EVALUATION OF JUVENILE SALMONID OUTMIGRATION AND SURVIVAL IN THE LOWER UMATILLA RIVER BASIN

ANNUAL REPORT 2009

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EXECUTIVE SUMMARY

In 2009, 3,745 natural and 28,880 hatchery smolts were collected in the juvenile bypass facility at Three Mile Falls Dam (TMFD). A total of 2,876 PIT tagged juvenile salmon and steelhead and 104 adults were detected. Mean fork length at emigration for natural summer steelhead was 168 mm. Age at emigration was 29.9% age-1 and 70.1% age-2. Condition factor for steelhead smolts was poor (< 1.00) throughout the season and *Neascus sp.* (black spot), continued to be prevalent. Median emigration time to TMFD and John Day Dam (JDD) for natural summer steelhead occurred in the middle of May (5/14-5/20) compared to late May (5/21-5/27) at Bonneville Dam (BON) and early June (5/28-6/3) at the Columbia River Estuary.

Abundance for natural origin summer steelhead was 33,883 ± 4,262 smolts. Survival from Meacham Creek to TMFD, TMFD to JDD, and JDD to BON for the 2009 outmigration year was 47%, 60%, and 38%; respectively. For brood year 2007, we estimated the production of 16 smolts-per-female for summer steelhead. Egg-to-smolt survival for summer steelhead in brood year 2007 was 0.3% and smolt-to-adult return for outmigration year 2007 was 5.4%.

The number of spawning females and egg deposition appeared to be associated with the growth, age composition, and production of summer steelhead smolts, thus providing evidence for density dependent effects. Growth appeared to be better during the first rearing season when fish densities were low, leading to a higher composition of age-1 smolts and more smolts produced per spawning female. The downward trend observed in egg-to-smolt survival and correlation between summer low flows and egg-to-smolt survival suggest that smolt production and freshwater productivity of summer steelhead is limited by the quantity and quality of available freshwater habitat.

INTRODUCTION

Populations of summer steelhead (*Onchorhynchus mykiss*) were substantially reduced, while Chinook (*O. tshawytscha*) and coho salmon (*O. kisutch*) were extirpated from the Umatilla River in the early 1900s as a result of extensive agricultural and irrigation development that resulted in habitat destruction, compromised fish passage, and inadequate stream flows (USBR 1988). In the early 1980s the Umatilla Basin Fisheries Restoration Program was initiated by the Oregon Department of Fish and Wildlife (ODFW) and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) to mitigate for population losses. A comprehensive plan incorporating habitat restoration, flow enhancement, fish passage improvements, and artificial production was developed in 1986 (Boyce 1986). The Northwest Power and Conservation Council's Columbia River Basin Fish and Wildlife Program authorized construction of the Umatilla Fish Hatchery in 1986. The Umatilla Hatchery Master Plan (CTUIR and ODFW 1989) was approved in 1990, and the hatchery was completed in 1991. Implementation of fish passage improvements began in 1984, whereas habitat restoration efforts began in 1987 and flow enhancement strategies were implemented in the 1990s (St. Hilaire 2007; USBR and BPA 1989).

The Umatilla Fish Hatchery is the foundation for reintroducing Chinook salmon and supplementing steelhead in the Umatilla River (CTUIR and ODFW 1989). Annual return goals for naturally-produced adults of each species were established in the Umatilla Subbasin Plan (DeBano et al. 2004), but they have rarely, if ever, been reached. In 1999, NOAA Fisheries listed natural steelhead within the Middle-Columbia River Distinct Population Segment (DPS), which includes the Umatilla River population, as threatened under the Endangered Species Act. Umatilla steelhead population viability is currently rated as “maintained” but the Major Population Group is below viability criteria. The Umatilla population must reach and remain at viable status for the DPS to attain delisting criteria (Carmichael and Taylor 2009; NMFS 2009).

The Evaluation of Juvenile Salmonid Outmigration and Survival in the Lower Umatilla River Basin (1989-024-01; O&S Project) was established in 1994. The project was requested by the ODFW and CTUIR based on both a local and regional high priority need for information on life history characteristics, survival, and success of hatchery- and naturally-reared salmon and steelhead in the Umatilla River (Boyce 1986; CTUIR and ODFW 1989; NPPC 1994). More specifically, the project was intended to supplement ongoing efforts by the Umatilla Hatchery Monitoring and Evaluation (1990-005-00) and Umatilla River Natural Production Monitoring and Evaluation (1990-005-01) projects to address critical uncertainties within the Umatilla Basin Fisheries Restoration Program. Critical uncertainties included:

1. Are juvenile salmon and steelhead surviving and successfully migrating out of the Umatilla River Basin?
2. What is the natural production potential for salmon and steelhead in the Umatilla River Basin?
3. What are the effects of supplementation on steelhead in the Umatilla River Basin?

The goal of the project was to provide data to facilitate assessment of the Umatilla Basin Fisheries Restoration Program and to evaluate the effectiveness of management actions by monitoring the outmigration and survival of juvenile salmon and steelhead from the Umatilla

River Basin. Project objectives in 2009 were: (1) PIT tag up to 3,000 natural origin juvenile steelhead to calibrate trap efficiency, estimate survival from Three Mile Falls Dam (TMFD) to John Day Dam (JDD), and estimate smolt-to-adult return, (2) determine migration timing and abundance of natural origin juvenile steelhead and monitor trends in natural production, (3) monitor juvenile life history characteristics of natural origin steelhead and assess trends over time, (4) coordinate with local and regional management as well as monitoring and evaluation groups, and (5) disseminate results.

STUDY AREA

The Umatilla River basin lies within Umatilla and Morrow Counties, Oregon, with a small portion of the headwaters located in Union County. The Umatilla River originates in the west slopes of the Blue Mountains near Pendleton, Oregon and flows northwest entering the Columbia River at river mile (RM) 289 near Umatilla, Oregon. The mainstem Umatilla River flows through the Columbia Plateau ecological province for a distance of 89 miles and the river and its tributaries drain an area of approximately 2,290 square miles (DeBano et al. 2004).

Elevation ranges from nearly 5,800 feet at the headwaters, to 260 feet at its confluence with the Columbia River (Saul et al. 2001). Identified by hydrologic unit number 17070103 (USDI 2010), it receives a mean annual precipitation of 10 to 50 inches per year within the lower and upper basin, respectively (Contor et al. 2000; Saul et al. 2001). The upper portion of the basin encompasses a section of the Umatilla National Forest as well as 172,000 acres of tribal land. The majority of land in the Umatilla River basin is privately owned (82%), with the remainder being divided amongst the State of Oregon, Umatilla County, and various cities (Saul et al. 2001).

Project activities are concentrated in the lower Umatilla River mainstem, between RM 3.7 and RM 5.0 (Figure 1). The average monthly discharge within the lower river varies from a low of 62 cubic feet per second (cfs) in the summer (July) up to 1,042 cfs during spring runoff (April; Figure 2). Water temperatures have been known to peak at levels of between 18°C and 27°C (Saul et al. 2001).

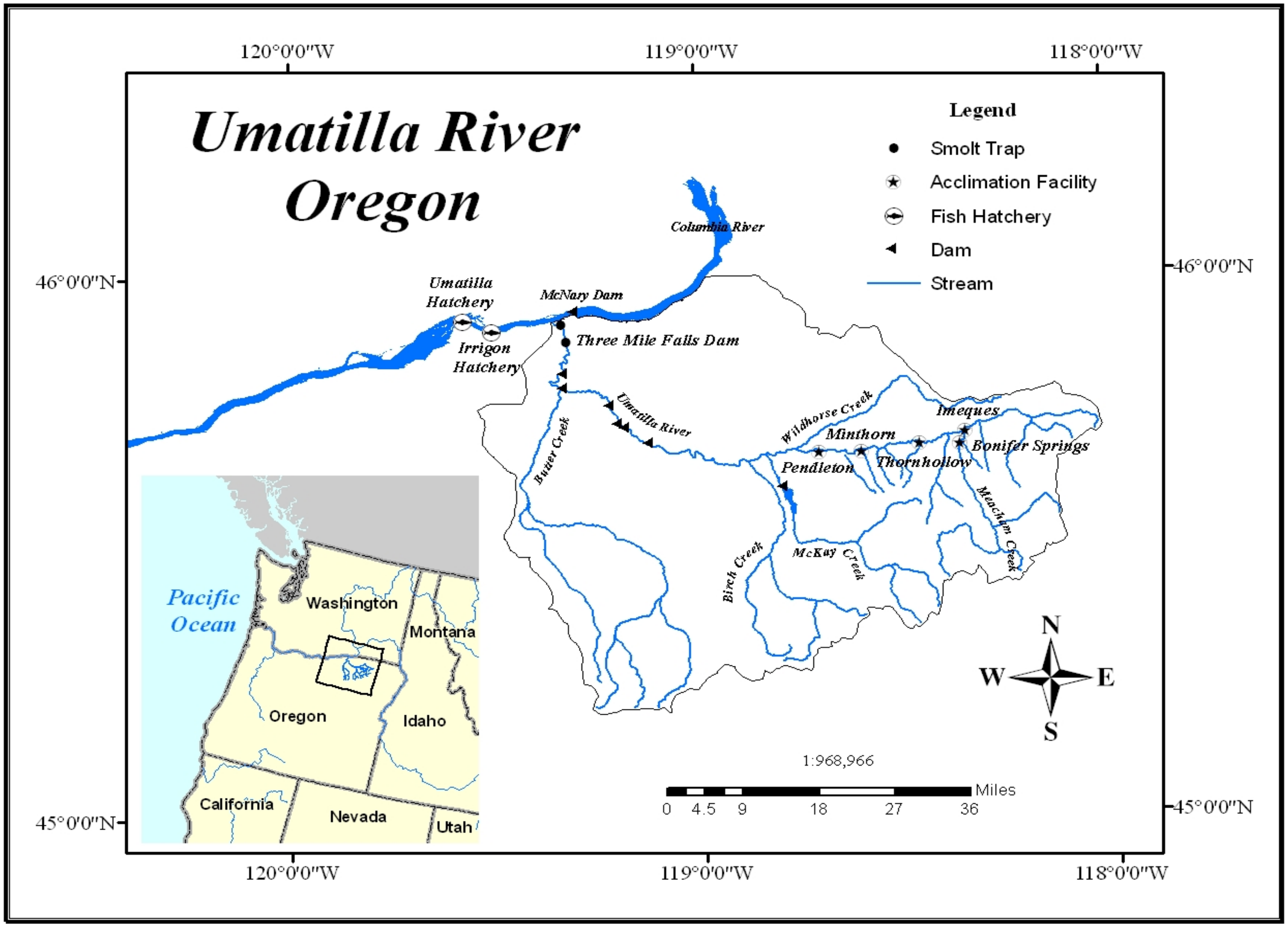

Figure 1. Map of the Pacific Northwest, the Umatilla River basin and sampling locations.

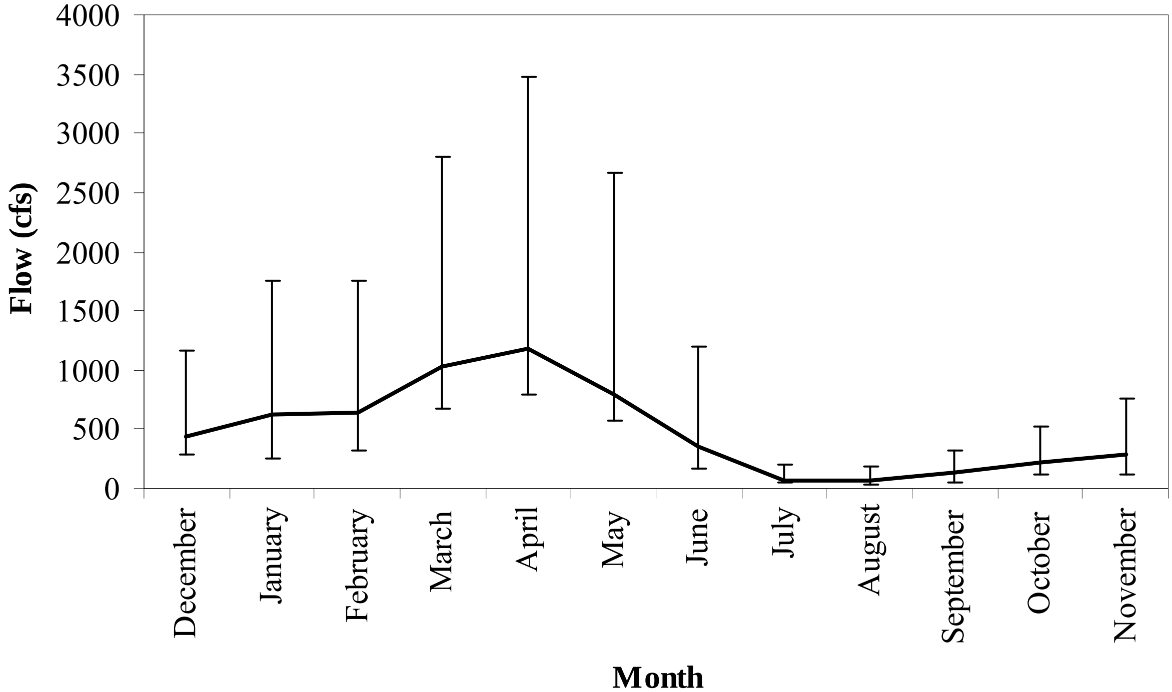

Figure 2. Mean, minimum, and maximum monthly flows for the Umatilla River at river mile 2.1, 2000-2009.

METHODOLOGY

Out migration Monitoring

Fish Trapping and PIT Tag Operations

Outmigration monitoring was conducted via smolt trapping and PIT tag interrogation at TMFD (RM 3.7). An inclined plane trap set in the juvenile bypass facility at West Extension Canal was used to capture emigrating salmonids. Trapping was typically conducted between February and June to coincide with the primary smolt emigration period. This was also the primary period when water was being diverted into West Extension Canal by the West Extension Irrigation District.

The trap was operated 24 hours per day and 7 days per week. Typically one sample per hour, over a 24 hour period (10 a.m. to 10 a.m.), was diverted to a sample tank. The sample rate was based upon the projected number of fish for the sample period, which in turn was based on the previous days collection, hatchery release schedules, propensity of target species, and best estimate of changes in passage. The goal was to sample between 250 and 500 outmigrants per day.

PIT tagged fish were interrogated at TMFD via one of three antenna arrays: in the juvenile bypass trap, at the juvenile bypass outfall, or the east bank adult fish ladder. Detection data was automatically uploaded to the PIT Tag Information System (PTAGIS) on a daily basis.

Fish Condition and Life History Characteristics

Captured fish were anesthetized with a stock solution of tricaine (40 mg/l) prior to sampling. Fish were enumerated by species, race, and origin. Origin was categorized as “natural” or “hatchery” based on the presence/absence of a fin clip, wire tag, or the appearance of wear on the dorsal or ventral fins. Race of natural Chinook salmon was categorized as spring or fall using body morphology, length, and age characteristics.

Natural summer steelhead smolts were examined to assess size, age, smolt development, condition, descaling, and health. Size at emigration was determined from length and weight data collected at TMFD. Fork length (FL) was recorded to the nearest millimeter (mm) and mass to the 0.1 gram (g). Scales were collected and mounted on mylar strips and examined under a microfiche at 24X or greater magnification, in order to discern annuli patterns reflecting freshwater age. Developmental (smoltification) stage was ranked as parr, intermediate, or smolt based on brightness and the absence or presence of parr marks. Condition of outmigrating steelhead was quantified using the following mathematical formula:

$$K_{FL} = (W/L^3) \times 10^5$$

where K_{FL} = condition factor, W = weight of fish in grams, and L = fork length of fish in millimeters.

Descaling was characterized as the proportion of cumulative scale loss evident on the fish at the time of emigration. Descaling was partitioned into one of three categories: good (missing < 3% of its scales), partially descaled (3-20% scale loss), or descaled (> 20% scale loss) based on criteria used by the Umatilla Hatchery Monitoring and Evaluation project (Keefe et al. 1994). Fish health was monitored through daily examination of emigrants for body injuries, external parasites, bird marks, obvious fungal infections of the body surface, and signs of potential disease.

The number of fish captured at West Extension Canal was expanded to characterize and compare natural and hatchery summer steelhead emigration timing to TMFD using the following equation:

$$C_w = \frac{\sum_{d=1}^{n} C_d / R_d}{P_w}$$

where C_w = estimated weekly number of fish passing through the juvenile bypass at TMFD, C_d = daily number fish captured, R_d = daily sample rate, P_w = weekly ratio of time sampled to unsampled. Weekly estimates were summed, cumulative frequencies were calculated, and the week of the 10^{th}, 50^{th}, and 90^{th} percentiles were determined. The Kolmogorov-Smirnov procedure was used to determine if the hatchery and natural origin groups differed significantly ($\alpha = 0.05$).

Migration timing past JDD and Bonneville Dam (BON) was estimated by expanding the weekly number of PIT tag detections based on the proportion of water passing through the powerhouse.

$$D_w = \sum_{d=1}^{n} D_d \,/\, f_p$$

and

$$f_p = \frac{\sum_d \left(f_d + s_d\right) / f_d}{7}$$

where D_w = estimated weekly number of PIT tagged fish passing a project, D_d = daily number of PIT tagged fish detected at a project, f_p = mean weekly proportion of water passing through the powerhouse at a project, f_d = daily flow through the powerhouse at a project, and s_d = daily flow being spilled at a project. Separate estimates were made for each powerhouse at BON and then summed to generate week-by-week totals. Weekly estimates from each project were summed, cumulative frequencies were calculated, and the week of the 10^{th}, 50^{th}, and 90^{th} percentiles were determined.

The relationship between abiotic variables and the weekly proportion of emigrants passing each site was tested using the Spearman rank correlation test. Abiotic variables included river flow, water temperature, water clarity, and spill. The time period used for the analysis was between the first and last week an emigrant was observed. Flow and temperature data from the Yoakum gauging station (RM 37.6) and water clarity measured at TMFD were utilized for the analyses at TMFD. Data for JDD and BON were downloaded from Columbia River DART. Any missing flow or temperature records were estimated by taking the average of the mean daily flow or temperature three days prior and three days after the missing record.

Production and Survival

Trap Efficiencies

To calibrate the collection efficiency of the trap and estimate outmigrant abundance, fish were tagged with 12 mm PIT tags and released 1.3 miles upstream of the trap for recapture. Fish were PIT tagged according to standards outlined in the PIT Tag Marking Procedures Manual (CBFWA, PIT Tag Steering Committee, 1999). Tests were conducted weekly at minimum. Tagged fish that died or dropped their tags prior to release were removed from the release group. Tag retention and fish survival was assumed to be 100% after release. It was also assumed that all marked and unmarked smolts migrated downstream independently of one another and had equal catchability.

Detection information recorded at TMFD was downloaded from PTAGIS and trap efficiency estimates were computed using the following formula:

$$TE = R / M$$

where TE = estimated trap efficiency, R = number of recaptured fish, and M = number of tagged fish released.

Smolt Abundance

Smolt abundance was estimated by dividing the number of fish passing through the juvenile bypass and estimated trap efficiency:

$$A_t = \sum_{m=1}^{n} C_m / TE_m$$

and

$$C_m = \frac{\sum_{d=1}^{n} C_d / R_d}{P_m}$$

where A_t = estimated number of outmigrants, C_m = estimated monthly number of fish passing through the juvenile bypass at TMFD, P_m = monthly ratio of time sampled to unsampled, and TE_m = mean estimated monthly trap efficiency. The Bootstrap method (Efron and Tibshirani

1986; Thedinga et al. 1994) with 1,000 iterations was used to derive a variance, coefficient of variance, and 95% confidence intervals for abundance estimates. Bootstrapping was performed using A_t and the mean estimated annual trap efficiency. Extrapolation for unsampled time prior to seasonal trap installation and after removal was not performed.

Smolt Survival

Cormack-Jolly-Seber (CJS) survival probabilities of PIT tagged natural summer steelhead from TMFD to JDD, and JDD to BON were calculated using the PIT Pro 4.1 program (Westhagen and Skalski 2009) with a single release-recapture model (Lady et al. 2001). Recapture information recorded at JDD, BON, and in the Columbia River Estuary was downloaded from the PTAGIS database.

Smolts -Per-Female

Smolts-per-female was calculated for naturally spawning summer steelhead using the following equation:

$$SPF_t = \frac{\sum_{j=1}^{4} A_j S_{t+j}}{FS_t}$$

where SPF_t represents the number of smolts produced by females that spawned in year t, A_j is the proportion of fish having age j at emigration (j = 1, 2, 3, and 4), S_{t+j} is the number of smolts in year $t + j$, and FS_t is the number of females that spawned in year t. Age j at emigration was derived from scales of annually returning adults from 1991 to 2000. Annual age composition was applied when available; otherwise a mean age composition (1991-2000) was used.

Egg-to-Smolt Survival

Egg-to-smolt survival was estimated for naturally spawning summer steelhead using the following formula:

$$ESS_t = \frac{\sum_{j=1}^{4} A_j S_{t+j}}{ED_t}$$

and

$$ED_t = \sum_{i=1}^{2} A_i FS_t E_i$$

where ESS_t represents the ratio of smolts produced per egg deposited by females that spawned in year t, ED_t is the total egg deposition, A_i is the proportion of females having ocean age i at return (i = 1 or 2) and E_i is the age-specific fecundity (E_1 = 3,979; E_2 = *6,965*; ODFW and CTUIR, unpublished data). Fecundity was determined from brood fish collected from 1993-2004. Ocean age i of females was classified based on scale analyses and fork length-age relationships. Females less than 600 mm were assumed to have spent one winter in the ocean and those greater than 600 mm, two winters.

Smolt-to-Adult Return

Smolt-to-adult return for naturally produced summer steelhead was calculated as:

$$SAR_t = \frac{\sum_{n=1}^{2} A_n R_{t+n}}{S_t}$$

where SAR_t represents the ratio of adults returning from smolts that emigrated in year t, A_n is the proportion of fish having ocean age n at return (n = 1 or 2), R_{t+n} is the number of adults in year $t + n$, and S_t is the number of smolts that emigrated in year t. Ocean age n of adults was classified based on scale analyses and fork length-age relationships. Adults less than 600 mm were assumed to have spent one winter in the ocean and those greater than 600 mm, two winters.

RESULTS AND DISCUSSION

Outmigration Monitoring

A total of 32,625 juvenile salmonids were sampled at TMFD in 2009 (Table 1). This was 53.4% below the average number sampled from 1995 to 2007. Catch was dominated by hatchery fish and unmarked coho (88.5%). Natural summer steelhead accounted for only 2.4% of the total catch. The reduced catch was primarily a result of trapping operations starting in April whereas in the past efforts began in early February. In addition, higher than average river flow made trapping conditions less than optimal and resulted in reduced effort on three separate flow events (Figure 3).

A total of 2,876 PIT tagged juvenile salmonids were detected at TMFD in 2009 (Table 2). The majority of detections (65.3%) were from hatchery steelhead released in the Umatilla River. A total of 104 PIT tagged adults were detected at TMFD (Table 3). Eight of 24 natural summer steelhead adults detected were tagged and released as juveniles in the John Day River and five of 25 hatchery summer steelhead adults were out-of-DPS strays. Twelve of 26 adult spring Chinook salmon were tagged and released in the Columbia River downstream of the confluence with the Umatilla River. One originated from the Snake River. Eight of 28 adult fall Chinook salmon originated from the Snake and Clearwater rivers. Eighteen summer steelhead detected at TMFD were thought to be residual hatchery fish. The majority of these fish (72.2%) were tagged and released in the spring of 2008 and observed at TMFD in the spring of 2009. These fish were part of the United States Bureau of Reclamation's (BOR) assessment of incidental take at BOR diversion structures. Four of the fish were from the standard production release in Meacham Creek and equated to less than 1% of the total hatchery steelhead PIT tagged and released in 2008 (4,458; Clarke et al. 2009).

The mean fork length for natural summer steelhead was smaller in 2009 compared to the long term average (Table 4). One and two-year freshwater rearing accounted for 29.9% and 70.1% of natural summer steelhead emigrating past TMFD in 2009 (Table 4). The percentage of age-1 summer steelhead emigrants increased, while age-3 decreased, over the past several years. Fork length and age at emigration for summer steelhead was influenced by egg deposition (Figure 4). Fork length for both age-1 and age-2 smolts decreased as egg deposition increased ($R^2 = 0.63$, *P-value = 0.06* and $R^2 = 0.82$, *P-value = 0.01*; respectively); where as the composition of age-1 smolts decreased and age-2 smolts increased as egg deposition increased ($R^2 = 0.34$, *P-value = 0.22* and $R^2 = 0.19$, *P-value = 0.38*; respectively). The fork length of age-1 and age-2 smolts was longer and more similar at lower levels of egg deposition compared to higher levels. It is likely that intra-specific competition for space and food was reduced, which resulted in improved growth during periods of lower egg deposition. The amount of variation explained by egg deposition decreased with the addition of the 2009 smolt monitoring data in all relationships. Most notably was the decrease in the relationship between the percentages of age-1 smolts and egg deposition ($R^2 = 0.80$, *P-value = 0.04* to $R^2 = 0.34$, *P-value = 0.22*). This was likely a result of our small sample size (n = 154) used to age smolts in 2009.

Table 1. Number of juvenile salmonids sampled at TMFD, Umatilla River, 1995-2009.

Outmigration year[ab]	Spring Chinook		Fall Chinook			Summer steelhead		Coho		Total
	Hatchery[c]	Natural	Hatchery 1+	Hatchery 0+	Natural 0+	Hatchery	Natural	Hatchery	Unmarked[d]	
1995[e]	90,499	1312	346	38,205	420	10,652	1,869	85,003	164	228,470
1996	2,952	156	42,000	97,230	20	12,432	3,451	66,315	59	224,615
1997	6,099	8	80	25,802	31	162	194	4,763	6	37,145
1998	18,171	867	5,110	4,764	5,471	1,924	2,642	7,265	243	46,457
1999	8,160	725	28	3,143	75	1,882	1,816	3,805	43	19,677
2000	4,180	47	3,031	6,664	3,425	1,078	626	13,856	5,702	38,609
2001	3,745	148	3,496	4,398	1,565	4,980	847	1,032	16,563	36,774
2002	7,892	922	4,066	5,030	1,247	1,029	630	621	7,416	28,853
2003	11,510	679	9,377	5,520	991	1,172	1,015	1,387	16,714	48,365
2004	6,278	351	10,532	5,297	2,206	1,071	660	266	5,563	32,224
2005	16,481	606	9,958	6,825	9,488	2,197	1,992	682	13,371	61,600
2006	12,317	445	9,654	9,864	1,159	1,720	1,020	446	13,371	49,996
2007	8,505	492	16,755	13,531	4,528	763	693	715	11,578	57,560
Mean 95-07	***15,138***	***520***	***8,803***	***17,406***	***2,356***	***3,159***	***1,343***	***14,320***	***6,984***	***70,027***
2009	3,803	97	1,031	14,427	2,862	1,575	786	528	7,516	32,625

[a] *1995 to 2004 includes fish sampled using a rotary screw trap at river mile 1.5.*
[b] *No smolt monitoring conducted in 2008.*
[c] *1995 to 2001 includes spring and fall Chinook salmon.*
[d] *Includes unmarked hatchery and natural coho.*
[e] *Includes fish sampled using a fyke net at river mile 0.5 and at Feed, Maxwell and Westland Canal traps.*

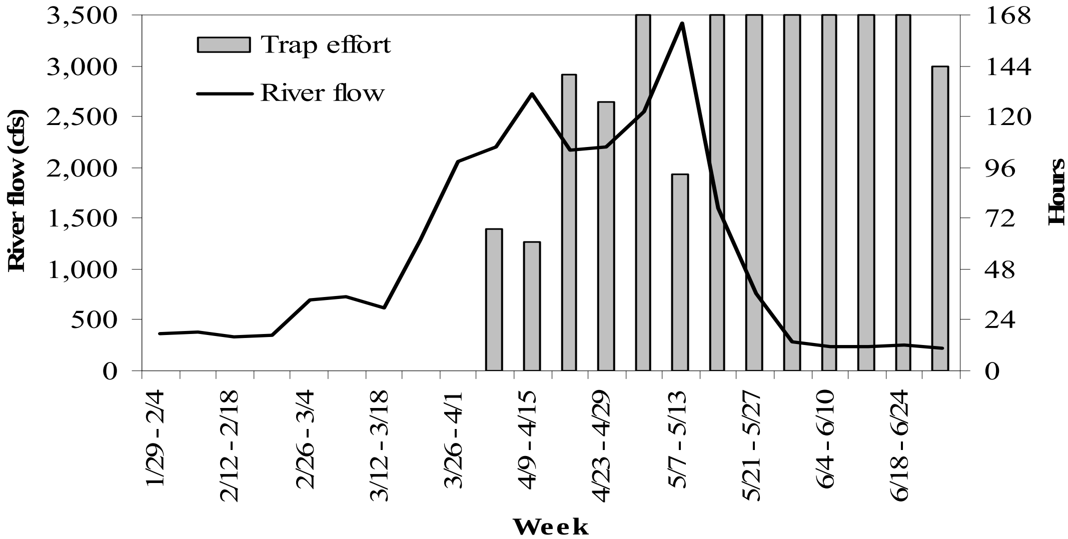

Figure 3. Weekly river flows and number of hours a subsample was taken at TMFD, Umatilla River, 2009.

Table 2. Number of PIT tagged juvenile salmonids detected at TMFD, Umatilla River, 2009.

Species	Detection site: Adult ladder	Detection site: Juvenile bypass	Total
Hatchery spring Chinook	78	170	248
Natural spring Chinook	0	0	0
Hatchery yearling fall Chinook	0	0	0
Hatchery subyearling fall Chinook	118	294	412
Natural fall Chinook	7	0	7
Coho	0	0	0
Hatchery summer steelhead	137	1740	1877
Natural summer steelhead	89	243	332
Total	429	2447	2876

Table 3. Number of PIT tagged adult salmonids detected at TMFD, Umatilla River, 2009.

Species	Detection site: Adult ladder	Detection site: Juvenile bypass	Total
Hatchery spring Chinook	26	0	26
Natural spring Chinook	0	0	0
Hatchery yearling fall Chinook	5	0	5
Hatchery subyearling fall Chinook	23	0	23
Natural fall Chinook	1	0	1
Coho	0	0	0
Hatchery summer steelhead	23	2	25
Natural summer steelhead	22	2	24
Total	100	4	104

Table 4. Natural summer steelhead smolt size and age at TMFD, Umatilla River, 1995-2009.

Outmigration year[a]	Mean fork length (mm) (SD)	Sample size[b]	Fork length (mm) by freshwater age class				Percent of freshwater age class[c]			
			1 (SD)	2 (SD)	3 (SD)	4 (SD)	1	2	3	4
1995	175 (28)	1,612	--	--	--	--	--	--	--	--
1996	176 (24)	2,970	--	--	--	--	--	--	--	--
1997	157 (23)	183	--	--	--	--	--	--	--	--
1998	186 (33)	2,547	--	--	--	--	--	--	--	--
1999	181 (22)	1,704	--	--	--	--	--	--	--	--
2000	180 (26)	619	--	--	--	--	--	--	--	--
2001	178 (28)	844	--	--	--	--	--	--	--	--
2002	166 (30)	571	--	--	--	--	--	--	--	--
2003	176 (30)	959	102 (6)	170 (27)	211 (42)	270 (53)	3.4	79.6	16.0	1.0
2004	167 (30)	655	104 (16)	165 (25)	292 (32)	202 (--)	5.9	82.6	11.3	0.2
2005	179 (25)	1,511	160 (28)	185 (27)	210 (44)	--	7.5	88.1	4.4	0.0
2006	179 (26)	1,005	164 (31)	184 (28)	191 (23)	--	17.6	77.4	5.0	0.0
2007	186 (20)	691	173 (15)	190 (19)	209 (25)	--	24.9	73.9	1.2	0.0
Mean 95-07	***176 (8)***	***1,189***	***160 (34)***	***180 (11)***	***202 (10)***	***256 (48)***	***11.9***	***80.3***	***7.6***	***0.2***
2009	168 (16)	781	166 (17)	173 (13)	--	--	29.9	70.1	0.0	0.0

[a] *No smolt monitoring conducted in 2008.*
[b] *Sample sizes for age/length analysis from 2003 to 2009 were 381, 475, 588, 562, 575, and 154; respectively.*
[c] *Derived from scale analysis of smolts trapped at TMFD.*

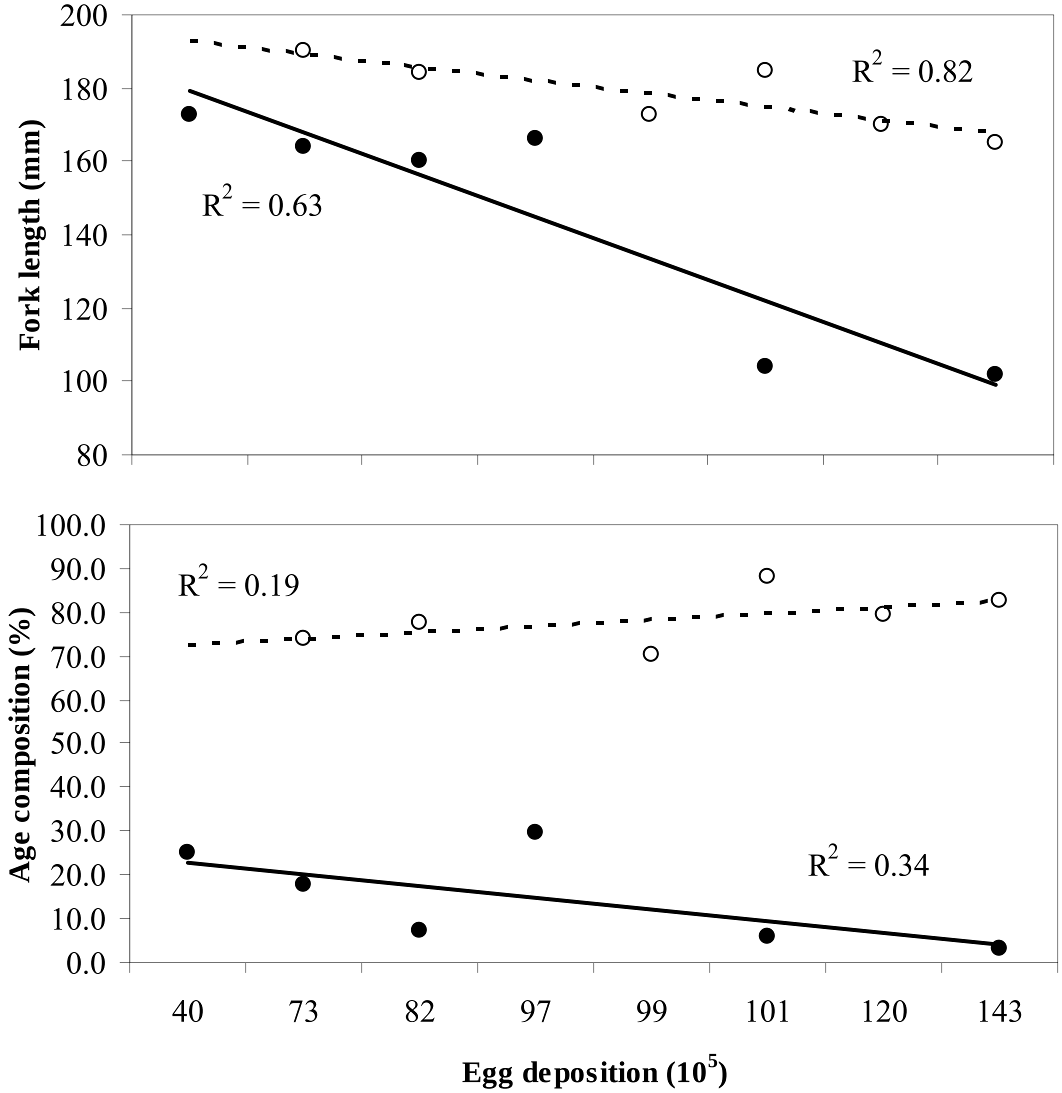

Figure 4. Relationship between fork length and egg deposition, and age composition and egg deposition. Brood years 2002-2008 and 2001-2007 for age-1 and age-2 smolts; respectively. Brood years 2006 for age-2 and 2007 for age-1 smolts are not included in the analysis because no smolt monitoring was conducted in outmigration year 2008. The solid circles and lines represent age-1 smolts and the open circles and dashed lines represent age-2 smolts.

Based on observed trends in smolt age at emigration, natural origin summer steelhead appeared to be shifting toward a shorter residency time in the Umatilla River. Rearing conditions were possibly the mechanism for this phenomenon. Freshwater age derived from returning adult scales support this observed trend. Contor et al. (2010) reported an above average composition of natural adult summer steelhead returning to TMFD that spent one year in freshwater before outmigration. Quinn (2005) suggested that the age composition of smolts depends on growth and reflects the trade-off between growth and mortality regimes in freshwater and marine habitats.

Mean fork length, mass, and condition factor varied throughout the season; however, no distinct trends were evident (Figure 5). Fish tended to be slightly larger at the beginning and end of the season; condition factor was poor throughout the season (Barnham and Baxter 2003). Fish captured in the first week of the season were in the poorest condition (0.90) and ranged from 0.92 to 0.95 throughout the remainder of the season. The project began assessing age-specific condition in 2010; however, analysis was not completed prior to this report.

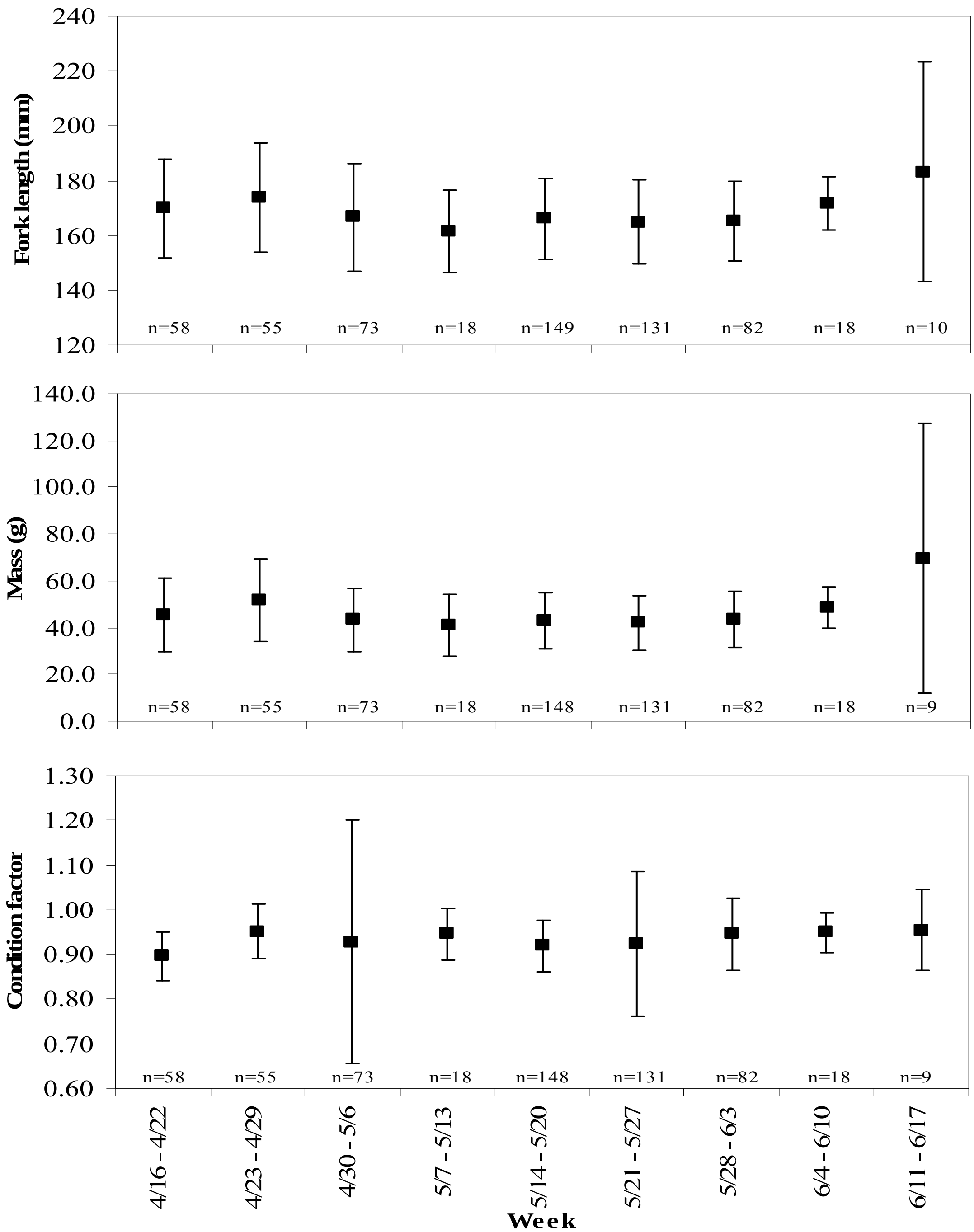

Figure 5. Mean length, mass, and condition factor of steelhead smolts PIT tagged and released at TMFD by time period, Umatilla River, 2009. Error bars represent ± 1 standard deviation.

In 2009, the percentage of steelhead emigrants classified as smolts was significantly lower than the long term average, but similar to 2007 (Table 5). Mortality due to trapping and tagging activities was nearly three times the long term average (Table 5). Sixteen of the 29 mortalities occurred in early June when water temperatures increased rapidly. The rate of descaling and proportion of fish with bird marks was less than half the long term average (Table 5). Body injuries were observed at a similar rate in 2009 compared to past years, and parasites, primarily *Neascus sp.* (black spot), continued to be prevalent (Table 5). It is not known whether black spot affects the emigration success of juvenile steelhead; however, severe infections can cause spinal deformities or secondary infections in fishes (Steedman 1991). Steedman (1991) concluded that poor habitat quality increased the incidence of black spot infestation in a variety of fish species.

Table 5. Smolt status, mortality, descaling, and health summary for natural summer steelhead sampled at TMFD, Umatilla River, 1995-2009.

Outmigration year	% smolted	% mortality	% descaled	% bird mark	% body injury	% parasite
1995	59.6%	0.4%	1.0%	--	--	--
1996	55.6%	0.4%	2.2%	2.1%	1.6%	3.1%
1997	27.0%	3.6%	2.2%	0.5%	4.3%	1.4%
1998	30.8%	2.3%	1.0%	2.0%	2.3%	1.0%
1999	20.0%	1.5%	4.6%	1.4%	0.8%	8.3%
2000	52.4%	0.2%	2.0%	4.5%	3.0%	6.0%
2001	--	1.8%	3.2%	3.6%	3.5%	7.0%
2002	4.5%	1.0%	0.7%	2.3%	1.2%	6.8%
2003	42.9%	3.4%	1.8%	4.5%	2.6%	17.5%
2004	52.2%	0.9%	1.7%	0.9%	4.1%	19.3%
2005	69.6%	0.5%	1.7%	2.5%	2.1%	10.0%
2006	31.3%	1.8%	1.7%	1.1%	2.4%	17.0%
2007	1.2%	1.0%	0.6%	2.3%	3.5%	14.9%
Mean 95-07	***37.3%***	***1.4%***	***1.9%***	***2.3%***	***2.6%***	***9.4%***
2009	1.9%	3.7%	0.8%	0.8%	2.1%	12.2%

Little change was observed in migration patterns of hatchery or natural steelhead compared with previous years (Tables 6 and 7). Median emigration for natural summer steelhead was roughly one week later than their hatchery counterparts in 2009. Both groups exhibited a bimodal distribution (Figure 6). Ninety-nine percent of steelhead emigrants, both hatchery and natural, passed TMFD prior to the second week of June (6/4-6/10). The cumulative distributions were statistically different between natural and hatchery fish; however, no large-scale seasonal divergence in emigration timing between hatchery and natural summer steelhead smolts appeared evident. These results were similar to those observed in 2006 and 2007 when paired releases of PIT tagged hatchery and natural summer steelhead were released during concurrent migration to compare emigration timing using weekly abundance estimates (Hanson and Carmichael 2009). However, the 2009 assessment should be interpreted with caution because the observed decrease in fish from May 7 to May 13 was partly due to environmental conditions. High flows and debris restricted trap operations, reduced capture efficiency, and resulted in a complete blockage of the trap which prohibited fish from entering the trap or passing through the primary PIT tag array for several hours.

Table 6. Week of 10th, 50th, and 90th percentiles of natural summer steelhead smolts passing TMFD, Umatilla River, 1995-2009.

Outmigration year	10% emigration	50% emigration	90% emigration	Peak emigration
1995	2/19 - 2/25	4/23 - 4/29	5/14 - 5/20	4/23 - 4/29
1996	4/23 - 4/29	5/14 - 5/20	5/28 - 6/3	5/14 - 5/20
1997	2/19 - 2/25	4/23 - 4/29	5/7 - 5/13	4/23 - 4/29
1998	4/16 - 4/22	4/30 - 5/6	5/21 - 5/27	4/23 - 4/29
1999	3/26 - 4/1	5/21 - 5/27	5/28 - 6/3	5/21 - 5/27
2000	4/23 - 4/29	4/30 - 5/6	5/21 - 5/27	4/30 - 5/6
2001	4/9 - 4/15	5/21 - 5/27	5/28 - 6/3	5/21 - 5/27
2002	4/16 - 4/22	4/30 - 5/6	5/21 - 5/27	4/30 - 5/6
2003	4/9 - 4/15	4/30 - 5/6	5/21 - 5/27	5/14 - 5/20
2004	4/16 - 4/22	4/30 - 5/6	5/14 - 5/20	5/7 - 5/13
2005	3/26 - 4/1	4/23 - 4/29	5/7 - 5/13	5/7 - 5/13
2006	4/16 - 4/22	5/7 - 5/13	5/21 - 5/27	5/14 - 5/20
2007	4/9 - 4/15	4/30 - 5/6	5/21 - 5/27	4/30 - 5/6
Mean 95-07	***4/23 - 4/29***	***5/7 - 5/13***	***5/21 - 5/27***	***5/7 - 5/13***
2009	4/16 - 4/22	5/14 - 5/20	5/28 - 6/3	5/14 - 5/20

Table 7. Week of 10th, 50th, and 90th percentiles of hatchery summer steelhead smolts passing TMFD, Umatilla River, 1995-2009.

Outmigration year	10% emigration	50% emigration	90% emigration	Peak emigration
1995	4/19 - 4/15	4/23 - 4/29	5/21 - 5/27	4/23 - 4/29
1996	5/7 - 5/13	5/14 - 5/20	5/28 - 6/3	5/14 - 5/20
1997	4/9 - 4/15	4/30 - 5/6	5/14 - 5/20	4/30 – 5/6
1998	4/23 - 4/29	4/30 - 5/6	5/21 - 5/27	4/30 – 5/6
1999	4/30 - 5/6	5/21 - 5/27	5/28 - 6/3	5/21 - 5/27
2000	4/2 - 4/8	4/30 - 5/6	5/21 - 5/27	4/30 – 5/6
2001	4/9 - 4/15	4/30 - 5/6	5/21 - 5/27	4/30 – 5/6
2002	4/30 – 5/6	4/30 - 5/6	5/21 - 5/27	4/30 – 5/6
2003	4/30 – 5/6	5/14 - 5/20	5/21 - 5/27	5/14 - 5/20
2004	4/23 - 4/29	5/7 - 5/13	5/14 - 5/20	5/14 - 5/20
2005	4/30 – 5/6	4/30 - 5/6	5/7 - 5/13	4/30 – 5/6
2006	4/23 - 4/29	5/7 - 5/13	5/21 - 5/27	5/14 - 5/20
2007	4/30 – 5/6	5/14 - 5/13	5/21 - 5/27	5/14 - 5/20
Mean 95-07	***4/23 - 4/29***	***5/7 - 5/13***	***5/21 - 5/27***	***5/7 - 5/13***
2009	4/23 - 4/29	5/7 - 5/13	5/21 - 5/27	4/30 – 5/6

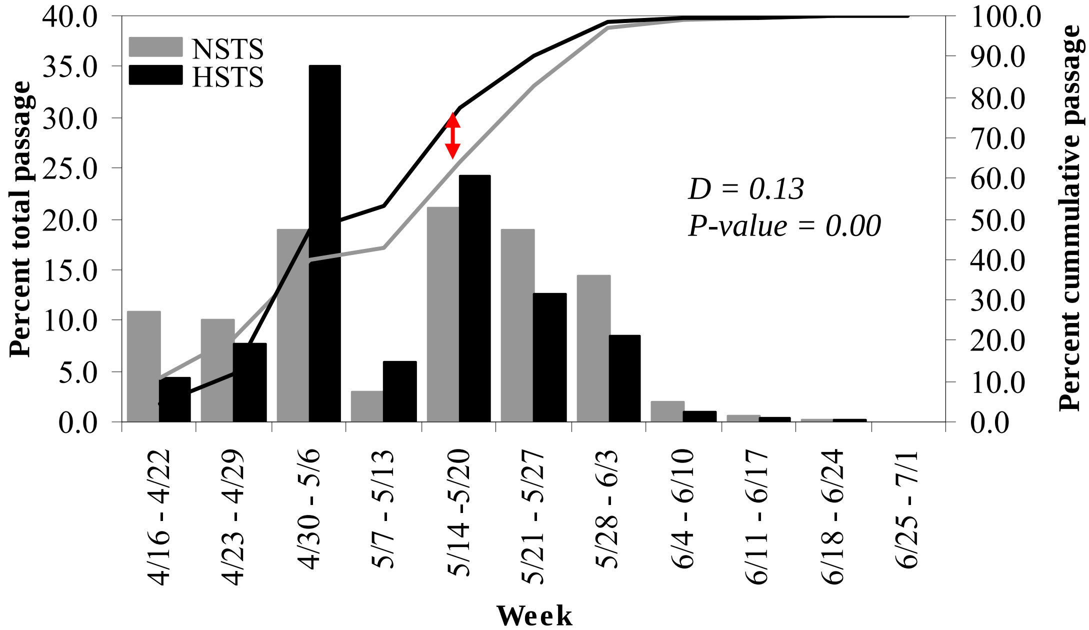

Figure 6. Hatchery and natural summer steelhead passage timing at TMFD, Umatilla River, 2009. Bars represent percent and lines represent cumulative percent of total passage. Red arrow indicates week with maximum difference between cumulative distributions.

The estimated migration timing of natural summer steelhead past detection sites within the Columbia River are shown in Figure 7. Fifty percent of the estimated migration passed JDD by the middle of May (5/14 – 5/20) compared to late May (5/21 – 5/27) at BON and early June (5/28 – 6/3) at the Columbia River Estuary. Contor et al. (2010) estimated that 50% of the Meacham Creek population passed JDD by May 9. No detections were observed downstream of JDD past the second week in June (6/4 – 6/10). However, detections were observed at JDD until June 27. Detection dates for Umatilla hatchery summer steelhead were similar to natural fish (Table 8). Fifty percent of the tagged fish were detected at JDD by 5/16, at BON by 5/12, and at the Columbia River Estuary by 5/18. In past years, we have observed PIT tag detections of natural steelhead at TMFD and JDD one full year after the expected migration year and a decreasing trend in survival of hatchery summer steelhead as the emigration period progressed (ODFW, unpublished data). Based on these past observations, the late migrants detected at JDD may have ceased emigration or perished in the Columbia River between JDD and BON.

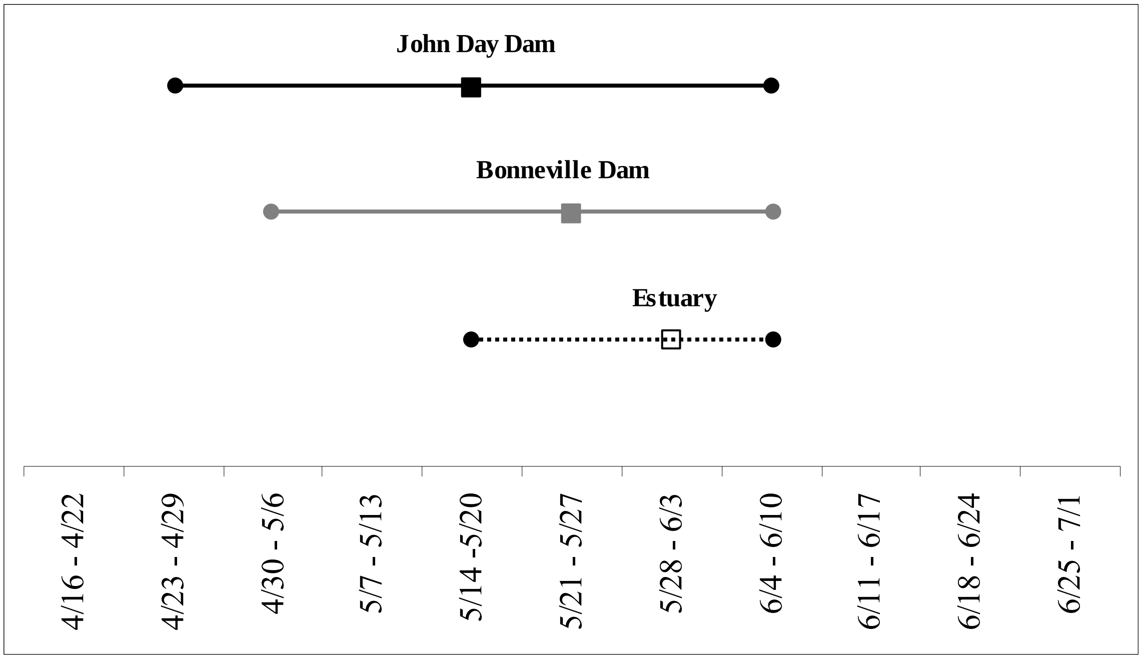

Figure 7. Percentile dates (10th, 50th, and 90th) of emigration timing of natural summer steelhead past JDD and BON based on PIT tag detections expanded for the proportion of water passing through the powerhouse and unexpanded detections for the Columbia River Estuary, 2009.

Table 8. Percentile dates of PIT tag detections of hatchery summer steelhead smolts past TMFD, JDD, BON, and the Columbia River Estuary, 2009.

Cumulative detection	TMFD	JDD	BON	Estuary
10%	4/30	5/4	5/4	5/2
50%	5/16	5/16	5/12	5/18
90%	6/2	6/2	5/28	5/26

A negative association with water temperature and a positive association with spill and emigration timing of natural summer steelhead were observed at JDD in 2009 (Table 9). Associations between abiotic factors and emigration timing of summer steelhead were not observed at TMFD or BON.

Table 9. Spearman correlation coefficient for environmental conditions and natural summer steelhead smolt passage at TMFD, JDD, and BON, 2009. *P-value* in parentheses.

Abiotic variables	TMFD	JDD	BON
River flow	0.38 (*0.20*)	0.40 (*0.25*)	0.16 (*0.72*)
Water temperature	-0.07 (*0.82*)	-0.64 (*0.05*)	0.38 (*0.40*)
Water clarity	-0.25 (*0.42*)	--	--
Spill	--	0.84 (*0.00*)	0.31 (*0.50*)

Production and Survival

A total of 594 natural summer steelhead were tagged and released for trap efficiency estimates in 2009 (Table 10). Mean recapture rate was 31.5% and median days to recapture was 0.3 (~ 7 hours). Recapture rates were slightly higher and more variable in 2009 compared to the 1999-2007 average (30.5%). The high variability was partly explained by environmental conditions. On two separate occasions, 4/22 and 5/6, river flow and debris resulted in a complete blockage of the trap which prohibited fish from entering the trap or passing through the primary PIT tag array for several hours. Also, on 6/3 we observed an abnormally high rate of tagging mortality (8.9%) when water temperatures increased rapidly. We suspect post-release mortality may have occurred. In addition, it took considerably longer for this group of fish to pass the site (2.1 days) in comparison to the other groups, suggesting their behavior was different.

Table 10. Weekly trap efficiency estimates for natural summer steelhead smolts at TMFD, Umatilla River, 2009.

Release date	No. released	No. recaptured	% recaptured	Med. days to recap.	Avg. fork length (mm)	Avg. weight (g)
04/22/2009	58	4	6.9	0.1	170	45.4
04/29/2009	55	22	40.0	0.3	174	51.8
05/06/2009	73	0	0.0	--	167	43.4
05/13/2009	18	12	66.7	0.2	162	41.1
05/20/2009	149	75	50.3	0.3	166	42.9
05/27/2009	131	60	45.8	0.6	165	42.1
06/03/2009	82	8	9.8	2.1	165	43.6
06/09/2009	18	3	16.7	0.7	172	48.5
06/17/2009	10	3	30.0	0.9	183	69.5
Mean (SD)	***66 (49)***	***21 (28)***	***29.6 (22.7)***	***0.7 (0.6)***	***169 (6)***	***47.6 (8.9)***

The 2009 smolt abundance estimate for natural summer steelhead was below the 1995-2007 average (Table 11). This was partly due to a truncated trapping season. Trapping operations started in April whereas in the past, efforts began in early February. Up to 10% of summer steelhead smolts may have passed the trap before operations began in 2009. Smolt abundance varied from year to year, ranging form a low of 7,899 in 1997 to a high of 82,005 in 2002 (Figure 8).

In-basin survival for natural summer steelhead in 2009 was 13% higher than the average survival from 1999 to 2001 (Table 12) and similar to survival for hatchery summer steelhead released in Meacham Creek (CJS = 0.47 [0.05]). Spatial and temporal distribution of natural steelhead tagged in the upper basin varied between years; however, survival estimates varied little (standard deviation = 0.08). Estimated survival for Umatilla River natural steelhead from TMFD to JDD was 9% lower than the long-term average (Table 10) and similar to survival for hatchery steelhead (CJS = 0.65 [0.14]). Trends in survival through Lake Umatilla were similar to those reported by Faulkner et al. (2010) for Snake River steelhead ($R^2 = 0.31$, $P\text{-value} = 0.15$; Figure 9). Estimated survival from JDD to BON was 38%; this was similar to that observed in 2007. As expected, the precision of estimates continued to be low. Schwartz and Cameron (2006) estimated a tag size of 1,700 was needed to obtain a survival rate from TMFD to JDD for natural summer steelhead with a coefficient of variation (CV) ≤ 20%. An average of 559 steelhead smolts were tagged from 1999-2009; with 594 fish tagged in 2009. The standard error ranged form 0.07 to 0.21 and decreased as the number of tagged fish increased ($R^2 = 0.62$, *P-value = 0.02*).

Table 11. Abundance estimates for natural summer steelhead smolts at TMFD, Umatilla River, 1995-2009.

Outmigration year	Abundance ± 95% CI	Coefficient of Variation
1995	46,657 ± 8,167	8.9
1996	44,459 ± 4,827	5.5
1997	7,899 ± 2,181	14.1
1998	69,328 ± 8,151	6.0
1999	49,516 ± 2,971	3.1
2000	56,007 ± 8,028	7.3
2001	32,853 ± 3,964	6.2
2002	82,005 ± 7,914	4.9
2003	24,601 ± 3,220	6.7
2004	32,105 ± 3,100	4.9
2005	51,897 ± 5,530	5.4
2006	36,080 ± 2,561	3.6
2007	31,647 ± 3,760	6.1
Mean 95-07	***43,466 ± 4,952***	***6.4***
2009	33,883 ± 4,262	6.4

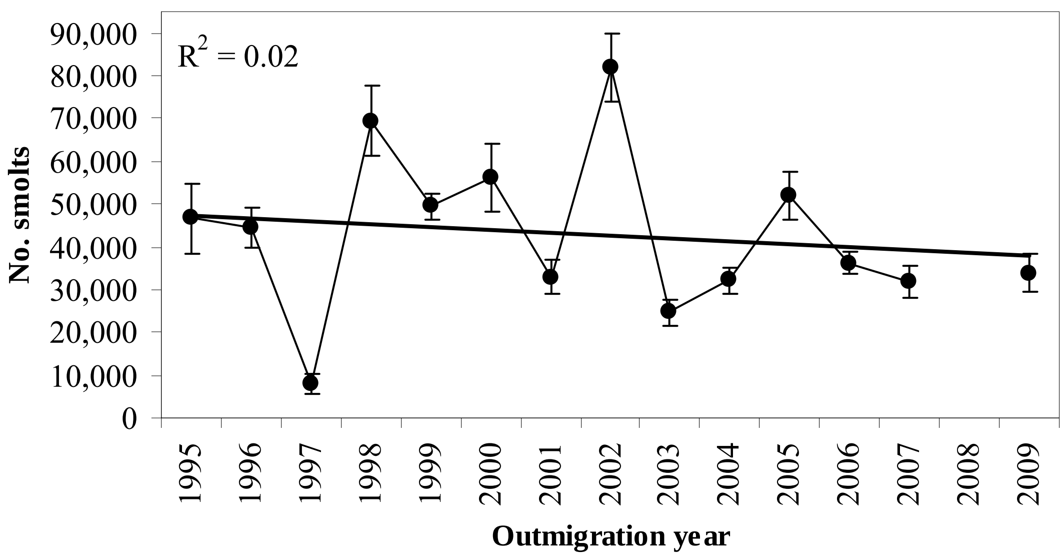

Figure 8. Abundance estimates for natural summer steelhead smolts at TMFD, Umatilla River, 1995-2009. Error bars represent ± 95% confidence interval.

Table 12. Estimated survival and standard error through reaches of the Umatilla and Columbia rivers for natural summer steelhead smolts originating in the Umatilla River, 1999-2009.

Outmigration year	Upper Basin to TMFD[a]	TMFD to JDD[b]	JDD to BON[b]
1999	0.26 (0.02)	0.69 (0.07)	--
2000	0.37 (0.04)	0.57 (0.14)	--
2001	0.40 (0.05)	0.53 (0.20)	--
2002	--	0.61 (0.17)	--
2003	--	0.64 (0.12)	--
2004	--	0.44 (0.16)	--
2005	--	0.54 (0.12)	--
2006	--	0.68 (0.14)	1.10 (1.04)
2007	--	0.82 (0.21)	0.43 (0.19)
Mean 99-07	***0.34 (0.04)***	***0.69 (0.19)***	***0.77 (0.62)***
2009	0.47 (.08)	0.60 (0.15)	0.38 (0.19)

[a] *Tagged fish used to estimate survival from Upper Basin to TMFD were released by CTUIR at multiple locations from 1999 to 2001 and from the Meacham Creek rotary screw trap in 2009.*

[b] *Tagged fish used to estimate survival from TMFD to JDD and JDD to BON were released approximately 1.3 miles above TMFD for trap calibration tests.*

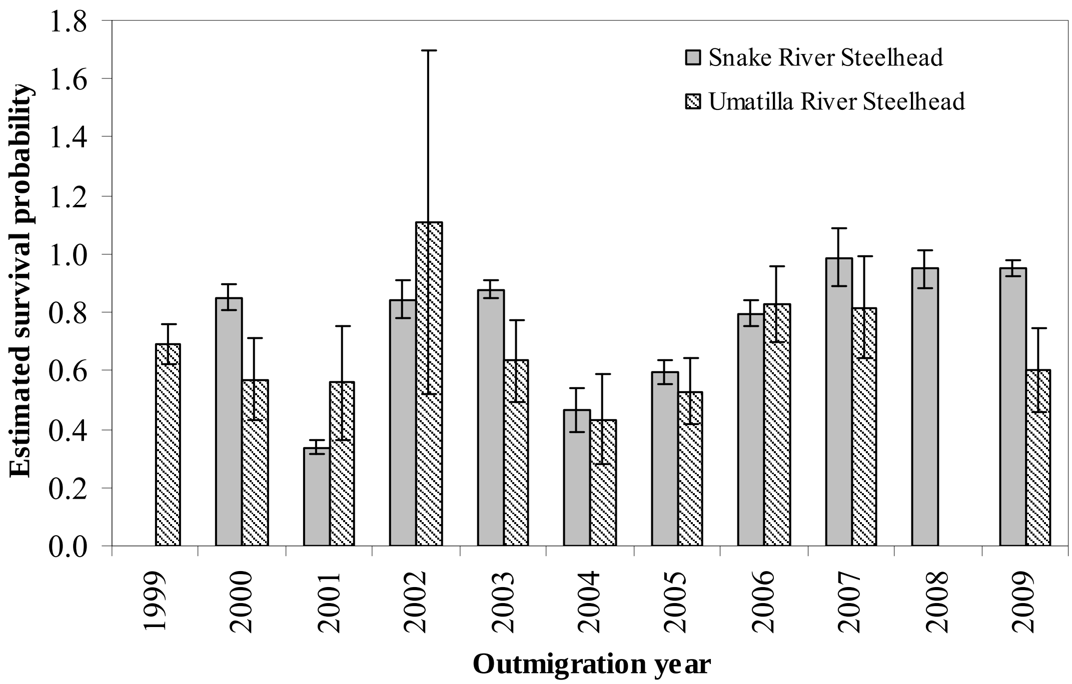

Figure 9. Comparison of survival estimates for Snake River and Umatilla River steelhead smolts through Lake Umatilla, Columbia River, 1999-2009. Error bars represent ± 1 standard error. Survival estimates and standard error for Snake River steelhead smolts from Faulkner et al. 2010.

Female spawning escapement for summer steelhead (1,904) was above the 14-year average (1,414; brood year 1993-2006), with natural fish dominating escapement (Figure 10). The number of smolts produced per spawning female (16) was 47% below the 14-year average (34; Figure 10). Smolt recruitment remained relatively constant from brood year 1993 to 2007 (mean = 44,189; CV = 36%) irrespective of fluctuations in adult recruitment. This resulted in a downward trend for smolts produced per spawning female (Figure 10) and a strong relationship between female escapement and smolts-per-female (Figure 11).

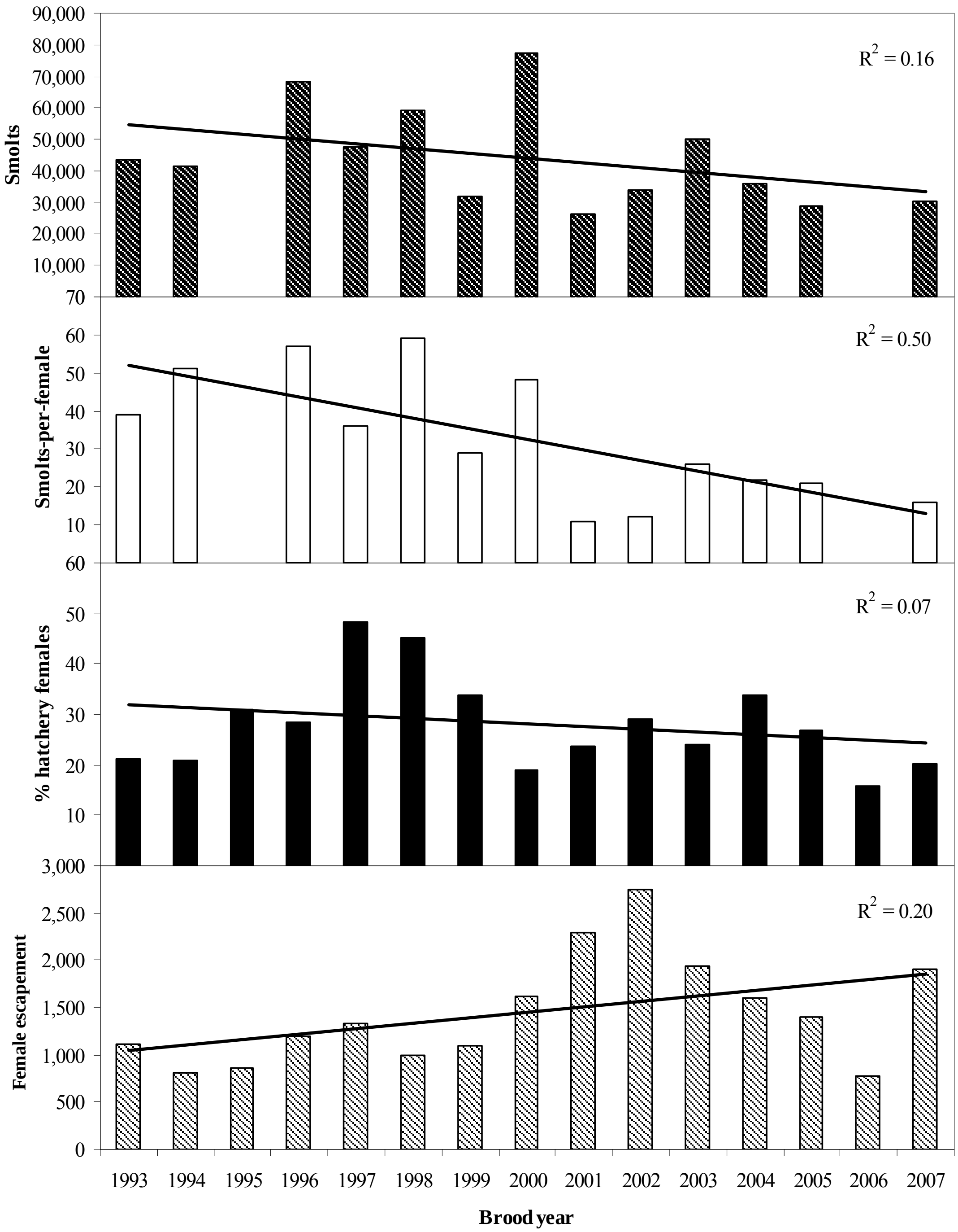

Figure 10. Smolt and adult recruitment for Umatilla River summer steelhead, brood years 1993-2007.

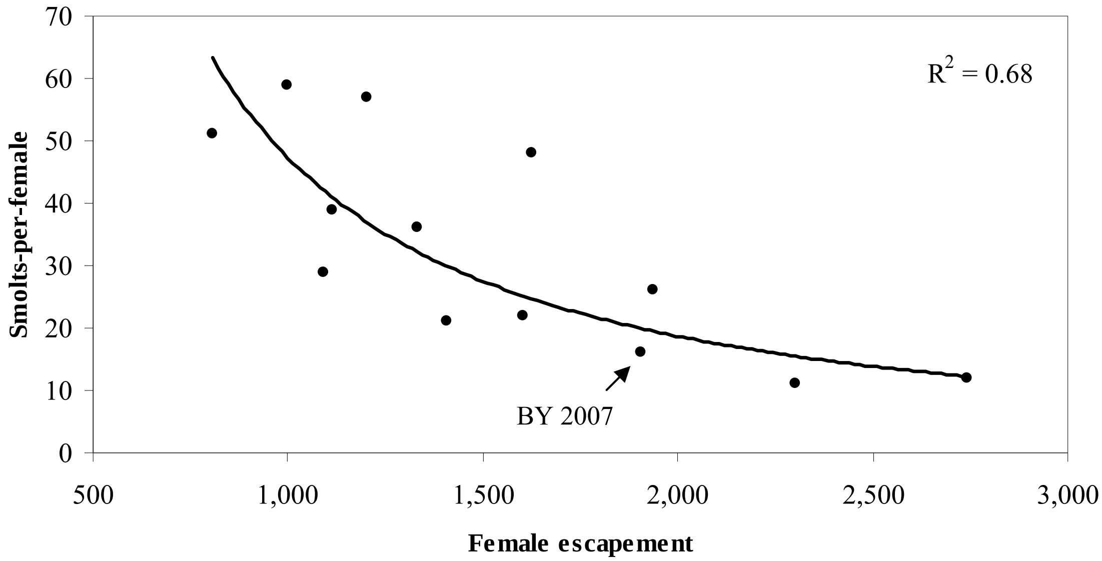

Figure 11. Relationship between female spawning escapement and smolts-per-female for Umatilla River summer steelhead, brood years 1993-2007.

Mean egg-to-smolt survival for summer steelhead was lower over the last seven brood years (0.4%; 2001-2007) compared to brood years 1993 to 2000 (mean = 0.9%), resulting in a decreasing trend (Figure 12). Much of the variation was explained by summer base flows (R^2 = *0.51*, *P-value = 0.01*; Figure 13). Smolt-to-adult return was 2.8% or above in all years except 1995 and 1996, therefore resulting in an increasing trend (Figure 14). All estimates for brood year 2007 are preliminary as they did not include age-3 and age-4 smolts and only included adults spending one winter in the ocean.

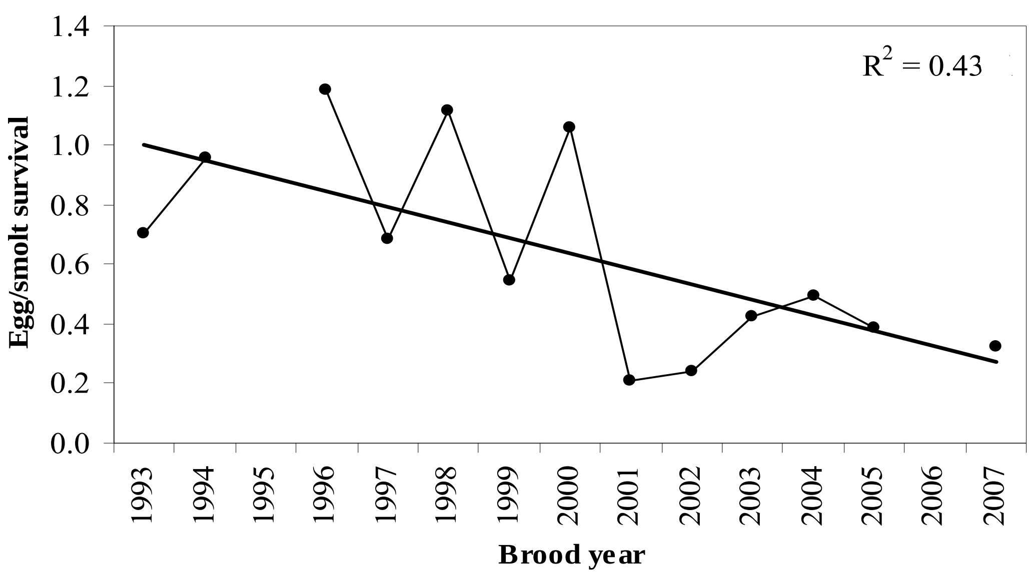

Figure 12. Egg-to-smolt survival for Umatilla River summer steelhead, brood years1993-2007.

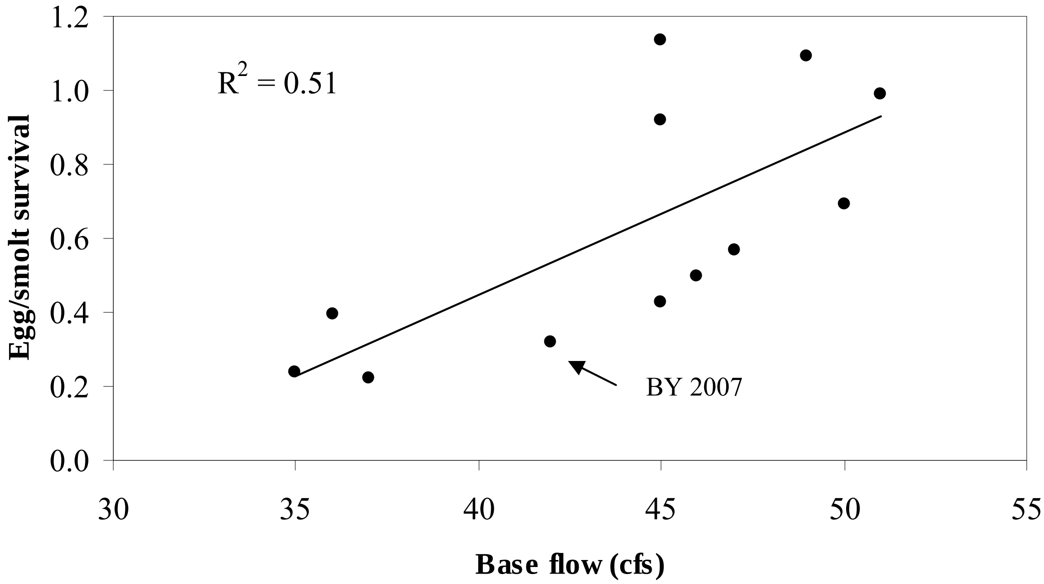

Figure 13. Egg-to-smolt survival as a function of the mean August and September flow the previous two summers before emigration, brood years 1994-2007.

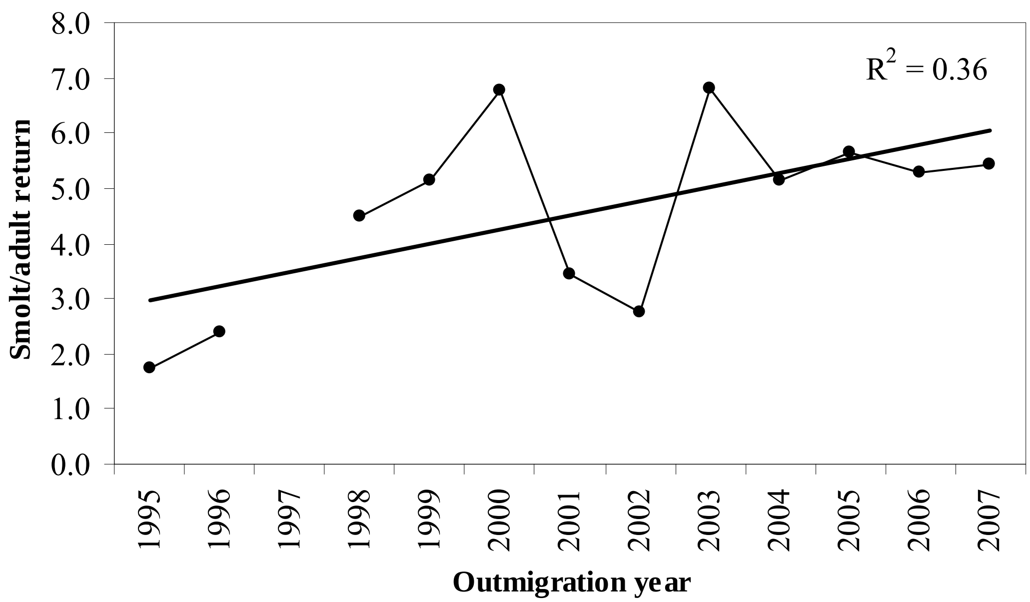

Figure 14. Smolt-to-adult return for Umatilla River summer steelhead, outmigration years 1995-2007.

CONCLUSIONS

In-basin and TMFD to JDD survival estimates suggested that smolt passage conditions were less than optimal in both the Umatilla and Columbia rivers and have limited reestablishment of natural Chinook salmon and viability of summer steelhead populations in the Umatilla River. NMFS (2009) identified the Columbia River hydrosystem and in-basin water storage, irrigation diversion, and hydro projects as major limiting factors and threats for the Umatilla River steelhead population. Expansion of PIT tag detection capabilities within the Umatilla River and increased tagging of natural emigrants is necessary for identification of critical periods and locations associated with smolt survival. Most notably, survival of smolts through the lower 33 miles of the Umatilla River which is extensively developed for irrigation, and survival downstream of JDD are needed to articulate strategies and actions for water management and habitat restoration in the Columbia and Umatilla rivers.

Long-term monitoring indicated that ocean survival increased while freshwater survival decreased for Umatilla River summer steelhead. This suggested that production and productivity were most influenced by the quantity and quality of available freshwater habitat. Increases in female escapement were a function of both artificial supplementation and ocean productivity. The number of spawning females and egg deposition appeared to be associated with the growth, age composition, and production of summer steelhead smolts, thus providing evidence for density dependent effects. Improved growth occurred during the first rearing season when fish densities were low, leading to a higher composition of age-1 smolts and more smolts produced per spawning female.

Our findings suggest that significant increases in freshwater production and productivity of summer steelhead are not likely to occur until improvements to water quality, fish passage, stream habitat, and riparian habitat is effectively implemented across a broad scale throughout the Umatilla River basin. This supports observations and recommendations presented by Contor (2004). He showed a decrease in catch-per-unit-effort for juvenile steelhead as redds-per-mile increased in the Umatilla River. He concluded that juvenile summer steelhead production was limited by flow and other habitat related factors and recommended significant habitat improvements were needed to increase natural production beyond existing levels. NMFS (2009) identified similar limiting factors and proposed a recovery strategy that combines tributary habitat improvements with enhanced survival through the migration corridor for the Umatilla River summer steelhead population. Carmichael and Taylor (2009) modeled these actions, and suggested they would result in a 67% increase in abundance and 71% increase in productivity for the Umatilla River steelhead population.

Habitat enhancement efforts should focus on restoring a range of conditions that would occur naturally. Efforts also need to be monitored for biological effectiveness to provide information necessary for adaptive management. Only by increasing our understanding of the biological responses resulting from habitat improvement projects will we be able to strategically manage enhancement efforts to achieve reintroduction and recovery objectives in the Umatilla River.

LITERATURE CITED

Barnham, C. and A. Baxter. 2003. Condition factor, K, for salmonid fish. ISSN 1440-2254. State of Victoria, Dept. of Primary Industries.

Boyce, R.R. 1986. A comprehensive plan for rehabilitation of anadromous fish stocks in the Umatilla river basin. Final report prepared by the Oregon Department of Fish and Wildlife for the Bonneville Power Administration, Portland, Oregon.

Carmichael, R.W. and B.J. Taylor. 2009. Conservation and recovery plan for Oregon steelhead populations in the middle Columbia River steelhead distinct population segment.

Clarke, L.R., W.A. Cameron, R.W. Stonecypher, Jr., and R.W. Carmichael. 2009. Umatilla hatchery monitoring and evaluation: 2009 annual report. Oregon Department of Fish and Wildlife report to Bonneville Power Administration, Portland, Oregon.

Columbia River Basin Fish and Wildlife Authority. PIT Tag Steering Committee 1999. PIT-tag marking station procedural manual. Version 1.0.

Confederated Tribes of the Umatilla Indian Reservation and Oregon Department of Fish and Wildlife. 1989. Umatilla Hatchery Master Plan. Report to the Northwest Power Planning Council, Portland, Oregon.

Contor, C.R., E. Hoverson, and P. Kissner. 2000. Umatilla basin natural production monitoring and evaluation: annual progress report 1997-1998. Prepared by the Confederated Tribes of the Umatilla Indian Reservation for the Bonneville Power Administration, Portland, Oregon.

Contor, C.R, editor. 2004. Umatilla basin natural production monitoring and evaluation: summary report 1998-2002. Prepared by the Confederated Tribes of the Umatilla Indian Reservation for the Bonneville Power Administration, Portland, Oregon.

Contor, C.R., and K. Reznicek, editors. 2010. Umatilla basin natural production monitoring and evaluation: annual progress report 2009. Prepared by the Confederated Tribes of the Umatilla Indian Reservation for the Bonneville Power Administration, Portland, Oregon.

DeBano, S., D. Wooster, and six organizations. 2004. Umatilla/Willow subbasin plan. Prepared for the Northwest Power and Conservation Council.

Efron, B. and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 1(1): 54-77.

Faulkner, J.R., S.G. Smith, W.D. Muir, D.M. Marsh, and J.G. Williams. 2010. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia river dams and reservoirs, 2009. Prepared by the National Marine Fisheries Service for the Bonneville Power Administration, Portland, Oregon.

Hanson, J.T. and R.W. Carmichael. 2009. Evaluation of Juvenile salmonid outmigration and survival in the lower Umatilla River basin: Annual progress report 2007 prepared by the Oregon Department of Fish and Wildlife for the Bonneville Power Administration, Portland, Oregon.

Keefe, M.L., R.W. Carmichael, S.M. Focher W.J. Groberg, and M.C. Hayes. 1994. Fish research project – Oregon. Umatilla hatchery monitoring and evaluation: 1993 annual report. Oregon Department of Fish and Wildlife report to Bonneville Power Administration, Portland, Oregon.

Lady, J.P., Westhagen, J.R., and J.R. Skalski. 2001. SUPRH 2 User Manual. SURPH 2.1, Survival under Proportional Hazards. School of Aquatic and Fisheries Sciences, University of Washington, Seattle, WA http:/www.cqs.washington.edu/parmESt/SURPH.

NMFS. 2009. Middle Columbia River Steelhead Distinct Population Segment ESA Recovery Plan. http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Mid-Columbia/upload/Mid-C-Plan.pdf.

Northwest Power Planning Council. 1994. 1994 Columbia River Basin Fish and Wildlife Program. Northwest Power Planning Council, Portland, Oregon.

Quinn, T.P. 2005. The behavior and ecology of Pacific salmon and trout. Seattle: University of Washington, 2005.

Saul, D., C. Rabe, A. Davidson, and D. Rollins. 2001. Umatilla Subbasin Summary. Prepared for the Northwest Power Planning Council for the Columbia Plateau Rolling Provincial Review, August 2001.

Schwartz, J. and W. Cameron. 2006. Comprehensive research, monitoring, and evaluation plan for Umatilla subbasin summer steelhead and Chinook salmon. Prepared by ODFW and CTUIR for BPA and NPCC, Portland, OR.

St. Hilaire, D. 2007. Umatilla River Subbasin Fish Habitat Improvement Program. Report to the Bonneville Power Administration, Portland, Oregon.

Steedman, R.J. 1991. Occurrence and environmental correlates of black spot disease in stream fishes near Toronto, Ontario. Transactions of the American Fisheries Society 120:494-499.

Thedinga, J.F., M.L. Murphy, S.W. Johnson, J.M. Lorenz, and K.V. Koski. 1994. Determination of salmonid smolt yield with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. North American Journal of Fisheries Management 14:837-851.

United States Bureau of Reclamation. 1988. Umatilla Basin Project Oregon planning report – Final environmental impact statements. United States Bureau of Reclamation Pacific Northwest Region, Boise, Idaho.

United States Bureau of Reclamation and Bonneville Power Administration. 1989. Umatilla basin project. Initial project workplan presented to the Northwest Power Planning Council, May 1989.

United States Department of Interior. USGS. "Boundary descriptions and names of regions, subregions, accounting units and cataloging units". Water resources of the United States. USGS, 1 Jun 2010. Web. 2 Jul 2010. http://water.usgs.gov/GIS/huc_name.html#Region17.

Westhagen, J.R. and J.R. Skalski. 2009. Program PitPro 4: PIT-Tag Processor. School of Aquatic and Fisheries Sciences, University of Washington, Seattle, WA.