Possible Causes and Effects of Shifts in Trends of Abundance in Pink Salmon of Southern Sakhalin and Iturup Islands

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Abstract: Data on the abundance of spawning pink salmon (*Oncorhynchus gorbuscha*) are presented for rivers of southern Sakhalin Island and Iturup Island. Fluctuations in abundance are more dependent on marine survival than on the abundance of fry migrating downstream. This is explained by the favorable spawning conditions in small rivers with dense aggregations on the spawning grounds. We found stable long-term trends in changes in abundance, fish length and the seasonal dynamics of spawning migrations. These trends suggest an important role for climatic-oceanological cyclical processes in pink salmon stock dynamics.

Keywords: pink salmon, Sakhalin Island, Iturup Island, spawning migration, abundance, body length, reproduction

INTRODUCTION

Many researchers consider density as an important factor when explaining decreases in body size and female fecundity, increases in age-at-maturity and delays in timing of the Pacific salmon spawning migration of abundant year-classes (Yefanov and Chupakhin 1982; Ishida et al. 1993; Welch and Morris 1994; Bigler et al. 1996; Volobuev and Volobuev 2000). However, not all the indices mentioned above fall into this pattern on a consistent basis. For instance, a decline in catches and body size in pink salmon (*Oncorhynchus gorbuscha*) was observed during the 1970–1980s on the Russian coast of the Japan Sea (Gavrilov and Pushkareva 1996; Temnykh 1999); and, in contrast, their synchronous increase in some areas of the Okhotsk Sea coast in the late 20th century (Nagasawa 2000; Temnykh et al. 2002; Kaev and Chupakhin 2003). These examples suggest that a variety of changes occurs in Pacific salmon stocks in different years.

To understand the patterns of these natural processes it is important to study salmon stocks in different regions. The pink salmon was selected for this study because it is the most abundant species of Pacific salmon. Further, the intensive pink salmon commercial fishery facilitates a higher degree of accuracy in determining the size of individual year-class stocks and the dynamics of spawning runs. Among Pacific salmon, the pink salmon shows the greatest fluctuations in abundance, which is related, primarily, to its short life cycle (two years). From July through October these fish migrate from the sea to rivers for spawning. During spawning they lay eggs in redds, which are located at 20–30 cm depth. Hatching and larval development take several months. Pacific salmon progeny at early developmental stages are comparatively well protected on spawning grounds. As a rule, during a spring flood the fry begin migrating downstream. These processes take place from late April to early July. During the first summer, juveniles feed in the Okhotsk Sea and then move into the Pacific Ocean in late autumn to overwinter. The next summer, beginning in July, mature pink salmon return to natal rivers to spawn, thereby completing the cycle. Thus, fluctuations in abundance reflect the influence of environmental factors mainly during the period when pink salmon are adapting to their marine habitat. All of these factors make the pink salmon an attractive subject for studying fish abundance (Nikolsky 1974). Here we have analyzed changes in reproduction, abundance, and size composition of pink salmon in different spawning areas of the Sakhalin-Kuril Region.

MATERIALS AND METHODS

The three largest Sakhalin-Kuril pink salmon groups, each with very different spawning areas, both climatically and hydrographically, were chosen for this study. Quantitative data on fry migrating downstream, the abundance of spawners, and several biological indices have been collected during 30–35 years for fish from each area.

The number of wild fry migrants was calculated based on fish sampled in fyke nets (Volovik 1967) in the following rivers: the Bakhura and Dudinka rivers located in the southeastern Sakhalin coastal zone; the Bystraya (tributary of Lutoga River), Kura and Sheshkevich rivers located in the Aniva Bay coastal zone; and the Rybatskaya and Olya rivers

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located on Iturup Island. The number of wild smolts in other rivers of these regions was estimated based on the number of pink salmon entering spawning grounds and the average number of fry migrants from one female in the above sampled rivers. Data on the quantity of hatchery fry released were taken from the statistical reports prepared by the staff of "Sakhalinrybvod" (Sakhalin Basin Department for Reproduction of Water Biological Resources) on fry releases from salmon hatcheries.

The number of returns of pink salmon was determined as the sum of individuals caught during commercial fishing and at fish weirs, and those migrating up rivers to spawn. The number of spawners on spawning grounds was counted by on-foot observations when there were maximum pink salmon concentrations in rivers (mainly the first half of September). Fish have been counted in this way in 13 rivers on the southeastern coast of Sakhalin Island (spawning grounds make up 67% of the total area of these rivers), in 21 rivers on the Aniva Bay coast (74%, respectively), and in 11 rivers on Iturup Island (73%, respectively). Numbers of pink salmon in other rivers of these regions were calculated based on the ratio between the spawning areas and the average number of fish per 1 m² in the studied rivers. The survival index of pink salmon was calculated as the ratio of returned adults to the total number of fry migrants. This calculation was based on the assumption that pink salmon catches from coastal waters reflect, in general, the reproduction level of the local pink salmon populations. High rates of straying of fin-clipped pink salmon and subsequent low recoveries of returning adults (Rukhlov and Lubaeva 1980) were not seen when we studied recent data in more detail (Kaev and Chupakhin 2003; Kaev and Antonov 2005).

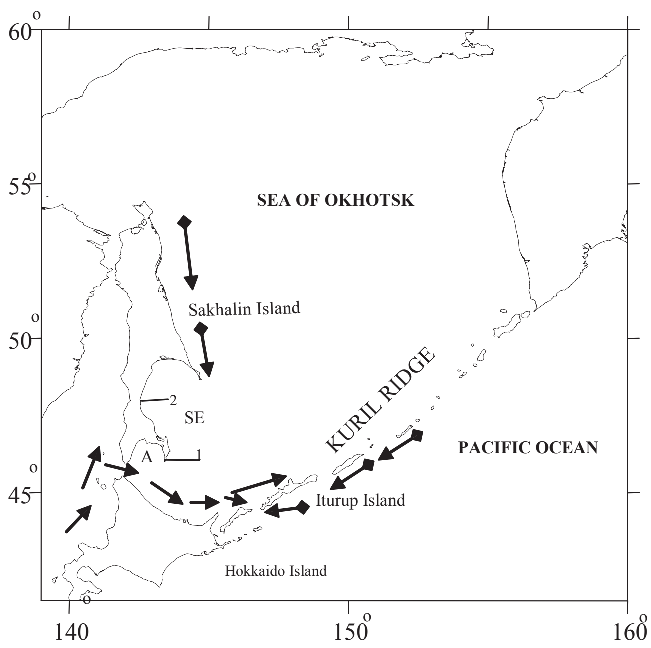

Fig. 1. Study regions for pink salmon. A, Aniva Bay; SE, southeastern coast of Sakhalin Island between Cape Aniva (1) and Cape Tikhiy (2). Single headed arrows = warm currents; two-headed arrows = cold currents.

Biological analyses were done for fish from trap-net commercial catches and from beach-seine research catches in rivers. Usually one sample consisted of 100 randomly selected individuals. Biological analysis included determination of sex, standard body length and weight, and individual fecundity of 25–30 females from the sample. A total of 152 samples (13,938 individuals) was collected from 1979–2004 on the southeastern Sakhalin coast, 316 samples (28,379 individuals) from 1976–2004 in Aniva Bay, and 255 samples (26,008 individuals) from 1967–2004 at Iturup Island.

To study the long-term changes in fish abundance and biological indices, the collected materials were organized in such a way that the data used for analysis were obtained by the same methods in all observation years. This applies to determining the abundance of fry migrants and adults, the mean values of fish length and weight, and the fecundity of females from individual year-classes (Kaev and Chupakhin 2003; Kaev et al. 2004b). To study the timing of the pink salmon prespawning migration in coastal areas we used only data from trap-net catches (passive fishing gear). Differences in the timing of the spawning migration for different year-classes were estimated by the dates when half of the fish were caught.

Standard statistical methods were used (Plokhinsky 1970). Trend lines were calculated based on 4-year moving averages, because the interannual changes in pink salmon abundance and biological indices are related to their two-year life cycle. While studying long-term relationships among pink salmon abundance, migration timing, and fork length, all the calculations were performed using the original data.

The following symbols are used in the text: *M*, mean; *SD*, standard deviation; *CV*, coefficient of variation; *R*, coefficient of correlation; *p*, statistical significance; *N*, sample size.

RESULTS

Southeastern Sakhalin Island, the Aniva Bay coast and Iturup Island are relatively small areas of the Okhotsk Sea coast (Fig. 1). However, the pink salmon catches in these areas comprise more than half (55%) of the total Russian pink salmon catch in the Okhotsk Sea. The average annual catch of pink salmon in 1995–2004 totaled 19,211 tons in southeastern Sakhalin, 13,446 tons in Aniva Bay and 25,133 tons in Iturup Island. Further, reproductive conditions differ in these areas, despite their relatively close geographic proximity. Southeastern Sakhalin is distinguished by its cold winters. Most of the Aniva Bay rivers are concentrated on its western coast which has the warmest winters on Sakhalin Island. Iturup Island, which is located in the southern part of the Large Kuril Ridge, has even seasonal dynamics in air temperature and snowy winters with frequent thaws. While Sakhalin rivers are almost completely covered with ice in winter, the Iturup rivers, as a rule, freeze only during periods of low discharge. The rivers on Iturup are short; the upper spawning grounds in the longest ones are located only 8 to 10 km from the mouth. In southeastern Sakhalin, the majority of pink salmon also spawn in the comparatively short rivers with the upper spawning grounds located only 10 km from the mouth. On the Aniva Bay coast, pink salmon spawn mainly in rivers that are up to 30 km long or more.

The early marine period in the juvenile pink salmon life cycle has different characteristics in each area. The coastal zone of southeastern Sakhalin is under the influence of the cold Eastern Sakhalin Current. Aniva Bay's hydrological regime is influenced by the cyclonic circulation that results from the interaction of the cold Eastern Sakhalin Current and a branch of the warm Tsushima Current. The coastal conditions of Iturup Island are determined by the interaction of several currents that form a local frontal zone with high productivity (Naletova et al. 1997).

Aniva Bay (Kaev et al. 2004a; kaev@sakhniro.ru, unpublished data, 2004)

In Aniva Bay, pink salmon spawn in 60 rivers with a total spawning area of 1.67 million m^2. During 1975–2003, from 0.3 to 6.93 million individuals (average 2.6 million), entered these rivers. The result of their spawning was from 26 to 486 million fry migrants (average 164 million). In addition, between 18 to 101 million hatchery fry (average 59 million) were released. Total spawning returns after a year in the ocean were from 0.5 to 34.5 million individuals (average 8.9 million). From 0.0 to 29.8 million of the spawning returns were taken in the commercial fishery. On average, pink salmon abundance during the observation years was almost three times as high in odd years (12.6 million individuals) than in even years (4.2 million individuals); however, variation in abundance in even years (CV = 94.3%) was higher than in the odd years (CV = 76.2%).

Southeastern Sakhalin (Kaev et al. 2004a; kaev@sakhniro.ru, unpublished data, 2004)

Pink salmon spawn in 29 rivers, with a total spawning area of 1.49 million m^2. In 1970–2003, from 0.4 to 10.6 million individuals (average 4.1 million), entered these rivers. A result of their spawning was from 35 to 1,230 million fry migrants (average 240 million). In addition, between 27 to 259 million hatchery fry (average 118 million) were released. Pink salmon spawning returns after a year feeding in the ocean were from 1.4 to 43.4 million individuals (average 16.1 million). From 0.4 to 36.4 million fish were taken in the commercial fishery. On average, pink salmon abundance during the observation period was almost twice as high in odd years (21.5 million individuals) than in even years (10.4 million individuals); however, variation in abundance in even years (CV = 92.6%) was almost twice as high as in odd years (CV = 50.7%).

Iturup Island (Kaev and Chupakhin 2003; Kaev et al. 2006)

On Iturup Island, pink salmon spawn in 87 rivers, but the majority of their spawning grounds (82%, or 600,000 m^2) are concentrated in 54 rivers on the Okhotsk Sea coast. In 1970–2003, from 0.8 to 2.5 million individuals (average 1.4 million), entered these rivers. A result of their spawning was from 66 to 460 million fry migrants (average 210 million). In addition, between 62 to 215 million hatchery fry (average 134 million) were released. Spawning returns after a year in the ocean were from 5.9 to 32.1 million individuals (average 15.5 million). From 4.9–30.0 million fish were taken in the commercial fishery. On average, the variation in pink salmon abundance during the observation years was approximately equal in odd years (15.2 million individuals, 39.5%) and even years (15.7 million individuals, 41.4%). However, this does not necessarily mean that the change in the variation in abundance was small in both odd and even years. Until 1981, few differences between contiguous years were observed. Then from 1982–1992 mean pink salmon abundance was higher in odd years (21.4 vs. 11.4 million individuals). Since 1993 abundance has been higher in even

Table 1. Correlation coefficients for changes in abundance, escapement timing and fork length of pink salmon from different areas of the Sakhalin-Kuril region.

Area	Period	Abundance – Escapement timing		Abundance – Fork length	
		By the untransformed values	By the trend lines	By the untransformed values	By the trend lines
Aniva Bay	1975–2004	-0.19	0.10	0.08	0.80***
Southeastern Sakhalin	1975–2004	-0.04	0.01	-0.04	0.55**
Iturup Island	1967–2004	0.34*	0.56***	-0.28	-0.36*
	1975–2004	0.01	-0.23	-0.09	0.33

Note: Asterisks indicate the values of Fisher's criterion exceeding the critical values at 95% (*), 99% (**) and 99.9% (***) significance levels.

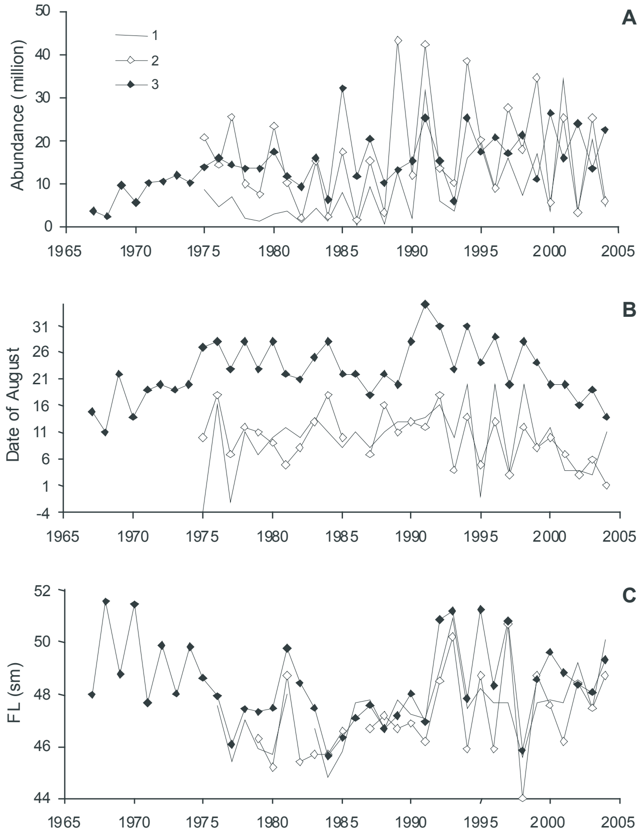

Fig. 2. Changes in abundance (A), escapement timing (B: date of the 50% capture) and fork length (C) of pink salmon from different spawning areas. 1, Aniva Bay; 2, southeastern Sakhalin; 3, Iturup Island.

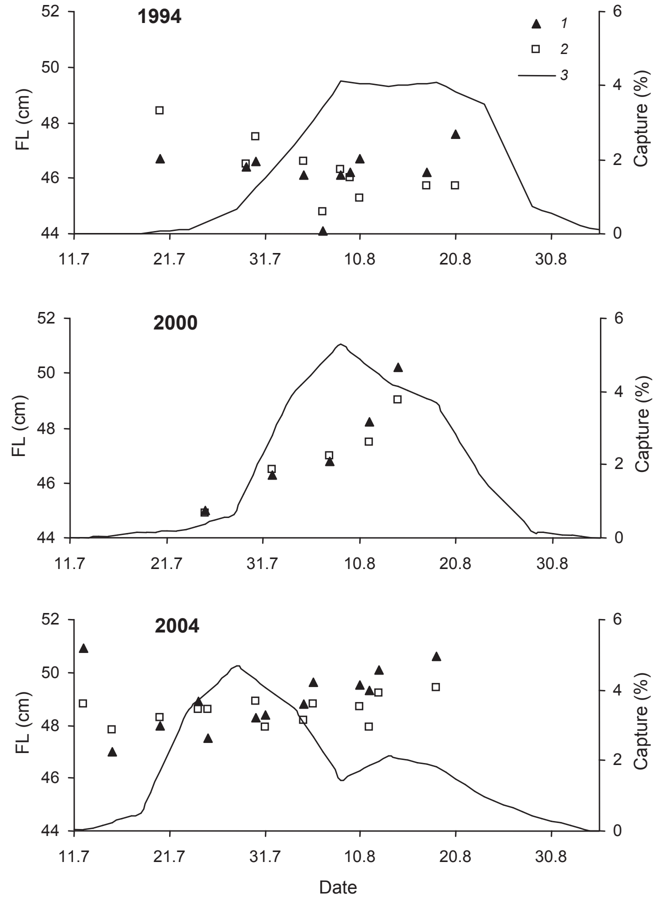

Fig. 3. Dynamics of catches and changes in pink salmon fork length on the southeastern Sakhalin coast in 1994, 2000, and 2004. 1, male fork length; 2, female fork length; 3, daily catches.

years (23.4 vs. 13.6 million individuals).

Despite the differences in pink salmon abundance between odd and even years, periods of synchronous increase or decrease in indices such as abundance, escapement timing, and fork length are observed. Consider the changes in the Iturup fish which have the longest data record. An increase in abundance, delayed escapement timing, and a decrease in fork length were observed until the second half of the 1970s (Fig. 2). The 1980s were characterized by a decrease in abundance for the even-year-classes, whereas the abundance of the odd-year-classes remained the same, except for 1985, which had record levels of escapement (32.1 million). This resulted in a rise in the trend line in the mid 1980s. During the 1980s, pink salmon were smaller in size, and the migration timing of different year-classes did not vary significantly. Since the end of the 1980s an increase in abundance has been recorded, and, until the mid 1990s, returning fish were larger and they returned at later dates. Further, fish continued to be abundant and comparatively large but escapement timing began to shift to earlier dates. This became especially evident at the beginning of 21st century. As the result, the correlation between abundance and escapement timing was positive, and between abundance and fork length, negative. However, correlation coefficients were low, except for the one characterizing changes in the trend lines for abundance and escapement timing (Table 1).

Changes in the same indices in the Aniva Bay and southeastern Sakhalin pink salmon differed from those for the Iturup fish only in details. For instance, in these regions the most noticeable decline in pink salmon abundance was in the 1980s, when a trend toward delays in spawning times began to appear, and fish were smaller in size, on average. A relatively strong, positive relationship was found only between the trend lines for fish abundance and fork length (Table 1). Two features should be taken into account when comparing correlation coefficients in the three study regions. First, the data record for Sakhalin Island is shorter; it begins during a decrease in abundance, but before the period of very low abundance in the 1980s. Correlation coefficients for Iturup fish, calculated for the same period, are close to the corresponding indices for fish from both regions. Second, after the abrupt decline in pink salmon abundance in 1993 in all regions, the even-year-classes began dominating in abundance on Iturup Island. On Sakhalin Island the high abundance of the odd-year-classes re-appeared. Despite this phenomenon, pink salmon abundance continued to be at a comparatively high level and increased fish returns were recorded. Simultaneously a trend toward shifting escapement timing to earlier dates was observed.

In our analysis, we took into account changes in pink salmon body length during the spawning run. Usually, a trend toward a gradual increase in fish size and changes in the ratio between male and female size are common. In the second half of fish run there is an abrupt increase in male size. As a result, compared to the first half of the run, males become larger than females. Such changes are shown for southeastern Sakhalin pink salmon during the beginning, middle, and end of the last period during which there was a shift in run timing toward earlier dates (Fig. 3).

When considering the long-term trends in changes in fish abundance, escapement timing and fish size (Fig. 2), the great differences in these parameters in contiguous years become important. To study these changes, the data were grouped according to the changes in abundance (increase, decrease, or no change, compared to the previous year). A rank "without changes" corresponded to parameters where changes did not exceed a statistical error of the mean value of the sample examined. Taking into account that the Kuril-Hokkaido even-year-classes and the Sakhalin odd-year-classes more often dominate in abundance, the data were compared in two ways. In the first approach we used the abundance of the stocks studied. In the second, we considered the regional abundance including pink salmon from eastern Sakhalin, the southern Kuril Islands and Hokkaido. We found no co-dependence using either approach to study changes in parameters (Table 2).

Prior to analyzing the data in Table 2, recall that the changes corresponding to the concept of the density-dependent regulation are reflected in either the delay (or acceleration) in the dates of migration timing and the decrease (or increase) in fork length corresponding to an increase (or decrease) in abundance. Such changes have been shown only for the Iturup fish, for which the synchronous changes in escapement timing occurred in 57-62% of cases, and asynchronous changes in fork length in 59-62% of cases coinciding with changes in abundance. Similar changes between the fork length and abundance were recorded for pink salmon from southeastern Sakhalin in only half of the cases (52%). For the Aniva Bay fish such situations were seen less frequently (36-43%). Changes in escapement timing that were synchronous with changes in abundance were also not frequently seen in fish from Aniva Bay (25-29%) and southeastern Sakhalin (28-31%).

A reliable relationship between the number of pink salmon returns and number of spawners was found only in Aniva Bay (Fig. 4). There, the number of downstream fry migrants increased concurrent with an increase in the abundance of spawners on spawning grounds (Fig. 4). Quantitative dependence of pink salmon returns on the total number of fry migrating from rivers to the ocean was strong in all regions (Fig. 5). However, even in these instances the correlation coefficients were average, because the number of pink salmon returns is mainly determined by survival during the marine period. The same trend toward a decrease in survival index for both the highly abundant year-classes and less abundant fry migrants was observed in Aniva Bay and southeastern Sakhalin (Fig. 5). When analyzing the data in Table 3, we note the great importance of the marine period in determining the abundance of pink salmon returns. In all the regions, the periods with abundant pink salmon returns were characterized by high survival indices. This reflects a high level of survival during the marine period. It was only in Aniva Bay in 1995–1998 where comparatively high returns were related to an abundant fry harvest. Along with high

Table 2. Percent changes in pink salmon escapement timing and fork length (FL) in Aniva Bay, southeastern Sakhalin and Iturup islands in relation to species abundance in the study area (upper value) and in the broader region* (lower value) in contiguous years.

Changes in indices		Aniva Bay		Southeastern Sakhalin		Iturup Island	
Species abundance	Escapement timing and fork length	Escapemt. timing (n = 28)	FL (n = 28)	Escapemt. timing (n = 29)	FL (n = 25)	Escapemt. timing (n = 37)	FL (n = 37)
Increase or decrease	Synchronous with abundance	25 29	39 36	31 28	28 28	57 62	32 32
	Asynchronous with abundance	54 54	36 43	69 69	52 52	33 33	59 62
	Without changes	14 14	18 18	0 0	20 20	5 5	3 6
Without changes	With changes	7 3	7 3	0 3	0 0	5 0	3 0
	Without changes	0 0	0 0	0 0	0 0	0 0	3 0

*Pink salmon abundance on the eastern coast of Sakhalin, the southern Kuril and Hokkaido islands (Anonymous 2004).

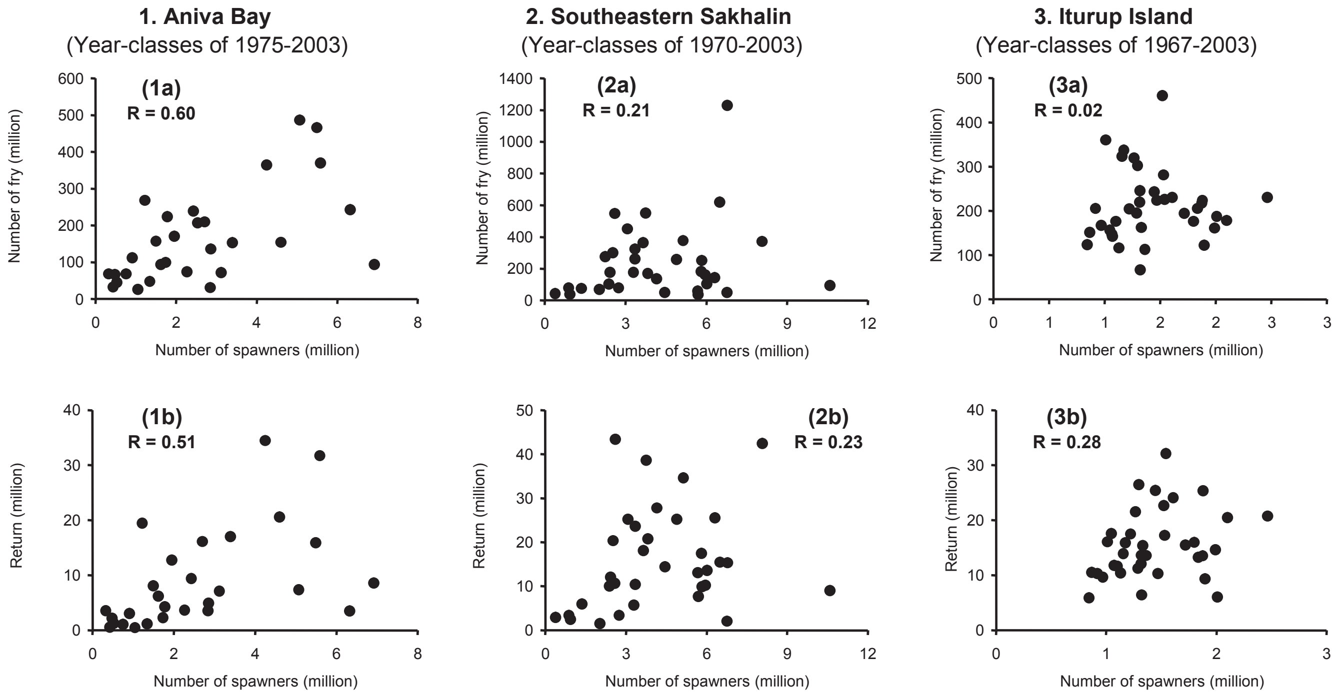

Fig. 4. Dependence of pink salmon fry migrants (a) and returns (b) on the number of spawners in rivers from different spawning areas.

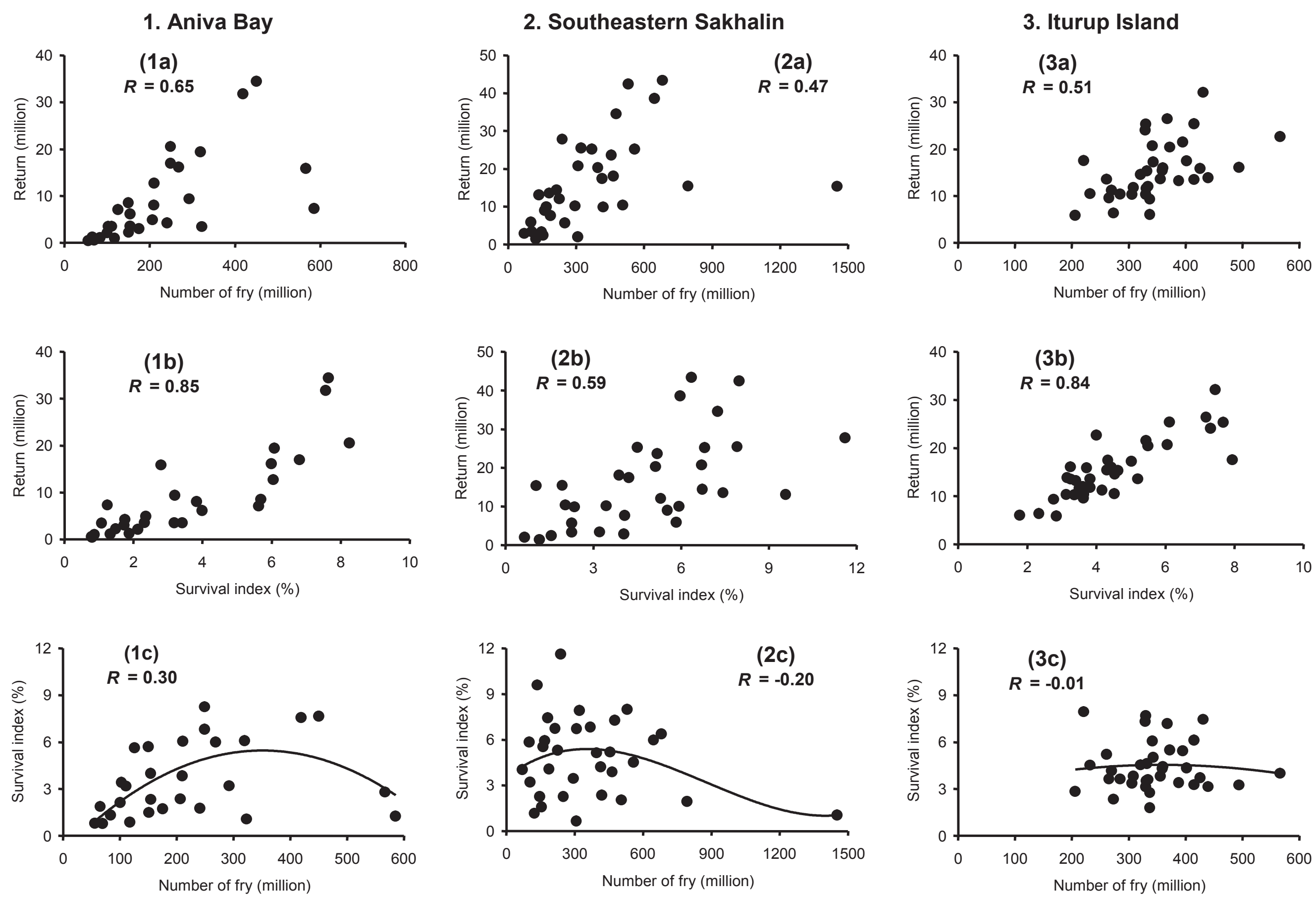

Fig. 5. Co-dependence of reproduction indices for pink salmon during the marine period in different spawning areas. (a) dependence of pink salmon returns on the harvest of fry migrants; (b) fish survival during the marine period; (c) dependence of pink salmon survival during the marine period on the harvest of fry migrants.

fish survival in the ocean, an increase in fry migrants was also correlated with increased pink salmon returns to Iturup Island in 1999–2002.

DISCUSSION

The data on the ratios among the abundance of spawners, number of fry migrants, and pink salmon returns illustrate the uniqueness of each of the regions considered here. First, we note the weak dependence of the abundance of fry migrants on the abundance of their parents in regions with very dense aggregations of fish on the spawning grounds in the Iturup rivers (average 2.11 ind/m^2) and southeastern Sakhalin (average 2.76 ind/m^2). In southeastern Sakhalin, especially in the large rivers, there are reserves of unused spawning grounds, which, when fully occupied in particular years, leads to an increase in the abundance of downstream fry migrants. As a result, the importance of spawners' abundance in determining the abundance of fry migrants in this region (Fig. 4) is greater than that in the Iturup Island rivers (Fig. 4). By contrast, in the Aniva Bay rivers, where the number of spawners per area of spawning grounds (average 1.56 ind/m^2) is the lowest, the number of fry migrants depends more strongly on the number of their parents (Fig. 4).

Patterns of changes in year-class marine survival are different in each of the study regions. If we proceed from

Table 3. Mean abundance (in millions) of pink salmon adults and fry in different Sakhalin–Kuril regions for year-classes, according to years of fish spawning.

Years of spawning	Abundance of adult fish in rivers	Abundance of fry migrants*	Abundance of returns	Survival index (%)
Aniva Bay				
1975–1978	1.78	133.7 (38)	3.36	2.51
1979–1982	0.85	133.7 (25)	2.50	1.87
1983–1986	1.35	157.0 (28)	4.60	2.93
1987–1990	2.42	221.0 (21)	13.19	5.97
1991–1994	4.30	265.1 (23)	11.88	4.48
1995–1998	4.21	376.0 (25)	10.90	2.90
1999–2002	3.50	265.2 (31)	15.87	5.98
Southeastern Sakhalin				
1971–1974	4.09	206.9 (54)	14.54	7.03
1975–1978	5.30	346.1 (50)	16.65	4.81
1979–1982	4.47	605.1 (32)	7.53	1.25
1983–1986	3.81	358.9 (34)	9.42	2.62
1987–1990	4.79	405.2 (26)	27.83	6.87
1991–1994	5.71	374.7 (26)	19.50	5.20
1995–1998	4.06	357.6 (27)	21.50	6.01
1999–2002	3.03	294.1 (27)	14.91	5.07
Iturup Island				
1967–1970	1.04	258.3 (36)	9.07	3.51
1971–1974	1.10	393.5 (30)	13.07	3.32
1975–1978	1.61	349.8 (50)	14.78	4.22
1979–1982	1.52	319.5 (60)	10.86	3.40
1983–1986	1.47	354.8 (51)	18.63	5.25
1987–1990	1.58	373.5 (46)	17.34	4.64
1991–1994	1.85	307.5 (35)	17.40	5.66
1995–1998	1.35	344.0 (20)	19.10	5.55
1999–2002	1.41	419.3 (24)	19.04	4.54

*Proportion of hatchery-released pink salmon fry (%) in parentheses.

the fact that the mortality rate of pink salmon is the highest and changes the most during the first months of marine life (Parker 1962; Ricker 1964; Heard 1991; Karpenko 1998), we can attribute the increase in mortality for year-classes with very abundant fry migrants in Aniva Bay and southeastern Sakhalin (Fig. 5) to density-dependent factors. Further, based on other results for Aniva Bay (Shershnev et al. 1982) and the southeastern Sakhalin coast (Shubin et al. 1996; Ivankov et al. 1999), juvenile pink salmon leave the shallow coastal zone relatively quickly after their downstream migration. Early departure of juvenile salmon will increase the relative losses to predators for non-abundant year-classes. Thus, it likely results in a decline in marine survival of such generations. On the contrary, on Iturup Island pink salmon fry migrate to sea after a period of intense growth in the shallow coastal zone where zooplankton are abundant (Yefanov et al. 1990; Kaev and Chupakhin 2002; Kaev 2003). Perhaps, this is why Iturup pink salmon show less variability in year-class survival during the marine period (survival index ranged from 1.78 to 7.94, SD = 1.56) compared to the southeastern Sakhalin fish (survival index ranged from 0.65 to 11.61, SD = 2.60) and Aniva Bay fish (survival index ranged from 0.79 to 8.25, SD = 2.37).

Despite these differences, there appears to be one common pattern for all three regions which is that changes in stock abundance are mainly the result of pink salmon survival during the marine period. Table 3 shows that some periods are characterized by low survival, and others by high survival. In particular, the increase in pink salmon abundance during the 1990s was determined mainly by the increase in year-class survival during the marine period. While fluctuations in abundance are still somewhat determined by changes in reproductive efficiency in rivers, the changes in pink salmon growth in different years depends entirely on the feeding and habitat conditions in the ocean. Researchers often identify an insufficient oceanic food supply for abundant year-classes of Pacific salmon as an a priori reason for delays in fish growth and, as a consequence, later dates of maturation and migration (Kaganovsky 1949; Gritsenko et al. 1983; Welch and Morris 1994; Bigler et al. 1996). That may explain the later spawning migrations and decreases in growth and fecundity in the 1970s on Iturup Island (Yefanov and Chupakhin 1982). However, this may not always be the case (Kaev and Chupakhin 2003).

Because pink salmon are widely distributed in the northwestern Pacific Ocean (Klovatch et al. 2002), one might think that data on the abundance of different stocks inhabiting the same vast areas are required (Fig. 2). However, we used data for only a few individual stocks. We chose this approach based on the strong relationship between fluctuations in the pink salmon catches in each region (correlation coefficients have ranged from 0.72 to 0.88 since 1946) and the total catches on eastern Sakhalin and the southern Kuril islands. This very abundant group of pink salmon, provides for about 70%, on average, of the Russian pink salmon catch

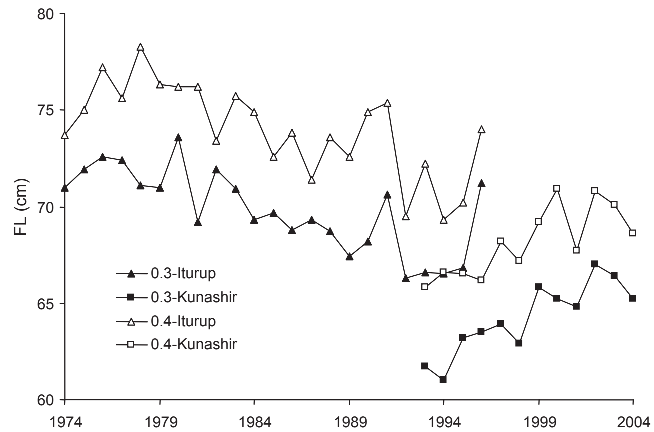

Fig. 6. Changes in fork length in chum salmon ages 0.3 and 0.4 on Iturup and Kunashir islands in 1974–2004. Data collected in 1974–1996 at Iturup Island (Kaev 1999) and since 1993 at Kunashir Island (Kaev and Romasenko 2003).

from the Okhotsk Sea, and is partially isolated during the marine period from the other two large groups—i.e. fish from the rivers in the western and eastern Kamchatka Peninsula. The west Kamchatka and Sakhalin-Kuril juveniles are spatially separated in the Okhotsk Sea until September (Erokhin 2002). This separation is partially maintained during the migration to the Kuril Ridge straits (Temnykh 2004). In other words, the three large groups of pink salmon are already partially separated in the ocean prior to the spawning migration to natal rivers (Temnykh 2004). The possibility of other species (e.g. the comparatively abundant chum salmon) affecting the pink salmon food supply in the Okhotsk Sea and adjacent ocean waters is unlikely because each species has a different diet composition (Fig. 6) (Temnykh 2004).

Density and abundance characteristics of local fish stocks may explain the patterns we are seeing. We note the consistent relationship between changes in escapement timing and fish length, and corresponding changes in pink salmon abundance in all three study areas (Table 2). Changes found in these indices were greater in the Iturup pink salmon than in the southeastern Sakhalin and Aniva Bay fish which can be explained by density-dependent regulation. In order to fully understand the differences in results for the Iturup and Sakhalin fish, we should keep in mind that the data record for the Iturup Island fish is longer. It includes the 1970s, when the concept of the density-dependent regulation was well confirmed.

Peculiarities in pink salmon size composition and escapement timing are also connected with intraspecific structuring. Historically, ichthyologists paid attention to the heterogeneity of the pink salmon migration to the Sakhalin and Kuril rivers (Ivankov 1967, 1986; Gritsenko 1981; Yefanov 1989). Presently, pink salmon from the two ocean groups, one with an early spawning migration and one with later dates, are represented in catches from the study regions (Kaev 2002). Fish from the later group are larger, on average. The males, especially, increase in length and eventually become larger than females. Based on this information, the increase in catches since the end of 1980s may be the result of the rise in pink salmon abundance, mainly from the later ocean group (Kaev et al. 2004b), which corresponds to the later dates for 50% capture (Fig. 2). However, it appears that since the mid 1990s the migration of the main bulk of pink salmon has tended to shift toward earlier dates. This became even more noticeable at the beginning of the 21st century. Note that the changes in dates of the beginning and the end of the fishing season are not as apparent as the changes in the ratio of early to later-run fish in the catches (Fig. 3).

Finally, one should note the concurrence of the two seemingly different processes. On one hand, the increase in pink salmon abundance and body size, beginning in the second half of the 1980s, coincided in time with a delay in chum salmon growth (Kaev 1994; Helle and Hoffman 1995; Kaeriyama 1996). However, the delay in growth for Asian stocks of chum salmon was observed mainly during their spawning migration in the northeastern Pacific Ocean, while in the Okhotsk Sea and adjacent waters of the Pacific Ocean (the habitat of the pink salmon stocks considered here) such changes in growth of chum salmon were not observed (Kaeriyama 1996; Kaev 1999). On the other hand, the shift toward earlier migration dates coincided in time (second half of the 1990s) with changes in chum salmon growth. We can evaluate this phenomenon by looking at the changes in body length of wild chum salmon populations in the southern Kuril Islands (Fig. 6). At present, there are insufficient data to explain these processes. The patterns observed in both pink and chum salmon, support the point of view of V.P. Shuntov (2000), who reported that since the late 1990s the dynamic processes in the northern Pacific Ocean started to trend in opposite directions. Development of this process may result in a decrease in abundance Asiatic pink salmon stocks.

CONCLUSIONS

The existence in different stocks of permanent and synchronous tendencies toward changes in abundance, as well as in biological indices of fish and escapement timing, points to the important role of long-term cyclical processes in the dynamics of pink salmon stocks in the Sakhalin-Kuril region. At the same time, interannual changes in those indices corresponding with the principles of density regulation have been observed only sporadically, despite the known differences in abundance of pink salmon between odd and even years. Thus, we think that factors connected with habitat changes play the most important role in dynamics of pink salmon stocks.

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