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Migratory Behaviour of Underyearling *Oncorhynchus tshawytscha* and Survival to Adulthood as Related to Prerelease Gill (Na^+-K^+)-ATPase Development

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ABSTRACT

Zaugg, W.S., 1989. Migratory behavior of underyearling *Oncorhynchus tshawytscha* and survival to adulthood as related to prerelease gill (Na^+-K^+)-ATPase development. *Aquaculture*, 82: 339-353.

Fall run, underyearling chinook salmon (*Oncorhynchus tshawytscha*) were released to the Columbia River from Spring Creek National Fish Hatchery over the period 1978-1982 at various stages of smolt development as indicated by measurements of gill (Na^+-K^+)-ATPase activity. The outmigrant populations which had experienced more completely developed enzyme cycles (from low to elevated, back to low activities) during hatchery rearing tended to: (1) be caught in greater numbers at the juvenile recovery site at the upper entrance to the estuary, (2) be caught in mid-river as contrasted with near shore, and (3) contribute greater numbers of adults. Adult recovery was not correlated with size at or time of release.

INTRODUCTION

Nearly 140 million juvenile chinook salmon are released annually from about 45 hatcheries into streams of the Columbia River Basin in Northwestern United States (Wahle and Pearson, 1987). Timing of releases from these rearing facilities is generally based on size, economics, space requirements, or a variety of other management decisions. Often, releases are made to coincide with seaward movement of wild smolts regardless of the status of smolt development in the hatchery population. This practice, however, is not generally considered to have a significant negative impact on survival since there is little information available to suggest otherwise. Juveniles are usually released either as

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underyearlings during the spring and summer months, and occasionally in the fall, or as yearlings in the spring of their second year.

As expected, the survival rate of these juveniles as measured by recoveries of tagged adults varies widely among the rearing facilities and between years at each hatchery. A recent study of contributions by 4 brood years of chinook salmon reared at 24 hatcheries in the Basin showed ranges from 0.01 to 2.2% survival (Vreeland, 1986). In addition, survival of fish released from individual hatcheries varied as much as 5- to 10-fold during the 4 years of the study.

These observations give rise to questions regarding the relative importance to survival of factors such as smolt condition at release, in-river migration environments, disease, predation, ocean conditions and food supply. It seems reasonable, given any set of riverine and oceanic conditions, that well-smolted fish would have the greater chance of survival. Yet at any one time, other factors such as disease, adverse ocean conditions, reduced food supply or abundant predators may be so significant as to be the primary determinant of survival. It may be impossible to separate completely the variables associated with survival of anadromous salmonids, but careful observation over a period of years can provide clues to their relative importance.

This report discusses smolt development as measured by gill (Na^+-K^+)-ATPase activity in underyearling chinook salmon prior to release and shows how this enzyme activity relates to post-release performance, including seaward migration and adult survival.

MATERIALS AND METHODS

During all 5 years of the study underyearling chinook salmon (fall run) were sampled by random dip-netting at intervals of approximately 2 weeks or less from production ponds at the following facilities: Washington State Hatcheries: Kalama Falls, Washougal and Toutle; U.S. Fish and Wildlife National Fish Hatcheries: Little White Salmon and Spring Creek. From each hatchery sampled during the period 1978–1980, 30 fish were collected on each date, killed with a blow to the head, weighed (g) and measured (mm), and divided into 10 groups of three fish each for (Na^+-K^+)-ATPase analysis. In 1981, fish were sampled from production ponds at the Spring Creek hatchery in the same manner as described above and gill samples were taken from 20 fish each time for individual ATPase analysis. In 1978–1981, fish were sampled from one of the ponds scheduled for the March release, then after their release, from a pond scheduled for the April release, and likewise with the May release, and lastly, from a pond held over beyond the May release. In 1982, fish were sampled throughout the monitoring period from ponds scheduled for each of the three release times with 10 to 40 fish taken at each sampling period for individual ATPase analysis. Gill samples were stored frozen at $-25\,^\circ C$ for later analysis of (Na^+-K^+)-ATPase activity (μmoles P_i mg protein^{-1} h^{-1}; Zaugg, 1982a).

Juvenile out-migrants (coded wire tagged) were captured daily and identified at Jones Beach, OR, 75 km upriver from the mouth of the Columbia River, by seining from the beach with a 95-m seine and in deepwater, mid-river channels with a purse seine (Dawley et al., 1985). Numbers of migrants caught were adjusted to a standard fishing effort. Migration rates were estimated by dividing the distance from release point to recovery point at Jones Beach by the number of days from the first day of release to the date of median fish recovery. Adult recovery information was obtained from the Pacific Marine Fisheries Commission, Portland, OR and from Vreeland (1986). Adult recovery has been estimated from samples of the commercial and sport fisheries catch and hatchery returns.

RESULTS

Underyearling chinook salmon released in the Columbia River system from four different hatcheries, prior to any development of elevated levels of gill $(Na^+\text{-}K^+)$-ATPase activity, showed that migration rate was a function of the distance traveled (Table 1). Correlation coefficients (r) for distance versus rate were 0.98 ($P<0.01$) for fish captured in the beach seine and 0.82 ($P<0.05$) for those caught in the purse seine. Size (wt) had no influence on the rate of migration ($r=0.10$ and 0.44 for beach and purse seine fish, respectively; wt vs rate, NS). The ratio in numbers of fish caught in the beach seine to numbers caught in the purse seine decreased with distance traveled (Table 1; for ratio vs distance, $r=-0.84$, $P<0.01$).

Changes in migration speed and horizontal distribution were also characteristics of fish serially released from the same hatchery. Underyearling chinook salmon released during March to May from the Spring Creek hatchery experienced increased median migration rates to Jones Beach with time (March to May), from a range of 8–21 to 28–39 km/day for fish captured in the beach seine and 3–25 to 18–65 km/day for those caught in the purse seine (Table 2). In addition, the proportion of fish caught in the purse seine generally increased (ratios of beach/purse seine decreased) from March to May releases (Table 2). An exception was seen in May 1981 when very few fish were caught in the purse seine.

Gill $(Na^+\text{-}K^+)$-ATPase activity profiles were used in evaluating post release performance. Of the total area under most profiles (Fig. 1) only a certain percent had developed by each final release date in May. This portion of the total area is shaded in Fig. 1 and its percent of the total area under the profile is compared with: (1) the percent of released juveniles that were caught at the upper entrance to the estuary (Jones Beach, Fig. 2A; Table 3) (2) the percent of released fish caught in the midriver purse seine (Fig. 2B); (3) the ratio of the number of fish caught in the beach seine to those caught in the purse seine (Fig. 2C); and (4) the percent adult recovery (Fig. 2D).

TABLE 1

Dependence of migration rate and location of capture (near shore-beach seine; mid-river-purse seine) on distance migrated by underyearling chinook salmon

Hatchery[a]	Release		$(Na^+$-$K^+)$-ATPase activity[b]	Migration dist. (km)[c]	Numbers caught at Jones Beach[d]		Ratio beach/purse	Migration rates (km/day)[e]	
	Date	wt (g)			Beach	Purse		Beach	Purse
Kalama Falls	12 Jul 78	4.2	baseline	66	941(83)	45(85)	20.9	4	14
Kalama Falls	15 Sep 78	13.4	baseline	66	648(93)	0	-	4	-
Kalama Falls	30 Jun 79	2.5	baseline	66	2799(75)	206(85)	13.6	2	2
Toutle	17 Jun 79	2.8	baseline	85	85(82)	11(78)	7.7	4	7
Toutle	17 Jun 79	2.8	baseline	85	973(82)	108(77)	9.0	4	7
Washougal	14 Jun 79	4.8	baseline	138	318(80)	43(80)	7.4	10	10
Washougal	14 Jun 79	4.8	baseline	138	634(80)	104(80)	6.1	9	10
Little White	22 Jun 79	4.3	baseline	186	221(74)	131(79)	1.7	15	27
Little White	22 Jun 79	3.7	baseline	186	400(72)	161(74)	2.5	14	27

[a]See Methods section for hatchery locations.
[b]Enzyme activity (μmoles P_i mg protein^{-1} h^{-1}) showed no increase prior to release.
[c]From the hatchery to the Jones Beach capture site on the Columbia River, 75 km from the mouth.
[d]Numbers adjusted for fishing effort (Dawley et al., 1985). Fish were identified from coded wire tags. Average fork length (mm) in parentheses.
[e]From Dawley et al. (1985).

TABLE 2

Numbers, lengths, and migration rates of migrant underyearling chinook salmon from Spring Creek hatchery captured at Jones Beach in either the beach or the purse seine[a]

Release date	Number of migrants caught in: beach seine		purse seine		Ratio (adjusted numbers)	Migration rates (km/day)[c]		Ave. fork length (mm) migrants		Average river flow[d] (1000 m^3/s) Jones Beach	River temp. (°C)
	actual	adjusted[b]	actual	adjusted[b]		beach	purse	beach	purse		
1978											
21 Mar	168	217	6	11	19.7	8	4	81	113	7.7	7.2
18 Apr	160	185	15	19	9.7	13	28	85	88	8.8	10.0
18 May	75	91	31	41	2.2	28	39	89	91	8.7	13.3
Total	403	493	52	71	6.9					8.4 ave.	
1979											
20 Mar	211	366	18	45	8.1	10	25	70	70	7.3	4.4
20 Apr	229	280	52	58	4.8	14	33	83	83	7.4	8.9
18 May	25	27	73	86	0.3	39	49	91	95	8.4	13.9
Total	465	673	143	189	3.6					7.7 ave.	
1980											
10 Mar	120	270	3	6	45.0	14	3	74	116	5.6	5.0
10 Apr	96	148	12	25	5.9	14	33	81	87	7.3	9.4
9 May	23	28	32	53	0.5	39	65	90	95	8.8	13.9
Total	239	446	47	84	5.3					7.2 ave.	
1981											
25 Mar	91	155	1	2	77.5	21	25	77	77	6.2	8.3
15 Apr	104	118	9	16	7.4	13	36	84	85	5.6	9.4
5 May	102	106	3	3	35.3	33	18	86	94	6.7	12.8
Total	297	379	13	21	18.1					6.2 ave.	
1982											
25 Mar	99	134	7	7	19.1	11	4	75	119	10.4	6.7
15 Apr	217	245	5	7	13.0	20	14	82	97	9.4	8.3
20 May	56	59	17	17	3.5	39	49	95	97	11.9	13.9
Total	372	438	29	31	14.1					10.6 ave.	

[a]Information from Dawley et al. (1985). Jones Beach is 194 km from Spring Creek.
[b]Adjusted to a standard fishing effort.
[c]Median migration rate is the distance traveled (194 km) divided by the number of days from the first day of release to the date of median fish recovery.
[d]Average river flow at time of median catch (Dawley et al., 1985).

TABLE 3

Information on migrant chinook salmon captured at Jones Beach and on recovered adults (lengths) from Spring Creek releases 1978–1982

Release date	Wt (g)	Number of tagged fish released	Total migrants caught[a]	Percent of release	Percent adj. to flow[b]	Percent ct. in purse seine	Percent adj. to flow[b]	Mean length (cm) and number ( ) of adults measured by age[c]			Percent adult recovery[c]
								2	3	4	
1978											
21 Mar	4.4	149 532	228	0.15	0.16	0.007	0.007	56.9(21)	77.2(312)	90.7(21)	0.87
18 Apr	6.7	92 109	204	0.22	0.25	0.021	0.024	56.9(33)	78.9(344)	89.9(55)	1.41
18 May	8.1	155 013	132	0.09	0.10	0.026	0.030	57.1(8)	77.5(219)	89.9(40)	0.54
Total		397 654	564	0.14	0.16	0.018	0.020				0.87
1979											
20 Mar	3.6	245 745	411	0.17	0.17	0.018	0.018	57.8(51)	76.2(365)	88.0(104)	0.55
20 Apr	5.8	135 239	338	0.25	0.26	0.043	0.044	55.4(82)	77.2(702)	88.8(176)	1.93
18 May	8.7	140 839	113	0.08	0.09	0.061	0.068	55.8(48)	76.4(464)	90.0(103)	1.22
Total		521 823	862	0.17	0.18	0.036	0.038				1.09
1980											
10 Mar	3.7	130 081	276	0.21	0.19	0.005	0.004	60.4(106)	79.0(396)	88.2(26)	0.99
10 Apr	5.5	77 700	173	0.22	0.23	0.032	0.033	60.3(109)	78.6(409)	88.8(39)	1.82
9 May	8.9	61 707	81	0.13	0.15	0.086	0.099	58.0(105)	79.5(384)	90.6(28)	2.12
Total		269 488	530	0.20	0.20	0.031	0.032				1.49
1981											
25 Mar	4.7	162 523	157	0.10	0.09	0.001	0.001	60.0(5)	77.3(53)	87.8(13)	0.11
15 Apr	6.4	107 529	134	0.12	0.11	0.015	0.013	53.8(10)	76.1(64)	86.7(23)	0.32
5 May	6.9	63 014	109	0.17	0.17	0.005	0.005	-	76.0(47)	82.7(10)	0.25
Total		333 066	400	0.12	0.11	0.006	0.006				0.20
1982											
25 Mar	4.1	151 260	141	0.09	0.12	0.005	0.006	58.4(23)	75.1(127)	83.1(9)	0.24
15 Apr	6.2	130 343	252	0.19	0.23	0.005	0.006	55.9(17)	74.6(173)	88.8(23)	0.34
20 May	9.3	58 238	76	0.13	0.18	0.029	0.041	57.6(13)	73.6(133)	84.9(27)	0.72
Total		339 841	469	0.14	0.18	0.009	0.012				0.36

[a]Total migrants caught in both beach and purse seines.
[b]Numbers of migrants caught adjusted to a river flow of 7000 m^3/s (Dawley et al., 1985).
[c]From Pacific Marine Fishery Commission; not all recovered tagged adults were measured.

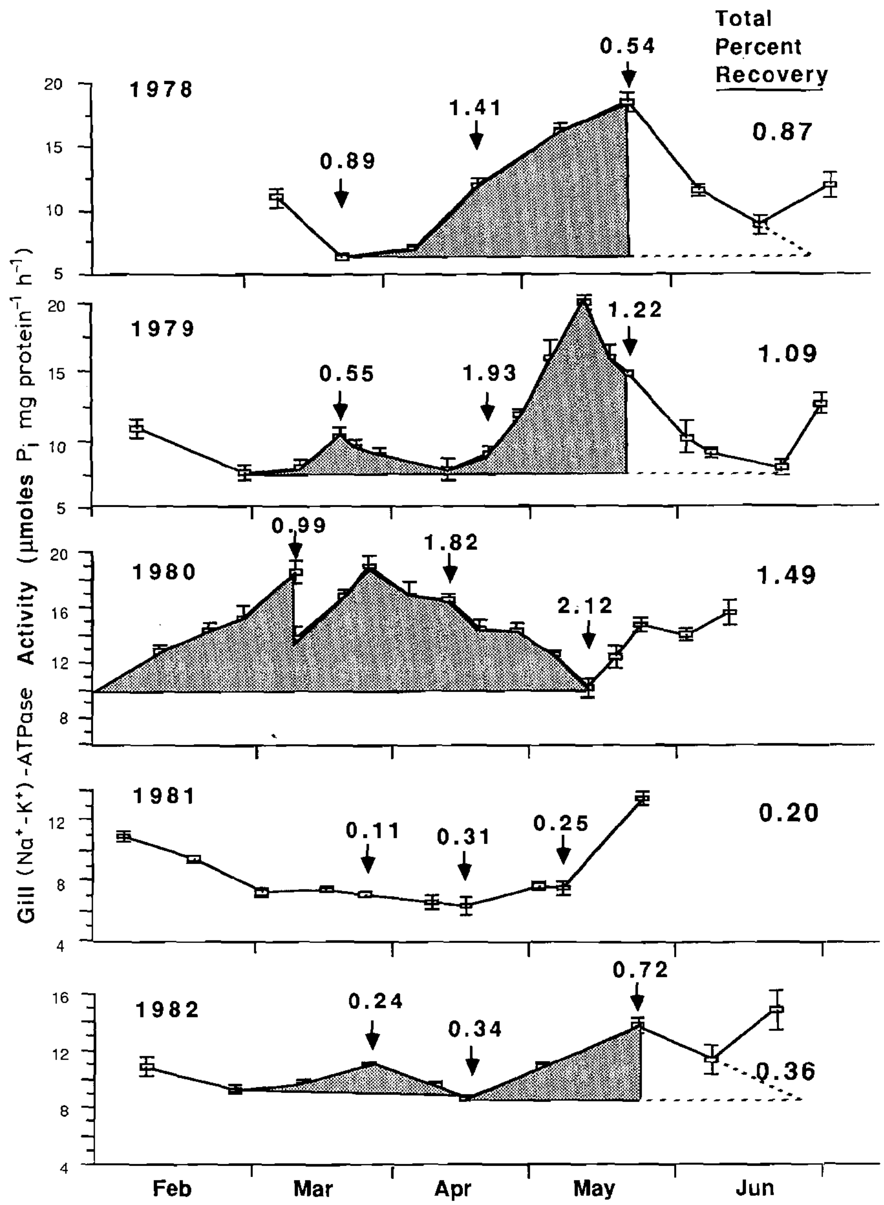

Fig. 1. Gill $(Na^{+}\text{-}K^{+})$-ATPase profiles, release dates, and percent adult recoveries of chinook salmon released from Spring Creek hatchery as underyearlings, 1978–1982. Releases of juvenile salmon were made at three times each year and are shown by arrows; percent adult recoveries are also indicated. Total percent adult recovery for each brood year is shown in the right margin. The approximate area boundaries are indicated under each ATPase profile (including dashed lines) with the shaded portion representing that part of the area encompassed by the time of the final May release. Vertical lines indicate standard errors. March 1980 release group experienced elevated ATPase levels from being fed a salt-enriched diet.

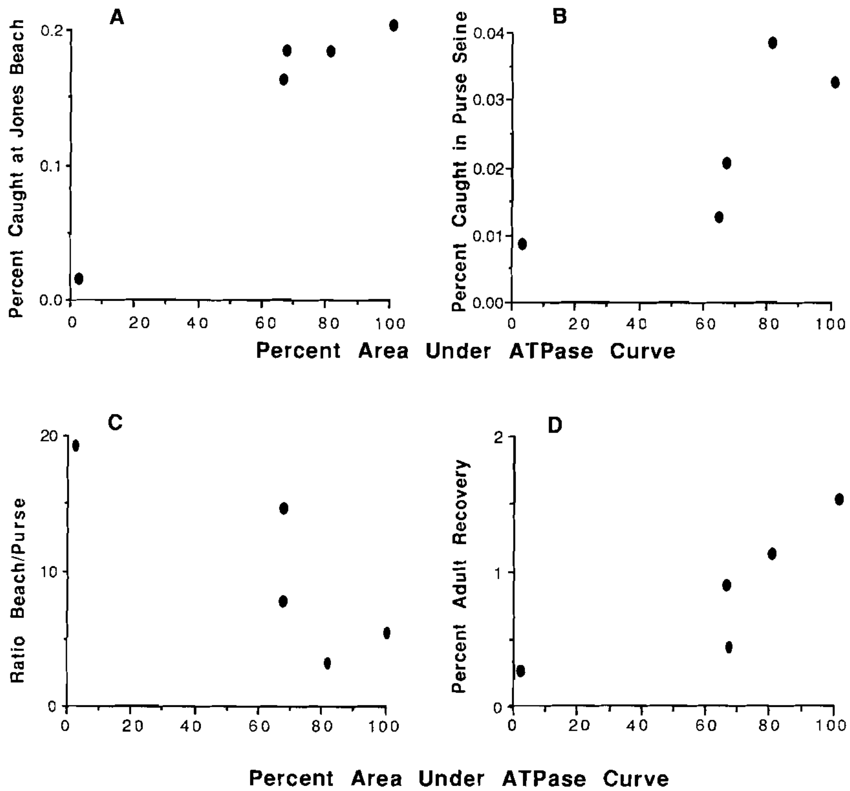

Fig. 2. Relation between the shaded area under ATPase profiles (expressed as percent of total area under the profile; Fig. 1) and percent of the released juveniles caught (beach and purse seines) at Jones Beach (A), percent of the release caught in the purse seine only (B), ratio of beach/purse seine catches (C), and percent adult recovery (D) for each brood year of underyearling chinook salmon released from Spring Creek hatchery, 1978–1982. The shaded areas under the profiles of Fig. 1 are used as measures of smolt development.

Adult recovery was related to total juvenile catch at Jones Beach (Fig. 3A) and to numbers caught in the purse seine (Fig. 3B), but was not significantly correlated with either fish size (wt) at release or time of release (Fig. 4A and B). Comparison of adult recoveries at several hatcheries from 1979–1981 releases showed differing trends (Fig. 5; Table 4). Both Big Creek and Spring Creek hatcheries showed dramatic drops in adult survival in 1981, but the other hatcheries failed to show this trend.

DISCUSSION

Studies conducted in 1968 established that downstream migration rates (km/day) increased with distance traveled by underyearling chinook salmon in the

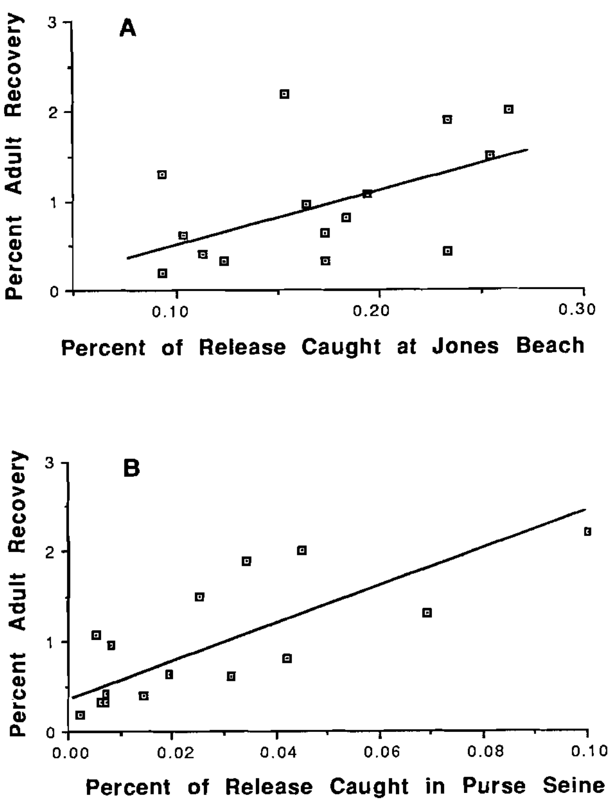

Fig. 3. Relation between percent adult recovery and percent of the juvenile fish recaptured at Jones Beach for underyearling chinook salmon released from Spring Creek hatchery, 1978–1982. Numbers of juveniles recaptured (total, A; purse seine only, B; adjusted for fishing effort) at Jones Beach (river km 75) are shown as a percent of the release from Spring Creek hatchery (river km 269) for each released group (three groups/year). Catch was adjusted to a river flow of 7000 m^3/s (see Table 3). For A, correlation coefficient (r) $=0.5$, $P=0.05$; for B, $r=0.74$, $P<0.02$.

Columbia River (Dawley et al., 1986), but no measurements of prerelease smolt development were made. In the present study, the lack of increasing levels of gill (Na^+-K^+)-ATPase activities in all of the groups used for rate/distance comparisons suggested little smolt development prior to release. The distance-dependent migration rates probably resulted from two main factors: (1) delays in initial downstream movement immediately following release, having a greater effect on the calculated rates of fish traveling shorter distances, and (2) the rapid progress of smolting during seaward migration, resulting in increased downstream migration speed with time. Accelerated smolting after liberation is indicated by increases in gill (Na^+-K^+)-ATPase activities (Zaugg, 1982b; Zaugg et al., 1985; Rondorf et al., 1985) and succinic dehydrogenase levels (Langdon and Thorpe, 1985; Chernitsky, 1986) in the migrants.

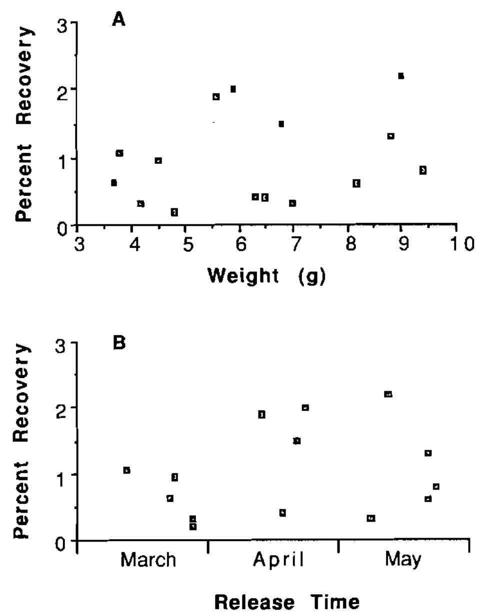

Fig. 4. Percent adult recoveries from releases of Spring Creek chinook salmon compared to weight (g) at release (A) and time of release (B). There is no statistically significant correlation of these values.

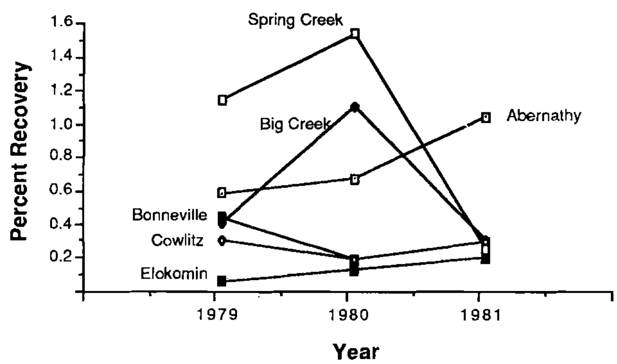

Fig. 5. Percent adult recoveries from 1979–1981 releases of underyearling chinook salmon from the following Columbia River hatcheries: Abernathy (river km 91), Big Creek (river km 49), Bonneville (river km 231), Cowlitz (river km 189), Elokomin (river km 94), and Spring Creek (river km 269). See Table 4.

The trend to higher percentages of migrants captured in the purse seine (decrease in ratio of beach/purse seine catches), as migration distance and rate increased, suggests that more completely smolted fish move away from the nearshore areas into faster flowing water. In most cases, fish caught in the mid-

TABLE 4

Release dates, weights, and percent adult recoveries of various release groups of underyearling chinook salmon from several Columbia River hatcheries, 1979–1981[a]

Hatchery	Release dates	Wt (g)	Percent recovery
Abernathy			
1979	17 Apr.–18 May	7.4	0.54
1980	9 Apr.–14 May	7.7	0.63
1981	15 Apr.–26 May	6.6	1.00
Big Creek			
1979	21 May	5.6	0.36
1980	13 May	5.8	1.06
1981	7–18 May	5.9	0.26
Bonneville			
1979	1–29 May	6.1	0.40
1980	20–28 May	6.1	0.14
1981	12 May	6.7	0.27
Cowlitz			
1979	27 Jun.	5.3	0.25
1980	3–11 Jun.	3.8	0.14
1981	12 Jun.	5.9	0.24
Elokomin			
1979	15 Jun.	4.6	0.01
1980	19 Jun.	5.7	0.08
1981	1 Jun.	4.5	0.15
Spring Creek			
1979	20 Mar.–18 May	3.6–8.7	1.09
1980	10 Mar.– 9 May	3.7–8.9	1.49
1981	25 Mar.– 5 May	4.7–6.9	0.20

[a]From Vreeland (1986) and Dawley et al. (1985).

river purse seine were larger (except for Toutle hatchery fish) and migrated more rapidly than fish captured in the beach seine. More rapid migration may result from a combination of size and of smolt development, which is generally more advanced in larger fish. However, size alone does not always dictate migration rate or location within the river. It was previously observed (Zaugg, unpublished, 1978) that large (120–150 g) yearling chinook salmon migrated over 100 km to Jones Beach at a rate of only 3 to 4 km/day and were caught primarily in the beach seine (beach/purse = 1884/184). These fish were released from the Cowlitz hatchery early in March prior to any indication of smolt development (elevation in gill (Na^+-K^+)-ATPase activity). Thus, large size alone appears inadequate to cause rapid, mid-river migration if smolt development has not progressed sufficiently.

Underyearling chinook salmon released serially from the Spring Creek hatchery generally showed increased migration rates with later releases, as determined from both beach and purse seine catches, although there were exceptions (March 1981 – beach; May 1981 – purse). In some instances, too few fish were captured in the purse seine to establish reliable values for migration rates or catch ratios. Contrary to the normal trend, those few fish that were caught in the purse seine from March releases of 1978, 1980, 1982, and April 1982 were much longer yet migrated more slowly than those caught in the beach seine. Their slow migration was apparently accompanied by considerable growth.

At least three factors appear to be involved in determining migration rates: smolt development, size and perhaps water temperature. There is no clear evidence of river flow influence, possibly because there was little variation in this factor. Of the five groups released in March, the migration rate (for beach-seined fish) was greatest in 1981, the year of poorest ATPase development. Fish in this group were the largest of any March release and March temperature of the river was highest (8.3°C) in 1981. Temperature has been shown to be important in determining seaward movements of some salmonids (Smith, 1985). The endocrine system is important to smolt development and the thyroid is especially involved in developing and coordinating a variety of physiological systems (Dickhoff and Sullivan, 1987). Just what role size, water temperature or thyroid hormones may have played in inducing a migratory urge in these fish is not known. Nevertheless, this group produced the lowest percent adult recovery of all releases.

Catch ratios (beach/purse seine catches) decreased for all April and May release groups with a major exception in May 1981 where very few fish were captured in the purse seine. Fish in this brood year failed to develop elevated levels of gill (Na^+-K^+)-ATPase activity during the normal spring smolting period (March–June), and adult survival was very poor.

Of the total area under an ATPase activity profile, the percent area reached by the May release was considered a measure of smolt development for each brood year and was compared with postrelease performance (migration characteristics and survival). In this way, allowance was made for potential development of groups released with low gill-enzyme activity. For example, fish released in March of 1978 and 1981 had similar low levels of activity. However, activities increased in fish held for later releases in 1978, but not in 1981. Although these two March groups had similar enzyme activities at release, the potential for development was much greater in the fish released in 1978 than in 1981, suggesting that these two groups were physiologically very different at time of release.

Fish released in March 1980 had been fed a diet containing about 5% added NaCl for 6 weeks prior to release. Although this caused an increase in gill (Na^+-K^+)-ATPase activity, it is thought that smolt development was not affected.

In a subsequent study (unpublished), fish fed similarly and released in April exhibited the same migratory behavior (rate and location of capture at Jones Beach) as controls. Whether the salt feeding influenced survival is questionable. Previously, salt feeding of Spring Creek fish released in April resulted in a 60% increase in survival (Zaugg et al., 1983), but replication of these studies for two successive years has failed to show the same effect (unpublished). Recalculation of the total recovery for fish released in 1980, decreasing the March contribution by that assumed 60% increase in survival because of salt feeding, gives a total 1980 recovery of 1.31%. This does not affect general conclusions reached in this study.

The degree of gill (Na^+-K^+)-ATPase development achieved during the hatchery rearing period may be related to numbers of fish that successfully migrated to the juvenile fish recapture-location in the upper estuary, and to adult recovery. Although these comparisons were not evaluated statistically because of small numbers, there appears to be a basis for such conclusions. Correlations between juvenile migrants caught at Jones Beach, either total numbers or purse seine catches, and adult recovery were found to be statistically significant. However, no statistical significance was found between adult recovery and release size (wt) or time.

Under conditions of declining ATPase activity, fish begin to lose their silvery, smolt appearance, and appear visually to be reverting to a parr stage. Nevertheless, when released in this stage, migration is rapid, elevated gill ATPase activity is rapidly regenerated (Zaugg, 1982b), and survival is relatively high. However, the conditions of release that lead to acceptable survival for chinook salmon from the Spring Creek hatchery may not apply elsewhere. Migration distance and stock genetic traits are probably very important in determining what particular stage of smolt development at release would maximize survival of a particular hatchery population. Fish in hatcheries located near the ocean probably have much different requirements in terms of smolt status at release than those in hatcheries located at great distances upriver.

Adverse ocean conditions, such as El Niño in the Eastern Pacific during fall 1982 and 1983 have major influences on survival. This particular event may have affected survival of groups released from Spring Creek in 1982. A review of sizes of adult fish taken in the fishery and returning to the hatchery indicated that adults from some of the fish released in 1982 were slightly smaller than those of the previous 4 years. Nevertheless, survival of this brood year was better than that of the previous brood year (released in 1981), which by most measurements (ATPase activity, numbers caught at Jones Beach, and beach/purse seine ratios) might have been expected to be the poorest performers in this 5-year study.

The decrease in adult recoveries observed for fish released from Spring Creek in 1981 was not observed at some of the other Columbia River hatcheries. Big Creek hatchery (river km 49) showed a recovery trend similar to Spring Creek (river km 269), but other hatcheries did not. Eruption of Mt. St. Helens occurred on 18 May 1980 and resulted in major silting of the lower Columbia River. Most of the fish released on 9 May from Spring Creek were probably not greatly affected since 90% of those migrants caught at Jones Beach were captured by 18 May (Dawley et al., 1985). Other 1980 groups, released after the eruption, would have experienced the silted conditions in the river. However, adult recoveries for fish released in the period 1979–1981 do not suggest serious deviations for fish released in 1980.

An association between some measurement of smolt development and migrant survival should not be unexpected. Nutritional deficiencies, health problems, and rearing stresses may seriously impair the smolting process as well as affect survival immediately following release. Rate of migration and distribution in the river during migration may determine susceptibility to predation. It is possible, therefore, that proper rearing and appropriate timing of releases of quality smolts may be as important as ocean conditions in determining the rate of adult return. Soivio and Virtanen (1985) reported some correlation between return rates of Atlantic salmon (*Salmo salar*) and certain smolt indices (migration readiness, energy stores, body silvering, etc.). Consistently poor adult recoveries have been noted from releases of underyearling chinook salmon showing no increases in gill (Na^+-K^+)-ATPase activity prior to release, as well as slow migratory rates (Zaugg, unpublished, 1988). In contrast, Ewing et al. (1985) have reported that physiological measurements of smolt development were not related to adult survival in coho (*Oncorhynchus kisutch*) and yearling chinook salmon. The results of the present study indicate, however, that the stage of smolt development as measured by gill (Na^+-K^+)-ATPase activity may be related to migratory behavior and survival in underyearling chinook salmon. Further investigations into the role of smolt development in hatchery-reared salmonids and their survival to adulthood seem justified.

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