Size of Sockeye Salmon Smolts and Freshwater Age of Adults in Azabachye Lake (Kamchatka River Basin)

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Abstract: Analysis of age composition of early-run sockeye salmon (*Oncorhynchus nerka*) spawners in Azabachye Lake, in the lower reaches of the Kamchatka River, showed that in 1997 45% had spent only one year in fresh water (1.2, 1.3, 1.4). Previously, 80–99% spent two years in freshwater (2.1, 2.2, 2.3, 2.4, 2.5). The freshwater zone of scales from spawners of age 1.2, 1.3 and 1.4, caught in Azabachye Lake qualitatively resembled those of sockeye from tributaries in the lower and middle reaches of Kamchatka River. I hypothesized that high abundance of sockeye of one-year freshwater life in the basin of Azabachye Lake in 1997 arose from presence of spawners from lower and middle Kamchatka River, and that they had come to the lake as juveniles in 1993 to take advantage of excellent feeding there. In 1994, the largest sockeye smolts ever observed between 1979 and 1996 migrated out of Azabachye Lake. A significant correlation (r_s = 0.66–0.82, p < 0.05–0.01, n = 17) was obtained between the numbers of sockeye spawners with one freshwater year on their scales and length-weight of smolts leaving the Lake three years earlier.

INTRODUCTION

Azabachye Lake is the big sockeye salmon (*Oncorhynchus nerka*) nursery lake in the Kamchatka River basin. The lake plays an important role for reproduction of this species as it is a feeding area not only for local sockeye salmon (stock A) but also for juveniles from the low and middle reaches of the Kamchatka River (group E) migrating to the lake at age 0+ (Bugayev 1983, 1995a).

Sockeye salmon migrating to the lake at age 0+ start feeding and form a zone of closely-spaced circuli on their scales which is not an annulus. Smolts of group E migrate from the lake at age 1+, and smolts of the Azabachye stock migrate from the lake at age 2+. Annually spawners mainly of age 2.3 return to Azabachye Lake. Sockeye salmon spawners of group E return to the tributaries of the middle and lower reaches of the Kamchatka River at age 1.3 (Bugayev 1983, 1995a).

One-year old fry of group E have two zones of closely-spaced circuli (the first, indistinct, an accessory; the second, distinct, an annulus). Two-year old smolts of stock A have on their scales two distinct zones of closely-spaced circuli (annuli). Individuals from stock A and group E can be differentiated by the distinctness of the zones of closely-spaced circuli (and to a smaller extent by the number of circuli in the growth zone), infection by *Diphyllobothrium sp.* plerocercouds and the number of gill rakers (Bugayev 1983, 1986, 1995a; Bugayev and Bazarkin 1987). Photos of scales from stock A and group E sockeye salmon have been published earlier (Bugayev 1986, 1987, 1995a).

Early run sockeye salmon in Azabachye Lake make up 80% of the stock, late run 20% (Ostroumov 1972). Analysis of age composition, of spawners of early run sockeye in Azabachye Lake from 1982–1998 indicates that in 1997 45% (n = 332) of the fish had spent only one-year in freshwater (1.2, 1.3, 1.4). This is contrary to the generally accepted idea that 80–99% of sockeye from this lake spend two years in freshwater (ages 2.1, 2.2, 2.3, 2.4, 2.5) (Bugayev 1995a). This paper presents an analysis of the current situation.

MATERIAL AND METHODS

Data on age composition of early-run sockeye salmon from Azabachye Lake were collected from 1982 to 1998. In addition, data on length and weight of sockeye smolts of stock A and group E migrating from Azabachye Lake in 1984–1996 were collected. Individuals of group E and stock A were identified according to methods presented in Bugayev and Bazarkin (1987).

Data on run abundance of sockeye of Azabachye Lake at the mouth of the Kamchatka River and at the mouth of the Azabachya tributary were obtained from fisheries statistics, and from estimates of spawner

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abundance on the spawning grounds. Sockeye from Azabachye Lake, were distinguished from fish sampled in coastal and river catches by structure of scales and infection by *Diphyllobothrium sp.* (Bugayev 1986).

The annual ocean abundance of mature sockeye returning to Azabachye Lake between 1977 and 1998 (prior to beginning of gillnet fishing season) was estimated on the basis of gillnet catches in the Russian economic zone (Bugayev and Dubynin this volume) and on the occurrence of Azabachye sockeye salmon in the run at the mouth of the Kamchatka River.

In this article we calculated Spearman's rank correlation coefficients (r_s) using the program "STATISTICA" (Borovikov and Borovikov 1998). When percentage data are used in regressions, they usually need to be transformed (e.g., arcsine transformation) (Zar 1984). I used an arcsine transformation on my percentage data.

RESULTS

Earlier analysis of the age composition of sockeye salmon spawners in Azabachye Lake (1982–1994) indicated that on average 5.3% migrated from the lake at age 1+ (1.2, 1.3, 1.4), 92% at age 2+ (2.1, 2.2, 2.3, 2.4, 2.5), and 2.7% at age 3+ (3.2, 3.3, 3.4) (Bugayev 1995b). Between 1995 and 1998, however, 22.9% migrated at age 1+, 71.7% at age 2+, and 5.4% at age 3+. The age at migration appeared to be different during these two periods (Table 1).

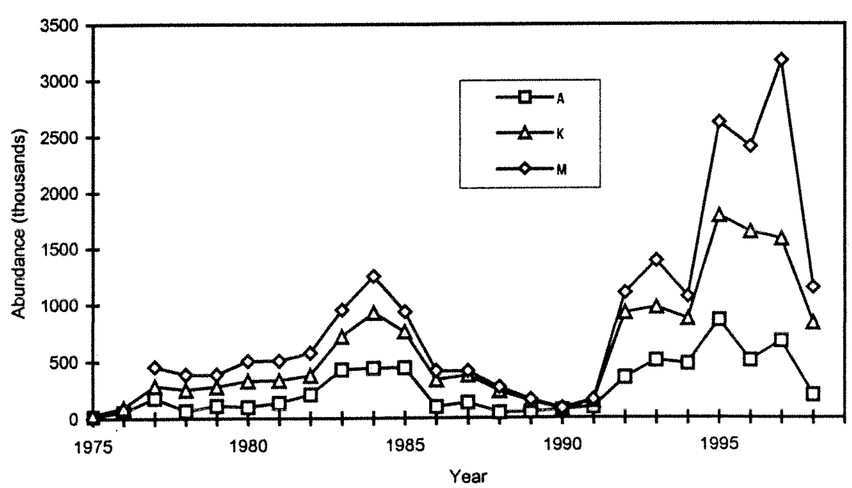
Abundance of sockeye salmon in Azabachye Lake between 1982 and 1994 was lower than in the period 1995–1998 (Fig. 1). Between 1982 and 1994, the average abundance of mature fish at sea was 672,000 fish, whereas in the period 1995–1998, it was 2,335,000 fish. At the mouth of the Kamchatka River the early run averaged 526,000 in the early period, while in the later period it averaged 1,460,000,

Table 1. Age composition of spawners of early-running sockeye of Azabachye Lake in 1982–1998, %.

	Freshwater and sea years of age[1]											
Year	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	3.2	3.3	3.4	n
1982	-	1.2	-	-	32.5	63.9	2.4	-	-	-	-	83
1983	1.0	1.0	-	-	7.0	88.0	2.0	-	-	1.0	-	100
1984	-	2.5	-	-	10.2	83.1	-	-	-	4.2	-	118
1985	-	5.1	-	-	10.1	76.8	2.0	1.0	-	4.0	1.0	99
1986	-	2.2	-	-	13.0	80.4	3.3	-	1.1	-	-	92
1987	-	0.7	-	-	8.7	86.6	4.0	-	-	-	-	150
1988	-	-	0.6	0.6	14.4	76.9	6.3	-	0.6	0.6	-	173
1989	-	2.5	0.5	-	7.5	78.4	8.6	-	0.5	2.0	-	199
1990	1.0	1.0	-	-	39.3	44.1	9.2	-	0.5	4.4	0.5	206
1991	11.6	2.2	-	-	34.8	43.4	2.2	-	4.4	1.4	-	362
1992	2.3	12.8	-	-	7.1	72.9	1.5	-	-	3.4	-	266
1993	1.3	2.6	0.4	-	14.7	72.3	6.9	-	-	0.9	0.9	231
1994	1.6	15.3	-	-	7.1	71.1	1.6	-	0.4	2.5	0.4	242
1995	7.0	1.7	-	-	30.4	46.8	4.1	-	4.7	5.3	-	171
1996	5.8	12.7	-	0.4	13.1	57.0	2.0	0.4	2.9	5.7	-	244
1997	2.8	40.6	1.6	-	6.5	44.1	1.6	-	-	2.8	-	322
1998	2.0	14.3	2.9	-	13.3	66.6	0.6	-	-	0.3	-	308

[1]The first figure in the head of the table is the length of the freshwater life-period; the second figure is the length of the marine life-period.

Fig. 1. Abundance of Azabachye Lake sockeye salmon (1975–1998) at sea (M), at the mouth of the Kamchatka River (K), and at the mouth of Azabachya tributary (A).



and at the mouth of the Azabachye tributary numbers averaged 255,000 from 1982 to 1994, and 557,000 between 1995 and 1998.

Freshwater age and abundance at sea between 1982 and 1998 (n = 17) appeared to be linked. The percentage of age 1.3 fish (the most common age group with one freshwater year) among those returning was positively correlated with the abundance of mature fish at sea ($r_s = 0.583$, $p < 0.05$). The correlation coefficient (r_s) between frequency of this age group and abundance of the run at the mouth of the Kamchatka River was 0.570 ($p < 0.05$), and between this age and abundance at the mouth of the Azabachye tributary was 0.532 ($p < 0.05$). When the percentage of all age 1+ (1.2, 1.3, 1.4) migrants was used to calculate Spearman's rank correlation coefficients over the same period (1982–1998, n = 17), r_s = 0.601 ($p < 0.05$) with abundance at sea, r_s = 0.606 ($p < 0.01$) with abundance at the mouth of the Kamchatka River, and r_s = 0.551 ($p < 0.05$) with abundance at the mouth of the Azabachye tributary. There seems little doubt that increasing proportions of spawners that migrated to sea at age 1+ were positively related to increasing abundance of stock A spawners (those spawning in the Lake).

Length and weight of sockeye salmon smolts migrating from Azabachye Lake over the period 1984–1996 peaked in stock A in 1994 and group E sockeye in 1993 (Fig. 2). Frequency of sockeye spawners with one freshwater year (various sea years) were positively correlated with length and weight over the years 1984–1995 (Table 2). In stock A, the correlation was stronger between age and length (Fig. 3) than between age and weight (Fig. 4), while in group E the reverse was true.

When these correlations between age and abundance, and size and abundance are considered together, one can conclude that as smolts reach a larger size at a younger freshwater age, the abundance of adult fish in the sea and in the river appears to increase. When data on males and females were examined separately, some significant correlations were obtained for males, but more rarely among females (Table 3).

DISCUSSION AND CONCLUSIONS

At least two hypotheses can be proposed to explain the correlation between the younger (higher proportion of 1+) bigger smolts and their greater abundance as returning adults. The first hypothesis is that improved growing conditions in Lake Azabachye between 1995 and 1998 resulted in faster growing fish that migrated to sea earlier in their lives. These fish would all be offspring of stock A parents (who themselves came from the lake), and the greater

Fig. 2. Body length (L) and weight (W) of sockeye salmon smolts of stock A (age 2+) and group E (age 1+), migrating from Azabachye Lake in 1984–1996.

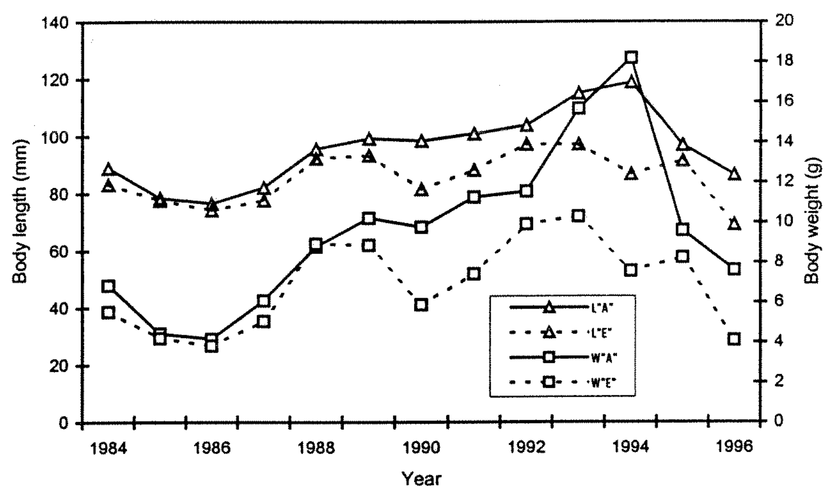


Table. 2. Spearman's rank correlation coefficient (r_s) between occurrence in 1987–1998 in Azabachye Lake of sockeye spawners with one freshwater year on their scales and body length and weight in sockeye smolts migrating from Azabachye Lake in 1984–1995.

Stock, group	Age	Body length r_s	Body weight r_s
A	1.3	0.685 *	0.664 *
A	1.2, 1.3, 1.4	0.818 **	0.776 *
E	1.3	0.336	0.378
E	1.2, 1.3, 1.4	0.601 *	0.664 *

Note. * - $p < 0.05$, ** - $p < 0.01$.

Fig. 3. Relation between frequency of sockeye spawners of ages 1.1, 1.3 and 1.4 and their mean length as smolts for stock A migrating from Azabachye Lake.

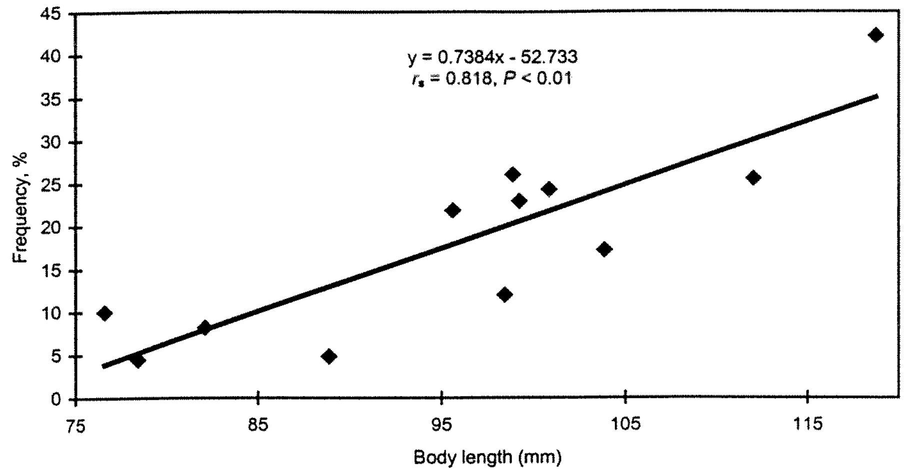


Fig. 4. Relation between frequency of sockeye spawners of ages 1.1, 1.3 and 1.4 and their mean weight as smolts for stock A migrating from Azabachye Lake.

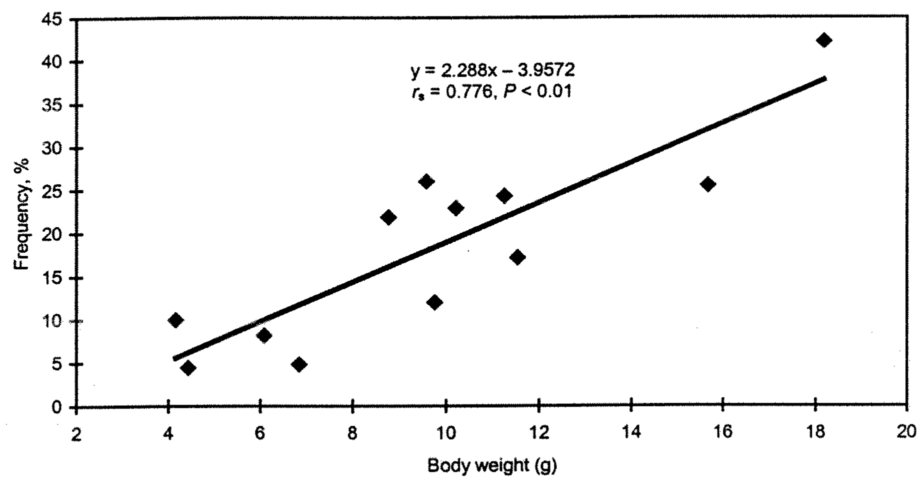


Table. 3. Spearman's rank correlation coefficient (r_s) between occurrence in 1987–1998 in Azabachye Lake of sockeye spawners with one freshwater year on their scales and body length and weight of sockeye smolts migrated from Azabachye Lake in 1984–1995 when separated by sex.

Stock, group	Age	Sex	Body length r_s	Body weight r_s
A	1.3	Female	0.719 **	0.684 *
A	1.2, 1.3, 1.4	Female	0.718 **	0.690 *
A	1.3	Male	0.671 *	0.636 *
A	1.2, 1.3, 1.4	Male	0.797 **	0.755 **
E	1.3	Female	0.484	0.540
E	1.2, 1.3, 1.4	Female	0.438	0.539
E	1.3	Male	0.371	0.413
E	1.2, 1.3, 1.4	Male	0.594 *	0.671 *

Note. * - $p < 0.05$, ** - $p < 0.01$.

abundance of returning adults presumably would have arisen from either or both an improved survival of fry experiencing better feeding in the lake, and or greater survival in the sea as a result of arriving there as larger smolts.

The second hypothesis is that a portion of the fish rearing in Azabachye Lake were group E fish, which normally spawn in the lower and middle reaches of Kamchatka River. The independent support for this hypothesis is that many of the adults returning to the lake with one freshwater year of life (1.2, 1.3, 1.4) have two closely spaced circuli on their scales typical of the scales of group E fish. These adults appear to have returned to the lake instead of the river to spawn. They possibly did so because of an advanced state of maturity, which prevented them from reaching their native spawning grounds 100–200 km upstream from the lake. The presence of stock A fish in the lake may have acted as an incentive to group E fish to remain there. Also, Ilyin et al. (1983) found in the basin of Azabachye Lake that if sockeye on the point of spawning were transported from one tributary to another, they remained in the new location. Therefore I currently favour this second hypothesis.

After some years of successful spawning in Azbachye Lake by group E fish, returning there may have become an inherited behavioural pattern. This lake from time to time has provided a better than normal food supply because of periodic eruption of volcanoes of the nearby Kluchevskaya group. This provided natural fertilization of the lake in the form of volcanic ash. Group E fish returning to spawn in the Kamchatka River from 1982–1991 have rate of return between 0.4 and 10.1 (average 4.2), whereas the rate of return of stock A over the same period is 0.2 to 55.5 (average 18.9). If this greater survival of stock A fish is linked to rearing in the lake, group E fish which spawned in the Lake would presumably experience the same advantage, which would strengthen their numbers in the Lake.

In the pleistocene era and later a large lake existed in the lower reaches of the Kamchatka River in the area of the Yelovka River and Kamakovskaya lowland lakes (lakes Kurazhechnoye, Kobylkino, Sobachye, Urokolon and others) located upstream from lakes Nizovtsevo, Krasikovskoye, Azabachye, and Kursin (Kurenkov 1967; Krogius 1983). It is likely, therefore, that current stock A and group E populations had the same ancestors. This could facilitate straying of group E spawners to Azabachye Lake. Gene exchange between the two populations would enhance both the genetic and phenotypic resemblance between these two populations (Mina 1986).

The assumption of straying of group E to Azabachye Lake is not contradicted by the literature. Quinn (1985) showed, for example, that sockeye populations inhabiting two closely located lakes had straying rates of 0.2%. To determine the degree of straying by group E fish to Azabachye Lake, marking studies will be needed. Age 0+ individuals of group E can be marked (e.g. with magnetic tags) as they enter Azabachye Lake, and then their movements and residence times in the lake can be followed.

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