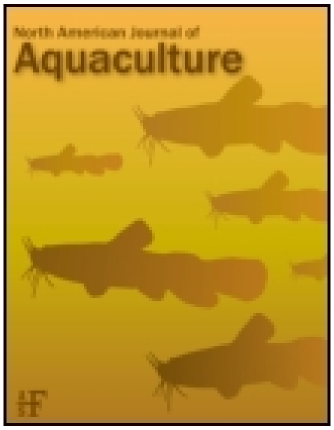

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The Effect of Hatchery Spawning Protocols on Coho Salmon Return Timing in the Cowlitz River, Washington

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The Effect of Hatchery Spawning Protocols on Coho Salmon Return Timing in the Cowlitz River, Washington

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Abstract.—We compared the pre- and posthatchery return times of adult coho salmon *Oncorhynchus kisutch* on the Cowlitz River, Washington, after 30 years of hatchery operation. In addition, at the Cowlitz Salmon Hatchery in fall 1998, 1999, and 2000, we differentially tagged juveniles for release in 1999, 2000, and 2001 that were produced from broodstock originating from early (August to mid-October), middle (mid-October through November), and late (December and thereafter) time arrival windows to determine the fidelity of adult return time distribution to the window of origin. We found that posthatchery mean and median coho salmon adult return times were delayed about 2 weeks compared with prehatchery conditions, that October–November returns increased from 46% to 81% after hatchery operation, that a mean of 57% of 3-year-old adult fish returned in the return time window of origin, and that many of the early- and late-origin fish returned in the middle time period. A mean of 70.4% of 2-year-old jacks from all releases returned in the middle return window. Much of the increase in October–November returns was probably due to a hatchery production emphasis of the middle-returning fish. We recommend that broodstock be accumulated at historically proportional rates with respect to run timing, which may require additional adult holding ponds at the hatchery.

Prudent management of anadromous hatchery broodstocks minimizes genetic selection, which impairs postrelease survival or alters adult return timing, age at maturity, ocean distribution, or body size. Return timing in Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* has been shown to be heritable (Crawford 1979; Smoker et al. 1998; Mackey et al. 2001) and is likely important to population fitness, especially where water temperatures and river flows may exert survival influences (Chilcote et al. 1986). Flagg et al. (1995) suggested a causal relationship between hatchery practices and a 10-fold reduction in wild coho salmon *O. kisutch* spawner densities; they argued that hatchery practices included selection for early spawn timing, which rendered the fish maladapted for establishing natural, self-reproducing populations. Further, Flagg et al. (1995) suggested that hatchery timing selection had condensed adult return times and spawn timing by about 7 weeks.

The historical return timing of coho salmon in the Cowlitz River, a Columbia River tributary in southwest Washington (river kilometer 109 as measured from the mouth of the Columbia River), ranged from August through March, most fish returning from September through November (Thompson and Rothfus 1969; Table 1). Wild coho salmon in the Cowlitz River upstream of the Toutle River were reported to have had two major spawning peaks, one in late October and the other in late November (Thompson and Rothfus 1969). However, the spawning distribution associated with these spawning peaks was not well documented.

In 1967, the Cowlitz Salmon Hatchery was constructed to mitigate the construction of hydroelectric dams (Tacoma Public Utilities) on the Cowlitz River that blocked access to many miles of coho salmon habitat. To conserve the apparent variation in adult coho salmon return timing, three broodstock return time windows were established: early (August to mid-October), middle (mid-October through November), and late (December–February). Eggs were taken in specified proportions from returnees in the three time windows. The proportions chosen were not intended to mimic the original return timing of the population, which would have been approximately 40% : 33% : 27%, but rather to make the return timing somewhat later so commercial harvest rates could be increased without concern for bycatch of less abundant Chinook salmon *O. tshawytscha* in the Columbia River. Thus, the spawning proportions for most of the time that the hatchery has been operating were 10% : 80% : 10%, reflecting the desire to have the greatest number of returnees in the middle window, while conserving (at some level) the genetic variation underlying the early and late run timing.

Coho salmon broodstock are collected at the Cowlitz Salmon Hatchery via a fish ladder adjacent to an anadromous barrier dam. At the terminus of the fish ladder, fish jump at a false weir and then pass through a chute while an observer counts them. Hatchery fish were not marked (adipose fin

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TABLE 1.—Return time distribution (%) of coho salmon passing Mayfield Dam on the Cowlitz River at various times. The 1961–1966 returns are from Thompson and Rothfus (1969): other returns are from hatchery records. The 1967–1969 returns are the mean of the 2 years prior to initial hatchery returns; subsequent returns are the mean of 3 years.

Month	1961–1966	1967–1969	1979–1981	1989–1991	1999–2001
Aug	1.1	0.3	0.0	0.0	0.0
Sep	27.2	21.9	4.3	1.6	1.2
Oct	25.5	30.1	41.5	38.4	32.8
Nov	20.6	20.7	39.9	50.7	40.7
Dec	14.9	13.4	12.3	8.0	20.4
Jan	7.9	8.9	2.0	1.4	4.6
Feb	2.4	3.5			0.3
Mar	0.4	1.2			0.0
N	147,471	43,417	110,258	115,610	198,543

clip) until the 1990s, so for many years of hatchery operation they could not be identified from wild fish and, thus, broodstock probably included a few but unknown number of wild fish each year. However, the proportion of wild fish in the broodstock was subjectively thought to be minor due to the large number (3–5 million) of hatchery smolts released annually from the hatchery. Although the correlation between adult arrival time and spawning time for individual fish is uncertain, peak spawning time of early-, middle-, and late-returning coho salmon at the Cowlitz Salmon Hatchery has been late November to early December, mid-December, and mid-January, respectively (hatchery records, 1998–2002).

The hatchery operation has intentionally spawned coho salmon for run timing for over 30 years using the system of three arrival time windows. Our purpose in conducting this study was to determine how this selection regime has affected the run timing of coho salmon as measured at the Cowlitz Salmon Hatchery and how successful it has been in conserving variation in run timing. We approached these questions by evaluating historical run timing data and return timing of the progeny of within-arrival window matings.

Methods

Coho salmon return time distribution to the area of the Cowlitz Salmon Hatchery was summarized from Thompson and Rothfus (1969), Tacoma Public Utilities records and Washington Department of Fish and Wildlife (WDFW) hatchery records for 1961–1966 (prehatchery), 1967–1969 (the first 2 years of hatchery operation and before the first hatchery returns), and for 3-year time periods in 1979–1981, 1989–1991, and 1999–2001 so that return time distribution could be compared. The 1967–1969 and 1999–2001 return time distributions were compared using a *G*-test of heterogeneity ($\alpha = 0.05$; Sokal and Rohlf 1981).

In addition, in fall and winter of 1997–1998, 1998–1999, and 1999–2000, about 5,000 adult coho salmon at the hatchery were spawned over three return-time groups: August–October 15, October 16–November 30, and December 1 through February. Fish within each group were spawned about weekly after the initial spawning within the group. Progeny from these groups were segregated during rearing as early-, middle-, and late-returning fish. In July and August 1998, 1999, and 2000, juvenile coho salmon were coded-wire-tagged and placed into Burrows-style raceways and reared until release as yearlings in spring 1999, 2000, and 2001, respectively. Therefore, adult fish returning in fall 1997 produced juvenile fish that were released in 1999. Because of the different spawn times, fish from later egg takes were fed at slightly greater rates throughout the year so that fish sizes would be similar at release. Although smolt length was not anticipated to alter return time distribution, we sought to release fish at similar sizes.

For the 1999 release, about 90,000 fish were tagged and placed in three raceways of early, middle, and late groups, for a total of nine raceways, each containing about 10,000 tagged fish. For the 2000 release, the early and middle groups had about 20,000 tagged fish within each of three raceways (60,000 tagged fish per group), while the late group was contained within one raceway of about 60,000 tagged fish. The 2001 release was similar to the 2000 release except that the number of fish tagged was reduced to about 30,000 fish per group. Groups were randomly assigned each year to 1 of 34 raceways. The early and middle groups had three replicate raceways for each of 3 years; the late group had three replicates in one year. In each year, the raceway populations were supplemented with untagged fish as part of hatchery production so that the total population in each raceway was about 180,000 fish. Fish from each raceway were released concurrently in May 1999, 2000, and 2001. At release, 100 fish (tagged and untagged) from each raceway were measured for fork length.

Adult coho salmon returns to the Cowlitz Salmon Hatchery were recovered after the fish entered the fish ladder, jumped at a false weir, and passed down a flume into holding vessels; both 3-year-old adults and 2-year-old jacks were readily collected. The fish were segregated in holding ponds, separated by the aforementioned three return time windows. After each group was spawned at the hatchery, coho salmon were scanned for the presence of a wire tag with a tag detector (Northwest Marine Technology, Shaw Island, Washington) and, if tagged, the snout was removed and labeled for its return time group and decoded in the WDFW coded wire tag laboratory. The recovery of coded wire tags requires lethal removal; tag recovery after spawning was standard hatchery protocol since fish were killed for spawning. Some coho salmon were passed upstream after being scanned for the presence of a wire tag; wire-tagged fish were not passed upstream. However, in 2002, some fish were inadvertently passed upstream without being scanned for a coded-wire tag; tag recoveries at the hatchery were expanded proportionally for fish passed upstream. For the early-returning group, 7.86% of 16,802 fish were scanned for tags, resulting in an 11.72 expansion factor. For the middle return group, 12,455 unscanned fish were passed upstream, resulting in an expansion factor of 5.74. All late-returning fish were scanned. Coho salmon were recovered as 2-year-old jacks and 3-year-old fish, with the last recoveries occurring in winter 2002–2003.

Return data were analyzed with a *G*-test of heterogeneity ($\alpha = 0.05$; Sokal and Rohlf 1981), in which returns in the three return windows were tested for independence from timing of origin in parents. Data for each release year was compared separately and for all years combined for both 2-year-old jacks and 3-year-old fish, a total of eight tests. Therefore, 2-year-old jacks had four tests (one for each of the three release years and one for all years combined), and 3-year-old adult fish had a similar test regime for a total of eight tests. Mean and median return times for various years were also calculated for comparison; the median return date was determined as the day that 50% of the population had entered the hatchery.

The number of tagged fish from each group that was captured in the Columbia River commercial gill-net harvest was obtained through the Pacific States Marine Fisheries Commission regional mark information system database. The dates and duration of the commercial fishing seasons for 2000–2002 were obtained from the Columbia River Joint Staff Report (Joint Columbia River Management Staff 2003).

Results

Since initial hatchery operation, the pattern of coho salmon return timing has changed substantially so that more fish now return at a time corresponding to the middle window and fewer fish during the times of the early and late windows. For the 9 years observed within 1979–2001 (Table 1), 81.3% of returns occurred in October–November compared with 46.1% in 1961–1966. August and September returns diminished from a mean of 28.3% in 1961–1966 to only 2.4% in later years. January–March returns of coho salmon averaged 10.7% in 1961–1966 but only 4.9% in 1999–2001.

A comparison by *G*-test of the 1967–1969 return timing with that observed in 1999–2001 was highly significant ($G > 10^6$, df $= 7$), but this is misleading. The large numbers of fish returning make it likely that nearly any comparison of distributions here would be significant statistically, but not necessarily biologically. To make the comparison more biologically meaningful, we tested to determine if the difference would be significant with much smaller sample sizes. We found that the difference would still be highly significant ($G = 271.0$, df $= 7$) even if it were based on only 100 returns in each period.

The average time of return has been delayed about 2 weeks. In 1967–1969, the last 2 years prior to hatchery returns, the mean and median return dates of coho salmon to the hatchery were November 1 and November 7, respectively, whereas for 1999–2002, the mean and median return dates were November 14 and November 15, respectively. However, the 2001–2002 mean (November 22) and median (November 26) return dates were about 3 weeks later than those from 1967 to 1969.

Returns of 2-year-old jack coho salmon from the test mating groups were significantly nonrandom for each year of release and were highly significantly nonrandom in two of the releases and when all years were combined (Table 2). Most fish with early-timed parents returned in the middle window (70.1%), as did most fish from the middle-timed group (76.8%) and late-timed group (64.2%).

TABLE 2.—Number and mean fork length (mm) of smolts released and 2-year-old jacks and 3-year-old coho salmon returning in the early (August–October 15), middle (October 16–November 30), and late (December 1–February) time periods to the Cowlitz Salmon Hatchery. In the G-value column, asterisks indicate that returns were not equally proportional to expected returns; $P < 0.05$*, $P < 0.005$**.

Release year	Progeny	Number of smolts	Smolt length	Number of adult returns: 2-year-old jacks Early	Middle	Late	G-value	3-year-old coho salmon Early	Middle	Late	G-value
1999	Early	28,596	150	12	8	1	11.4*	51	108	15	53.8**
	Middle	29,652	150	5	11	3		16	121	34	
	Late	29,626	148	1	11	2		12	122	51	
2000	Early	58,474	147	19	155	22	23.8**	161	456	111	990.1**
	Middle	59,361	145	1	126	28		29	419	301	
	Late	59,515	144	0	29	8		0	64	585	
2001	Early	30,013	145	16	1	0	44.5**	585	196	28	863.8**
	Middle	30,456	144	1	2	4		216	296	139	
	Late	29,862	147	0	3	13		127	108	416	
Total	Early			47	164	23	53.2**	797	760	154	1,652.8**
	Middle			7	139	35		261	836	474	
	Late			1	43	23		139	294	1,052	

Returns of 3-year-old coho salmon also overlapped in return times; a mean of 46.6, 53.2, and 70.8% of progeny from early-, middle-, and late-returning parents returned in the early, middle, and late return windows, respectively. The G-test results indicated a highly significant association between progeny groups of differing return time origins and adult return times for each year of release and when all years were combined. When adult returns were examined by brood year (all returns from same release), 33.0, 55.7, and 69.3% of progeny returned to the early, middle, and late time window of origin, respectively.

The relative contribution of each tagged group to the Columbia River gill-net harvest was similar among groups for the 1999 release but substantially lower in the late group for the 2000 and 2001 releases (Table 3). The harvest rate in the gill-net fishery of the 2000 release late group was only 8.1%, compared with a mean of 27.2% for the early and middle groups. For the 2001 release, the harvest rate in the gill-net fishery for the late group was 17.5%, compared with a mean of 38.4% for the early and middle groups. However, because it is not known how harvest may have differentially impacted fish destined to become early-, middle-, and late-returning fish within these groups, there is no way to properly adjust the within-group return time distributions for harvest.

TABLE 3.—Percentage of Cowlitz Salmon Hatchery coho salmon (catch plus escapement) harvested in the late-fall gill-net fishery in the main-stem lower Columbia River by release year. Early, middle, and late groups were progeny of broodstock entering the hatchery from August to mid-October (early), from mid-October through November (middle), and from December and after (late). Data were obtained from the Pacific States Marine Fisheries Commission regional mark information system database.

Group	Release year: 1999[a]	2000[b]	2001[c]	Mean
Early	36.9	27.2	37.0	29.8
Middle	28.4	27.1	39.7	29.2
Late	35.8	8.1	17.5	16.6

[a] Commercial season: 21 d (September 18–November 1).
[b] Commercial season: 33 d (September 17–October 31).
[c] Commercial season: 21 d (September 16–October 31).

Discussion

When the Cowlitz Salmon Hatchery began operation and the three coho salmon broodstock collection time windows were established, return timing was assumed to have a high heritability. The broodstock conservation plan implemented at that time appears to have been mostly successful in preserving coho salmon return timing, which was fortuitous since efforts to reestablish anadromous runs above the dams on the river were initiated in the late 1990s. However, the posthatchery mean and median return times were delayed about 2 weeks and the contribution of early- and late-returning fish greatly diminished. October–November adult salmon returns increased from 46% to 81% after the hatchery began operation, and the change was probably due to the increased hatchery production of juvenile fish from middle-timed broodstock. Likewise, the decrease in early- and late-returning fish was due to the relatively diminished production of hatchery fish from those time periods. Although our tagging study was not designed to estimate the heritability of return timing, the fact that an overall average of 57% of 3-year-old coho salmon returned in the same time period that their parents were collected suggests a substantial genetic determination of this trait. However, with progeny from each of the three parental time groups returning at relatively high rates in the two time periods different from parental origin, perhaps much of the early and late return-timed fish could have been maintained by only collecting broodstock in the middle return window, although such a strategy would ignore other possibly important heritable traits.

Because the commercial fishery consistently operated in the lower Columbia River from mid-September to early November from the 1960s through 2002 (Joint Columbia River Management Staff 2003), that fishery probably had little long-term influence on changes in the distribution of coho salmon return time to the Cowlitz Salmon Hatchery. However, the harvest rates of the late group for the 2000 and 2001 releases were substantially less than those of the early and middle groups in the same years. We do not know the correlation between Columbia River entry time and entry time to the Cowlitz Salmon Hatchery, but conceivably, the return rate distribution could have favored the late group returning in the late time window for the 2000 and 2001 releases. A total of 86.4% and 64.3% of the late group returned to the hatchery in the late time window for the 2000 and 2001 releases, respectively, compared with only 26.6% of the late group for the 1999 release.

Many WDFW hatcheries have only one pond to hold broodstock. Unless fish are tagged on entry, having only one pond constrains broodstock management to be based on spawn timing, not adult return timing, due to the uncertainty of when individual fish volitionally entered the pond. Further, spawn timing may not correlate to arrival time so using spawn timing to represent broodstock return timing could result in undesired representation. To adequately maintain run timing, several segregated adult holding areas are needed at hatcheries, requiring either additional ponds to be constructed or, if sufficiently large, subdividing an existing pond.

We believe that improved Cowlitz River broodstock return time representation and biological diversity would be attained by accumulating broodstock and basing hatchery production on an apportioned monthly basis, mimicking the historical return timing identified by Thompson and Rothfus (1969). The ongoing efforts to reestablish naturally reproducing populations of coho salmon above the Cowlitz River dams by trucking adults that are excess to hatchery needs upstream could also benefit since historical return time was undoubtedly influenced by varying selection regimes throughout the basin (Flagg et al. 1995). Brannon et al. (2002) state that rather than simply attempting to preserve salmon populations, the challenge is to provide opportunities to expand their range to new or restored habitat that can accommodate genetic adaptation as directional environmental changes are elaborated. Further, artificial propagation must emphasize the ability for anadromous salmonids to respond to change by assuring that the genetic diversity to facilitate such responses is present.

In summary, we found that posthatchery mean and median coho salmon adult return times were delayed about 2 weeks compared with prehatchery conditions, that returns of early- and late-returning fish were greatly diminished, that most 3-year-old adult fish returned in the return time window of origin, and that many of the early- and late-origin fish returned in the middle time period. We recommend that variability in run timing or other natural life history traits be maintained at historically proportional rates if hatchery fish are allowed to spawn naturally or are being conserved to someday reestablish natural spawning populations, which will, in turn, require periodic monitoring.

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