North Pacific Anadromous Fish Commission
Bulletin No. 4: 319–326, 2007

Possible Causes and Effects of Shifts in Trends of Abundance in Pink Salmon of Kunashir Island, a Population near the Southern Limit of Its Range in Asia

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Kaev, A.M., and L.V. Romasenko. 2007. Possible causes and effects of shifts in trends of abundance in pink salmon of Kunashir Island, a pupulation near the southern limit of its range in Asia. N. Pac. Anadr. Fish Comm. Bull. 4: 319–326.

Abstract: The results of monitoring pink salmon (*Oncorhynchus gorbuscha*) spawning in the rivers of Kunashir Island are presented. The abundance of this small stock is shown to be related to its spawning location which is close to the southernmost limit of spawning for this species. Long-term changes in the number of spawners and body size are similar to those for other larger pink salmon stocks in the Sakhalin-Kuril region. These similarities suggest that factors related to habitat changes play an important role in pink salmon stock dynamics.

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

INTRODUCTION

Pink salmon (*Oncorhynchus gorbuscha*), because of its unique biology (large fluctuations in abundance and the shortest life cycle of all Pacific salmon) is an attractive subject for studying stock dynamics as a process of interaction between salmon and their habitat. One way to approach such studies is to look at life cycle processes of pink salmon in different regions. In a companion paper (Kaev et al. 2007) changes in pink salmon reproduction, abundance and fork length were analyzed for the three large stocks in the Sakhalin-Kuril region, which provide more than half of the Russian pink salmon catch in the Okhotsk Sea. In this paper the pink salmon in the rivers of Kunashir Island are analyzed. The abundance of this stock is significantly less than those of the Sakhalin-Kuril stocks. However, Kunashir stock of pink salmon is interesting to researchers because their range is close to the southernmost limit of spawning for the species (Heard 1991).

MATERIALS AND METHODS

Despite the historical existence of a pink salmon fishery on Kunashir Island, regular observations of pink salmon reproduction there only began in 1994. Annual changes in reproduction indices were studied in the Ilyushin River located in the center of the island's Pacific coast (Fig. 1). The Ilyushin is a typical Kunashir river with a 9.3-km-long main stem and 21,000 m^2 of spawning grounds (Kaev and Strukov 1999). Each year the numbers of adult fish in the river are counted twice (in mid-September and the first half of October) at individual sites on spawning grounds. The estimate of mean density of fish (ind/m^2) was multiplied by 4 (a factor we consider reasonable to account for the duration of the run and the occurrence of aggregations of fish outside the spawning grounds), and then extrapolated to obtain the total number of pink salmon that entered the river in that particular year. The numbers of pink salmon in other rivers on Kunashir were calculated based on the ratio between the size of their spawning areas and those in the Ilyushin River. In some years data were corrected if the densities of fish on spawning grounds in some rivers were significantly either greater or less than those in the Ilyushin River (Kaev and Strukov 1999). The density of pink salmon aggregations on spawning grounds is determined occasionally in the following Kunashir rivers: Tyatinka, Mostovaya, Filatov, Prozrachniy, Asin, Valentina, Pervukhin, and Severyanka (see Fig. 1). The numbers of pink salmon returns were determined as the total number of fish counted in rivers plus those caught in the commercial fishery.

Juvenile downstream migrants were counted in the Ilyushin River by the sampling method of Volovik (1967). A probable number of migrants from other rivers of the island was calculated based on the annual ratio between the number of spawners in the Ilyushin River and the number of their fry migrating downstream. Based on these data, the pink salmon survival index was calculated as the proportion of returning spawners to the total number of downstream migrants.

In the Ilyushin River, sex, stage of maturity, fork length, body weight, and fecundity were measured in fish sampled

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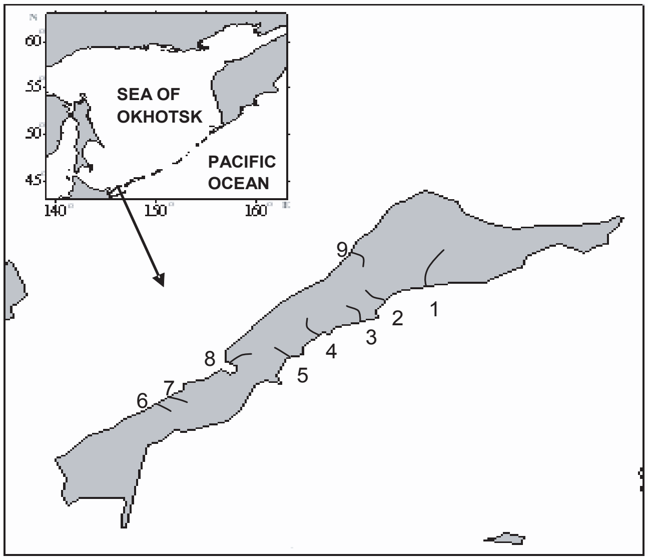

Fig. 1. Map of Kunashir Island and the location of rivers mentioned in the text. 1, Tyatinka R.; 2, Mostovaya R.; 3, Filatov R.; 4, Ilyushin R.; 5, Prozrachniy R.; 6, Asin R.; 7, Valentina R.; 8, Pervukhin R.; 9, Severyanka R.

at the river mouth with beach seines. During the observation period, a total of 55 samples (4,089 fish) were collected in 1991–2004; additionally, three samples (300 fish) were collected in 2003–2004 from trap nets in the sea. Previously, the mean indices from samples collected during a year were used for determining pink salmon biological characteristics (Kaev and Romasenko 2003). In this paper, in order to study long-term changes in pink salmon biological indices, we used the weighted average values for each index in accordance with the dynamics of commercial catches. To study the timing of fish approaches to the coast, we used data only from trap-net catches (passive fishing gear). Differences in dates of approach for the different year-classes of pink salmon were estimated by the dates when half of the fish were caught.

Standard methods were used for statistical analysis (Plokhinsky 1970). Trend lines were calculated by 4-year moving averages because the inter-annual changes in pink salmon abundance and biological indices are related to its two-year life cycle.

The following symbols are used in the text: *M* (mean), *SD* (standard deviation), *CV* (coefficient of variation), *Lim* (range), *R* (coefficient of correlation), *P* (level of probability), and *N* (sample size).

RESULTS

Kunashir is the southernmost island in the Large Kuril Ridge (Fig. 1). The climate there is relatively mild, but with snowy winters with frequent thaws, as is common for the southern Large Kuril Ridge. The coastal temperature regime is influenced by the warm waters of the Soya Current. Kunashir Island is located in a relatively "warm" zone compared to nearby Iturup Island (Brodsky 1959; Kusakin 1971) where the pink salmon reproduce very successfully (Kaev et al. 2006).

The mean annual pink salmon catch in Kunashir Island waters was 3,539 tons in 1994–2004. This value reflects a stock level that increased dramatically in the 1990s following a long period of decline (Fig. 2). Based on the synchronous changes ($R = 0.92$; $P < 0.001$; $N = 15$) in commercial catches

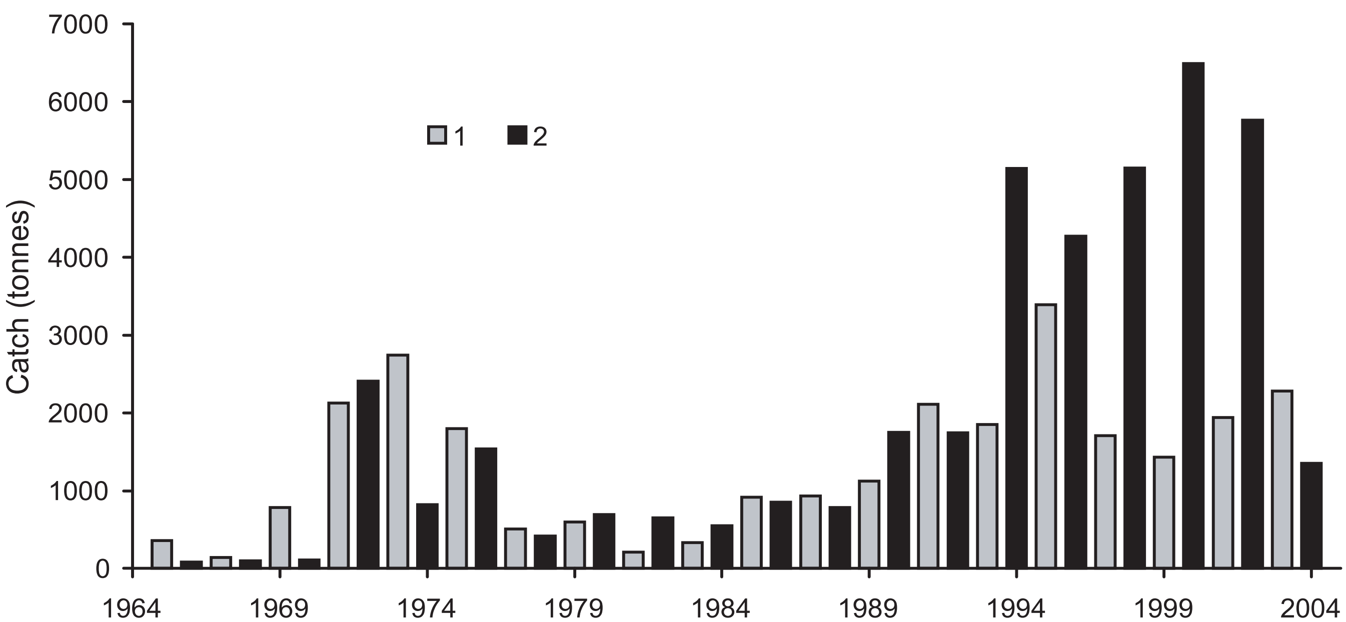

Fig. 2. Dynamics of pink salmon commercial catches in odd (1) and even (2) years on Kunashir Island from 1965–2004.

Table 1. Ratio between the numbers of pink salmon entering the rivers of Kunashir Island, the numbers of fry migrating downstream and the numbers of adult returns. Numbers of fish are given in thousands of individuals.

Spawning		Number of fry migrants	Adult returns		
Year	Fish entering rivers		Comm. fishery	Fish entering rivers	Total (SI*, %)
1989	–	55,477	1,376	1,647	3,023 (5.45)
1990	1,115	67,598	1,177	1,216	2,393 (3.54)
1991	1,647	160,794	1,022	988	2,010 (1.25)
1992	1,216	–	4,186	2,153	6,339
1993	988	–	2,019	1,026	3,045
1994	2,153	123,518	3,164	1,743	4,907 (3.97)
1995	1,026	84,317	1,007	830	1,837 (2.18)
1996	1,743	220,729	4,051	2,622	6,673 (3.02)
1997	830	37,367	859	596	1,455 (3.89)
1998	2,622	99,837	4,062	2,888	6,950 (6.96)
1999	596	67,480	1,154	469	1,623 (2.41)
2000	2,888	271,735	3,409	2,613	6,022 (2.22)
2001	469	22,243	1,427	671	2,098 (9.43)
2002	2,613	187,277	816	426	1,242 (0.66)

*SI, survival index.

and the number of fish in rivers (Table 1), the fishery is based on a single (local) stock. The stock reproduces in 40 rivers and brooks, and the inlets to 5 lakes. The total spawning area of the local pink salmon stock is approximately 266,000 m^2. The island's rivers are relatively short. In most rivers, aggregations of pink salmon spawn at sites several kilometers upstream from the mouth. From 426 to 2,888 (average 1,400 thousand fish) entered Kunashir rivers in 1990–2004. From 22,243 to 271,735 (average 116,531 thousand) fry migrated downstream in 1990–1992 and 1995–2003. Pink salmon returns in 1991–2004 ranged from 1,242 to 6,950 (average 3,544 thousand individuals), of which 816 to 4,062 (average 2,124) thousand fish were caught in the commercial fishery. On the average, during 1991–2004 the number of pink salmon in even years (4,932 thousand fish, $CV = 42.2\%$) was higher than in odd years (2,156 thousand fish, $CV = 27.4\%$).

Despite the odd-year/even-year changes in pink salmon numbers, the mean number, based on the trend lines, changed insignificantly during the observation period (Fig. 3A). When pink salmon numbers in the even years (1992, 2004) were lower than in the following odd year, a decline in the mean stock level was observed. After the abrupt shift in the dates of run in 1993, they changed insignificantly in the following odd year. At the same time, earlier fish returns were observed in even years resulting in a consistent decrease in the trend line (Fig. 3B). After a slight decrease in the second half of the 1990s, a trend toward an increase in pink salmon fork length was seen (Fig. 3C). In most years there was an inverse relationship between pink salmon numbers and fork length. The correlation between fish numbers and dates of run was weak and differed by sign ($R = 0.44$; $P > 0.05$) and trend lines ($R = -0.32$; $P > 0.05$). The correlation between fish numbers and fork length was more significant, when we analyzed the actual measured values ($R = -0.68$; $P < 0.01$), than the trend lines ($R = -0.56$; $P < 0.05$). A relation among the biological indices measured is closer than the calculated values in the trend lines. This may be a result of changes in contiguous years. To study this problem (see Kaev et al. 2007), we combined the data on pink salmon numbers, dates of run, and fork length into groups. In the first group the number increased compared to those of the previous year. In the second group the number declined. In the third group the number did not change. Changes in the timing of the spawning run and fork length in contiguous years were considered within each group. The designation 'without change' was applied if a change did not exceed the statistical error of the mean of the sample being examined. Data from two groups of pink salmon were analyzed: (1) abundance of fish from Kunashir Island; and (2) abundance of fish from the broader region, encompassing eastern Sakhalin Island, the southern Kuril Islands and Hokkaido. For Kunashir pink salmon changes in dates of run and fork length were shown to coincide with the corresponding changes in abundance in most cases (Table 2). In 12 of 13 cases with an increase (or decrease) in numbers, the dates of run were shifted toward later (or earlier) dates ($R = 0.77$; $P < 0.01$; $N = 13$). Changes in the fork length also varied synchronously with the abundance numbers in 10 of 13 cases, but these changes were opposite in direction ($R = -0.69$; $P < 0.01$; $N = 13$). When we used the data on abundance of fish from the broader region,

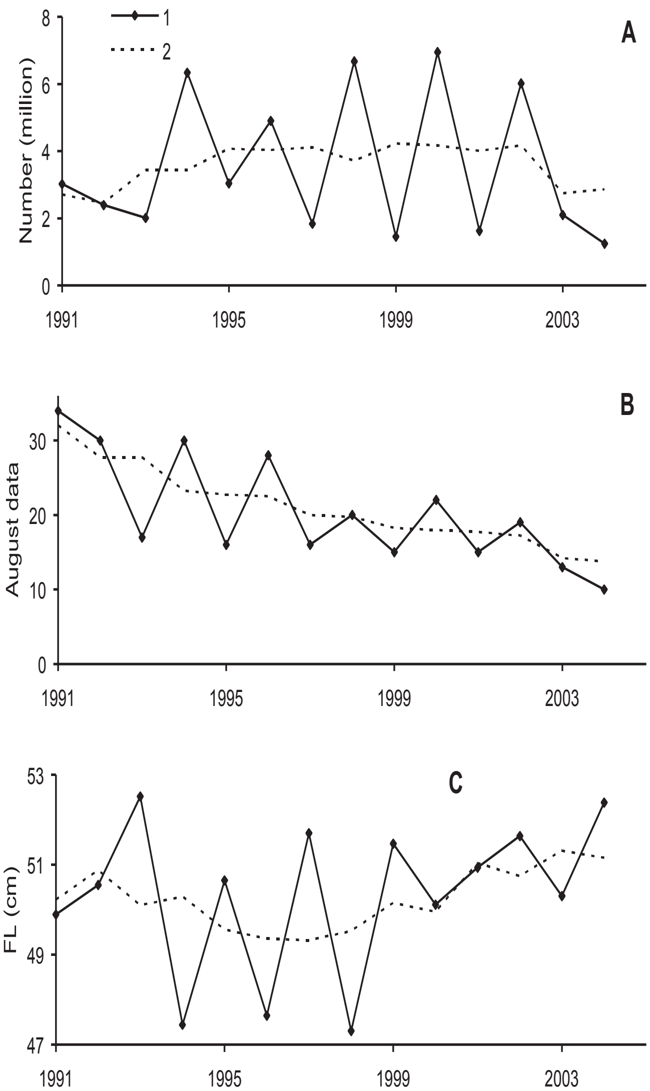

Fig. 3. Changes in numbers (A), date of 50% capture (B) and fork length (C) of pink salmon from Kunashir Island from 1991–2004. 1, measured values; 2, trend lines.

there was no clear pattern regarding either changes in dates of run (R = 0.22) or fork length (R = -0.38).

A close relation between the number of spawners entering rivers and the number of the subsequent downstream migrating fry was established (Fig. 4A). Taking into account the almost seven-fold fluctuation in the number of spawners on the spawning grounds in different years, this dependence becomes the essential factor in determining the number of offspring. However, a dependence of the number of offspring on the number of their parents numbers weakens significantly at the final stage of the reproductive process (actual returns) (Fig. 4B), because different pink salmon year-classes have different levels of survival during the marine period (Fig. 5A). In particular, an increase in pink salmon mortality during the marine period has been shown for year-classes with high numbers of downstream migrating fry (Fig. 5B).

DISCUSSION

The pink salmon of Kunashir Island have some unique biological characteristics that distinguish them from other pink salmon stocks in the Sakhalin-Kuril region (Kaev et al. 2007). First, during spawning in the Kunashir rivers a close relationship is seen between the number of spawners and the subsequent number of downstream migrating fry. This pattern is uncommon in fish from similar small rivers in other reproductive areas. Second, a clear decrease in fish survival during the marine period is seen in Kunashir pink salmon year-classes with high numbers of downstream migrating fry. Third, Kunashir pink salmon returns from abundant year-classes were typically smaller in length and approached the coast at later dates, in accordance with the principles of density regulation. The question arises whether these differences in Kunashir pink salmon occur because of interaction(s) with their habitat or for other reasons. While searching for the answer to this question, we noted the comparatively low density of spawners on the spawning grounds of the Kunashir rivers. Since 1994 through 2004 the mean

Table 2. Co-dependence of changes in dates of run and fork length (FL) with species abundance in pink salmon from Kunashir Island (Kunashir) and in the broader region* (Region) in contiguous years.

Changes in indices		Kunashir		Region	
Abundance	Dates of run and fork length	Dates of run	FL	Dates of run	FL
Increase or decrease	Synchronous with abundance	12	2	5	5
	Asynchronous with abundance	0	10	7	7
	Without change	0	0	0	0
Without changes	With change	1	1	1	1
	Without change	0	0	0	0

*The eastern coast of Sakhalin, and the southern Kuril and Hokkaido islands (Anonymous 2004).

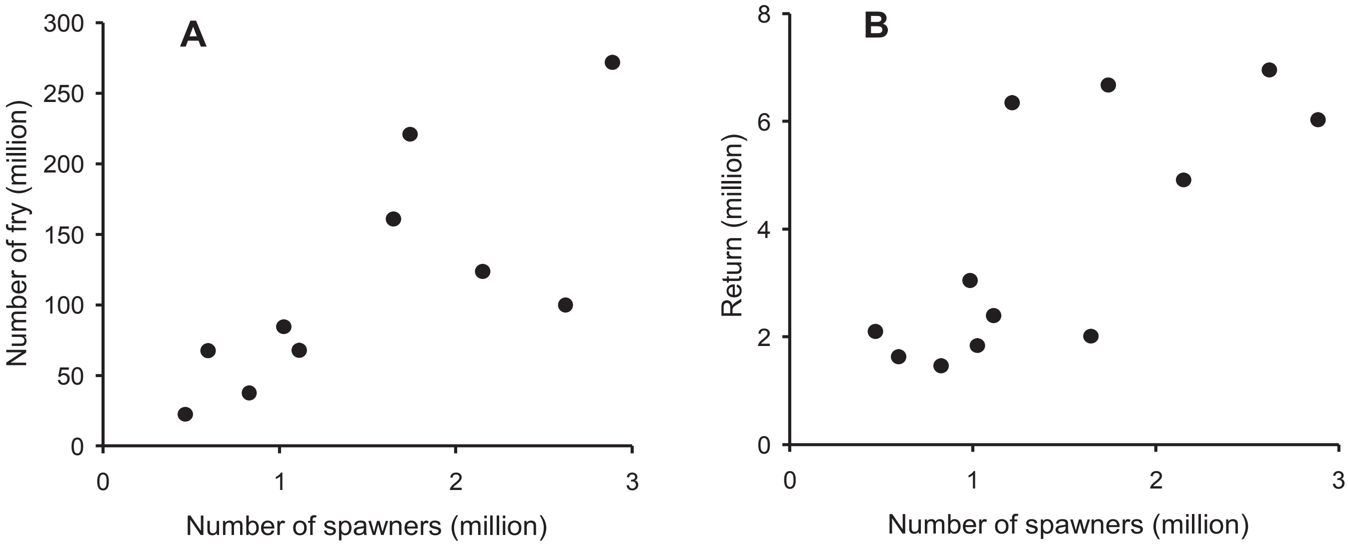

Fig. 4. Dependence of numbers of pink salmon fry migrants (A) ($R = 0.78$; $P < 0.01$; $N = 12$) and returns (B) ($R = 0.53$; $P > 0.05$; $N = 13$) on the number of spawners in Kunashir Island rivers from 1990–2004.

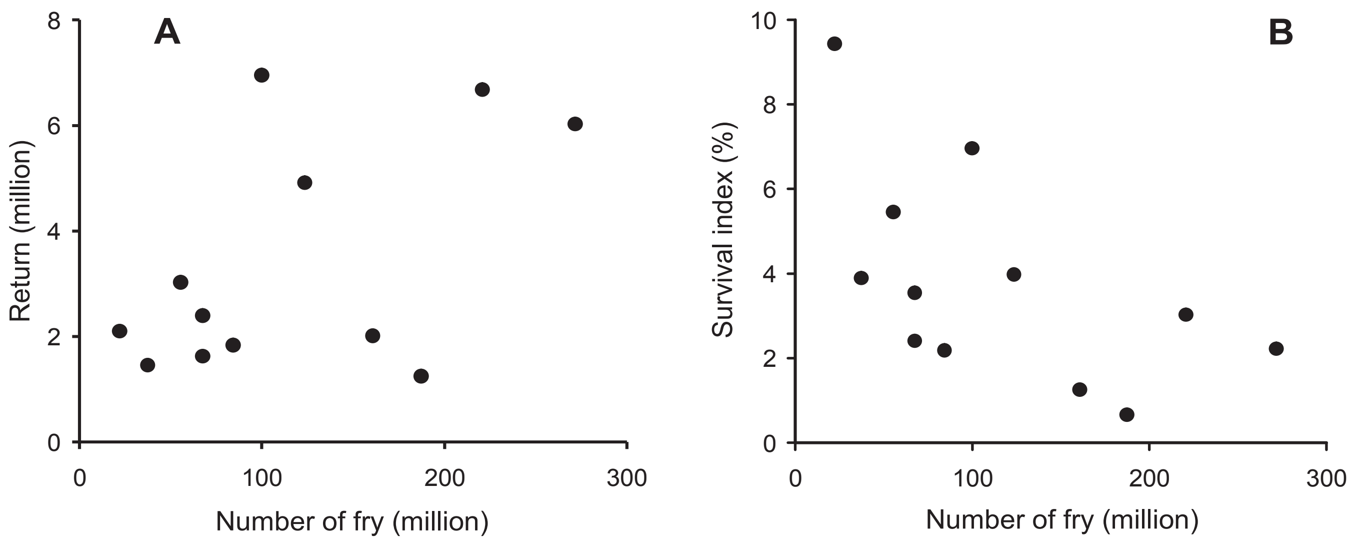

Fig. 5. Dependence of pink salmon returns (A) ($R = 0.52$; $P > 0.05$; $N = 12$) and fish survival during the marine period (B) ($R = -0.57$; $P < 0.05$; $N = 12$) on the harvest of fry migrants in Kunashir Island rivers from 1990–2004.

pink salmon concentration on the Kunashir spawning grounds during the peak of spawning (mid-September) was 1.35 ind/m^2, while on neighboring Iturup Island the level was 2.11 ind/m^2. Also, the number of spawners in Kunashir rivers in different years varied significantly ($CV = 59.4$, a 6.8-fold difference between extreme values) compared to Iturup rivers ($CV = 27.1$, a 2.9-fold difference). We also note that the only region of the three areas considered by Kaev et al. (2007) where a consistent positive relation was observed between the number of downstream migrating fry and the number of their parents, is the Aniva Bay coast. The mean concentration of spawners there was 1.56 ind/m^2 during the peak of spawning. Thus, we suggest that the increase in numbers of fry migrants, observed simultaneously with an increase in the number of spawners in the Kunashir rivers, is related to the complete use of the spawning grounds.

Based on occasional observations, juvenile pink and chum (*O. keta*) salmon remain in the shallow water at the coast of Kunashir Island after they migrate downstream, as they do on Iturup Island (Kaev and Chupakhin 2002). These observations are documented by the rare occurrence of juveniles in purse-seine catches and in trawls in June and July close to the island shores (Kaev et al. 1994; Kovalenko et al. 2004; Shubin et al. 2005). We have no reason to think that the survival of Kunashir pink salmon in the open ocean differs significantly from that of pink salmon stocks in surrounding areas. The increase in mortality for year-classes with high numbers of fry migrants, occurs in the early marine period that is characterized by the highest and most variable rate of pink salmon mortality (Heard 1991; Karpenko 1998). A comparatively slow rate of growth (determined by examination of scales) during the early marine period is common for Kunashir chum (Kaev 1998) and pink salmon (Kaev and Romasenko 2001). Therefore, the increase in pink salmon mortality in year-classes with very abundant fry migrants (Fig. 5B) can be attributed to density-dependent factors. In this vein, we should note that the level of Kunashir pink salmon survival during the marine period (the mean survival index is 3.75%) is lower and its variability higher ($SD = 2.66$) than the corresponding indices in the same years of observations in the pink salmon of Iturup Island ($M = 5.32$; $SD = 1.81$), and the southeastern coast ($M = 5.71$; $SD = 2.49$) and Aniva Bay ($M = 4.66$; $SD = 2.49$) on Sakhalin Island.

As in other areas of the Sakhalin-Kuril region (Kaev et al. 2007), the differences in size composition and the timing of the pink salmon run on Kunashir Island are related to the dates when early- and late-spawning groups enter the rivers (Kaev, 2002). From 15 through 25 August the early-spawning group is replaced by the late-spawning group. We know this because of the presence of large males in catches (Fig. 6). Following the abrupt decline in numbers of the late-spawning group in 1993, during 1994–2003 the odd year-classes became significantly less abundant than the even year-classes. Because the early-spawning group was more abundant during odd years from 1994–2003, the approach to the coast in odd years ended earlier than in even years, suggesting a clear relationship between the inter-annual changes in Kunashir pink salmon numbers and dates of run (Fig. 3). However, in recent years a gradual decline in dates of approach of late-spawning fish was also seen in even year-classes (Fig. 6), producing a decline in the pink salmon stock in 2004 (Fig. 2). The two-year cycle in changes of pink salmon body length, shown in the 1990s, has also been

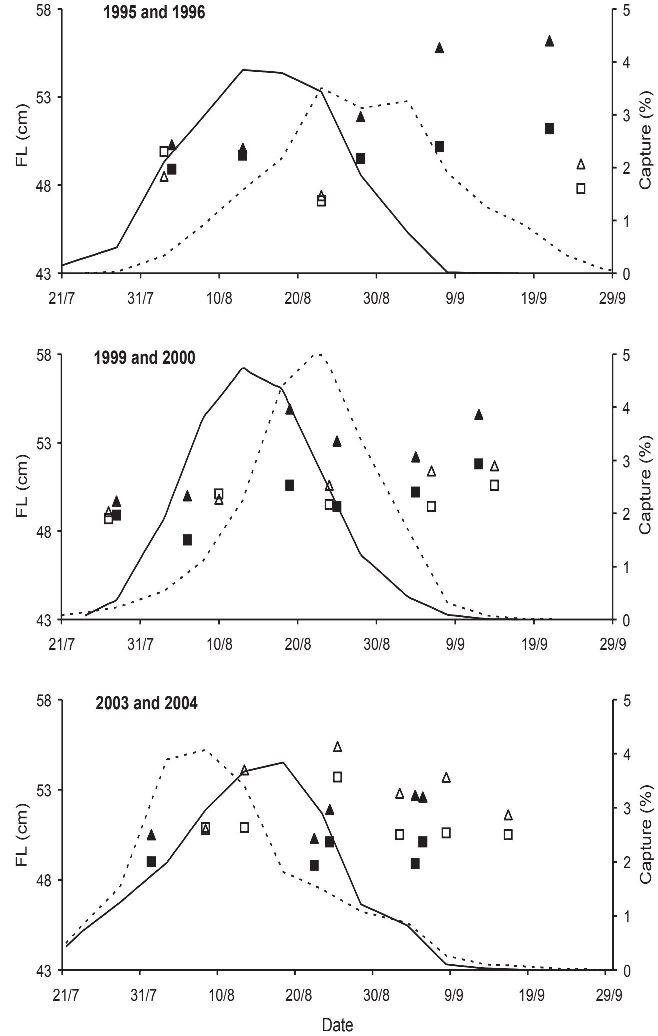

Fig. 6. Dynamics of catches and changes in pink salmon fork length on Kunashir Island in 1995–1996, 1999–2000, and 2003–2004. Lines indicate daily catches in odd (solid line) and even (dotted line) years; symbols indicate male (triangle) and female (square) fork lengths in odd (dark symbols) and even (light symbols) years.

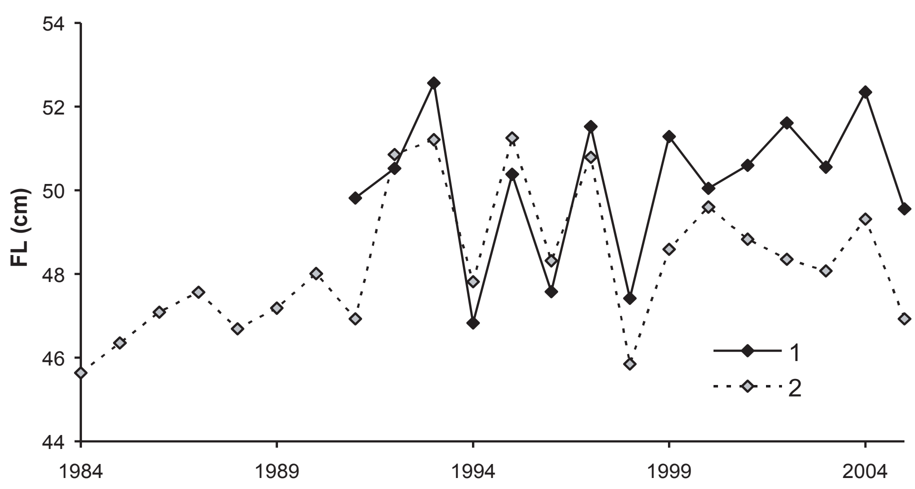

Fig. 7. Changes in fork length of pink salmon from Kunashir (1) and Iturup (2) (from Kaev et al. 2006) islands in 1984-2005.

broken in recent years (Fig. 3).

Changes in abundance and biological indices of pink salmon on Kunashir Island have been studied for only a comparatively short period of time, beginning in the 1990s. During these years, changes in commercial catches correlated ($R = 0.97$; $P < 0.001$; $N = 14$) with changes in the total abundance of pink salmon (fish caught, plus fish entering the rivers). Thus, we suggest that the increase in pink salmon catches on Kunashir Island since the 1990s (Fig. 2) is related to the increase in stock abundance, not to other causes (for example, an increase in catch rate). Since the 1990s, the fork lengths of Kunashir pink salmon (Kaev and Romasenko 2003) were close to those of the Iturup pink salmon (Kaev and Chupakhin 2003) and larger than the fork lengths of the southern Sakhalin pink salmon (Kaev et al. 2004). The inter-annual changes in the fork lengths of Kunashir pink salmon were similar to those of pink salmon on Iturup Island (Fig. 7) where the abundance of pink salmon was also higher in even years during the period of investigation. Thus, we suggest that large sizes of fish corresponded to periods of large catches of pink salmon on Kunashir Island as well as on Iturup Island and southern Sakhalin Island (Kaev et al. 2007). However, changes in the fork length of Kunashir pink salmon, occurring together with changes in abundance, can be explained by a density-dependent concept. These changes could be considered as a special case, because the pink salmon on Kunashir Island, unlike in other areas (Kaev et al. 2007), have been studied for a comparatively short period of time. In addition, the relationship between abundance and fork length revealed for the Kunashir pink salmon becomes weaker on a larger scale, when instead of this small stock of Kunashir Island we use the abundance of the regional pink salmon stock (Table 2). A shift in the timing of fish approaches to the coast toward earlier dates is also not unique to Kunashir pink salmon. In other areas similar trends have been seen since the mid 1990s (Kaev et al. 2007).

At the same time, the Kunashir pink salmon have some features that distinguish them from fish from other Sakhalin-Kuril areas. First, the number of fry migrants increases with an increase in number of spawners which is not common for such small rivers. This feature is caused by an incomplete use of spawning grounds in rivers that is attributed to low stock abundance. Second, there is a clear decline in fish survival during the marine period for year-classes with abundant fry migrants; this may be caused by a lack of resources during the early marine period for very abundant year-classes of fry. We suggest that these observations reflect specific habitat requirements of pink salmon near the limit of the spawning habitat for this species.

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