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Wild Steelhead and Introduced Spring Chinook Salmon in the Wind River, Washington: Overlapping Populations and Interactions

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Abstract

We investigated interactions of introduced juvenile spring Chinook salmon *Oncorhynchus tshawytscha* with wild juvenile steelhead *O. mykiss* in the upper Wind River watershed (rkm 24.6 to rkm 43.8), Washington. Our objective was to determine if the presence of introduced spring Chinook salmon influenced populations of wild juvenile steelhead and if other biotic or abiotic factors influenced distribution and populations of these species. We snorkeled to assess distribution and abundance in one to six stream reaches per year during 2001 through 2007. Juvenile steelhead were found in each sampled reach each year, but juvenile Chinook salmon were not. The upstream extent of distribution of juvenile Chinook salmon varied from rkm 29.7 to 42.5. Our analyses suggest that juvenile Chinook salmon distribution was much influenced by flow during the spawning season. Low flow appeared to limit access of escaped adult Chinook salmon to upper stream reaches. Abundance of juvenile Chinook salmon was also influenced by base flow during the previous year, with base flow occurring post spawn in late August or early September. There were no relationships between juvenile Chinook salmon abundance and number of Chinook salmon spawners, magnitude of winter flow that might scour redds, or abundance of juvenile steelhead. Abundance of age-0 steelhead was influenced primarily by the number of steelhead spawners the previous year, and abundance of age-1 steelhead was influenced primarily by abundance of age-0 steelhead the previous year. Juvenile steelhead abundance did not show a relationship with base or peak flows, nor with number of escaped Chinook salmon adults during the previous year. We did not detect a negative influence of the relatively low abundance of progeny of escaped Chinook salmon on juvenile steelhead abundance. This low abundance of juvenile Chinook salmon was persistent throughout our study and is likely a result of hatchery management and habitat conditions. Should one or both change in the future, the potential for negative interactions with wild steelhead could change.

Introduction

The effects of hatchery-produced and non-native fish on wild populations, particularly at-risk salmonid stocks, have been a concern of fisheries managers in the Pacific Northwest region of the United States. Recommendations have been made to asses potential effects on wild fish and aquatic communities (USFWS 1998; NMFS 1999; Flagg et al. 2000; ISAB 2001). Hatchery-produced and non-native fish may affect native fish in a number of ways. They can increase competition for food and space (McMichael et al. 1997; McMichael et al. 1999; Hilderbrand and Kershner 2004), potentially resulting in density dependent affects on native species (Kostow and Zhou 2006). Introduced species may indirectly increase the number of predators (Holt 1984; Nickelson 2003), directly prey on juveniles or eggs of native species (Johnson 1981; Levin et al. 2002; McGrath and Lewis 2007; Zorn and Nuhfer 2007), or introduce parasites and pathogens (Mitchum et al. 1979; Kruger and May 1991). Conversely, increases in spawning adults from an introduced anadromous run could benefit native fish by increasing nutrient levels in a river through carcass and egg deposition (Bilby et al. 1998; Wipfli et al. 1998; Wipfli et al. 2004). Many Pacific Northwest rivers, particularly headwater areas, are naturally nutrient poor and some have suffered from oligitrophication from anthropogenic effects (Stockner et al. 2000). Historically, returning Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* provided marine derived nutrients that helped sustain riverine ecosystems (Cederholm et al. 1999; Gresh et al. 2000). Addition of nutrients that mimic this natural input from salmon and steelhead can increase productivity (Ashley and Slaney 1997). Fertilization of the Keogh River, Canada, increased periphyton standing crop and fish size (Johnston et al. 1990). Experimental carcass addition has increased density of benthic insects (Claeson et al. 2006) and the production, condition, and lipid content of fish (Bilby et al. 1998; Chaloner et al. 2002; Wipfli et al. 2004). Because many rivers in the Pacific Northwest provide habitat for threatened and endangered native species, but also contain non-native hatchery fish, investigations are warranted to determine effects of non-native fish on native populations.

In this study, we investigated factors influencing distribution and abundance, and potential interactions between, populations of hatchery-origin spring Chinook salmon and wild summer steelhead in a portion of the Wind River, WA. The Wind River is included in the Lower Columbia River Evolutionary Significant Unit, where steelhead are listed as threatened under the Endangered Species Act (ESA; NMFS 1998; NMFS 2006). The U.S. Fish and Wildlife Service

(USFWS) raise and release spring Chinook salmon (hereafter referred to as Chinook salmon) at the Carson National Fish Hatchery (CNFH) at river kilometer (rkm) 28.0 on the Wind River. Each year there are some escaped or naturalized adult Chinook salmon that spawn in the river. Historically, Shipherd Falls (rkm 4.0) was a barrier to Chinook salmon, but a fish ladder was installed in 1956 to allow adult Chinook salmon to access CNFH (USFS 1996). An early goal of CNFH was to establish a naturalized population of wild spawned spring Chinook salmon (Wahle and Chaney 1981) to the Wind River. Currently the goal of CNFH is to contribute to spring Chinook salmon upstream of Bonneville Dam available for sport and tribal harvest, but not to establish a naturalized population. Yearly spawning ground surveys from 1959 to 1978 found from 24 to 1,476 adult Chinook salmon and from 25 to 527 redds in the Wind River. From 1979 through 1999, no spawning ground surveys were conducted, but in 2000 the Washington Department of Fish and Wildlife (WDFW) began counting adult Chinook salmon in the Wind River during August snorkel surveys and found from 71 to 476 adult Chinook salmon per year between rkm 24.6 and 30.0. During each year of our study, adult Chinook salmon spawned in the Wind River. Managers were concerned that non-native but naturally-spawned juvenile Chinook salmon might negatively interact with native wild steelhead in the upper Wind River.

Though Chinook salmon are not native to the Wind River above Shipherd Falls, there are many rivers and streams nearby and throughout their range where they co-evolved and live in sympatry with other salmonids, including steelhead (Quinn 2005). Different salmonid species within a stream often segregate themselves by microhabitat, which may be related to body morphology, size, and prey selection (Everest and Chapman 1972; Dolloff and Reeves 1990; McMichael and Pearsons 1998). Species may also segregate themselves by preference for different stream reaches (Roper et al. 1994; Hicks and Hall 2003; Quinn 2005). Species-specific habitat selection for spawning and rearing may decrease potential negative interactions, particularly if total juvenile density is below that when density-dependent processes are likely to occur.

Chinook salmon and steelhead in the Wind River have somewhat different life histories. Adult Chinook salmon enter the Wind River from April through June. Most quickly migrate upstream to the area near CNFH, where the majority return to the hatchery. The Chinook salmon adults that remain in the river spawn during late August and early September. Fry emerge several months later in February and March. The Chinook salmon in the Wind River have a

"stream type" life history with juveniles smolting during April and May after a full year in freshwater. Adult steelhead enter the Wind River during all months of the year, but most do so between mid June and early August. Most of these adults spend the summer in the canyon reaches of the mainstem, and then move upstream to spawning areas as fall and winter rains increase flow. Spawning occurs from March through May. Most fry emerge during June and July. Steelhead parr may rear in the Wind River or tributaries from two to four years before they smolt. Age composition of Wind River steelhead smolts during 1999 was 73% age-2, 23% age-3, and 1% age-4 (Rawding and Cochran 2001). There is a downstream migration of primarily age-1 parr steelhead during the spring and early summer (Rawding and Cochran 2005), and the number of parr migrants can exceed the number of smolts (Rawding and Cochran 2001). The extent of parr migration during summer, fall, and winter is unknown. Interactions between Chinook salmon and steelhead may occur at any life stage.

Prior to the work described here, extent of distribution and abundance of naturally-spawned juvenile Chinook salmon in the Wind River were unknown. Adult Chinook salmon not returning to the hatchery were known to construct redds and exhibit spawning behavior. Some juveniles had been observed, indicating that successful spawning was occurring, but juvenile abundance and variation between years was unknown.

Study Area

The Wind River is a fifth-order tributary of the Columbia River in southwest Washington's Columbia River Gorge. The Wind River watershed extends north nearly 50 km from its confluence with the Columbia River. Elevations range from 29 m at the mouth to 1,190 m on ridge tops in the northern portion of the subbasin. The climate is temperate with most of the average annual precipitation of 280 cm occurring between November and April.

Our main stem study section was from rkm 24.6 to rkm 41.0, which we separated into reaches with distinct geomorphic features (e.g. change in floodplain confinement, tributary confluences) to better estimate populations and characterize use of the river by juvenile Chinook salmon and juvenile steelhead. When necessary, we surveyed upstream of rkm 41.0 to determine upstream distribution of juvenile Chinook salmon. Reach 1 (R1; rkm 24.6 to 26.0) was characterized by a wide floodplain with cobble and gravel substrate. Reach 2 (R2; rkm 26.0 to 30.0), which began at the lower end of Beaver Campground and ended at Trapper Creek, was

also characterized by a wide floodplain with a generally wide and shallow channel with cobble and gravel substrate. Carson National Fish Hatchery was in R2 at rkm 28.0. Although R1 and R2 had no clear geomorphic separation, we treated them separately for two reasons: 1) we were unable to sample in R1 during 2004 because it was privately owned, but we sampled there in 2005 through 2007 after the U.S. Forest Service bought the property, and 2) there were future plans for stream restoration in R1, prompting a desire to assess potential fish response. Reach 3 (R3; rkm 30.0 to 35.0) consisted of a narrow bedrock-controlled canyon with primarily boulder and large cobble substrate. The upstream end of R3 was at the confluence with Falls Creek, which contributed a large percentage of the summer flow (greater than 65% of the flow during base flow conditions; Jezorek et al. 2005) and cooled the mainstem Wind River. Reach 4 (R4; rkm 35.0 to 35.4) was a short bedrock controlled canyon upstream of Falls Creek. Reach 5 (R5; rkm 35.4 to 40.0) flowed through an alluvial valley with gravel and cobble substrate. Many side channels and logjams made R5 complex. During 2000, the U.S. Forest Service completed a restoration project in R5 involving addition of 1,700 pieces of large woody debris with diameter 0.3 – 0.6 m (Bair et al. 2002). Reach 6 (R6; rkm 40.0 to 44.0) began at Paradise Creek and ended at Oldman Creek. It was characterized by a steep-walled valley with a moderately confined stream channel. Geomorphic differences between reaches had potential to provide differing habitats favored by either Chinook salmon or steelhead.

Throughout the study section, there was habitat that met spawning and rearing needs of both Chinook salmon and steelhead. During surveys from 1960 through 1978, the estimated percentage of Chinook salmon redds located in the Wind River above CNFH averaged 26 percent (Wahle and Chaney 1981). According to a figure showing redd distribution in Wahle and Chaney (1981), many redds upstream of CNFH were near the confluence with Trapper Creek (The upper end of our R2). In the upper end of R2 and the very lower end of R3, there were a number of springs and seeps that feed the Wind River. The largest of these was Tyee Springs, which provides water to CNFH. Potential upwelling and cool spring water may have made the upper portion of R2 and the very lowest portion of R3 attractive spawning locations for Chinook salmon. The canyon habitat in R3 and R4 provided little quality spawning habitat. A 1985 steelhead spawning survey from Stabler (rkm 19.0) to Paradise Creek (rkm 40.0) found a redd density of 9.5 redds/km from Stabler to CNFH and 2.7 redds/km from CNFH to Paradise Creek (Lucas and Nawa 1985). Though these surveyors found fewer redds in the upper portion

of their survey, they did not further separate this section into the bedrock canyon (R3 and R4 of our study) and alluvial reaches (R5 of our study). Substrate of the size preferred for spawning by Chinook salmon and steelhead (Bjornn and Reiser 1991) was common in R1, R2, R5, and R6, but rare in R3 and R4. In addition to Chinook salmon and steelhead, fish assemblage in the study area included mountain whitefish *Prosopium williamsoni* (up to rkm 30.0) and shorthead sculpin *Cottus confuses*. Pacific lamprey *Lampetra tridentata* have been sighted just downstream of our study area and may be present within it.

Methods

Snorkeling – From 2000 through 2007, we snorkeled the Wind River between rkm 24.6 to 44.0 to determine upstream distribution of juvenile spring Chinook salmon. We estimated abundance of juvenile spring Chinook salmon and juvenile steelhead in two to six reaches per year (Table 1). We performed a stratified-systematic survey following the first-phase methodology of the basinwide visual estimation technique (Hankin and Reeves 1988; Dolloff et al. 1993). A habitat-unit survey was conducted from downstream to upstream. All habitat units were categorized into pool, glide, riffle, or side-channel strata. Length and width were measured to the nearest 0.1 m. Subsamples within each stratum were snorkeled (every other pool, every third glide, every fourth riffle, and every fourth side channel). In R1 and R2, we sampled additional side-channel units (every unit or every other) because there were few functioning side channels (maximum of eight during any one year). One or two snorkelers covered a habitat unit depending on size and complexity. Snorkelers moved from downstream to upstream following procedures described by Thurow (1994). All snorkeling was done during August and the first two weeks of September. Due to funding, and personnel constraints, we did not snorkel every reach each year (Table 1). Each year, we determined the upstream distribution of juvenile Chinook salmon by snorkeling at least 500 m upstream of the last point we observed them. Because our longest data record was in R5, much of our analysis of factors influencing juvenile salmonid abundance and potential interactions was focused there.

Salmonids observed during snorkeling were identified and categorized by age class (steelhead: age-0, age-1, age-2 or older; Chinook salmon: age-0). Based on observation and length-frequency data, juvenile Chinook salmon older than age-0 were not present during the late summer or were extremely rare. Because age-1 “stream-type” Chinook salmon smolts

outmigrate in spring (Healey 1991; Quinn 2005), most are gone by late summer. In each reach, we calculated mean fish densities for each stratum, which were expanded to the unsampled areas to estimate abundance by stratum (Hankin and Reeves 1988; Dolloff et al. 1993). To estimate total reach abundance and associated variance, we combined strata estimates in each reach following stratified-sampling guidelines of Schaeffer et al. (1990, equations 5.4 and 5.5). We used analysis of variance to test for differences in mean abundance by reach, followed by Tukey's Studentized Range Test (HSD).

Counts of adult Chinook salmon and estimates of adult steelhead – We used counts of adult Chinook salmon from WDFW snorkel surveys. During August surveys, adult Chinook salmon were counted in the Wind River between rkm 25.0 and 30.0 (WDFW; unpublished data). Some adult Chinook salmon returned to CNFH after the August snorkel survey (B. Galyean, USFWS, personal communication). Since these adult Chinook salmon did not spawn or die in the river, we subtracted them from the August snorkel count for an adjusted in-river count. We used these adjusted adult Chinook salmon counts in analyses examining factors influencing juvenile Chinook salmon and juvenile steelhead abundance. We used adult steelhead estimates from WDFW snorkel mark-resight surveys during August and September each year (Rawding and Cochran; 2007; all estimates had CV < 25%).

Electrofishing – During August through early October, we electrofished to collect juvenile steelhead in portions of the upper Wind River watershed where they were in sympatry with Chinook salmon and where they were in allopatry. Sample sites included Dry Creek (Figure 1), the only site sampled in 2000 with no Chinook salmon present. Juvenile steelhead were measured for fork length (L) to the nearest mm and wet weight (W) to the nearest 0.1 g. Fulton's condition factor ($K = 10^5 \cdot W/L^3$) was calculated for each fish. After processing, fish were held in ambient temperature stream water, and once recovered they were released near their point of capture.

Flow – Flow measurements were taken every two weeks from June through October at rkm 29.7. Flow was measured with a Marsh-McBirney meter following the protocol of Gallagher and Stevenson (1999). These measurements were used to determine lowest flow during the Chinook salmon spawning period and to record base flow each year, which usually occurred after Chinook salmon spawning.

It was not possible to measure flow at our site during the winter (when water was too high and fast to wade), so we used data from the East Fork Lewis River gage near Heisson, WA (USGS Station 14222500) as a surrogate for the magnitude of peak flow events. The East Fork Lewis River is located to the immediate northwest of the Wind River with very similar geography, climate, rainfall, and flow regime. Though flows are not equal on the two rivers, the flow pattern is similar. Historic data from a Wind River gage (USGS Station 14128500; dates of operation: 1 October 1967 through 30 September 1977) were strongly correlated with data from the East Fork Lewis gage for the same period ($r = 0.90$; $P < 0.0001$). Because our measurements for the descending limb of the hydrograph and base flows each summer were taken on a two week interval, we compared our measures with those on the East Fork Lewis to make sure this interval was adequate to capture base flow. Mean difference (days) between the date that we recorded lowest flows and those on the East Fork Lewis River was five days for low flow during Chinook spawning, and seven days for yearly base flow. Because the East Fork Lewis gage is located lower in its watershed than our flow site, this discrepancy was expected, and we felt our two week measurement interval was adequate to capture low flows.

Temperature – A series of six Onset Optic Stowaway Temperature Loggers were deployed in the Wind River within the study section. These units logged water temperature every two hours from May through September of each year. Because summer temperatures throughout the study section were within the range preferred by salmon and steelhead (Brett 1952; Bell 1986; Viant et al. 2003), we did not further consider temperature as a variable influencing distribution or populations.

Influences and Interactions - We investigated relationships between numerous independent variables and the distribution and abundance of juvenile Chinook salmon, and abundance of age-0 and age-1 steelhead. Variables that were investigated for influencing the distribution of juvenile Chinook salmon were: flow at rkm 29.7 during the Chinook salmon spawning period the preceding year (8 August to 7 September), and adult Chinook salmon counts the preceding year (spawners for that cohort). Variables that were investigated for influencing juvenile Chinook salmon abundance in R5 were: adult Chinook salmon counts the preceding year, the abundance of age-1 or older steelhead co-occurring in the reach, the adult steelhead runsize corresponding to time of emergence of an age-0 Chinook salmon cohort, peak flow recorded on the East Fork Lewis River during the preceding October through April time

period (when Chinook salmon eggs would be in redds and subject to scouring, or fry would be hatching and subject to displacement due to high flows), and base flow at rkm 29.7 during the preceding year. Variables investigated for influencing age-0 steelhead abundance in R5 were: adult steelhead counts for spawners for that cohort, the juvenile Chinook salmon abundance co-occurring in the reach, adult Chinook salmon counts during that year, and base flow during that year. Variables investigated for influencing of age-1 steelhead abundance were: adult steelhead runsize of spawners for that cohort, the estimate of age-0 steelhead abundance in a reach the preceding year, the abundance of juvenile Chinook salmon co-occurring in the reach, adult Chinook salmon counts during the preceding year, peak flow during the preceding winter, base flow at rkm 29.7 during the preceding summer, and base flow at rkm 29.7 during the current summer. These variables are likely to be those with some of the greatest influence and are those with consistent data records.

We used simple linear regression, multiple-regression, and non-linear regression to investigate potential influences on abundance of age-0 steelhead, age-1 steelhead, and juvenile Chinook salmon. Significance level for tests was $P \leq 0.05$ unless indicated otherwise. We used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank models of variables influencing age-0 and age-1 steelhead. To determine support for different models, we used guidelines from Burnham and Anderson (2002), where, relative to the best model, ΔAIC_c values 0-2 indicate substantial support, values of 4-7 indicate considerably less support, and values greater than 10 indicate essentially no support. We used analysis of variance (ANOVA) to test for differences in abundance estimates of age-0 and age-1 steelhead by reach. Age-1 steelhead abundance values were log transformed to meet normal frequency requirements. We used ANOVA to test for differences in mean condition factor of age-0 and age-1 or older steelhead in allopatry and in sympatry with Chinook salmon.

Results

Distribution - The uppermost point where we observed juvenile Chinook salmon during 2000 through 2007 varied from rkm 29.7 to 42.5. During our study, Chinook salmon spawning was most frequent in R2, particularly near CNFH and near the mouth of Trapper Creek (D. Rawding, WDFW, personal communications). Steelhead spawning was most concentrated in R5, though juvenile steelhead were present through all reaches surveyed each year. Simple

linear regression between the upstream distribution of juvenile Chinook salmon and low flow of the Wind River during Chinook salmon spawning the preceding year (1999 – 2006: Range 0.18 - 0.62 m^3/s) showed a significant positive relationship ($r^2 = 0.68$, $P = 0.002$). During three years when flow was less than 0.5 m^3/s during the Chinook salmon spawning season, no juvenile Chinook salmon were found upstream of rkm 30.2 (Figure 2). When juvenile Chinook salmon were found upstream of rkm 30.2 (n = 5), there was a significant positive relationship between low flow the previous year during Chinook salmon spawning and the upstream extent of juvenile Chinook salmon ($r^2 = 0.77$, $P = 0.050$; Figure 2). No relationship was evident between the upstream distribution of juvenile Chinook salmon and adult Chinook salmon counts the preceding year ($r^2 = 0.01$, $P = 0.499$). Flow during the Chinook salmon spawning season appeared to strongly regulate the upstream distribution of juvenile Chinook salmon the following year.

Abundance – Annual juvenile Chinook salmon abundance was highly variable between and within reaches, ranging from 0 to 99 fish/100 m (Tables 1 and 2). The highest mean abundance was in R1 (35 fish/100 m) and the highest median abundance was in R2 (14 fish/100 m). Juvenile Chinook salmon were present in R1 and R2 during each year we sampled (R1, n = 3; R2, n = 4). Juvenile Chinook salmon were not always found in R3 and R4 when we sampled there (R3, present 2 of 5 years; R4, present 2 of 3 years). When juvenile Chinook salmon were found in R3 and R4, abundance was low (< 4 fish/100 m). Juvenile Chinook salmon were found in R5 during five of the eight years we sampled it (mean abundance = 3 fish/100 m; median abundance = 1 fish/100 m.

Age-0 steelhead were present in each reach surveyed during each year (Table 1). Age-0 steelhead were more prevalent in the upper reaches of the study area. Abundance of age-0 steelhead was highest in R5 and R6 (mean abundance: R5, 154 fish/100 m; R6, 98 fish/100 m). The highest abundance of age-0 steelhead was 309 fish/100 m in R5 in 2003. Abundance was low in R1 through R4, with the highest value of 53 fish/100 m in R1 in 2005. Age-0 abundance in R5 was not significantly different from R6, but was different from all other reaches (ANOVA; $\alpha = 0.05$). During the years 2005 through 2007, we snorkeled R1, R2, R5, and R6 each year (Table 1), and mean age-0 steelhead abundance was 34 fish/100 m in R1, 12.5 fish/m in R2, 147 fish/100 m in R5, and 91 fish/100 m in R6. During those three years, age-0 steelhead abundance in R5 was significantly greater than R6, R1, and R2, and age-0 steelhead abundance in R6 was

significantly greater than in R1 and R2 (ANOVA; $\alpha = 0.05$; Table 3). In the reaches that we surveyed at least four times (R2, R3, R5, and R6), age-0 steelhead abundance in R5 was significantly greater than R2 and R3 (ANOVA; $\alpha = 0.05$; Table 4), at $\alpha = 0.10$, age-0 steelhead abundance in R6 was greater than in R2 and R3.

Age-1 steelhead were present in each reach surveyed during each year, but abundance was highly variable between reaches and years (Tables 1 and 2). Age-1 steelhead abundance followed a similar pattern as age-0 steelhead, higher in R5 and R6 than the lower reaches (mean abundance: R5, 34 fish/100 m; R6, 26 fish/100 m). Mean abundance for R1 through R4 did not exceed 14 fish/100 m. During the years 2005 through 2007, we snorkeled R1, R2, R5, and R6 each year (Table 1), and mean age-1 steelhead abundance was 14 fish/100 m in R1, 15 fish/m in R2, 43 fish/100 m in R5, and 27 fish/100 m in R6. In the reaches that we surveyed at least four times (R2, R3, R5, and R6), age-1 steelhead abundance in R5 was significantly greater than R2 and R3 (ANOVA; $\alpha = 0.05$; Table 3), and age-1 steelhead abundance was significantly greater than in R2. Age-1 steelhead abundance in R5 and R6 was considerably lower than age-0 abundance during most years, but followed a similar pattern through time.

Influences and Interactions – Juvenile Chinook salmon abundance in R5 was significantly influenced by base flow the previous year (linear regression: $r^2 = 0.86$, $P = 0.001$; Figure 4). Linear regression showed no significant influence on abundance of juvenile Chinook salmon in R5 by: counts of Chinook salmon spawners ($r^2 < 0.01$, $P = 0.971$), co-occurring populations of age-1 steelhead ($r^2 = 0.06$, $P = 0.592$), adult steelhead populations during Chinook salmon emergence ($r^2 = 0.12$, $P = 0.453$), or peak flow since egg deposition the previous fall ($r^2 < 0.01$, $P = 0.976$).

Age-0 steelhead abundance in R5 was significantly influenced by adult steelhead spawners for that cohort, which showed a strong positive relationship (linear regression: $r^2 = 0.89$, $P < 0.001$; Figure 5). Age-0 steelhead abundance in R5 was not significantly influenced by counts of adult Chinook salmon ($r^2 = 0.01$, $P = 0.877$), or base flow ($r^2 = 0.04$, $P = 0.662$). There was a negative trend in R5 between abundance of juvenile Chinook salmon and abundances of age-0 steelhead co-occurring in a year (linear regression: $r^2 = 0.48$, $P = 0.058$; Figure 6). Because the magnitude of abundance of age-0 steelhead and juvenile Chinook salmon were disparate (age-0 steelhead: range, 16.6 to 309.9 fish/100 m; juvenile Chinook salmon: range, 0.0 to 12.1 fish/100 m; Table 1), and because during two of the years (2000 and 2001)

when juvenile Chinook salmon abundance was highest (Figure 5) steelhead spawners counts were lowest, we question the biological significance of this relationship. A multiple linear regression model with abundance of juvenile Chinook salmon and steelhead spawners as independent variables and age-0 steelhead abundance as the dependent variable was significant ($r^2 = 0.85$, $P < 0.004$), but only steelhead spawners was a significant variable (steelhead spawners: $r^2 = 0.80$, $P < 0.007$; juvenile Chinook salmon: $r^2 = 0.47$, $P = 0.568$). Results from AIC_c identified steelhead spawners the previous year as the best variable to explain age-0 steelhead abundance (Table 5). Both other models had ΔAIC_c values (> 6) that indicated little support relative to the best model.

Variation of age-1 steelhead abundance in R5 was best explained by age-0 steelhead abundance the previous year. This relationship was best expressed by a curvilinear equation, which was significant ($r^2 = 0.81$; $P = 0.006$; Figure 7). Use of a curvilinear equation was suggested by the plotted data, which show a pattern consistent with a population approaching carrying capacity, and produced a higher r^2 value. Age-1 steelhead abundance in R5 was also significantly influenced by the number of steelhead spawners the previous year (linear regression: $r^2 = 0.71$, $P = 0.008$), though the relationship did not explain as much of the variability as the abundance of age-0 steelhead the previous year. Age-1 steelhead abundance in R5 was not significantly related to: counts of adult Chinook salmon the previous year ($r^2 = 0.05$, $P = 0.640$), peak flow during the previous winter ($r^2 = 0.21$, $P = 0.257$), base flow the previous summer ($r^2 = 0.16$, $P = 0.325$), or base flow during a cohort's age-1 year ($r^2 = 0.03$, $P = 0.696$). There was a significant negative relationship in R5 between juvenile Chinook salmon abundance the previous year and abundance of age-1 steelhead (linear regression: $r^2 = 0.58$, $P = 0.047$; Figure 8). This relationship expresses the potential effect of juvenile Chinook salmon on a cohort of steelhead throughout their first year. However, similar to results with age-0 steelhead, the abundances were disparate (age-1 steelhead: range, 8 to 55 fish/100 m; juvenile Chinook salmon: range, 0 to 12 fish/100 m), and during the two years (2001 and 2002) when juvenile Chinook salmon abundance was highest (Figures 3 and 8), steelhead spawners and age-0 steelhead abundance had been at their lowest levels the previous two years (Figure 5). Results from AIC_c identified age-0 steelhead abundance the previous year as the best variable to explain age-1 steelhead abundance (Table 6). The two other models tested had ΔAIC_c values (> 4) that indicated little support relative to the best model.

Steelhead Condition – Condition factor (Fulton's K) of age-0 and age-1 or older steelhead was generally good during each year we collected fish. Mean condition factor of age-0 steelhead in allopatry ranged from 1.03 to 1.26, and in sympatry with juvenile Chinook salmon, ranged from 1.10 to 1.28. During each of the three years when we electrofished to collect juvenile steelhead occurring in allopatry and sympatry with juvenile Chinook salmon, mean condition factor of age-0 steelhead was slightly higher when they occurred in sympatry (Figure 9), but the difference was significant (ANOVA: $P = 0.02$) only in 2003. Mean condition factor of age-1 or older steelhead varied from 1.06 to 1.14 when in allopatry and from 1.10 to 1.16 when in sympatry. Mean condition factor of age-1 or older steelhead did not differ significantly (ANOVA: $P > 0.09$) whether in allopatry or sympatry with Chinook salmon.

Discussion

During the period of our study, non-native spring Chinook salmon spawned in the Wind River, with the highest concentrations of redds consistently occurring within our study area (rkm 24.6 – 43.8). Juvenile Chinook salmon were produced naturally and occurred in sympatry with wild juvenile steelhead. Although the potential existed for negative interactions with juvenile steelhead populations, our data do not suggest that juvenile Chinook negatively influenced steelhead abundance.

The distribution of juvenile Chinook salmon appeared to be highly influenced by flow during spawning the previous year, which likely determined adult access to upstream portions of the study area. Chinook salmon were consistently found in the lower reaches of our study, but not consistently in the upper reaches. Our data indicate a threshold flow (about 0.5 m^3/s) at which adult Chinook salmon are able to pass through R3 and may spawn in the upper reaches of the study area. There are several cascades in R3 that may be impassable to adult Chinook salmon at low flows. During years with low flow, the spring areas at the upper end of R2 may have been particularly attractive to spawning Chinook salmon. During years that juvenile Chinook salmon were found above R3, their distribution upstream was related to flow during spawning the previous year. Reach 5 is a shallow reach with many long riffles and complex log jams where low flow may have inhibited upstream movement of adult Chinook salmon or provided little spawning habitat. Thompson (1972) reported minimum depth and velocity criteria for upstream migration of adult spring Chinook salmon to be 24 cm and 30 cm/s. During

many years, flow, and thus depths and velocities, in the upper portion of R5 and throughout R6 was likely inadequate for adult Chinook salmon migration or spawning.

Base flow did have a relationship to juvenile Chinook salmon abundance in R5. Base flow generally occurred after spawning, possibly dewatering redds or reducing egg survival. Factors other than those we investigated may have acted to influence juvenile Chinook salmon abundance. Flow conditions or channel changes at the entrance to CNFH and operation of the ladder there could influence the proportion of adults that stay in river. Many years of hatchery breeding may have contributed to lack of fitness for reproduction in a natural stream (Waples 1991; Fleming and Gross 1993; Araki et al. 2007). Changes to spawn timing can occur through artificial selection at hatcheries, resulting in spawning that is out of synch with the local flow regime (Cederholm 1984). Cederholm et al. (1997) found populations of juvenile coho and age-0 steelhead to be influenced by severity of winter flow, and Spina (2001) found peak discharge during incubation to be inversely related to year-class strength of brown trout. Peak flow during winter and spring, which can scour redds of fall spawning salmonids and affect year class strength (Warren 2009), may have influenced juvenile Chinook salmon abundance in R2, but there was no relationship evident in our data for R5. Reach 5 carried much less water and had more complex habitat than R2, partially due to habitat restoration efforts. Study by Solazzi et al. (2000) on two Oregon coastal streams showed that improvements to winter habitat that provided refuge from high flows increased overwinter survival of coho salmon *O. kisutch* and increased trout migrants. Restoration actions in R5 may have decreased bedload movement and improved high flow refuge areas for juvenile Chinook salmon.

Juvenile Chinook salmon are likely vulnerable to predation, which may influence their abundance. Shorthead sculpin, which can be a major predator on salmonids (Quinn 2005), were common in our study section. Some larger juvenile steelhead or non-anadromous rainbow trout were large enough to take age-0 Chinook salmon. Other predators found on the Wind River include mergansers *Mergus merganser* and river otters *Lutra Canadensis*. Between 24 and 65% of the juvenile coho salmon in the Big Qualicum River, British Columbia, were estimated to be taken by mergansers (Wood 1987). Dolloff (1993) estimated that four otters ate at least 3,300 juvenile coho and Dolly Varden in the Kadashan River watershed in Alaska during a six week period. Determining the most influential factors on abundance of juvenile Chinook salmon in the Wind River would require more extensive study.

On 24 May 2005, there was an accidental release of 4,565 age-0 Chinook salmon from CNFH, after they had been adipose clipped. It is possible that some of these fish residualized in R1 and R2 and that they would have been included in our snorkel counts the following summer. However, WDFW personnel began to catch these adipose clipped Chinook salmon at the smolt trap at the mouth of the Wind River nearly immediately following the release, and they continued to capture them through June. During summer 2005, we electrofished and handled over 300 juvenile Chinook salmon in R1 and R2, and did not note any that were adipose clipped. No adipose clipped juvenile Chinook salmon were noted during our snorkel surveys. Considering the quick movement of these fish downstream to the smolt trap and the lack of adipose-clipped fish in our electrofishing samples, we believe that a minimal number of these fish were in the sample area during our snorkel surveys; however, we cannot rule out that some may have been present.

Steelhead, which spawn during relatively high flows in spring, likely had ready access to the entire study section and were found in each reach during each year. Though both age-0 and age-1 steelhead were found in all reaches, their abundance was highest in reaches 5 and 6. The distributions of the two species overlapped, but steelhead were more common in the upper reaches and Chinook salmon were more common in the lower reaches. Distribution of spawning Chinook salmon is concentrated near CNFH, but it appears that CNFH is near a natural geomorphic feature that limits upstream movement of adult Chinook salmon at low flows. Our results on the influence of flow are consistent with findings of other studies (Roper et al. 1994; Hicks and Hall 2003; Quinn 2005). This partial segregation by reach may minimize potential competition or other negative interactions with steelhead.

Abundance of age-0 steelhead was primarily influenced by the number of steelhead spawners during each year. Abundance of age-1 steelhead was primarily influenced by age-0 steelhead abundance the previous year. Though regression suggested that juvenile Chinook salmon presence had a negative influence on age-0 and age-1 steelhead, we think these relationships are spurious. During the years when juvenile steelhead abundance was lowest, and juvenile Chinook salmon abundance was highest, the total abundance of juvenile salmonids in R5 was low compared to that found in other Pacific Northwest systems (Roper and Scarnecchia 1994; Cederholm et al. 1997; Sharma and Hilborn 2001), and during the later years of this study in the Wind River. During the years when juvenile steelhead abundance was lowest, the

numbers of steelhead spawners for those cohorts were also at their lowest; this likely had greater effect on juvenile steelhead abundance than the minimal presence of juvenile Chinook salmon.

The apparent lack of influence of Chinook salmon on juvenile steelhead in the Wind River could be related to habitat preferences. Habitat segregation can limit negative interactions. Though Chinook salmon and steelhead exhibit partial separation by reach, they also segregate by microhabitat at the unit scale (Edmunson et al. 1968; Everest and Chapman 1972; Hearn 1987; Roper and Scarnecchia 1994). Preferences in microhabitat selection are influenced both by fish size (Bisson et al. 1988; Moore and Gregory 1988; Dolloff and Reeves 1990; Quinn 2005) and species (Bisson et al. 1988; Bjorn and Reiser 1991). McMichael and Pearsons (1998) found that growth rates of juvenile rainbow trout in enclosures and natural streams sections did not differ with juvenile Chinook salmon present or absent. They also found that abundance of rainbow trout did not differ in natural stream sections with juvenile Chinook salmon present or absent. McMichael et al. (1997) introduced hatchery steelhead into enclosures with wild rainbow trout and juvenile spring Chinook salmon and found the introduced steelhead reduced growth of the wild rainbow trout but no reduction was demonstrated for the juvenile Chinook salmon. They hypothesized that the finding of no difference for Chinook salmon was due to niche differences. Kelsey et al. (2002) compared behavior of juvenile Chinook salmon in sympatry with hatchery juvenile steelhead, and in allopatry, and found behavioral changes by Chinook salmon with the introduction of steelhead. The hatchery steelhead frequently attacked the Chinook salmon, but attacks by Chinook salmon on steelhead were rare. Several authors have reported that hatchery salmonids were more aggressive than their wild counterparts (Swain and Riddell 1990; Mesa 1991; Noble 1991). McMichael et al. (1999) reported that aggression by hatchery steelhead often involved contact but aggression by wild steelhead rarely involved contact. They speculated that aggressive displays without actual contact were a behavior to enforce hierarchies but minimize energy expenditures. Many stream-dwelling salmonids do not change their microhabitat habitat preferences whether in allopatry or sympatry (Everest and Chapman 1972; Dolloff and Reeves 1990) and presence of non-native juvenile Chinook salmon may not have influenced the behavior of wild juvenile steelhead in the Wind River.

Although salmonids can be piscivorous, it is unlikely that juvenile Chinook salmon were consuming age-0 steelhead. Few of the juvenile Chinook salmon present were large enough to consume juvenile steelhead, and many studies of juvenile Chinook salmon diets in streams have

found that they consume primarily insects (Becker 1973; Loftus and Lenon 1977; Kjelson et al. 1982; Sagar and Glova 1988).

Competition for food has been shown to limit growth or survival of individuals of some native species when in sympatry with non-natives (Waters 1983; Moore et al. 1986; Levin et al. 2002). Our condition factor data did not indicate reduced fitness for individual juvenile steelhead when in sympatry with juvenile Chinook salmon. A number of mechanisms could have served to keep conditions factor of steelhead in sympatry as high as, or higher, than those in allopatry. Increased marine derived nutrients from salmon carcasses may have increased productivity and increased insects (Wipfli et al. 1998; Chaloner et al. 2002; Wipfli et al. 2004), which typically dominate juvenile steelhead diets (Wydoski and Whitney 2003; Godby et al. 2007). Juvenile steelhead could have fed on Chinook salmon carcasses and eggs (Claeson et al. 2006). Bilby et al. (1998) found that stomach contents of juvenile coho salmon and juvenile steelhead consisted primarily of eggs and flesh from salmon carcasses added experimentally to two small Washington streams.

It is also possible that no evidence of negative influence of Chinook salmon on juvenile steelhead populations was evident because the reaches in our study section were below carrying capacity, with adequate food and space to accommodate juveniles of both species. Analysis of the Wind River subbasin by Ecosystem Diagnosis and Treatment model (EDT; Lestelle et al. 1996; LCFRB 2004) estimated adult steelhead production of the Wind River to be 1,230 fish. During every year of our study, adult returns were below this value (range = 193 to 1,067; mean = 573; Rawding and Cochran 2007). The EDT model indicated that the production capacity was 24,673 steelhead smolts from the entire subbasin. During five of the eight years of our study, smolt production was below this value (range, 11,101 to 42,846; mean, 24,138). In R2, our data did not suggest that the reach was near capacity for juvenile salmonids. Abundance was low relative to R5 and R6, even though R2 had more area. Data from R5 suggest that this reach may be nearing carrying capacity for age-1 or older steelhead, but abundance of juvenile Chinook salmon was low there. If R5 is near carrying capacity for steelhead, it will be important to investigate possible interactions if naturally spawned juvenile Chinook salmon populations were to increase.

Though we primarily used data from R5 to investigate influences of juvenile Chinook salmon on steelhead, we feel the lack of observed negative effect likely applies to the Wind

River as a whole. Negative influences are unlikely upstream of R5 since we found juvenile Chinook salmon present in only one of seven years of sampling. Because juvenile steelhead populations were highest in R5, which has little stream area, it was likely to exhibit density-dependent interactions. Reaches 4 and 3 had very low populations of juvenile Chinook salmon and juvenile steelhead, probably due to the bedrock-control nature of these reaches. Chinook salmon spawning was more common closer to the hatchery in R1 and R2, but both had relatively low populations of juveniles of both species and much stream area allowing potential segregation by micro-habitat preference. Though juvenile Chinook salmon from R1 and R2 likely could migrate into upstream reaches, the low densities in R1 and R2 during our study period probably did not give them cause to leave. Whether an upstream migration of juvenile Chinook salmon might occur at higher densities is unknown.

Though our data do not indicate a negative interaction between naturally spawned hatchery-origin Chinook salmon and abundance or condition of wild juvenile steelhead, this could change. Changing environmental conditions, strength of runs, or management actions could influence this interaction, especially if carrying capacity is met in the watershed or specific reaches. If hatchery-origin Chinook salmon continue to spawn in the Wind River, managers may want to periodically evaluate the potential for negative interactions. Abundance of natural-spawning adult Chinook salmon, and subsequent juvenile Chinook salmon abundance, were generally low during our study, but could change in future years with changing environmental conditions or operational changes at CNFH that result in additional Chinook salmon remaining in the Wind River.

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Table 1. Abundance estimates, by snorkel survey, of juvenile Chinook salmon (CHK), age-0 steelhead (age-0 STH), and age-1 steelhead (age-1 STH) in reaches of the upper Wind River. Numbers in parentheses are standard errors. Reaches not snorkeled during a year are indicated by -.

Species Year	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
CHK						
2000	-	-	0.8 (0.4)	0.9 (0.6)	12.1 (1.6)	7.3 (1.0)
2001	-	-	-	-	5.9 (1.7)	-
2002	-	-	0.0	0.0	0.5 (0.2)	0.0
2003	-	-	-	-	1.7 (0.5)	-
2004	-	26.5 (16.9)	0.0	-	0.0	0.0
2005	98.9 (40.7)	97.5 (60.7)	2.0 (0.7)	3.4 (2.2)	5.4 (1.7)	0.0
2006	3.8 (0.4)	0.7 (0.5)	0.0	-	0.0	0.0
2007	0.8 (0.4)	2.4 (0.9)	-	-	0.0	0.0
Age-0 STH						
2000	-	-	0.4 (0.2)	17.5 (2.7)	16.6 (5.8)	4.3 (0.9)
2001	-	-	-	-	48.2 (5.2)	-
2002	-	-	13.9 (7.6)	19.2 (11.6)	140.6 (71.7)	38.7 (6.9)
2003	-	-	-	-	309.9 (18.2)	-
2004	-	13.2 (3.2)	16.4 (7.3)	-	277.7 (96.4)	273.6 (37.7)
2005	53.7 (2.9)	18.8 (3.9)	19.9 (1.8)	24.4 (6.3)	137.6 (18.3)	73.0 (14.3)
2006	40.7 (4.5)	6.5 (2.4)	11.5 (3.3)	-	175.5 (16.4)	117.8 (20.6)
2007	6.3 (1.6)	12.3 (3.3)	-	-	126.0 (18.9)	81.7 (10.8)
Age-1 STH						
2000	-	-	1.6 (0.4)	20.1 (1.5)	22.3 (2.4)	14.0 (1.2)
2001	-	-	-	-	17.3 (2.7)	-
2002	-	-	2.0 (0.4)	1.8 (1.5)	7.7 (1.6)	2.3 (1.3)
2003	-	-	-	-	38.7 (4.4)	-
2004	-	6.0 (3.3)	3.0 (1.8)	-	54.7 (11.5)	56.6 (8.6)
2005	29.7 (3.2)	32.4 (20.8)	10.4 (1.3)	11.6 (2.2)	43.8 (5.6)	20.8 (2.4)
2006	6.8 (0.9)	0.4 (0.4)	2.5 (0.9)	-	34.0 (4.0)	23.1 (5.3)
2007	6.7 (3.1)	11.8 (2.2)	-	-	50.2 (7.3)	36.0 (4.9)

Table 2. Mean abundance estimates (fish per 100 m), by snorkel survey, of juvenile Chinook salmon (CHK), age-0 steelhead (age-0 STH), age-1 steelhead (age-1 STH), and all steelhead and Chinook salmon in reaches of the upper Wind River from 2000 through 2007. Not all reaches were surveyed each year.

Species	Reach 1 (n = 3)	Reach 2 (n = 4)	Reach 3 (n = 5)	Reach 4 (n = 3)	Reach 5 (n = 8)	Reach 6 (n = 6)
CHK						
Median	3.8	14.4	0.0	0.9	1.1	0.0
Mean	34.5	31.7	0.6	1.5	3.2	1.2
CV	161.7	143.2	150.0	120.0	134.4	250.0
Min.	0.8	0.7	0.0	0.0	0.0	0.0
Max.	98.9	97.5	2.0	3.4	12.1	7.3
Age-0 STH						
Median	40.7	13.0	13.9	19.2	139.1	77.3
Mean	33.6	12.8	12.3	20.4	154.1	98.2
CV	72.9	39.1	58.5	17.6	65.5	96.0
Min.	6.3	6.5	0.4	17.5	16.6	4.3
Max.	53.7	18.8	19.1	24.5	309.9	273.6
Age-1 STH						
Median	6.8	8.9	2.5	11.6	36.3	21.9
Mean	14.4	12.7	3.9	11.2	33.6	25.5
CV	91.7	110.2	94.9	82.1	49.4	73.3
Min.	6.7	0.4	1.6	1.8	7.7	2.3
Max.	29.7	32.4	10.4	20.1	54.8	56.6
All STH & CHK						
Median	60.7	38.4	16.0	44.5	191.4	111.1
Mean	86.2	61.3	18.6	38.3	198.8	129.8
CV	101.5	110.3	59.1	37.5	54.4	84.9
Min.	14.2	8.4	5.5	21.9	64.3	32.5
Max.	183.5	159.9	35.6	48.6	361.3	335.2

Table 3. Matrix of differences in mean snorkel estimates of abundance of age-0 steelhead (fish per 100 m) in reaches of the upper Wind River from 2005 to 2007. We used analysis of variance to test for differences in mean abundance followed by Tukey's Studentized Range Test (HSD). Reaches are ordered by fish abundance, with R5 having the highest, and R2 the lowest. Significance levels (α) are indicated by: NS > 0.10, * = 0.10, ** = 0.05.

	R5	R6	R1	R2
R5		**	**	**
R6			**	**
R1				NS
R2				

Table 4. Matrix of differences in mean snorkel estimates of abundance of juvenile steelhead (fish per 100 m) in reaches of the upper Wind River with four or more years of sampling from 2000 to 2007. A = age-0 steelhead, B = age-1 steelhead. We log transformed the values for age-1 to normalize the data. We used analysis of variance to test for differences in mean abundance followed by Tukey's Studentized Range Test (HSD). Reaches are ordered by fish abundance, with R5 having the highest, and R3 the lowest. Significance levels (α) are indicated by: NS > 0.10, * = 0.10, ** = 0.05.

A.

	R5	R6	R2	R3
R5		NS	**	**
R6			*	*
R2				NS
R3				

B.

	R5	R6	R2	R3
R5		NS	**	**
R6			NS	**
R2				NS
R3				

Table 5. Summary of three models to explain abundance of age-0 steelhead in Reach 5 (R5). Independent variables are: estimates of steelhead spawners (SS) and estimates of age-0 Chinook salmon in R5 (C0). K = estimable parameters, AIC_c = Akaike's Information Criterion adjusted for small sample size, $\Delta AIC_c = AIC_i - AIC_{min}$, w_i = Akaike weights. Also shown are linear regression statistics for models using the same variables.

Variables	n	K	AIC_c	ΔAIC_c	w_i	r^2	*P*-value
SS	8	3	63.34	0.00	0.96	0.89	<0.001
SS, C0	8	4	70.10	6.76	0.03	0.85	<0.004[a]
C0	8	3	75.58	12.24	0.01	0.48	0.057

[a] In multiple regression, only SS was significant at $\alpha = 0.05$, $P < 0.007$.

Table 6. Summary of three models to explain abundance of age-1 steelhead in Reach 5 (R5). Independent variables are: estimates of age-0 steelhead the previous year (S0) and estimates of age-0 Chinook salmon in R5 the previous year (C0). K = estimable parameters, AIC_c = Akaike's Information Criterion adjusted for small sample size, $\Delta AIC_c = AIC_i - AIC_{min}$, w_i = Akaike weights. Also shown are linear regression statistics for models using the same variables.

Variables	n	K	AIC_c	ΔAIC_c	w_i	r^2	*P*-value
S0	7	3	30.56	0.00	0.88	0.77	< 0.010
C0	7	3	42.69	4.13	0.11	0.58	0.047
S0, C0	7	4	49.91	11.36	0.01	0.79	0.045[a]

[a] In multiple regression, neither individual variable was significant at $\alpha = 0.05$.

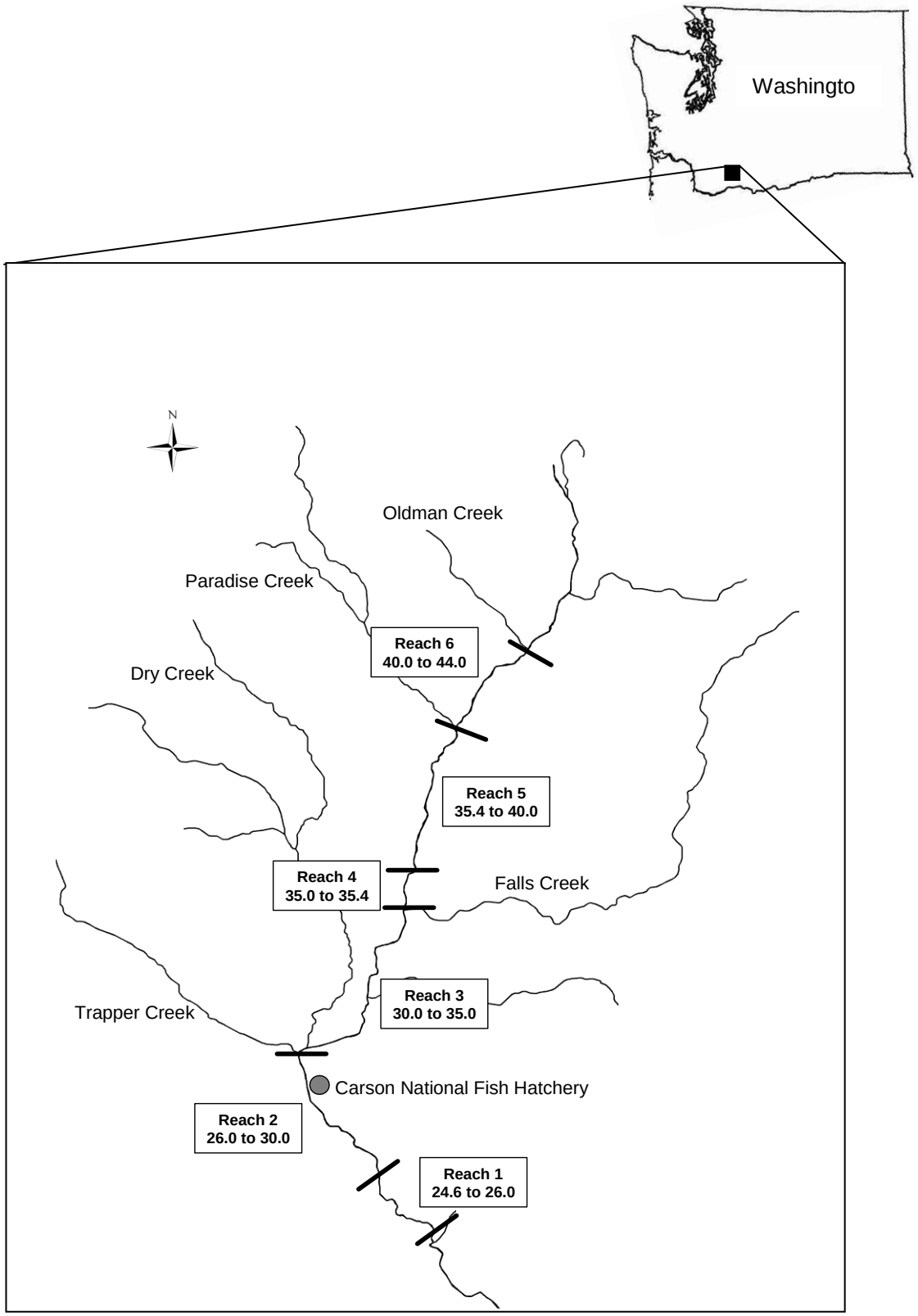

Figure 1. Map of the Wind River watershed above river kilometer 26.0. The six study reaches and their corresponding river kilometers are shown.

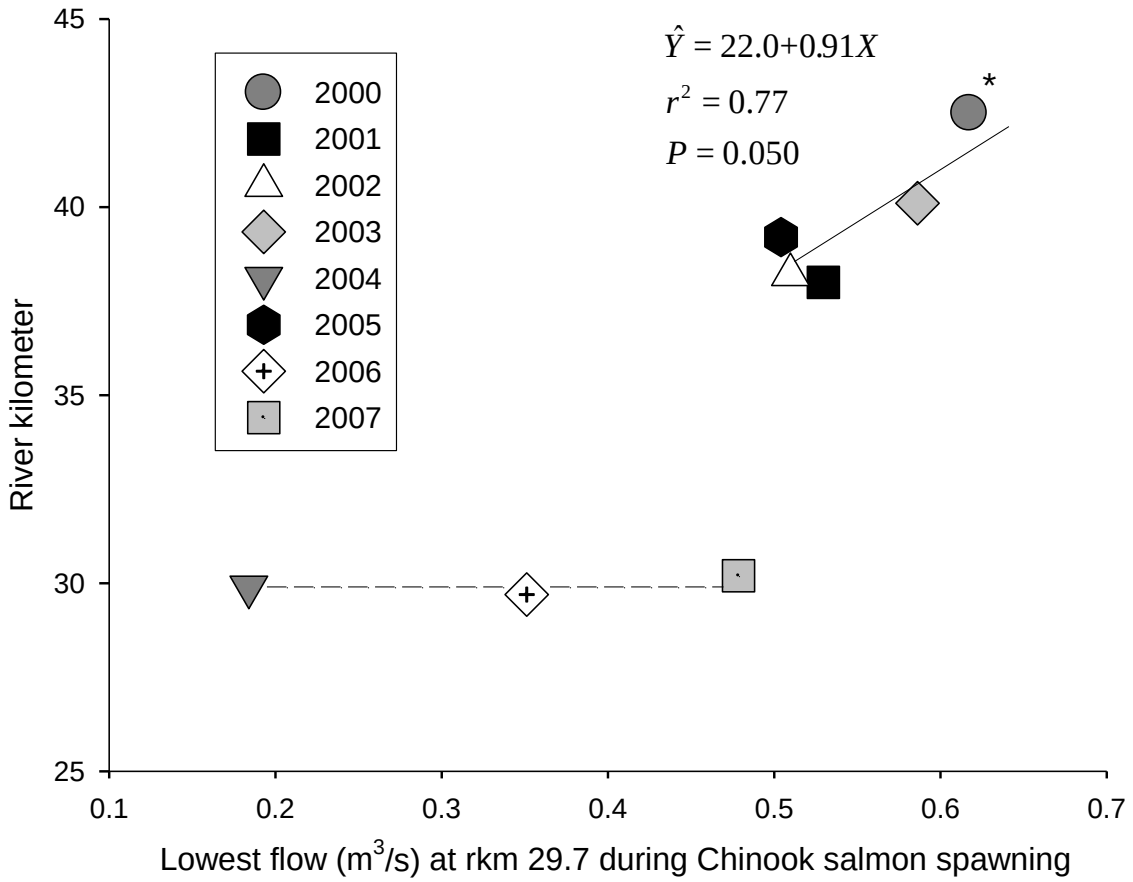

Figure 2. Upstream extent of juvenile Chinook salmon observed by snorkeling in the Wind River during each year (2000 – 2007) and lowest flow recorded at rkm 29.7 during Chinook salmon spawning season (8 August to 7 September) during the previous year. The dashed line indicates a potential flow threshold below which adult Chinook do not spawn upstream of about rkm 30.0. The solid line represents a linear regression of upstream river kilometer and flow greater than 0.5 cms.

* = during 1999, we measured flow on 5 October only; flow during the August - September period may have been slightly higher.

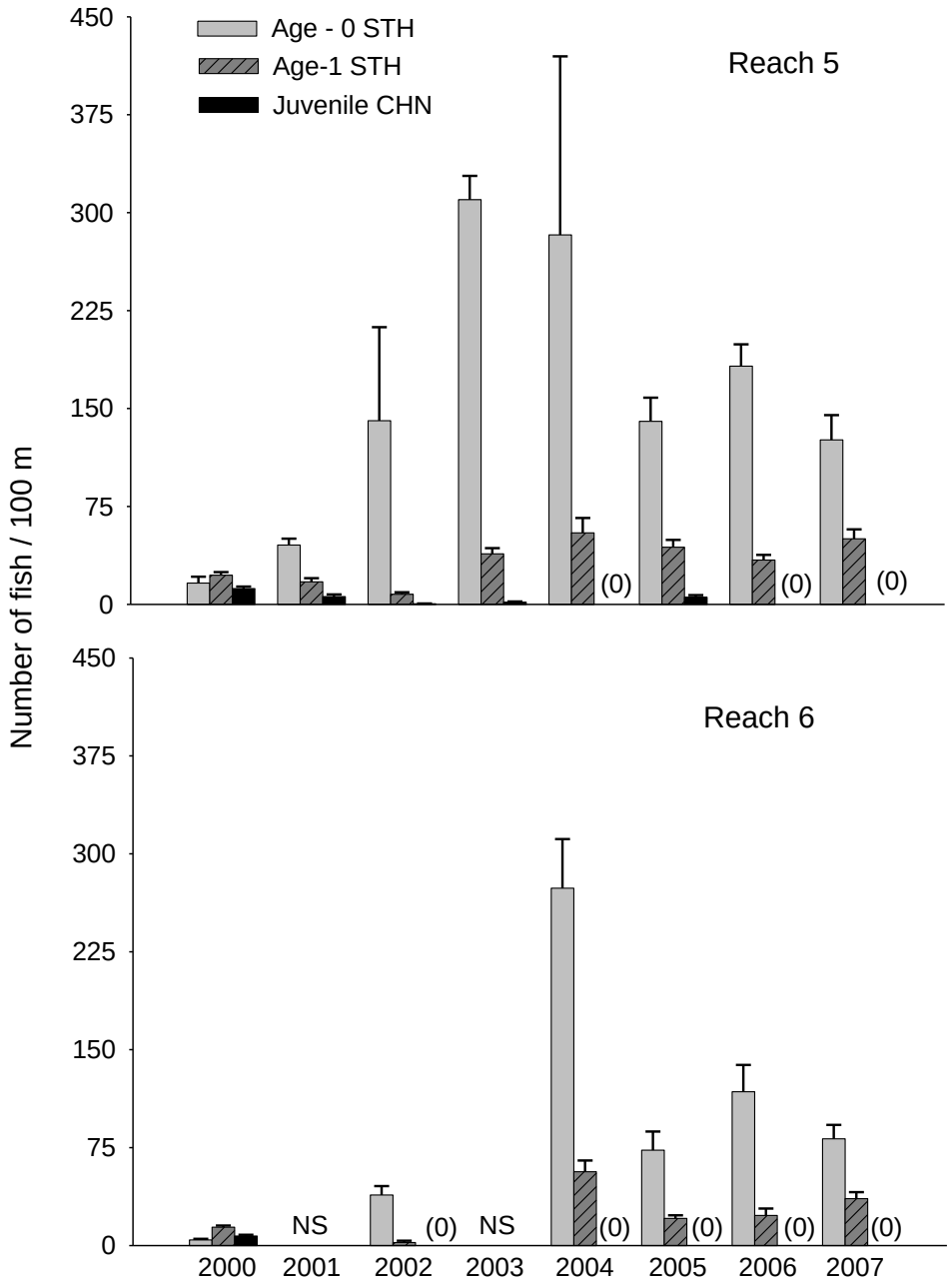

Figure 3. Abundance estimates (+/- 1 SE) of age-0 steelhead (STH), age-1 STH, and juvenile Chinook salmon (CHK) in Reach 5 (rkm 35.4 to 40.0) and Reach 6 (rkm 40.0 to 44.0) for the years 2000 through 2007. NS = Not sampled.

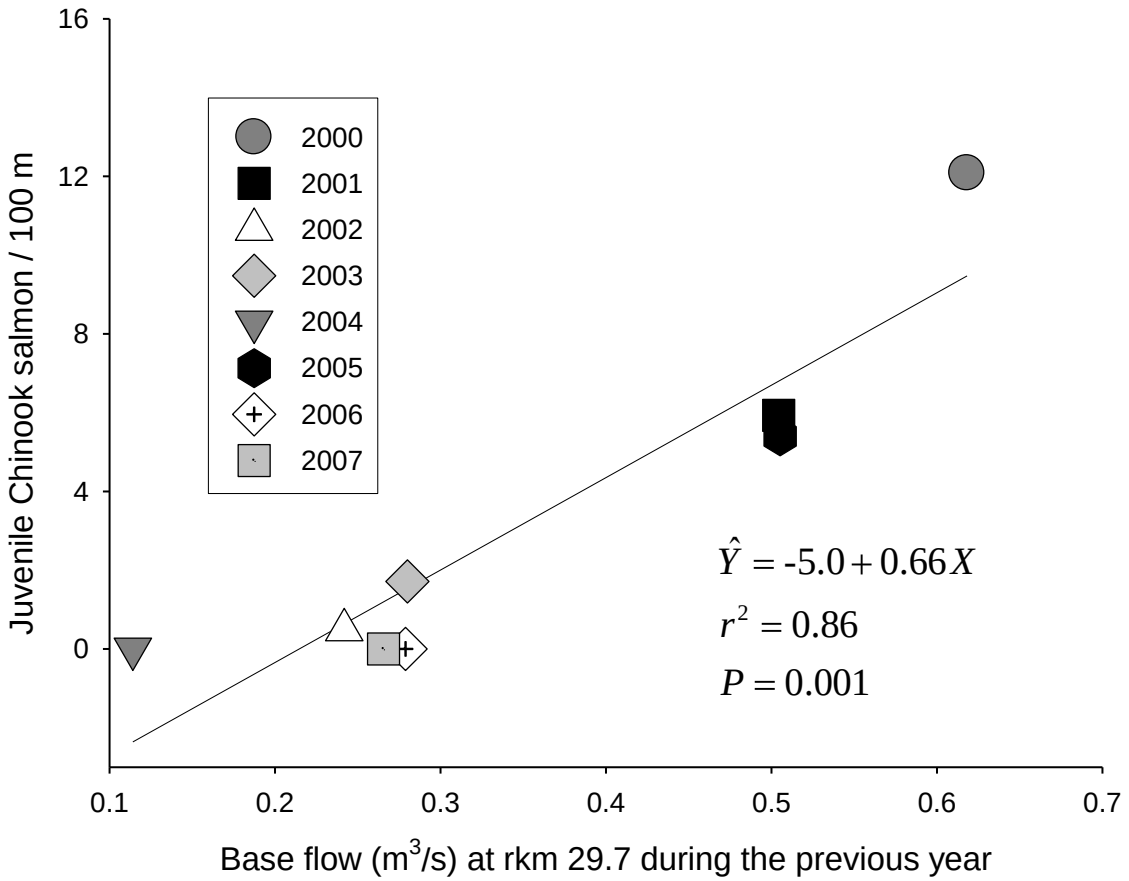

Figure 4. Juvenile Chinook salmon abundance estimates in Reach 5 (rkm 35.4 to 40.0) and base flow during the previous year, measured at rkm 29.7 of the Wind River.

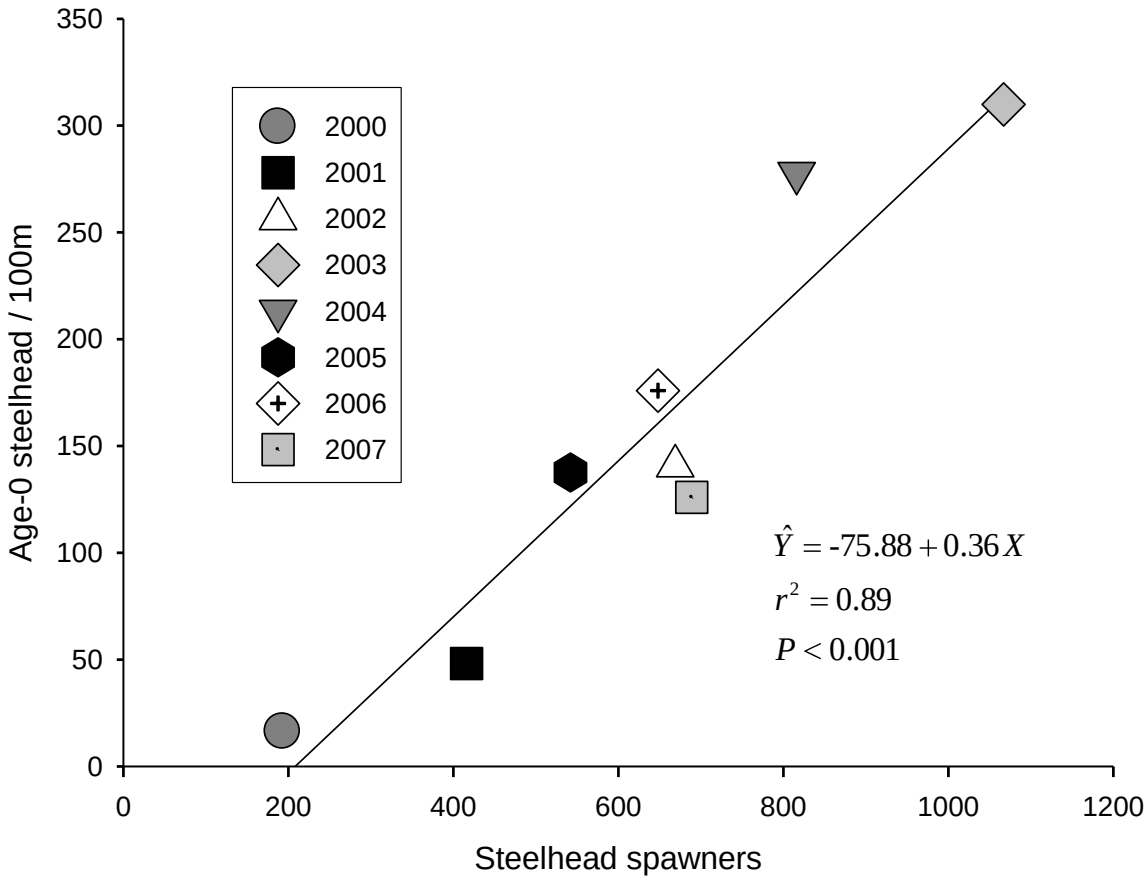

Figure 5. Age-0 steelhead abundance estimates in Reach 5 (rkm 35.4 to 40.0) and adult steelhead estimates from WDFW during the preceding year.

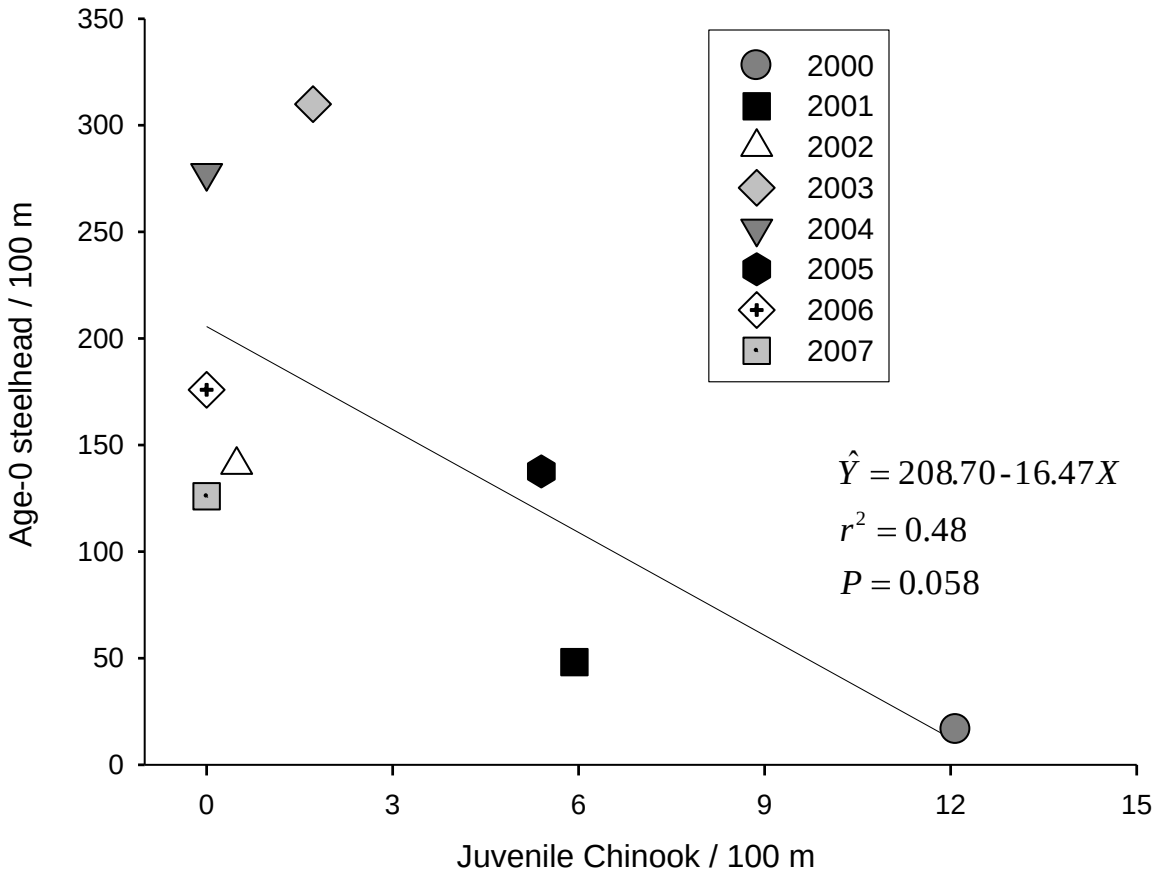

Figure 6. Age-0 steelhead abundance estimates and concurrent juvenile Chinook salmon abundance estimates in Reach 5 (rkm 35.4 to 40.0). Though this relationship suggests a possible negative effect of juvenile Chinook salmon on age-0 steelhead, the reader should exercise caution in interpretation. During each of the two years with the highest juvenile Chinook salmon abundance, the number of steelhead spawners was low. Multiple regression of age-0 steelhead against steelhead spawners and juvenile Chinook salmon showed a significant relationship only with steelhead spawners.

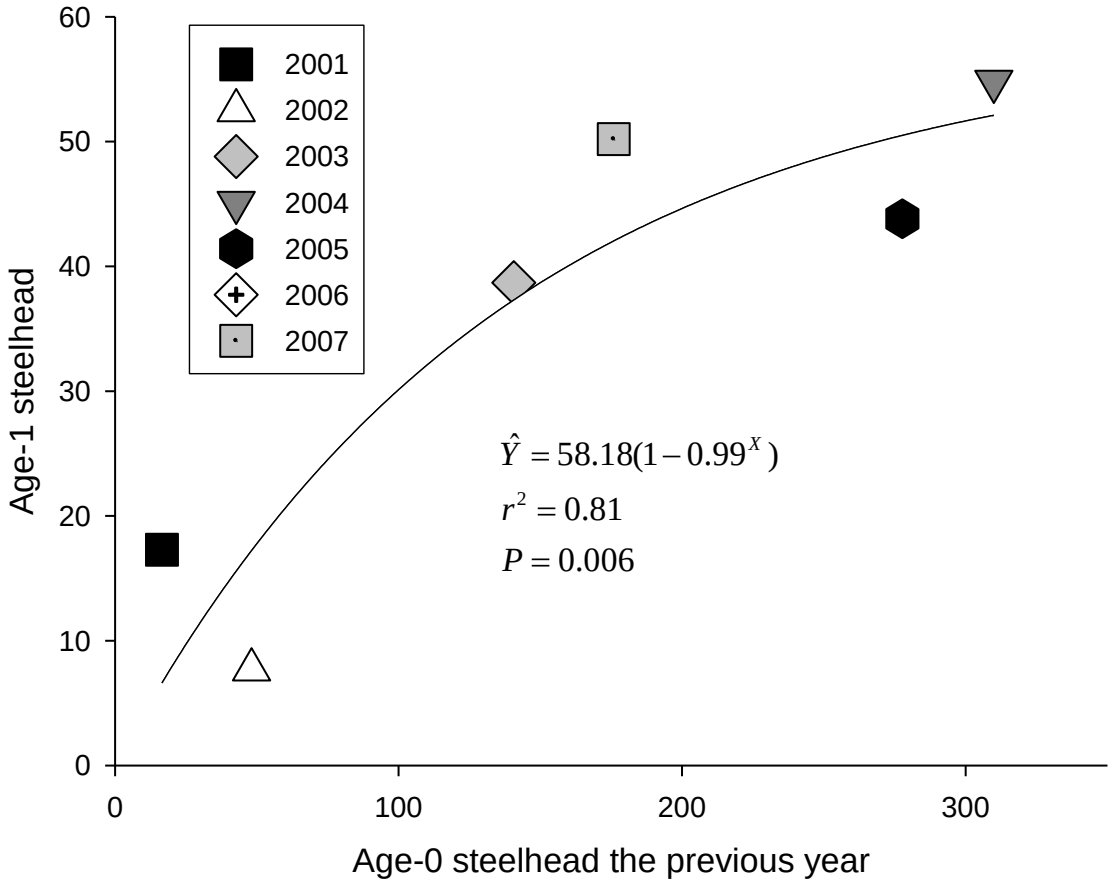

Figure 7. Abundance estimates of age-1 steelhead and age-0 steelhead the previous year in reach 5 (rkm 35.4 to 40.0).

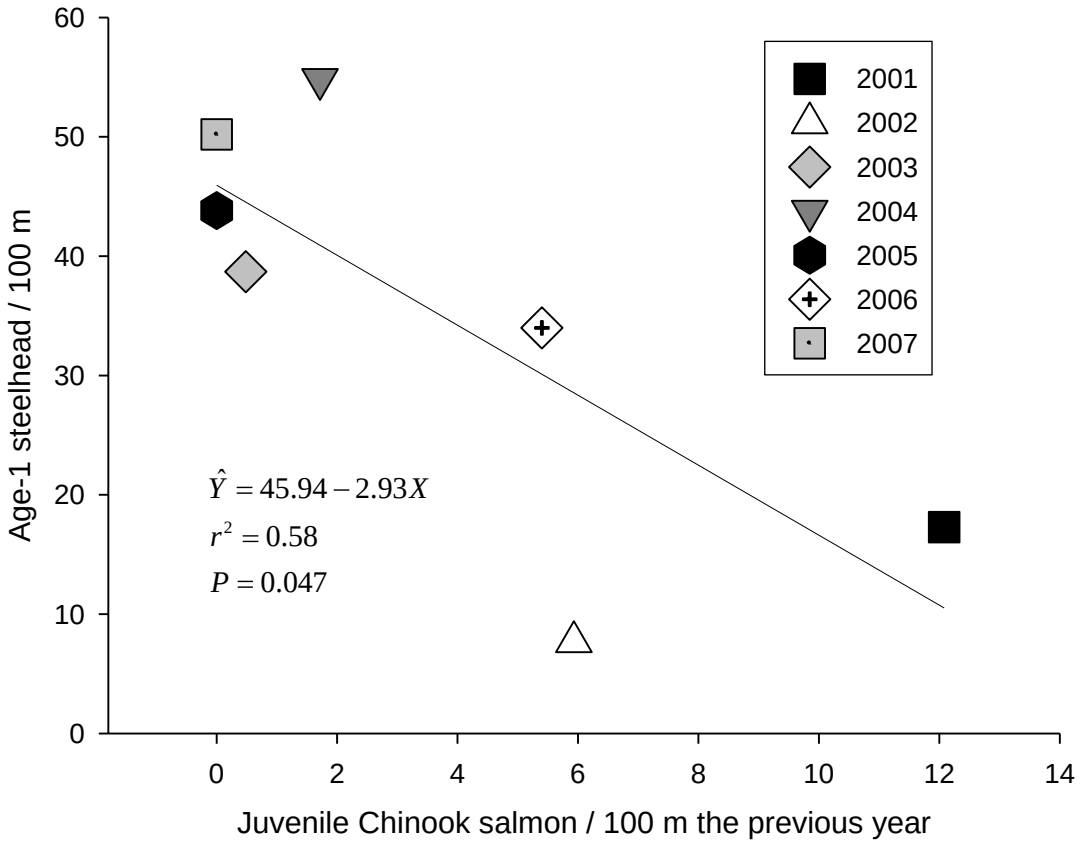

Figure 8. Abundance estimates, by snorkel count, of age-1 steelhead and juvenile Chinook salmon the previous year in reach 5 (rkm 35.4 to 40.0). Though this relationship suggests a negative effect of juvenile salmon on abundance of age-1 steelhead, the reader should exercise caution in interpretation. Abundance of age-0 steelhead the previous year explained more variation of age-1 steelhead (r^2 = 0.81, P = 0.006; Figure 7) than abundance of juvenile Chinook salmon the previous year. During the years when juvenile Chinook salmon abundances were highest, the adult steelhead returns for the broods of age-1 steelhead had been low.

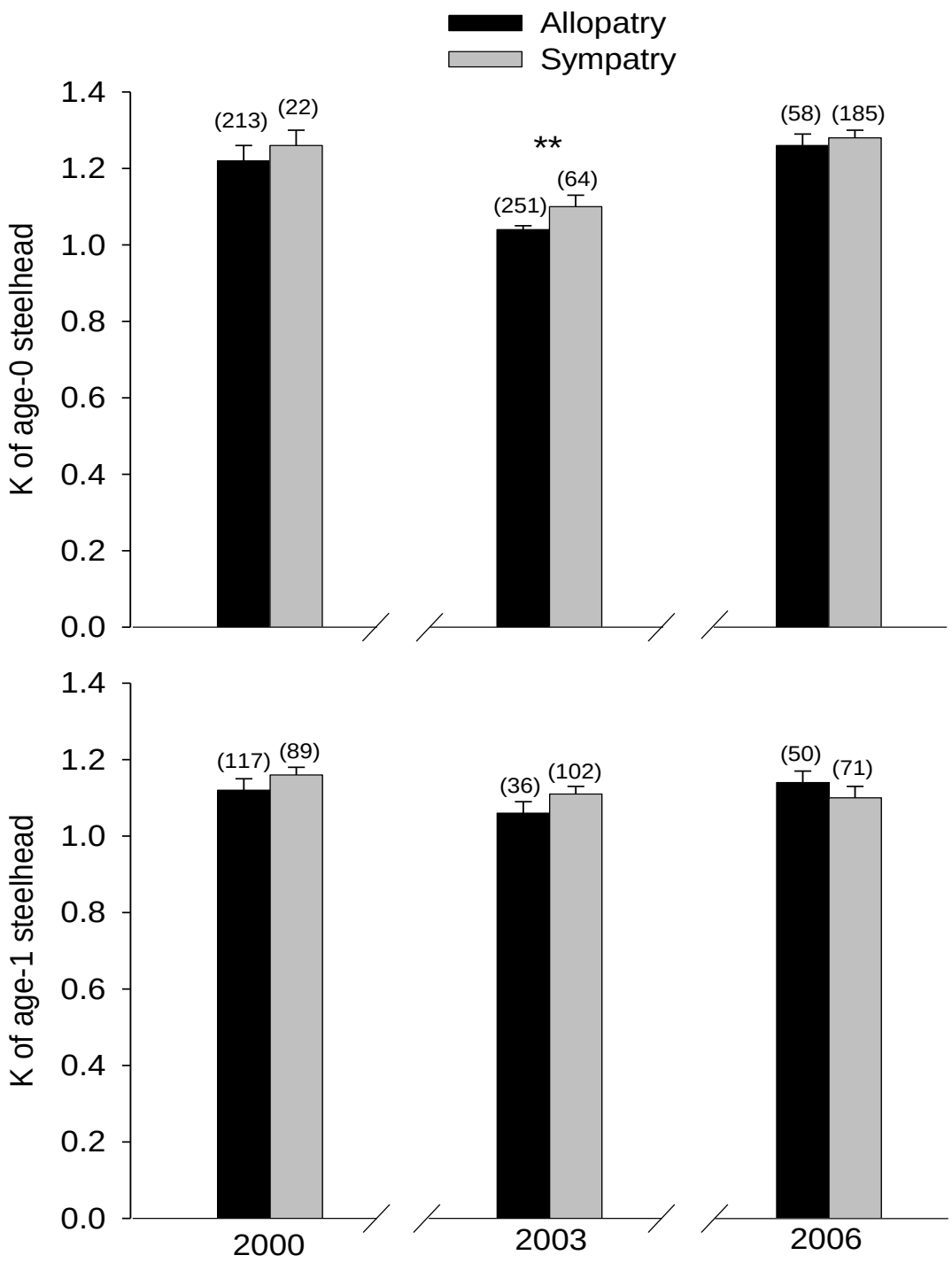

Figure 9. Mean condition factor (Fulton's $K = 10^5 \cdot W/L^3$) of age-0 and age-1 and older steelhead (+95% CI) collected during late August through early October during three years. The steelhead were collected in stream sections where they were in allopatry and sections where they were in sympatry with Chinook salmon. Numbers in parenthesis are the number of individual fish sampled. Significant differences ($P < 0.05$) within years are indicated by "**".