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A Comparison of Run Timing, Spawn Timing and Spawning Distribution of Natural and Hatchery Spring Chinook Salmon *Oncorhynchus tshawytscha* in the Imnaha River, Oregon

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A Comparison of Run Timing, Spawn Timing and Spawning Distribution of Natural and Hatchery Spring Chinook Salmon *Oncorhynchus tshawytscha* in the Imnaha River, Oregon

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Abstract

We compared fourteen years (1990-2003) of weir collection and spawning ground survey data to examine differences in run timing, spawning distribution and spawn timing between adult natural and hatchery-reared Chinook salmon *Oncorhynchus tshawytscha* in the Imnaha River, Oregon. We compared run timing using arrival time at the weir and found that natural salmon arrived earlier than hatchery salmon in 12 of 14 years. Natural carcasses, of either or both sexes, were recovered earlier than hatchery carcasses for all years combined and during 6 of 14 years, indicating earlier spawning by natural salmon. We compared spawning distribution using the percent of female carcasses recovered in each spawning ground survey reach. A greater percent of natural female carcasses were recovered in reaches above the weir and further upstream than carcasses of hatchery-reared females, which were more commonly found in reaches closer to and below the weir. Management strategies designed to maintain the genetic integrity and life history characteristics of the Imnaha River Chinook salmon should be considered, implemented and evaluated. Collected broodstock should mimic the wild run and spawn timing. Release strategies should be developed to promote a broader spatial spawning distribution of returning hatchery adults.

Introduction

Due to a precipitous decline in the Imnaha River spring/summer Chinook salmon *Oncorhynchus tshawytscha* spawning population, a hatchery mitigation program was initiated in 1982 (Carmichael et al 1998) with an annual mitigation goal of 3,210 returning adults (Herrig 1998). Numbers of natural adults continued to decline and the National Marine Fisheries Service listed the Imnaha River Chinook salmon population as threatened in 1992 (Federal Register, volume 57, number 78). Until hatchery returns could be established, from 1982-1984, the program used only wild Imnaha River salmon for broodstock. The first hatchery-reared adults returned in 1985 and all age classes of hatchery-reared adults were present in 1987 (Figure 1). Since 1985, both hatchery and natural salmon have been used as broodstock in an effort to reduce genetic divergence between hatchery and natural salmon while attempting to increase the number of returning adults (Carmichael and Messmer 1995).

Since its inception in 1982, the Imnaha River Chinook salmon hatchery program has been managed under the guidance of four management objectives: "1) restore natural populations of chinook salmon in the Imnaha River basin to historic abundance levels; 2) reestablish traditional tribal and recreational fisheries for chinook salmon; 3) maintain genetic and life history characteristics of the endemic wild population while pursuing mitigation goals and management objectives; and 4) operate the hatchery program to ensure that the genetic and life history characteristics of the hatchery fish mimic the wild fish" (Carmichael and Messmer 1995). However, the focus of the program has shifted, since its inception, from that of mitigation and hatchery production, as mandated by the Lower Snake River Compensation Plan (LSRCP), to enhancing and supplementing natural production as the Oregon Department of Fish and Wildlife (ODFW) implemented the LSRCP program (Carmichael and Messmer 1995). Accordingly, management protocols for the program have shifted and now vary, depending on projected returns. We now restrict the percent of natural salmon retained for broodstock to 30-50% of the natural returns, the percent of hatchery salmon released above the weir to spawn naturally to 50-70% of the total released above the weir and the percent of the broodstock comprised of natural salmon to 20-30%. In addition, the co-management agencies (ODFW, Nez Perce Tribe, NOAA Fisheries, U.S. Fish and Wildlife Service) have decided that no more than 10% of the total males released above the weir may be hatchery origin jacks and no more than 10% of eggs used in the hatchery program may be fertilized with milt from hatchery origin jacks (ODFW 1998).

Each year a portion of the spawning run is collected at the weir and transferred to Lookingglass Fish Hatchery, in the nearby Grande Ronde Basin, for holding and spawning of adults and rearing of offspring. To accomplish our management objectives, the weir must be installed as early as possible each year in order to "ensure all components of the run are represented in the broodstock" (Carmichael and Messmer 1995). Collecting hatchery broodstock that are representative of the wild population is complicated by two factors. First, spawning occurs both upstream and downstream from the weir so not all salmon will migrate to the weir to be trapped. Second, due to high river discharge, the weir is normally installed in July, which is after a portion of the run has passed upstream of the weir site.

The period of weir operation varies annually. Weir installation and management is based on environmental, mechanical and safety considerations and it can be installed only after river discharge has dropped to approximately 28 m^3/s, to allow personnel to safely access the river and minimize the threat of debris destroying the weir (Bob Lund, ODFW, personal communication). Once installed, the weir is very efficient but the estimated percent of the run captured during

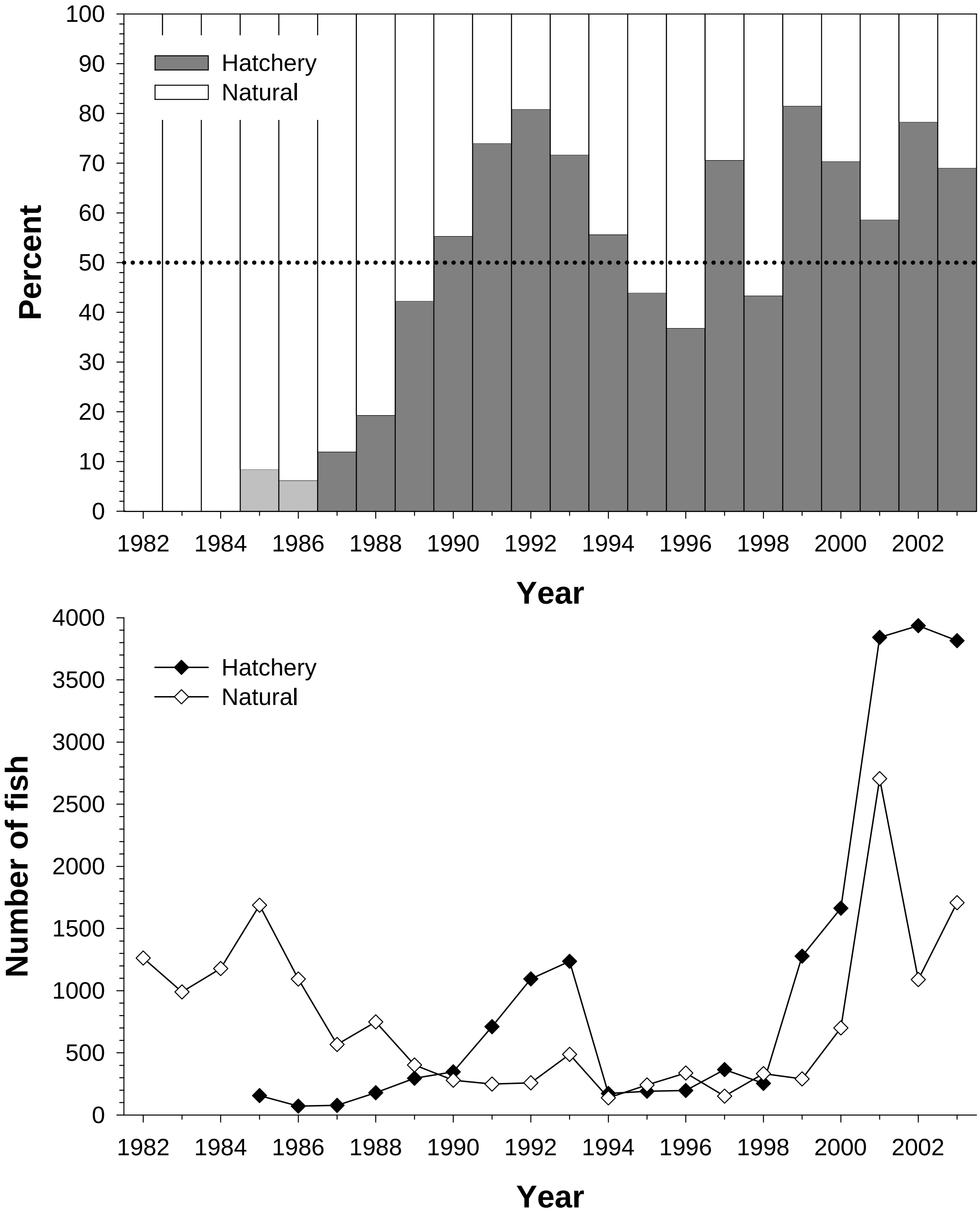

Figure 1. Percent (top) and total number (bottom) of hatchery and natural Chinook salmon that returned to the Imnaha River, 1982-2003. Note: 1987 was the first year that full cohorts of hatchery salmon returned to the river. In 1985 and 1986 (light gray bars) only age 3 and ages 3 and 4 hatchery salmon, respectively, returned to the river.

Table 1. Beginning and ending week and duration of Chinook salmon collections at the Imnaha River weir, capture efficiency and broodstock collections and spawning, 1982-2003. Weir removal date was not recorded for 1982. We retained some captured adults for broodstock, outplanting into tributary streams, control of hatchery:wild ratio for spawning in nature above the weir and control of hatchery jacks spawning in nature.

	Week		Duration	Estimated percent of run captured		Percent captured	Percent spawned	
Year	Start	End	(weeks)	To river	To weir	that were retained	Hatchery	Natural
1982	34			2.3		100	0	100
1983	31	35	5	6.9		100	0	100
1984	32	36	5	3.2		100	0	100
1985	28	37	10	8.9	12.6	78.2	3.3	96.7
1986	24	37	14	28.8	38.1	100	2.3	97.7
1987	25	37	13	29.0	37.9	56.1	12.7	87.3
1988	24	38	15	47.6	56.6	47.1	17.8	82.2
1989	25	37	13	64.0	97.0	65.5	38.1	61.9
1990	28	38	11	65.4	75.1	58.5	56.8	43.2
1991	28	37	10	52.7	84.7	62	48.7	51.3
1992	24	36	13	62.4	92.8	45.6	82.5	17.5
1993	27	37	11	72.2	90.8	36.3	66.0	34.0
1994	26	37	12	52.4	92.6	31.3	65.1	34.9
1995	31	35	5	15.7	27.2	100	41.0	59.0
1996	30	36	7	42.8	66.0	58.1	28.6	71.4
1997	27	36	10	55.7	65.6	59.7	87.4	12.6
1998	28	36	9	45.2	63.4	50.6	47.8	52.2
1999	30	36	7	25.3	36.3	69.7	91.7	8.3
2000	27	37	11	46.9	58.0	58.9	85.2	14.8
2001	23	38	16	53.5	80.4	24.6	66.3	33.7
2002	28	36	9	23.9	31.2	43.2	86.2	13.8
2003	28	36	9	23.6	31.3	57.1	83.1	16.9
Mean	27.6 ~4 JUL	36.6 ~5 SEP	10.2	37.7	59.9	63.8	45.9	54.1

each spawning run varies, based on weir installation date and annual migration timing. From 1982-2003, the weir was installed between weeks 24 and 31 (mean=27.6, approximately 4 July) and continued to collect salmon until weeks 35-38 (mean=36.6, approximately 5 September), a mean duration of 10.2 weeks (Table 1). Therefore, due to the timing of weir installation, coupled with approximately 28% of the salmon spawning naturally below the weir, we estimate that we captured a mean of 37.7% of the total salmon returning to the river each year from 1982-2003 and 59.9% of those passing the weir site from 1985-2003. Since 1982 we have retained a mean of 63.8% of the captured run, which were used for broodstock, outplanting into tributary streams, control of hatchery:wild ratio for spawning in nature above the weir and control of hatchery jacks spawning in nature. A mean of 45.9% of those spawned have been hatchery salmon and 54.1% natural. Random-split cross mating is used to increase the number of family groups (Carmichael and Messmer 1995) and the resulting progeny are reared to smolt at age 2 and a mean target weight of 23 g. At that time, smolts are transported to the acclimation site, located at the weir, for 30 to 60 days of acclimation prior to release.

Genetic control over timing of upstream migration and spawning has been established for many salmonid species (Siitonen and Gall 1989). Several hatchery programs have been established using non-endemic stocks that spawn earlier or later than the endemic stocks in order to minimize interactions between hatchery and wild populations. In Forks Creek, Washington, hatchery steelhead *O. mykiss* from Puget Sound were selectively bred for early run timing, allowing managers to keep stocks genetically separate with a high level of success (Mackey et al 2001). The Imnaha River supplementation program uses the endemic Chinook salmon stock and one of its goals is to limit the potential negative impacts of the hatchery program on the existing wild population. To accomplish this goal, hatchery salmon should mimic the characteristics of the wild population in every way. We seek to achieve this by encouraging breeding between hatchery and natural salmon. Conversely, the goal of the Forks Creek Hatchery program was to enhance fisheries while minimizing interactions between wild and non-endemic hatchery steelhead by selecting only early returning salmon for hatchery broodstock. Overlap in spawn timing and spatial distribution encourages genetic and ecological interactions (Mackey et al 2001) and, with proper broodstock selection, genetic integrity can be maintained (Olson et al 1995). Due to restrictions on weir operation and failure to collect broodstock from across the entire run, we could cause a divergence between wild and hatchery-reared salmon and/or a shift of some life history characteristics in the Imnaha River Chinook salmon population, which would be counter to program goals.

Carmichael and Messmer (1995) cited the influence of the hatchery program on life history and genetic characteristics as an uncertainty of the Imnaha River supplementation program. Herein, we examine the affect of the Imnaha River hatchery program on run timing, spawn timing and spawning distribution of hatchery Chinook salmon, in comparison to natural salmon, in the Imnaha River to determine whether we are achieving the goal of producing hatchery salmon with characteristics of wild Imnaha River Chinook salmon.

Study Area

The Imnaha River is a tributary of the Snake River at river kilometer (RK) 309 in northeast Oregon (Figure 2). The study area was divided into nine reaches, for survey logistics, which vary in length and quantity of available spawning habitat: four reaches extend 25.6 km upstream of the weir, located at RK 74, and five reaches extend 25.1 km below the weir. A 6 km reach below the weir (RK 58.7-64.7) was not surveyed because we could not access the private property. This unsurveyed reach has steep gradient, except in the very uppermost part, so little spawning normally occurs in this reach (B. Knox, ODFW, personal communication). Also, there is evidence of spawning as far as 29 km upstream from the weir, at least in some years. However, due to inconsistent survey efforts, particularly in early years, this reach was not included in our study.

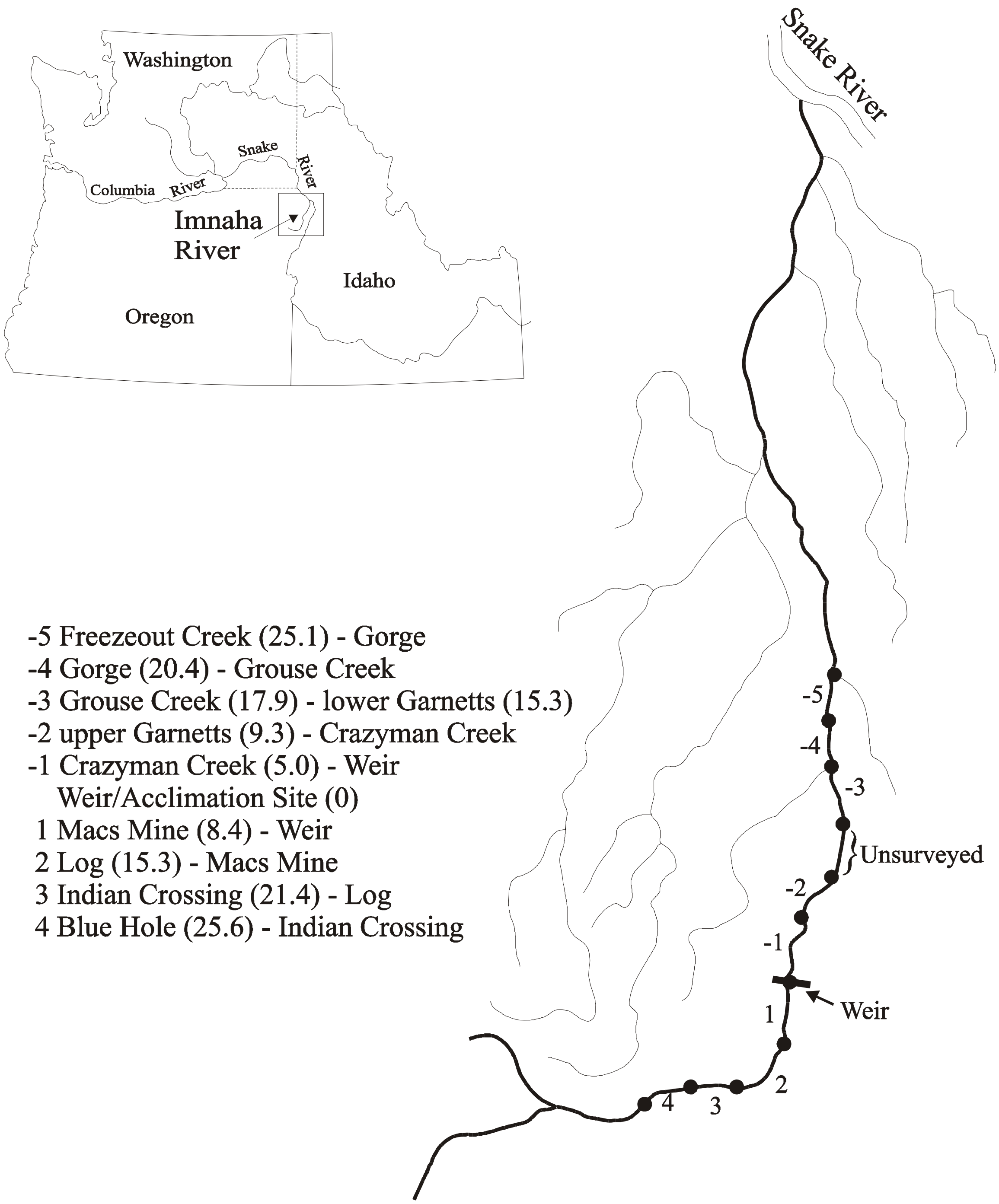

Figure 2. Imnaha River, Oregon, with study reaches and boundaries (boundary locations are designated as river kilometers above or below the weir/acclimation site).

Methods

We used data from 1990-2003 for these analyses. Prior to 1990, data collection was not sufficiently complete to be used for these analyses. Date, sex and origin (hatchery or natural, based on fin clips or other marks) are recorded for each adult captured at the weir. Adults released above the weir are marked with an opercle punch. Each year, weekly spawning ground surveys are conducted over three weeks to estimate redd and adult salmon numbers. Surveys are conducted at the mean time of peak spawning and when few salmon remain alive during the last survey. Location (reach) of recovery, length and sex are recorded for each carcass and they are examined for marks indicating origin and prior capture at the weir. We used weir collection and spawning ground survey data to compare run timing, spawn timing and spawning distribution between hatchery and natural salmon (α=0.05).

Run Timing

Run timing was determined by the number of salmon (both sexes) arriving at the weir during each week of weir operation from 1990-2003 and was analyzed using a Kolmogorov-Smirnov (K-S) test (Sokal and Rohlf 1981). We also visually compared median and mode of the weekly number of salmon captured at the weir during each year. We know that a substantial, but variable, portion of the run passes the weir site each year before the weir can be installed, which may affect our comparison of run timing. Therefore, to examine the number of hatchery vs. natural salmon that passed the weir site prior to weir installation, we compared the numbers of hatchery and natural adults captured at the weir in each year with the numbers of unpunched (i.e., salmon that passed the weir site prior to weir installation) hatchery and natural carcasses recovered on spawning ground surveys using a chi-square test (Sokal and Rohlf 1981). If run timing did not vary between hatchery and natural salmon, then the hatchery:natural ratio should be similar between adults captured at the weir and unpunched carcasses recovered on spawning ground surveys.

Spawn Timing

Spawn timing was determined by recovery date (survey number) of all carcasses on spawning ground surveys from 1991-1993 and 1997-2003, omitting data from prior to 1991 and 1994-1996 due to low sample sizes in one or both groups. We compared the number of carcasses found on each survey for all years combined and in each year using a G-test (Sokal and Rohlf 1981). We also visually compared median and mode of the number of carcasses collected during each survey week. Additionally, since we know that spawning occurs earlier in upstream reaches due to earlier cooling of water temperature, we also compared spawn timing within specific reaches and for each year within a specific reach.

Spawning Distribution

Spawning distribution was determined by recovery location of female carcasses, only. Because males do not guard the redd post spawn, their recovery location may be less definitive of spawning location than that of females. We compared spawning distribution using data from 1991-1994 and 1997-2003 (1995-1996 data were omitted due to extremely low samples sizes and specific recovery location was not recorded prior to 1991). These data were analyzed by a K-S test (Sokal and Rohlf 1981) of the number of hatchery vs. natural female carcasses collected in each survey reach for all years combined and during each year. We also visually compared median and mode of the number of salmon collected in the reaches during each spawning season.

Additionally, we examined whether the weir affected salmon spawning distribution by hindering access to upstream reaches. No spawning ground data were available prior to weir installation, so we used two different regressions to examine for relationships that should be present if there is a ‘weir effect’. First, if some salmon are blocked, there will be increasing spawning below the weir, not only by the blocked salmon but also by their offspring, which would home to those sites (Quinn et al 1999). So, we examined whether the percent of the salmon spawning below the weir was increasing over time. Second, if there is a ‘weir effect,’ in those years in which the weir is installed earlier, a higher percent of the salmon should be spawning below the weir, as more of the run would have been affected by the weir. Here, we looked for a relationship between time of weir installation (week of the year) and percent of the total run spawning below the weir.

Results

Run Timing

For 12 of the 14 years studied (1990-2003), hatchery Chinook salmon arrived at the weir site later than natural salmon. Except when a total of only 5 and 28 unpunched carcasses were recovered, 1994 and 1998 respectively, the percent of the unpunched carcasses comprised of hatchery salmon was less than ($P<0.05$) the percent of hatchery adults captured at the weir (Table 2; Figure 3). The relationship for natural salmon was the opposite of that for hatchery salmon.

Weir collection data also show that run timing varied ($P<0.01$) between hatchery and natural salmon for 5 of the 14 years examined. During 1991, 1992, 2001 and 2003, natural Chinook salmon were captured at the weir earlier than hatchery salmon (Figure 4). In 1996, hatchery salmon comprised a greater percent of early collections than natural salmon. However, in 1995 and 1996 the weir was not installed until weeks 31 and 30 (late July and early August), respectively, and it is likely that the majority of the natural run had already passed the weir site by that time, as demonstrated by the spawning ground survey recoveries reported above. Natural females arrived at the weir earlier than hatchery females in 2001 and hatchery males arrived earlier than natural males in 2001 and 2003 ($P<0.01$). Median time of arrival to the weir was earlier for natural salmon in 1990, 1991, 1992, 2000 and 2001 but earlier for hatchery salmon in 1995 and 1999. Peak (mode) time of arrival to the weir was earlier for natural salmon in 1991 and 2000 and for hatchery salmon in 1995, when the weir was installed late.

Spawn Timing

For the pooled years of 1990-2003, the percent of carcasses recovered on each of the three surveys varied ($P<0.001$) between hatchery and natural salmon for females, males and total recoveries (Figure 5). A greater mean percent of the total natural carcasses (34.5%) than hatchery carcasses (19.7%) were recovered on the first survey. On the second and third surveys, a greater percent of the total hatchery carcasses were recovered (44.9% and 35.4%, respectively) than natural carcasses (37.6% and 27.9%, respectively). This pattern held for the individual years of 1992, 1993 and 2000 (females and total), 1998 (females), 2001 (males and total) and 2002 - 2003 (females, males and total; Figure 6). On the first survey, the percent of hatchery carcasses recovered never exceeded that of natural salmon.

For all years combined, natural salmon spawned earlier than hatchery salmon in all reaches above the weir ($P<0.05$) but carcass recovery time was similar between groups in

Table 2. Number and percent of natural and hatchery-reared Chinook salmon collected at the weir and as unpunched carcasses on spawning ground surveys in the Imnaha River and chi-square tests comparing proportions of adults captured at the weir vs. the proportions of unpunched carcasses recovered on spawning grounds, 1991-2003.

	Natural				Hatchery					
	Weir collections		Unpunched carcasses		Weir collections		Unpunched carcasses			
Year	N	%	N	%	N	%	N	%	χ^2	P-value
1990	183	44.6	14	63.6	227	55.4	8	36.4	17.3	<0.0001
1991	131	25.9	34	55.7	374	74.1	27	44.3	24.2	<0.0001
1992	162	19.2	107	68.6	682	80.8	49	31.4	179.9	<0.0001
1993	352	28.3	63	81.8	892	71.7	14	18.2	95.4	<0.0001
1994	72	44.2	4	80.0	91	55.8	1	20.0	2.7	0.1003
1995	38	55.9	17	77.3	30	44.1	5	22.7	4.4	0.0359
1996	145	63.3	25	89.3	84	36.7	3	10.7	9.8	0.0017
1997	84	29.2	24	44.4	204	70.8	30	55.6	5.6	0.0180
1998	150	56.6	14	50.0	115	43.4	14	50.0	0.5	0.4795
1999	73	18.4	67	68.4	323	81.6	31	31.6	116.9	<0.0001
2000	329	29.7	98	67.6	780	70.3	47	32.4	88.6	<0.0001
2001	1503	42.9	38	84.4	2003	57.1	7	15.6	33.3	<0.0001
2002	268	22.3	226	53.6	932	77.7	196	46.4	193.8	<0.0001
2003	411	31.5	211	56.4	893	68.5	163	43.6	98.4	<0.0001

reaches below the weir (P≥0.05; Figure 7). Within years, there were no differences in time of carcass recovery in any reach until 1999. In the Blue Hole to Indian Crossing reach, natural carcasses were recovered earlier in 1999, 2002 and 2003. From Indian Crossing to Log, natural carcasses were recovered earlier in 2002 and 2003. From Log to Macs Mine, natural carcasses were recovered earlier in 2000-2002. There were no differences for any specific year (P≥ 0.05) in time of carcass recovery in the Macs Mine to Weir reach. Below the weir, natural carcasses were recovered earlier than hatchery carcasses in 2001-2002 in the Weir to Crazyman reach and in 2000 from Crazyman to Garnetts. There were no years with differences in the Garnetts to Grouse Creek reach but little spawning occurs there.

Spawning Distribution

No index of carcass location ever indicated mean female carcass location to be further upstream for hatchery than natural carcasses. For the combined years of 1991-2003 (omitting 1995-1996), a greater mean percent (P<0.0001) of natural female carcasses were recovered further upstream and hatchery female carcasses were more commonly recovered closer to the weir/acclimation site and downstream from it (Figure 8). This pattern held for the individual

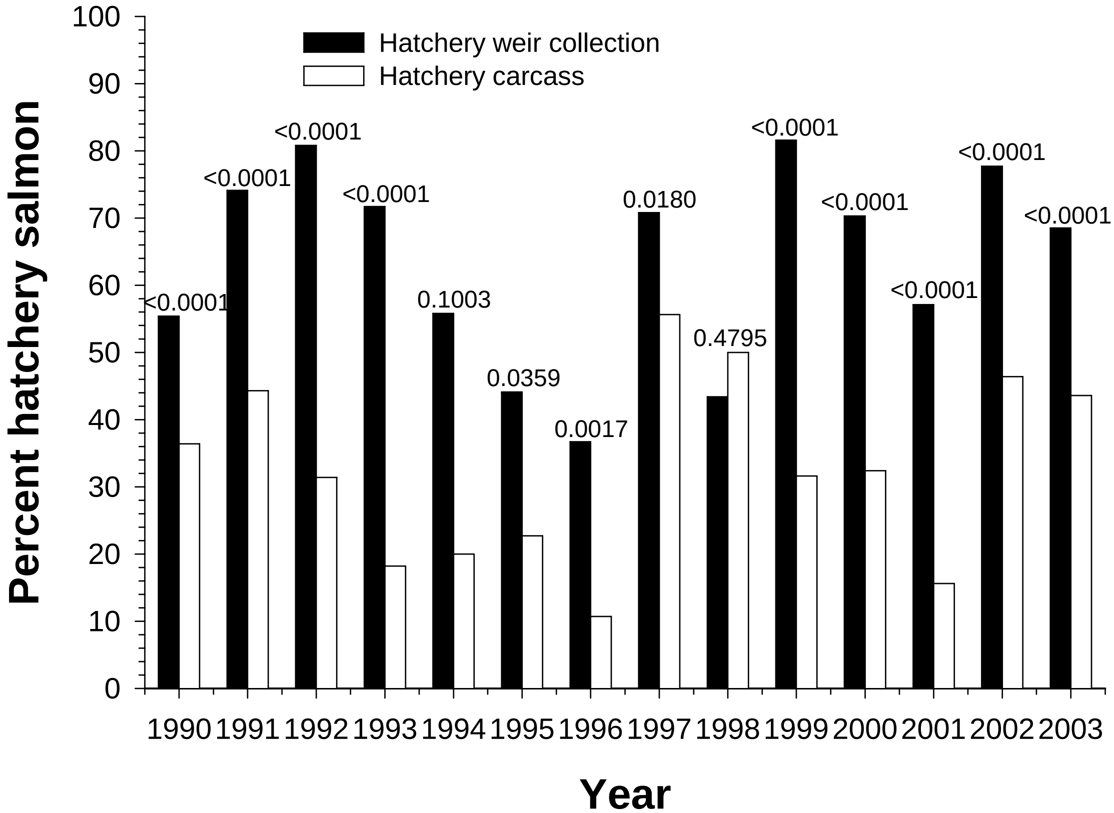

Figure 3. Percentage of hatchery Chinook salmon recovered as carcasses on spawning ground surveys (passed the weir before weir installation) and captured at the weir on the Imnaha River, 1991-2003. Percentage of natural salmon = 100 - hatchery percentage. P-values for annual comparison of percent of weir collection vs. carcass recovery are above the bars.

years of 1993 ($P<0.05$), 2000 and 2001 ($P<0.001$). Median carcass recovery location was also further upstream for natural females than for hatchery females for the pooled data and in 1991, 1993, 2000 and 2001. Modal carcass location was further upstream for natural females than for hatchery females in 1993 and 1999-2001.

We found no evidence that the weir affected spawning distribution (Figure 9). There was no trend in the percent of salmon spawning below the weir from 1985-2003 ($P=0.8901$) nor was there a relationship between the time of weir installation and the percent of salmon spawning below the weir ($P=0.3455$).

Discussion

Hatchery-reared Chinook salmon tended to return to the Imnaha River later and spawn later and further downstream than natural Chinook salmon. These differences are most evident in recent years, indicating an ongoing shift in these parameters, which is counter to the goals of the Imnaha River supplementation program.

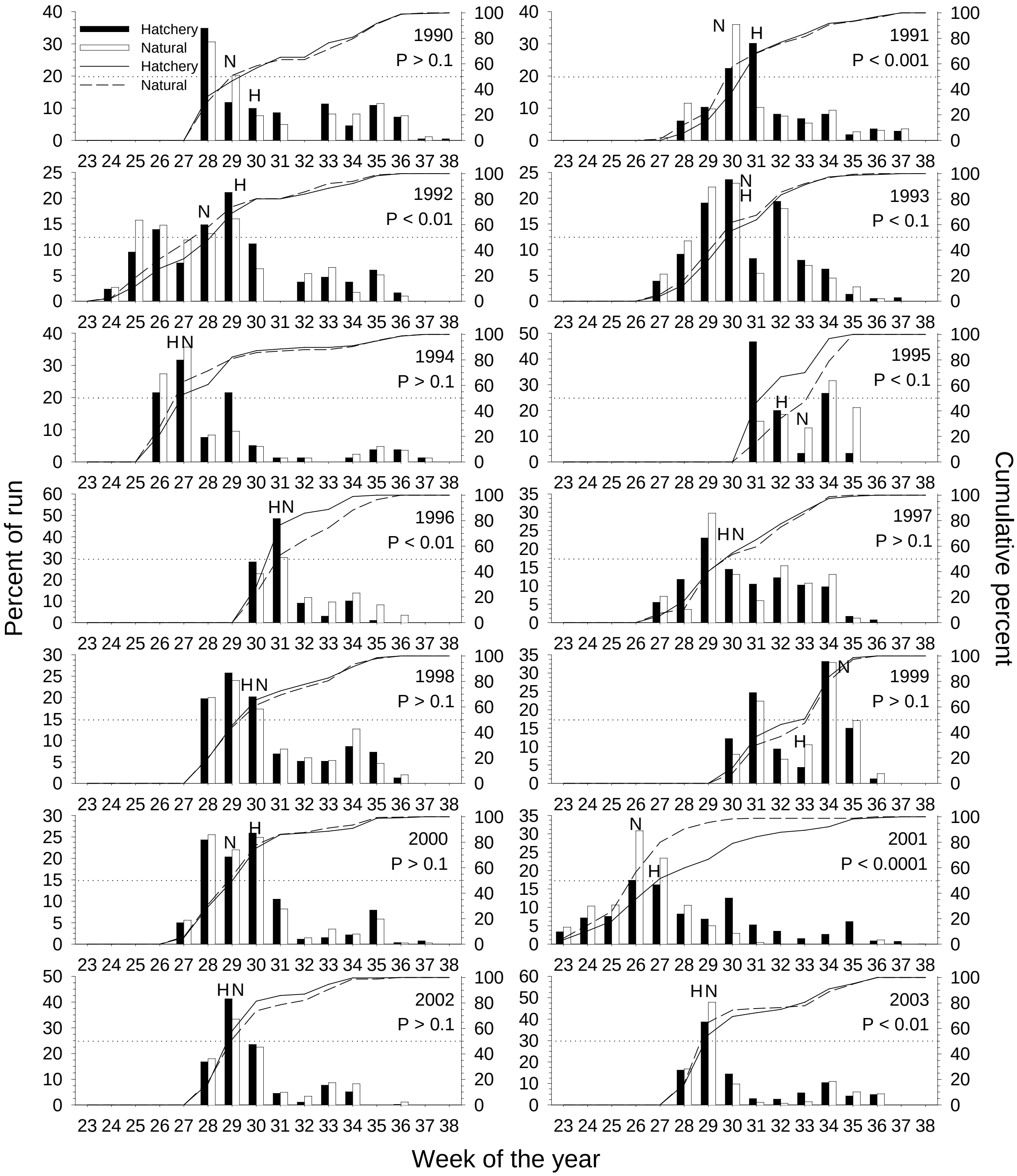

Figure 4. Percent and cumulative percent of the run arriving at the Imnaha River weir during each week of the year that the trap was in operation, 1990-2003. Note: dotted line indicates 50% (cumulative) and letters represent median week of arrival for hatchery (H) and natural (N) fish.

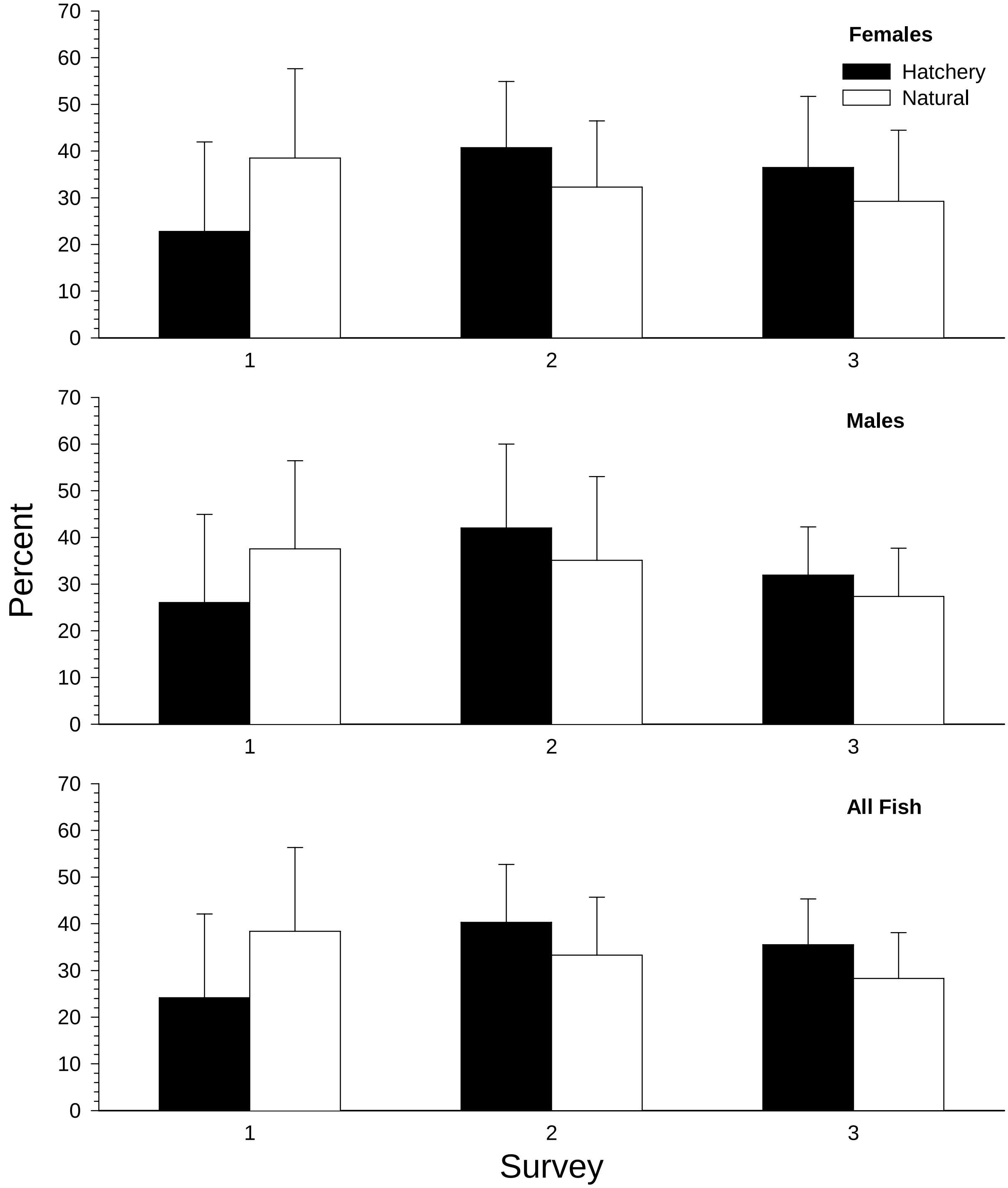

Figure 5. Mean (±1 SD) percent of female, male and total Chinook salmon carcasses recovered on the first, second and third spawning ground surveys conducted each year in the Imnaha River, 1991-2003 (excluding 1994-1996 due to low sample size).

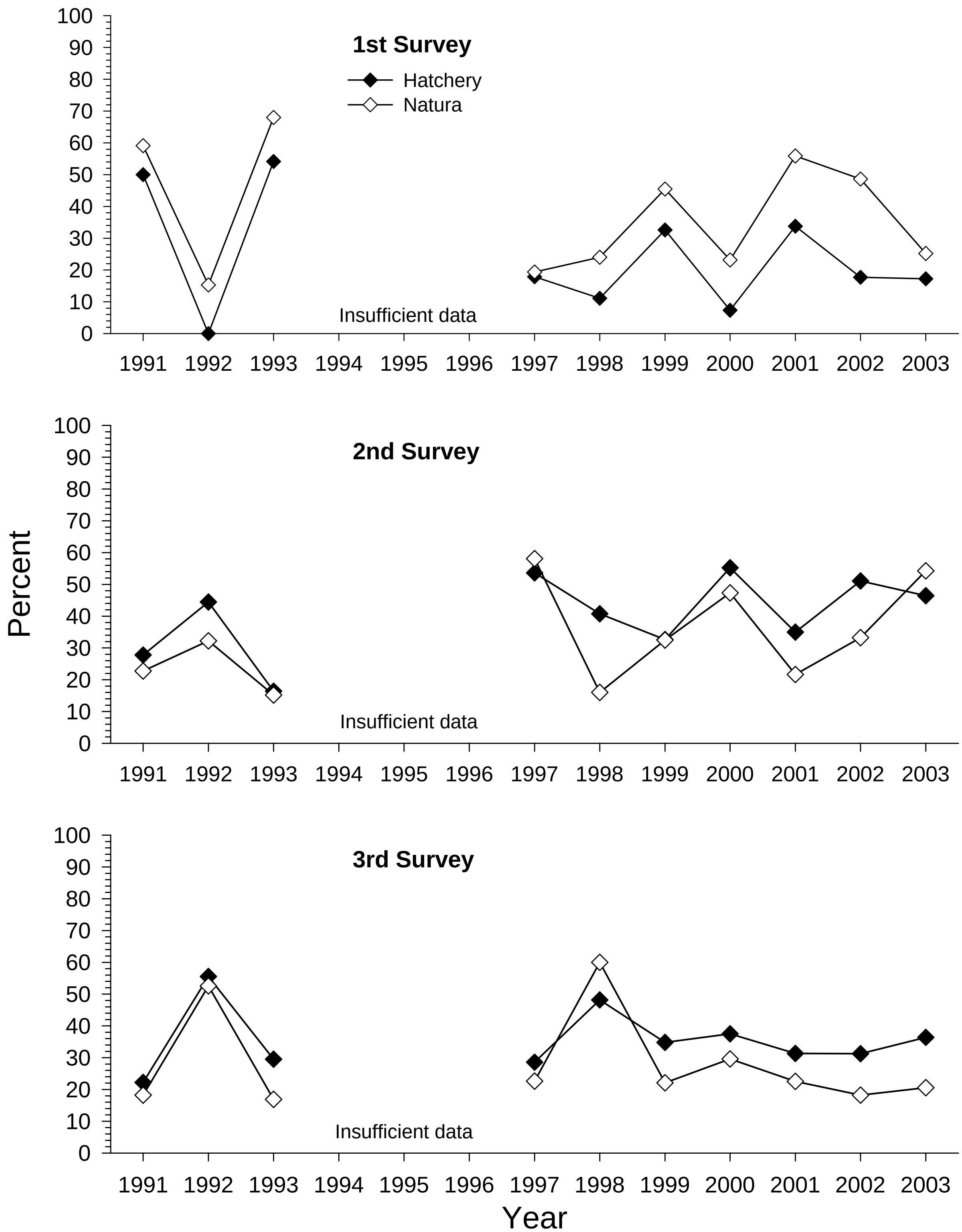

Figure 6. Percent of total hatchery and natural Chinook salmon carcasses recovered each year during the first, second and third spawning ground surveys on the Imnaha River, 1991-2003.

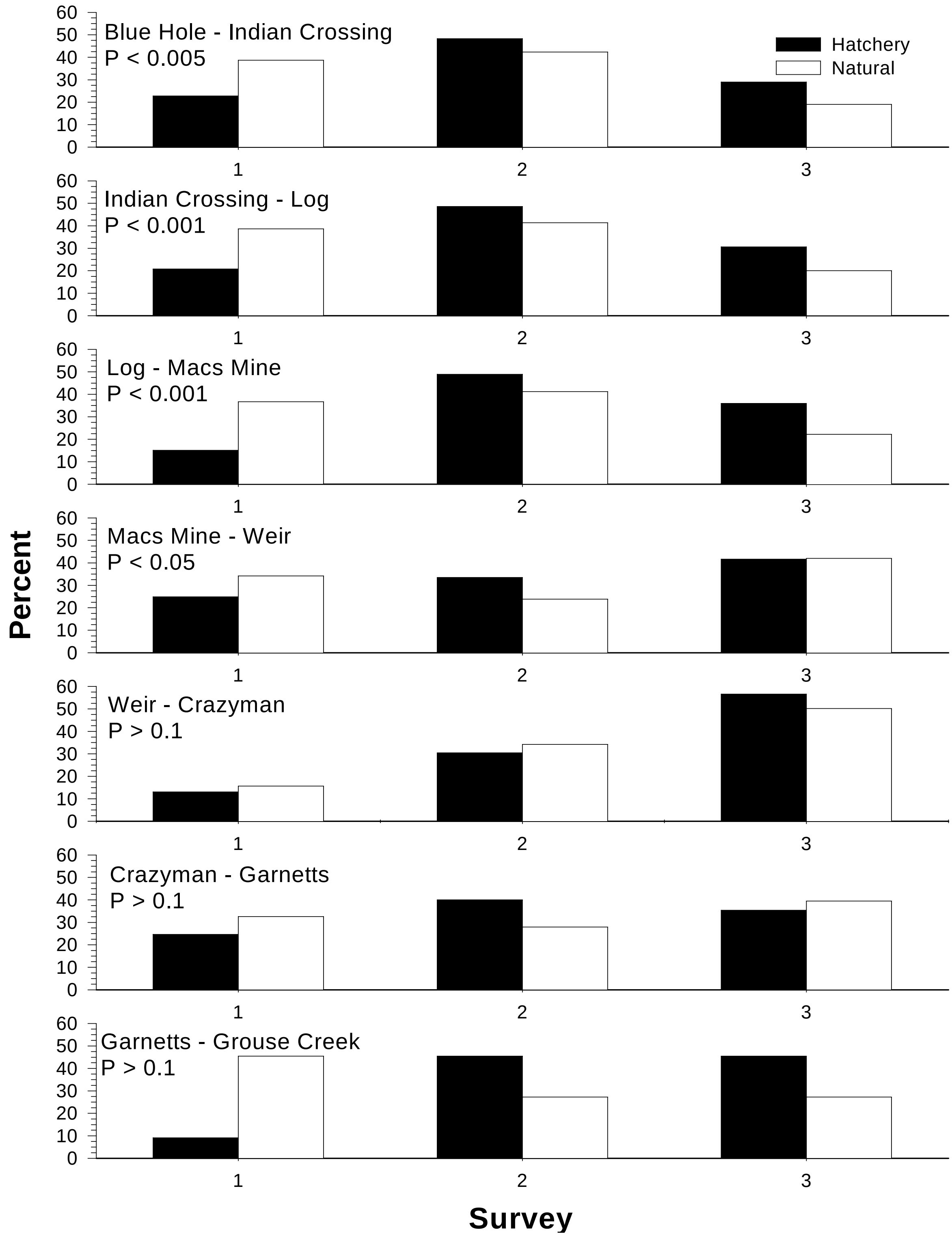

Figure 7. Mean percent of total hatchery and natural Chinook salmon carcasses recovered in each reach and during each spawning ground survey on the Imnaha River, 1993-2003. Reaches are arranged in order from furthest upstream (Blue Hole – Indian Crossing) to furthest downstream (Garnetts – Grouse Creek).

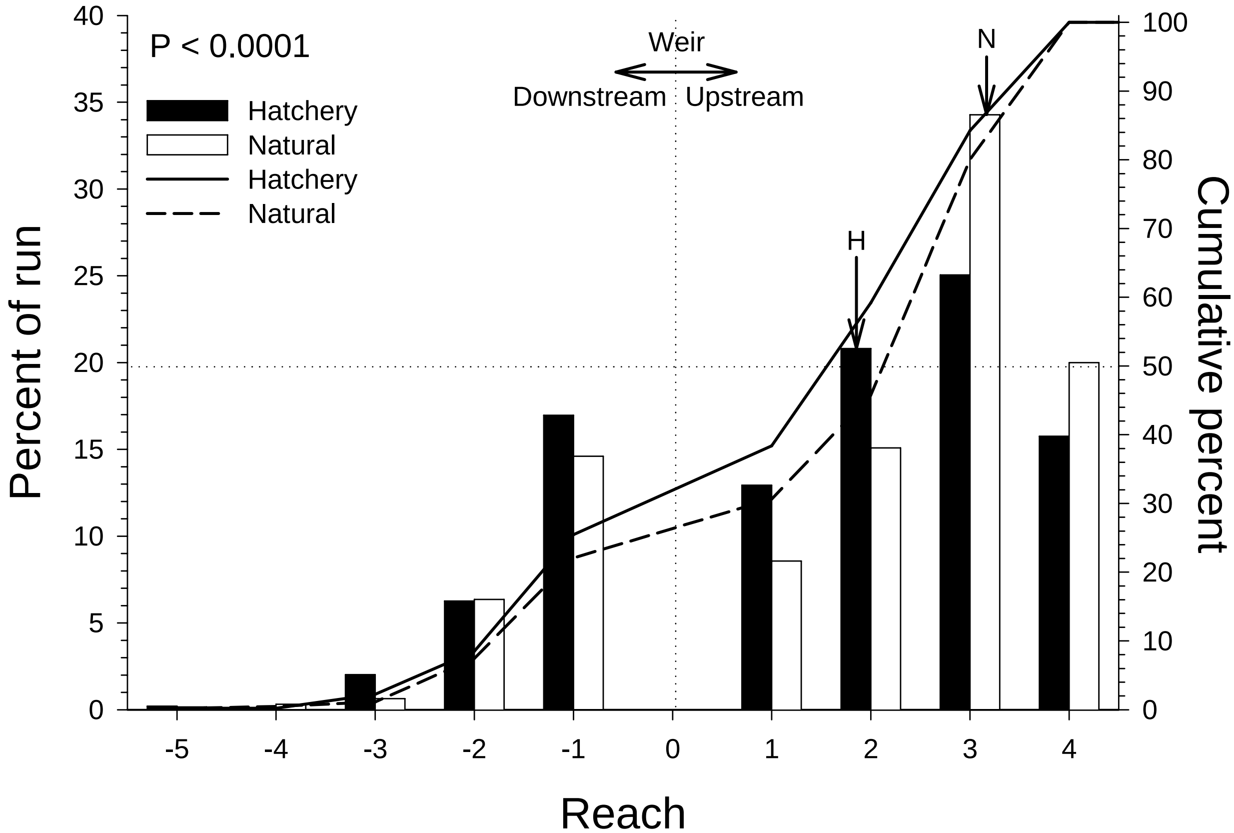

Figure 8. Percent and cumulative percent of female Chinook salmon carcasses recovered in each of the nine reaches of the Imnaha River, pooled data from 1991-1994 and 1997-2003. Note: horizontal dotted line indicates 50% (cumulative; right Y axis) recovery and vertical arrows indicate median for hatchery (H) and natural (N) salmon.

Run Timing

From 1990-2003, with the exceptions of 1994 and 1998 (in which sample sizes were low), natural salmon arrived at the weir earlier than hatchery salmon. Timing of upstream migration and spawning is genetically controlled in Chinook salmon (Quinn et al 2002) and many other salmonids (Siitonen and Gall 1989; Hansen and Jonsson 1991; Smoker et al 1998). These differences in run timing contribute substantially to the apparent population structure in the Columbia River Basin (Robards and Quinn, 2002) and "migration timing seems to reflect natural selection imposed by conditions affecting passage and survival of adults" (Mackey et al 2001). Therefore, run timing may shift over time, depending on the reproductive success of adults, due to intentional or unintentional artificial selection of hatchery broodstock. In Washington, an intentional program of selection of run and spawn timing to discourage hybridization between wild and introduced hatchery steelhead has resulted in a much earlier return of hatchery than wild steelhead (Mackey et al 2001). Similar to the Imnaha river, run timing of hatchery Chinook salmon in the Warm Springs River, Oregon, from 1982-1989 was 1-3 weeks later than that of wild salmon (Olson et. al 1995). Warm Springs National Fish Hatchery managers realized that this was due to hatchery broodstock collections which "lagged

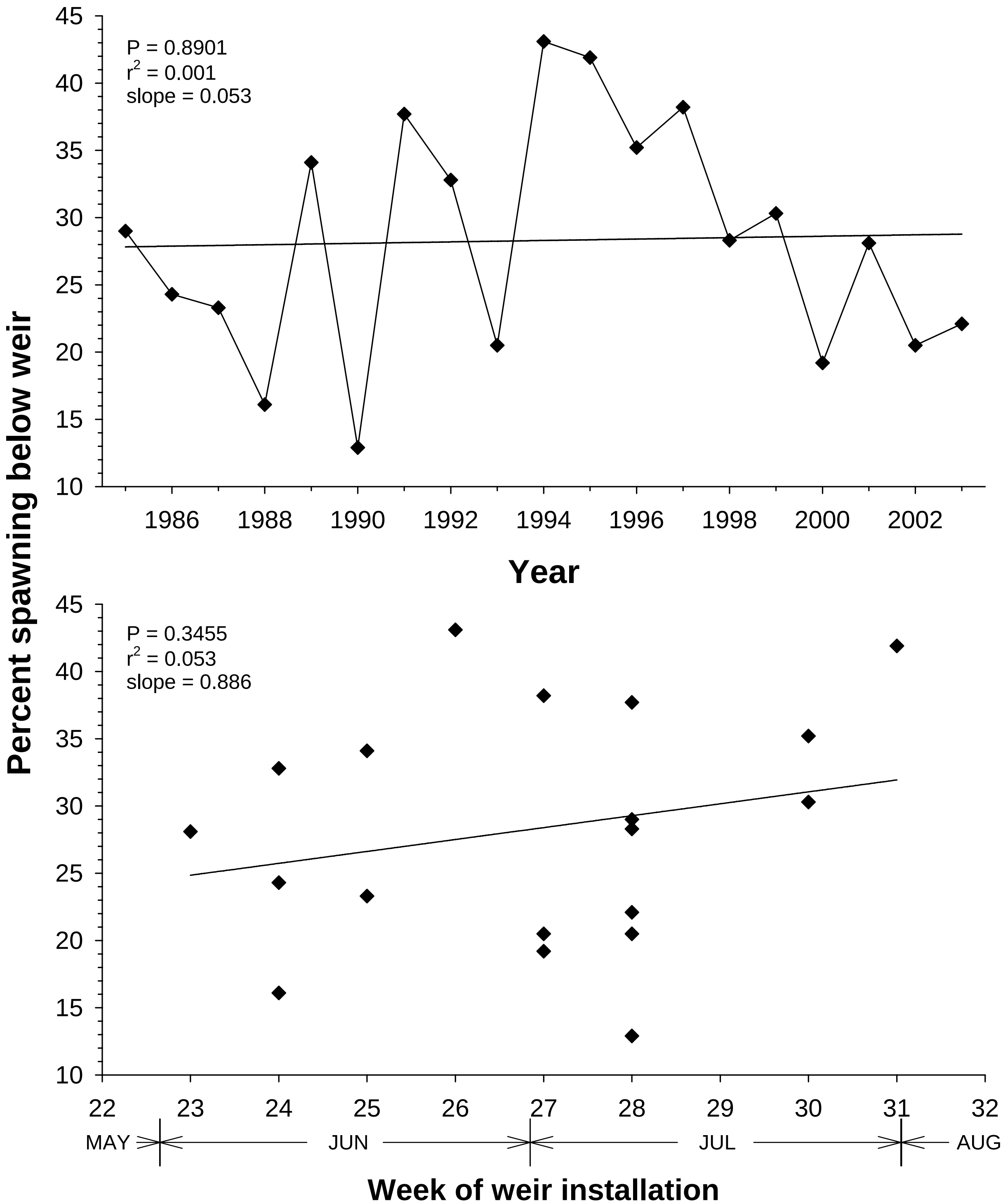

Figure 9. Percent of Chinook salmon spawning below the weir (top) and relationship of week of weir installation vs. percent of Chinook salmon spawning below the weir (bottom) in the Imnaha River, 1985-2003.

behind the proportional return of wild fish" and have modified their broodstock collection practices to counter this effect and the difference in run timing between hatchery and wild salmon has been reduced to 1-2 weeks (Olson et al 2004).

In the Imnaha River, our objective is to encourage breeding between hatchery and natural salmon in order to avoid altering the characteristics of the Imnaha River Chinook salmon population. Here, our inability to install the weir prior to the first salmon arrival, has affected broodstock selection, with the result that hatchery broodstock is regularly collected from the middle to end of the run. This was particularly acute in the early years of the program and during years of high spring discharge when the weir is installed late in the summer and a large portion of the run has already passed the weir site. Carmichael and Messmer (1985) reported that in the 1982-1985 run years, we were collecting the broodstock from the latest part of the run and were "removing this component of the run from the wild population." The resulting broodstock collection creates the potential to skew the hatchery/natural ratio in the hatchery broodstock as well as in the natural spawning population. If the weir could fish over the entire run, this run timing difference could be diminished or eliminated, as is happening in the Warm Springs River (Olson et al 2004). Carmichael and Messmer (1985) recognized the need for a weir that could be operated during periods of high runoff so that the broodstock would reflect the entirety of the natural run timing.

Spawn Timing

Spawn timing of salmon is heritable (Quinn et al 2002) and this is likely an adaptation to the temperature and flow regimes of a particular stream (Lura and Saegrov 1993; Montgomery et al 1999; Stefanik and Sandheinrich 1999). Tipping and Busack (2004) reported that early-, middle- and late-returning coho salmon *O. kisutch* were early-, middle- and late-spawners, respectively. Run timing and spawn timing appear to also be correlated in steelhead (Mackey et al 2001) and sockeye salmon *O. nerka* (Boatright et al 2004). If run and spawn timing are correlated in Chinook salmon, then our broodstock selection practice may also be selecting for late spawn timing. The majority of our hatchery broodstock has consisted of salmon arriving late to the weir and, theoretically, the progeny of this broodstock would also return later and be more likely to spawn with each other rather than with the natural population, exacerbating the situation. However, at Warm Springs National Fish Hatchery, although they found a difference in run timing between hatchery and wild Chinook salmon, they found little change in spawn timing at either the hatchery or in nature (Olson et al 1995). In the Imnaha River, we found natural salmon spawning earlier in nature. We do not see a difference in spawn timing between natural and hatchery salmon collected for broodstock and spawned at Lookingglass Fish Hatchery but natural salmon are beginning to spawn later into the year, lengthening their spawning period (Hoffnagle et al *in press*). This may be evidence of the result of hatchery offspring spawning in nature and retaining their later spawn time. The difference in spawn timing exacerbates the difference in spawning distribution in the Imnaha River, further segregating the hatchery and natural salmon. Although the extent to which this is happening is unknown, our evidence suggests a developing trend toward later spawning in the Imnaha River Chinook salmon population. Natural spawn timing is important, as demonstrated in Forks Creek, Washington, where wild steelhead produced 9-42 times as many offspring as hatchery steelhead spawning in nature (McLean et al 2003). This was attributed to incorrect spawn timing by hatchery salmon and domestication.

Spawning Distribution

The critical period of imprinting is at the time of smoltification (Hasler and Scholz 1983; Dittman et al 1996). Often, smolts are acclimated in the section of river where management and broodstock needs are most easily met, usually at a hatchery or acclimation facility. Therefore, smolts released in a particular section of river are more likely to return to that section than other sections (Donaldson and Allen 1958; Quinn 1993). Across all years studied, a higher percent of natural Imnaha River salmon carcasses were found in the reaches above the acclimation site and further upstream. Conversely, carcasses of hatchery-reared salmon were more commonly found in reaches closer to and below the acclimation site. Similarly, steelhead reared in Washington hatcheries tended to return to the section of river in which they were stocked while wild steelhead tended to go farther upstream, indicating that spawning site is influenced by imprinting as juveniles and creating some measure of spatial isolation between hatchery and wild steelhead (Mackey et al 2001).

Hatchery vs. Natural Divergence

It seems that a potential problem is developing in the Imnaha River supplementation program. Because of these differences in migration and spawn timing and spawning distribution, we are failing in two of the four management objectives listed by Carmichael and Messmer (1995). We have failed to “operate the hatchery program to ensure that the genetic and life history characteristics of the hatchery fish mimic the wild fish” (Objective 4) because we have inadvertently developed hatchery salmon with differing run and spawn timing, although the divergence in these characteristics from the natural salmon is not yet large. This divergence makes it harder to “maintain genetic and life history characteristics of the endemic wild population while pursuing mitigation goals and management objectives” (Objective 3). With the lengthening of the spawning season of natural salmon spawned at Lookingglass Fish Hatchery (Hoffnagle et al *in press*) we are seeing signs of failure here, as well.

We are now faced with the question of how to resolve this problem. Our hypothesis has been that hatchery x natural spawning is desirable under the theory that hatchery domestication effects will be lost by breeding in nature with wild salmon. However, the opposite (hatchery salmon will alter wild characteristics) could also occur and may be occurring. Alternatively, we could encourage a separation between hatchery and natural salmon, which could result in maintaining a pure wild strain that returns and spawns early and in the upper reaches of the river. This is also the fast track to developing a domesticated hatchery stock and a huge violation of Objective 4, as we would also develop a late returning and spawning hatchery stock that spawns in the lower reaches of the river.

It appears that our broodstock collection and acclimation/release practices are the cause of these problems. By changing these management protocols, we may be able to fix these problems, since they appear to be just beginning. Broodstock collection is currently limited by our ability to install the weir, the date of which varies annually with stream discharge. The weir is not permanent and cannot be installed until river discharge decreases to approximately 28 m^3/s. This problem could likely be solved by an improved weir proposed under the Northeast Oregon Hatchery Project spring Chinook salmon master plan (Ashe et al 2000), which will allow us to collect broodstock from across the entire run. We can then develop collection protocols that may correct the run and spawn timing problems, such as collecting broodstock in a distribution of arrival at the weir resembling that of wild salmon. This, and the natural selection of spawn timing in nature may produce hatchery salmon that return to the Imnaha River and spawn at the same time as wild salmon.

Although differences in spawning distribution in the Imnaha River were discovered, substantial overlap in spawning distribution remains between hatchery and natural salmon - there were no reaches in which only hatchery or natural salmon carcasses were recovered. Therefore, differences in spawning distribution are probably the least worrisome of the three documented differences between hatchery and natural Imnaha River Chinook salmon. However, the difference in spawning distribution does exacerbate the difference in spawn timing and further segregates hatchery salmon from natural salmon. Acclimating and releasing hatchery smolts from a single location, an acclimation facility located at the weir and to which they imprint, is the cause of this difference in spawning distribution. Imprinting occurs at specific times in the life history of salmon and can be very precise (Quinn et al 1999). In order for the hatchery salmon to broaden their spawning distribution in nature, individuals from each cohort must imprint to parts of the river throughout the entirety of the spawning area. To do so, hatchery smolts must be present throughout the spawning areas when they imprint or we must force hatchery adults to spawn elsewhere by physically transporting some adults to different reaches when they return to spawn. Transporting adults to specific spawning areas can widen their spawning distribution as long as they do not move back to the site to which they imprinted. Cramer (1981) found that transporting hatchery steelhead 26 km upstream from their location of capture, also their location of release, resulted in 54% moving back downstream but transporting them 47 km upstream resulted in only 36% dropping back. In the Grande Ronde Basin in 1987-1989, adult Chinook salmon that returned to Lookingglass Fish Hatchery were transported and released into headwater spawning areas in the basin (Carmichael et al 1988; Messmer et al 1989; 1990). Salmon that were transported a shorter distance from the hatchery returned at a greater rate than those that were transported a longer distance. Of the tagged salmon released on the spawning grounds, a mean of 16.0% had returned the 74 km to the hatchery from the Wallowa River release site, 13.8% returned 159 km from Catherine Creek and 10.6% returned 290 km from the upper Grande Ronde River. The furthest that we could feasibly transport adults in the Imnaha River is 21.4 km above the weir (Indian Crossing) so we should expect a significant portion of the salmon to drop back.

It is unlikely that we will build new facilities for imprinting smolts, so direct stream release strategies appear to be the only alternative for changing hatchery smolt imprinting. There has been much debate over the effectiveness of direct stream release versus acclimation. Regarding smolt-to-adult survival and adult return distribution, there are benefits from both types of releases. It is likely that stocking smolts at the correct time and at different locations along the river, rather than exclusively from the hatchery/acclimation site, would increase the distribution of hatchery adults (Slaney et al 1993), therefore encouraging breeding interactions with natural salmon. Reduced survival, increased straying and increased ecological interactions, in comparison to acclimated releases, is a concern with direct-stream released smolts (Johnson et al 1990; Pascual et al 1995; Hayes and Carmichael 2002). Kenaston et al (2001) found no significant difference in survival between hatchery steelhead acclimated for thirty days and those trucked from the hatchery and released directly into the stream. Conversely, Messmer et al (1993) reported consistently better smolt-to-adult survival for acclimated steelhead released from Wallowa Fish Hatchery and, based on these results Whitesel (1998a; b) recommended acclimation for steelhead released into the Grande Ronde and Imnaha river basins in Oregon. However, direct stream release did not affect survival of the 1990, 1992 or 1993 cohorts of hatchery reared Chinook salmon released into the Imnaha River (ODFW unpublished data).

Direct stream release of some smolts into the upper reaches of the Imnaha River has been discussed. Deep snow on the road to the upper Imnaha River during early spring is a deterrent but equipment may be available to overcome this problem (J. Harbeck, Nez Perce Tribe, personal communication). Warm Springs Fish Hatchery allows a period of volitional fall emigration, during which 10-30% of the juvenile salmon leave the hatchery and overwinter in the Deschutes River, which has proven to result in more returning adults than releasing only smolts in the spring (Olson et al 2004). In the Imnaha River, a portion of the juvenile production migrates to the Snake River in the fall (Cleary et al 2004). We could transport and direct release some parr into the stream in late autumn, although fall migration is likely a heritable trait and we have no way of knowing which individuals have this trait. Therefore, transporting and releasing a human-selected proportion of the parr into the Imnaha River in the fall would likely reduce survival of hatchery salmon and may also affect natural parr by increasing parr density and agonistic behavior (Weber and Fausch 2003). The other option to increase spawning between natural and hatchery adults is to transport hatchery adults upstream for release at Indian Crossing, the furthest upstream point of vehicle access. Undoubtedly, some of the transported adults would simply drift back downstream to the areas in which they intended to spawn. If implemented, both direct release and adult transport strategies must be evaluated for effectiveness and to insure that our efforts to increase spawning distribution do not reduce survival of hatchery salmon.

Conclusions

Our findings indicate that broodstock collection timing affects run and spawn timing of hatchery-reared salmon and that focused release of smolts at the weir/acclimation site affects spawning distribution of hatchery fish. Further attempts to collect broodstock from across the entire run are recommended to reduce the difference in spawn timing. Direct stream release of some juvenile hatchery-reared salmon and transport of hatchery-reared adults into locations upstream from the acclimation site should also be considered to increase spawning interactions between hatchery and natural Chinook salmon to achieve the goals of the Imnaha River Chinook salmon supplementation program. However, once run/spawn timing has been resynchronized, the relatively small differences in spawning distribution may become unimportant – in no reaches did we find only natural or hatchery salmon spawning. In order to protect the wild salmon (our primary concern) we may not want to attempt to change spawning distribution until we have corrected the run/spawn timing problem and feel certain that encouraging hatchery x natural spawning will not detrimentally affect the wild population.

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