Russia

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The Fishery

Total catch of marine commercial resources in the Russian Exclusive Economic Zone (EEZ) increased from 1980 until 1986, and then declined (Table 32). In 1988, there were large landings of two highly abundant species: walleye pollock and Pacific sardine. These two species made up about 80% of the Russian total catch in the 1980s. In general, the late 1980s and early 1990s were years of high abundance of walleye pollock and sardine stocks. In the 1990s walleye pollock stocks declined, resulting in a general decline in catches. In 1992, no Pacific sardines were harvested commercially in the Russian EEZ as a result of a natural decline that was related to changes in the climate and ocean. Pacific herring catches grew from 2.5 to 25% from 1985 to 2000 as a result of an increase in herring stock abundance in 1990. In the late 1990s, the share of pink salmon catch increased 2 to 3 times compared to 1980s, and constituted 9% of the total catch. Variability in catch data for other fishes was also observed, *e.g.*, during 1985–2000, the share of flatfishes and cod increased in the total catch.

In this report we consider how climate and ocean conditions have affected the abundance and catch of key species in the fishery since 1980 (Table 33). From 1980 until about the mid-1990s, the species examined here represented over 80% of the catch. In the early 1990s, they represented larger percentages of the catch, exceeding 90% of the total catch (Table 33).

Climate and Ocean Influences

Inter-annual, decadal, and long-term variability in the climate and ocean cause considerable rearrangements in marine communities. Historically, there were warm and cold periods. Assuming long-term variability with natural cycles lasting hundreds of years, the last large cold period was 13 to 18 centuries ago (a small “ice age”). The average global temperature has risen gradually since the mid-19th century (Fig. 72). In this case, the 20th century belongs to the recent warm epoch. Shorter

Table 32 Total catch (t) of all marine fishes off the Pacific coast of Russia (FAO data).

Year	Catch
1980	3,200,111
1981	3,501,358
1982	2,927,611
1983	4,139,148
1984	5,351,074
1985	5,351,074
1986	5,701,672
1987	5,357,587
1988	5,198,130
1989	4,838,540
1990	4,363,064
1991	3,867,734
1992	3,144,203
1993	2,673,173
1994	2,192,418
1995	2,733,097
1996	2,979,211
1997	3,004,145
1998	2,839,042
1999	2,414,667
2000	2,190,343
2001	2,010,554
2002	1,554,057

cycles of 2 years to decadal periods can be distinguished within these longer cycles. It is very important to take into account natural cycles of both short-term and longer duration to properly forecast future changes (Shuntov, 2001). Some data show that 40- to 60-year-long cycles can be of primary importance (Klyashtorin and Sidorenkov, 1996; Shuntov *et al.*, 1997). These cycles significantly influence the environment, providing inter-decadal faunal changes and long-term fluctuations in various species. Shorter cycles may also have an impact on marine communities and species dynamics, but their effect is much smaller.

In the last century, the first period of warming lasted 30 years, from 1920 to 1940. At that time, summer seasons could be described as the first "sardine epoch" of the 20th century. Large-scale migrations of subtropical, and even tropical, fishes and other southern species occurred into the Far Eastern temperate waters.

The second period of warming lasted from 1970 to the 1980s. These years were characterized by the second rise in Pacific sardine abundance, and by warm-water species migrations to the Far Eastern region. During that period, the temperature was generally higher than in the 1920s and 1930s (Fig. 72).

Table 33 Catches (t) of key species in the Russian fishery and total catch as a percentage of the total catch of all species (FAO, 2000).

	1980	1985	1990	1995	2000
Pink salmon	77,367	85,976	71,374	139,369	132,851
Chum salmon	14,556	20,556	23,602	12,632	21,944
Sockeye salmon	1,629	3,260	5,177	5,998	12,676
Walleye pollock	2,111,669	3,343,034	2,863,937	2,208,410	1,215,065
Pacific herring	79,251	189,584	97,357	116,787	361,241
Pacific saury	38,600	23,423	72,618	25,140	17,390
Pacific sardine	359,289	748,158	879,393	0	0
Pacific cod	23,346	188,443	121,397	100,730	68,415
Total	2,710,187	4,602,434	4,134,855	2,609,066	1,829,582
Total all species	3,200,111	5,351,074	4,363,064	2,733,097	2,190,335
% of total of all species	84.6	86.0	94.8	95.5	83.5

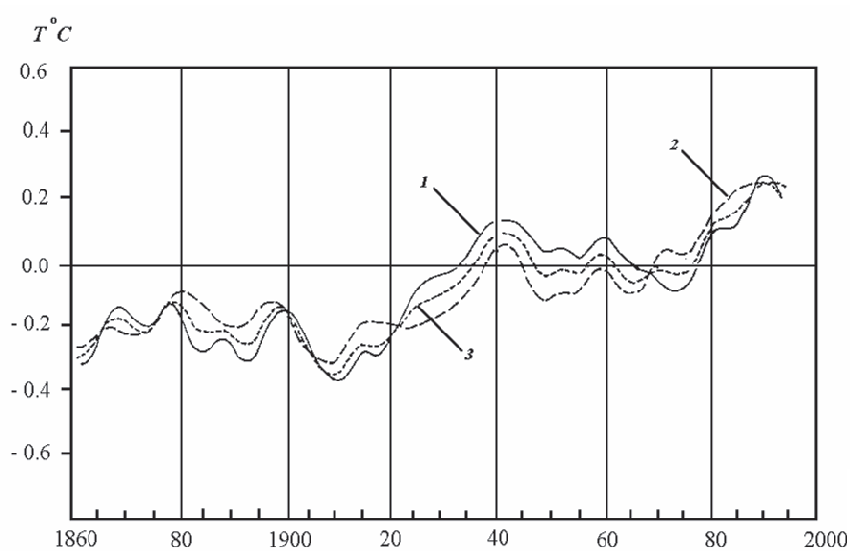

Fig. 72 Anomaly of integrated temperature over land and ocean surface temperature from 1880 to 1993: 1 indicates northern hemisphere, 2 indicates southern hemisphere, and 3 refers to global (Halpert *et al.*, 1994).

The last warm period was longer, with a gradual rise in temperature (Fig. 72). Recently, marine communities have become influenced by a temperature decline that started in the mid-1990s. At the same time, the average global temperature remains high. Pacific sardine abundance decreased in the early 1990s. Considerable rearrangements in nekton and plankton communities of the Far Eastern seas were noticed at that time (Shuntov, 1986; Klyashtorin and Sidorenkov, 1996; Shuntov *et al.*, 1997).

There are a lot of arguments in favour of both global warming and cooling. A compromise might be to describe it as, “cooling on the background of global warming” (Anonymous, 1993), which does not either support or refute the concept of greenhouse gas-induced climate change. This compromise in wording suggests that there can be an interaction between climate cycles of different duration and character.

In the 20th century, the human impact on nature started to have a negative on the environment. As a result, numerous investigations of the anthropogenic influence on climate took place. In these studies, the greenhouse effect that resulted from carbon dioxide increase in the atmosphere, as well as other sources of air pollution, was considered. The effect of these factors on temperature can be mutually exclusive. Speaking of the human impact on climate change, we should also keep in mind that there were warm periods even greater than the recent one in the history of the Earth. Climate changes that historically appeared as alterations of warm and cold periods are proceeding as natural cycles with regional features (Shuntov, 2001). This was observed in the Far Eastern seas at the brink of the 20th and 21st centuries. Cyclic changes in atmospheric processes over, and ice conditions in, the Far Eastern seas have shown that after the very hot year of 1997, ocean temperature cooled in the Far Eastern seas (Glebova, 2002). Most data sets were obtained during TINRO-Centre research cruises in the Okhotsk Sea, the main area for Russian commercial fishery operations (Shuntov *et al.*, 2002). After 1997, considerable cooling was observed judging from average water temperature (Table 34), ice conditions (Fig. 73), and the extent of cold areas (Figs. 74 and 75). Similar trends were observed in the western Bering Sea where the late 1990s, as well as 2001 and 2002, were relatively cold (Radchenko, 2001; G.V. Hen and others, pers. comm.). Environmental processes were not always synchronous in the northwestern and southwestern parts of the sea, which also showed considerable annual variability. Around the Kuril Islands (Fig. 76), variability patterns, including circulation and temperature, were different from the adjacent Okhotsk Sea area. In some years that were cold in the northern Okhotsk Sea, there were positive temperature anomalies along the Kuril Islands (Samko and Novikov, 2002).

Key Species in the Fishery

Pink salmon (*Oncorhynchus gorbuscha*)

Biology

Pink salmon are the most numerous among the Pacific salmon species, constituting about 40% of the biomass and 60% of the number of total salmon landings in the North Pacific Ocean. Pink salmon have the shortest and simplest life cycle. As soon as the fry leave their spawning sites, they migrate downstream into the sea where they grow first in the coastal areas and then in the central North Pacific Ocean. After 12 to 14 months, maturing individuals come back to their native rivers to spawn and die.

The freshwater natural habitat of pink salmon includes Asian and North American rivers north of approximately 40°N. Pink salmon are distributed north of 40°N in the sea, and dwell in southern areas in winter. In spring, as soon as the water warms, they move northward to their spawning streams. The spawning period lasts from June to November, depending on the region.

Table 34 Average water temperature (°C) at 50 at 200 m depth on the western Kamchatka shelf (April) and in the northern Okhotsk Sea (May–June) from 1996 to 2000 (Ustinova *et al.*, 2002).

Region	1996	1997	1998	1999	2000
Western Kamchatka shelf	0.40	1.13	0.01	– 0.25	– 0.28
Northern Okhotsk Sea	– 0.45	– 0.12	– 0.72	– 0.94	– 0.98

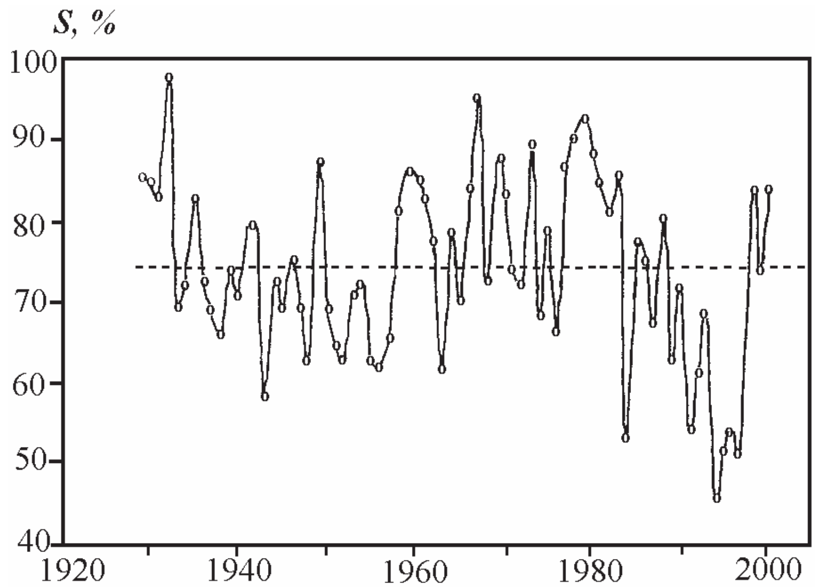

Fig. 73 Ice conditions in the Okhotsk Sea in March and the average long-term value (dashed line) (Ustinova *et al.*, 2002).

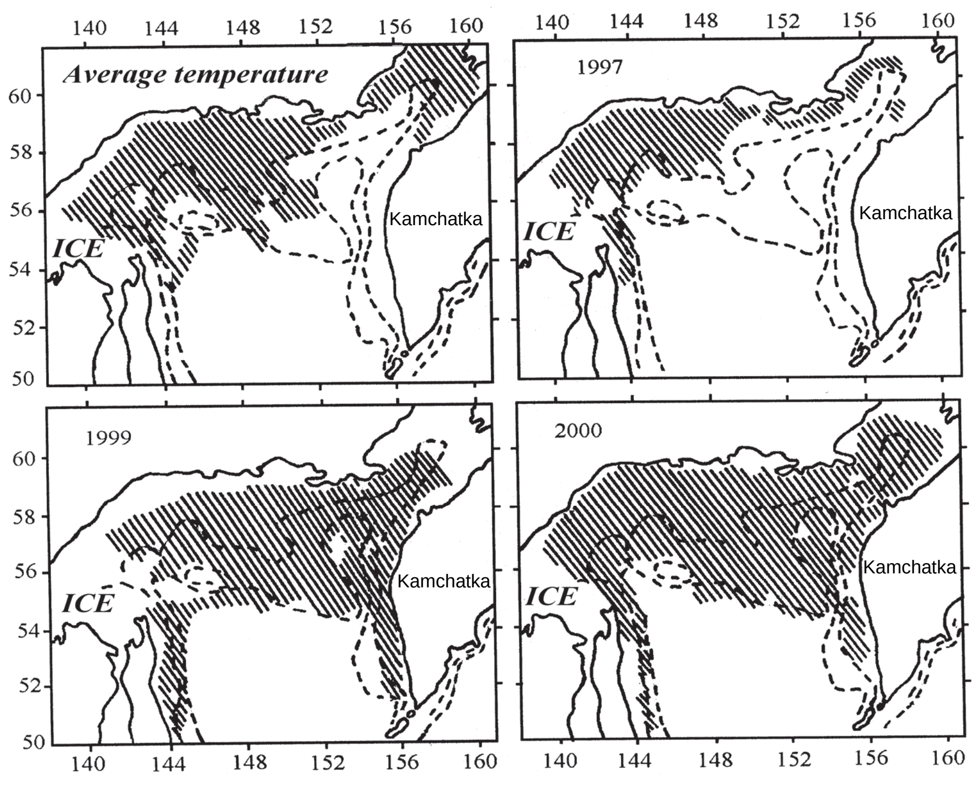

Fig. 74 Distribution of subsurface cold waters (shaded area) with temperatures less than 1°C in the core of the cold intermediate layer for the Okhotsk Sea in May–June (Khen *et al.*, 2002). Dashed lines indicate bathymetry.

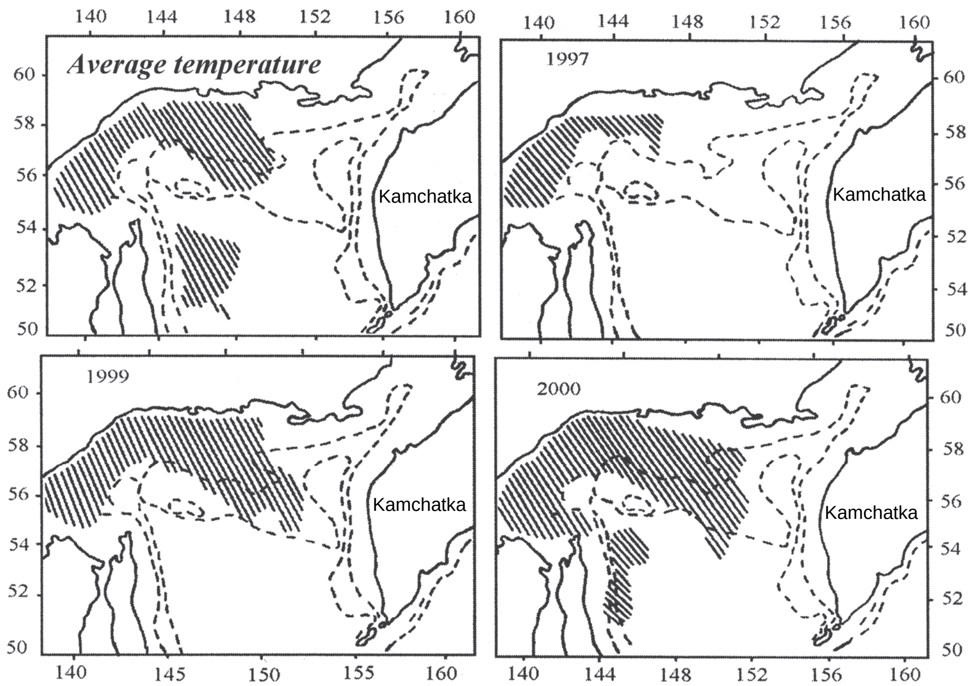

Fig. 75 Distribution of subsurface cold waters (shaded area) with temperatures less than 1^{o}C in the core of the cold intermediate layer for the Okhotsk Sea in September (Khen *et al.*, 2002). Dashed lines indicate bathymetry.

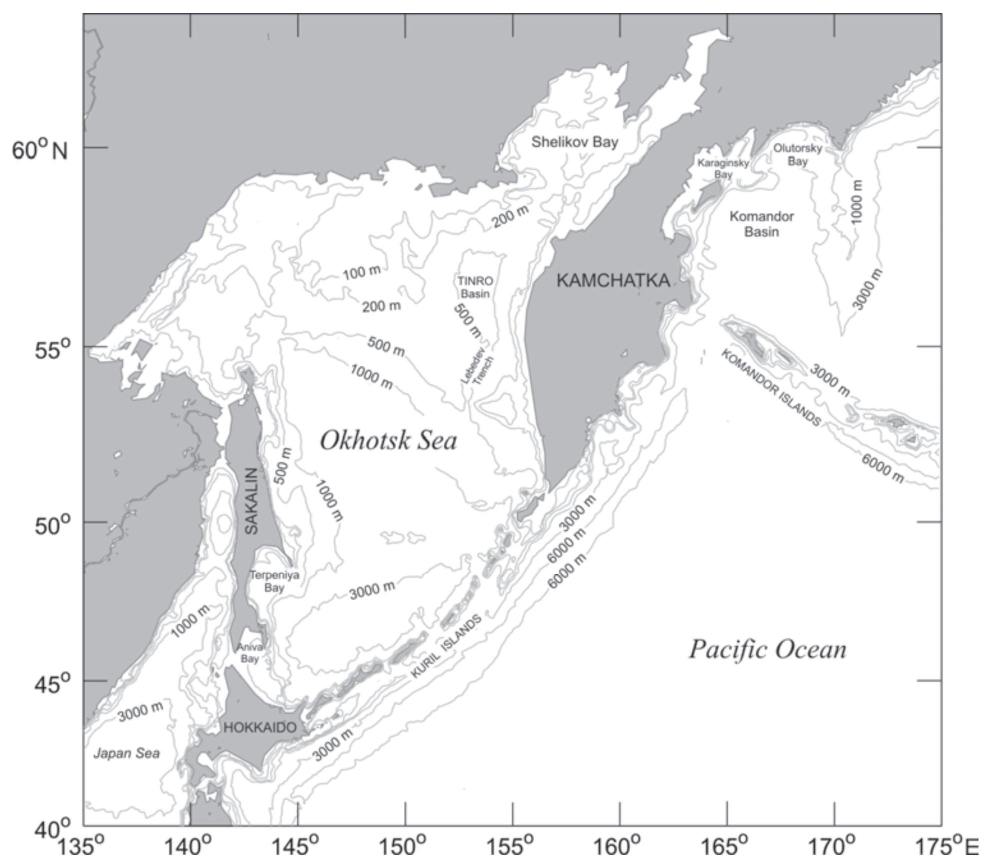

Fig. 76 Map of the Okhotsk Sea and Kamchatka area.

Pink salmon differ from other Pacific salmon species because (1) they have a 2-year life cycle; (2) mature individuals are the smallest of all the species, (1.0 to 2.5 kg, on the average); (3) young fish leave the spawning sites and migrate downstream immediately after hatching (chum salmon also behave this way), and (4) mature males possess a distinctive hump. The 2-year cycle results in reproductively isolated generations of odd and even years that may differ in abundance. Today, in eastern Kamchatka, odd-year generations of pink salmon are more numerous, while in western Kamchatka even-year broods are more abundant. However, this odd- and even-year behaviour can change and deviations from the 2-year life cycle may occur. Unlike other Pacific salmon species, pink salmon do not conduct long-distance spawning migrations up rivers. Most reproduce close to the river mouth, usually within 10 km of the ocean. The homing instinct is rather weakly developed in this species, and some individuals can stray for several hundreds, and even thousands, of kilometres away from their native places. Pink salmon individual fecundity varies from 900 to 2,700 eggs, with an average range of 1,300 to 1,600 eggs.

Fishery

Pink salmon are fished only in the coastal areas of Russia. Most of the fish are harvested as they migrate along the shoreline and approach their natal rivers. Large stationary traps are usually placed along the coast near the spawning river mouths, with a lead stretching from the shore area to the trap. Pink salmon catches increased in the 1980s and 1990s for both even- and odd-year runs (Table 35). Even-year catches were largest in 1998 as were odd-year catches in 1991; however, catches have remained high relative to the early 1980s. Landings of pink salmon in the Russian EEZ (Fig. 77) from 1971 to 2002 show that during the last 5 odd years, reserves have remained at a high level. The average annual catch for odd years is about 128,000 t. The biggest catches of pink salmon for odd years take place in three areas: eastern Kamchatka, and the eastern Sakhalin and southern Kuril islands. The rivers on the west coast of the Okhotsk Sea provide a considerable contribution to the total catches. During the last 2 odd years in particular, catches of pink salmon have increased on the eastern coast of Sakhalin Island.

Table 35 Pink salmon catches (t) off the Pacific coast (FAO and NPAFC data).

		NPAFC[1]	
Year	**FAO**	**Russia**	**Asia**
1980	77,367	79,300	99,700
1981	79,813	87,900	113,600
1982	42,157	47,800	68,600
1983	96,270	107,700	133,000
1984	50,537	56,700	75,500
1985	85,976	96,400	123,700
1986	37,988	41,000	56,700
1987	92,311	98,800	118,200
1988	36,808	40,700	56,500
1989	144,748	149,600	167,200
1990	71,374	76,100	88,900
1991	216,124	211,900	230,800
1992	79,414	87,300	107,400
1993	104,855	113,000	138,000
1994	117,533	126,300	157,200
1995	139,369	148,300	172,600
1996	104,377	110,900	143,700
1997	169,070	190,200	206,100
1998	177,382	193,000	218,200
1999	158,560	188,500	205,300
2000	132,851	148,600	175,400
2001	149,421	171,200	181,600

[1] Eggers *et al.* (2003); NPAFC – North Pacific Anadromous Fish Commission

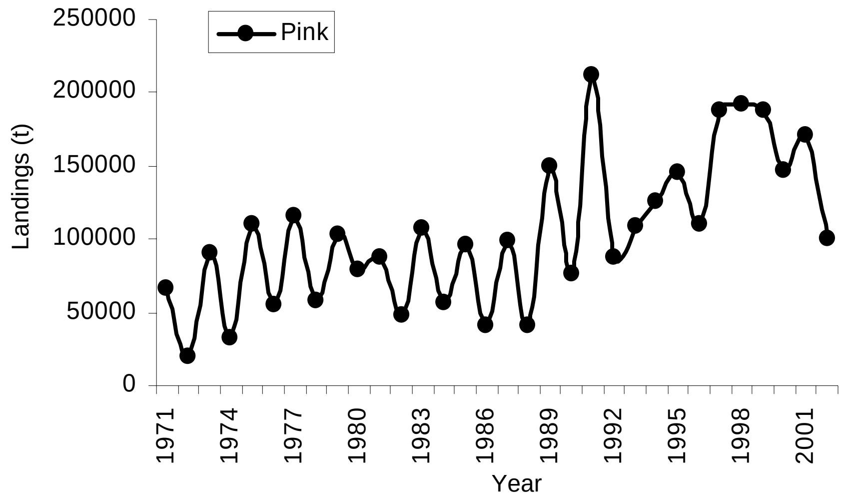

Fig. 77 Annual landings (t) of pink salmon in the Russian Exclusive Economic Zone (EEZ).

Climate and ocean effects

In the 1990s, the dynamics of climatic processes over the North Pacific appear to have become unfavourable for salmon production (Beamish and Bouillon, 1993; Chigirinsky, 1993). However, pink salmon are the most difficult of all the salmon species to forecast future runs. Currently, the even-year stocks are very productive in western Kamchatka and in the southern Kuril Islands; if this situation continues, a return comparable to the high harvest levels of 1920–1930 could occur (Radchenko, 1998).

Chum salmon (*Oncorhynchus keta*)

Biology

Asian chum salmon consist of numerous reproductively isolated local populations that differ in some biological traits. The population structure is complicated by geographical differences and seasonal races. Young chum salmon migrate early from the spawning grounds, mostly as fry, though some migrate later. In Kamchatka, the fry migrate from early April to July, with a peak in mid-May to early June. In the Anadyr River, fry begin downstream migrations in late May to early June. In the northern Okhotsk Sea, fry migrate from May until June, with a maximum run in early June.

In summer, in the coastal areas of the Russian Far Eastern seas, juveniles are present from late July until early August. Yearlings migrate to the southeastern Bering Sea by late November. While in the southern Okhotsk Sea, they may feed until early winter because of favourable hydrologic conditions. In the Okhotsk Sea, the yearlings feed primarily on amphipods (*Themisto japonica* and *Primno abissalis*) and euphausiids (*Thysanoessa longipes* and *Euphausia pacifica*). Pteropods, copepods, and tunicates are of less importance in their diet.

During the winter–spring feeding period in the open ocean, chum salmon live primarily within the area of subarctic and subtropical water masses, where the temperature ranges from 3° to 11°C. By late May, age 2+ chum salmon migrate back to the Kuril, Aleutian and Komandor islands and enter the Okhotsk and Bering seas. The Bering Sea serves as the main feeding area for immature fish during the summer, while the Okhotsk Sea is less important. In general, the distribution of older chum salmon in the Far Eastern seas during summer–autumn is as follows: large immature fish stay in the coastal regions; age 2+ and older immature fish are located over the slope and outer-shelf areas, while 2-year-old fish are offshore over deep-water basins.

Chum salmon range in age from 2 to 6 years old. There are mostly 3+ (sometimes 4+) fish among those returning to spawn. Spawning fish of ages 1+, 2+ and 5+ are rare in Asian rivers. The average weight of age 3+ and 4+ chum salmon from the summer spawning run range from 2.90 to 3.75 kg, and from the autumn spawning run, from 3.6 to 5.4 kg.

A survey conducted in chum feeding regions has shown that the temperature range for this species is much wider than was considered previously, ranging from 1.5° to 20°C. In the first year of marine life, chum salmon prefer water colder than 10.8°C. Older fish have been observed in warmer waters. Mature fish can be found beyond these limits, and can dwell not only in the surface layer but can also migrate within a wide depth range. The number of immature fish feeding in the Okhotsk and Bering seas depends on the extent of Pacific water advection. When the inflow of the Pacific waters into the seas is weak, the immature chum migrations are also small, and vice versa.

Chum salmon are not necessarily a typical planktivorous species in the Far Eastern seas. In summer they often feed on nekton, including mostly young pelagic, and occasionally, mesopelagic fishes. In the Bering Sea, they feed mainly upon pteropods. In the Okhotsk Sea, they prefer pteropods in reproductive areas and in areas with dense aggregations of these molluscs. For zooplankton diet, chum salmon prefer euphausiids. Gelatinous plankton dominates in mature chum salmon stomach contents in the Okhotsk Sea, which could be related to their physiology.

Fishery

From the early 1950s to the mid-1970s, the Russian harvest of chum salmon decreased. This decrease was gradual but rather significant and was undoubtedly connected to the depleted condition of the Russian chum salmon stocks. A slow recovery of chum salmon stocks occurred in the 1980s, but during the 1990s these stocks began to decrease again (Table 36). It is believed that competition with the chum salmon juveniles of Japanese hatchery origin during the marine rearing phase has prevented recovery of the wild Russian chum salmon stocks to some degree.

Sockeye salmon (*Oncorhynchus nerka*)

Biology

Sockeye (also known as red) salmon reproduce in the rivers flowing into the Pacific Ocean and its northern seas from northern Hokkaido to the northern Bering Sea along the Asian coast (Bugaev, 1995). They enter spawning rivers from mid-May until September, depending on the region. Upon entering a river, pre-spawning fish may stay there as long as 1 month, and up to 1–2 or 3–4 months in lakes before spawning. There are well-defined seasonal stocks of sockeye salmon that have different spawning times. The differences may be as much as 15 to 20 days. In the Asian sockeye populations early (spring) and late (summer) runs occur. Spawning grounds are confined to rivers, and lakes with groundwater springs. Spawning time depends on the average temperature for the incubation of eggs: the higher the temperature, the later the spawning time (Brannon, 1987; Burgner, 1991). Embryonic and larval development takes from 5 to 8 months. The hatching period can be extended, depending on spawning time and temperature in the spawning grounds. Most sockeye salmon rear in fresh water for at least 1 year. Beginning from the larval stage, the species exhibit shoaling behaviour. The freshwater period of young sockeye from different stocks lasts from 1 to 4 years. Fry with a yolk sack start feeding mainly upon benthic organisms that they find on the spawning grounds. Pelagic yearlings consume primarily zooplankton.

Table 36 Chum salmon catches (t) in the Russian EEZ (FAO and NPAFC data).

Year	FAO	NPAFC [1]
1980	14,556	17,600
1981	12,914	17,000
1982	10,840	15,700
1983	18,980	23,900
1984	9,622	15,200
1985	20,556	27,900
1986	21,480	25,600
1987	16,640	29,800
1988	24,532	29,100
1989	15,160	25,400
1990	23,602	30,400
1991	12,640	22,000
1992	14,060	21,600
1993	12,610	31,600
1994	14,603	42,500
1995	12,632	47,000
1996	16,413	39,600
1997	15,899	32,000
1998	18,737	37,100
1999	20,025	36,300
2000	21,944	42,200
2001	17,940	37,500
2002	22,698	–

[1] Eggers *et al.* (2003),
NPAFC – North Pacific Anadromous Fish Commission

In most cases, sockeye salmon migrate to the sea at age 2, and rarely at age 3. Smolts stay in coastal waters before migrating offshore in fall. Sockeye salmon feed mainly on plentiful crustaceans, pteropods, and small pelagic fish. Survival, growth, and migration patterns of the fish during during their marine period largely depend on conditions within feeding areas and stock abundance.

Fishery

Stocks of Pacific salmon species along the Asian coast are harvested by driftnet, set in coastal areas and rivers. Catch statistics for the Russian and Asian fisheries are usually combined into a total for all "Asian" catches (Table 37). However, driftnet data are considered separately in Table 37 because it is difficult to estimate the origin of fish in high-seas catches. Asian sockeye salmon catches were low in the late 1940s through to the mid-1950s. From the mid-1950s to the mid-1980s catches were 1,150 to 5,590 t. In 2002, total sockeye salmon landings were 22,800 t, close to maximum catches taken in the 1920s and 1930s when 14,570 to 39,750 t of sockeye salmon were annually harvested.

Climate and ocean effects

Catch statistics for sockeye salmon generally follow the trend for combined Pacific salmon landings in Asia and North America (Klyashtorin, 1998; Klyashtorin and Rukhlov, 1998; Radchenko, 1998), suggesting that similar factors may influence the abundance of different Pacific salmon species. Judging from the literature, the most significant factors are: climate regimes, food competition, fishery pressure, and ecosystem rearrangements of biological communities (Radchenko and Rassadnikov, 1991; Shuntov *et al.*, 1997; Klyashtorin, 1998; Klyashtorin and Rukhlov, 1998; Bugaev and Dubynin, 2002).

Table 37 Sockeye salmon catches (t) off the Pacific coast (FAO and NPAFC data).

		NPAFC[1]	
Year	**FAO**	**Russia**	**Asia**
1980	1,629	3,900	–
1981	1,534	3,800	–
1982	1,335	3,000	–
1983	1,425	4,300	–
1984	5,082	6,300	–
1985	3,260	9,300	–
1986	3,577	7,500	–
1987	4,922	11,900	–
1988	5,099	8,400	–
1989	3,003	9,700	–
1990	5,177	16,400	–
1991	6,279	14,400	–
1992	6,408	15,400	–
1993	5,490	14,000	21,700
1994	5,658	10,700	14,400
1995	5,998	14,200	20,300
1996	13,630	16,800	22,400
1997	6,698	9,000	18,100
1998	8,820	10,100	12,800
1999	7,792	11,900	14,600
2000	12,676	15,100	17,200
2001	10,369	18,100	20,800
2002	14,701	–	–

[1] Eggers *et al.* (2003); NPAFC – North Pacific Anadromous Fish Commission

There are two important points regarding the influence of global physical factors on production and size of salmon catches. First is the influence of the quantity of atmospheric condensation and air temperatures, especially during the winter period in spawning areas. Second is the influence of atmosphere circulation through change in the scheme of the mass transfer of water in areas of forage migration during the sea period of salmon. In ontogenesis, salmon are influenced by various natural factors that influence orientation and production. Changes in water mass transfer in the North Pacific sector and increases in zooplankton production are some of principal causes of changes in salmon production. During the periods of a more southern position of the subarctic front and intensive distribution to the south of the subarctic waters, annual catches of all species of salmon are higher than average.

Walleye pollock (*Theragra chalcogramma*)

Walleye pollock are a highly valuable commercial species in Russia. They are widely distributed in the pelagic zone in the Russian Far Eastern seas. Major stocks of are fished in the Okhotsk Sea and western Bering Sea.

Okhotsk Sea pollock

Biology

Walleye pollock are the most numerous commercial fish in the Okhotsk Sea. During high abundance, they occur throughout almost the entire sea, from shallow coastal shelf areas to deep-water basins in the south and central parts of the sea Fig. 76). Walleye pollock have a vertical distribution range from the surface down to the lower mesopelagic layers. When abundance is low, walleye pollock are restricted to the shelf and continental slope. Medium-aged mature pollock are characterized by the greatest migratory activity. During their first 2 years of life, they remain within their spawning areas, while older fish feed mainly in the northwestern part of the sea, over the slope of the TINRO Basin (Fig. 76). On the western Kamchatka shelf, their reproductive period lasts from February until late June, with a peak in March and early April. In the northwestern areas, the peak shifts to later in the year. In Shelikhov Bay, the spawning peak is in late April; in the Taui region, it is from late April to early May; on the eastern Sakhalin shelf, it is in early June. Eggs, larvae and yearlings are distributed within spawning areas. Patterns of both spawning and early developmental stages are related to water dynamics, particularly to quasi-stationary anticyclonic eddies that retain eggs and larvae and prevent them from being transported over large areas. The areas of walleye pollock concentration are also areas where small copepods aggregate. Copepod eggs and nauplii are the main food sources for pollock larvae and juveniles. By fall, the young fish start to feed on euphausiids, along with copepods. Mature walleye pollock are practically euryphagous, although copepods and euphausiids remain the primary prey. Individuals over 60 cm in length live mostly near the bottom, leading a nektonic way of life, and at this stage, nektonic and benthic prey play an important role in walleye pollock feeding.

At age 2 years, western Kamchatka pollock begin to migrate to near-slope areas, primarily in northern and northwestern directions, to the TINRO Basin and Lebedev Trench[1] where they dwell, conducting short seasonal migrations until maturation. Males normally mature at 5 years, with an average length of 35 to 36 cm, and females mature at the age of 6 with a length of 37 to 39 cm. The sex ratio is generally 1:1, and remains that way until age 6 to 7 years, when the percentage of females increases. In older age groups (14–17 years), males are found only occasionally, suggesting that females live longer than males.

Individual fecundity of the Okhotsk Sea pollock varies considerably, ranging from 30,000 to 40,000 eggs in first maturing females to 1.3–1.5 million eggs in older, larger fish. The average absolute individual fecundity is within 150,000 to 270,000 eggs per female. Gonads mature in a continuous and synchronous manner. Several medium-aged groups (5–8 years) make up the basis of exploitable stock, and the proportion of older fish is small. The maximum age of Okhotsk Sea pollock is 21 years, as determined from the aging of scales.

[1] For alternate spelling and for additional information on place names, refer to PICES Scientific Report No. 8 on *Multilingual Nomenclature of Place and Oceanographic Names in the Region of the Okhotsk Sea.*

Fishery

Walleye pollock catches in the Russian EEZ are given in Table 38. The largest portion of this catch was landed in the Okhotsk Sea (Fig. 78). The largest catches were related to the appearance of average and strong year classes.

Climate and ocean effects

The population dynamics of the Okhotsk Sea pollock has been studied only since the recent commercial development of the species. Beginning in the 1970s, walleye pollock abundance fluctuated with a regularity related to 11-year cycles of solar activity and 8- to 10-year cycles in atmospheric processes. Cyclic patterns in the variability of walleye pollock abundance are achieved through long-term changes in marine ecosystems, and by reorganizations in pelagic communities caused by water and heat exchange between the Okhotsk Sea and the Pacific Ocean. The appearance of strong walleye pollock year classes coincides with the extent of moderately warm circulations of water. Stock abundance increases along with macro-zooplankton biomass during the warming of the Okhotsk Sea. Such periods of warming were observed during global climate changes in the middle 1970s, 1980s, and 1990s. The main factor in determining the survival of the Okhotsk Sea pollock progeny during their critical stages of development is the amount of food supply available. The direct impact of climate and oceanographic factors (such as storm wind intensity, extent of ice cover, and water and air mass conditions) on the survival rate at early ontogenetic stages, when the strength of age classes is formed, is less important.

Table 38 Walleye pollock catch (t) in the Russian Exclusive Economic Zone (EEZ; FAO data).

Year	Catch
1980	2,111,669
1981	2,137,875
1982	2,497,907
1983	2,747,044
1984	3,449,559
1985	3,343,034
1986	3,584,140
1987	3,421,719
1988	3,369,858
1989	3,133,152
1990	2,863,937
1991	2,495,808
1992	2,340,700
1993	2,114,456
1994	1,746,629
1995	2,208,410
1996	2,439,980
1997	2,252,742
1998	1,930,650
1999	1,500,450
2000	1,215,065
2001	1,145,016
2002	826,707

Bering Sea pollock

Biology

Walleye pollock are the most abundant gadoid fish species in the Bering Sea. There are reproductively isolated populations of the species in the eastern and western Bering Sea. There is evidence that the "basin" pollock, which spawn in the deep-water region off the eastern Aleutian Islands, and the "shelf" pollock, which spawn in shelf areas, belong to independent reproductively isolated stocks, with possible genetic differences. Reproduction of the eastern Bering Sea pollock takes place in a vast area from the central Aleutian Islands (Kanaga Sound) and southeast shelf (Unimak Island and Pribilof Islands area) up to the north in Anadyr Bay, with the main spawning grounds located in the southeastern Bering Sea. The western Bering Sea pollock spawn in the Olutorsky and Karaginsky bays (Fig. 76), and adjacent southern part of the Koryak coast. Each large spawning stock consists of smaller groups that differ in age composition, time of active spawning, behaviour, and distribution patterns for feeding and pre-spawning fish.

Biomass of eastern Bering Sea pollock was estimated at 8.6 million t; biomass of western Bering Sea pollock was assessed as 286,000 t using echo integration midwater trawl and bottom trawl surveys in 2002.

The spatial distribution range of both mature and immature walleye pollock usually expands significantly during their feeding period. Eastern Bering Sea pollock migrate to the northwestern Bering Sea shelf and deep-water Aleutian basin. The extent of the eastern Bering Sea distribution in the Aleutian basin depends on the population biomass and abundance of "basin" pollock.

Western Bering Sea pollock migrate from their spawning area in Olutorsky and Karaginsky bays to the northeast, where they are distributed off the Koryak coast and in Cape Navarin area in summer and fall. Some older fish are found in the Komandor Basin.

Eggs and larvae of the eastern Bering Sea pollock are carried away by currents from the spawning grounds near Bogoslof and Unimak islands into the Bristol Bay and Pribilof Islands area. Eggs and larvae can presumably drift from the Pribilof Islands spawning grounds into the northwestern Bering Sea.

Walleye pollock first mature at age 3+ (30% of the fish), and at 5 years old the majority of fish (about 85%) are mature. Most walleye pollock in the fishery are 3 to 8 years old. Natural mortality increases sharply in fish older than 8 to 9 years. Fish of about 24 to 25 years old are extremely rare in the Bering Sea population.

Generally, individuals from the northwestern Bering Sea are slightly smaller at age than those from the southeastern area. There are certain growth rate differences by sex, areas, and year classes.

Fishery

The walleye pollock fishery started about 1970 in the Russian EEZ of the Bering Sea. During the 1970s, walleye pollock were basically fished out in the western seas (Karaginsky and Olutorsky bays). The highest catch took place in 1972 when it exceeded 2 million t. The second highest catch was in 1988 when 1.3 million t were caught in Russian waters. On the western shelf of the Bering Sea (west of 174°), high and stable catches were observed from 1976 to 1994. Catches averaged 273,000 t a year (549,000 t maximum). From 1995 to 2002, the annual catch decreased 3.2 times (the maximum in 1999 was 149,000 t).

Climate and ocean effects

Abundance and biomass of Bering Sea pollock year classes vary significantly, depending on climate changes and oceanographic conditions during the spawning period. Larval and juvenile survival may depend on the direction of currents, activity of eddies, frequency of storms, water turbulence, temperature and salinity gradients in the upper water layer, as well as on food supply. The drift of pollock larvae into the coastal waters of Bristol Bay and Pribilof Islands has potentially positive impacts on their survival, because in coastal areas, oceanographic conditions are more stable and the

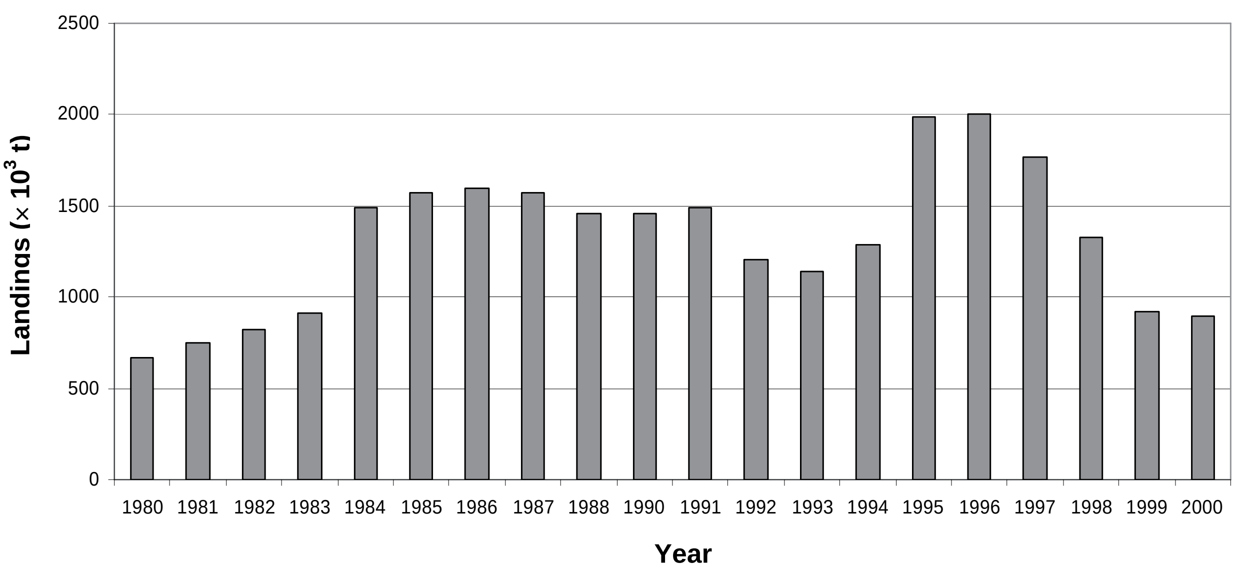

Fig. 78 Annual landings (thousands of t) of walleye pollock in the Okhotsk Sea.

food supply is better. Survival of juveniles and year class abundance also depends on how long juveniles remain under the ice cover in winter. Long periods of residence under the ice have a potentially negative impact on their survival.

Abundance and biomass the Bering Sea pollock decreased from the mid-1980s until the mid-1990s. A trend of increasing abundance and biomass of eastern Bering Sea pollock started in the late 1990s. Abundance of western Bering Sea pollock decreased significantly in the 1990s, and have remained at low levels until the present time.

The possibility of strong year classes is higher in relatively warm years, and is connected with a relatively strong inflow of the Pacific Ocean water into the Bering Sea through the Aleutian Islands passes.

Pacific herring (*Clupea pallasii*)

Biology

Pacific herring are widely distributed in the North Pacific Ocean. Their geographic range along the Asian coast stretches from the Yellow Sea in the south to the Bering Strait and southern Chukchi Sea in the north.

Within this area, Pacific herring are subdivided into several geographical groups that differ in abundance and ecology. Three main ecological forms of herring are known: off-shore (marine), coastal, and lagoon–lake. Marine herring are abundant, living entirely in oceanic water with high salinity, mainly in the shelf area. Coastal herring are usually confined to large bays and gulfs, and are less abundant. Lake herring are restricted to small bays, lagoons and lakes, where they reproduce and spend the winter, visiting neighbouring marine areas only during feeding migrations. Their biomass is low, estimated at tens or hundreds of tons.

There are four populations of marine herring in the northwestern Pacific Ocean: the Okhotsk and Gizhigin–Kamchatka stocks are distributed in the northern Okhotsk Sea, the Sakhalin–Hokkaido stock is found in the southern Okhotsk Sea and adjacent Japan Sea areas, and the Korf–Karaginsky stock lives in the Bering Sea. There are five populations of coastal herring: Korean, Peter the Great Bay, Plastun-Nelmin, and Dekastri in the Japan Sea, and Anadyr Bay in the Bering Sea. The number of local lake herring stocks is unknown. Local stocks from the bays of northeastern Sakhalin, Terpeniya and Aniva bays, as well as from lakes and lagoons of southeastern Kamchatka and Hokkaido Island are well studied. At the same time, there are almost no data on numerous small stocks inhabiting practically all brackish-water lakes and lagoons along the eastern Kamchatka coast.

Pacific herring can attain a body length of 44 cm, a body weight of 1,090 g, and can live up to 18 years, but such old individuals are rare. Most mature fish live 3 to 8 years and have a body length of 25 to 32 cm. The size and age of fish may vary, depending on ecological conditions, generation abundance and fishery pressure.

Lake herring are characterized by a short life cycle, small body size and weight, and early maturation. These fish spend the winter in brackish waters where they also spawn (bays, lagoons, and lakes that have connections with the sea). Local stocks are usually named after the lakes they spend the winter and spawn in. They do not conduct long migrations. Unlike lake herring, marine herring are larger, spawn along the shore on seaweeds such as *Zostera* and *Fucus*. They are widely distributed in shelf waters during feeding, and spend the winter on the slope (150–250 m depth), forming dense slow moving demersal aggregations.

Pacific herring are a neritic or coastal fish species, and their life cycle is associated with the shelf areas and neighbouring slope waters. Feeding migrations of herring are usually 800–900 miles (~1290–1450 km) at most.

Mature Pacific herring spend the winter in depths from 150 to 250 m, usually at temperatures from 1.5° to 3.5°C in areas 60–400 miles (~96–645 km) from the spawning regions. The most distant wintering regions are located in the wide shelf areas of the northwestern Okhotsk Sea and eastern Bering Sea. Young herring are distributed at depths from 50 to 200 m, and can be found at water temperatures less than 0°C. Pacific herring usually stay near the bottom during the day and move up the water column to the surface at night.

Some populations of Pacific herring (*e.g.*, from Peter the Great Bay) mature in their second year and at a body length of 17 to 20 cm. However, most mature at the age of 3. Sakhalin–Hokkaido herring mature in their fourth year, while Korf–Karaginsky herring mature in their fifth. Usually, it takes 3 to 4 years for the fish to mature. Males mature earlier and faster than females.

The fecundity of Pacific herring varies from 9,000 to 140,000 eggs, depending on the age and size of the fish. Herring populations from the southern areas are characterized by a high growth rate and fecundity. The average fecundity of Pacific herring from Peter the Great Bay is 72,000 eggs, in the western Hokkaido region it is 60,000 eggs, and in southwestern Sakhalin it ranges from 70,000 to 87,000 eggs. Korf–Karaginskyi herring have a fecundity of about 60,000 eggs. Population fecundity has annual variations, depending on age composition of the spawning stock, and feeding conditions.

Pacific herring feed the whole year round, though the intensity differs by season. The highest feeding activity is observed immediately after spawning. In winter, the feeding rate is low, and increases just before spawning time. Pacific herring feed mainly on copepods, eupahusiids, and chaetognaths. In the Bering Sea, they also feed on amphipods and decapod larvae. Fish (sand lance larvae, pollock eggs and larvae, juvenile herring) are extremely rare in herring stomach contents.

The spawning period of different Pacific herring populations depends on the geographical area. In Peter the Great Bay, and near the coast of Hokkaido, spawning starts in late February–early March and ends in April. Spawning continues until April in the southwestern Sakhalin area, from May–June in the Okhotsk and Bering seas, and from late June to early July in Anadyr Bay and Chukchi Sea. Spawning takes place in brackish water at a temperature range from 0° to 14°C, with an optimum temperature of 2° to 6°C and salinity of 5 to 28 psu for egg development.

Pacific herring stocks differ in their abundance. Annual and long-term trends in the dynamics of herring abundance are similar. Biomass has increased considerably since the early 1990s.

In recent years, the Okhotsk, Korf–Karaginskyi, and Gizhigin–Kamchatka populations have been highly abundant, and form the basis for the Russian herring fishery (Fig. 79, Tables 39 and 40). Other stocks are less important.

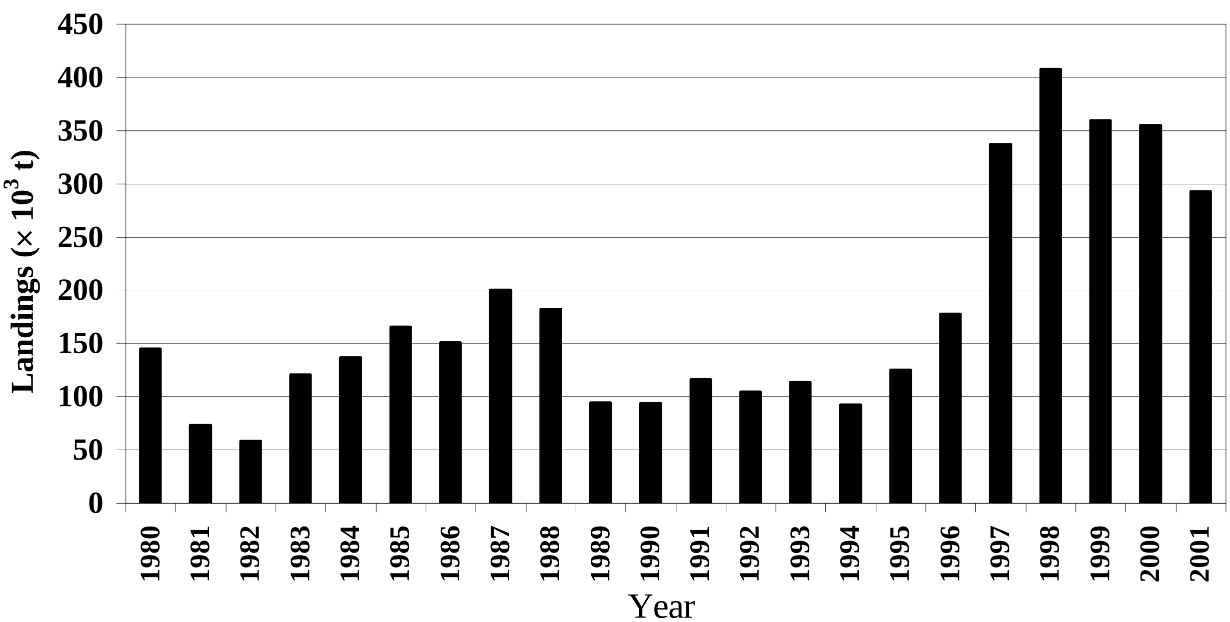

Fig. 79 Annual landings (thousands of t) of Pacific herring in the Russian Exclusive Economic Zone.

Table 39 Pacific herring catches (t) in the Russian EEZ (FAO data).

Year	Catch
1980	79,251
1981	85,552
1982	89,032
1983	132,892
1984	150,161
1985	189,584
1986	168,356
1987	220,712
1988	189,477
1989	99,966
1990	97,357
1991	98,326
1992	109,279
1993	115,148
1994	85,218
1995	116,787
1996	171,810
1997	313,397
1998	395,595
1999	359,194
2000	361,241
2001	278,511
2002	203,411

Fishery

It should be mentioned that every year herring landings are lower than the Total Allowable Catch (TAC), with annual catches not exceeding 60 to 70% of the TAC. This is because only two (Okhotsk and Korf–Karaginskyi) of the three potential populations, accounting for 95 to 97% of the TAC, are harvested commercially. Only 5 to 20% of the Gizhigin–Kamchatka herring TAC, estimated at 73,000 to 97,000 t in 1999–2001, was taken because there is no specialized fishery for this fish during its feeding period. It is harvested only in spring on the spawning grounds as a bycatch during the fishery for the Okhotsk herring stock. Gizhigin–Kamchatka herring catches may also decrease due to a decline in stock abundance, which is related to the elimination of the highly abundant 1993 year class from the commercial stock. Forecasts for stock abundance of Pacific herring have been made, taking into account the regularity in the appearance of highly abundant generations (Table 40).

Pacific saury (*Cololabis saira*)

Biology

Pacific saury, a subtropical species, occurs in the upper epipelagic layers of the North Pacific Ocean. In the offshore areas, its range is bounded by the Japanese and Kuril islands in the west, North American coast in the east, Komandor and Aleutian islands in the north, and northern subtropical convergence zone in the south. Pacific saury is common in the Japan Sea and southern Okhotsk Sea. The species occasionally occurs in the southern Bering Sea, and off western and eastern Kamchatka.

Pacific saury reproduce in the Kuroshio Current and its extension, the North Pacific Drift, and to the east in the California Current. Spawning is extended, and takes place in the South China and Japan seas. The species spawns all year round, with a peak in winter–spring in the Kuroshio, and in spring–autumn in the South China and Japan seas. Average individual fecundity is about 16,000 eggs. Eggs are released in small portions and are laid on floating algae.

As a rule, almost all eggs are fertilized. Embryonic development lasts 10 to 15 days, and survival rate is 30 to 45% by the time of hatching. The size of newly hatched larvae is about 6 mm. The larval phase ends at a body length of about 25 mm, fry phase at 60 mm, and juvenile phase at 240 mm. Most individuals spawn at body length of 29 to 30 cm. Spawning and feeding individuals have different distributional patterns. The main food items are: copepods (*Neocalanus*, *Paracalanus*), euphausiids (*Thysanoessa*), amphipods, and pteropods. Pacific saury larvae consume mainly small copepods (*Oncacea*, *Corycaeus*, *Oithona*, *Clausocalanus*, *Paracalanus*, *Calocalanus*).

The maximum length of Pacific saury is 38 cm. In commercial catches, it ranges from 10 to 34 cm, with individuals 24 to 30 cm long being the most abundant. No sexual dimorphism is observed. The Pacific saury life cycle is short and does not exceed 2 years. One-year-old (7–14 months) individuals constitute the bulk of commercial and total stock.

Table 40 Expected catch (t) of Pacific herring in the Russian Exclusive Economic Zone (EEZ) from 2000 to 2015.

Region	2000	2005	2010	2015
Western Bering Sea	52.5	30.0	45.0	60.0
Eastern Kamchatka	117.5	70.0	110.0	150.0
Okhotsk herring	260.0	410.0	325.0	120.0
Gizhigin–Kamchatka herring	87.0	80.0	90.0	110.0
Okhotsk Sea total	347.4	440.0	415.0	230.0
Japan Sea	4.2	4.0	4.5	5.0
Total	521.6	594.0	574.5	445.0

Fishery

Pacific saury catches increased through the 1980s, reaching a maximum in 1990 (Table 41). Catches declined to very low levels in the mid-1990s, with the lowest levels since 1980 occurring in 1998 and 1999. Beginning in 2000, they increased and current catches are similar to those of the early 1990s.

Table 41 Pacific saury catches (t) in the Russain EEZ (FAO data).

Year	Catch
1980	38,600
1981	31,700
1982	26,293
1983	7,606
1984	30,447
1985	23,423
1986	24,902
1987	23,484
1988	50,927
1989	68,368
1990	72,618
1991	49,943
1992	50,172
1993	48,145
1994	26,385
1995	25,140
1996	10,280
1997	7,091
1998	4,665
1999	4,808
2000	17,390
2001	40,407
2002	51,709

Climate and ocean effects

Pacific saury abundance depends primarily on the conditions within spawning areas, and on survival at early ontogenetic stages. In the ocean, 19-year-long natural cycles of Pacific saury high abundance were observed, related to the tidal rhythm of the moon. Lunar activity affects the position of frontal zones, processes of meandering, and the formation of eddies. The Kuroshio path is considered to be of primary importance for the reproduction of pelagic fishes in the northwestern Pacific Ocean. Southward shifts of the current position normally lead to enhanced yields of fish generations, while stock abundance decreases in years when the flow approaches the coast.

A rise of Pacific saury abundance in the Japan Sea is observed during periods of warm winters. This is related to the increase in non-predatory plankton biomass, matching with the production of the saury larvae. The decrease in food competition between Pacific saury and other pelagic fish is another factor for the increase in saury abundance.

In both the Pacific Ocean and Japan Sea, the increase in Pacific saury abundance occurs during intensification of the Kuroshio, and is related to the extent of water warming. In the Pacific Ocean, an intensive meandering of the stream is a necessary condition favouring the increase in abundance.

Pacific sardine (*Sardinops sagax*)

Biology

In winter–spring (December to May), mature Pacific sardines are concentrated in the coastal area of Japan where they spend winter and spawn. Small immature sardines are concentrated in the subarctic frontal zone. Beginning in April, just after spawning, the fish migrate to feeding areas in the northern Japan Sea. Feeding migrations end at different times, depending on the length of spawning periods, and abundance. At low abundance, the last schools of sardine approach Primorye and Sakhalin in late June. At high abundance, the time of migration is prolonged until mid-June, and in this case, small first maturing fish are the last to appear in the region. In September, after a period of growth, sardines start migrating back to the southern areas. Fall cooling of surface layers in the feeding areas, resulting from warm water moving off the shallow shelf zone, promotes the beginning of sardine migration to their spawning regions. By late October –early November, almost all schools of sardine move away from the coasts of Primorye and Sakhalin. In December, sardines are distributed in the Japan Sea only along the western coast of the Japan. Across their wide distributional range, sardines are found in large numbers at water temperatures of 8° to 25°C.

Pacific sardines mature at the age of 3+ and body length of 17 to 19 cm. By the age of 4, 99% of the fish are mature (Ishigaki *et al.*, 1959; Ito, 1961).

Individual fecundity varies from 39,900 to 318,800 eggs. Gonad maturation begins in November, gaining intensity from December to February. Spawning occurs from March until May. By the beginning of spawning, the majority of females have two generations of oocytes which are later released in two pools during one spawning period. Sardines release from 24,000 to 27,000 hydrated eggs into the surface layer during a single spawning event. Eggs are pelagic, free-swimming, with an adipose capsule. Embryonic development lasts 35 to 85 h, depending on water temperature. Sardines spawn at 14° to 17°C, with a mass spawning at 15.5°C.

Fishery

Catches increased through the 1980s, reaching a maximum in 1989 and 1990 (Table 42). They started to decline in 1991 and by 1995, there was no catch. Virtually no sardines have been caught since 1994.

Climate and ocean effects

Pacific sardines are characterized by a relatively short life span. In the Japan Sea, five to seven age groups are found. In the 1980s, the most numerous were fish aged 3+, accounting for 62 to 79% of the total catch (Dudarev, 1985). The sex ratio for Pacific sardine caught in the Japan Sea is 1:1.

Five large rapid rises in sardine abundance were reported during the last 500 years. They were observed during periods of low solar activity. These periods are accompanied by climate warming, favourable for an increase in sardine abundance. Shuntov (1982) considered that favourable conditions for sardine reproduction were related to a zonal type of atmospheric circulation. The late 1980s proved this hypothesis. During that period, zonal (westerly winds) processes prevailed over meridional (north–south) processes in the atmosphere.

Two periods of high sardine abundance occurred in the last century: one in the 1920s and 1930s and one 1970s and 1980s. Temperature and hydrological conditions were suitable for the high rates of young fish survival. It is known that favourable conditions within the entire ecosystem are essential for a rapid increase in sardine abundance. Observed variability

Table 42 Pacific sardine catches (t) in the Russain EEZ (FAO data).

Year	Catch
1980	359,289
1981	461,000
1982	594,151
1983	579,914
1984	798,764
1985	748,158
1986	820,798
1987	764,687
1988	794,641
1989	861,401
1990	879,393
1991	655,772
1992	165,270
1993	4,314
1994	28
1995	0
1996	0
1997	0
1998	0
1999	3
2000	0
2001	0
2002	0

in sardine abundance on the northern and southern spawning grounds was associated with favourable warm conditions for reproduction. In this regard, Shuntov (1982) and Davydov (1986) were correct in predicting that a 22-year cycle of solar activity, resulting in a relatively warm period, would last until the early 1990s.

At present, it is difficult to forecast the next rapid rise in Pacific sardine abundance. We suggest that, considering the duration of high and low sardine abundance periods, the state of the environment, and that sardine demographic cycles are species specific, a highly abundant generation of Pacific sardine should be expected in the second decade of the 21st century.

Pacific cod (*Gadus macrocephalus*)

Biology

Pacific cod are widely distributed in the North Pacific Ocean. Their natural habitat stretches from the Yellow Sea through the Japan Sea, the Okhotsk Sea, the northern part of the Bering Sea, and along the coast of North America to Santa Monica Bay, California. The bathymetric distribution of Pacific cod is 10 to 50 m, where the young fish concentrate. Maximum depths are up to 800 m. Mature fish live mainly at depths from 30 to 300–400 m.

As a rule, Pacific cod are not subject to vast migrations in the Russian EEZ. The majority of fish dwell in definite local regions, primarily moving from deeper depths to shallower areas and back during some seasons. The main commercial aggregation of Pacific cod in the northern part of the Bering Sea in Karaginsky and Olyutorsky bays are found above the continental shelf during summer–fall and above the shelf edge and continental slope in winter (Karpenko and Balykin, 2006).

Pacific cod are noted for their large size among the ground fishes of the Far Eastern seas. In the Japan Sea, most fish range from 45 to 75 cm in length. In the Okhotsk Sea, along the western Kamchatka coast, the species range from 45 to 80 cm in length. On the eastern side, the main group of fish ranges from 55 to 90 cm in size. In the western Bering Sea, they range from 55 to 95 cm in length. Males mature at 4 to 5 years and females mature at 5 to 6 years. The sex ratio of mature Pacific cod is 1:1, although males are smaller than females. Most fish larger than 80 cm are females. Large abundance is one of the characteristic features of Pacific cod. Biomass varies from 700,000 to 7,200,000 spawners.

The spawning period and location are connected to water temperature. During spawning, Pacific cod avoid regions that have warm near-bottom water temperatures > 10°C, as well as cold ones. In the Okhotsk and Bering seas, spawning occurs at water temperatures from 1° to 2°–2.5°C and at depths of 150 to 400 m from February to April (the peak is primarily in March). Pacific cod spawn small eggs, 1.25–1.3 mm in diameter, on the bottom. There is no adipose capsule in spawn, so its weight is greater than the water and the eggs sink immediately to the bottom. The incubation period lasts not more than 20 days, depending on the water temperature. The larvae are not larger than 3.7 mm and remain near the bottom at the site of spawning. When the young fish grow to 20 mm they migrate to the coastal area where the temperature reaches up to 15°C. Here, they grow from 40–80 mm in length and then move to deeper water.

Unlike the majority of the groundfishes, Pacific cod are characterized by great fluctuations in year class, which has an impact on catches. Warm advection of Bering Sea water, due to the warm Pacific water, influences the dynamics of the Anadir–Navarin and eastern Bering Sea cod year class.

According to Vershinin (1987), the eastern Navarin cod quantity is inversely proportional to the ice cover in the Bering Sea. In this case, ice cover is an index of water enthalpy during the spawning period. Actually, the majority of large- and average-yield generations appeared in quite hot years, and were not numerous in cold years. However, this relationship occurred only up to the end of 1970. In the 1980s, large and small year classes appeared despite the large water enthalpy. Hence, there are other factors besides the environment that play an important role in year class formation.

Fishery

Pacific cod have always made up the largest part of groundfish catches in the Russian EEZ. In the 1980s, catches of this species were 23,000 t, reaching a maximum of about 175,000 t in 1987 (Table 43). The largest catches were on the shelves of western and eastern Kamchatka, and in the western Bering Sea.

Table 43 Pacific cod catches (t) in the Russain EEZ (FAO data).

Year	Catch
1980	23346
1981	40997
1982	80016
1983	88600
1984	140523
1985	188443
1986	168445
1987	175271
1988	148397
1989	140365
1990	121397
1991	106519
1992	154297
1993	95823
1994	81445
1995	100730
1996	93890
1997	79927
1998	94282
1999	101929
2000	68415
2001	59783
2002	60625

Red king crab (*Paralithodes camtschaticus*)

Biology

Red king crabs are distributed along the North Pacific Ocean rim. There are two populations in the Okhotsk Sea, one in western Kamchatka and one in the Ayan–Shantarsk area. Populations with low abundance are found in the northern Japan Sea, off Sakhalin, eastern Kamchatka, and along the Kuril Islands. Within the Russian EEZ, the western Kamchatka population is the most abundant.

Productivity of red king crab populations depends on a generation yield, growth rate, temperature, size of shelf area, food availability, and natural and fishery mortality (Rodin, 1985). Red king crab migrate seasonally into the shelf areas in the spring through fall. Crabs spend the winter in the offshore areas at depths of 110 to 200 m because of low temperatures in the shallow coastal areas.

In spring, when the near-bottom temperature falls below zero in places where red king crabs spend the winter, mature crabs begin their migration to the coastal zone to spawn. On their way to the spawning grounds, they pass through a cold-water area where temperatures sometimes fall to –1.2°C. When warm patches with a water temperature of up to +4°C appear in those areas, they move within these warm cores. Males and females migrate separately. Every migratory crab pool has its own regional pattern (Levin, 2001). A month after the migration starts, males join females in warmer coastal regions with temperatures of 2° to 4°C. Males become mature at a carapace width of 10 to 12 cm. Carapaces of large males can reach 25 to 28 cm in width. The smallest females with eggs have a carapace width of 8 cm. Most females with a 9 cm carapace width are mature and carry eggs.

Individual fecundity of females during maturation depends on conditions such as food and hydrological regime (Rodin, 1967). Annual egg production may vary within a female. Females carrying different numbers of eggs were observed by Sato (1958). This author found groups of females with a carapace width up to 15.6 cm having as many as 75,000, 150,000 and 200,000 eggs per female. The number of eggs is positively correlated with size. On the western Kamchatka shelf, red king crab fecundity increases from the north to the south. During years with moderate temperatures, individual fecundity for all size groups increases by 4,000 to 25,000 eggs. Females keep up to 300,000 fertilized eggs for 11.5 months. On the third month of egg care, a new portion of eggs appear in the female's ovaries.

Larvae hatch at 24 to 40 m depth from April to May. On the eastern Kamchatka shelf they are transported north of the spawning sites. Larvae with different stages of development present different distributional patterns by depth and along the coastline. Larvae, hatched near the shore, migrate to deeper areas as they grow. They settle on the bottom in August. The largest aggregations of the crab larvae and juveniles are found within the coastal zone.

Red king crabs feed mainly upon mollusks, as well as on different crustacean species and polychaetes. They also regularly prey upon echinoderms, sponges, rhizopods, bryozoans, and hydrants, such as *Obelia* (Logvinovich, 1945; Kun and Mikulich, 1954; Nadtochij *et al.*, 1998).

Fishery

The most complete information about red king crab landings in the western Kamchatka area was collected during its intensive harvest from 1924 to 1983 (Slizkin *et al.*, 2001). In the last decade, the annual catch was less than half of the maximum annual catch.

Eight relatively high-yielding generations have been recruited into the western Kamchatka red king crab population during the last 40 years of observations (Fig. 80). These generations appeared every 4 to 7 years. In 1993–1994, two high-yielding generations appeared, one after the other. These generations were recruited into the fishery stock and were harvested in the 1990s until 2000. Currently, a decline in crab abundance is expected due to the lack of high-yielding generations.

Climate and ocean effects

The study of mechanisms affecting productivity shows that during cold years, when crab migrations to the coastal zone are delayed, females begin spawning in the outer shelf areas. Larvae from those females that cannot pass through the cold water belt below –1°C, hatch at depths from 80 to 120 m. In these cases, severe conditions, as well as larval drift to the regions with unfavourable conditions for settling (for example, outside the western Kamchatka shelf), usually result in higher larval mortality than in the moderate and warm years. Thus, generations appearing in cold years are relatively low-yielding. In warmer years, larvae hatch in coastal waters, and as a result, they aggregate within a 30 to 50 m depth where they are successfully transported into eastern Shelikhov Bay, which is favourable for their growth. Strong year classes appeared in 1958, 1963, 1970, and 1971.

In the 1980s and 1990s, only two strong year classes of red king crab were observed in the western Kamchatka shelf (Slizkin *et al.*, 2001). During 1996–1998, an abnormally low number of males and non-migrating juveniles were observed. In the late 1990s, the most numerous groups were recruits and pre-recruits (males with a carapace width of 1.1 to 14.5 cm). They were able to effectively replenish the commercial part of the stock only until 2001. In future years, a decrease in the number of males recruiting into the harvested stock (with a carapace larger than 15 cm) will result in a stock decline.

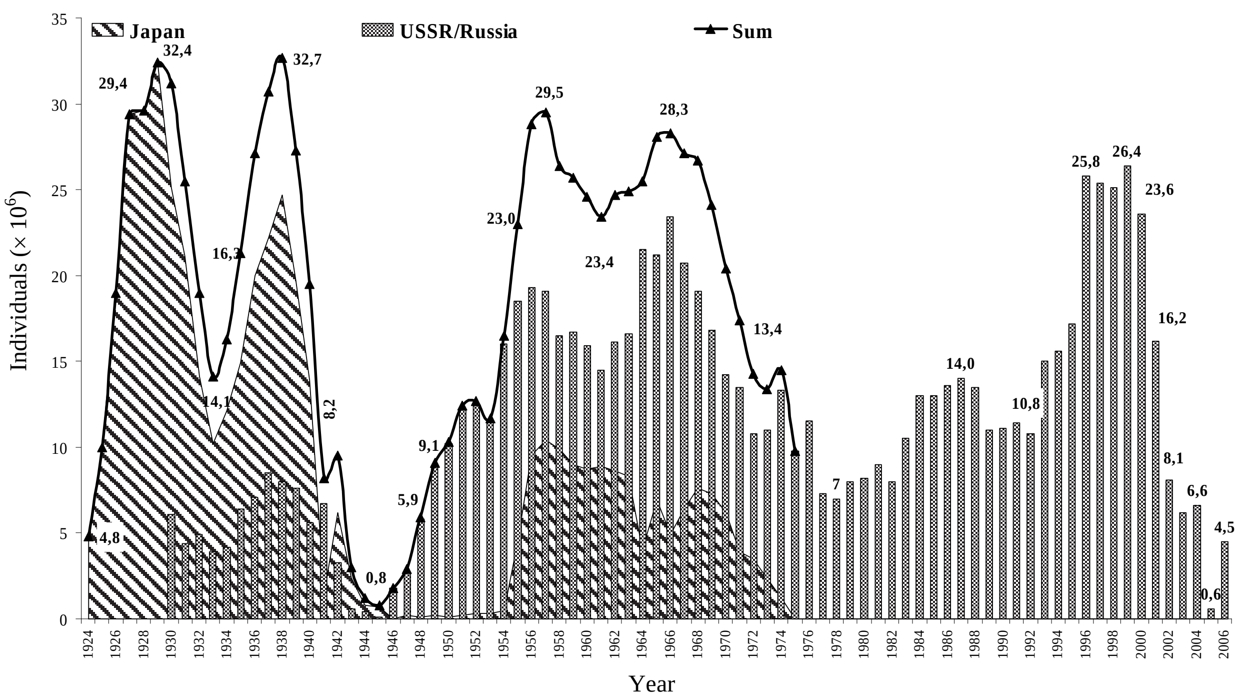

Fig. 80 Annual landings of red king crab in the Russian Exclusive Economic Zone (EEZ) (Slizkin and Safronov, 2000), with modifications.

In the 1990s, an unusual behaviour of crabs was observed when over half of all males and a notable number of females were found in nontraditional spawning areas (Slizkin *et al.*, 2001). This resulted in an increased catch of females and non-commercial sized males. Long-term environmental changes, together with high fishing pressure, were the basic reasons for the unusual spatial distribution pattern of the crabs with their aggregation south of 54°N.

An analysis of oceanographic conditions showed that in 1998, western Kamchatka coastal near-bottom water (15–100 m deep) was cold relative to the annual average, while in the outer shelf area (130– 200 m and deeper), the water was relatively warm. Unlike previous years, the cold compensatory current in 1998 prevented the western Kamchatka coastal area from access to the West Kamchatka Current warm water. As a result, water temperature near the bottom in the coastal area was 2° to 4°C lower than in 1997.

In the spring and summer of 1998, abnormal oceanographic conditions in the coastal reproductive and breeding shelf areas appeared as a result of the development and persistence of a cold counter-current. These unusual environmental conditions caused a number of changes in the distribution and biology of bottom organisms. Permanent cooling of the near-bottom water layer along the western Kamchatka coast resulted in a red king crab migration from the Hairuzovo to Ichin regions in the shelf, which, in turn, led to a sharp decline in their abundance in the northernmost areas.

Climate, Ocean and Fishing Effects on Key Species in the Fishery

An important question to consider is whether the productivity of a stock is affected by common factors, which also control the synchronous fluctuations of the principal climatic, geophysical and biological indices.

In the late 1980s, the annual commercial catch in the Pacific was close to 54 million t. The total catch of the five main Pacific commercial species (Japanese and Peruvian sardine, Alaska pollock (also referred to as walleye pollock), Chilean jack mackerel, and Peruvian anchovy) made up 52% of this total (28 million t).

Major species in the commercial catch off the east coast of Russia can be placed in two groups. Group I includes Pacific salmon, walleye pollock and Japanese sardine. Group II includes Pacific herring. The maximum catch of species in Group I occurred in the late 1930s and early 1990s, with the minimum catch in the 1960s. The maximum catch for Group II fish occurred in the 1960s, with minimum catches in the 1930s and 1990s.

The population dynamics of fish in the first group corresponds to the global trend in surface temperatures and to large-scale climate indices in the Pacific, such as the Pacific Decadal Oscillation (PDO) and Aleutian Low Pressure Index (ALPI). The PDO characterizes an area of low pressure in the North Pacific and is considered a basic climate-forming factor of the region. Group I fishes can be conditionally considered to be “warm-watered” because the increases in catch coincide with periods of global temperature rise, and with periods of prevailing “zonal” Atmospheric Circulation Index (ACI), positive PDO, and intense ALPI. The fluctuation of catches, PDO, and ALPI has an approximately a 60-year periodicity (Fig. 81).

Group II fishes can be conditionally described as “cold-watered” because periods of increased catch coincide with lower global temperatures and with periods of “meridian” ACI domination, negative PDO, and weak Aleutian Lows.

The concept of an approximately 60-year periodicity of fluctuations in climate and catches is based on a relatively short time series (100–150 years) analysis, and an even shorter time series of catches. Time series with a length of hundreds, and even thousands, of years are necessary in order to be clear about the periodicity in climate changes.

We propose that the modern fluctuations of climate and fish productivity will continue to follow 50- to 60-year cycles. According to the model production, catches of the so-called “warm-watered” or the zonal group of fishes, such as Pacific salmon, walleye pollock, Japanese sardine and others will decrease to about 2020. After 2020, production will begin to increase (Fig. 82). Catches of the so-called “cold-watered” fishes, or the meridian group, such as Pacific herring, will increase up to 2020 and then decrease.

Klyashtorin and Lyubushin (2007) show that the increasing trend of global temperatures may change, resulting in a declining trend until 2020.

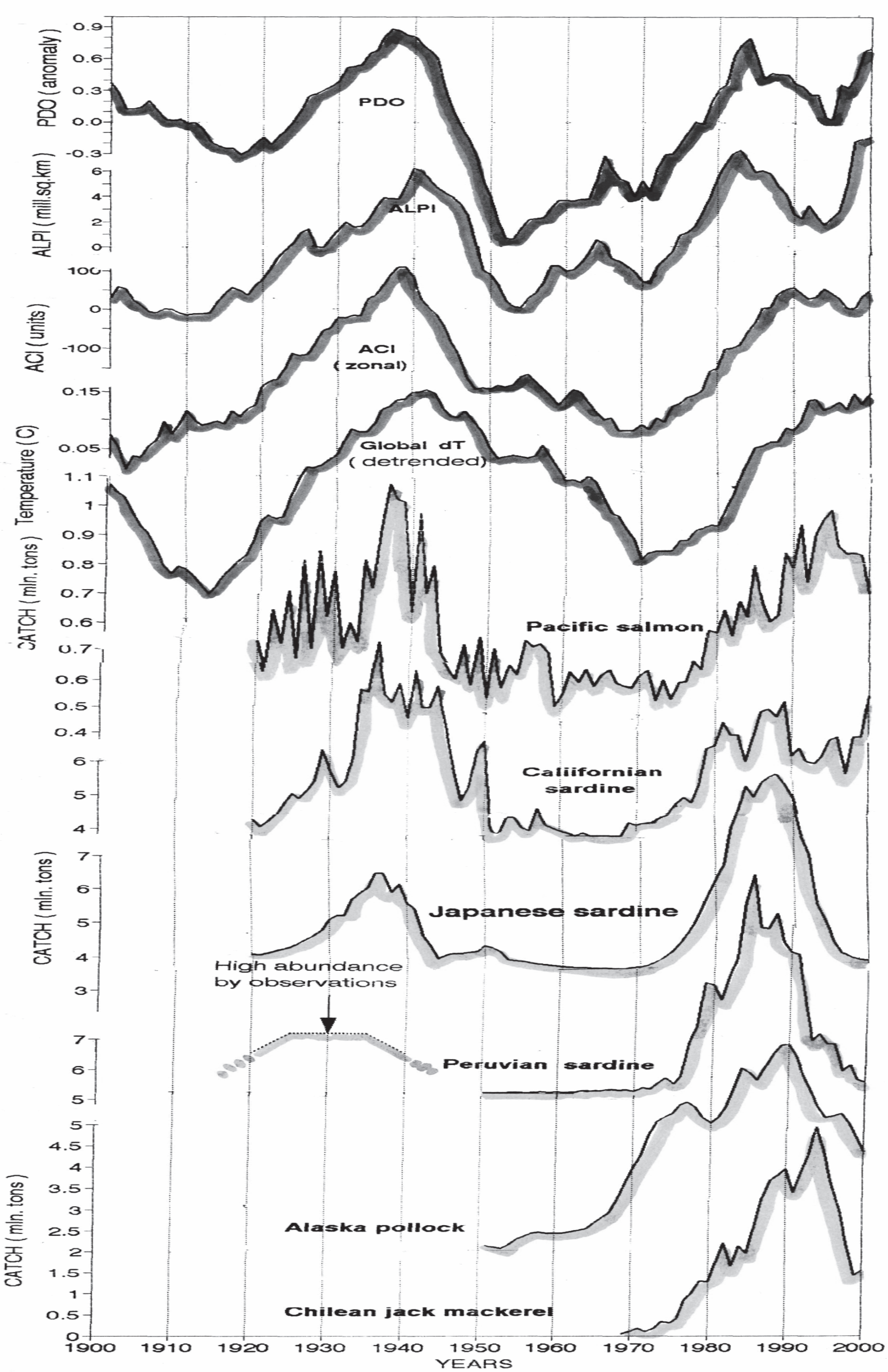

Fig. 81 Coherency of climate and commercial catch dynamics in the Pacific from 1900 to 2000.

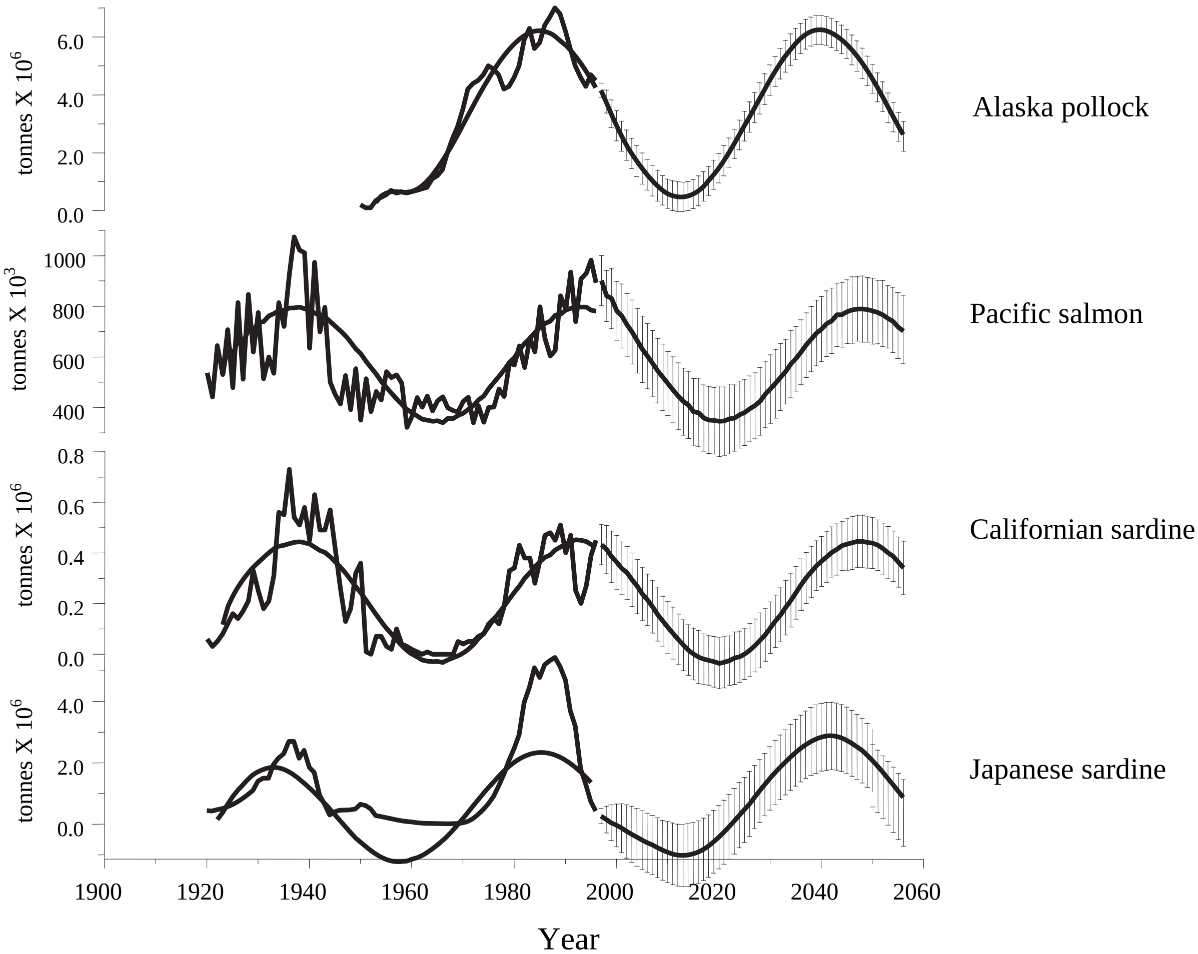

Fig. 82 Model-generated dynamics of "zonal-dependent" (thermophilic group) stocks of major commercial species for 2000 to the 2050s.

Future Responses

The processes that regulate yield are very complicated and are governed by many factors, with climate and oceanographic influences being important. Numerous factors influencing the abundance of generations and populations can be classified as follows: (1) cosmophysical and global climate–oceanic factors, which form long-term periods and epochs; (2) climate and hydrological conditions of a particular year and region; (3) biocenological relations, connected with the density factor (through food competition); (4) predation at different ontogenetic stages; (5) population factors, including those with auto-control; and (6) anthropogenic impact on the biota and environment, including fisheries and aquaculture. Theoretically, it is very difficult to forecast trends in the dynamics of marine organism abundance because potential factors are numerous, and it is hard to assess possible impacts and variability within an ecosystem. That is why regular annual monitoring plays an important role in forecasting for a commercial fishery.

The current low level of catch in the Far Eastern seas fisheries was forecasted (Shuntov, 1986). This period will last for two decades according to the 40- to 60-year cycles in climate and the ocean environment, and the associated variability in the biological structure of ecosystems.

As for the global warming idea, at the present time there are no serious grounds to consider it the first priority problem, at least, in the next few decades. Besides, the frontier of the 20th and 21st centuries was unusually cold in the Far Eastern seas. According to long-term climate variability, the 21st century is going to be warmer than the 20th century. Such a scenario will favour biological productivity in the sense that biological and fish production will increase in the new century. Presently, it is the relatively cold and severe environmental conditions that serve to limit fish productivity in the Far Eastern seas.

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