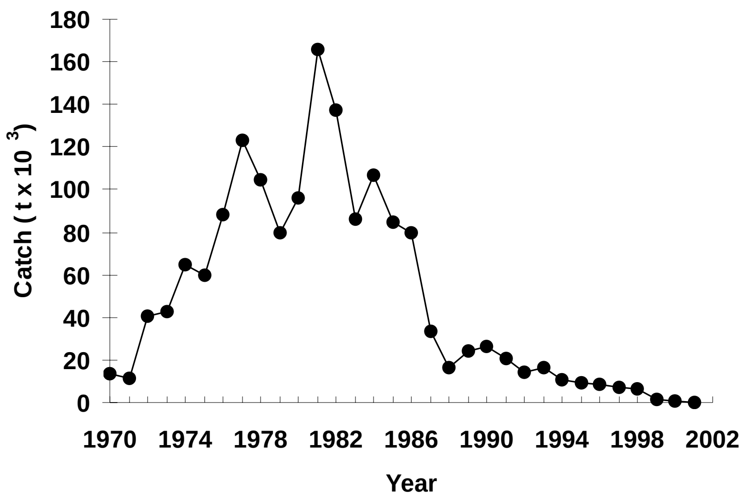

Fig. 46 Annual catches (t) of pollock in Korean waters from 1970 to 2002.

Climate and ocean effects

The majority of pollock reside in northern Korean Peninsula waters, but no fisheries or environmental data are available. The fishing areas in the 1990s (*i.e.*, warm seawater and low pollock biomass) were restricted to coastal areas, apparently because of the higher SST in the south. This contrasts with a broader fishing area in the late 1970s when SSTs were cooler. A shift in fishing season was also noticed in the 2000s. The highest catches were recorded in January–March during the 2000s, compared to November–December during the 1980s. There is a negative correlation between fish catch and seawater temperature at 50 to 100 m depth (Fig. 47). A negative anomaly in SST during the early 1980s was coincident with a positive anomaly of pollock catch, while warm water masses in the early 1970s and 1990s resulted in low pollock catches. Pollock catches are also significantly related to the Northeastern Pacific Pressure Index (Kang *et al.*, 2000).

Chum salmon (*Oncorhyncus keta*)

Biology

Five species of Pacific salmon, chum (*Oncorhynchus keta*), cherry (*O. masou*), pink (*O. gorbuscha*), silver (*O. kisutch*), and sockeye (*O. nerka*) are distributed in the Korean waters. However, the distributions of pink, silver, and sockeye salmon are limited to the northern Korean Peninsula. Chum salmon and cherry salmon are the only species released for salmon enhancement in Korea. Hatcheries were established in 1913 on the northern Korean Peninsula, and intensive enhancement activities resumed in the mid-1980s in Korea.

Adult chum salmon are distributed throughout the North Pacific Ocean, and return to their home stream when they sexually mature at age 3 or 4. They lay eggs in streams (or ripened eggs are removed in the hatcheries), and the eggs require 100 to 120 days for hatching in in fresh water of around 4°C. In the spring, hatched larvae with yolk become fry in hatcheries, and the fry enter (or are released) to the sea. They remain in estuaries or coastal areas for a while, then migrate northward along the coast during the summer. They stay in the ocean for 2 to 5 years until they return to their natal rivers to spawn. The main diet of chum salmon caught from the Subarctic Current and Alaskan Gyre areas consist of zooplankton, such as copepods, pteropods, amphipods, euphausiids, and jellyfish (Nakamura *et al.*, 2001).

Fishery

Chum salmon catches were very poor until the late 1980s. However, since 1990, catches from set net fisheries were included in these catch statistics so that an abrupt artificial increase in catches in 1990 was shown (Fig. 48). The proportion of catch by set net fisheries in total catch was about 70 to 80% for the 1990s and decreased to 50–70% in the 2000s. Salmon catches were seriously reduced from 553 t in 1997 to 51 t in 2000. Catches increased slightly in 2002 though they were still less than 200 t.

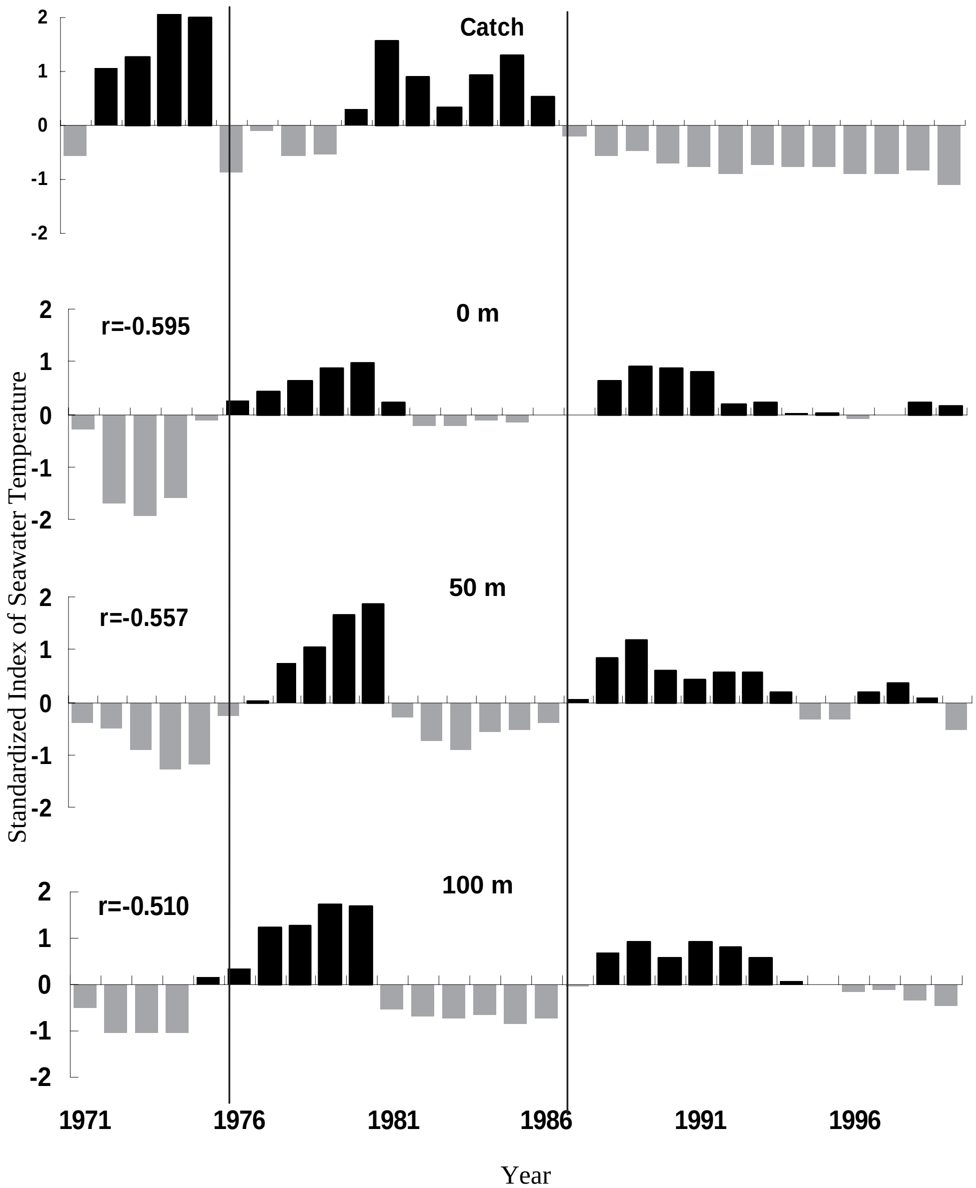

Fig. 47 The relationship between pollock catch and seawater temperature anomalies in Korean waters.

Climate and ocean effects

Because of the wide distribution of salmon throughout its whole life span, certain environmental conditions at specific areas influence salmon growth, migration route, and return rates. The homing success of chum salmon might depend on seawater temperature in the coastal areas because high temperatures have resulted in mass mortality of salmon fry when released. The returning rate of chum salmon released from Korean hatcheries is less than 1% currently, which is relatively low compared to American and Japanese chum salmon. There was a negative correlation between return rates and SST in the coastal areas during the release time. The high temperatures in the spring of 1988–1990 and 1997–1998 appeared to be detrimental to the survival of released salmon fry and, in turn, resulted in the lower return rates of spawners in the 1991–1994 and 2000–2001 spawning periods, respectively (Fig. 49).

Bottom-up processes and seawater temperature seemed to influence the growth of chum salmon populations in Korea. Growth during their early life history in fresh water and river mouth areas was

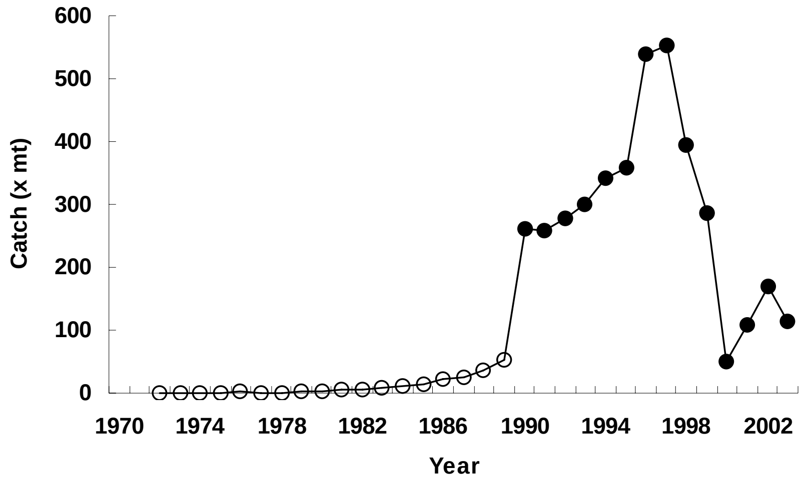

Fig. 48 Annual catches of chum salmon in Korean waters from 1991 to 2003. Open circles represent the catch amount in Korean rivers. Closed circles represent total catch amounts from rivers and set net fishery.

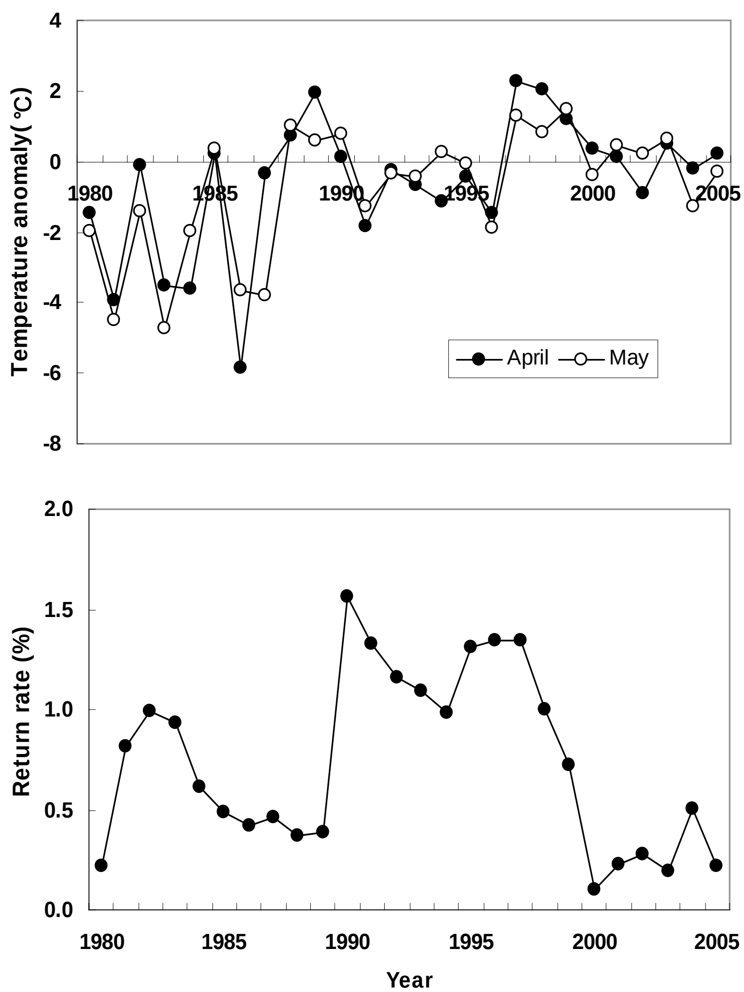

Fig. 49 Seawater temperature anomalies near salmon hatcheries and the return rate of Korean chum salmon. Note that the return rate before 1990 does not include salmon catch in coastal areas of Korea.

better in the early 1990s than in the 1980s. This phenomenon might be related to the increase in seawater temperature and zooplankton abundance off Korea (Fig. 50). On the other hand, salmon growth in the open ocean was better in the 1980s than in the early 1990s. The 1988/89 regime shift might have caused a change in environmental conditions, and ultimately, the growth of chum salmon in the open sea (Fig. 51). Interestingly, summer growth conditions at their first year of ocean life in coastal areas seemed to be stable during the 1980s and 1990s. In the southern Okhotsk Sea, there were relatively no big differences in seawater temperature and zooplankton biomass during the same time (figure not shown).

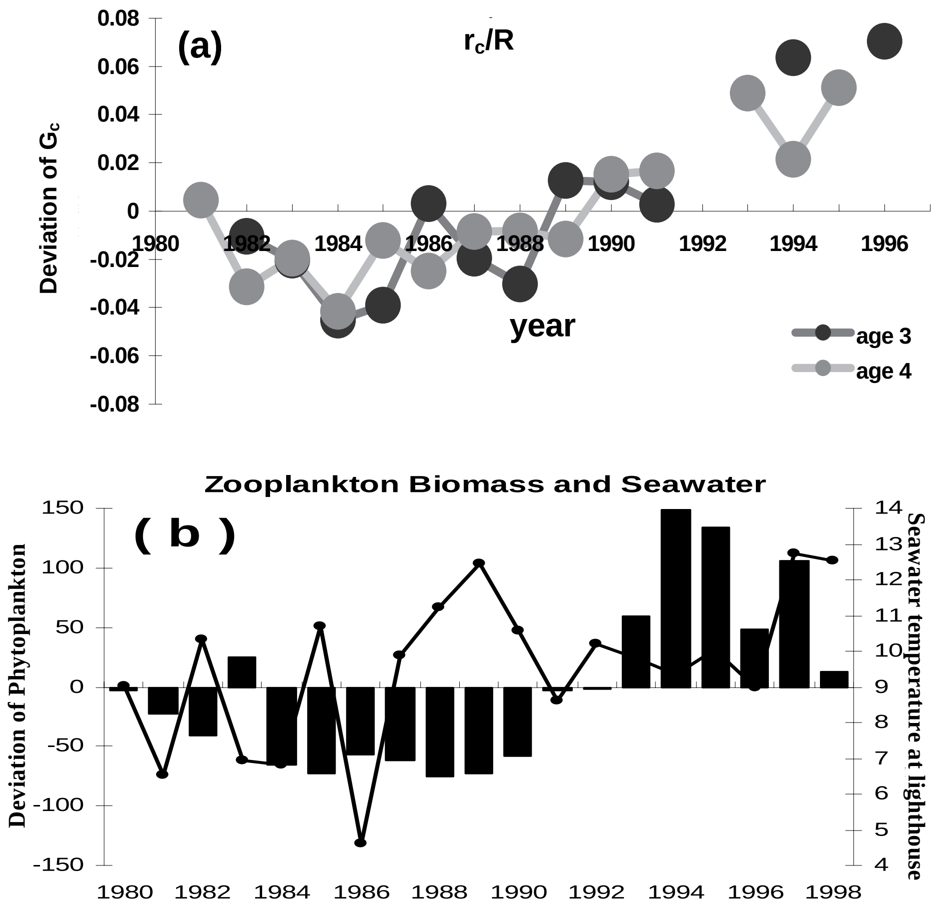

Fig. 50 (a) Deviations (G_c) from the average annual proportions of total scale growth of young chum salmon occurring in fresh water (r_c/R) where r_c is the distance from the focus to the scale check formed during the transition from the freshwater/coastal environment to ocean life, divided by R, the total distance from the focus to the perimeter of the scale and (b) deviations of zooplankton biomass (bars) and seawater temperature (line) in April off the east coast of Korea.

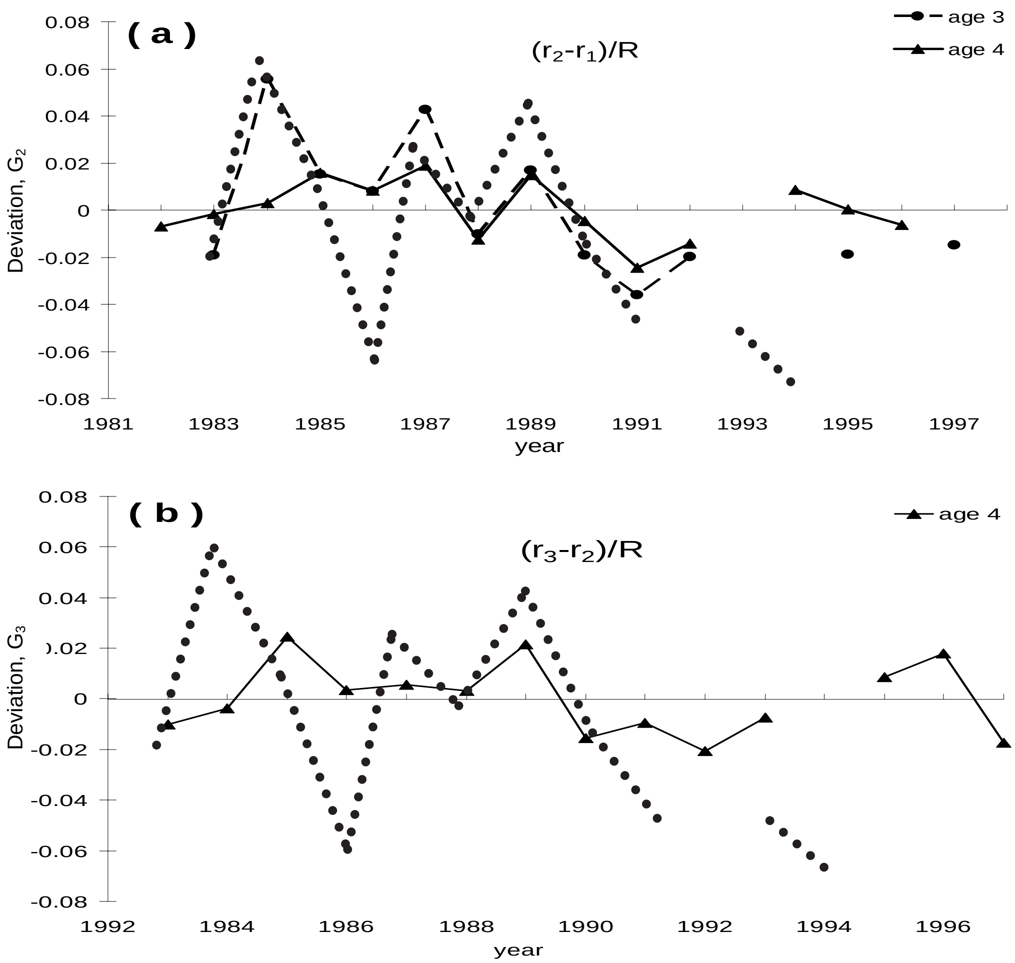

Fig. 51 Deviations (anomalies) from the average annual proportions of total scale growth occurring in (a) the second year (r_2/R) where r_2 is the length of scale added during the second year of growth at sea ($r_2 - r_1$) divided by R, the total distance from the focus to the perimeter of the scale. Similar in (b) for the third year of growth at sea. Year-to-year variation in the mean macro-zooplankton biomass (dotted line) in the eastern Bering Sea was superimposed (Sugimoto and Tadokoro, 1997). Growth information was derived from returning female salmon to their natal streams at age 3 and age 4 years from 1984 to 1998. The *x*-axis represents the year of growth.

Small yellow croaker (*Pseudosciaena polyactis*)

Biology

Small yellow croakers migrate to the East China Sea in the winter and return to the Yellow Sea to spawn in the spring. The spawning season is from April to June, with a peak in May in the eastern part of the Yellow Sea. The species used to mature at age 5 (NFRDI, 2005), but recently they seem to be maturing earlier. The majority of fish in the fishery are 1- or 2-year-olds, with a mean age of 1.6 years (Kim *et al.*, 1997).

Fishery

Small yellow croaker is an important commercial species off the west coast of the Korean Peninsula. Fishing fleets traditionally target spawning schools. However, recent heavy exploitation has resulted in limited spawning schools in the Yellow Sea. Since the 1980s, the main fishing activities have moved from the Yellow Sea to the East China Sea. Annual catches of small yellow croaker have fluctuated largely in the Yellow Sea and the East China Sea. From the early 1970s to the early 1980s, the annual catches were about 30,000 to 50,000 t, but decreased below 10,000 t after the mid-1980s (Fig. 52). Catches increased in the early 1990s, and have since continuously decreased. Recent catches were below 10,000 t. The annual catches per unit effort (CPUE) were higher in the 1970s, but lower after the 1980s (figure not shown).

Climate and ocean effects

Small yellow croaker is a demersal species in the Yellow Sea and the East China Sea, so that the survival of newly spawned eggs might be affected by temperature at depth. It was found that cold and variable temperatures, especially seawater temperature at 75 m depth in the Yellow Sea, during the early life history of yellow croaker resulted in poor yields or weak year classes in the following years (Kim *et al.*, 1997). The seasonal anomaly of mean temperature at 75 m depth with the seasonal anomaly of fish catch was positive and significant, with a time lag of 8 to 14 months (Fig. 53).

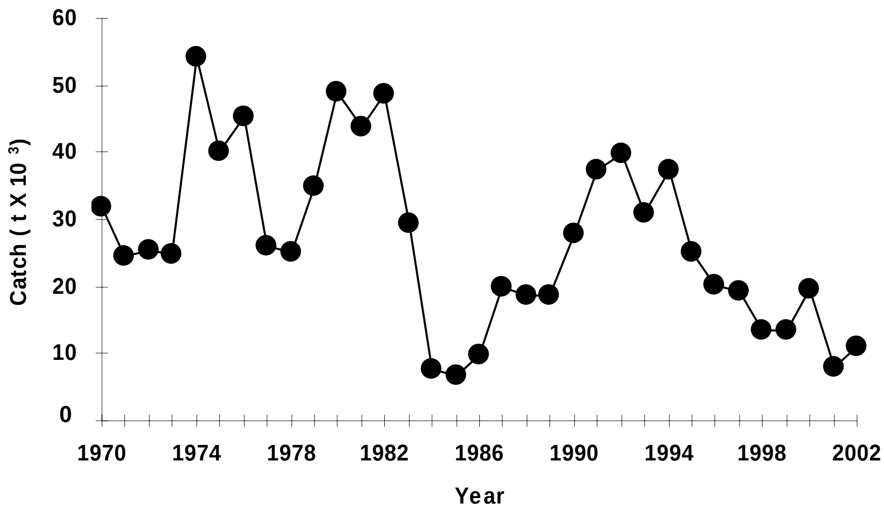

Fig. 52 Annual catches of small yellow croaker in the Yellow Sea and the East China Sea from 1970 to 2002.

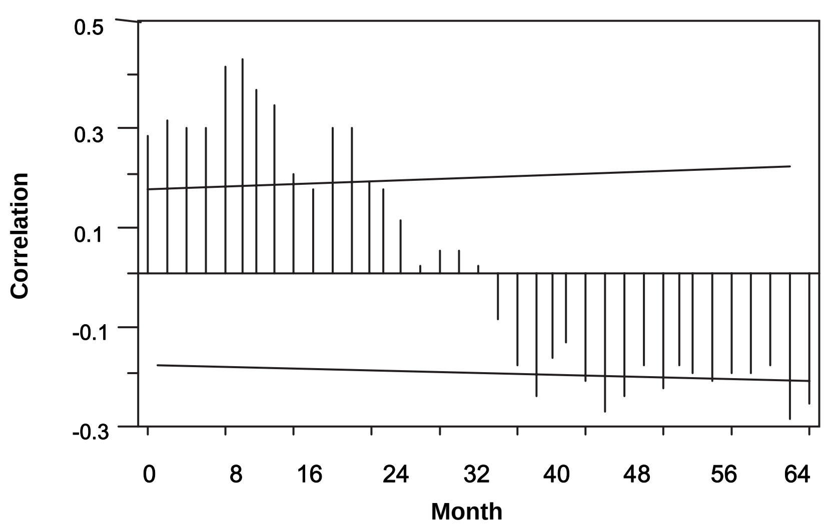

Fig. 53 Cross-correlation coefficient between seasonal anomalies of small yellow croaker catch and seawater temperature at 75 m depth.

Hairtail (*Trichiurus lepturus*)

Biology

Spawning occurs between June and October with a peak in August. Hairtail are multiple spawners that spawn two or three times in a single season. Fecundity ranges from 13,000–126,000 eggs (Kim *et al.*, 1998). Hairtail are carnivorous and consume mainly fish, crustaceans (such as copepods, euphausiids and shrimps), and chaetognaths. Their diet also includes small quantities of small squid. Hairtail have an ontogenetic progression in their feeding stages: an initial stage is planktivorous, in which they feed mainly on copepods, followed by a mixed feeding stage in which euphausiids, mysids, shrimps, chaetognaths and fish are the major food items. Anchovies are major prey of large hairtail (Huh, 1999).

Fishery

The annual catch of hairtail was relatively large, with over 100,000 t, caught from the mid-1970s to the mid-1980s. There was a decreasing trend beginning in the late 1980s that has continued to recent years (Fig. 54).

Hairtail are distributed in the southwestern waters off Jeju Island from January to March. The majority migrates northward along the west coast of the Korean Peninsula and reaches the central part of the Yellow Sea in July and August. The return migration southward begins in September and reaches the wintering area off Jeju Island by November. However, some groups of the stock also migrate northeast in March, and stay off the southern coast of the Korean Peninsula in May to June, and the southeastern waters in September. In September, these groups move back to the wintering ground off Jeju Island (Park *et al.*, 2002).

Climate and ocean effects

When the bottom water of western Jeju Island was above 14°C in the summer, the catch was large. In contrast, the catch was poor when the temperature was below 13°C. Therefore, the temperature of the bottom layer can be used as an index for forecasting the catch of hairtail (Kim and Rho, 1998).

Anchovy (*Engraulis japonicus*)

Biology

Anchovy occur primarily in the warm water area of the Korea Strait and the southern area of the Yellow Sea during the winter, and migrate shoreward to the southern coast of Korea to spawn from April to August. Spawning occurs at a fork length of 9 to 12 cm during May through July, whereas adults above 12 cm spawn from March to September. Anchovy are serial spawners, and fecundity ranges from about 15,000 to 23,000 eggs, with specific batch fecundity of 438 ± 146 (Kim and Kang, 1992).

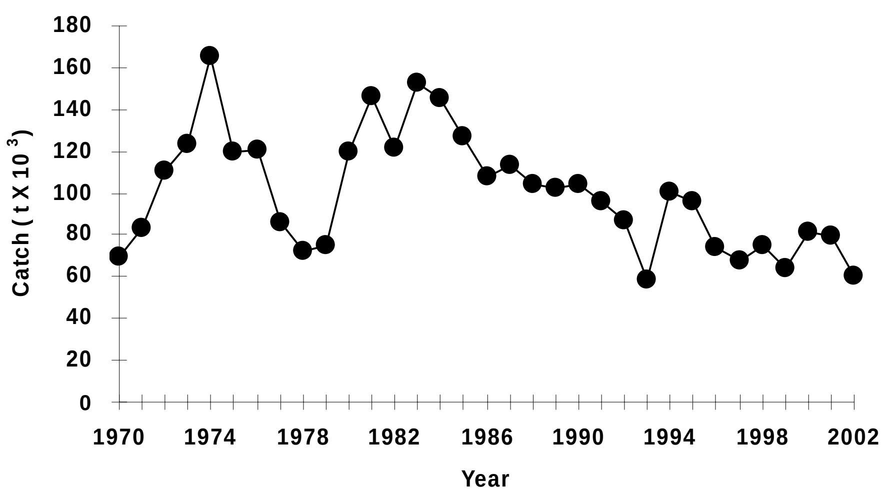

Fig. 54 Annual catches (t) of hairtail in the Korean waters from 1970 to 2002.

Fishery

The fishing grounds for anchovy are in the southern coastal waters within 35 to 55 km off the Korean Peninsula. Annual catches of anchovy increased from 1970 and remained around 150,000 to 200,000 t from 1975 to 1993 (Fig. 55). The catch increased to about 240,000 t in recent years. However, the CPUE was remarkably low after the peak in 1975. The fishery targets juveniles with anchovy drag and set nets, and adults with drift gill nets.

Climate and ocean effects

Annual variation in oceanographic conditions affects the adult migration route and the distribution of eggs and larvae. The resulting changes in distribution affect the locations and time of fishing. Seasonal and long-term trends of the size of yolk-sac larvae (Kim, 1992), embryonic mortality, egg production, and spawning stock biomass of anchovy are related to spring warming, summer cooling, and zooplankton biomass (Kim and Lo, 2001). Seawater temperature data from 1983 to 1994 showed an increasing trend in April and a decreasing one in June (Fig. 56). The trend in egg mortality, however, was opposite: daily mortality decreased in the spring (May) and increased in the summer (July) during 1983 to 1994 (Table 26).

Anchovy eggs and larvae are produced in June and August. They are distributed in warm, saline water in June, and are carried offshore by currents in August. It is likely that the distribution of anchovy eggs and larvae in June are significantly correlated with oceanic conditions in the eastern waters of Korea (Kim, 1992). In summer (August), when the Tsushima Warm Current is strong near the coast, warm waters, such as warm streamers from the Tsushima Warm Current, intrude into the coastal area, and cyclonic circulations are formed. Anchovy eggs and larvae are transported to the coastal area by these eddies. Larval survival and growth have increased because of high primary production in these circulations (Choo and Kim, 1998).

Anchovy catch is highly correlated with chlorophyll (Chl-*a*) concentrations in June and August, and with large zooplankton such as chaetognaths, euphausiids, and amphipods during autumn through spring (Kim and Kang, 2000; Table 27).

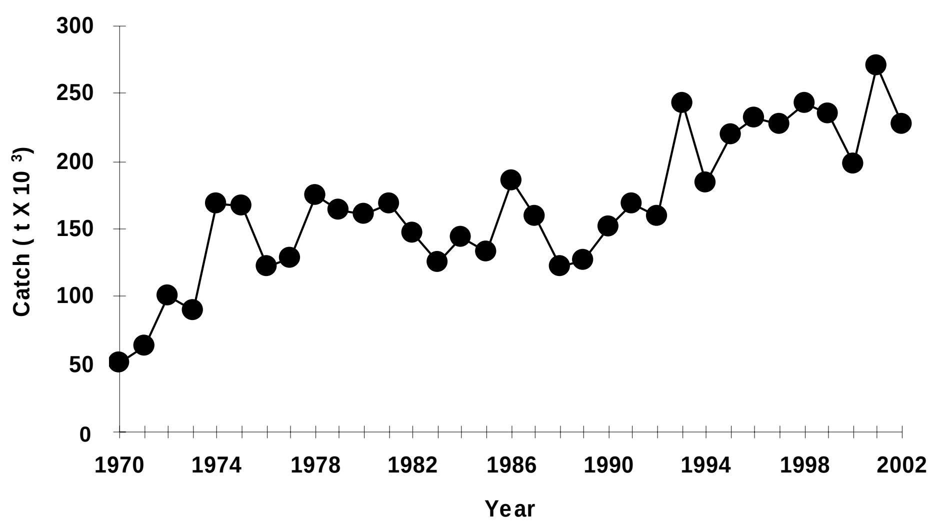

Fig. 55 Annual catches of anchovy in the Yellow Sea and the East China Sea from 1970 to 2002.

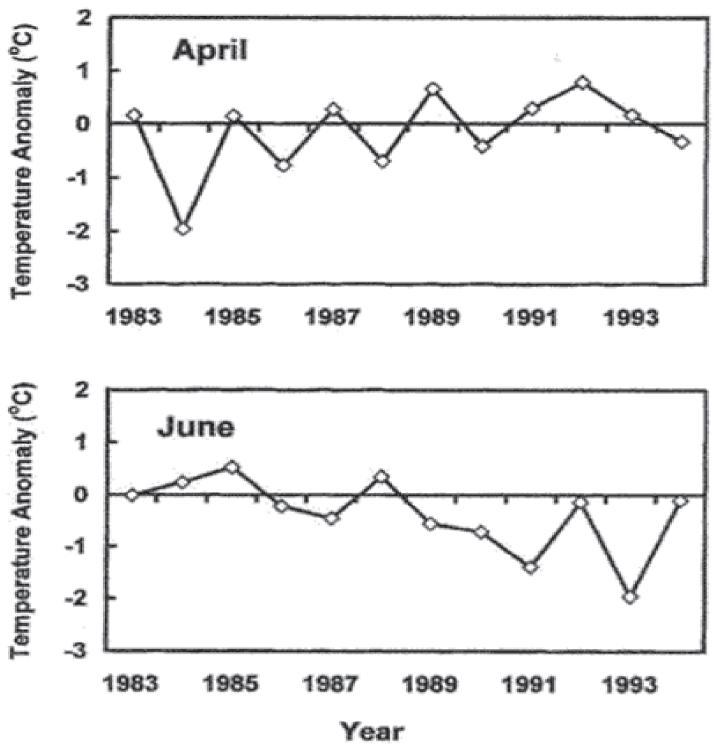

Fig. 56 Yearly variation of seawater temperature anomaly at 10 m depth in the southern waters of Korea from 1983 to 1994. Mean temperatures in April and June are 14.28 ° and 19.78 °C, respectively.

Table 26 Estimates and coefficients of variation (CVs) of daily egg production and mortality rate of the anchovy embryonic stage in spring and summer for three periods: 1983–1986, 1987–1989 and 1990–1994 (Kim and Lo, 2001).

	Number of samples		Egg production		Mortality at embryo stage	
Season and period	**Total**	**Positive station**	**Production (m^{-2})**	**CV**	**Mortality (day^{-1})**	**CV**
Mid 1980s (1983–1986)						
Spring (May)	171	137 (80%)	385.62	0.38	1.23	0.44
Summer (July)	140	111 (79%)	1356.19	0.39	0.78	0.81
Late 1980s (1987–1989)						
Spring (May)	105	68 (65%)	144.07	0.41	0.41	0.77
Summer (July)	106	88 (65%)	531.73	0.45	0.87	0.84
Early 1990s (1990–1994)						
Spring (May)	93	53 (57%)	174.29	0.23	0.33	0.53
Summer (July)	63	47 (75%)	1163.94	0.33	1.69	0.27

Table 27 Selected correlation coefficients, which are statistically significant for fish catch versus their biotic and abiotic environmental factors.

Variable	**Anchovy** *Engraulis japonica*	**Mackerel** *Scomber japonicus*	**Sardine** *Sardinops melanosticta*
Anchovy	1.0	0.790**	0.453*
Mackerel	0.790**	1.0	0.602**
Sardine	0.453*	0.602**	1.0
SST (Dec.)	0.419*	0.436*	0.327
Chl-*a* (Apr.)	0.186	0.019	0.561**
Chl-*a* (Jun.)	0.635**	0.523**	0.264
Chl-*a* (Aug.)	0.442*	0.377	0.276
Zooplankton (Feb.)	– 0.559**	– 0.406*	– 0.339
Zooplankton (Apr.)	– 0.304	– 0.408*	– 0.291
Copepods (Apr.)	0.563*	0.434	– 0.398
Copepods (Jun.)	0.121	0.571*	–0.042
Copepods (Dec.)	0.635*	0.477	– 0.277
Chaetognaths (Apr)	0.647**	0.307	– 0.499*
Chaetognaths (Oct.)	0.728**	0.512*	– 0.321
Chaetognaths (Dec.)	0.558*	0.129	– 0.427
Euphausiids (Jun.)	0.349	0.356	– 0.550*
Euphausiids (Dec.)	0.768**	0.603*	– 0.492
Amphipods (Apr.)	0.713**	0.504*	– 0.395
Amphipods (Dec.)	0.712**	0.616*	– 0.423

Sampling month in parenthesis; * indicates that the correlation is significant at the 0.05 level, and ** at the 0.01 level (Kim and Kang, 2000).

Japanese sardine (*Sardinops melanostictus*)

Biology

Sardines spawn off the southern waters of the Korean Peninsula from December through June with a peak spawning period in February to April. They migrate north in the summer to feed around 45°N along the eastern coast of the Peninsula and in November, move south to the southern coast. They recruit to the fishery at age 1 and mature at age 3.

Fishery

Japanese sardine catches show two high peaks in the northwestern Pacific in the 20th century: the late 1920s to the early 1940s and the mid-1970s to the early 1990s. In Korean waters, a peak harvest of 1,388,000 t was recorded in 1937. Catches declined over a period of 25 years from the mid-1940s to the 1960s. Sardine catches increased rapidly from about 38,000 t in 1980 to 200,000 t in 1987. However, they declined again from the late 1980s. Annual catches of sardines fell below 2,000 t from 2000 to 2002 (Fig. 57).

Climate and ocean effects

The intensity of the Kuroshio Current has increased since 1976. As a result the intensity and frequency of spring blooms has decreased in the East/Japan Sea and the intensity of autumn blooms has increased. Sardines are resident in the East/Japan Sea from June to November. Thus an autumn bloom is more advantageous to them than a spring bloom, and this may account for the dramatic increase in the sardine stock after 1976 (Zhang *et al.*, 2000). Sardine catch is positively correlated with Chl-*a* concentrations in April and negatively correlated with chaetognaths in April and euphausiids in June (Kim and Kang, 2000; Table 27).

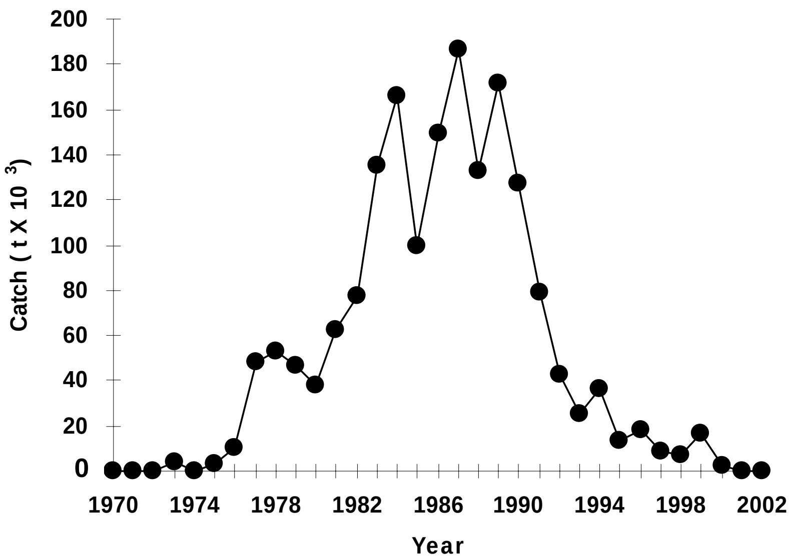

Fig. 57 Annual catches of Japanese sardine in the Yellow Sea and the East China Sea from 1970 to 2002.

The abundance and geographical coverage of sardine eggs and larvae were high in the 1980s when spawning biomasses were high in the mid-1980s, and vice versa in the late 1970s and the early 1990s. Decadal-scale changes in seawater temperature at 50 m depth during spring indicated warm temperatures in late 1970s followed by cool waters during the early to mid-1980s, and warm again since the late 1980s. Feeding and spawning areas, based on fisheries information, also exhibited the same pattern of extension and contraction as seen in ichthyoplankton surveys. The annual gonado-somatic index in spawning seasons (February–April) and the size of sardines were reduced during the high abundance period. It is possible that density-dependent processes affect the life-history parameters of the sardine populations in Korean waters (Kim *et al.*, 2006).

Chub mackerel (*Scomber japonicus*)

Biology

Chub mackerel that migrate throughout warm water are widely distributed and caught in the western, southern, and southeastern seas around the Korean Peninsula, in the East China Sea, and around Japan. This species is distributed on the continental shelf from the surface to 300 m depth in the Yellow Sea and the East China Sea (Fig. 58). Chub mackerel spawn from February to May when the water temperature ranges from 15° to 23°C. They migrate to the wintering grounds between Jeju Island and Tsushima Island in the East China Sea from December to February. The fecundity of chub mackerel ranges from 112,000 to 570,000 eggs, and the fork length of 50% mature females is 28.7 cm (Choi, 2003).

The mean length of chub mackerel has tended to decrease since the 1970s, and the portion of small mackerel has increased (Fig. 59). The fork length was about 32 cm in the early 1970s, but it has continuously decreased, and the mean fork length in 2002 was 29.2 cm. Some biological parameters, such as natural mortality, maturity length, and recruitment age have been estimated (Table 28).

Fishery

About 70 to 80% of the worldwide total catch of chub mackerel occurs in the northwestern Pacific Ocean by countries including Korea, Japan, and China (FAO, 2000). Korean annual catches were below 100,000 t until the mid-1980s, and increased to 150,000 t in 1988 and 1989 (Fig. 60). The annual catch was just 100,000 t in the early 1990s. However, it started to increase to over 150,000 t from the mid-1990s and reached its highest level of 415,000 t in 1996. Currently the catch is about 170,000 t. This species is usually caught by large purse seines, drift gill nets, and set nets in Korean waters. About 90% of the total chub mackerel catches are from the large purse seine fishery, mainly in the East China Sea and in the western and southeastern seas of Korea.

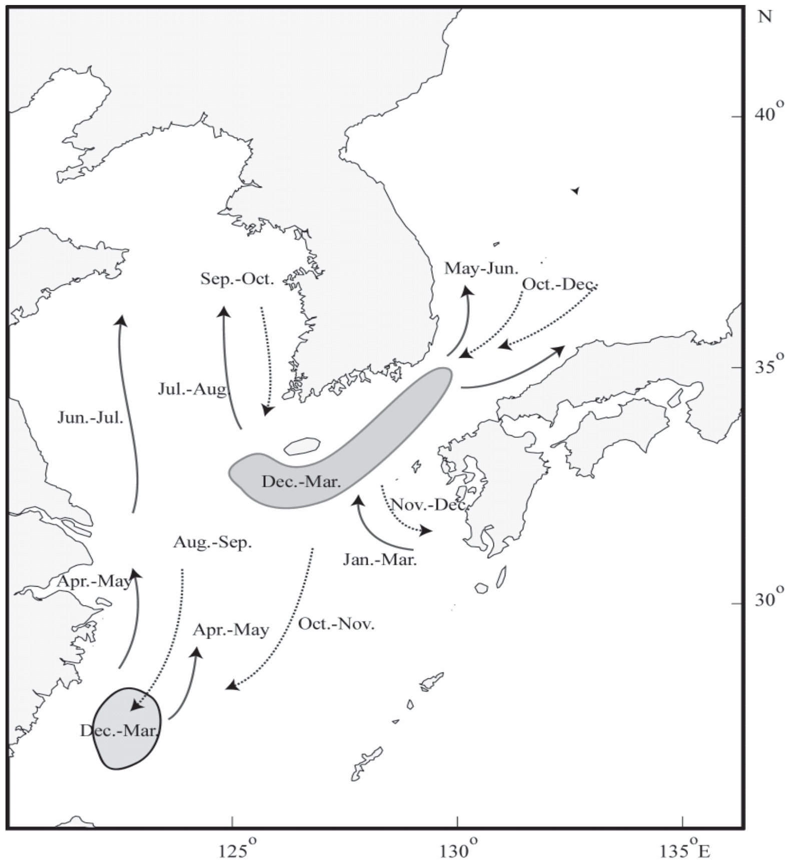

Fig. 58 Seasonal migration route of chub mackerel near the Korean Peninsula.

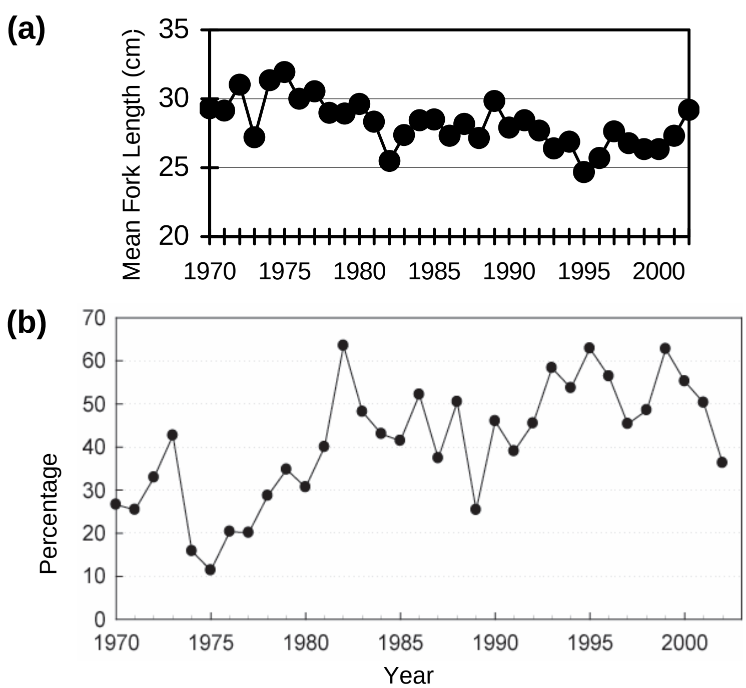

Fig. 59 (a) Long-term variation of mean fork length of captured mackerel, and (b) percentage of fish smaller than the 50% maturity length of the total mackerel catch from Korean waters.

Table 28 Estimated biological parameters of chub mackerel.

Parameters	Estimates	Addition
Natural mortality	0.6 $year^{-1}$	
Maturity length (50%)	24.0 cm	fork length
Recruitment age	0.5 year	
Mean length (2002)	29.2 cm	fork length
Mean age (2002)	2 years	

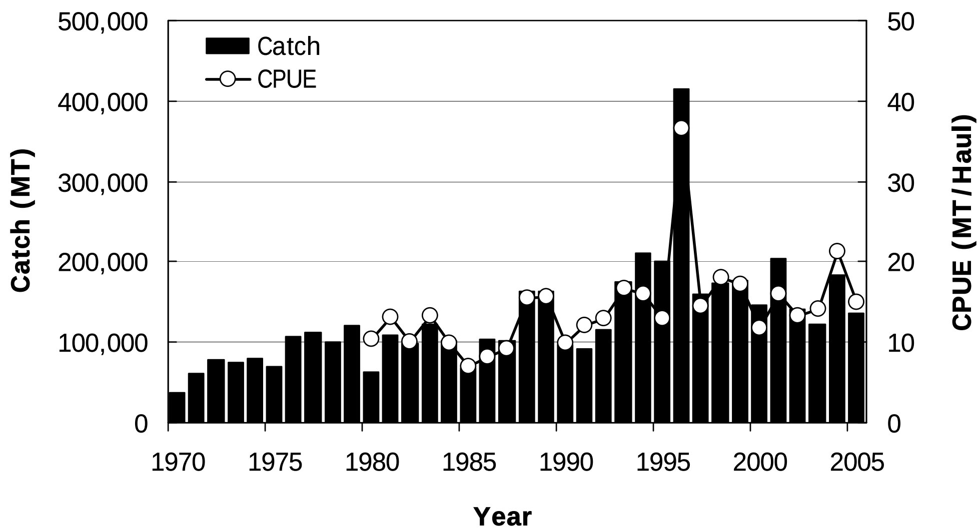

Fig. 60 Trend in annual catches and catch per unit effort (CPUE) of chub mackerel in Korean commercial fisheries in Korean waters from 1970 to 2006.

Climate and ocean effects

A significant change in recruitment was found in correlation with salinity (r = 0.454, P < 0.05), with zooplankton biomass (r = 0.692, P < 0.01), and with copepod biomass (r = 0.815, P < 0.01) (Choi *et al.*, 2000). Also, chub mackerel catches were highly correlated with SST in December, Chl-*a* in June, and large zooplankton in the fall and early winter (Table 27).

Chub mackerel share 35.7% of their habitat with both jack mackerel and Pacific sardine, and 28.6% with jack mackerel or 3.1% with Pacific sardine in Korean waters (Zhang and Gong, 2005). The 1988 climatic regime shift affected the habitat of chub mackerel by widening and moving it to the west of 128°E (Fig. 61). After 1988, the distributional overlap of chub mackerel and jack mackerel decreased. These shifts in the habitats of jack mackerel and chub mackerel resulted in Japanese sardines occupying a habitat area separated from the shared mackerel distributions. Replacement in biomass between chub mackerel and Japanese sardine stocks resulted from the competition of prey and space among major small pelagics in Korean waters (Zhang *et al.*, 2000).

Jack mackerel (*Trachurus japonicus*)

Biology

This species migrates to the northern East China Sea during January–March and to the spawning grounds near the western Kyushu Islands and areas between Jeju Island and Tsushima Island during April–May (Lee, 1970; Nakashima, 1982). Jack mackerel spawn when water temperatures range from 16° to 22°C. In the East China Sea, the main distribution area of larvae is the Kuroshio frontal region along the continental margin in the winter and spring. The species usually feeds on zooplankton, including larvae of anchovy and big-eye sardine (*Etrumeus teres*). As the fish grow older, they move to deeper water and feed on larger prey, such as amphipods and mysids, but usually not copepods (Cha, 1991).

There is evidence that the recruitment of jack mackerel is determined by the degree that eggs and larvae are affected by environmental factors. These factors are seawater temperature, salinity, volume transport of the Kuroshio Current, and zooplankton biomass in Korean waters (Zhang and Lee, 2001). Significant increases in salinity in April, volume transport of the Kuroshio Current, and zooplankton biomass were observed and were significantly correlated with increased recruitment of jack mackerel in the following year (Table 29).

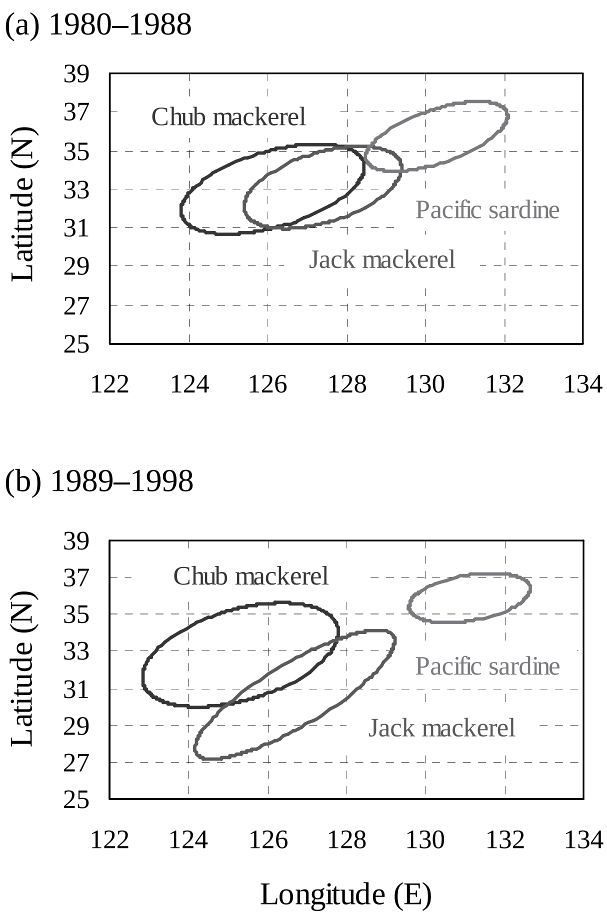

Fig. 61 Joint confidence regions in the habitat of major small pelagics in Korean waters during the periods of (a) pre- and (b) post-1988 climatic regime shift (Zhang *et al.*, 2004). Ellipses of the fishing block weighted by catch per unit effort (CPUE) were calculated for each species in the Korean large purse seine fishery.

Fishery

Jack mackerel (*i.e.*, horse mackerel) are widely distributed and caught in the Yellow Sea, the East China Sea, and the southern East/Japan Sea (Kim, 1970). They are usually caught by large purse seines, bottom trawls, and drift gill nets in Korean waters. About 80% of the total catches are from the large purse seine fishery, mostly in the East China Sea waters of Korea. Annual catches reached their highest level of 48,000 t in 1956, and then declined below 10,000 t in the late 1960s. In the early 1980s, the annual catch increased and has been about 23,000 t in recent years (Fig. 62). Over the past 70 years, the pattern of catch has been characterized by a cyclic behavior with a relatively low frequency of 30 years and a high coefficient of variation (CV) of 0.79.

Climate and ocean effects

The volume transport of the Kuroshio increased after 1977. The salty Kuroshio Warm Current intensified the Tsushima Warm Current connected with the Kuroshio in the inshore waters of southern Korea. Warm, saline waters had a positive correlation with the density of jack mackerel (Cho, 1981). Therefore, the increase in salinity of the East China Sea may have triggered the increases in the recruitment and biomass of jack mackerel in the early 1980s, resulting in increased catches.

The effects of the early 1980s environmental shift are hypothesized to have affected the productivity of the jack mackerel population (Fig. 63). As the volume transport of the salty Tsushima Warm Current increased, resulting in higher salinity in the East China Sea, spawning grounds for jack mackerel became more ideal. Consequently, high concentrations of the spawning stock were observed in this area. As the intensity of the Tsushima Warm Current increased, the variation of zooplankton biomass in the East China Sea waters of Korea was expected to correspond to the variation of stratification of ocean structure. Since the thermocline in the East China Sea is formed at 30 to 50 m depth, and the water is relatively shallow (75 to 150 m; NFRDI, 2005) where photosynthesis can be active in all seasons, the increase in zooplankton biomass may not have been directly related to the primary production in the early 1980s in the East China Sea waters of Korea. The increase of recruitment and biomass in the plankton-feeding jack mackerel stock after the early 1980s can be attributed to the aggregation of the spawning stock and the increase of prey in the East China Sea (Zhang and Lee, 2001).

Jack mackerel share 63.4% of their habitat with chub mackerel in Korean waters (Zhang and Lee, 2001). Jack mackerel share 36.6% of their habitat with both chub mackerel and Japanese sardine, and further, were not found to co-exist with Japanese sardine exclusively during the period from 1980 to 1998 (Fig. 61). The 1988 climatic regime shift affected the habitat of jack mackerel by shifting it southward to 27°N. After 1988, the distributional overlap of jack mackerel and chub mackerel decreased. These shifts in the habitats of jack mackerel and chub mackerel resulted in Pacific sardine occupying a habitat area separated from the shared mackerel distributions (Zhang *et al.*, 2004).

Table 29 Correlation coefficient matrix between the recruitment of jack mackerel and environmental factors (Zhang and Lee, 2001).

	Recruitment	Temperature	Salinity	Volume transport	Zooplankton biomass
Recruitment	1.000	–	–	–	–
Temperature	0.043	1.000	–	–	–
Salinity	0.529**	0.153	1.000	–	–
Volume transport	0.487**	–0.264	0.230	1.000	–
Zooplankton biomass	0.547**	–0.288	0.248	0.399*	1.000

** $P < 0.01$, * $P < 0.05$

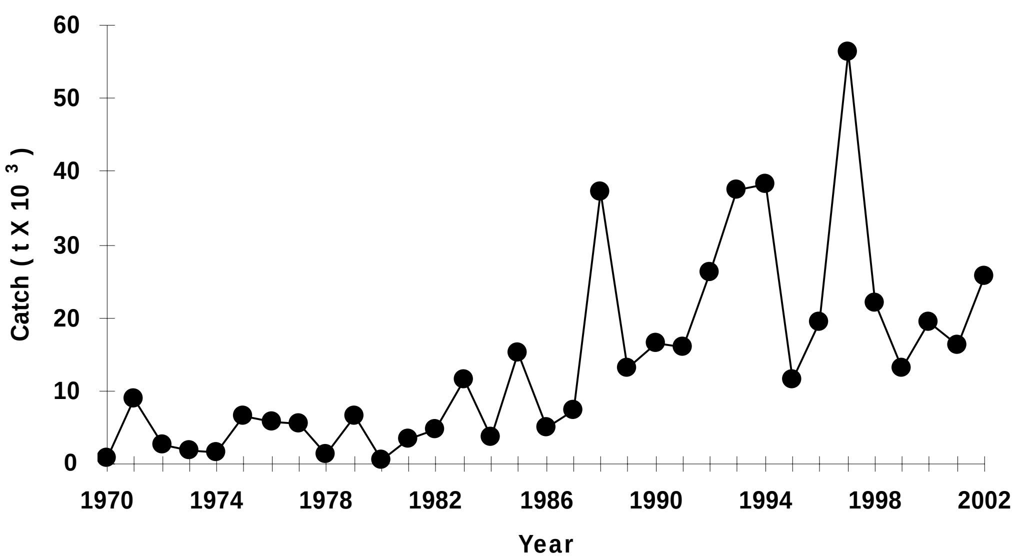

Fig. 62 Annual catches (t) of jack mackerel in Korean waters from 1960 to 2002.

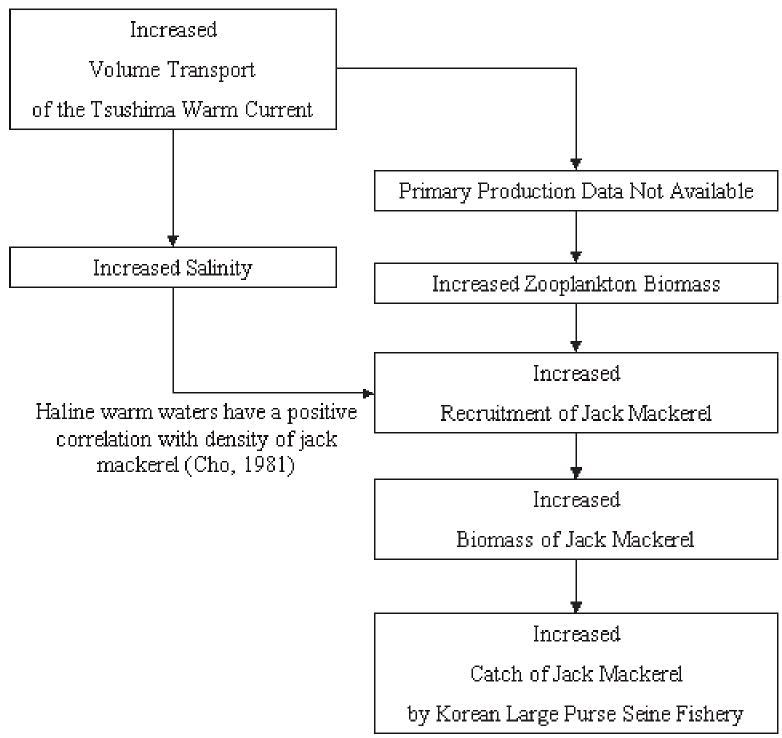

Fig. 63 Diagram showing the effects of the early 1980s climate regime shift on the jack mackerel population, based on the bottom-up hypothesis (Zhang and Lee, 2001).

Filefish (*Thamnaconus modestus*)

Biology

Filefish are a subtropical species that spend the winters in the East China Sea. They begin to migrate within the warm current in April, moving to the East/Japan Sea and the Yellow Sea. The northward migration to the East/Japan Sea along the Korean coastline begins in May, and some schools reach the northern Korean Peninsula coastal areas where they spend the summer. Eggs and larvae are advected by currents so that their distributions extend to the northern part of the East/Japan Sea. Another group that migrates to the Yellow Sea occupies the entire Yellow Sea in June, migrating southward beginning in October. Filefish are distributed from 5 to 200 m depth at seawater temperatures of 10° to 28°C. Spawning is from April to June. The total length at 50% maturity is 21 cm, and fecundity ranges from 210,000 to 1,460,000 eggs. The longevity of filefish is estimated to be 8 years, which corresponds to a total length of about 30 cm.

Fishery

Annual catches of filefish in Korean waters increased from 80,000 t in 1975, to about 230,000 t in 1979, and then declined slightly. After the mid-1980s catches increased sharply and peaked at 330,000 t in 1986. Catches fluctuated from the late 1980s to 1990, and dropped to 70,000 t in 1991, where they have remained at a very low level (Fig. 64).

Climate and ocean effects

Filefish productivity increased after 1976 when the warm currents became stronger (Fig. 65). There were some indications of climate regime shifts occurring in 1976 and around 1987 to 1989 in Korean waters. The indicators of these shifts were the patterns of seawater temperature, precipitation, volume transport of the Kuroshio, and mixed layer depth. Seawater temperature in the East/Japan Sea increased significantly in 1976 and 1987. In addition, precipitation and mixed layer depth in the East/Japan Sea, and the volume transport of the Kuroshio increased in 1976 and 1977. The increased volume transport of the Kuroshio in the East China Sea resulted in a strong influx of the Tsushima Warm Current into the Korea Strait and the East/Japan Sea.

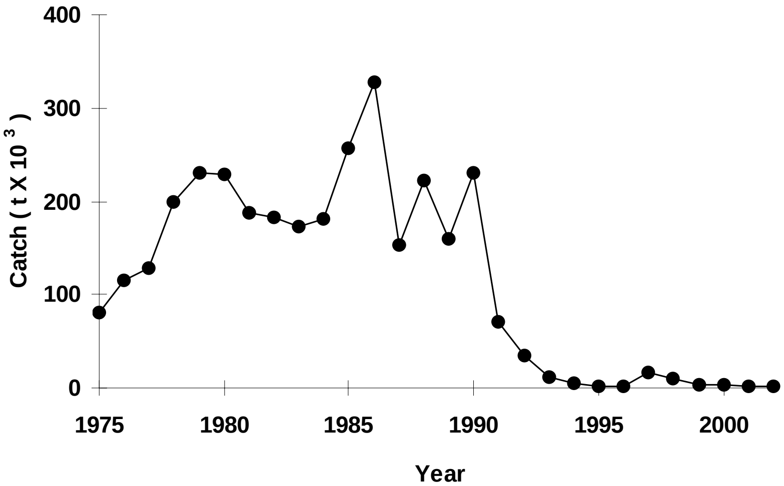

Fig. 64 Annual catches (t) of filefish in Korean waters from 1975 to 2002.

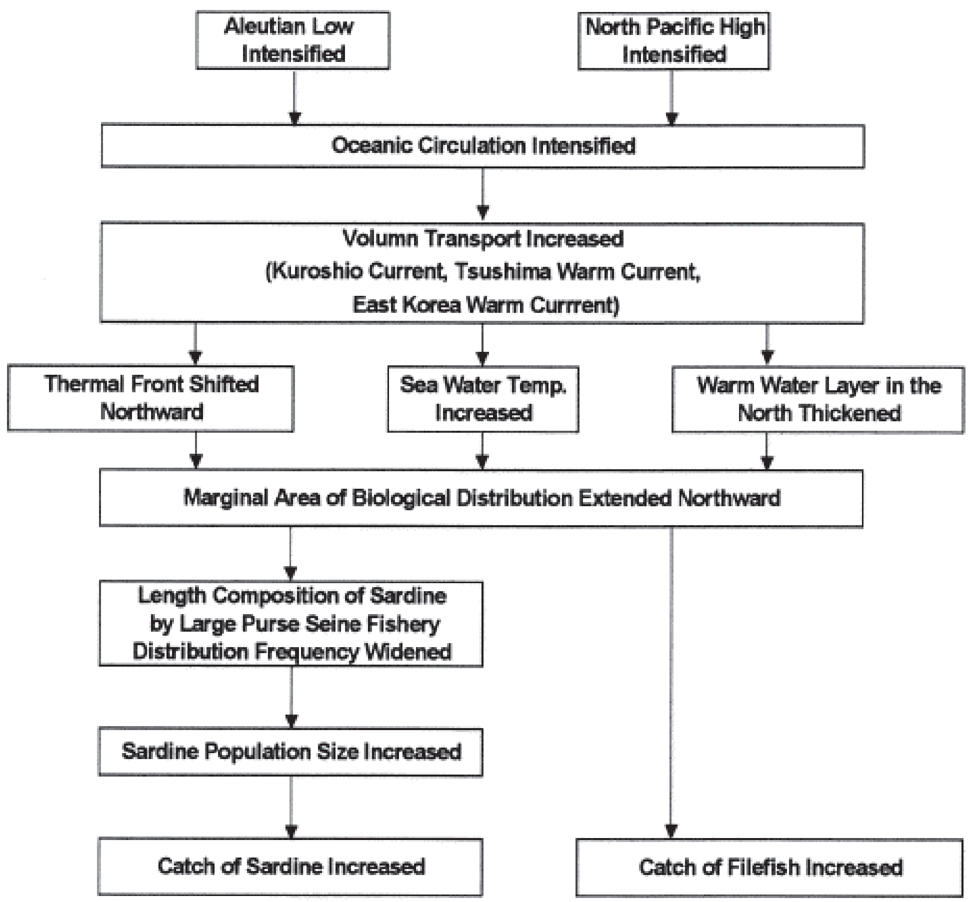

Fig. 65 Diagram showing the effects of the 1976 climate-driven regime shift on the filefish population in Korean waters (Zhang *et al.*, 2000).

Pacific saury (*Cololabis saira*)

Biology

The distribution of Pacific saury is determined by seawater temperature and salinity. They are not distributed in the western East China Sea and Yellow Sea, where salinity is low, but mainly reside in the East/Japan Sea and around Hokkaido. The migration area of Pacific saury has been limited to within the Tsushima Warm Current system. The stock that spends the winter near western Kyushu (January–March) moves to Ulleung Island in April to June. The southward migration of Pacific saury begins in September and reaches Tsushima Island in November to December.

Pacific saury are distributed from the surface to 30 m depth at seawater temperatures of 7° to 24°C. They spawn twice a year, in the spring and in autumn. The fork lengths at 50% maturity of the spawning groups in the spring and autumn are 22 and 30 cm, respectively, and the spawning periods are April to July and October to November, respectively. Fecundity ranges from 20,000 to 85,000 eggs. The longevity of Pacific saury is estimated to be 3 years, which corresponds to a length of about 35 cm.

Fishery

Pacific saury are caught mainly by stick-held dip nets and drift gill nets in Korean waters. Annual catches have fluctuated during the last four decades. The annual average catch was 25,000 t in the 1960s and early 1970s, but it started to decline sharply from 1976, dropping to about 2,000 t in 1984. Catches reached a minimum level of 500 t in 1992. They increased after the mid-1990s, and have fluctuated between 5,000 and 20,000 t in recent years (Fig. 66).

Climate and ocean effects

The increased volume transport of the Kuroshio in the East China Sea resulted in a strong influx of the Tsushima Warm Current into the Korea Strait and the East/Japan Sea that followed along into the North Pacific Current during the climate-driven regime shift in the mid-1970s and 1980s. Heavy rain, higher sea surface temperatures, unusual northward shifting of the polar front, and increased thickness of the warm water layer in the north resulted in a northward shifting of the overwintering ground of Pacific saury and an earlier-than-normal migration of the species to the spawning and feeding areas south and north of the polar front in the spring (Fig. 67).

The area of a stable thermocline in the coastal zone was reduced because of unusual westward and northward shifting of the polar front, which resulted in the reduction of primary production. The critical depth barely exceeded the deeper-than-normal mixed layer depth in the winter and early spring in the spawning and feeding grounds of Pacific saury during the early phase of the regime shift (1975–1977). Therefore, the delayed onset of the spring bloom of plankton (prey) and the earlier-than-normal arrival of spawning groups of Pacific saury resulted in the mismatch of prey and predator (larvae and

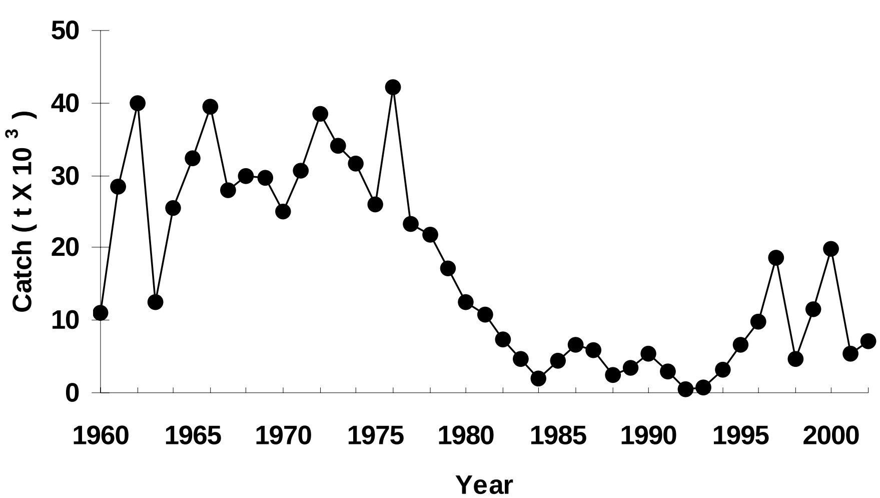

Fig. 66 Annual catches (t) of Pacific saury in Korean waters from 1960 to 2002.

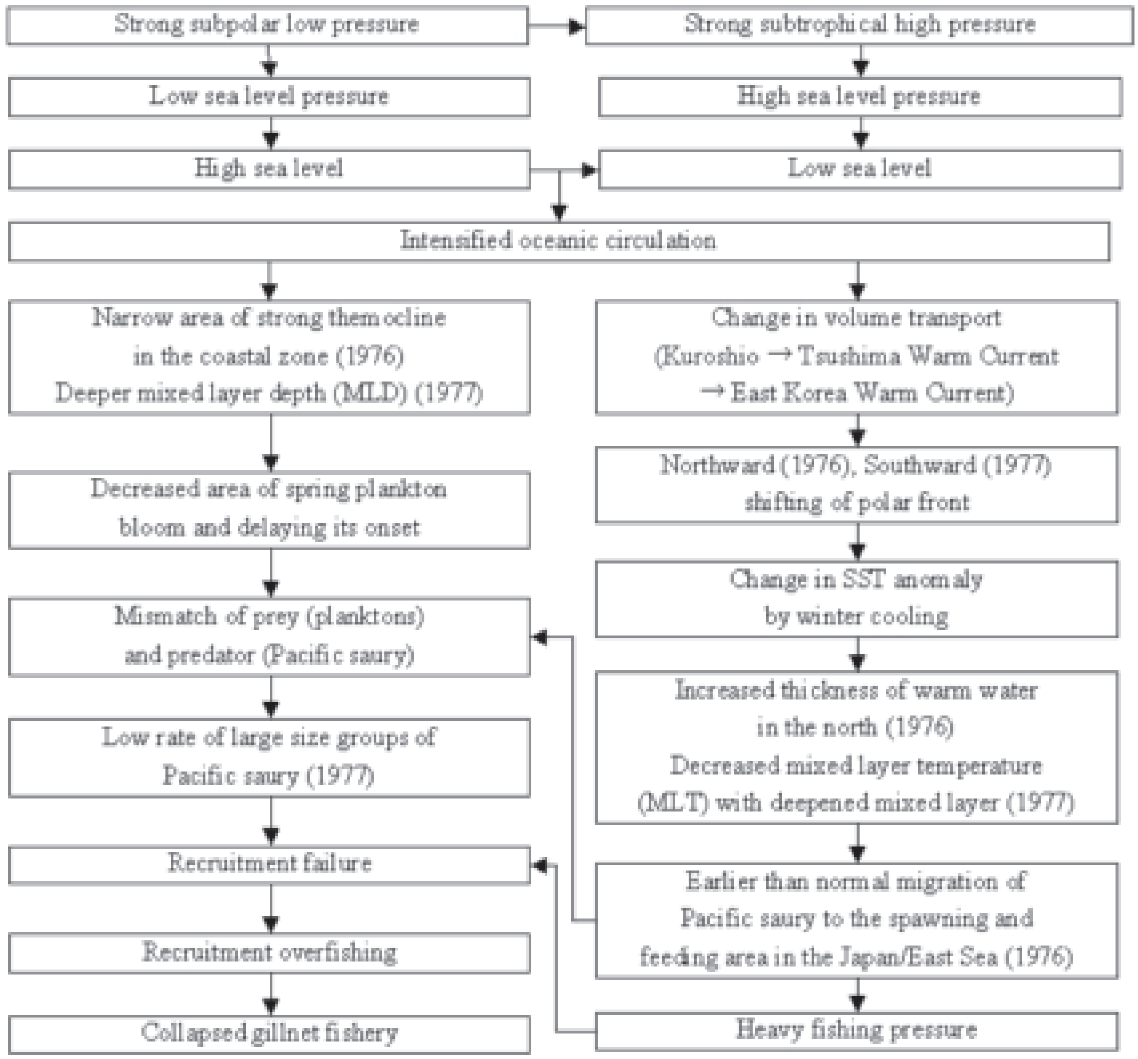

Fig. 67 Diagram showing the effect of the 1976 climate-driven regime shift on Pacific saury in the East/Japan Sea in the mid-1970s (Zhang and Gong, 2005).

adult) in the spawning and feeding grounds. The dramatic decrease in the ratio of the large size group of Pacific saury and abrupt drop of catches and abundance may have been caused by heavy fishing under the destructive recruitment failure and mass mortality of Pacific saury in the mid-1970s (Zhang and Gong, 2005).

Skipjack tuna (*Katsuwonus pelamis*)

Biology

Skipjack tuna is an epipelagic fish, occurring in waters ranging from 15° to 30°C. In the western Pacific, they have been captured as far north as 44°N off Japan, and as far south as 37°S off Australia (Forsbergh, 1980). However, in the eastern Pacific, they have been fished along the west coast of the Americas from 34°N off southern California to 27°S off northern Chile (Williams, 1970). This is due to the westward transport of warm surface waters and their poleward displacement along the western coast.

In warm equatorial water, skipjack tuna spawn year round. Sexual maturity may occur in fish as small as 40 cm in length (Matsumoto *et al.*, 1984). However, most fish appear to mature at larger sizes. Larger females produce significantly more eggs than smaller females, with the average adult producing 80,000 to 2 million eggs per year. Skipjack tuna feed primarily upon fishes, crustaceans, and mollusks. Cannibalism is common within this species as well. Their diet appears to be very broad and suggests an opportunistic method of feeding. Schools of skipjack are commonly found near convergences and upwellings.

Fishery

Skipjack tuna catches have been increasing at a rapid and fairly constant rate since the early 1970s. In the 1970s, the development of bait boat fisheries in Papua New Guinea and the Solomon Islands and the expansion of the Japanese distant-water, bait boat fishery led to the first large increases. In the 1980s, the development of large-scale purse seining in the Western Pacific Ocean (WPO) and the subsequent influx of vessels from several distant-water fishing nations resulted in further increases. In the 1990s, the policy of many canneries was not to buy tuna caught in association with dolphins, which has resulted in the relocation of many purse seiners to the WPO. This policy brought about further increases in the skipjack tuna catch in the WPO.

Korean fleets started to operate in the central WPO (WCPO) in the 1980 to 1981 season when large-scale purse seining developed in this area. Along with the increase in the number of fishing vessels, the fishing grounds expanded, and the catch increased. Since the catch first recorded over 100,000 t in 1990, it has increased to 174,000 t in 2002.

Climate and ocean effects

More than five major countries are catching skipjack tuna living in warmer waters other than in the WCPO. Korea is one of the major countries operating in these waters, along with Papua New Guinea, Japan, U.S., and Taiwan. The Korean catch was 153,328 t out of 823,849 t in total for the WCPO in 2003. Even though the Korean catch was not the main component of the total WCPO, (about 18% of total catch) the Korean data reflect a tendency similar to that of the whole WCPO data (R = 0.901**) (Fig. 68).

Korean fishing grounds have changed in time and space. As reported by Lehodey *et al.* (1997), computed longitudinal gravity centres of CPUE (G) from Korean fishery data were shifted toward the east during El Niño years (1986/87, 1991/92, 1997/98) (Fig. 69). The location of G and catch were compared with some environmental factors, such as the SOI, SST in NIÑO3.4, and SST in the main fishing ground (140°–170°E) to find some relationship between them. G shows a high correlation with ENSO factors: SOI (R = – 0.652*) and SST in NIÑO3.4 (R = 0.498*), and catch is significantly correlated with SST in the main fishing ground (R = 0.314*) (Table 30). Cross-correlation analysis with a time lag indicates that the evolution of the SOI and SST in NIÑO3.4 preceded the CPUE gravity center by four months (R = – 0.73**) and three months (R = 0.643**), respectively (table not shown).

There was no seasonality in the biological characteristics (length and GSI) of skipjack tuna. However, ENSO significantly affected skipjack length and maturation, though SST at 140–170°E (*i.e.*, distribution area of skipjack tuna) did not have influence. SOI and SST in NIÑO3.4 may have previously affected the fish length by 6 to 7 months ahead of time. Maturation was affected by environmental components about a year ahead.

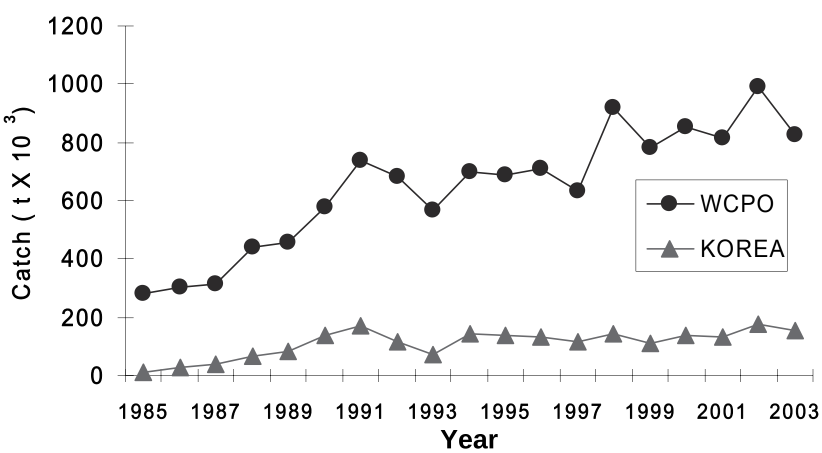

Fig. 68 Annual catches of skipjack tuna in the Western Central Pacific Ocean (WCPO) and Korea from 1985 to 2003.

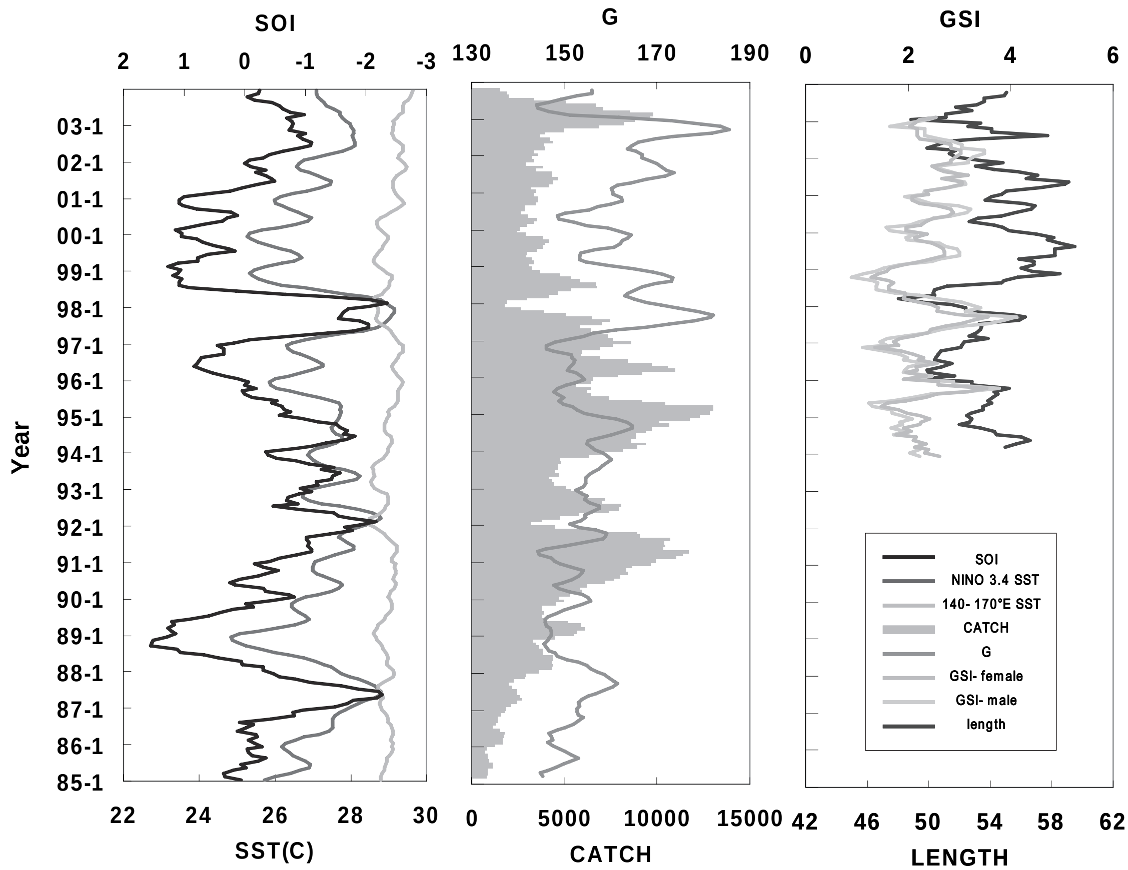

Fig. 69 Fluctuation of abiotic (SOI, SST) and biotic (G, catch (t), fork length (cm), GSI) factors with time. Monthly fluctuation of each factor was smoothed with a 5-month moving average. SOI, SST, G, and GSI represent the Southern Oscillation Index, sea surface temperature, computed longitudinal center of CPUE, and gonadal-somatic index, respectively.

Table 30 Correlation coefficients between environmental indices and fisheries/biological factors during the period 1985 to 1996. SOI, SST, NIÑO3.4, G, Catch, Length, and GSI indicate Southern Oscillation Index, sea surface temperature, the area confined by 5°N–5°S and 120–170°W, computed longitudinal center of catch per unit effort, monthly catch in the main fishing area, monthly mean fork length, and gonadal-somatic index, respectively.

	G	Catch	Length	GSI-male	GSI-female
SOI	– 0.652*	– 0.096	0.273*	– 0.350*	– 0.234**
SST in 140–170°E	– 0.252*	0.314*	– 0.193**	– 0.007	– 0.007
SST in NIÑO3.4	0.498*	0.107	– 0.367*	0.388*	0.254*

* P < 0.01, ** P < 0.05.

Common squid (*Todarodes pacificus*)

Biology

The life span of common squid is assumed to be 1 year (Nakamura and Sakurai, 1993), and their spawning season is spread throughout the year. As suggested for common squid in Japanese waters (Okutani, 1983; Yamada *et al.*, 1986), three spawning groups of common squid have been identified in Korean waters: summer (June–August), autumn (September–November) and winter (January–March) (Kim *et al.*, 1997). Male common squid mature about 2 months earlier than females. Females mature 2 or 3 weeks after mating. Once mature females spawn, they die (Yamada *et al.*, 1986; Ikeda *et al.*, 1993). Individuals are differentiated by mantle length, and the mantle sizes for winter, summer, and autumn spawning subpopulations have been measured at 24, 23 and 27 cm, respectively (Yamada *et al.*, 1986).

Stomach contents of the common squid consist of fish, cephalopods, crustaceans, algae, and unidentified matter. Fish are generally the most preferred prey. Although the major food items of summer and autumn populations are fish, those of the winter population are cephalopods. Algae and crustaceans are minor food sources. The three spawning groups seem to mix genetically, and contain the same stomach contents (Kim and Kang, 1998).

Fishery

In the East/Japan Sea, squid catches were at low levels (around 50,000 t) until the late 1980s, but increased rapidly after the early 1990s. Annual catches of squid ranged from 100,000 to 250,000 t during the 1990–2002 period (Fig. 70). The main fishing grounds of the squid angling fishery start to move to the north in the East/Japan Sea in April and to the south in September. The condition of common squid fishing largely depends on the fluctuation of water temperature in the southeastern coastal area. It is concluded that the high stability of water temperatures and the weak strength of cold water are the reasons for the good fishing conditions of common squid (Park *et al.*, 1998).

When catches were low in 1980s, the proportion of autumn spawners (*i.e.*, September and October) was the highest among spawning populations. However, as catches increased in the 1990s, the highest proportion of spawners shifted to November and December (Fig. 71). The increased catch from late autumn and early winter caused difficulties in distinguishing autumn and winter spawners. The amount of autumn catch was about double that of the winter catch during the 1980s, but catch levels were almost same in both populations during the 1990s. During the early 1990s, there was a rapid increase in winter catch while the autumn catch steadily increased (T. Sakurai, pers. comm.).

Climate and ocean effects

In the East/Japan Sea, squid catches increased continuously after the early 1990s. A correlation analysis was performed to evaluate the relationship between squid catch and zooplankton biomass (Table 31). In the northern and southern regions, the sum of squid catches from September to December is significantly correlated with zooplankton biomass except in two cases in the northern region: the sum of December (n – 1 year) and February, and February and April. The sum of zooplankton biomass in October and December in the n – 1 year showed the highest significant correlation with squid catches ($r = 0.864$ in the northern region and $r = 0.818$ in the southern region, $P < 0.001$). The squid catch is significantly associated with the abundance of euphausiids ($r = 0.578$ in the northern region and $r = 0.840$ in the southern region, $P < 0.05$) and amphipods ($r = 0.695$ in the northern region and $r = 0.648$ in the southern region, $P < 0.01$).

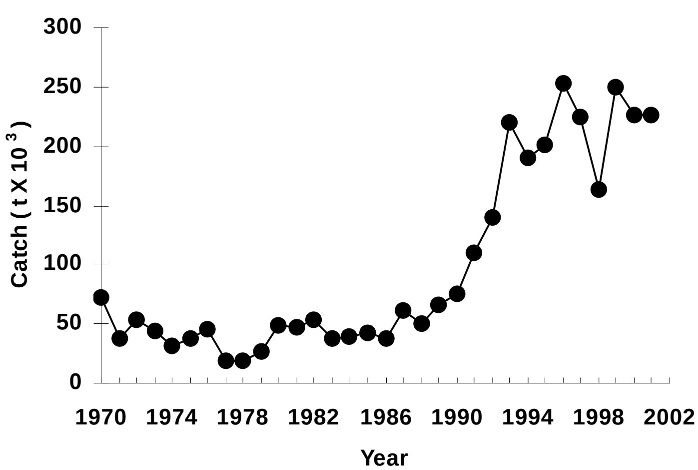

Fig. 70 Annual catches (t) of common squid in Korean waters from 1970 to 2002.

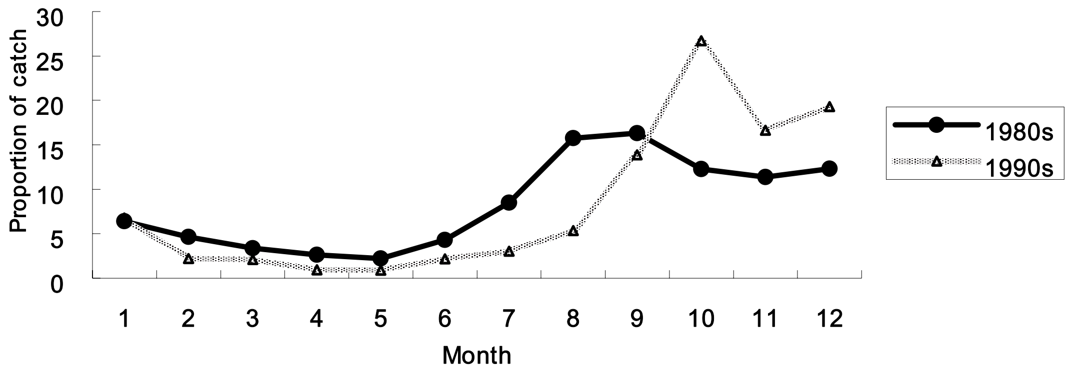

Fig. 71 Mean proportions of monthly catch of common squid in Korean waters during the 1980s and 1990s.

Table 31 Correlation coefficients between squid caught from September to December and zooplankton biomass in northern and southern regions in the East/Japan Sea (Kang *et al.*, 2002).

Variable of zooplankton biomass	Region	
	Northern	**Southern**
Sum of October and December (n – 1 years)	0.864***	0.818***
Sum of December (n – 1 years) and February (n year)	0.441	0.639**
Sum of February and April (n year)	0.402	0.654**
Sum of April and June (n year)	0.603**	0.679**
Sum of June and August (n year)	0.506*	0.575*

Correlation is significant at *0.01 < P < 0.05, **0.001 < P < 0.01, ***P < 0.001.

Variable	Region	
	Northern	**Southern**
Copepoda	– 0.188	0.152
Euphausiid	0.578*	0.840**
Amphipoda	0.695**	0.648**
Chaetognatha	0.371	0.496*

Correlation is significant at *0.01 < P < 0.05, **0.001 < P < 0.01.

Zooplankton biomass in October and December in the previous year showed a higher significant correlation with squid catches in September to December. Catch in October and December produced squid less than 10 cm in mantle size than in the previous year. Thus, zooplankton are more important for squid at the juvenile stage than for the adults, and it contributed to increased squid stocks after 1990. Of the four major zooplankton taxa, euphausiids and amphipods were significantly related with the squid catch. This shows that zooplankton, in particular euphausiids and amphipods, are very important for young squid in the East/Japan Sea. It is concluded that the most important factor for increased squid catches is increased zooplankton biomass, especially euphausiids and amphipods (Kang *et al.*, 2002).

Seawater temperature might be the most important parameter controlling stock abundance. When squid catches increased in the early 1990s, the SST in Korean waters increased at the same time. In particular, seawater temperature during winter seemed to be more important than during other seasons. When the winter temperature rose in 1990s, the winter population of common squid also showed a rapid increase compared to the autumn population.

Speculations on the Impact of Greenhouse Gas-induced Climate Change

This chapter speculates on the relationship between environmental changes and fish species in Korean waters. Environments are variable over time, and fish have a relatively routine life history. Fish spawning is influenced by some abiotic environmental factors, such as temperature, and their growth and survival are controlled by the abundance of prey and predators surrounding them. In order to figure out the ecological mechanisms, however, it requires extensive survey efforts, and a multi-disciplinary approach is essential to explain the relationship. In general, the marine ecosystems in Korean waters are varied and complex because large-scale climate events, such as ENSO, monsoons and the PDO, have an impact on water properties indirectly or directly. The fish species also exhibit numerous patterns of behavior. Oceanography and the biology of fish have not been extensively studied. Therefore, due to limited scientific knowledge, we are limited in explaining the relationship between climate change and marine ecosystems, including fish populations in Korean waters. Below is a brief speculation of the environmental impacts on major fish species around the Korean Peninsula.

Walleye pollock

Walleye pollock are a cold-water, demersal species and their spawning grounds in Korea are located at the southern limit of their distribution. They spawn in shallow bays off Korean Peninsula (Won-San Bay in the Democratic People's Republic of Korea), and juveniles might stay in the upper layer near the coastal areas. Although adults show demersal behavior, a future warming trend of SST might force fish distribution from south to north. The catch is traditionally made up of juveniles who would have to migrate into the fishing areas from the north. Furthermore, warming of the spawning grounds could be detrimental to the spawning adults, as well as to their early life stages. A general warming trend in the future, therefore, would probably result in low pollock abundance, although the impact of regimes would result in periods of cooler SST when pollock might return.

Chum salmon

Chum salmon are a cold-water species that stay in the surface layers of the ocean through most of their life cycle. Salmon hatcheries in Korea are at the southern range of their distribution and would be expected to be negatively affected by a warming of the ocean surface. Hatcheries could maintain a production of salmon fry, but ocean survival would be reduced, especially if there is higher seawater temperature at the timing of fry release. Production is affected by regimes which would suggest that there will be periods in the future when the marine survival of chum salmon would improve. However, a general warming trend in Korean waters would probably result in low chum salmon abundance and a low returning rate, even though climate/ environmental changes in the open ocean could also have a strong impact on the growth of chum salmon populations.

Small yellow croaker, hairtail, filefish

In the Yellow Sea, environmental conditions are influenced by many factors, such as the Kuroshio, seasonal monsoons and winds, and river runoff. Because of its shallow bathymetry, the Yellow Sea does not have truly demersal fish populations. However, in contrast to pelagic fish species, such as anchovy, some species (*e.g.*, small yellow croaker, hairtail, and filefish) locate in the relatively deep waters in the center of the southern Yellow Sea and the East China Sea.

The recruitment success of small yellow croaker is dependent upon seawater temperature, and consequently, catches would be improved 8 to 10 months later if warm and stable conditions formed at 75 m depth during the early life stages. However, the relationship between surface and bottom layers, and the cause–effect mechanism between environment and organisms have not been identified. There are too many unknown factors in the Yellow Sea ecosystem to determine the impact of warming on demersal fish species.

As we showed for small yellow croaker, it is not possible to speculate on the impact of global warming on demersal species, such as hairtail and filefish because the biology and ecology of these species is mostly unknown. One study on filefish indicated that catches were high in the 1980s and low in the 1990s. If the Aleutian Low intensifies under a global warming scenario, the volume transport of the Kuroshio would also increase which should favor improved filefish productivity. However, different fish species have different life cycles and habitat areas, and large-scale climate change might not show the same common effects for all fish species.

Anchovy, Japanese sardine, mackerels and common squid

In Korean waters, the portion of small pelagic fish species (anchovy, Japanese sardine, mackerels and common squid) has been increasing. In recent years, ten major small pelagic species have occupied 60 to 70% of the total catch, and common squid alone accounted for 20 to 25%. In many ecosystems around the world, abundance of anchovy follows trends that are opposite to those of the sardine. In Korean waters, however, an alternation between anchovy and sardine was not evident. There is improved larval survival and growth when the Tsushima Warm Current is strong near the coast of Korea, but it is not yet known what the relationship is between warming and Kuroshio strength.

There was a dramatic increase in sardine abundance after 1976, indicating that there are trends in abundance. The increase in abundance was related to an increase in the intensity of the Kuroshio and the increase in the plankton bloom in the autumn. One scenario for global warming forecasts is that there will be more frequent, intense Aleutian Lows which suggests that there will be more frequent periods typical of ocean conditions observed in the 1980s. If this is correct, periods of sardine abundance may be more frequent.

Chub mackerel and anchovy abundances increased in the mid-1990s, a period of high SST in December. ENSO might have an influence on seawater temperature in December. An elevated seawater temperature due to ENSO seemed to cause a high rate of growth and a good year class of those populations in Korean waters (Kim and Kang, 2000). In addition, there is clear evidence that climate, and climate shifts, affect the production of chub mackerel. More intense Aleutian Lows and a positive PDO may have a negative impact. Jack mackerel production follows a cyclic pattern of about 30 years.

There were large increases in the abundance of common squid in the 1990s when SST increased. If there are more frequent periods of intense Aleutian Lows, then abundance would decrease. However, if wind intensity is reduced and SST increased, then common squid will become more abundant.

Pacific saury

The abundance of Pacific saury is related more to the ENSO than to the PDO. The period of more frequent and intense El Niños in the mid-1990s appeared to be favorable for Pacific saury production. If wind intensity is reduced as a result of global warming, and El Niños become more frequent, Pacific saury production may increase. However, an intensification of the Aleutian Low may reduce abundance.

Skipjack tuna

ENSO evidently has an effect on skipjack tuna biology as well as its fishery. However, the relationship between ENSO and the global warming trend (*i.e.*, increase in greenhouse gas) is not clearly understood in tropical waters.

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