Changes in Hatchery Rearing and Release Strategies Resulting from Accelerated Maturation of Spring Chinook Salmon by Photoperiod Control

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Abstract

Early maturation and spawning of adult spring chinook salmon (*Oncorhynchus tshawytscha*) was induced by controlling photoperiod at the Little White Salmon National Fish Hatchery. Tagged groups of progeny from these adults were released as subyearlings in May and June, and again at their normal release time as yearlings in April of the following year. Fish released as subyearlings were recovered as adults 1) in a ratio of 1:3.5 to fish released during the same years (1984 and 1985) as yearlings; 2) at a higher ratio of males to females than yearlings; 3) with reduced numbers of precocious males (jacks) compared with yearlings; 4) predominantly as 4-year-old fish, similar to fish released as yearlings; and 5) at a larger size at the same age than adults released as yearlings. In spite of the lower return of adults from subyearling releases, this is a cost- effective method of supplementing the yearling release program and provides an excellent means of augmenting the run.

Introduction

Historically, the abundant runs of chinook salmon (*Oncorhynchus tshawytscha*) were used as an important food source and for barter among Native Americans inhabiting the Columbia River Basin. Later, as settlers immigrated into the basin, these fish became important to commercial harvesting and recreational fishing and were soon overharvested. Presently, stocks of chinook salmon are depleted in most of the basin because of blocked and degraded habitat; artificial production in hatcheries has become essential for the maintenance of harvestable numbers of adults. Methods used in the hatcheries to rear and release juvenile chinook salmon vary considerably, depending to some degree upon physical facilities and available water supplies of the individual hatcheries, but more importantly upon the subspecies of chinook salmon being reared.

Adult chinook salmon can be found in the Columbia River system, migrating to native waters or rearing facilities, in nearly every month of the year. There are, however, three principal groups: spring, summer, and fall chinook salmon, so designated to correspond approximately to their upstream migration and spawning times. These groups are described on the next page:

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Salmon group	Migration time	Spawning time	Length of time in river
Spring chinook	Jan–May	Jul–Sep	4–6 months
Summer chinook	Jun–Aug	Sep–Nov	3 months
Fall chinook	Aug–Dec	Sep–Jan	1 month

Spring chinook salmon remain longer in fresh water before spawning than the other major fish groups and for much of this time exist in excellent condition. They are highly prized by recreational and commercial freshwater fishermen. However, serious problems arise when these fish move into hatchery holding ponds early in the spawning run and must be held for an extended time before spawning. Such confinement often results in high prespawning losses due to stress, physical injury, and disease. At the Little White Salmon National Fish Hatchery (Little White Salmon NFH) in Washington State, measures have been taken to reduce some of the mortality associated with long-term holding by accelerating maturation with controlled photoperiods. Early spawning not only reduces prespawning mortality but allows earlier hatching of eggs. The resulting progeny experience greater growth because of longer rearing times and manifest physiological and behavioral characteristics of developing smolts from 10 to 11 months prior to the demonstration of such characteristics in progeny from adults spawned under normal conditions.

This report provides information on releases and subsequent adult recoveries of tagged subyearling and yearling spring chinook salmon from the Little White Salmon NFH. Some preliminary information has been reported previously (Zaugg et al. 1986).

Materials and Methods

The Little White Salmon NFH is located on the Little White Salmon River (Washington) about 2 km from its confluence with the Columbia River. Adult spring chinook salmon returning to holding ponds at the hatchery by mid-May were moved into portions of raceways covered by a metal building (9.9 × 13 m) equipped with six sodium vapor lamps (Lucalox G.E., LU 150/55) located 3.1 m above the water's surface. They were then subjected to a reduced photoperiod schedule that began with 12 hours of light per day and decreased at a rate of 30 minutes per week until spawning occurred about mid-July (Zaugg et al. 1986). After hatching, fry were reared inside in tanks containing water ranging from about 7 to 9° C. In November they were transferred to outside ponds where water temperatures ranged from 4 to 7° C. In late March and early April 1983–85, groups of approximately 50,000 juveniles each were tagged with coded wire tags and held for release as subyearlings in either May or June of the same spring or as yearlings in April of the following year (1984–86) as indicated below (brood year in parenthesis):

Year	Tagged	Released as subyearlings	Released as yearlings
1983	+ (82)	+ (82)	—
1984	+ (83)	+ (83)	+ (82)
1985	+ (84)	+ (84)	+ (83)
1986	—	—	+ (84)

Comparisons of adult returns between groups released in the same spring (different brood years) could only be made for 1984 and 1985, as in 1983 only tagged subyearlings were released and in 1986 only tagged yearlings were released.

Fish were fed Oregon Moist Pellets (OMP) throughout the rearing period. Groups of tagged subyearlings that, for six weeks prior to release, had received OMP to which 7% NaCl (on a dry weight basis) had been added, were liberated with May releases in 1984 and 1985. Thus, three groups of subyearlings were released in each 1984 and 1985; two in May (one salt-fed) and one in June.

Information on the post-release migratory performance of subyearlings released in 1983 was obtained from captures in beach seines and mid-river purse seines at the upriver boundary of the estuary (Jones Beach, Oregon) after fish had migrated 186 km (Dawley et al. 1985; Zaugg et al. 1986). Seining operations were not conducted after the 1983 season. Information on adult recovery was obtained from a data base of the Pacific States Marine Fisheries Commission, Portland, Oregon. Weights of recovered tagged adults were estimated from lengths by comparison with a length/weight relationship determined in 1989 on a group of 72 adults held at the hatchery for antibiotic injections.

Results

Figure 1 compares the abbreviated adult holding and juvenile rearing times that result from photoperiod treatment of adults with times for controls that undergo normal spawning and juvenile rearing. Under the accelerated spawning program, juveniles were released as subyearlings in both May and June. Progeny from the early spawn began feeding earlier and, consequently, were larger on any given date thereafter (Table 1; Zaugg et al. 1986).

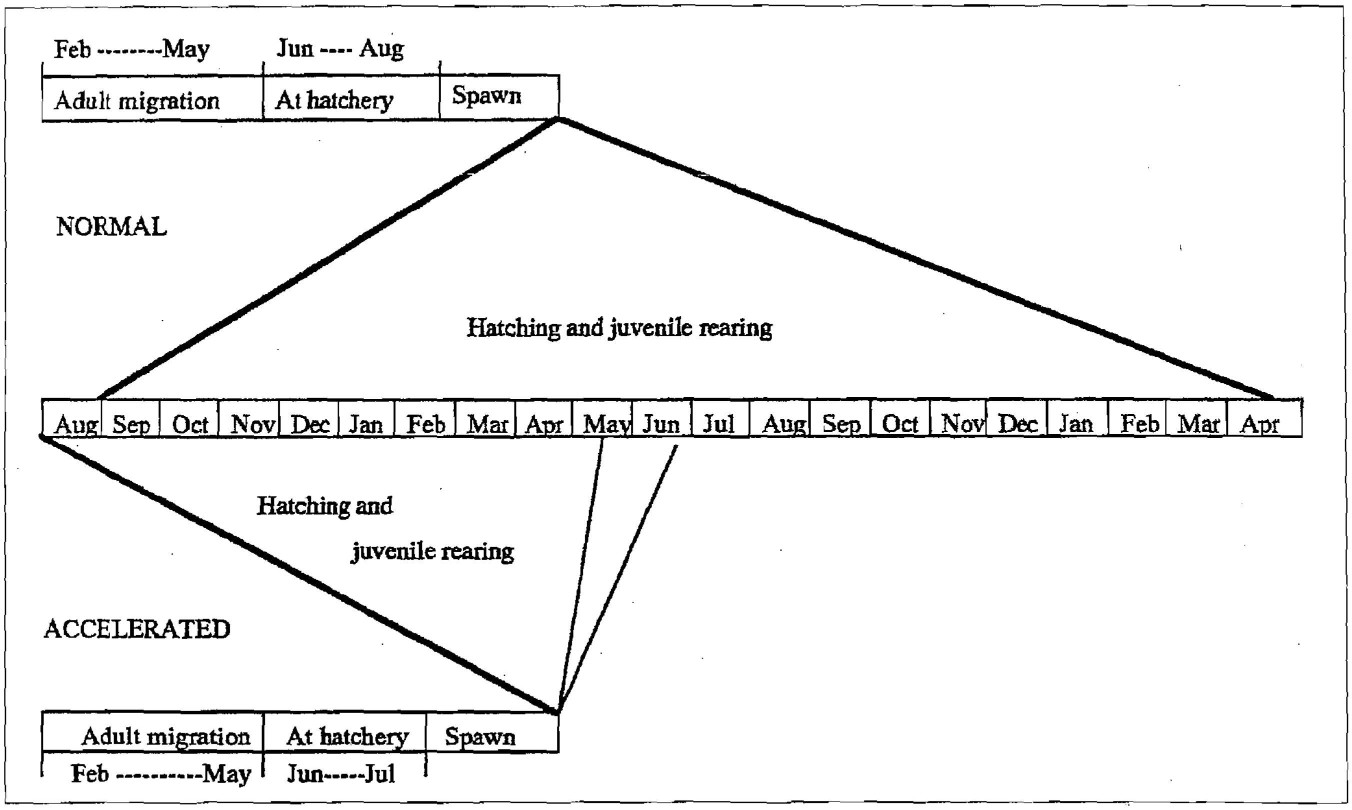

Figure 1

Comparison of spring chinook salmon adult handling and juvenile rearing between normal and advanced photoperiod schedules at the Little White Salmon National Fish Hatchery. Adults returning to this hatchery probably enter the Columbia River no earlier than February and are normally spawned in August. For release as yearlings, juveniles from normally spawned adults were reared in the hatchery until their second April. For subyearlings, juveniles from treated adults that were spawned in July were released as subyearlings the following May and June.

Table 1

Historical spawning, hatching, and fry information for spring chinook salmon from the Little White Salmon National Fish Hatchery (Zaugg et al. 1986).

Group	Spawning dates	Mean wt (g) at first feeding	Date of first feeding	Mean wt (g) on 1 October
Control (1976–79)	11–17 August	0.32	10–28 Dec	13.8
Photoperiod (1980–82)	16–22 July	0.27	29 Oct–12 Nov	24.4

Table 2

Juvenile migration of subyearling spring chinook salmon from the Little White Salmon National Fish Hatchery (1983), and adult recoveries.

Release date	Mean wt (g)	Number caught[a] Beach seine	Number caught[a] Purse seine	Migration rate (km/day)	Adult recovery[b] Number	Adult recovery[b] Percent
4 May 1983	6.7	37	7	12	14	0.03
24 June 1983	10.3	0	89	16	23	0.05

[a] Number caught adjusted for fishing effort (Dawley et al. 1985).
[b] Numbers adjusted to a release of 50,000; includes commercial and sport fishery catches and hatchery returns (source: Pacific States Marine Fisheries Commission data base).

Table 3
Adult recoveries from juvenile salmon released from the Little White Salmon National Fish Hatchery in 1984 and 1985.

Release year and group	Release		Adult recoveries[a]	
	Date	Wt (g)	Number	Percent
1984				
Yearling	19 Apr	36.6	109	0.22
Subyearling (salt fed[b])	7 May	7.0	5	0.01
Subyearling (controls)	7 May	7.0	11	0.02
Subyearling	22 Jun	11.7	30	0.06
1985				
Yearlings	17 Apr	43.7	266	0.53
Subyearling (salt fed[b])	6 May	7.6	104	0.21
Subyearling (controls)	6 May	7.1	101	0.20
Subyearling	20 Jun	10.5	68	0.14

[a] Based on 50,000 released; data includes commercial and sport fishery catches and hatchery returns (source: Pacific States Marine Fisheries Commission data base).
[b] Fed a diet containing an additional 7% (dry wt) NaCl for 6 weeks prior to release.

Table 4
Numbers of tagged female and male adult salmon returning to the Little White Salmon National Fish Hatchery from releases in 1984–85.

	Females	Males	Female/male
Yearling releases	199	89	2.24
less jacks	199	75	2.65
Subyearling releases	158	119	1.33
less jacks	158	118	1.34

During the first year of the study, juveniles released in June were larger, migrated faster, and produced more adults than those released in May (Table 2). Fish released in June were caught exclusively in the mid-river purse seine as they reached the lower river, whereas those released in May were captured primarily in the beach seine.

More adults were recovered from yearling than subyearling releases made in 1984 and 1985 (Table 3). Subyearlings released in June 1984 were recovered as adults in higher numbers than those released in May, whereas the opposite was true for subyearlings released in 1985. The overall rate of return for all groups was much higher for fish released in 1985 than for fish released in 1983 or 1984 (Tables 2 and 3).

Sex determinations on adults returning to the hatchery from tagged fish released in 1983–85 indicated a greater survival of females (Table 4). The female to male ratio for adults returning from subyearling releases was nearer to 1:1 than the same ratio for adults returning from yearling releases. Only one precocious male (jack) was observed out of 119 males (1%) returning from subyearling releases, whereas 14 jacks out of 89 males (16%) returned from yearling releases.

Examination of the age distribution of tagged adults from both the fishery and hatchery returns showed that fish released as either subyearlings or yearlings were recovered predominantly as 4-year-olds (Table 5). Age-4 adults from subyearling releases were equivalent in size to age-5 adults returning to the hatchery from yearling releases (Table 6), both age groups having spent about 3 years in the ocean.

Table 7 presents the ratios of numbers and weights of adults recovered from yearling releases in 1984 and 1985 to those of subyearlings released in the same years. The generally lower total weight ratios

Table 5
Numbers of adult salmon (% of total in parentheses) taken in the fishery and returning to the Little White Salmon National Fish Hatchery, according to age in years.

Release year and group	Age 2	3	4	5
1983				
Subyearling (May)	—	—	14 (100)	—
Subyearling (June)	—	1 (4)	24 (89)	2 (7)
1984				
Yearling (April)	—	1 (1)	62 (63)	35 (36)
Subyearling (May, salt)	—	—	5 (100)	—
Subyearling (May, control)	—	1 (9)	10 (91)	—
Subyearling (June)	—	10 (35)	19 (65)	—
1985				
Yearling (April)	—	13 (5)	173 (68)	69 (27)
Subyearling (May, salt)	—	18 (18)	80 (82)	—
Subyearling (May, control)	—	19 (19)	79 (81)	—
Subyearling (June)	1 (1)	12 (18)	54 (81)	—
Totals				
Yearling	—	14 (4)	235 (67)	104 (29)
Subyearling	1 (0.3)	61 (17)	285 (82)	2 (0.6)

Table 6
Mean fork lengths in centimeters (# of fish measured) of adult salmon returning to the Little White Salmon National Fish Hatchery, according to age in years.

Release year and group	Age 2	3	4	5
1983				
Subyearling (May)	—	—	89 (11)	—
Subyearling (June)	—	66 (1)	87 (20)	101 (2)
1984				
Yearling (April)	—	61 (1)	76 (63)	90 (30)
Subyearling (May, salt)	—		92 (4)	—
Subyearling (May, control)	—	72 (1)	90 (7)	—
Subyearling (June)	—	71 (10)	88 (19)	—
1985				
Yearling (April)	—	56 (13)	77 (156)	89 (58)
Subyearling (May, salt)	—	73 (18)	89 (65)	—
Subyearling (May, control)	—	71 (17)	90 (61)	—
Subyearling (June)	46 (1)	73 (12)	90 (52)	—
Totals				
Yearling	—	56 (14)	77 (209)	89 (88)
Subyearling	46 (1)	72 (59)	89 (239)	101 (2)

(compared to the total number ratios) reflects the larger average size of recovered adults from subyearling releases (86.3 cm fork length, 7.74 kg, $n = 348$) to yearling released fish (79.7 cm fork length, 5.95 kg, $n = 348$).

Discussion

Controlling photoperiod regimes to which adults are exposed is an effective way of accelerating maturation and spawning in salmonids (MacQuarrie et al. 1978, 1979; Whitehead et al. 1978a, 1978b; Eriksson and Lundqvist 1980; Bromage et al. 1982). Johnston et al. (1990) have shown that it is possible to mature Atlantic salmon (*Salmo salar*) at nearly any time of the year by making appropriate photoperiod adjustments. At the Little White Salmon NFH, the use of advanced photoperiods on returning adult chinook salmon accelerated maturation and spawning by 4 to 5 weeks, which has resulted in the accomplishment of

Table 7

Ratios of numbers and estimated weights of adults recovered from yearling releases to those of adults from subyearling releases.

Release year and group	Number of recovered adults [a]	Relative number of recovered adults (yearling/subyearling)	Estimated total wt (kg) of adults [b]	Relative weight of recovered adults (yearling/subyearling)	Average adult wt (kg)
1984					
Yearling	109	—	677	—	6.2
Subyearling (May, salt)	5	21.8	48	14.1	9.6
Subyearling (May, control)	11	9.9	91	7.4	8.3
Subyearling (June)	30	3.6	198	3.4	6.6
Subyearling average	15	—	112	—	7.5
1985					
Yearling	266	—	1,552	—	5.8
Subyearling (May, salt)	104	2.6	796	2.0	7.7
Subyearling (May, control)	101	2.6	782	2.0	7.7
Subyearling (June)	68	3.9	532	2.9	7.8
Subyearling average	91	—	703	—	7.7
Totals [c]					
Yearling (1984+1985)	375	—	2,229	—	5.9
Subyearling	106	3.5	816	2.7	7.7

[a] Based on release of 50,000; numbers include commercial and sport fishery catches and hatchery returns (Pacific States Marine Fisheries Commission data base).
[b] Weights estimated from length/weight relationships determined in 1989 from 72 returning adults.
[c] Averages of the three 50,000-fish release groups for each year are totaled and compared with the sum of values obtained from the two yearling release groups.

two original goals: 1) to reduce prespawning mortality by decreasing the adult holding time and 2) to produce larger yearling smolts because of a longer rearing time.

However, an unanticipated benefit resulted from the incorporation of photoperiod-accelerated spawning into the hatchery production scheme—that of smolt development in progeny during their first spring of rearing. Development of smolt-like characteristics, such as increased silver coloration, fin clarification, a dark band in caudal fins, crowding at the outlet screens, increased gill Na^{+}-K^{+} ATPase activities, and active seaward migration, suggested that these fish could possibly be released 10 to 11 months earlier than normal and survive to adulthood (Zaugg et al. 1986). This study was designed to test whether such early releases of subyearlings could be used to effectively augment current production and release of yearling juveniles. Adult recoveries from tagged subyearlings released in the first year of the study (1983) were low (0.03–0.05%). However, no tagged yearlings were released that year, so a comparison of relative recoveries from the two year classes was impossible. Adult recoveries from subyearling releases made in the second year (1984) were also low (0.01–0.06%), but these could be compared to adult recoveries from yearlings released at their normal time in April of the same year (0.22%). Adult recoveries from both subyearlings and yearlings that were released in 1985 were much higher (0.14–0.21 and 0.53%, respectively).

Although numbers of recovered adults were small, it is nevertheless apparent that the release of subyearlings resulted in a ratio of adult females to males more closely approximating 1 (1.33) than did the release of yearlings (2.24). In addition, very few jacks were observed in hatchery returns from subyearling releases (1 of 119 returning males), whereas there were 14 jacks of 89 males that returned from yearling releases. This greater proportion of adult males, and the lack of jacks, results in a greater opportunity to spawn individual pairs of fully matured adults, a practice presently being used to control disease.

Eighty-two percent of adults recovered from subyearling releases were age 4, whereas 67% of recoveries from yearling releases fell into this age group. This is a majority, however, for each release group. Age-4 adults from subyearling releases averaged 12 cm longer than age-4 adults from yearling releases, and were estimated to be about 1.75 kg heavier. This size differential, which was a characteristic of the adults in each age category, translated into an estimated ratio of 2.7 for the combined weight of adults recovered from yearling releases to the combined weight of adults recovered from subyearling releases made in 1984–85. The ratio of total numbers of recovered adults from these same two groups was 3.5.

Although the ratios of adults returning from yearling/subyearling releases varied considerably for the various groups released in the 2 years that comparisons could be made (1984 and 1985), the results suggest that it would be necessary to release three to four times as many subyearlings as yearlings to recover an equivalent number of adults. We estimate that three to four times as many subyearlings as yearlings could be reared in the same pond space, but for a much shorter rearing time and with lower production costs. In addition, the larger size of adults returning from subyearling releases and the reduced number of jacks makes this strategy even more economically beneficial. The release of subyearling progeny of adult spring chinook salmon matured early through the use of photoperiod control is an effective hatchery practice at the Little White Salmon NFH. A similar program might be used at other hatcheries to provide an effective method of maintaining and augmenting spring chinook salmon runs in the Columbia River Basin or elsewhere.

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