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Population Dynamics of Pink Salmon in the Sakhalin-Kuril Region, Russia

Alexander M. Kaev[1] and James R. Irvine[2]

[1]Sakhalin State University, Institute of Advanced Development,
Lenin Street, 290, Yuzhno-Sakhalinsk, Sakhalin 693008, Russia
[2]Fisheries and Oceans Canada, Pacific Biological Station,
3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, Canada

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Abstract: Pink salmon abundance has increased over the past four decades for much of the Sakhalin-Kuril region. Other than in the southern Kuril islands (Iturup and Kunashir), pink salmon returning in odd-numbered years were usually more numerous than genetically isolated even-year pink salmon; differences between these brood lines generally intensified in recent years. For three areas where we have the most confidence in our estimates (southeastern Sakhalin, Aniva Bay, and Iturup Island), marine survival indices and numbers of returning adults for both the odd-year and even-year lines increased. Downstream migrating fry numbers increased in Aniva Bay, but not in southeastern Sakhalin or Iturup Island, implying that increasing adult returns, at least to the latter two areas, were the result of improved marine conditions. Changing marine conditions were also important for pink salmon returning to Aniva Bay as evidenced by higher marine survival. Paired comparisons of data from the three areas found that the range of correlation coefficients for pink salmon returns and indices of marine survival were wider than correlations for adult size. This is consistent with what one would expect if early marine conditions in coastal areas were primarily responsible for discrepancies among stocks in terms of abundance and survival, while final fish size was chiefly the result of conditions later when salmon were farther offshore. This study demonstrates the importance of long time series of abundance data at the fry (smolt) and adult life-history stages, which enable the partitioning of survival patterns between freshwater and marine environments. Further work is necessary to understand reasons for declining returns for some groups during the last several years.

Keywords: pink salmon, Russia, Sakhalin-Kuril, population dynamics, abundance, body size, growth, survival

INTRODUCTION

Pacific salmon (*Oncorhynchus* spp.) are a unique group of fish. On the one hand, they occupy and mix in huge areas of the North Pacific Ocean where ecological conditions and processes largely determine their growth and survival. On the other hand, salmon home to spawn in their natal river and lake systems, providing researchers the opportunity to estimate salmon numbers during their juvenile downstream and adult upstream migrations, in theory allowing the partitioning of mortality estimates into freshwater and marine. In addition, Pacific salmon are semelparous (i.e., they die after spawning), enabling researchers to analyze growth and survival of individual generations.

In the Russian Far East, monitoring data from salmon fisheries in the coastal waters and estuaries of large rivers enables the estimation of relatively precise estimates of natural marine mortality. Therefore, when analyzing data on the status of different salmon stocks, indices of abundance and survival reflect habitat conditions. In this respect, pink salmon, *O. gorbuscha*, which are distinguished from other species of Pacific salmon by their rapid growth, short life, and greater variability in abundance, attract special attention as possible indicators of ecological processes (Beamish et al. 1999; Irvine and Riddell 2007). The Sakhalin-Kuril region (Fig. 1) is a fruitful area to study because more than half of the catches of pink salmon in the Far East of Russia are from there, and reasonable time series estimates of fry and adult abundance exist.

In this paper we report on relatively long-term variations in pink salmon abundance from various areas within the Sakhalin-Kuril region, their trends in survival and body size, and offer possible mechanistic explanations for the patterns we find.

All correspondence should be addressed to A. Kaev.
e-mail: kaev@outlook.com

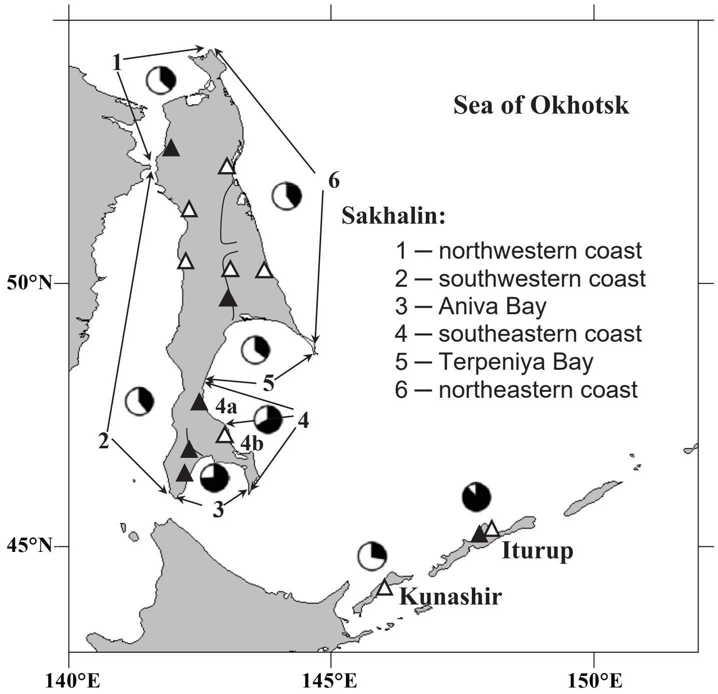

Fig. 1. Location of six pink salmon fishing areas around Sakhalin and various stock monitoring sites (triangles) for Sakhalin and the southern Kuril islands (Iturup and Kunashir). The proportion of total pink salmon spawning grounds monitored for each of the six Sakhalin areas and the two Kuril islands are indicated by the dark segments of pie charts; active and inactive monitoring sites for outmigrating pink salmon fry are indicated by dark and light triangles, respectively.

MATERIALS AND METHODS

Run sizes (catch plus escapement) were estimated for 6 areas around Sakhalin Island as well as the Iturup and Kunashir areas from the southern Kuril islands (Fig. 1). Five-day catch estimates (metric tonnes, t) were compiled, based on the mean weight of fish sampled in commercial fisheries (Kaev and Klovach 2014). The total number of adults returning was the sum of individuals caught during commercial fishing and at fish weirs, plus those that escaped fisheries to spawn. Estimated numbers of river spawners were based on visual foot survey estimates, generally during periods of maximum pink salmon abundance. To determine the total number of fish in all rivers, we first estimated the total area used for spawning in each river, and then categorized rivers into three groups based on the level of escapement monitoring. The first group contained regularly inspected rivers, the second group contained rivers inspected occasionally, and the third group contained unmonitored rivers. Estimates of visual survey-based spawner density were assumed to be accurate and precise in the first, well monitored group of rivers. For occasionally inspected rivers, measured spawner densities were adjusted as appropriate when surveys did not correspond to peak spawning periods. Finally, unmonitored rivers were assumed to have the same spawning habitat-specific densities as the average of the previous groups (Kaev et al. 2004, 2006; Kaev and Geraschenko 2008; Romasenko 2012).

Returning adult pink salmon were sampled from commercial trap-net fisheries and large research beach seine river surveys. Samples usually consisted of 100 randomly selected individuals for sex, standard body length, and weight; individual fecundity was measured for 25–30 females from each sample (Kaev et al. 2007).

Numbers of downstream migrating wild fry were estimated using stationary traps operated at various locations in the monitored rivers (Volovik 1967; Kaev 2010). Numbers of hatchery fry released were obtained from statistical reports on fry releases from salmon hatcheries prepared by the staff of the Sakhalin Basin Department on Reproduction of Water Biological Resources (*Sakhalinrybvod*).

Marine survival was indexed by dividing run size for each area (multiplied by 100) by the number of juvenile hatchery and wild salmon estimated to leave each river in the area. Because coastal pink salmon catches sometimes include non-local stocks of pink salmon, these are survival indices rather than absolute survival estimates. The assumption that catches reflect local stocks is particularly problematic along the western side of Sakhalin. Although an early report of high straying rates of fin-clipped hatchery pink salmon (Rukhlov and Lyubaeva 1980) was not verified by more recent studies (Kaev and Chupakhin 2003; Kaev and Antonov 2005; Stekol’schikova and Akinicheva 2013), Ivanova (2000) documented that local salmon populations frequently mix with salmon returning to the mainland. Assuming that stock compositions in the catch do not vary significantly through time at a location, survival time series indices should be comparable through time at individual locations.

Data were analyzed using EXCEL and standard statistical methods (Plokhinsky 1970). Overall trends (means of odd- and even-year data pairs) were analyzed and, because even- and odd-year returning pink salmon are genetically isolated (Waples et al. 2008), trends were also analyzed separately for even- and odd-year brood lines.

RESULTS AND DISCUSSION

The Sakhalin-Kuril region possesses a large pink salmon stock. In 2001–2014, annual pink catches on Sakhalin and the southern Kuril islands varied from 46,242 to 255,644 t, averaging 123,261 t. However, these catches were unevenly distributed within the region. Highest average catches were reported from southeastern Sakhalin (average 33,833 t) and Iturup Island (25,005 t). Catches in Terpeniya (22,140 t) and Aniva (21,274 t) bays were similar. Decreasing average catches were reported (in order) from northeastern Sakhalin (15,935 t), northwestern Sakhalin coast (2,055 t), Kunashir Island (2,053 t), and southwestern Sakhalin coast (948 t).

Aside from the southern Kuril islands (Iturup and Kunashir), pink salmon returning in odd years were more numerous than in even years with differences between brood lines tending to increase in recent years (Fig. 2). Working with a much longer time series, Irvine et al. (2014) noted an increase in the proportion of odd-year Asian pink salmon over time. Nagata et al. (2007) documented shifts in relative abundance in odd- and even-year pink salmon from the coast of Hokkaido in the Sea of Okhotsk. Nagata et al. found that odd-year returning salmon survived better than even-year fish when coastal sea surface temperatures were warm.

Recent hatchery releases do not appear to be translating into higher catches. For instance, although catches generally increased during the period of record (positive slopes in Fig. 2), the two regions with recent large increases of odd-year pink salmon (northeastern Sakhalin and Terpeniya Bay) were also regions with relatively few outmigrating hatchery fry (< 0.5% and ~12% of total outmigrating fry during 2001–2014, respectively; A. Kaev, unpublished data). In contrast, there were recent rapid declines in odd-year catches in southeastern Sakhalin, and odd- and even-year catches near Iturup Island and Aniva Bay, areas with relatively abundant hatchery-origin outmigrating fry (~29%, ~39%, and ~38%, respectively; A. Kaev, unpublished data). Pink salmon are not cultured on Kunashir Island.

Unfortunately there is considerable uncertainty with our time series for some areas, particularly northwestern Sakhalin, in part due to stock mixing as described earlier, but also because of inadequate monitoring. The mean proportion of rivers within each area actively monitored is indicated in Fig. 1 by the dark segments of the pie charts, while light and dark triangles indicate recently closed and currently operating fry monitoring research stations, respectively. Historically the

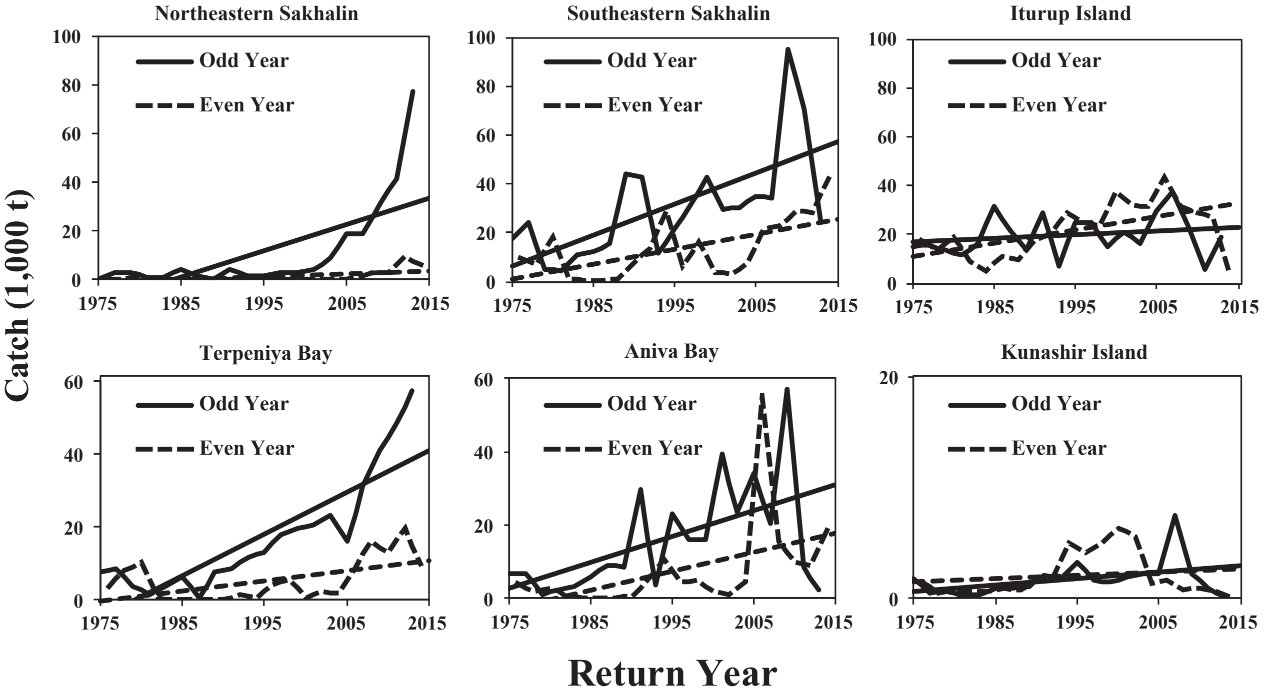

Fig. 2. Annual estimates of pink salmon catches in the four main Sakhalin fishing areas plus Iturup and Kunashir islands during odd- and even-numbered return years. Straight lines show linear regressions and jagged lines show annual estimates.

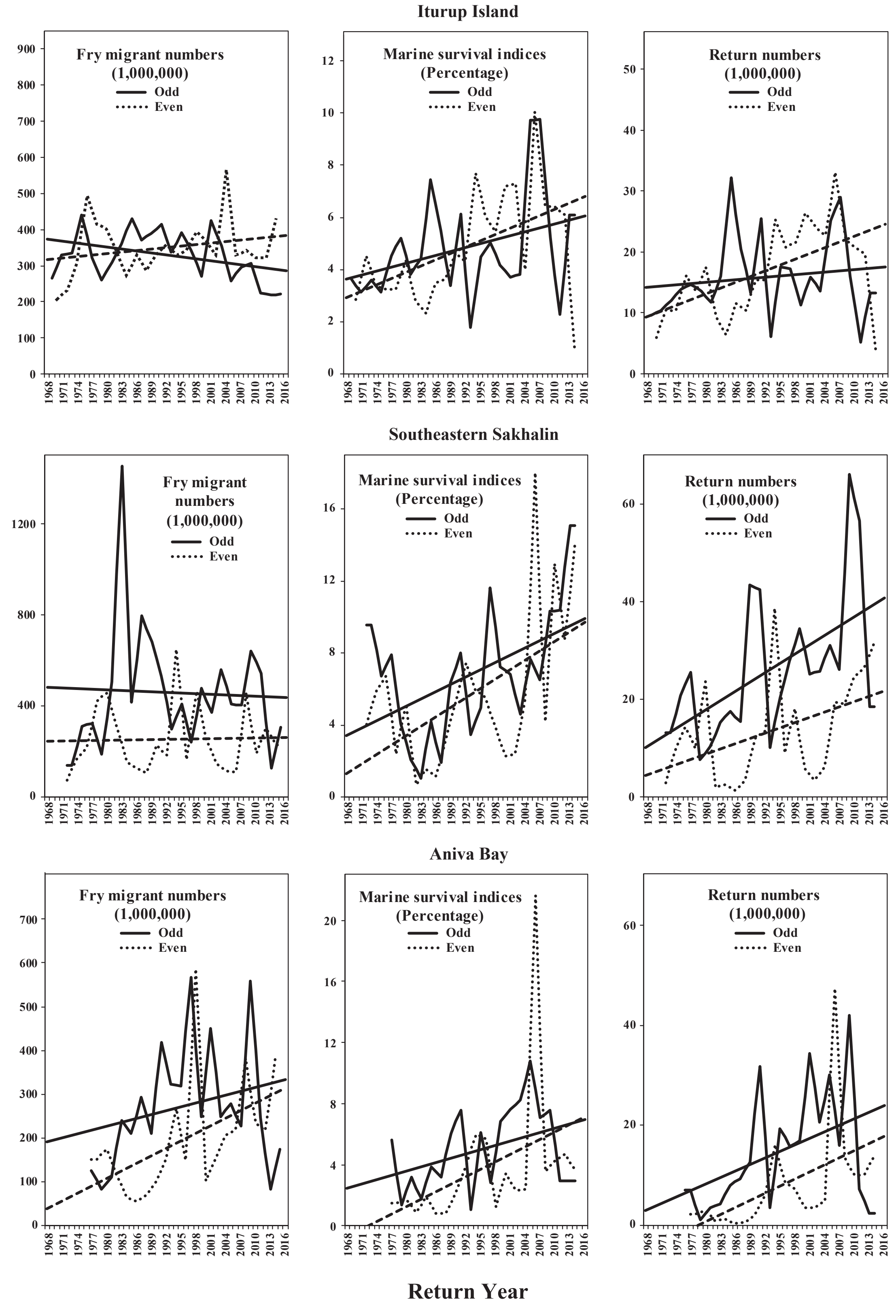

Fig. 3. Annual estimates of pink salmon fry abundance (millions of fry), indices of marine survival (percentage), and adult return numbers (millions of fish) for Iturup Island, southeastern Sakhalin, and Aniva Bay during odd- and even-numbered years. Straight lines show linear regressions and jagged lines show annual estimates.

density of juvenile counting stations in northern areas was less than in southern areas (except for Kunashir Island), and because of recent closures, this discrepancy has increased. We lost the station on southeastern Sakhalin (site 4b, Bakhura River), but began to count fry migrants in the adjacent Voznesenka River. After taking into account "blind-spots" and variations in time series of observations, the monitoring data allowed us to evaluate detailed changes in pink salmon abundance for three areas: southeastern Sakhalin, Aniva Bay, and Iturup Island (Appendix Table 1).

Marine survival and number of returning adults for both the odd- and even-year lines increased over the time series in southeastern Sakhalin, Aniva Bay, and Iturup Island (Fig. 3, positive slopes). Downstream migrating fry numbers increased for Aniva Bay, but not for southeastern Sakhalin or Iturup Island, implying that increasing adult returns, at least to the latter two areas, were the result of improved marine conditions. Changing marine conditions were also a major factor in Aniva Bay as evidenced by higher marine survival. Escalating fry numbers leaving Aniva Bay rivers were primarily a consequence of increased releases of hatchery juveniles to this area beginning in the 1990s (Kaev 2012).

Adult pink salmon abundance appears therefore to be primarily determined by survival in the sea rather than by the number of fry migrating downstream, but at what life-history stage, and where in the ocean? An indication of the role of early *vs.* later marine conditions was obtained by comparing trends in pink salmon abundance, marine survival, and body length from the three areas (Fig. 4). These populations enter locally distinct marine ecosystems but presumably share a common marine environment later in their lives. The coastal zone of southeastern Sakhalin is strongly influenced by the cold Eastern Sakhalin Current; Aniva Bay's hydrological regime is shaped by the cyclonic circulation that results from the interaction of the cold Eastern Sakhalin Current and a branch of the warm Tsushima Current. Coastal conditions near Iturup Island are determined primarily by the interaction of several currents that form a local frontal zone with high productivity (Kaev et al. 2007; Naletova et al. 1997). Therefore, if the early marine ecosystem is important in determining fish size and/or abundance, one might expect differences among these locations in these traits. Later in life, because pink salmon from the three areas occupy common marine habitats, one would expect fish from the three areas to be similarly affected (e.g., Myers et al. 1996). Paired comparisons of data from three areas (southeastern Sakhalin compared with Aniva Bay, southeastern Sakhalin compared with Iturup Island, and Aniva Bay compared with Iturup Island) found that the range of correlation coefficients for pink salmon adult returns (0.23–0.86) and the index of marine survival (0.33–0.96) was wider than for adult fork length (0.61–0.87, Table 1). This is consistent with what one would expect if early marine conditions in coastal areas were primarily responsible for discrepancies among stocks in terms of abundance and survival, and final fish size was chiefly the result of conditions later in the lives of these salmon, when they were located farther offshore. While this interpretation seems reasonable, it may be spurious because the variability in correlations for abundance and survival were driven primarily by the final sequence of data points gathered for southeastern Sakhalin (i.e., 2006–2014, Fig. 4).

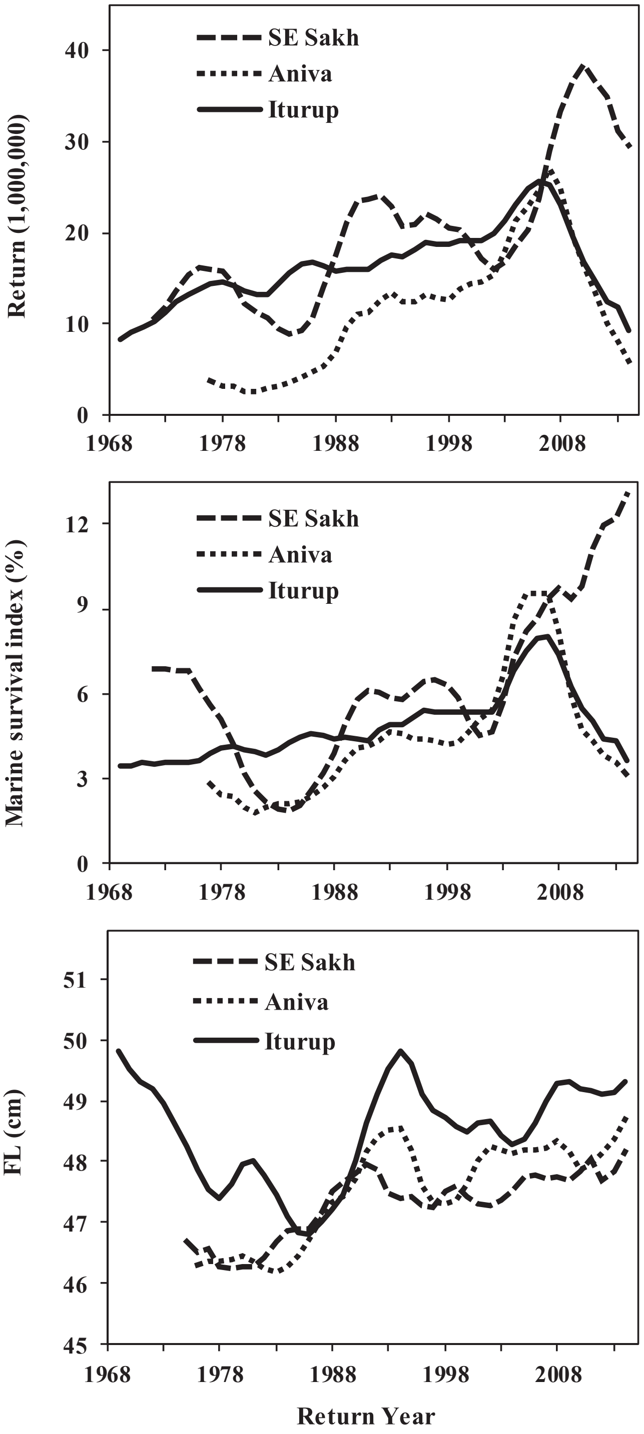

Fig. 4. Annual estimates of adult returns (millions of fish), indices of marine survival (percentage), and fork lengths (cm) for pink salmon from southeastern Sakhalin (SE Sakh), Aniva Bay, and Iturup Island.

Table 1. Correlations (*r*) between southeastern Sakhalin (SE Sakh) and Aniva Bay, southeastern Sahkalin and Iturup Island, and Aniva Bay and Iturup Island pink salmon for estimates of adult returns, marine survival indices, and body sizes (fork length).

Region	Adult returns	Marine survival index	Body size
SE Sakh-Aniva	0.56	0.50	0.87
SE Sakh-Iturup	0.23	0.33	0.61
Aniva-Iturup	0.86	0.96	0.80

Temporal patterns in fry and adult abundance and marine survival indices were not linear. Pink salmon abundance and survival appeared to increase primarily in the late 1980s and the beginning of the 21^{st} century, particularly in southeastern Sakhalin and Aniva Bay, and decrease in the last several years in all three areas (Fig. 3). In general, the boundaries of these periods corresponded approximately to climatic regime shifts described elsewhere (e.g., Beamish et al. 1999; Irvine and Fukuwaka 2011; Kotenev et al. 2010).

There is little consensus whether or not there are density-dependent effects on marine growth patterns for pink salmon. We found that increased pink salmon abundances were generally accompanied by increases in adult body sizes (Fig. 4). Correlations between smoothed trends for adult abundance and size were significant and positive for Aniva Bay ($r = 0.73$, $n = 38$, $p < 0.001$) and southeastern Sakhalin ($r = 0.79$, $n = 37$, $p < 0.001$) but not Iturup Island ($r = -0.04$, $n = 46$, $p > 0.05$) pink salmon. For Iturup Island, which had the longest time series, the correlation (or lack thereof) was influenced by a major decrease in fish size at the beginning of the time series coincident with an increase in abundance (Fig. 4). Yefanov and Chupakhin (1982), Gritsenko et al. (1983), Welch and Morris (1994), and Bigler et al. (1996) provide evidence of density-dependent effects on salmon sizes while Gavrilov and Pushkareva (1996), Temnykh (1999), Nagasawa (2000), Temnykh et al. (2002), and Kaev et al. (2007) provide the opposite perspective.

This study illustrates the importance of long-term monitoring programs and time series estimates at more than one life-history stage for salmon abundance and size. Without these, it is not possible to adequately understand where and when significant mortalities occur. Future research is needed to investigate (1) the role of various physical characteristics (fresh water and marine) on salmon growth and survival; (2) why recent trends in marine survival and adult return for pink salmon from southeastern Sakhalin appear to have diverged from those of salmon from Aniva Bay and Iturup Island, and (3) whether apparent shifts in the relative abundance of different return timing components of salmon runs (A. Kaev, unpublished data) are useful predictors of changes in stock status currently being experienced for some stocks.

CONCLUSIONS

For pink salmon in the Sakhalin-Kuril region of Russia, widespread increases in abundance do not appear to be the result of increasing fry numbers but rather the result of factors operating in the ocean, probably during the early marine period. In contrast, generally increasing adult sizes appear to be a consequence of conditions later in the lives of pink salmon when they were farther offshore. Continued monitoring of salmon abundances, their important biological traits and physical conditions will allow us to better understand the mechanisms responsible for variable survival patterns of salmon in the Sakhalin-Kuril region and elsewhere.

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Appendix Table 1. Annual estimates (in thousands) for southeastern Sakhalin, Aniva Bay, and Iturup Island of numbers of adult pink salmon entering rivers (escapement) by brood year, numbers of wild and released hatchery fry leaving in brood year + 1, and total returns (catch plus escapement) in brood year + 2. Catch is the difference between total returns and escapement (e.g., for southeastern Sakhalin, the estimated catch of pink salmon in 1972 was 2,872,000–2,388,000 = 484,000). Dash indicates that estimates are not available.

Spawning		Number of fry		Total adult return	Spawning		Number of fry		Total adult return
Brood year	Escapement	Wild	Hatchery		Brood year	Escapement	Wild	Hatchery	
Southeastern Sakhalin									
1970	389	41,555	29,500	2,872	1971	5,680	56,754	79,600	13,066
1972	2,388	101,612	66,800	9,984	1973	3,827	169,382	139,566	20,719
1974	4,461	49,277	164,586	14,388	1975	6,317	142,729	178,870	25,458
1976	5,830	251,130	168,600	9,902	1977	5,709	35,156	152,449	7,635
1978	3,357	260,009	195,395	23,616	1979	3,355	323,828	181,700	10,357
1980	6,773	48,541	259,400	2,016	1981	6,792	1,229,814	222,700	15,335
1982	945	36,863	117,700	2,430	1983	5,815	180,764	233,400	17,455
1984	2,039	67,994	55,420	1,438	1985	6,503	617,717	175,800	15,407
1986	888	78,091	26,500	3,363	1987	2,608	546,164	135,500	43,365
1988	2,429	176,455	50,000	12,020	1989	8,085	369,939	161,008	42,408
1990	6,028	102,957	78,900	13,526	1991	5,963	161,213	133,431	10,164
1992	3,754	550,159	96,651	38,590	1993	2,533	299,980	107,629	20,293
1994	10,597	92,569	69,505	8,966	1995	4,456	135,123	103,432	27,767
1996	3,658	362,342	102,200	18,032	1997	5,144	375,352	100,829	34,543
1998	3,299	176,324	74,034	5,676	1999	4,903	257,558	112,037	25,183
2000	2,747	77,242	69,878	3,537	2001	3,082	450,789	107,824	25,789
2002	1,565	85,222	26,675	6,098	2003	2,837	346,014	60,424	31,098
2004	902	61,481	46,415	19,445	2005	2,241	316,956	83,715	26,146
2006	2,222	395,696	60,379	19,148	2007	2,177	533,829	106,703	66,111
2008	1,920	117,863	70,881	24,523	2009	2,334	425,909	117,495	56,501
2010	2,407	227,473	74,749	26,504	2011	2,591	56,759	66,140	18,542
2012	3,035	140,073	86,366	31,683	2013	2,390	215,941	87,053	—
Aniva Bay									
1974	—	—	—	—	1975	3,126	71,718	53,760	7,059
1976	1,741	99,288	51,500	2,241	1977	1,346	47,793	35,684	1,110
1978	915	111,566	63,607	3,033	1979	330	67,932	42,700	3,522
1980	758	67,804	50,000	1,025	1981	1,787	223,301	17,700	4,220
1982	533	44,183	21,300	1,227	1983	1,499	157,081	52,800	8,042
1984	1,051	25,731	30,200	448	1985	2,434	239,026	53,400	9,351
1986	433	32,422	37,400	550	1987	1,958	169,960	40,600	12,737
1988	485	66,361	33,900	2,136	1989	5,595	369,092	50,130	31,729
1990	1,624	93,599	60,520	6,148	1991	6,333	242,009	80,731	3,474
1992	2,708	209,130	59,419	16,095	1993	1,230	268,040	51,366	19,408
1994	6,926	93,548	56,335	8,522	1995	5,500	465,665	100,950	15,832
1996	5,078	486,150	99,427	7,311	1997	3,398	152,606	96,240	16,956
1998	2,851	30,540	72,400	3,510	1999	4,254	364,021	86,604	34,447
2000	2,272	74,070	80,428	3,590	2001	4,606	153,803	95,298	20,557
2002	2,864	135,456	71,268	4,882	2003	2,538	206,552	71,400	30,054
2004	2,196	136,057	83,200	47,425	2005	3,092	139,274	88,535	16,056
2006	3,276	286,163	96,558	13,556	2007	2,349	458,029	100,130	42,098
2008	1,872	132,217	101,662	10,021	2009	3,991	150,958	95,829	7,253
2010	2,815	135,603	82,104	10,206	2011	824	27,405	55,877	2,434
2012	2,732	302,272	80,931	13,947	2013	957	85,258	89,423	—

Appendix Table 1. Continued.

Spawning		Number of fry		Total adult return	Spawning		Number of fry		Total adult return
Brood year	Escapement	Wild	Hatchery		Brood year	Escapement	Wild	Hatchery	
Iturup Island									
1966	—	—	—	—	1967	970	167,000	98,000	9,604
1968	845	123,000	83,000	5,862	1969	1,470	223,000	107,000	10,312
1970	870	151,000	81,000	10,482	1971	1,318	219,000	115,000	12,029
1972	920	205,000	101,000	10,294	1973	1,157	323,000	117,000	13,881
1974	1,011	360,000	134,000	16,066	1975	1,990	161,000	160,000	14,566
1976	1,877	217,000	198,000	13,511	1977	1,363	112,000	149,000	13,580
1978	1,223	204,000	198,000	17,441	1979	1,072	142,000	166,000	11,776
1980	1,898	122,000	215,000	9,332	1981	1,800	176,000	184,000	15,953
1982	1,322	66,000	207,000	6,380	1983	1,542	226,000	205,000	32,103
1984	1,102	176,000	155,000	11,612	1985	2,100	178,000	194,000	20,442
1986	1,131	116,000	169,000	10,370	1987	1,837	205,000	183,000	13,204
1988	1,332	162,000	170,000	15,350	1989	1,448	243,000	172,000	25,377
1990	1,718	194,000	165,000	15,440	1991	2,010	187,000	150,000	6,010
1992	1,880	223,000	107,000	25,330	1993	1,048	326,400	65,000	17,540
1994	2,467	230,000	112,000	20,710	1995	1,531	281,000	62,000	17,220
1996	1,266	319,000	76,000	21,505	1997	1,288	195,000	75,000	11,240
1998	1,298	302,000	66,000	26,416	1999	1,175	337,000	89,000	15,858
2000	1,610	230,000	99,000	24,060	2001	1,320	245,000	111,000	13,591
2002	1,523	460,200	106,000	22,658	2003	1,068	147,000	111,729	25,143
2004	1,768	203,370	126,150	33,093	2005	1,498	184,200	112,539	28,922
2006	1,493	207,968	134,475	22,035	2007	1,367	174,780	130,962	16,023
2008	1,325	198,804	124,346	20,664	2009	1,405	110,576	114,201	5,165
2010	1,430	189,894	131,056	19,585	2011	1,235	129,254	89,501	13,292
2012	1,323	297,974	129,374	3,917	2013	1,351	93,904	127,322	—