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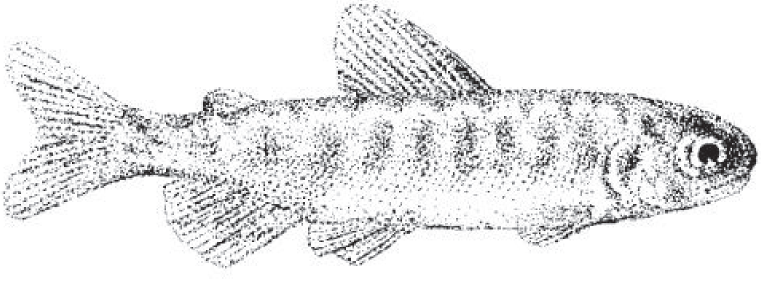
Predation of Naturally- Produced Subyearling Chinook by Hatchery Steelhead Juveniles in Western Washington Rivers



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Washington Department of
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Abstract

There is considerable uncertainty about the risk of hatchery steelhead predation on wild subyearling Chinook salmon and this is a particular concern in areas containing ESA-listed populations. Between 2003 and 2005 we studied juvenile steelhead predation on Chinook salmon fry using stomach content analysis. Juvenile hatchery-origin steelhead trout were released in the Deschutes, Green, Coweeman and Kalama rivers upstream of and within known fall Chinook rearing areas in western Washington. In all years, actively migrating steelhead smolts were captured in rotary screw traps and stomach contents were checked by gastric lavage or dissection. In 2003 and 2004, non-migratory steelhead were captured by angling and electrofishing in the Deschutes River and gut contents were inspected. Salmonid fry or parts thereof in the gut were identified to species. We attempted to compare the incidence of predation on Chinook fry by migrating hatchery steelhead under different release strategies including (1) high in a watershed vs. low, (2) early release vs. late, (3) release from acclimation ponds vs. direct plants and (4) release of local, native stock vs. domesticated stock. The actual incidence of predation by hatchery steelhead on fall Chinook was uniformly low across all release scenarios tested. Of 6,029 hatchery steelhead examined, 10 fall Chinook fry had recently been consumed (0.002 fry/stomach). The range of observed predation across the various release groups of hatchery steelhead was 0 and 0.01 fry/steelhead stomach with considerable variation in the incidence of predation between streams and years. The low incidence of predation precluded statistically valid inferences related to the effect of different release strategies on predation rates. We did show that steelhead release protocols used widely in the Pacific Northwest were associated with negligible predation by migrating hatchery steelhead on fall Chinook fry. The data on predation by non-migratory steelhead juveniles were limited but support the same conclusion. The low incidences of predation observed may be a result of the timing of hatchery steelhead releases. Most subyearling Chinook salmon had already emigrated or had grown large enough to reduce or eliminate their susceptibility to predation when hatchery steelhead entered the rivers.

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Introduction

After the federal Endangered Species Act (ESA) listing of Chinook salmon Evolutionary Significant Units in Puget Sound and the lower Columbia River (NOAA 1998) interactions between hatchery and wild fish became a high profile management issue. Among the interactions that have received attention is predation by hatchery fish on naturally produced endemic salmonids (NOAA 2005). Hatchery coho (McConnaughey 1998), Chinook (Sholes and Hallock 1979, Pearsons et al. 2006), and steelhead (Cannamela 1993, Martin et al. 1993, Jonasson et al. 1995, Hawkins and Tipping 1999) will eat wild salmonid juveniles. However, the magnitude of the impact on endemic populations is poorly understood. Accurate consumption estimates for prey populations at low abundances are difficult to generate because an increasing proportion of the hatchery fish population has to be sampled in order to confidently identify a biologically significant level of predation.

The maximum size of salmonids that hatchery fish can eat in freshwater is about 50% of the hatchery fish's body length. For example, hatchery coho salmon smolts ate fall Chinook up to 46% of their body length in controlled feeding experiments (Pearsons and Fritts 1999) and Jonasson et al. (1995) found that hatchery residual (non-migratory) steelhead ate juvenile salmonids up to 44% of their body length in controlled predation trials. Similarly, hatchery steelhead in the Tucannon River, Washington consumed salmonids up to 38% of their own body length (Martin et al. 1993). In contrast, yearling coho salmon (80-140 mm, FL) in Masset Inlet, British Columbia ate juvenile chum salmon up to 75% of their body length, though usually not greater than 50% of their body length (Hargreaves and LeBrasseur 1986).

Predation rate of hatchery salmonids is a function of multiple factors such as predator-prey encounter rate, bioenergetic capacity of the predator, and difference in proclivity for piscivory among species. Encounter rate is a function of prey availability, duration of predator-prey co-occurrence, and habitat complexity. Prey availability appeared to explain observed differences in predation rate between years within the Lewis River, Washington and between the Lewis River and tributaries further upstream in the Columbia basin (Hawkins and Tipping 1999). In Lewis River studies, relatively high and low predation rates were found in areas and years with high and low abundance of prey, respectively. Encounter rate is also theoretically important and can be further influenced by duration of overlap and habitat conditions. Complex habitats are more likely to offer prey refuges than simplified habitats. Greater overlap in time and space between hatchery and wild fish is likely to contribute to a greater potential for predation. Further, energetics of hatchery fish can significantly affect the number of prey consumed. Two components of energetics that affect predation rate are water temperature and fish activity. Many studies have shown the relationship between food consumption and water temperature (Reviewed in Groot et al. 1995). In general, the maximum amount of food that fish can process increases with increasing water temperature until water temperatures approach lethal limits and feeding decreases (Wurtsbaugh and Davis 1977; Li et al. 1994).

Some salmonid species are more piscivorous than others. Hawkins and Tipping (1999) found that hatchery cutthroat trout averaged 1.00 and 2.13 salmonid fry per stomach, steelhead 0.03 and 1.13 salmonid fry per stomach, and coho salmon 0.05 and 0.11 salmonid fry per stomach in the Lewis River during 1997 and 1998 respectively. We focused on predation by hatchery steelhead because smolts are released at relatively large sizes and can consume a relatively large size range of prey fish. In addition, steelhead are released into a variety of waters throughout the state, concurrent with the presence of ESA-listed species. Furthermore, some steelhead juveniles have a propensity to remain in freshwater (residualize), which might result in higher predation rates on species of concern.

We reviewed 13 studies that have investigated hatchery steelhead predation on Chinook salmon (Table 1). Of these studies, only one contained the minimum data necessary to calculate the proportion of the fall Chinook population consumed by hatchery steelhead. Most studies reported only the proportion of hatchery steelhead that had recently ingested a Chinook salmon fry. In addition, most samples were obtained from actively migrating smolts (before June 1). Importantly, per capita predation rate was higher after 1 June and probably represented samples of residual steelhead, not active migrants. In addition, most samples collected after 1 June were from the Columbia River Basin upstream of Bonneville Dam. Thus, there is considerable uncertainty about the impact of hatchery steelhead predation on Chinook salmon populations, particularly outside of the Columbia Basin.

The goals of this study were to define the extent of risk that juvenile hatchery steelhead pose as predators on naturally produced fall Chinook fry in western Washington and to develop procedures that can be used in other watersheds to objectively evaluate the same. Our approach was to track and estimate the relative abundance of the potential predators (hatchery steelhead) and their potential prey (Chinook fry) during their periods of freshwater residency, noting size of steelhead and Chinook as an index of predation risk. We used smolt trapping data to estimate migration timing and abundance. As a surrogate for observing predation, we captured hatchery steelhead and used gastric lavage and dissection to examine gut contents. We used radiotelemetry to track migration patterns of the hatchery steelhead and to attempt to validate migration patterns derived from smolt trapping data. We performed the work over a number of years in different watersheds where hatchery steelhead were released using different procedures. The different release protocols we evaluated reflect the range of strategies used to release steelhead in western Washington and elsewhere. We focused on particular strategies we thought might increase predation risk.

Table 1. Review of hatchery steelhead (HSH) predation studies. Under Methods, S, E, HL, and N indicate screw trap, electrofishing, hook and line, and seining (net), respectively.

		HSH Examined		Chinook in Guts		Predation Rate		Chinook Eaten		Percent consumed			
Location	Year	< June 1	> June 1	< June 1	> June 1	< June 1	> June 1	< June 1	> June 1	< June 1	> June 1	Methods	Citation
Lower Snake R. (Imnaha & Grande Ronde)	1992-1993	65	611	0	0	0.0000	0.0000					S, E	Whitesel et al. 1993
	1993-1994		358		0	--	0.0000					E	Jonasson et al. 1995
	1994		175		1	--	0.0057					E	Jonasson et al. 1995
Upper Salmon R	1992	6762		7		0.0010	--	7				HL, E	Canamella, et al. 1993
Lower Snake R. (Tucannon)	1992	1067	671	1	2	0.0009	0.0030	216	240	0.39	0.43	HL	Martin et al. 1993
Yakima R. (NF Teanaway & Jack Cr)	1992		55	0	0	--	0.0000					E	Pearsons et al. 1994
Yakima R. (NF Teanaway)	1993	31	28	0	0	0.0000	0.0000					S, E, HL	Harper 1999
Lewis R.	1995-1996	74		1		--	0.0135					N	Hawkins and Tipping 2002
	1997	100	10	2	1	0.0200	0.1000					N	
	1998	3	45	0	54	0.0000	1.2000					N	
Elochoman R.	1999		221		1	--	0.0045					HL	WDFW unpublished
	2000		45		1	--	0.0222					HL	
Kalama R.	2002	266		0		0.0000	--					S	
Deschutes R.	2002	29		0		0.0000	--					S	
Green R.	2002	398		0		0.0000	--					S	
Chehalis R.	2002	35		0		0.0000	--					S	
Skagit R.	2002	4	2	0	0	0.0000	0.0000					S	
Cedar R.	1983-1985	18		0		0.0000	--					E	Beauchamp 1995

Methods

Study Area

The work reported here was conducted in the Deschutes and Green rivers, which drain to Puget Sound in western Washington, and the Coweeman and Kalama rivers which are Columbia Basin tributaries in southwest Washington (Figure 1). The Deschutes River originates in the Bald Hills southwest of Mount Rainier, flows northwest into Budd Inlet at Olympia, Washington, is approximately 80 km in length, and contains few tributaries accessible to anadromous fish. Select species of anadromous fish are provided access to the watershed upstream of Deschutes Falls (RKm 4) via a fish ladder and direct handling at Deschutes Hatchery. A rotary screw trap for smolt capture was operated at the base of the falls at RKm 4. The Green/Duwamish drainage is a complex tributary to Puget Sound near Seattle. The lower 16 km is the Duwamish River draining into Elliot Bay. The Green River is the upper 88 km below Howard Hanson Dam. The smolt trap used for this study was located at RKm 35 on the Green River. The Kalama River is a westerly flowing tributary to the lower Columbia River draining approximately 531 Km^2. An eight foot diameter rotary screw trap is operated at RKm 19. The Coweeman is a smaller tributary to the Columbia River located in Cowlitz County, WA draining approximately 329 Km^2 and trapping was conducted with a five-foot diameter rotary screw trap at approximately RKm 12.

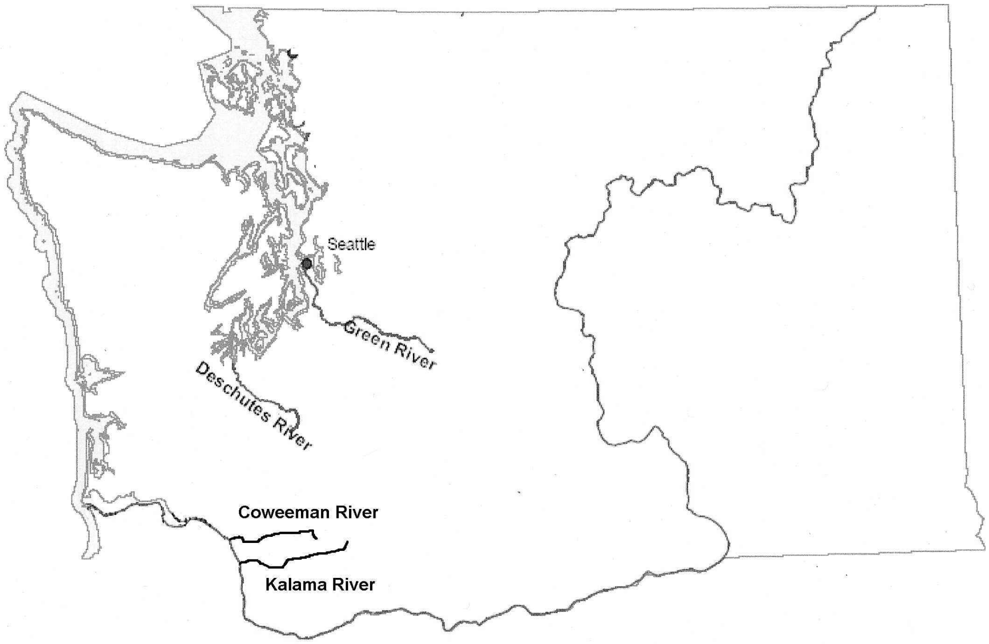


Figure 1. Map of Washington with Green, Deschutes, Coweeman and Kalama rivers.

Generalized Approach and Hypotheses Tested

In the Deschutes River during 2003 through 2005, we manipulated hatchery steelhead release timing and location to try and determine if, for example, an early release into waters containing smaller, more abundant prey or an upper-river release forcing migration through more Chinook rearing reaches were associated with a higher incidence of predation. Our hypotheses in the Deschutes were that early releases and upper-river releases could result in higher incidences of predation on Chinook fry than late (normal-timed) and lower-river releases, respectively. We reasoned that an early release, as early as is permitted under NOAA Fisheries guidelines, would include a larger proportion of steelhead juveniles that had not yet undergone the parr-smolt transformation. The pre-smolt steelhead would, in effect, be forced to reside in waters containing rearing fall Chinook fry and be afforded the opportunity to prey upon them. Manipulation of the release location was intended to force the migration of hatchery steelhead through a larger proportion of the fall Chinook rearing habitat and increase the number of encounters between the potential predators and their potential prey. In the Coweeman during 2005, we released steelhead from acclimation ponds and by direct plant from a hatchery transport truck to determine if either common release method was associated with a higher incidence of predation. Our hypothesis in this case was that fish released from an acclimation pond would consume more fall Chinook fry than steelhead planted directly from a truck due to their experience with natural prey. Directly planted steelhead are nearly naïve in terms of their encounters with natural prey, beyond what they might accidentally come across in their hatchery raceways. Further, directly planted fish might be expected to be undergoing a marked physiological stress response in reaction to loading into the transport truck, the transport itself, and release into a completely novel environment (Schreck 1981). A well-documented part of the secondary response to stress is cessation of digestive processes and feeding (Barton 2002). Conversely, steelhead in acclimation ponds have the opportunity to recover from transport stress, are typically reared at lower densities in an environment more closely approximating natural conditions, and may encounter natural food much more routinely. For example, while performing work for this study, we noted larval and adult insects in both Coweeman acclimation ponds and Chinook fry in one pond, which presumably were entrained from the stream providing water for the pond.

In the Kalama during 2005, we released two groups of hatchery steelhead, one derived from a traditional domesticated stock and one from wild broodstock. For both stocks final rearing occurred in an acclimation pond in the upper watershed and release was volitional. The traditional stock was of Chambers Creek origin (Crawford 1979), a stock in very wide use throughout western Washington exhibiting the characteristic early run- timing, spawn-timing, and relative ease of rearing of a domesticated winter-run steelhead stock. The wild-brood steelhead (both winter- and summer-run) used in the Kalama are of recent hatchery origin with naturally produced adults used as parental stock (Sharpe et al. 2000, Hulett 2004). Our intent in the Kalama was to determine if the level of domestication of the hatchery steelhead stock might be associated with variation in predation on natural prey. Our hypothesis in this case was that the offspring of wild broodstock would exhibit a higher rate of predation than the offspring of domesticated stock. It is important to note that in the Kalama very little fall Chinook production occurs in the watershed reaches where we released steelhead and monitored their migration patterns and diet. Instead, spring Chinook production occurs almost exclusively in monitored reaches. However, we reasoned that spring Chinook juvenile life history (size, temporal and spatial distribution) was similar enough to that of fall Chinook that we could conduct the work and extrapolate the outcome to watersheds with endemic fall Chinook where wild broodstock steelhead are released.

Finally, work conducted in the Green River during 2003 and 2004 involved passive monitoring of migrating steelhead from a variety of sources releasing a very large number of hatchery steelhead at approximately the same time. We did not manipulate the steelhead releases into the Green River in any way and we tested no specific hypotheses. Rather, our intent was to take advantage of an existing smolt trapping operation in a watershed where the opportunity to detect predator-prey interactions was high due to overlap in time and space of hatchery steelhead and fall Chinook fry.

Steelhead Releases

All hatchery steelhead in this study received adipose fin clips prior to release to allow identification upon capture in the traps. In addition, when particular groups of steelhead representing different release protocols (Deschutes, Coweeman) or releases of a specific stock of interest (Kalama) had to be identified, the fish received additional marks (coded wire tags or ventral fin clips). We recorded size (fork length [FL, mm] and weight [WT, gm]) and calculated condition factor for most of the release groups immediately prior to release. In some cases we obtained size data from hatchery planting records. When we obtained size data directly we also recorded a smolt index (SI) score (Beckman 2003) to qualitatively evaluate the readiness of the fish to migrate. A smolt (SI = 3) exhibited silvery, deciduous scales, clear paired fins, and a dark band on the anterior margin of the caudal fin. A pre-smolt (SI = 2) was less silvery with the parr marks partially visible, a trace of color in the paired fins, and a less well-developed dark band on the caudal fin. A parr (SI = 1) had clearly visible parr marks, yellow to orange paired fins, and no evidence of a dark caudal band. A summary of the numbers of steelhead released, size and condition parameters at release, and the marks used for identification is provided in Table 2.

Migrant Trapping and Production Estimates

We used rotary screw traps for migrant trapping in all watersheds. In general, the traps were operated continuously except for brief intervals when debris loaded a trap and had to be removed. In addition, the trap on the Deschutes stopped fishing on four occasions for a total of approximately 472 hr after hatchery fall Chinook juveniles were released from the Tumwater Falls Hatchery. Trappers could not keep up with the large number of hatchery fall Chinook that flooded the trap after the release. Following standard WDFW protocols, if the Deschutes and Green river traps stopped operating for any reason, trap captures immediately before and after the stoppage were used to derive an estimate of "missed catch", which was incorporated into the estimates of total catch. In the Coweeman and Kalama trapping operations, trap operation was essentially continuous and no adjustments were made.

In all traps, all salmonid fish captured were counted, identified to species, and checked for marks. Size (FL and, in some cases, WT) was recorded for representative samples of the captured fish. We were unable to obtain weight samples in all operations because much of the data were collected on board the floating traps and obtaining accurate weights was too cumbersome. After all steelhead releases, every hatchery steelhead captured was inspected to note fin clips and other marks (and, in the Deschutes, presence of a radiotag). Throughout the migration season some of the captured hatchery steelhead in each watershed were subjected to pulsed gastric lavage (described below).

The numbers of juvenile hatchery steelhead migrating in the Coweeman, Deschutes, and Kalama rivers and wild Chinook outmigrants in all four systems were estimated by using a trap efficiency method of releasing marked fish upstream of the trap (Dempson and Stansbury 1991, Thedinga et al. 1994). A variety of marking methods were used for identifying recaptured fish of different species and in different trapping operations. All fall Chinook were marked using the combination of caudal fin clipping and the bismark brown staining method (Steve Neuhauser, WDFW, pers. comm). In the Coweeman and Deschutes in 2005, we used a colored elastomer injectin in the adipose eyelid to mark hatchery steelhead (Sharpe and Glaser 2007). In the Deschutes in 2003 and 2004 we used caudal fin clips (upper and lower lobe). In the Kalama, hatchery steelhead were marked using a Microject^{R} injection of colored pigment into the anal fin. We attempted to use the Microject marking system for Chinook in the Kalama but we were unsuccessful, probably because of the small size of the fish.

Murphy et al. (1996) listed the standard assumptions of the Petersen mark-recapture method that apply in trap efficiency experiments: (1) the population is closed; (2) all fish have the same probability of capture in the first sample; (3) the second sample is either a simple random sample, or if the

Table 2. Summary information on hatchery steelhead released. Values in column labeled “N” depend on the row: “Released” is the number of hatchery steelhead reported as released; “Migrants” is the number of migrants estimated to have migrated past the smolt trap when a standard deviation (SD) is provided and is the raw trap catch when no SD is provided (see text); “Residuals” is the number of steelhead captured by electrofishing or angling. RVAD, LVAD, and AD indicate right ventral + adipose clip, left ventral + adipose clip, and adipose clip only, respectively. ADST indicates adipose clip + coded wire snout tag. “NA” indicates that the data were not available.

Watershed	Release Type or Location	Year of Release	Hatchery of Origin	Identifying Marks	Type	N (±SD)	Fork Length (mm: Mean ± SE)	Weight (gm: Mean ± SE)	Condition Factor (Mean ± SE)	Smolt Index (Mean ± SE)
Coweeman	Turner Creek Pond	2005	Elochoman	RVAD	Released	5100	193.6±1.76	81.2±1.89	1.10±0.09	2.89±0.03
					Migrants	3580±602	201.5±0.89	81.5±1.09	0.89±0.002	2.94±0.01
	Rauth Creek Pond	2005	Elochoman	LVAD	Released	5100	185.8±2.01	70.5±1.95	1.08±0.09	2.75±0.05
					Migrants	2994±425	198.5±0.89	75.3±1.00	0.95±0.004	2.98±0.06
	RKm 21 (Direct Release)	2005	Elochoman	AD	Released	10000	176.0±1.02	56.69	1.04	NA
					Migrants	9174±1139	182.9±0.57	55.7±0.53	0.99±0.004	3.0±0.02
Deschutes	Early Upper Release (@ RKm 40 on 28 April 2003)	2003	Puyallup	LVAD	Released	13000	210.8±1.56	87.3	0.94	NA
					Migrants	1668	208±0.43	84.3±3.2	0.9±0.02	NA
					Residuals	40	215±2.88	98.8±5.7	0.95±0.01	NA
	Late Lower Release (@ RKm 7 on 12 May 2003)	2003	Puyallup	RVAD	Released	14000	210.8	87.3	0.94	NA
					Migrants	1695	207.9±0.45	NA	NA	NA
					Residuals	229	212.9±1.46	99.3±2.19	0.98±0.01	NA
	Upper Release (@ RKm 40 on 5 May 2004)	2004	Puyallup	RVAD	Released	15500	208.1±2.18	90.1±3.16	1.0±0.01	2.5±0.06
					Migrants	1420	199.0±0.82	NA	NA	NA
					Residuals	44	188.3±4.13	72.5±5.10	1.0±0.01	1.8±0.13

Watershed	Release Type or Location	Year of Release	Hatchery of Origin	Identifying Marks	Type	N (±SD)	Fork Length (mm: Mean ± SE)	Weight (gm: Mean ± SE)	Condition Factor (Mean ± SE)	Smolt Index (Mean ± SE)
	Lower Release (@ RKm 7 on 5 May 2004)	2004	Puyallup	LVAD	Released	14900	194.6±2.27	77.1±3.04	1.0±0.01	2.4±0.06
					Migrants	1414	197.0±0.72	NA	NA	NA
					Residuals	42	169.2±5.14	55.6±5.49	1.0±0.01	1.4±0.12
	Early Release (@ RKm 40 on 15 April 2005)	2005	Puyallup	LVAD	Released	12300	182.6±2.26	64.7±2.63	1.0±0.01	NA
					Migrants	2241	196.3±0.55	NA	NA	NA
	Late Release (@ RKm 40 on 5 May 2005)	2005	Puyallup	RVAD	Released	12250	200.5±2.23	77.1±2.53	0.9±0.01	NA
					Migrants	2887	192.1±0.51	NA	NA	NA
Green	All Locations Combined	2003	Various	AD	Released	249315	NA	81.2±1.48	NA	NA
					Migrants	2184	NA	NA	NA	NA
	All Locations Combined	2004	Various	AD	Released	176900	197.2	79.3±3.67	NA	NA
					Migrants	3423	191.1±0.49	NA	NA	NA
Kalama	Wild Brood Winter-run	2005	Kalama Falls	ADST	Released	33232	158.6±4.07	46.6±3.22	1.1±0.01	2.2±0.12
					Migrants	915	179.0±0.72	NA	NA	NA
	Domesticated Brood Winter-run (Chambers Cr. Stock)	2005	Kalama Falls	AD	Released	26500	202.5±3.97	92.6±4.64	1.1±0.01	2.8±0.07
					Migrants	1606	208.3±1.16	NA	NA	NA

second sample is systematic, marked and unmarked fish mix randomly; (4) marking does not affect catchability; (5) fish do not lose their marks; and (6) all recaptured marks are recognized. During the smolt trapping season, we took steps to reduce the possibility that these assumptions were violated. Assumption 1 is that of closure, which assumes that no fish leave or enter between sampling occasions. Since smolts are actively emigrating this assumption cannot be met. However, the Petersen estimate is still consistent if the loss rate of tagged and untagged smolts is the same (Arnason et al. 1996). Therefore, the closure assumption is considered to be met in this study.

We tested for bias caused by violations of the remaining principle assumptions. We reasoned that the most likely violations of assumptions 2 and 3 would be because of a relationship between trap avoidance and size of the smolts, especially with steelhead, where large steelhead might avoid the trap more readily. We addressed this issue by testing for differences in recovery rates by length. Although Seber (1982) recommends a comparison of recaptured fish with those not seen again, this is not possible with the batch marks we used for all species in all trapping operations. For batch marked fish, we followed the recommendation of Thedinga et al. (1994) and compared size (FL) of recaptured fish with the size of all marked fish. Assumptions 4, 5, and 6 were tested by holding marked fish to assess tag loss, tag readability, and handling mortality. Also, we intentionally marked only those fish that were not obviously injured or severely descaled during trapping or handling. Further, we held all marked fish in live boxes for up to 8 h before transporting them to our upstream release sites. This protocol allowed us to release marked fish at or near dark, presumably decreasing the likelihood of predation on the marked fish. Importantly, we were also able to examine all the fish before releasing them. Marked fish that were dead, moribund, or simply swimming erratically were removed from each release group. Fork length of the fish that were removed from the release groups was noted so that those data could be extracted from the database. Taken together, by marking only healthy fish and waiting for delayed negative effects of handling and marking, we increased the likelihood that we were releasing groups of marked fish that were more representative of the populations we were assessing.

Deschutes Release Tests

In the Deschutes, we tested different release strategies for marked hatchery steelhead. We reasoned that, in earlier years of trapping, trap efficiency estimates may have been biased because marked fish were released too close to the trap and too soon after experiencing the handling stresses associated with capture and marking. In previous years, steelhead were anaesthetized (MS222), marked (caudal clipped) and sequestered in 20 l buckets with circulating fresh water until an adequate number (usually 50 or more) were collected. The buckets were then carried upstream, usually after dark, and the fish were poured into rapidly flowing water in a riffle approximately 100 m upstream of the trap. If the swimming performance and, especially, the ability of the marked fish to avoid the trap were compromised by residual effects of anesthesia or stress of capture, handling, transport and release, a larger, non-representative proportion of the marked fish might be captured in the trap. In 2005 we performed the release tests on three occasions (on 18 April, 6 May, and 7 May). An earlier attempt (on 16 April) was aborted because a high flow event loaded the trap with debris and trap operation was deemed too dangerous to proceed. Representative samples of marked fish were released simultaneously into (1) the normal release location 100m above the trap (LOWER DIRECT), (2) a fish ladder at Tumwater Falls Hatchery approximately 400m above the trap (UPPER DIRECT) and, (3) the same fish ladder location but after allowing a recovery period of 24 h in a covered livebox placed on top of a grating over the ladder (UPPER RECOVERED). All steelhead captured in the trap thereafter were then checked for marks.

Hatchery Steelhead Residence Time Estimates

Because the gastric lavage revealed only what the hatchery steelhead had recently consumed, we needed to estimate the average residency time of the steelhead in order to expand the predation rate and obtain an estimate of the total number of fry that might have been consumed. The average steelhead residency time was determined by multiplying the daily trap catch by the numerical date and dividing by the total trap catch over the season. That value was then subtracted from the numerical date and time of each steelhead plant.

Gastric Lavage

A system was developed to perform pulsed gastric lavage on the steelhead. Procedures were similar for all smolt trapping operations. A pressure tank was fitted to a trigger-activated sprayer approximately 10 cm in length. For the Green River and Deschutes trapping operations, the pressure tank was filled by means of an electric pump. On the Coweeman and Kalama the pressure tank was of the type used for hand-pumped garden sprayers. The steelhead were anaesthetized using MS222, length measured, and the sprayer inserted down the esophagus. The trigger was activated several times to ensure that all stomach contents were flushed. Stomach contents were inspected in a shallow plastic pan and categorized as either absent (empty), invertebrates, fish, or non-nutritive debris (commonly, sticks or other plant material). Stomach contents that appeared to contain fish or parts of fish were retained in buffered solution (sodium bicarbonate saturated solution) and later frozen for analysis. In some cases, it was not possible to discriminate between ingested Chinook and coho fry. When that occurred, we took the conservative measure of assuming that the fry was a Chinook.

In 2004, a subsample of the hatchery steelhead captured in the Deschutes trap (N=50) was processed as described above and then the specimens were sacrificed for necropsy to verify the efficiency of the evacuation technique and to estimate the sex ratio of migrant fish.

Radiotelemetry

Radiotelemetry was performed only in the Deschutes watershed and only in 2004 and 2005. On April 27-28 2004, samples of juvenile steelhead intended for UPPER (plant at RKm 40 on 5 May 2004) and LOWER (plant at RKm 7 on the same day) releases were removed from their respective rearing ponds and individually coded radiotags (LOTEK^R MCFT3HM: 2.0 gm, 9 X 20 mm) were surgically implanted following protocols of Hockersmith et al. (2000). After surgery, tagged UPPER and LOWER fish were placed in an above-ground 1m X 5m X 0.6m covered rearing vessel and allowed to recover. On April 12 and May 1 2005, similar radiotags (PISCES^R: 2.2 gm, 8 X 17 mm) were implanted as in 2004. In 2005, the fish were allowed to recover in a standard hatchery pond before trucking and planting with the EARLY (plant on April 15, 2005 at RKm 40)or LATE (plant on May 5, 2005 at the same place) release groups. Just prior to release, all radiotagged steelhead were inspected to ensure that they appeared healthy, loaded into oxygenated fish transport trucks, and taken to their release sites in the Deschutes watershed.

We used a combination of fixed receiver stations and mobile tracking to determine patterns of migration or locate fish that did not successfully migrate. In 2004, fixed stations were established at RKm 43 above the UPPER release site, at RKm 35 immediately downstream of the UPPER release site, at RKm 27 between the UPPER and LOWER release sites, at RKm 7 at the LOWER release site, on the smolt trap at RKm 3, and on Capitol Lake Dam. In 2005, we altered the locations of the fixed stations. The uppermost station was established at RKm 33 (vs. RKm 35 in 2004) because that location afforded easier access, a reliable power supply, and allowed the migrating fish to separate and increase the detection rate. In 2005 we did not have a lower river release, eliminating the need for a station at RKm 7. Receivers were placed on the smolt trap and on Capitol Lake Dam, as in 2004.

Mobile tracking involved a combination of watershed surveys on foot or catarafts and lake surveys to locate tagged fish in Capitol Lake. Lake surveys involved both driving and walking around the circumference of the lake to accurately establish the numbers of tagged fish present in the lake. Later, boat surveys were performed to precisely locate tagged fish in Capitol Lake. In addition, a single survey was conducted in the upper watershed above the upper fixed station to independently determine if any tagged fish had migrated far upstream.

In 2004, the watershed surveys were conducted twice weekly beginning on May 10. For each survey, three or four teams of two technicians each proceeded downstream locating and identifying each radiotagged fish or loose tag using portable radio receivers and a combination of directional (3-Element Yagi) and non-directional antennas. On the first survey each week, an attempt was made to determine if a particular radiotagged fish was alive by precisely determining the location of a tag using the directional antennas for triangulation, wading to that location, and noting if the apparent location of the tag changed. On the second survey each week, one of the technicians used snorkeling equipment to try and directly observe a tagged fish or locate the loose tag. In 2005, surveys were performed once for each release, on 2 through 5 May and on 26 through 27 May and covered the entire watershed below RKm 43, including Capitol Lake.

Residual Sampling

Residual steelhead were sampled in the Deschutes River in 2003 and 2004. Residuals are defined as hatchery origin fish of smolt age that fail to migrate with the remainder of their cohort (Sharpe et al. 2007). In 2003, using both electrofishing and angling, steelhead were captured and anaesthetized (MS222). Fork length, weight and fin clips were noted, and the gut contents were evacuated with pulsed gastric lavage and inspected. In 2003 we sampled fish soon after each release. We recognize that many of these fish might not yet have emigrated but would do so.

Work in 2004 differed in that we used only angling to obtain residuals, captured specimens were sacrificed, and we began angling later (on 15 May) to avoid capturing large numbers of fish that were actually delayed migrants, not residuals. Fork length and weight were noted and a necropsy was performed to check gut contents and determine sex. In both years, gut contents were recorded as described, above.

Abundance Estimation of Fall Chinook Fry

In 2004, we attempted to estimate the number of fall Chinook salmon fry, the potential prey, that were present in the Deschutes watershed at the time of the steelhead release by using mark-recapture techniques. Fry were captured using stick seines and marked by imbedding fluorescent grit in the epidermis of the fish (S. Schroeder, WDFW, pers. comm.).

Fry were sampled and marked between 30 April and 3 May from three river reaches: Lower

(RKm 3.4 to 7.4), Middle (RKm 7.4 to 18.7), and Upper (RKm 18.7 to 26.5). The reaches were arbitrarily defined by access points to the river. We also attempted to sample fry from reaches higher in the watershed (above RKm 26.5). The fall Chinook salmon production zone occurs from RKm 3.4 to 34.

We began seining at RKm 3.5 (immediately above Tumwater Falls) and sequentially sampled upstream to avoid inadvertently recapturing fry that had already been marked. Fry were transported in 20 liter (L) covered buckets to the Tumwater Falls Hatchery where we had assembled marking equipment. The mark was applied by dewatering and suspending the fry in a single layer on a fabric screen and then passing the spray gun containing the powdered fluorescent pigment at a fixed distance twice over the fry.

Lengths (FL; mm) and weights (g) were obtained from a representative sample of the captured fry. After marking, a count was obtained with number of immediate mortalities noted. Live, marked fry were transported back to the reach in which they were captured, transferred to covered, perforated, submerged 20 L buckets for recovery. After dark, at least 4 hours after marking, the fry were released. Delayed mortalities were noted.

Consumption Modeling

We developed a spreadsheet-based model to estimate the total consumption of Chinook fry. The model incorporated the observed consumption rate (Chinook fry/hatchery steelhead stomach: F_S), presumed abundance of hatchery steelhead for each week of the outmigration season (PA_W), and an estimate of the daily evacuation rate (Elliott 1991, Fritts and Pearsons 2004) given the mean weekly water temperature (^{0}C). Incorporating the gastric evacuation rate essentially accounts for fry that were ingested but were not observed because they had already passed through the stomach of the predators. We are not aware of published gastric evacuation rates for piscivorous juvenile steelhead but Elliott (1991) provided estimates for piscivorous brown trout (*Salmo trutta*) of similar size (range 190 – 320 mm) ingesting rainbow trout fry and showed that that gastric evacuation rates increased exponentially with temperature and were independent of prey or predator size. We converted the formulae provided by Elliot (1991) to obtain a formula for calculating the time (days) to evacuate 90% of ingested fry (ET_{90}): $ET_{90} = 2.653e^{-0.114T}$ where T is the average water temperature (^{0}C). Water temperatures were obtained from automatic temperature loggers in each watershed except that, in the Coweeman, the data logger failed and no direct estimates for water temperature were available while the hatchery steelhead were present in that watershed. We did have water temperature data for several weeks after most of the steelhead had emigrated and were able to use a regression approach to estimate earlier temperatures using highly correlated Coweeman and Kalama (the adjacent watershed) temperatures [Coweeman Temperature = 0.652 + (1.146 * Kalama Temperature); $R^2 = 0.81$, $P < 0.001$, see appendix.

Weekly predator abundance (PA_W) was derived by assuming that the weekly raw trap catch of hatchery steelhead adequately reflected the relative abundance of hatchery steelhead remaining in the watershed (i.e., when, for example, 25% or 50% of the total raw catch had been captured, then 75% or 50% of the fish planted remained in the watershed, respectively). Given the number of hatchery steelhead planted (N), the total catch of hatchery steelhead from a particular release (C_T), the cumulative number of hatchery steelhead caught by the end of a particular week (C_W), we estimated weekly predator abundance by: $PA_W = N * C_W / C_T$. Finally, we estimated the number of fry eaten per week (FE_W) by: $FE_W = F_S / ET_{90} * PA_W$ and obtained a total estimate of predation by summing FE_W over all weeks in each watershed. We think that this is a conservative approach to modeling predation in each system because the actual number of potential predators was less than the number of steelhead planted: some of the steelhead must quickly have been lost to avian, mammalian, and piscine predators and other sources of natural mortality. The net result of modeling with over-estimated predator abundance is that the estimates for fry consumption will be biased high.

Statistical Analysis

Abundance estimates for migrating steelhead and fall Chinook were obtained using the Darroch Analysis with Rank Reduction (DARR; Darroch 1961) method employing software (DARR v. 2.0) and documentation provided by Bjorkstedt (2005). For the DARR analyses, trap efficiency estimates were compared over time to determine if trap efficiency remained constant over contiguous weeks. When that occurred, weeks could be pooled thus increasing precision of production estimates over those time intervals. To accomplish this, we used the G-test (Sokal and Rohlf 1981) to compare the proportion of marked fish recaptured among weeks and used the outcomes to determine which weeks for which species could be pooled to generate the final, most precise abundance estimates.

For steelhead releases in the Deschutes and Coweeman, we used the G-test to compare the relative abundance of hatchery steelhead from different release groups in the catch and infer differences in migration timing among the release groups. We also used the G-test to compare the proportions of migrating and non-migrating radiotagged steelhead from the UPPER vs. LOWER and EARLY vs. LATE release groups and to test for deviations from an expected sex ratio of 50% male: 50% female among residuals. We report the calculated “G” statistic for the compared proportions, the degrees of freedom (df) for each test, and the probability (*P*) of test’s significance.

Variance in size between maiden and recaptured fish was examined using the Kolmorogrov-Smirnov (K-S) test. Variance in size over time was examined using the Kruskal-Wallis One Way Analysis of Variance. The non-parametric ANOVA proved to be very sensitive to small sample size, i.e. when a single specimen was captured within a trapping week. Therefore, when that occurred we arbitrarily pooled that specimen with the previous week's collection. We followed the Kruskal-Wallis One Way Analysis of Variance with Dunn's Multiple Comparison Procedure to provide statistical confidence in increasing or decreasing trends in size.

Variance in size among hatchery steelhead before release and after capture in the smolt trap was examined using ANOVA and Tukey's Multiple Comparison Procedure. We also used ANOVA to compare size distributions of Deschutes fall Chinook salmon fry sampled from different river reaches at the time of the fluorescent tagging and to compare migrants to non-migrants among radiotagged steelhead.

We used SigmaStat^{R} version 3.0.1 for most statistical procedures, PopTools Version 2.6.2 (Hood 2004) for G-tests comparing sex ratios, and DARR v. 2.0 to estimate numbers of migrants, and VassarStats (faculty.vassar.edu/lowry/VassarStats.html) to estimate confidence intervals around proportions of radiotagged migrants and estimates of fry per stomach. A significance level for estimated probabilities (*P*) of 0.05 was adopted throughout.

Results

Fry Found in Hatchery Steelhead Stomachs

Between 2003 and 2005, the gut contents of 6,029 hatchery steelhead released into the Deschutes, Green, Coweeman, and Kalama rivers were inspected and 10 Chinook salmon fry were detected (Table 3). Thus, under the release and migratory conditions of the hatchery steelhead and the demographic characteristics of the Chinook salmon in those watersheds, the detection rate was 0.0017 (fry/stomach: 95% CI 0.0009 – 0.0032). Individual watershed, year, and steelhead release estimates are provided in Appendix Table 1.

Size (FL) of hatchery steelhead with fry in their stomachs ranged from 167 to 239 mm (mean ± SE: 193.2 ± 7.1 mm), values closely matching the range and average size of hatchery steelhead routinely released from the hatcheries (Table 2).

Migration Timing and Overlap

In the Green and Deschutes rivers, the majority of the Chinook fry emigrated before the hatchery steelhead were released. We assume that the same is true for the Chinook in the Coweeman and Kalama watersheds, but in those rivers smolt traps were installed after early migrants were presumed to have left. In southwest Washington, smolt traps are operated on Cedar Creek, tributary to the Lewis River and on Abernathy Creek, tributary to the lower Columbia nearly year-round. In those watersheds, Chinook migrants do exhibit the characteristic bimodal pattern of migration (Volkhardt 2005) that we found in the Deschutes and Green rivers (Puget Sound) and we assume that Coweeman and Kalama patterns do not differ.

In most cases, the Chinook juveniles that were available as prey were small enough to be consumed throughout the time that the hatchery steelhead were migrating (Figures 2-4). For each of the panels in Figures 2-4, the size trajectory over time of Chinook migrant fry and smolts captured in each trap is provided (left axes). In general, migrants captured during the initial period of the trapping operations were numerous, small and uniform in size, indicating the fish were newly emerged or nearly so. Also provided (Figures 2-4) is an indication of the upper size limit of Chinook that could be ingested by hatchery steelhead planted in that watershed in that year (44% FL of the steelhead smolts captured in each of the traps). It is important to note that the size threshold is derived from the size of the steelhead smolts captured in the trap, not the size of the juveniles released from the hatchery programs. The actual size of the fish planted was not available from hatchery records for all plants. However, as indicated in Table 2, captured migrants were generally larger than fish planted, when data were available to make that comparison.

Table 3. Number of Chinook salmon fry in the stomachs of hatchery-origin yearling steelhead.

River System	Year	Release Group	Sample Type	Steelhead Checked	Fry Detected
Deschutes R.	2003	EARLY UPPER	Smolt Trap	521	0
		LATE LOWER	Smolt Trap	684	1
		EARLY UPPER	Residual	40	0
		LATE LOWER	Residual	229	0
	2004	UPPER	Smolt Trap	554	0
		LOWER	Smolt Trap	812	0
		UPPER	Residual	40	0
		LOWER	Residual	46	0
	2005	EARLY	Smolt Trap	795	3
		LATE	Smolt Trap	468	1
Green R.	2003	ALL	Smolt Trap	231	0
	2004	ALL	Smolt Trap	903	0
Coweeman R.	2005	POND	Smolt Trap	236	3
		DIRECT	Smolt Trap	232	2
Kalama R.	2005	WILD BROOD	Smolt Trap	99	0
		DOMESTIC BROOD	Smolt Trap	139	0
	TOTAL			6,029	10

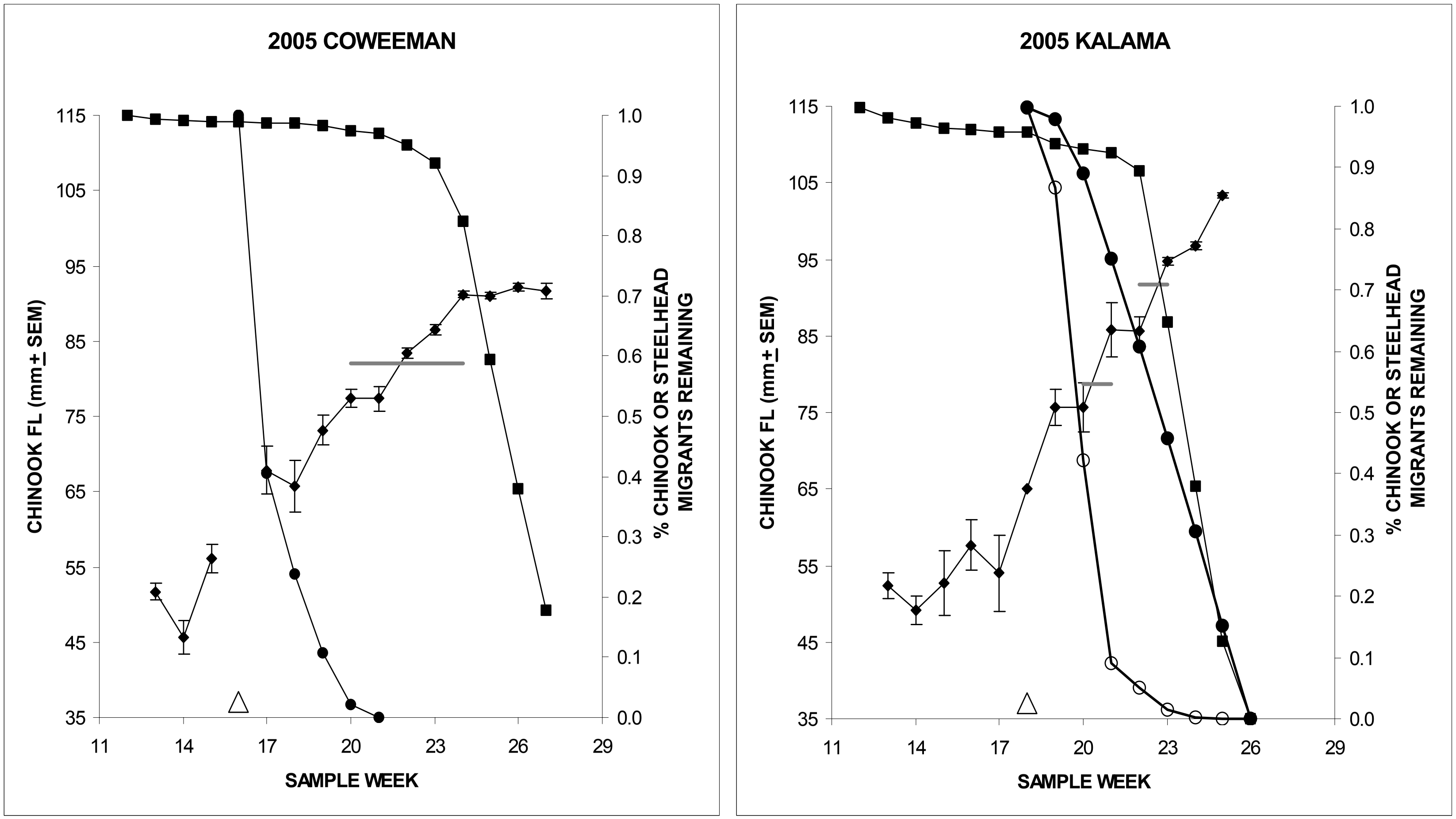


Figure 2. Coweeman and Kalama rivers patterns of migration (right axes) of hatchery steelhead (circles) and wild fall Chinook (squares) with size of migrant fall Chinook over time (diamonds, left axes, mean + SE). For the Kalama in 2005, open and closed circles indicate HWR (domesticated) and WWR (wild-origin) broods, respectively. The triangles indicate time of steelhead plant(s). The thick grey lines on the Chinook size trajectories indicate the prey size susceptibility threshold (the Chinook size equal to 44% of the size of hatchery steelhead captured in that watershed in that year -- see text). For the Kalama (right panel), the lower and upper grey lines refer to thresholds for WWR and HWR steelhead, respectively

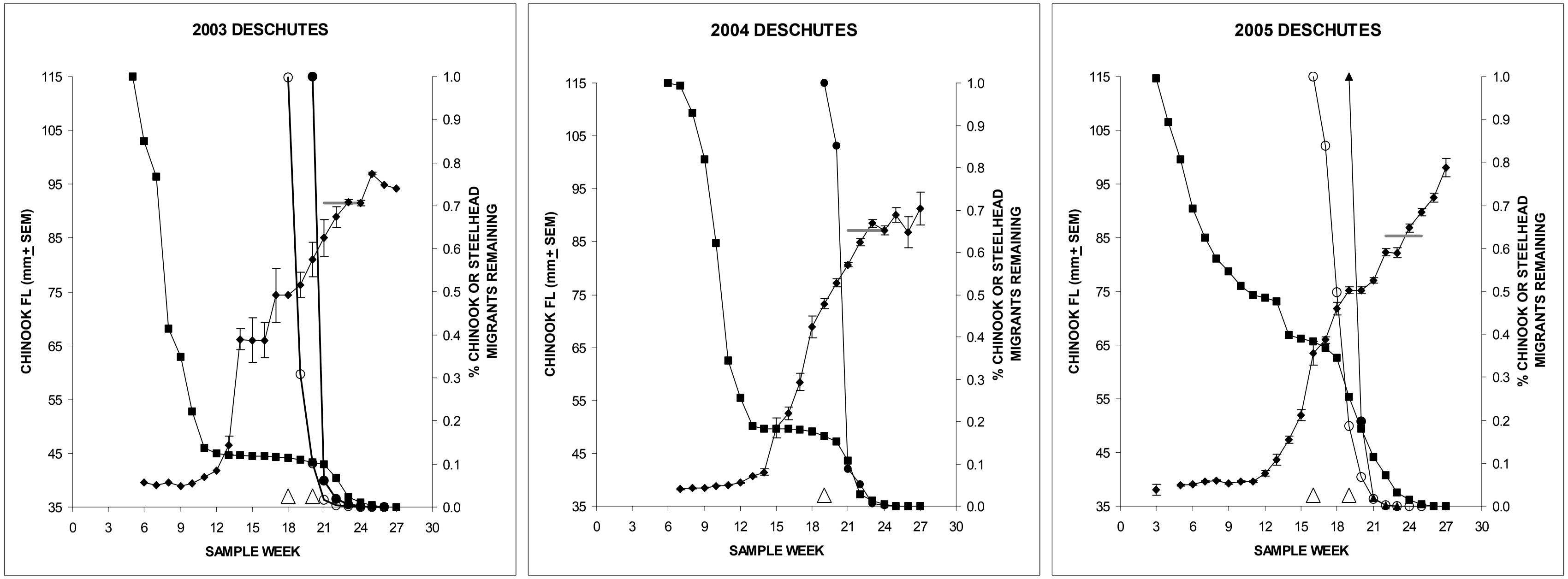


Figure 3. Deschutes River patterns of migration (right axes) of hatchery steelhead (circles) and wild fall Chinook (squares) with size of migrant fall Chinook over time (diamonds, left axes, mean + SE). In 2003 and 2005, open and filled circles indicate early and late plants, respectively. The triangles indicate time of steelhead plant(s). The thick grey lines on the Chinook size trajectories indicate the prey size susceptibility threshold (the Chinook size equal to 44% of the size of hatchery steelhead captured in that watershed in that year -- see text).

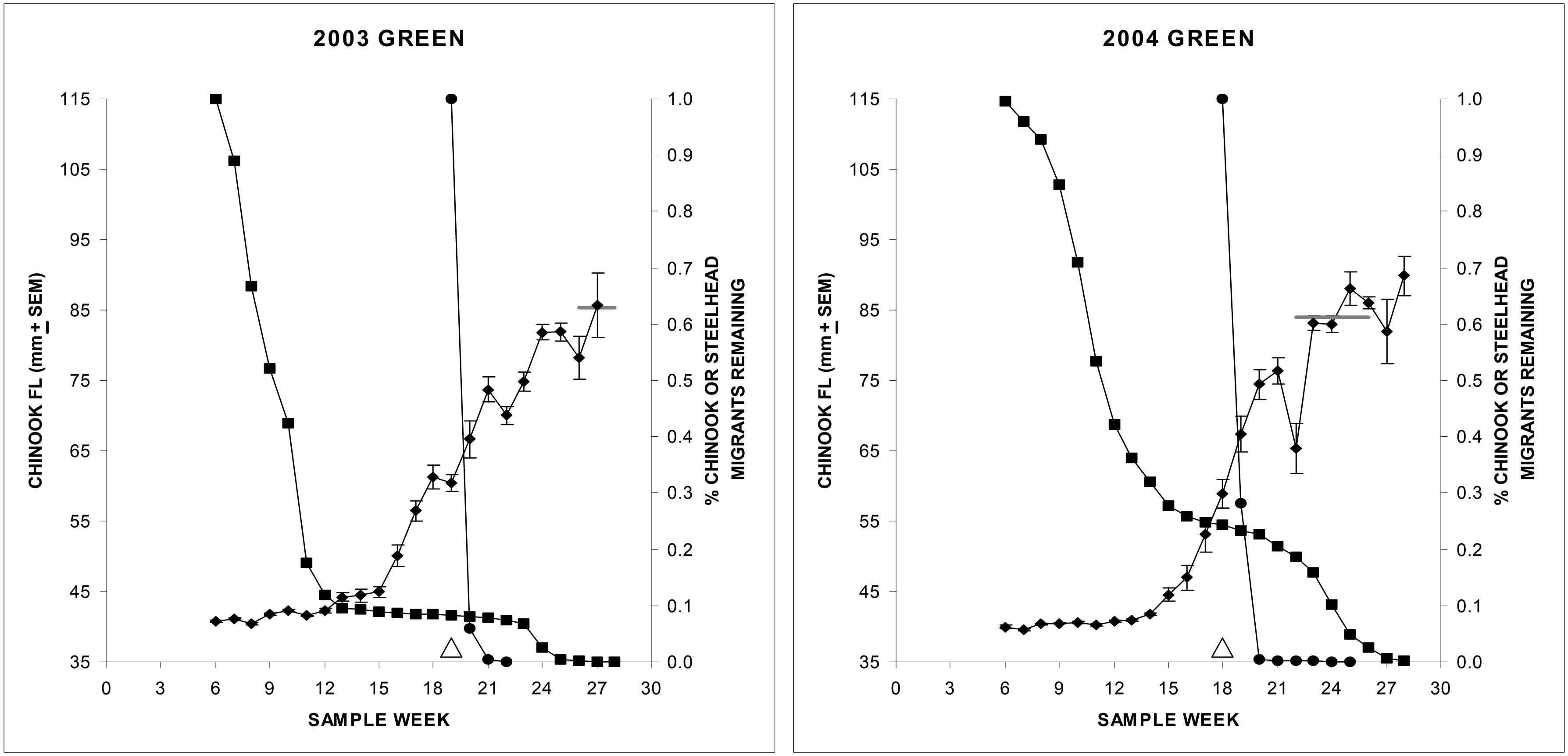


Figure 4. Green River patterns of migration (right axes) of hatchery steelhead (circles) and wild fall Chinook (squares) with size of migrant fall Chinook over time (diamonds, left axes, mean + SE). The triangles indicate time of steelhead plants. The thick grey lines on the Chinook size trajectories indicate the prey size susceptibility threshold (the Chinook size equal to 44% of the size of hatchery steelhead captured in that watershed in that year -- see text).

An indication of overlap in time between potential predators and prey is also provided in each panel of Figures 2-4 as the percent migrants of each species remaining in each watershed over time (right axes). The curve representing the Chinook migrants is derived from the actual abundance estimates (weekly trap catch adjusted by weekly trap efficiency estimates). The curve(s) representing steelhead migrants is derived from the raw weekly trap catch because we were generally not able to reliably estimate trap efficiency for that species (see Hatchery Steelhead Migration and Abundance Estimation section, below). In general, the largest proportion of Chinook emigrated before hatchery steelhead were released (an observation in all years for the Green and Deschutes rivers; an assumption for the Coweeman and Kalama rivers in 2005). In most cases, hatchery steelhead were released at approximately the same time that subyearling Chinook smolts began to appear in the traps. With one exception, virtually all hatchery steelhead that did emigrate did so before the Chinook migrants reached an average size too large to be consumed by the steelhead. The exception is the wild brood Kalama steelhead in 2005 (discussed below).

In General, Deschutes River 2003 to 2005 results indicated that steelhead releases early and/or high in a watershed extended the time of overlap between potential predators and prey. In 2003, the average residency times for the EARLY UPPER and LATE LOWER releases were 5.3 and 2.2 d, respectively. In 2004, the average residency times for UPPER and LOWER releases were 3.5 and 2.2 d, respectively. In 2005 the average residency times for EARLY and LATE plants were 8.7 and 2.9 d, respectively. Average residency time results clearly showed that late plants and, especially, late plants in the lower watershed were associated with the least time that steelhead migrants overlapped with potential prey.

Radiotelemetry

In 2004, 72 and 74 radio tags were surgically inserted into LOWER and UPPER Deschutes River-released steelhead, respectively. All of the fish receiving surgery survived throughout the recovery period until release. All of the fish were actively swimming in the recovery vessels at the time they were captured for loading and transport. We were not able to determine if all the fish were actively feeding throughout the recovery period but some were based on the presence of feces in the tank. All of the radiotags were transmitting continuously throughout the recovery period. In 2005, 50 and 49 radiotags were surgically inserted into Deschutes River EARLY release and LATE release steelhead, respectively. All 50 EARLY tags transmitted continuously during the recovery period before transport and release. Only 45 of the LATE tags were transmitting on May 4, the day before transport and release of that group. In addition, only 45 radiotagged fish were counted into the transport truck. We assume that four of the radiotagged

LATE fish escaped the raceway or were removed by an unobserved predator. Data for those fish were excluded from further analysis.

In 2004, radiotelemetry showed that 84% of the radiotagged fish entered Capitol Lake (Figure 5). A larger proportion of the tagged steelhead released in the lower river (LOWER: 92%) entered Capitol Lake than steelhead released in the upper river (UPPER: 77%), a difference that is statistically significant (G-test, G=5.98, df=1, *P*=0.01). For both radiotagged and non-radiotagged steelhead entering Capitol Lake, 90% did so within 9 d after release with migration timing of the steelhead released in the upper Deschutes watershed lagging behind the fish released in the lower watershed by approximately one to two days. Among radiotagged fish, migrant and non-migrant fish differed in length with migrants approximately 25 mm longer (FL: t-test; $P < 0.001$; Figure 6). It is not the case, however, that non-migrant fish were uniformly small fish; considerable overlap was apparent in the length distributions of migrant and non-migrant fish (Figure 7). Still, the non-migrants were not necessarily all residuals; they may include fish that were migrating but died before reaching the trap.

We compared the FL, WT, and condition factor between radiotagged migrants and non-migrants (see Figure 6) in each set of releases in each year (2-way ANOVA with migrant vs. non-migrant as the first factor and UPPER vs. LOWER [2004] or EARLY vs. LATE [2005] as the second factor). In 2004, we found no differences in length, weight, or condition factor between releases ($P = 0.419$, 0.558, 0.275, respectively) but within site-specific releases migrants were longer, heavier, and less robust ($P \leq 0.001$, P = 0.001, and P = 0.041, respectively) than non-migrants. In contrast, in 2005, we found no differences in length, weight, or condition factor between migrants and non-migrants ($P = 0.75$, 0.729, and 0.878, respectively) but EARLY fish were shorter, weighed less, and were more robust than LATE fish ($P \leq 0.001$, $P = 0.048$, and $P \leq 0.001$, respectively).

In 2005 two of the 50 radiotagged fish in the early release and two of the 45 radiotagged fish in the late release were never detected after planting. We assume those fish were immediately removed from the watershed by predators and they are excluded from further analysis. Thus, in 2005, inferences on migration patterns for radiotagged steelhead were drawn from 48 steelhead planted early and 43 steelhead planted late. Twenty-eight of the 48 radiotagged steelhead planted early (EARLY: 58%) and 35 of 43 steelhead planted late (LATE: 81%) entered Capitol Lake (see Figure 5, bottom panel), a difference that is statistically significant (G-test, G = 5.7, df = 1, $P = 0.017$). As in 2004, the average time for radiotagged migrants to enter Capitol Lake was greater than the estimates derived from smolt trapping, suggesting again that radiotagging did delay migratory behavior (see section entitled Radiotelemetry vs. Smolt Trapping).

Fall Chinook Migration and Abundance Estimation

Deschutes River

In all years, Deschutes River fall Chinook exhibited bimodal emigration timing characteristic of Puget Sound Fall Chinook (WDFW unpublished data) with most of the fish emigrating before any steelhead plants occurred (Figures 2-4). In all years trap efficiency estimates varied significantly over time and thus final estimates of fall Chinook migrants (Table 4) are derived from separate mark-recapture intervals. In 2003, 2004, and 2005, we captured 30,760, 85,899, and 24,839 fall Chinook migrants, respectively, between mid-February and mid-June. We marked and released 1,295, 3,479, and 5,120 juveniles in those years, respectively and recaptured 195, 781, and 1,402 to generate our estimates of trap efficiency.

We attempted to derive a mark-recapture estimate of the absolute number of Chinook fry available as prey in the Deschutes near the time of the steelhead plant by pigment marking rearing fry and then recapturing them as emigrating smolts. We believe that that effort was not successful because, as noted below, the abundance estimates we obtained were unrealistically high. However, we report the results here to provide a complete record of the work. We captured, pigment-marked and released alive 864 fall Chinook fry between April 30 and May 4, 2004. The fry varied significantly in length and weight among the three sample reaches (Figure 8 a and b). The patterns of variation suggest that fry size increased upstream (ANOVA: $P < 0.001$). Despite our attempts, no fry were captured above RKm 27. All fry in the subsamples were smaller than 44% of the mean length of hatchery steelhead planted on May 5 2004 (Figure 8 c).

Of the 864 marked fry, 28 were recaptured in the screw trap between May 5 and June 13, 2004. A total of 15,164 fry were trapped over that time interval and checked for marks. Thus, the estimate for number of fry present in the watershed at the time of the steelhead plant is 452,335, a number far in excess of the total estimated emigration of juvenile fall Chinook past the trap after May 5 (114,019) and is suggestive of either a very high fry mortality rate in the last few weeks prior to emigration or an inaccurate estimate of fry abundance at the time of the steelhead plant. Some fry may have lost their marks through severe descaling on 29 May 2004, the date when the single largest number of marked fry were noted (11 fish). Because of an error in trap operation, the live box became overloaded with fish overnight on that date, significant mortality of both steelhead and fall Chinook occurred, and the trap operators noted great difficulties in detecting the mark. On that date, the single largest daily number of potentially marked juvenile fall Chinook migrated past the trap. We conclude, therefore, that it is more conservative to use as an abundance estimate for the number of prey available for consumption the total number of fry emigrating past the trap after the steelhead are planted in each watershed (see Table 4).

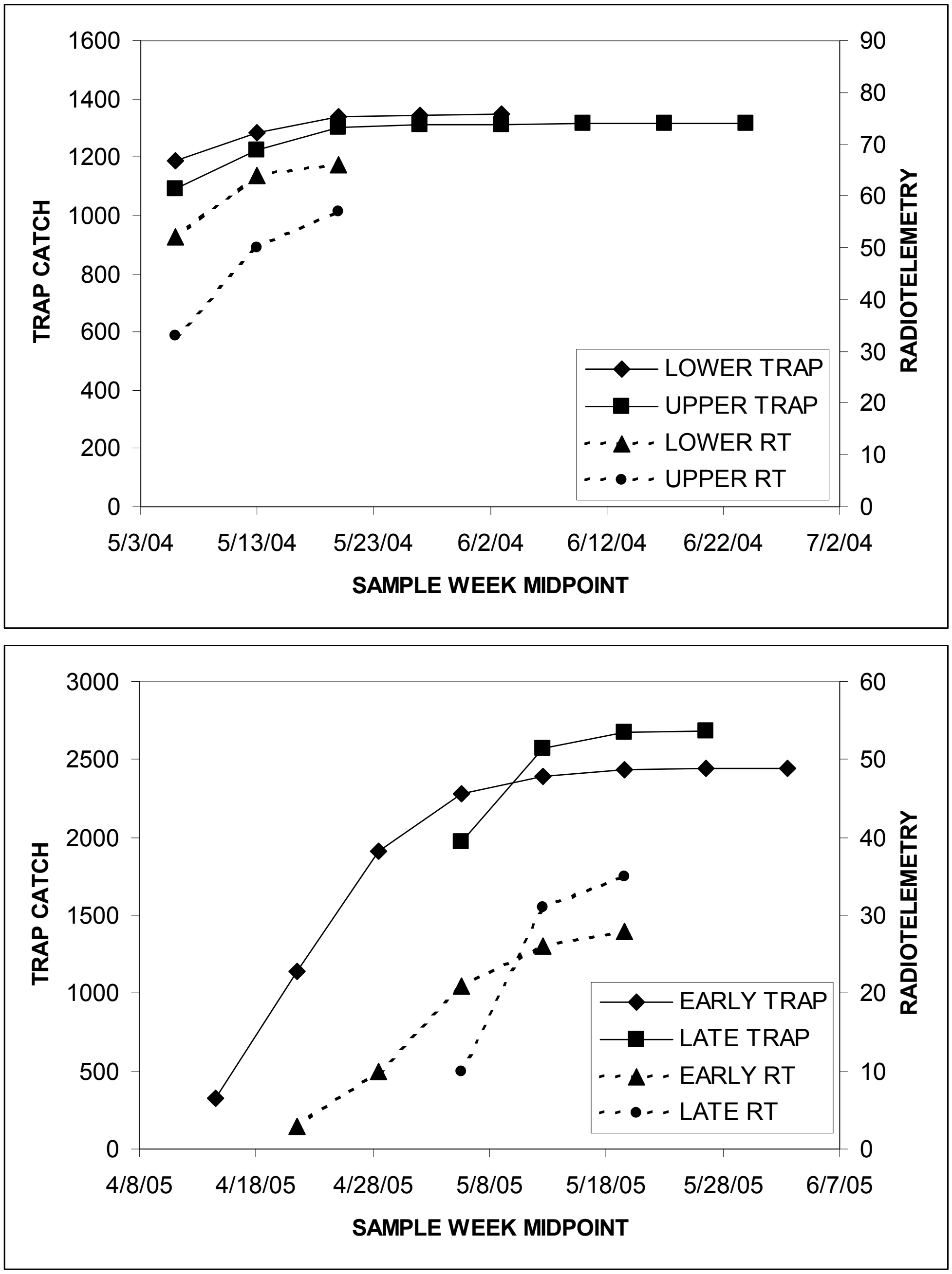


Figure 5. Entry of radiotagged (RT) and all smolt trapped hatchery steelhead into Capitol Lake in 2004 (top) and 2005 (bottom). Solid lines indicate the cumulative counts of all steelhead captured in the Tumwater Falls rotary screw trap (left axis). Dashed lines indicate cumulative counts of radiotagged fish passing the Tumwater Falls Trap radiotelemetry fixed station (right axis).

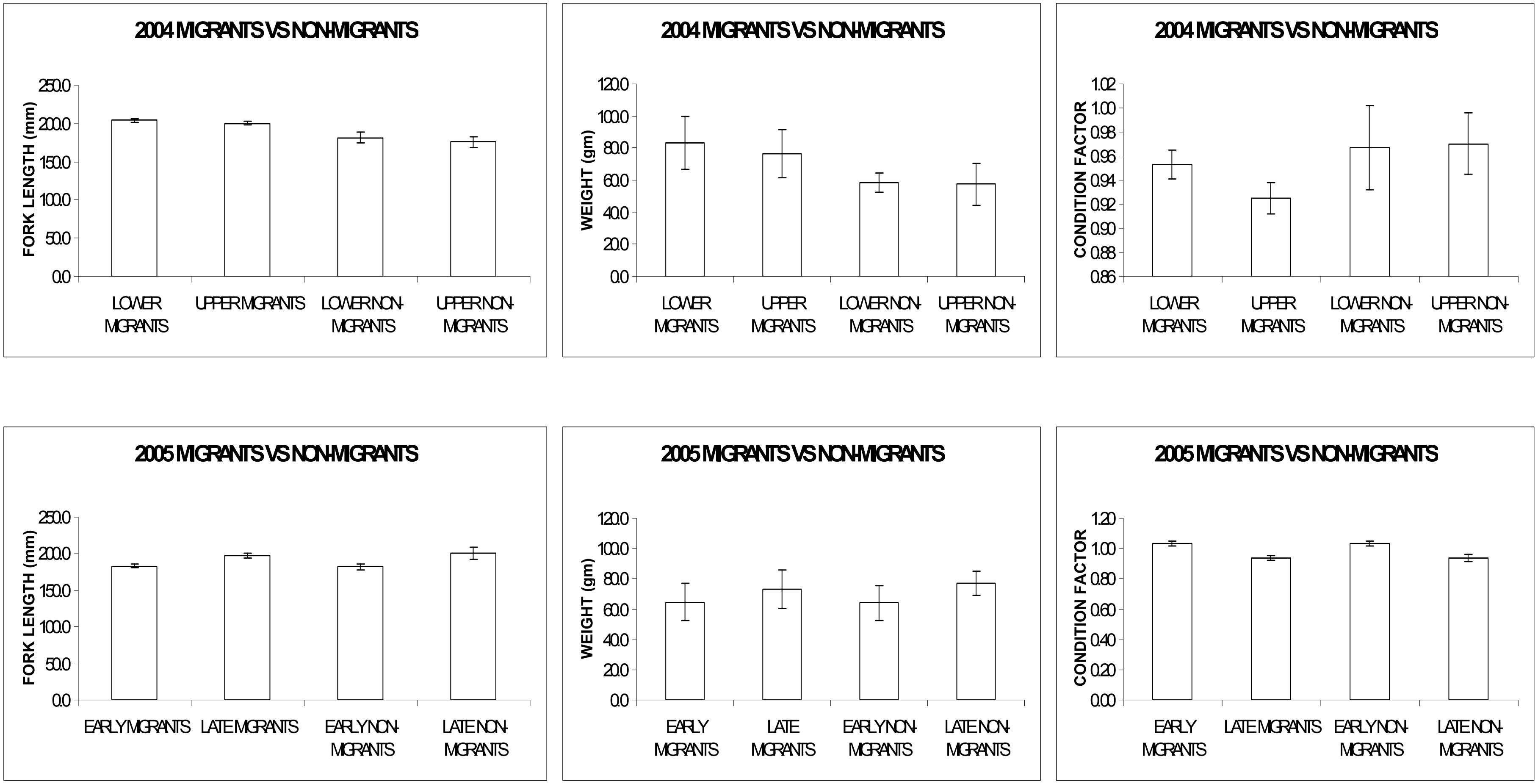
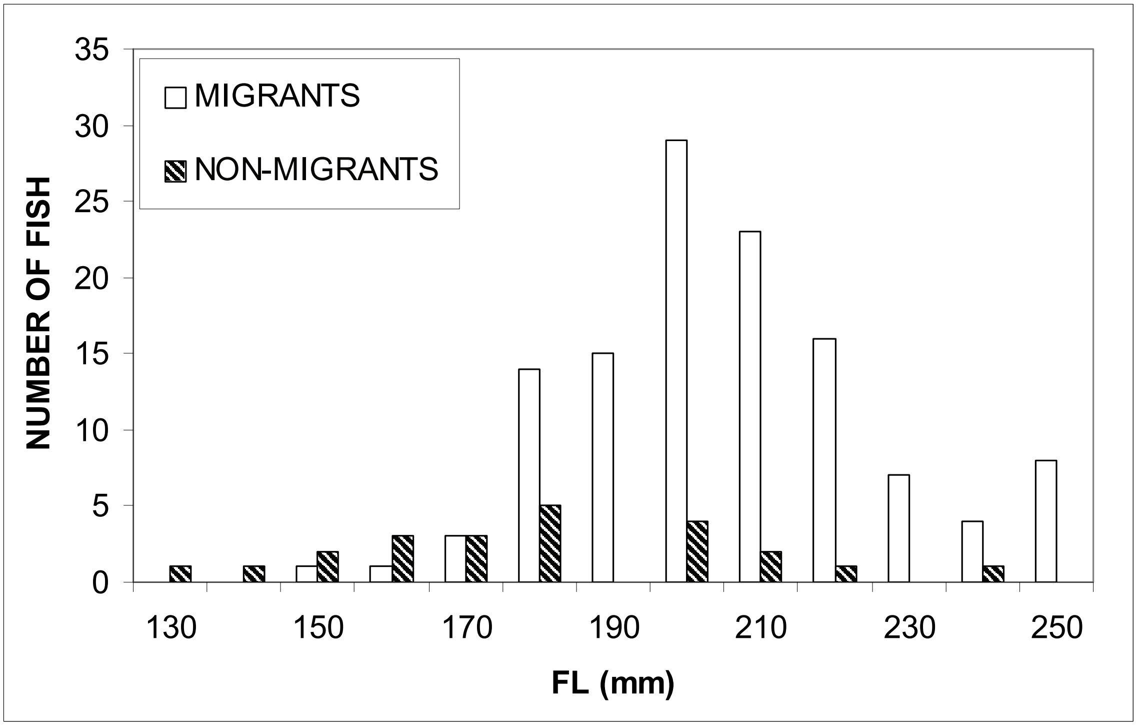


Figure 6. Fork length, weight, and condition factor (+SE) of Deschutes River migrant and non-migrant hatchery steelhead, determined from size of radiotagged fish at the time of surgery for fish that passed the Tumwater Falls trap (MIGRANT) and fish that were not detected at the Tumwater Falls trap or in Capitol Lake (NON-MIGRANT) in 2004 and 2005.



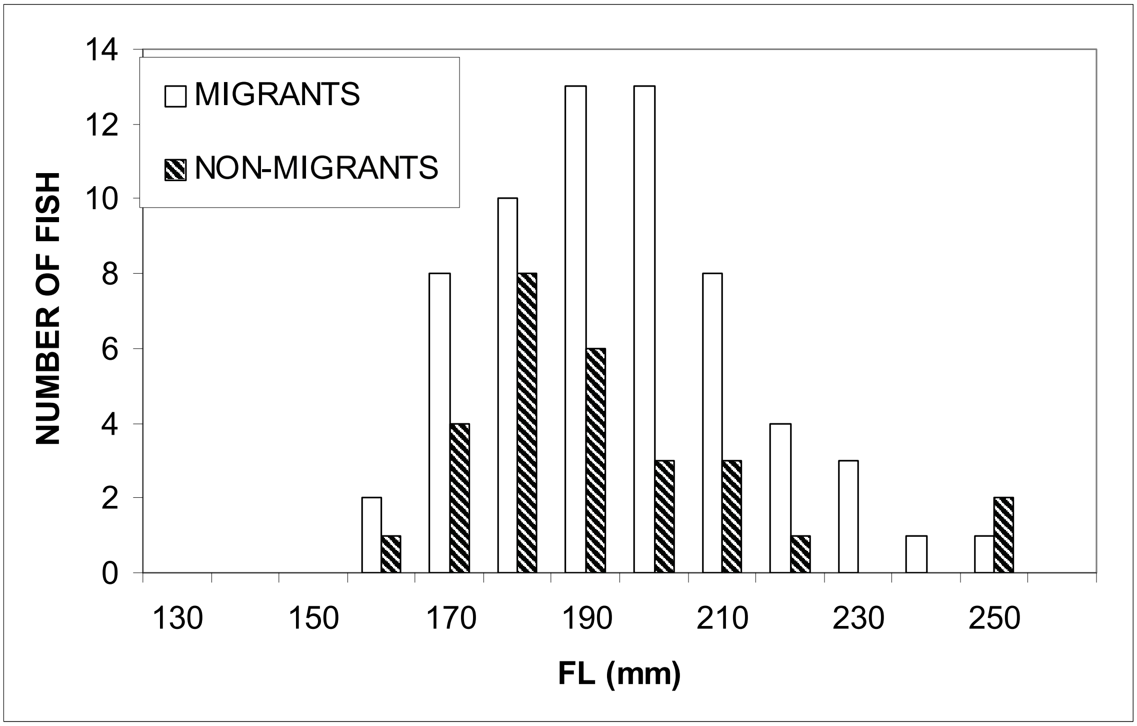


Figure 7. Size frequency distributions for migrants entering Capitol Lake and non-migrants (hatchery steelhead that did not reach Capitol Lake) in 2004 (top) and 2005 (bottom). Fork length data are from surgical records. Criteria for migrants vs. non-migrants are from radiotelemetry records only.

Table 4. Estimated number of fall Chinook migrants from each watershed in each year that the data are adequate to derive the estimates (i.e. Kalama River data are excluded – see text), percent, and number of fall Chinook migrating after hatchery steelhead are planted.

Watershed	Year	Fall Chinook Migration Estimate (SD)	Estimated Percent Fall Chinook Migrants After Steelhead Plant	Minimum Number of Fall Chinook Available to Hatchery Steelhead as Prey
Coweeman	2005	52,126 (3,258)	99%	51,605
Deschutes	2003	296,018 (56,038)	11%	32,562
	2004	441,715 (28,010)	17%	75,092
	2005	102,306 (6,876)	38%	38,876
Green	2003	246,449 (28,073)	8%	19,716
	2004	232,782 (21,080)	23%	53,540

Green River

The timing of emigration of fall Chinook and changes in mean size of migrants in the Green River were similar to those in the Deschutes River (Figures 2-4). In 2003 we captured 17,792 fall Chinook migrants, 1,719 were marked and released, and 163 were recaptured. In 2004 we captured 11,185 fall Chinook migrants, 4,901 were marked and released, and 291 were recaptured. Abundance estimates are provided in Table 4.

Coweeman River

In the Coweeman River, we captured 10,081 subyearling fall Chinook and marked for recapture 1,276. We recaptured 218 marked fish throughout the course of the migration between 26 March and 8 August 2005, the dates that the first and last wild Chinook migrants were noted in the trap, respectively. Importantly, very large numbers of subyearlings likely emigrated soon after emergence in January, February, and March, before we began trapping (Pat Hanratty, WDFW, pers. comm.) and some Chinook were still being captured each day of trap operation at the end of the season. The production estimate provided herein is thus an estimate of abundance of emigrants in late Spring and early Summer and, at that, is biased low since migrants were still leaving when the trap was removed.

Trap efficiency estimates ranged from 8% to 23% with highly significant differences among capture intervals (G-test, G = 19.3, df = 7, *P* <0.01). Thus, it was necessary to partition the production estimate among trap intervals (weeks). We reasoned that trap efficiencies for Chinook subyearlings likely varied inversely with flow. Because a smaller proportion of the stream passed through the trap at high flow, a lower trap efficiency was achieved at high flow (early season; Figure 9). Further, at low flow later in the season a higher proportion of the stream passed through the trap (but the trap was still operating at 7 RPM or greater, a speed more than adequate to entrain subyearling Chinook). We iteratively tested contiguous subsets of the weekly trap efficiency estimates to see if some could be pooled to increase precision of the overall production estimate. Of the eight intervals with efficiency estimates, weeks one through four were statistically homogeneous (G-test, G = 2.53, df = 3, $P = 0.47$) as were weeks 5 through 8 (G-test, G = 2.98, df = 3, $P = 0.39$). Independent emigration estimates for those two pooled intervals were summed and the production estimate for fall Chinook leaving the Coweeman in

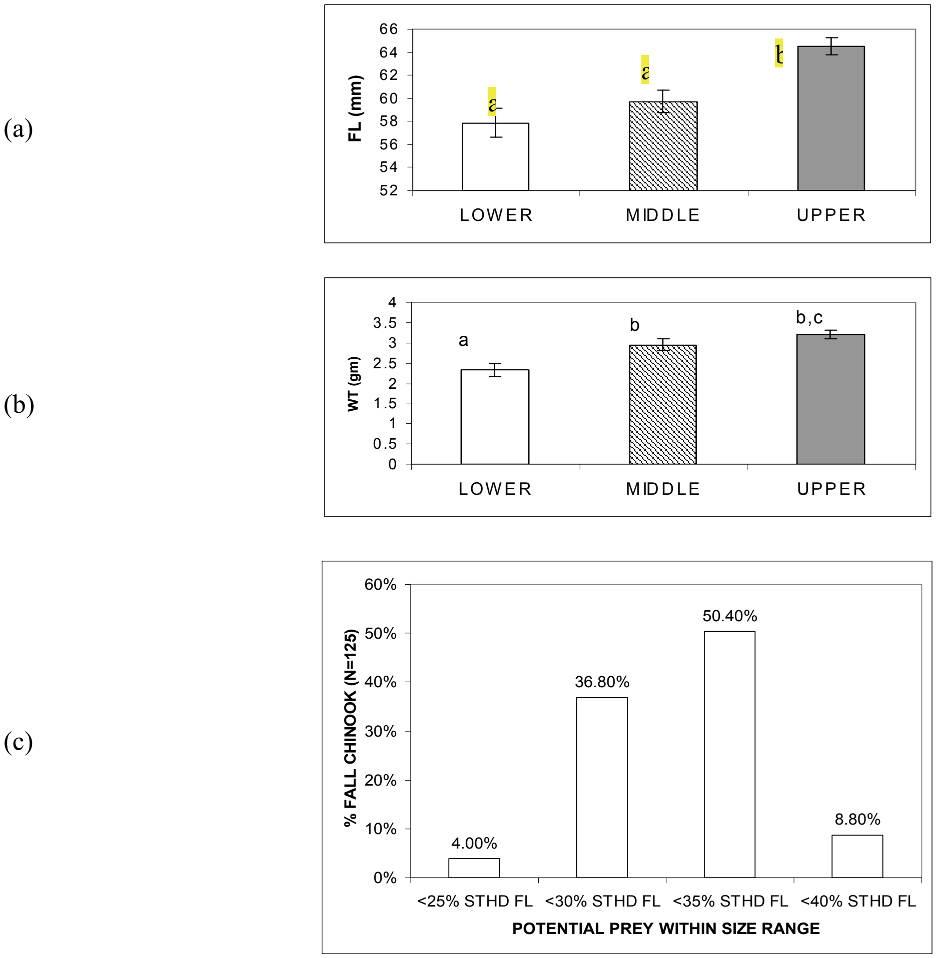


Figure 8. (a) Fork length (FL; +SE), (b) weight (WT; +SE) and (c) size frequency distribution of Deschutes River fall Chinook fry subsampled from fish captured for fluorescent marking. N = 30, 30, and 65 for lower, middle and upper subsamples, respectively. Both fork length and weight differed significantly among samples (ANOVA: $P < 0.001$). When letters labeling each bar differ, the pairwise test (Tukey's Multiple Comparison Procedure) indicates a statistically significant difference ($P < 0.05$) between any pair. Fall Chinook fry size distribution is expressed relative to mean size of the hatchery steelhead that were planted (200 ± 1.3 mm).

spring and early summer 2005 (N ± SD) was 52,126 ± 3,258. Nearly all of these fish emigrated after the steelhead plant on 15 April 2005.

As noted, trap efficiency estimates were only obtained for the early portion of the trapping season (19 May through 13 July). Thereafter, we could not tag or transport fish because of high water temperatures that increased mortality of fry during marking. We did attempt to relate estimated trap efficiency to estimated flow and derive an adjusted trap efficiency for trapping intervals 16 through 19 when flows decreased and efficiency could have increased. However, the relationship was not statistically significant (Linear Regression, *P* = 0.059: Figure 10). Therefore, after 13 July, we assumed that the trap efficiency remained constant. Still, the statistical power of the test was low (Power = 0.473) and inspection of Figure 10 does suggest a negative relationship between flow and trap efficiency. For future work, increased precision in estimates of flow or trap efficiency or both might permit a better estimate of late-migrating fall Chinook. If the trap efficiency estimates used for the DARR analyses were biased high, actual estimates of fall Chinook production are further biased low and, for the purposes of this report, more fall Chinook would then have been available as prey.

Fall Chinook subyearling smolt emigration from the Coweeman was protracted and late, beginning in early June and peaking late that month. The timing of the emigration was unexpected because in other Lower Columbia tributaries (Pat Hanratty, WDFW, pers. comm. for Abernathy, Germany and Mill Creeks;

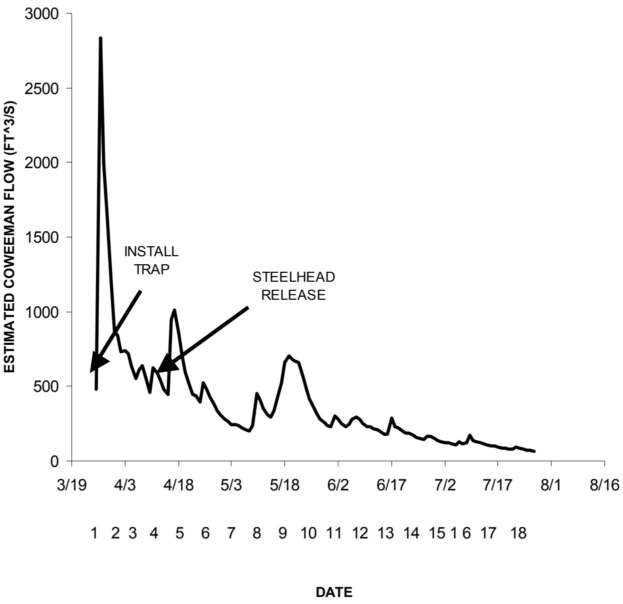


Figure 9. Estimated daily mean flows in the Coweeman. X-axis has date and the 1 to 18 trapping intervals.

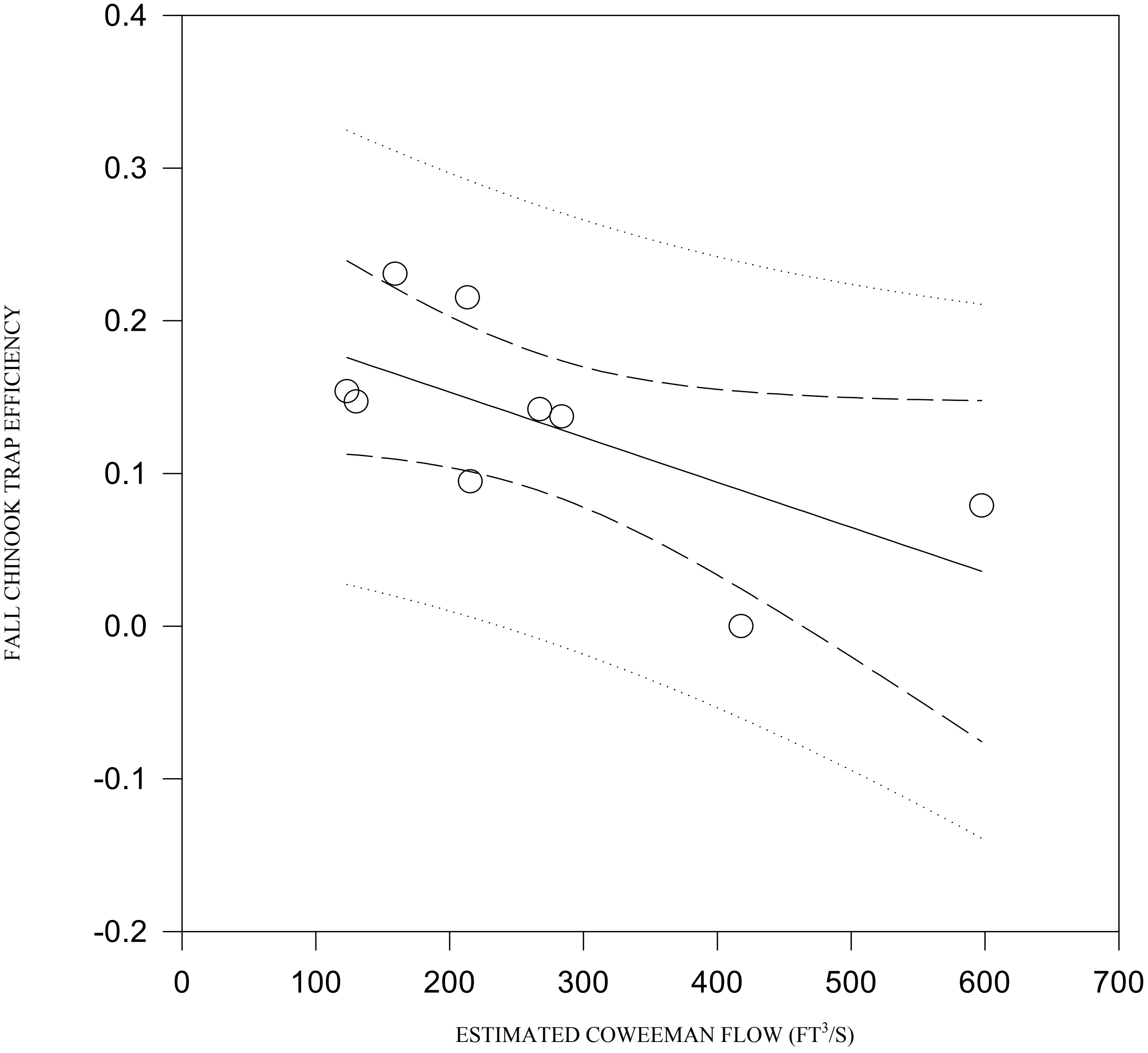


Figure 10. Relationship between Coweeman estimated trap efficiency for fall Chinook and estimated flow for trap intervals 8 through 15 with regression line (solid) 95% confidence intervals (dashed) and prediction intervals (dotted) shown. Relationship is not statistically significant. See text.

Dan Rawding, WDFW, pers. comm. for Cedar Creek) and in the authors' (CS, PT, HF) experience in Puget Sound watersheds, significant emigration begins in March and ends early in June. Size of the emigrants increased significantly over time among the migrants (Kruskall-Wallace, $P < 0.001$; Figure 4).

Kalama River

As noted, few fall Chinook spawn in the reaches of the Kalama watershed where we conducted our work. Rather, Chinook production was from approximately 2,967 spring Chinook (1,258 females) passed upstream in 2004 (WDFW 2004). Trapping in the Kalama began on 17 March and ended 22 June 2005. Total capture of naturally produced Chinook subyearlings was 795 fish. Because we did not obtain reliable estimates of trap efficiency for this species, we cannot calculate an estimate of total emigration of Chinook fry in 2005 from the Kalama River.

Hatchery Steelhead Migration and Abundance Estimation

Deschutes River

In 2003, a total of 3,397 hatchery steelhead were captured from two releases, 28 April (EARLY UPPER) and 12 May 2003 (LATE LOWER), of 27,000 fish total. Four separate releases of marked steelhead 100m above the trap generated trap efficiency estimates ranging from 3% to 20%, averaging 10% (Table 6). Using average trap efficiency, we calculated a total abundance estimate of 35,138 ± 5,901 (N ± SD) migrants. Given that we found highly significant differences among trap efficiency estimates (G-test, $G = 20.5$, df = 3, $P = 0.0001$), the presumably more appropriate use of separate trap efficiencies across trap intervals generated an abundance estimate of 61,303 ± 32,757 (N ± SD) migrants. Both estimates are considerably larger than the 27,000 steelhead reported as planted. We conclude that in 2003 Deschutes trap efficiency estimates were biased low.

In contrast, in 2004, given the total capture of 2,677 migrants from 30,500 fish planted and an estimated trap efficiency of 17.6% (26 recaptures of 148 marked fish), trap data predicted that 15,238 ± 2,711 (N ± SD) steelhead emigrated from both releases (UPPER and LOWER combined, 48%). In 2004, trap efficiency estimates did not differ across trapping intervals (G-test, $G = 0.296$, df = 2, $P = 0.5$). The 2004 abundance estimate was lower than the number of fish planted and, while some steelhead fail to migrate after planting, the estimate was sharply lower than expected based on 2004 radiotelemetry data (most radiotagged steelhead migrated), and was not supported by observations on relative abundance of residuals we attempted to capture by angling (both discussed below). We conclude that in 2004 our Deschutes trap efficiency estimates were biased high.

In 2005, steelhead trapping results closely matched those obtained in 2003, i.e., substantially more fish were estimated from trapping data than were planted (approximately 24,550 fish). The total trap capture was 5,127 (EARLY and LATE, combined). Trap efficiency estimates varied widely (nine separate tests, G = 26.4, df = 8, *P* = 0.001; see Deschutes Release Tests, below) but averaged 10%. Assuming that efficiency estimates can be pooled across the season, the overall estimate of steelhead migrants in 2005 was 52,833 ± 5,539 (N ± SD), an estimate far in excess of the number of fish actually planted. We conclude that, as in 2003, trap efficiency estimates were biased low.

We do not think that inaccurate planting records are the reason that the smolt-trap estimates differed so markedly from what was reported as planted. While estimates of fish loaded into a planting truck can vary by as much as 15% from the number actually loaded (Tipping, WDFW, pers. comm.), the Deschutes plants would have had to have been up to twice (or more) larger in 2003 and 2005 and one-half as large in 2004. We think that it is far more likely that our estimates of trap efficiency were in error in all years (discussed in the section entitled Deschutes Steelhead Release Tests, below).

Because of the difficulties in obtaining accurate or precise estimates of steelhead migrants based on the Deschutes trapping operation, a more appropriate use of Deschutes steelhead data is for general description of steelhead migration patterns. For example, the data do permit expression of when steelhead from the various releases first appeared in the trap, the relative abundance of steelhead throughout their migration, and the time steelhead stopped migrating.

Green River

In 2003, 857 hatchery steelhead were captured between 12 February and 13 June, the dates that the first and last hatchery steelhead were captured in the watershed, respectively. Twenty-four of those fish (2.8%) were captured before the 2003 steelhead plant of 249,315 smolts on 1 May and 7 May and thus must be from an earlier year's plant, escaped fish, or some unknown release. In 2004, the trap catch of 3,423 hatchery steelhead occurred between 3 February and 13 June, the dates that the first and last hatchery steelhead were captured, respectively. Eleven of those fish (0.3%) were captured before the 2004 steelhead plant of 176,900 smolts between 26 April and 10 May 2004 and must be from potential sources mentioned above. Hatchery steelhead migration patterns shown in Figures 2-4 were derived only from fish captured after the known plants in 2003 and 2004. Average residency time for steelhead planted in the Green was 9.4 and 7.9 days in 2003 and 2004, respectively.

Coweeman River

An estimated 20,200 hatchery winter-run steelhead were recorded as delivered from the Elochoman Hatchery -- 10,000 for direct release and 5,100 each for two acclimation ponds (but see below). All releases occurred on 15 April 2005. We captured 1,967 hatchery smolt and presmolt steelhead and marked 1,046. We recaptured 129 marked fish throughout the course of the migration between April 15 and May 26, 2005, the dates that the first and last hatchery steelhead migrants were noted in the trap, respectively. Trap efficiency estimates ranged from 7% to 14% but did not vary significantly among capture intervals (G-test, $G = 0.95$, $df = 3$, $P = 0.81$). Thus, after pooling recaptures across trapping intervals, the production estimate for emigrating hatchery steelhead from the Coweeman watershed in 2005 was 15,666 ± 1,285 (N±SD). Hatchery steelhead from the three release groups began migrating in large numbers immediately after release. The average residency time across all releases was 7.4 days. Overall, the size of the hatchery steelhead emigrants decreased significantly over time, paralleling the pattern noted for wild steelhead (data not shown). Direct plant steelhead were significantly smaller than acclimation pond fish at the time of planting (Table 2; t-test, $P < 0.05$).

Some problems with the Coweeman steelhead release became apparent after the project began. In pre-release samples for fork length and weight from the two acclimation ponds, hatchery coho salmon were noted. In Turner Creek pond, three of 103 fish sampled were hatchery coho: two were adipose clipped and one was both adipose and right ventral fin clipped. In Rauth Pond, out of 105 fish sampled, five were hatchery coho: one was adipose clipped and four were both adipose and left ventral clipped. In addition, we captured 138 hatchery coho in the smolt trap. Sample sizes from acclimation ponds were inadequate to accurately estimate actual coho abundance, and we do not know if a similar proportion of hatchery coho were included with the 10,000 steelhead planted directly. Still, if we use a trap efficiency for wild coho (approx. 10%, Sharpe and Glaser 2008) as a proxy for trap efficiency of the hatchery coho, approximately 1,300 hatchery coho were inadvertently planted in the Coweeman, a watershed not intended by WDFW to receive hatchery coho (B. Glaser, WDFW, pers. comm.).

If the total steelhead plant was actually ~18,900 fish (20,200 fish – 1,300 coho), a high proportion of the plant (83%) actually migrated. A higher proportion of acclimated fish appeared to migrate than direct plant fish (Table 2; ANOVA, $P<0.001$). This may be an outcome of the fact that direct plant fish were smaller than those from either acclimation pond group (Table 2; ANOVA, $P<0.001$). Mean size of migrants captured in the trap was greater than mean size of fish from each group at release (Table 2; ANOVA and Tukey's Multiple Comparison Procedure, $P < 0.001$).

Kalama River

We trapped 2,521 hatchery winter-run steelhead between 25 March and 21 June 2005. Of these, 1,606 were from domesticated broodstock (HWR) and 915 were from wild broodstock (WWR). A total of 311 hatchery steelhead (both groups combined) were marked and released upstream of the smolt trap. Seventeen were recaptured throughout the season. Trap efficiency estimates did not differ significantly across intervals (G-test, G = 1.47, df = 4, *P* = 0.83). However, the total number of recaptures was so low that we reasoned the statistical power to detect differences was also low and pooling trapping intervals was not warranted. Also, because recaptures were low, we made an important, un-tested assumption that we could combine HWR and WWR marks and recaptures despite size and timing differences between the groups. The final estimates for HWR and WWR steelhead past the trap were 29,966 ± 7,507 and 15,263 ± 4,037 (N ± SD), respectively. Our estimates for the number of fish planted from each group were 33,232 HWR and 26,500 WWR so we conclude that approximately 90% and 60% of the HWR and WWR fish successfully migrated past the trap, respectively

An important distinction regarding Kalama steelhead releases is that the winter-run steelhead are released volitionally from their acclimation pond in the upper watershed. The time of release (28 April 2005, Figure 2, right panel) is the time that steelhead are given the opportunity to emigrate (i.e., the screen blocking emigration was removed). Earlier work monitoring migration patterns of these fish (Hulett et al. 2004; Sharpe et al. 2007) showed that the domesticated-origin fish were larger, displayed a higher smolt index (Table 2) and left the pond more quickly with fewer fish expressing residualism. Wild broodstock juveniles expressed a more protracted emigration from the pond, which translated into delayed appearance at the trap (see Figure 2). This delay in migration may affect Chinook predation potential. If Kalama WWR continued to rear in the pond, they were not necessarily exposed to Chinook fry. The estimated average residency time of the Kalama steelhead was 21.4 and 15.7 days for WWR and HWR, respectively.

Deschutes Steelhead Release Tests

In prior years, Tumwater Falls trap efficiency estimates were obtained by releasing marked fish into rapidly flowing water approximately 100 m above the trap location immediately or soon after the marks were applied. We reasoned that the release location's proximity to the trap and/or lack of a stress recovery period might alter the behavior of marked fish relative to behavior of unmarked fish, violating a principle assumption of mark/recapture protocols. In 2005 on 18 April for the hatchery steelhead EARLY release we marked and released UPPER RECOVERED (fish given 24 h to recover from capture, marking and transport), UPPER DIRECT (same release as UPPER RECOVERED but without a recovery period), and LOWER DIRECT (the normal release protocol 100 m above trap without recovery). Recapture rates from the various Deschutes releases suggested a trend for a higher recapture rate for fish released close to the trap without a recovery period (Figure 11), but there were no statistically significant differences among recapture rates (G-test, G = 1.18, df = 2, *P* = 0.55).

From LATE (May 6-7, 2005) release group tests we recaptured UPPER RECOVERED, UPPER DIRECT, and LOWER DIRECT fish at rates of 16, 2, and 12%, respectively. The May 6 release test was severely compromised because fish were initially captured so quickly we exceeded the holding capacity of the trap's live boxes. Many of the captured fish lost equilibrium before they could be tagged and were released directly. Of fish we did tag, approximately 5% were dead or moribund just prior to release and were excluded from the release group. We are reasonably certain that fish we did release, although upright and swimming at the time, were also distressed. Therefore, we discount the outcome of the May 6 release test and report those results here only to provide a complete record of the work (Figure 11).

On 7 May, we took greater care in controlling the number of fish held for marking at any one time. Marking, transport, and release occurred without any mortality. Recapture rates for UPPER RECOVERED, UPPER DIRECT, and LOWER DIRECT were 5, 6, and 13%, respectively, an outcome matching the pattern for EARLY release tests (Figure 11) but, again, not significantly different (G-test, $G = 4.49$, $df = 2$, $P = 0.11$).

Deschutes Estimates from Radiotelemetry vs. Smolt Trapping

In both 2004 and 2005, abundance estimates for hatchery steelhead migrants differed substantially depending on whether they were derived from the smolt trapping operation or the radiotelemetry tracking data. In 2004, a small proportion of the total plant was accounted for by smolt trapping with no significant differences in the relative abundance of fish from LOWER and UPPER release groups. In contrast, the radiotelemetry data in 2004 indicated that, overall, most fish migrated but a relatively smaller proportion from the UPPER release did so. In 2005, migrant estimates based on smolt trapping indicated a much larger number of steelhead migrants than were actually planted in the watershed. Both radiotelemetry and smolt trapping estimates did, in 2005, show a significant difference in the relative abundance of emigrants from the EARLY and LATE release groups (LATE > EARLY).

In summary, radiotelemetry results suggested that the majority of hatchery steelhead did migrate in each year, and smaller proportions of the UPPER and EARLY plants were detected emigrating than LOWER and LATE, respectively. Those outcomes were as expected given that UPPER (2004) fish had to migrate further to reach the smolt trap and EARLY (2005) plant fish were smaller, less ready to smolt and had to survive longer in freshwater before they could emigrate. Estimates derived from smolt-trapping were either unusually low (2004) or impossibly high (2005).

Emigration patterns based on smolt trap data match those from radiotelemetry data in that 90% of the trapped fish were trapped 9 or fewer days after release (Figure 5). Also, fish released at the upper site took an additional day to reach the trap (average residency times for UPPER and LOWER releases were 3.5 and 2.2 days, respectively). However, no difference in the relative abundance of smolt-trapped fish released from the different sites was apparent (i.e., the relative proportions of fish from the upper and lower release sites did not differ from expected proportions given the numbers of fish planted at each site [G-test, $G = 0.07$, $df = 1$, $P = 0.79$]). Peak migration of all radiotagged fish appeared to be delayed by approximately 1-2 days compared to untagged fish captured in the trap (Figure 5).

We attempted to use the radiotagged fish as an independent estimator of trap efficiency because radiotag antennae were unlikely to be missed by trap operators. In 2004, 123 of 146 radiotagged fish were known to have passed the smolt trap because they were detected either by receivers at the smolt trap or Capitol Lake dam or by mobile survey of the lake.

Of the 123 detected migrants, 17 were captured in the smolt trap and inspected by trap operators. Trap efficiency was 13.8% based on the trap captures. This 13.8% estimate did not differ significantly from the 17.5% estimate based on standard mark-recapture methods described above (G-test, $G = 0.48$, $df= 1$, $P = 0.49$). In 2005, 63 radiotagged fish entered Capitol Lake based on electronic detection and 11 were captured in the smolt trap, yielding an overall trap efficiency estimate of 17.5%.

In 2005, 5,127 hatchery steelhead were captured in the smolt trap (2,447 EARLY and 2,680 LATE). We estimated that 24,550 steelhead were planted (12,300 EARLY and 12,250 LATE). Assuming that every steelhead emigrated, trap efficiency would have to be in excess of 20% to account for the total number of fish captured. In contrast, the 2005 radiotelemetry data suggested that 58% of the EARLY plant (95% CI: 0.42 – 0.72) and 81% of the LATE plant (95% CI: 0.66 – 0.91) migrated. If the true number of migrants was 17,056 (the number planted per release group multiplied by percent radiotagged migrants per group), trap efficiency would have to have been in the range of 30%, a value greater than any we ever actually obtained.

In summary, none of the 2004 trap efficiency estimates were adequately low to explain the low number of migrants actually captured and none of the 2005 trap efficiency estimates were adequately high to explain the high number of migrants captured.

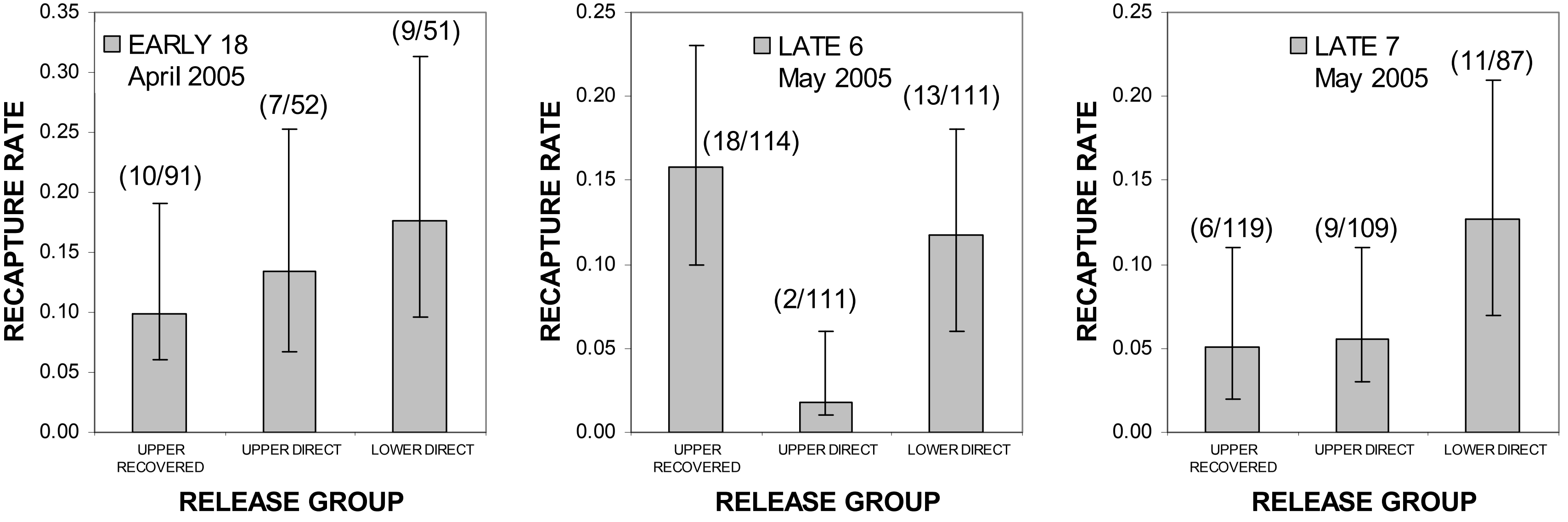


Figure 11. Results of three steelhead release tests in the Deschutes River in 2005. Y-axis is proportion of marked fish recaptured from each release. Actual recaptured to marked fish numbers shown above bars. "UPPER RECOVERED" indicates fish marked and released after recovering in a live box for 24 h after capture, marking, and transport to the release site at TFH. "UPPER DIRECT" indicates fish released at the same time and location as "UPPER RECOVERED" except without a recovery period. "LOWER DIRECT" indicates fish released 100 m above trap immediately after marking. Error bars are 95% confidence intervals.

Deschutes Residuals

In 2003, 269 hatchery steelhead (2002 brood year) were captured by electrofishing (N = 252) or angling (N = 17) between 29 April and 20 May in the Deschutes River. None contained fall Chinook fry. In 2004, 90 residual steelhead (2003 brood year) were captured by angling between May 15 and 20 and, again, none contained fall Chinook fry. Four of these steelhead were from the 2002 brood release and were excluded from further analysis except to note stomach contents. Of the eighty-six 2003 brood specimens, 42 and 44 were from the lower- and upper-river releases, respectively. Both fork length and weight differed significantly between LOWER and UPPER residuals with UPPER residuals larger than LOWER residuals, an outcome in agreement with the differences in size at release noted above (ANOVA, $P < 0.001$ and $P = 0.002$ for FL and WT, respectively).

The sex ratio of all residuals was strongly biased towards males (G-test, G=11.49, df=1, $P < 0.001$). Of the males, the majority (61%) were sexually maturing. Twenty-two percent were precociously mature and an additional 39% had enlarged testes, the latter indicating that they were likely to reach maturation the next year.

Gastric Lavage Comparisons

Gastric lavage was effective for evacuating stomach contents. Of the 50 Deschutes hatchery steelhead receiving gastric lavage followed by necropsy (2004) to see if any stomach contents remained, 49 had completely empty stomachs. A single stomach had a trace (approximately 1mm^3) of unidentified material lodged in the distal portion of the stomach. Forty-five of the fish originally had some material in their stomachs. Thus, a conservative estimate of evacuation efficiency was 98% (44/45). Actual efficiency was probably higher since most of the gut contents in the specimen that still had material in it was evacuated. The necropsies also afforded the opportunity to determine sex ratio of the migrating fish. Sex was determined on 48 of the 50 necropsied fish with 24 females and 24 males (50%F:50%M), an outcome exactly matching the expected ratio.

The sex ratio of fish captured as residuals in the Deschutes River (74% M: 26% F) contrasts sharply with the sex ratio of fish captured as migrants in the smolt trap (50% M: 50% F). If, as the 2004 Deschutes smolt trap data suggested, approximately one-half of the steelhead failed to migrate, we should have noted a deviation from equal sex ratio in the gastric lavage trap sample because proportionately more males would not have migrated. Assuming a 50% residualism rate, the sex ratio of smolt-trapped fish should have been approximately 26% male to 74% female. A G-test comparing the observed number of males (24) and females (24) in the trap sample to expected numbers based on this extrinsic hypothesis (12 males and 36 females should have been observed) was statistically significant (G = 6.39, df = 1, *P* = 0.012). If, as 2004 radiotelemetry data suggested, 85% of the steelhead migrated, the expected number of males and females in the smolt trap sample should have been 22 and 26, respectively. Those values do not differ significantly from the observed (G = 3.84, df = 1, *P* = 0.69). These results suggest that the estimate of hatchery steelhead migrants derived from smolt trap data was an underestimate and supports our decision to limit the use of those data to a qualitative description of emigration patterns of Deschutes steelhead.

Percent Impact of Hatchery Steelhead Plants on Fall Chinook Populations

Given predator abundances from each release for each week during the period when fall Chinook fry were present (Figures 2-4), the overall observed number of fry per stomach examined (Table 3), and our estimates of gastric evacuation rates as they varied over time (Appendix Table 3), we estimated that a grand total of 10,688 fry might have been consumed in the Deschutes (2003 – 2005), Green (2003 and 2004), and Coweeman (2005) rivers. Given that we estimated nearly two million fry were produced from those watersheds over those years (Table 4), approximately 0.32% of fry produced might have been consumed by hatchery steelhead. Of course, far more fry were actually produced than were accounted for by trapping estimates because many fry were removed by other predators or otherwise died of natural causes before they had the opportunity to emigrate. Therefore, while we measured the overall effect of hatchery steelhead on fall Chinook at 0.32%, that proportional impact is very likely an overestimate, assuming more Chinook fry were present than we could measure during the period of hatchery steelhead outmigration. Expressing the total potential fry consumption as a proportion of the total fry actually available as prey during the steelhead migration (late Chinook sub-yearling migrants), approximately 1.62% of that portion of the total Chinook cohort might have been consumed by hatchery steelhead. Again, this is most likely an overestimate of predation impacts because more subyearling Chinook must have been present in watersheds but died before emigrating.

Although the number of hatchery steelhead stomachs checked was large, the presence of a fry in a stomach was such a rare event that confidence intervals around predation estimates were large (0.00173 fry/ stomach; 95% CI: 0.0009 – 0.0032 fry/stomach). Therefore, we repeated the modeling exercise described above using the upper confidence limit as the number of fall Chinook fry observed per hatchery steelhead stomach. Using this value, 19,806 fry might have been consumed overall, representing 0.60% of our total fry production estimate and 3.00% of Chinook migrating as subyearling smolts.

In our simulations it appeared that residence time of hatchery steelhead drove the magnitude of predation risk. We converted the model output from total fry potentially consumed to fry consumed per hatchery steelhead planted and ranked those values from lowest to highest (Figure 12). When hatchery steelhead emigrated quickly (e.g., Green 2003 and Deschutes LOWER LATE in 2003), the apparent incidence of predation was low. When emigration was protracted (e.g., Deschutes EARLY in 2005 and both Deschutes plants in 2004) the apparent incidence of predation was high. In addition, water temperatures later in the season tended to be higher, estimates of ET_{90} decreased, and apparent total predation increased (data not shown).

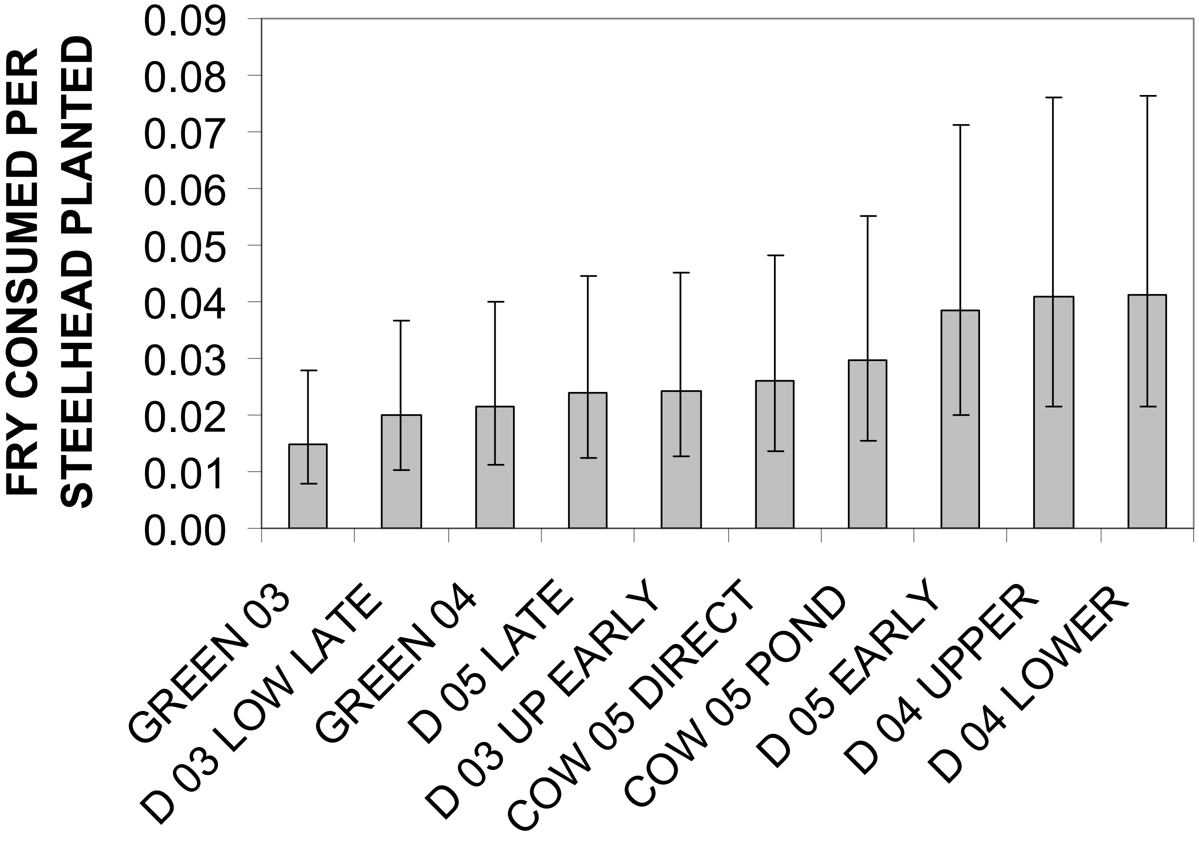


Figure 12. Modeled fry consumption for hatchery steelhead plants in the Green, Deschutes (D) and Coweeman (COW) Rivers. Error bars are 95% confidence intervals derived from model input when upper and lower 95% confidence limits were entered as the fry/stomach parameter.

Discussion

In all watersheds over all years tested, large numbers of migrant hatchery steelhead averaging approximately 200 mm FL migrated through waters containing Chinook fry small enough to be consumed (averaging less than 88 mm FL). We estimated that 0.00173 (95% CI 0.0009 - 0.0032) fry/steelhead had recently been ingested. We compared our observed fry/stomach values to those reported in the literature (Table 1). Across all the studies listed in Table 1, overall fry detection rate was 0.0064 (71 fry/11,073 stomachs examined), a value heavily influenced by the number of fry detected in Lewis River in 1998 (54 fry in 48 stomachs). Excluding 1998 Lewis River data yielded an overall detection rate of 0.00154 fry/stomach (17 fry/11,025 stomachs), very similar to our estimate (0.00173 fry/stomach). We think Lewis River 1998 predation results may reflect particular local demographics of fall Chinook where very large numbers of small, late emerging fry were available as prey in the lower river downstream of hatchery steelhead release sites.

Based on modeled patterns of steelhead predation, we concluded that the impact of hatchery steelhead on fall Chinook – the percent of fall Chinook juveniles eaten by hatchery steelhead – was at most 0.6%. One striking outcome of the modeling is that it reinforced our assumptions related to the likely consequences of planting steelhead early. In 2003 and 2005 in the Deschutes when the plants occurred early and late, the early releases were associated with protracted residence times, relative to the late plants. Since fish planted early overlapped temporally with fall Chinook fry, more fall Chinook were eaten. While the model did not specifically include variation in prey abundance as one of its parameters, it also seems likely that because prey could be more abundant during an early steelhead plant, additional predation could result. The 2003 early plant in the Deschutes was also in the upper watershed but it does not seem likely that the slightly longer residence time resulted in increased predation in the model, probably because actual residence time was approximately 1 day longer while the temporal scale of the model was weekly. Similarly, we noted that the steelhead planted directly in the Coweeman took slightly longer to emigrate past the trap site than fish released from acclimation ponds but the model does not reveal an increase in apparent predation.

We recognize that the work presented here is focused upon predation by migrating hatchery steelhead and less thoroughly addressed the potential impact of residual (non-migrating) steelhead. We present, however, the following reasons why residual steelhead in this study were unlikely to have contributed substantially to predation on fall Chinook fry.

First, no fall Chinook fry were found in the stomachs of hatchery steelhead over the two years we sampled residuals. Second, residuals did not overlap substantially in time and space with fry that emigrated in the year steelhead were released. Virtually all Chinook fry had emigrated soon after the normal time that hatchery steelhead were planted and the few remaining subyearling Chinook soon become too large to be ingested by the average residual. Residuals have to survive until emergence of the next year's Chinook cohort before they overlap again with a large number of prey-sized fall Chinook. Third, over-wintering survival of residual steelhead is low based on our observations and those of others. In the Deschutes, we captured only four hatchery steelhead from a previous year's plant while sampling residuals. Tipping et al. (1995) reported the capture of a single residual three months post-release and a single two-year old migrant steelhead in a study in Snow Creek, WA when they estimated that 28% of the steelhead planted failed to migrate. Ward and Slaney (1990) reported that for two releases in the Keogh River up to 40% of juvenile steelhead were not detected at the counting fence in the year of release and, on average, 1% survived to migrate the subsequent year. Finally, although we only captured four two-year old hatchery steelhead, they were resident in the reach directly downstream of Tumwater Falls Hatchery where very large numbers of hatchery Chinook fry were noted during sampling and none of the steelhead had recently consumed any fry.

Therefore, we do not expect that significant predation impacts occurred in our study streams from non-migrating hatchery steelhead. It is reasonable to expect that similar streams with similar hatchery programs and Chinook demographics also would have negligible predation impacts from any residualizing steelhead.

Literature Cited

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapement and other populations. Canadian Tech. Report of Fisheries and Aquatic Science 2106. 37p.

Barton, B.A. 2002. Stress in fishes: A diversity of responses with particular reference to changes in circulating corticosteroids. Integ. And Comp. Biol. 42:517-525.

Beckman, B.R., D.A. Larson, and W.W. Dickhoff. 2003. Life history plasticity in Chinook salmon: relation of size and growth rate to autumnal smolting. Aquaculture. 222 (2003) 149–165.

Beauchamp, D.A. 1995. Riverine predation on sockeye salmon fry migrating to Lake Washington. North American Journal of Fisheries Management 15:358-365.

Bjorkstedt, E.P. 2005. DARR 2.0: Updated software for estimating abundance from stratified mark-recapture data. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFSC-368. 21pp.

Cannemella, D.A. 1993. Hatchery steelhead smolt predation of wild and natural juvenile Chinook salmon fry in the upper Salmon River, Idaho. Idaho Department of Fish and Game, Boise, Idaho.

Crawford, B.A. 1979. The origin and history of the trout brood stocks of the Washington Department of Game. WDG Fishery Research Report. 91pp.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260.

Dempson, J. B., and D. E. Stansbury. 1991. Using partial counting fences and a two sample stratified design for mark recapture estimation of an Atlantic salmon smolt population. North American Journal of Fisheries Management 11:27 31.

Elliott, J.M. 1991. Rates of gastric evacuation in piscivorous brown trout, Salmo trutta. Freshwater Biology 25(2), 297-305.

Fritts, A. L., and T. N. Pearsons. 2004. Smallmouth bass predation on hatchery and wild salmonids in the Yakima River, Washington. Transactions of the American Fisheries Society 133:880–895.

Groot C., L. Margolis, and W. C. Clarke (eds.). 1995. Physiological Ecology of Pacific Salmon. Univ. British Columbia Press, Vancouver.

Hargreaves, N. B., and R. J. LeBrasseur. 1986. Size selectivity of coho (Oncorhynchus kisutch) preying on juvenile chum salmon (O. keta). Canadian Journal of Fisheries and Aquatic Sciences 43:581-586.

Harper, D. D. 1999. The food habits and microhabitat use of wild and hatchery-reared Oncorhynchus mykiss in the Teanaway River, Washington. Masters Thesis. Central Washington University, Ellensburg, Washington.

Hawkins, S. and J. Tipping. 1999. Predation by juvenile hatchery salmonids on wild fall Chinook salmon fry in the Lewis River, Washington. California Fish and Game. 85:124-129.

Hockersmith, E.E., W.D. Muir, S.G. Smith, B.P. Sandford, Noah S. Adams, J.M. Plumb, R.W. Perry, D.W. Rondorf. 2000. Comparative Performance of Sham Radio-tagged and PIT-tagged Juvenile Salmonids. US Army Corps of Engineers, Walla Walla and Portland Districts, WA.

Hulett, P.L., C. S. Sharpe, C. W. Wagemann. 2004. Critical need for rigorous evaluation of salmonid propagation programs using local wild broodstock. Pages 253-262 in M.J. Nickum, P.M.Mazik, J.G. Nickum, and D.D. MacKinlay, editors. Propagated fish in resource management. American Fisheries Society, Symposium 44. American Fisheries Society, Bethesda, Maryland.

Jonasson, B. C., R. W. Carmichael, and T. A. Whitesel. 1995. Residual hatchery steelhead: characteristics and potential interactions with spring Chinook salmon in northeast Oregon. Oregon Department of Fish and Wildlife, Progress Report. Portland, Oregon.

Li, H. W., G. A. Lamberti, T. N. Pearsons, C. K. Tait, J. L. Li, and J. C. Buckhouse. 1994. Cumulative effects of riparian disturbances along high desert trout streams of the John Day Basin, Oregon. Transactions of the American Fisheries Society 123:627-640.

Martin, S. W., A. E. Viola, and M. L. Schuck. 1993. Investigations of the interactions among hatchery reared summer steelhead, rainbow trout, and wild spring Chinook salmon in southeast Washington. Washington Department of Wildlife, Report #93-4, Olympia, Washington.

McConnaughey, J. 1998. Predation by coho salmon smolts (Oncorhynchus kisutch) in the Yakima and Klickitat rivers. Yakama Indian Nation Report. Toppenish, Washington.

Murphy, M. L., J. F. Thedinga, and J. J. Pella. 1996. Bootstrap confidence intervals for trap efficiency estimates of migrating fish. National Marine Fisheries Service, Juneau, AK.

NOAA. 1998. Endangered and Threatened Species: West Coast Chinook Salmon; Listing Status Change; Proposed Rule. Docket No. 980225050-8050-01; I.D. 022398C. March 9, 1998 Volume 63, Number 45. p 11481-11520.

NOAA. 2005. Federal Register Vol. 70, No. 247 Tuesday, December 27, 2005 / Notices. [I.D. 121905A].

Pearsons, T. and A. Fritts. 1999. Maximum size of Chinook salmon consumed by juvenile coho salmon. North American Journal of Fisheries Management. 19:165.

Pearsons, T.N., C.L. Johnson, B.B. James and G.M. Temple. 2006. Spring Chinook Salmon Interactions Indices and Residual/Precocious Male Monitoring in the Upper Yakima Basin Yakima/Klickitat Fisheries Project Monitoring and Evaluation. Annual Report for 2005 work to Bonneville Power Administration. Project #1995-063-25. 137 pp.

Robson, D.S. and H.A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Transactions of the American Fisheries Society 93: 215-226.

Ruggerone, G. T., and D. E. Rogers. 1992. Predation on sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: Implications for salmon management. North American Journal of Fisheries Management 12:87-102.

Sandercock, F. K. 1991. Life history of coho salmon (Oncorhynchus kisutch). Pages 395-445 in C. Groot and L. Margolis, editors. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, British Columbia.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin and Company, London.

Sharpe, C.S. and B.G. Glaser. 2007. 2005 Coweeman River juvenile salmonid production evaluation. WDFW Report FPA07-07. 32 pp.

Sharpe, C.S., P.L. Hulett, and C.W. Wagemann. 2000. Studies of hatchery and wild steelhead in the lower Columbia region. WDFW Progress report for 1998. 36 pp. + appendices.

Sharpe, C.S., B. R. Beckman, K.A. Cooper, and P.L. Hulett. 2007. Growth modulation during juvenile rearing can reduce rates of residualism in the progeny of wild steelhead broodstock. North American Journal of Fisheries Management 27:1355-1368.

Schreck, C.B. 1981. Stress and compensation in teleostean fishes: response to social and physical factors. In A.D. Pickering (ed.) Stress and fish, pp.295-321 Academic Press, New York.

Sokal and Rohlf . 1981. Biometry, second edition. W.H. Freeman and co., San Francisco. 859 pp.

Tipping, J.M., R.V. Cooper, J.B. Byrne, and T.H. Johnson. 1995. Length and condition factor of migrating and non-migrating hatchery-reared winter steelhead smolts. The Progressive Fish-Culturist. 57:120-123.

Viola, A.E. and M.L. Schuck. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. North American Journal of Fisheries Management. 15: 488-493.

Ward, B.R. and P.A. Slaney. 1990. Returns of pen-reared steelhead from riverine, estuarine, and marine releases. Transactions of the American Fisheries Society. 119:492-499.

WDFW. 2004. Washington State Department of Fish and Wildlife Fish Program Hatcheries Division semi-annual Mitchell Act Hatcheries Operations Report. FPMA 04-02. Pages 14-23.

Wurtsbaugh, W. A., and G. E. Davis. 1977. Effects of temperature and ration level on growth and food conversion efficiency of Salmo gairdneri, Richardson. Journal of Fish Biology 11:87-98.

Volkhardt, G., S. Neuhauser, P. Hanratty, L. Kishimoto, and L. Peterson. 2005. 2004 Juvenile Salmonid Production Evaluation and Adult Escapement. WDFW IMW program. http://www.iac.wa.gov/Documents/SRFB/Monitoring/appendix_a_2004_IMW_Fish_Monitoring_Report.pdf. 89pp.

Appendix

Appendix Table 1. Input Parameters for consumption modeling.

Initial Input Parameters	Deschutes 2003 UPPER EARLY	Deschutes 2003 LOWER LATE	Deschutes 2004 UPPER	Deschutes 2004 LOWER	Deschutes 2005 LATE	Deschutes 2005 EARLY	Green 2003	Green 2004	Coweeman 2005 POND	Coweeman 2005 DIRECT
Fall Chinook Migrants (Total annual production)	296,018	296,018	494,425	494,425	102,306	102,306	265,090	232,121	512,200	512,200
Fall Chinook Migrants After Steelhead Plant	37,617	34,229	158,866	158,866	17,864	30,723	21,902	96,077	51,220	51,220
Number of Steelhead Planted	12,500	12,500	14,900	15,500	12,250	12,300	249,315	176,900	8,900	10,000
Observed Fry/Stomach	0.0000	0.0011	0.0000	0.0000	0.0021	0.0038	0.0000	0.0000	0.0127	0.0086
Upper 95% CI of Observed Fry/Stomach	0.0085	0.0071	0.0080	0.0056	0.0137	0.0120	0.0204	0.0053	0.0397	0.0341
Overall Fry/Stomach	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
Upper 95% CI of Overall Fry/Stomach	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032

Appendix Table 2. Number of hatchery steelhead present in each watershed per statistical week. Estimates were derived by reducing the number of steelhead planted by the proportion of total raw trap catch in each week in each watershed.

Statistical Week	Deschutes 2003 UPPER EARLY	Deschutes 2003 LOWER LATE	Deschutes 2004 UPPER	Deschutes 2004 LOWER	Deschutes 2005 LATE	Deschutes 2005 EARLY	Green 2003	Green 2004	Coweeman 2005 POND	Coweeman 2005 DIRECT
16						12300			8900	10000
17						10315			3734	3873
18	12500					6116		176900	2411	1987
19	3846		14900	15500	12250	2286	249315	49974	1239	688
20	1257	12500	12346	11667	2417	835	14909	724	251	144
21	220	754	1710	2651	244	209	828	465	84	44
22	53	239	727	939	24	32		413		
23	23	67	54	167		12		258		
24		15	52	55				52		
25		7		11						

Appendix Table 3. Mean weekly water temperatures and estimates of ET90 (days; in parentheses) for each year in each watershed.

Statistical Week	Deschutes 2003	Deschutes 2004	Deschutes 2005	Green 2003	Green 2004	Coweeman 2005
16			8.4 (1.016)			9.3 (0.914)
17			10.3 (0.821)			12.0 (0.673)
18	11.6 (0.705)		11.9 (0.682)	10.0 (0.846)	11.4 (0.725)	12.8 (0.613)
19	11.0 (0.758)	13.4 (0.574)	13.0 (0.601)	9.9 (0.86)	11.4 (0.722)	13.6 (0.564)
20	12.1 (0.671)	12.8 (0.617)	12.1 (0.664)	10.4 (0.813)	11.5 (0.711)	13.0 (0.6)
21	12.9 (0.611)	13.7 (0.554)	10.8 (0.771)	11.1 (0.747)	12.1 (0.67)	12.8 (0.619)
22	14.9 (0.486)	13.7 (0.559)	13.2 (0.587)	12.3 (0.65)	12.2 (0.661)	13.9 (0.541)
23	16.1 (0.421)	14.0 (0.537)	13.9 (0.541)	14.4 (0.516)	11.9 (0.684)	
24	14.8 (0.489)	13.9 (0.541)		13.4 (0.573)	12.3 (0.654)	
25	15.0 (0.479)	15.5 (0.454)				

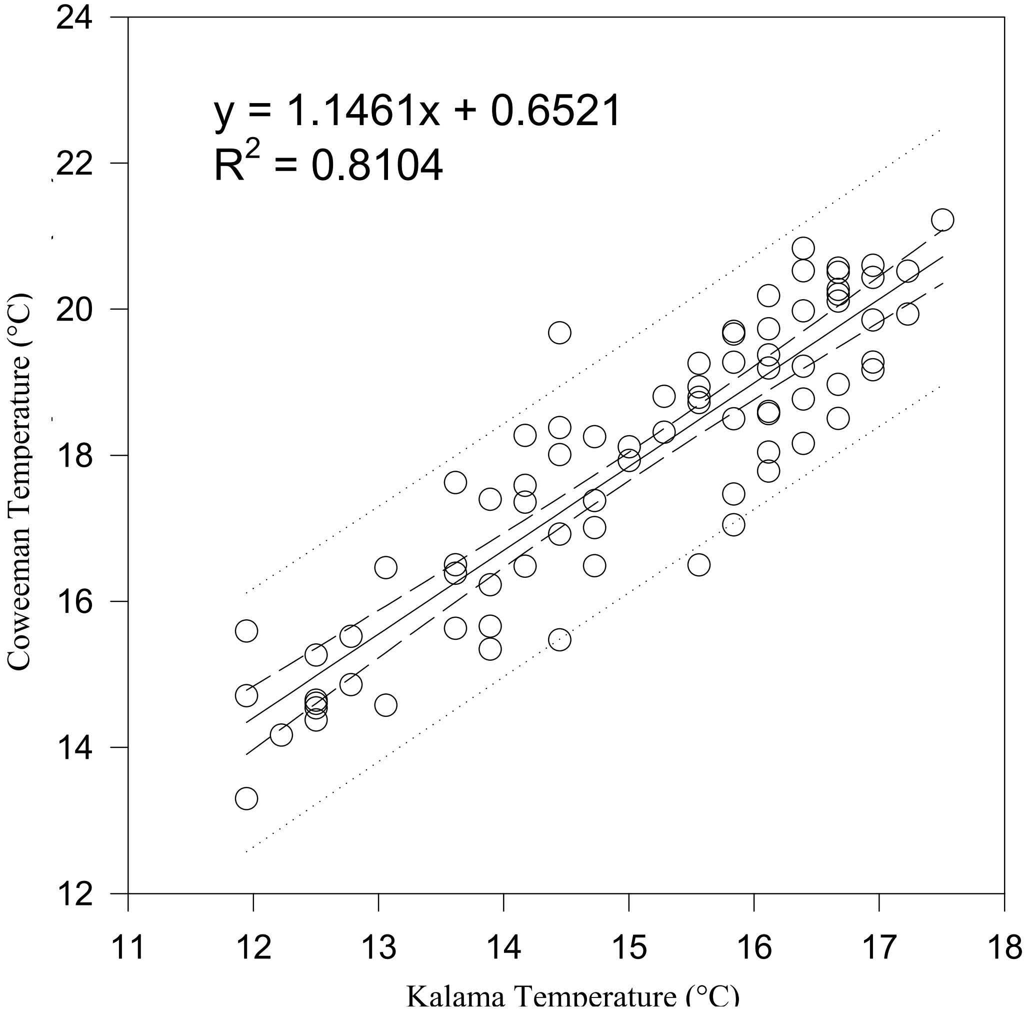
Appendix Table 4. Estimated weekly consumption of fall Chinook fry using the overall estimate of fry consumption rate (0.00173 fry/stomach)

Statistical Week	Deschutes 2003 UPPER EARLY	Deschutes 2003 LOWER LATE	Deschutes 2004 UPPER	Deschutes 2004 LOWER	Deschutes 2005 LATE	Deschutes 2005 EARLY	Green 2003	Green 2004	Coweeman 2005 POND	Coweeman 2005 DIRECT
16						146			118	132
17						152			67	70
18	214					108		2948	48	39
19	61		314	326	246	46	3503	836	27	15
20	23	225	242	228	44	15	222	12	5	3
21	4	15	37	58	4	3	13	8	2	1
22	1	6	16	20	1	1		8		
23	1	2	1	4				5		
24			1	1				1		
25										
Total	305	248	611	638	295	472	3738	3818	266	259
% of all fall Chinook	0.103	0.084	0.124	0.129	0.288	0.461	1.410	1.645	0.052	0.051
% of fall Chinook available after steelhead plants	0.810	0.725	0.384	0.401	1.650	1.535	17.068	3.974	0.518	0.507

Appendix Table 5. . Summary of estimated fry consumption using various estimates of fry consumption rates (from Appendix Table 1). Continued on next page.

Fry Consumption Parameter	Model Output	Deschutes 2003 UPPER EARLY	Deschutes 2003 LOWER LATE	Deschutes 2004 UPPER	Deschutes 2004 LOWER	Deschutes 2005 LATE	Deschutes 2005 EARLY	Green 2003	Green 2004	Coweeman 2005 POND	Coweeman 2005 DIRECT
Observed Fry/Stomach	Total	0	157	0	0	365	1031	0	0	1955	1295
	% of all fall Chinook	0.000	0.460	0.000	0.000	0.357	1.008	0.000	0.000	0.382	0.253
	% of fall Chinook available after steelhead plants	0.000	0.053	0.000	0.000	2.042	5.774	0.000	0.000	3.816	2.529
Upper 95% CI of Observed Fry/Stomach	Total	1499	1020	2830	2068	2339	3280	44161	11718	6104	5124
	% of all fall Chinook	0.507	2.980	1.781	1.302	2.286	3.206	16.659	5.048	1.192	1.000
	% of fall Chinook available after steelhead plants	3.986	0.345	0.956	0.699	13.092	18.361	201.630	12.196	11.918	10.003
Overall Fry/Stomach (0.00173)	Total	305	248	611	638	295	472	3738	3818	266	259

Fry Consumption Parameter	Model Output	Deschutes 2003 UPPER EARLY	Deschutes 2003 LOWER LATE	Deschutes 2004 UPPER	Deschutes 2004 LOWER	Deschutes 2005 LATE	Deschutes 2005 EARLY	Green 2003	Green 2004	Coweeman 2005 POND	Coweeman 2005 DIRECT
	% of all fall Chinook	0.103	0.084	0.124	0.129	0.288	0.461	1.410	1.645	0.052	0.051
	% of fall Chinook available after steelhead plants	0.810	0.725	0.384	0.401	1.650	1.535	17.068	3.974	0.518	0.507
Upper 95% CI of Overall Fry/Stomach (0.0032)	Total	565	460	1132	1182	546	875	6927	7075	492	481
	% of all fall Chinook	0.191	1.343	0.712	0.744	0.534	0.855	2.613	3.048	0.096	0.094
	% of fall Chinook available after steelhead plants	1.501	0.155	0.382	0.399	3.058	4.896	31.628	7.364	0.961	0.939



Appendix Figure 1. Mean daily temperature in the Coweeman and Kalama watersheds between 15 July and 31 August 2005. The regression equation was used to estimate Coweeman water temperatures because the temperature logger in the Coweeman failed.