A Review of Abundance Trends, Hatchery and Wild Fish Interactions, and Habitat Features for the Middle Columbia Steelhead ESU

Prepared for:

Mid Columbia Stakeholders

Prepared by:

S.P. Cramer
D.B. Lister
P.A. Monk
and
K. L. Witty

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S.P. Cramer & Associates, Inc.
39330 Proctor Blvd
Sandy, OR 97055
(503) 826-9858
www.spcramer.com

FOREWARD

The Mid-Columbia Stakeholders consist of the Yakima Basin Joint Board, the Washington State Water Resources Association, the City of Richland, the Hop Growers of Washington and the Ahtanum Irrigation District.

Executive Summary

- All streams in the Middle Columbia ESU share similar patterns of steelhead trout production.
- Evidence suggests that hatchery steelhead are a small fraction of spawners in primary tributaries for wild steelhead production.
- Productivity of steelhead populations in streams with all wild steelhead was not significantly different from the productivity of steelhead populations in streams with mixed hatchery-wild stocks.
- Genetic and behavioral studies showed steelhead and rainbow trout interbreed when mature in the Middle Columbia ESU; steelhead are usually more closely related to nearby rainbow trout populations than to steelhead populations in other watersheds.
- Available data suggests that extinction risks for wild populations of *O. mykiss* are low throughout the Middle Columbia steelhead ESU.

Steelhead trout were listed under the Endangered Species Act as a threatened species in the Middle Columbia Evolutionary Significant Unit (ESU) following a period of low returns in the mid-1990's. Listings were based upon a limited amount of evidence at a period of low abundance. Negative trends in population abundance, and concerns over the impacts of hatchery fish on wild populations, especially in the Deschutes River, were cited as the primary reasons for listing the Middle Columbia steelhead ESU as a threatened species.

This report assembles new information developed since the steelhead listing, and integrates it with existing information to evaluate the long term viability of Middle Columbia steelhead populations. Since the listing occurred, trends in abundance of natural adult steelhead have been strongly upward in all major basins of the Middle Columbia ESU. Evidence suggests that all wild populations in primary wild production areas are near capacity, including those within the Deschutes and Umatilla basins.

Recent studies from the from the Middle Columbia Basin indicate that resident and anadromous forms of *O. mykiss* interbreed and share a common gene pool. Laboratory and field studies have shown that not only are resident trout and steelhead capable of interbreeding, but also of having offspring that express the alternate life history form; that is, anadromous fish can produce non-anadromous offspring, and vice versa.

Comparisons of natural recruitment between streams with high and low proportions of hatchery hatchery steelhead did not demonstrate adverse impacts on streams with hatchery fish present. The rise and fall of recruitment rates of natural fish per natural spawner have been parallel in the Yakima, Deschutes, John Day, Umatilla, and Warm Springs rivers, even though estimates of the hatchery proportion of the steelhead run to these streams ranges from 0% to greater than 50%. The assumption hatchery steelhead negatively impact the productivity of wild steelhead in the Middle Columbia region was not supported by data available from streams in the region.

The rate of change in steelhead abundance over time is strongly affected by how close the population level is to carrying capacity of the habitat. There is clear and repeated evidence within the Middle Columbia ESU and elsewhere, that survival of juvenile steelhead during their freshwater rearing is density-dependent, i.e. survival increases as density decreases. Density-dependent survival occurs primarily during juvenile rearing, rather than during spawning. Supporting evidence is presented from long-term studies in the Keogh River, Rogue River, Lemhi River, and Fish Creek.

Population viability models are used to assess the probability that steelhead populations will persist for the foreseeable future. The most comprehensive viability analysis of Middle Columbia steelhead populations was performed by Chilcote (2001). Chilcote's estimates of extinction probability are appropriate, except in the Deschutes and Umatilla basins, the only two streams in the ESU with significant steelhead hatchery production. Chilcote (2001) estimated the probability of extinction in the Warm Springs and all six areas of the John Day basin was essentially 0 for harvest rates under 20%, and only exceeds 5% when harvest rates reached 30-35% or greater.

Models often assume that the presence of hatchery origin fish in a stream will negatively impact wild fish, and viability models such as Chilcote (2001) assign a negative factor to population viability when hatchery fish are present. However, Chilcote's assumptions about the presence of hatchery fish in wild spawning areas were incorrect, based upon the analysis provided within. Chilcote's assumptions about hatchery steelhead may have led to an over-estimate of extinction probability in the Deschutes and Umatilla rivers. Estimates of fish runs in both the Umatilla and Deschutes rivers show high proportions of hatchery fish passing dams in the migration pathway, but surveys in the primary areas of wild fish spawning show a much lower proportion of hatchery fish.

In addition to the population viability model developed by Chilcote (2001),Cramer and Beamesderfer (2001) developed a stochastic life-cycle model for Deschutes River steelhead. We used that model to explore population viability. Five hundred runs of 100 years each were simulated and with various harvest rates to explore their effects on extinction probability. The simulation showed zero risk of the population dropping below 300 fish given prevailing harvest regulations. Even with harvest rate nearly 80%, the probability of run size dropping below 300 was less than 10%. This result suggests the population is substantially more robust than predicted by Chilcote (2001).

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1.0 Introduction

Summer steelhead, *Oncorhynchus mykiss*, in the Middle Columbia were listed by the National Marine Fisheries Service (NMFS) as a threatened species under the Endangered Species Act in 1999. The steelhead listing was developed in response to a biological review which concluded summer steelhead in the Middle Columbia Evolutionarily Significant Unit (ESU) were "likely to become endangered in the foreseeable future" (NMFS 1999). The purpose of this report is to review the status of summer steelhead in the Middle Columbia River to assess if the listing is still justified.

The Middle Columbia region includes the Deschutes, John Day and Umatilla rivers in Oregon, the Walla Walla River in Oregon and Washington, and the Yakima and Klickitat rivers in Washington.

The most prominent factors leading to NMFS' conclusion that Middle Columbia steelhead were threatened included, (1) declines in abundance of wild steelhead populations, (2) levels of abundance well below historic levels, (3) large numbers of hatchery-origin steelhead entering the Deschutes River basin, and a lack of information regarding this phenomenon, (4) large numbers of hatchery steelhead relative to wild steelhead, and a general lack of information regarding the impacts of hatchery steelhead on wild steelhead populations throughout the region, (5) a lack of information regarding the interactions between resident rainbow trout and anadromous steelhead, and (6) habitat alterations in the region resulting in a loss of spawning and rearing habitat for steelhead, including habitat changes which have exterminated some steelhead runs. (Busby et al. 1996; NMFS 1999).

New information has been developed since the initial listing of steelhead, and some of the old information has been revised. In recent years the region has seen the largest returns of steelhead in decades. More studies of the interactions between hatchery and wild steelhead have been conducted. On February 11, 2002, NMFS published a notice in the Federal Register that the population status of Middle Columbia Steelhead is being reviewed.

This report assembles and reviews new data related to the Middle Columbia populations, and presents original analyses of these data. The report describes; 1) historic steelhead abundance in the mid-Columbia ESU, 2) recent trends in steelhead abundance, 3) new methods to assess population status of hatchery and wild steelhead, 4) factors associated with rainbow and steelhead trout interactions, and 5) the viability of steelhead populations using new trend data.

2.0 Steelhead Abundance Patterns

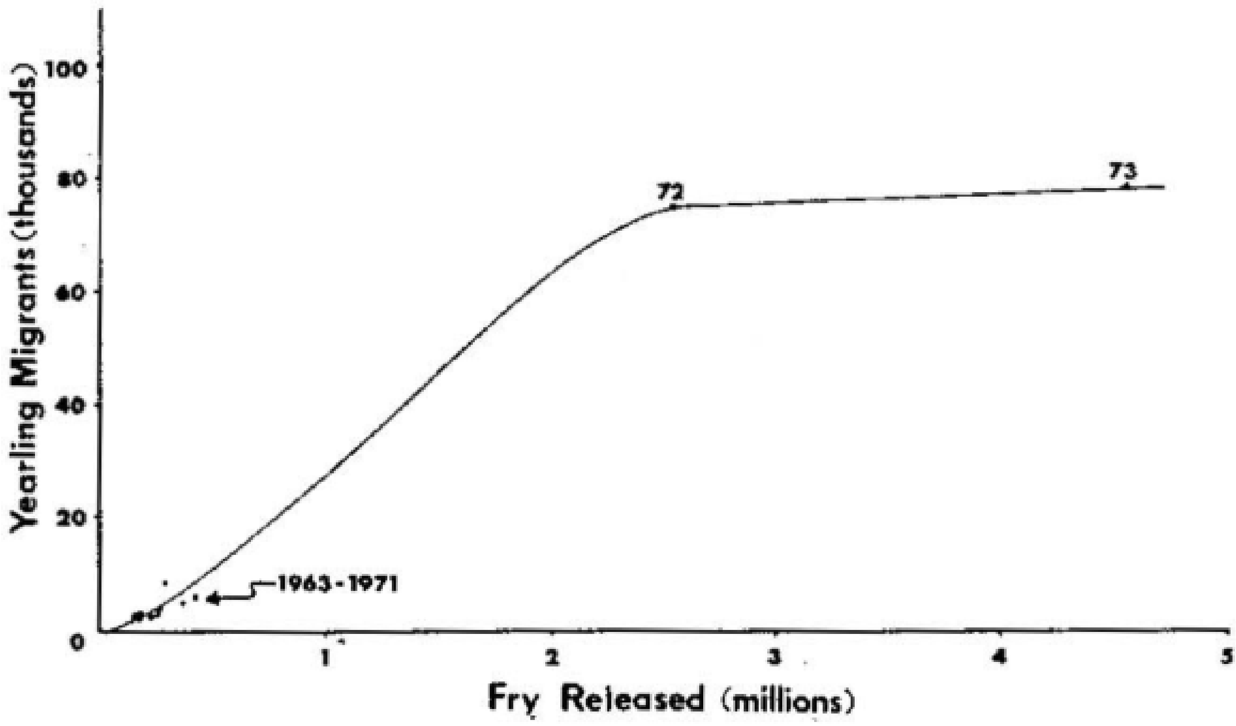
Abundance patterns across years should be interpreted relative to the capacity of a basin to produce steelhead. Healthy populations will fluctuate up and down around the level that seeds the basin to capacity with juveniles. The rate of population change in spawner abundance over time is strongly affected by how close the population level is to carrying capacity of the habitat. Carrying capacity or production potential of a basin is a function of the quantity and quality of available habitat and the existence of a capacity limit is also revealed in changing survival rates of fish as density increases. Because of the critical importance of density-dependent survival and of habitat carrying capacity to assessment of steelhead population viability, we describe the evidence that demonstrate these factors before we present and interpret abundance trends in each basin of the Middle Columbia ESU

2.1 Density Dependence and Carrying Capacity

There is clear and repeated evidence within the Middle Columbia ESU (which we present in this report) and elsewhere (which we will summarize) that survival of juvenile steelhead during their freshwater rearing is density-dependent, i.e. survival increases as density decreases. Standardized metrics recommended by NMFS for assessment of population viability assume that survival and the abundance trends it drives are density independent. An assumption that survival of steelhead is not density dependent would ignore best available science, and would strongly bias estimates of population viability by over estimating the risk of extinction. Because of the critical importance of density dependence to the population dynamics of steelhead, we focus here on the evidence that demonstrates its influence on steelhead. In this section, we present evidence for density-dependence in studies outside the ESU, and then we describe evidence that carrying capacity can be estimated from measurements of habitat features. We present evidence for density dependence within the Middle Columbia ESU when we describe population trends for each basin.

Several studies have found that the life stage at which the density dependence shows up for steelhead is during juvenile rearing rather than during spawning. This means that evidence of density dependence is likely to be vivid only where abundance of both parr and smolts have been estimated for a number of years and demonstrate a wide range in abundance. Sampling to demonstrate parr and smolt abundance over a period of years is uncommon. The presmolt life stage when density dependence is most evident is when juveniles are largest, defend the largest territories, and have the most demanding requirements for preferred habitat. On the Keogh River in British Columbia, Ward and Slaney (1993), found that the relationship of eggs-to-fry was linear, while the relationship between fry and smolts was asymptotic showing strong density dependence (Figure 1). Cramer et al. (1985) found the same correlation in the Rogue River where sub-yearling steelhead abundance was a positive linear function of spawner abundance (linear indicates absence of density dependence). Cramer et al. (1985) did not estimate smolt abundance, so they could not examine parr-to-smolt survival. Bjornn (1978) found that abundance of yearling steelhead migrants from the Lemhi River over 12 years approached an asymptote at which more age 0 steelhead did not produce more yearling migrants (Figure 1). Data from 5 years of study (1982-1986) in Fish Creek, Oregon show that abundance of age 1+ steelhead remained relatively stable (18,500 to 26,900) between years while abundance of age 0+ steelhead varied two-fold (60,000 to 116,000) (Everest et al. 1987). Further, abundance of age 1+ steelhead in Fish Creek was not correlated to abundance of age 0+ steelhead the year before (Everest et al. 1987). Reeves et al. (1997) show that abundance of age 0+ steelhead produced in Fish Creek dropped in half during 1989-1995 (mean of 39,811 annually) compared to 1982-1988 (mean of 85,114 annually), but abundance of age 1+ steelhead remained stable between 20-25,000 during those years. These data show there is substantial density compensation after the age 0 rearing year. These findings suggest that carrying capacity of a stream for steelhead is determined by competition for space among advanced fry and parr. The findings suggest rearing habitat, not spawning habitat, limits steelhead production.

Next, we show that the habitat features which limit carrying capacity for parr rearing have been identified in various studies, and can be measured to estimate a stream's carrying capacity for steelhead parr. Cramer and Beamesderfer (2001) review the evidence showing that capacity for steelhead is determined by the surface area of stream, the form of instream habitat, the food supply, and water quality. They present a model, known as the Unit Characteristic Method (UCM) for estimating stream carrying capacity for steelhead based on habitat measurements taken from standard stream surveys by ODFW. Evidence supporting the model was presented in a previous submittal concerning the status of Middle Columbia steelhead (Cramer et al. 2002). The UCM is based on the finding that rearing densities (fish/m^2) of juvenile salmonids consistently differ between channel unit types (pool, riffle, or glide), and that stratification of parr densities by channel unit type is a useful starting point for classifying parr rearing habitat capacity. Pools support the highest densities of steelhead parr, and riffles support the lowest. However, greater than average depth, cover, and substrate roughness substantially increase densities of steelhead in riffles and glides with those features.. Further, use by steelhead in large channels drops off sharply at distances over 40 ft from shore and in the mid section of large pools where velocity dissipates. These habitat features are incorporated in the UCM by first assigning average fish densities specific to each unit type, and then decrementing or incrementing those fish densities according to the amount that habitat features deviate from average. Standard parr densities used in the UCM are the average densities observed by ODFW for age 1 and 2 steelhead parr in 19 coastal streams that were believed to be seeded to capacity.



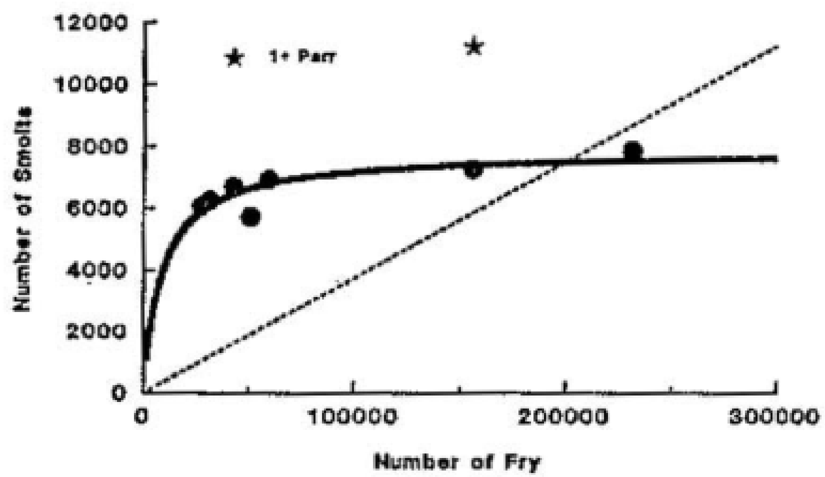


Figure 1. **Examples of density-dependent survival from fry-to-migrant life stage for juvenile steelhead. Upper graph is data for Lemhi River, 1963-73, from Bjornn (1978). Lower graph is data for the Keogh River, fry years 1976-1982, from Ward and Slaney (1993).**

The UCM was used to predict carrying capacity in the Trout Creek watershed of the Deschutes River basin. Trout Creek is a primary steelhead-producing tributary in the Deschutes basin. Beginning in 1998, a smolt trapping project has estimated smolt production in Trout Creek (Nelson 2001). Between 1991 and 1998, the ODFW and USFS conducted stream habitat surveys in the Trout Creek basin. Ackerman and Cramer (2002) compiled stream habitat data from these surveys and used them in the UCM to estimate the carrying capacity for steelhead parr and smolts. They converted parr-to-smolts by assuming a 50% survival over-winter between the two stages. Smolt capacity for the Trout Creek watershed was estimated to be about 50,000 and this production was partitioned among numerous reaches of varying capacity.

The Trout Creek subbasin has 23 potential steelhead bearing streams with over 116 miles of habitat. These 116 miles include 49 miles of the mainstem Trout Creek and 67 miles of tributaries extending upstream into the Ochoco National Forest (StreamNet 2002). Of the Trout Creek basin habitat, 42% is large stream (active channel width (ACW) >5m), 9% moderate sized stream (ACW 3-5m) and 49% is small streams (ACW >3m) (Ackerman and Cramer 2002). Based on habitat features, Ward and Trout creeks have the highest steelhead parr production potential (Ackerman and Cramer 2002). These two streams have the lowest gradients, highest boulder densities, and among the highest pool compositions by surface area in the Trout Creek subbasin. While gradient is not a factor that is directly incorporated into the UCM, its impact on habitat characteristics is indicated by the correlation between decreased gradient and increased estimated capacity (Figure 2). Gradient plays a role in determining unit composition, embededness and cover which are factors taken into account by the model.

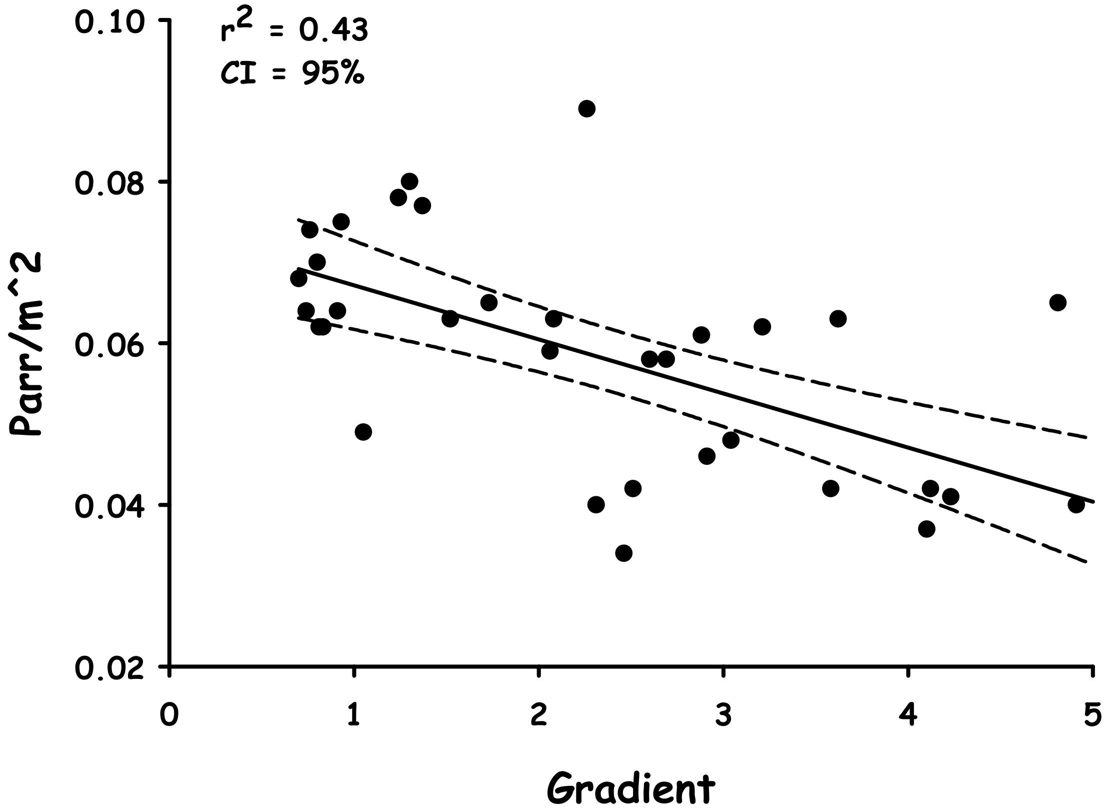


Figure 2. Regression of gradient vs. estimated capacity for steelhead parr in Trout Creek. Each point represents a stream reach. From Ackerman and Cramer (2002)

The estimated capacity of 50,000 smolts for Trout Creek appears reasonable compared to the estimated number of smolts leaving the stream each spring, 1998-2002 (Figure 3). The high number of smolt in 1998 was inflated by an unusually high portion (64%) of smolts that were age-1. Nelson (2001) reported that 83% of smolts in 1999 and 69% of smolts in 2000 were age 2, while only 35% of the smolts were age-2 in 1998. Steelhead smolts in the Deschutes Basin are typically age 2, and survival from age 1 to age 2 is typically 50%, which means it usually takes two age 1 fish to produce one age 2 fish. What we see in the Trout Creek data is that many fish which normally would have smolted at age 2 in 1999 instead smolted at age 1 in 1998, causing smolt abundance to appear high in 1998 and low in 1999. If age at smolting had followed the typical pattern, then smolt production from Trout Creek during 1998 to 2001 would have ranged from 40% to 100% of the capacity predicted by the UCM for average flow conditions. Such variation in filling the rearing capacity should be expected, given the variation in water supply, steam temperature, and spawner escapement between years. We conclude that direct estimates of smolt production from Trout Creek, compared to carrying capacity predicted by the UCM, demonstrate that habitat measurements provide a basis for approximating the rearing capacity of a stream for steelhead parr.

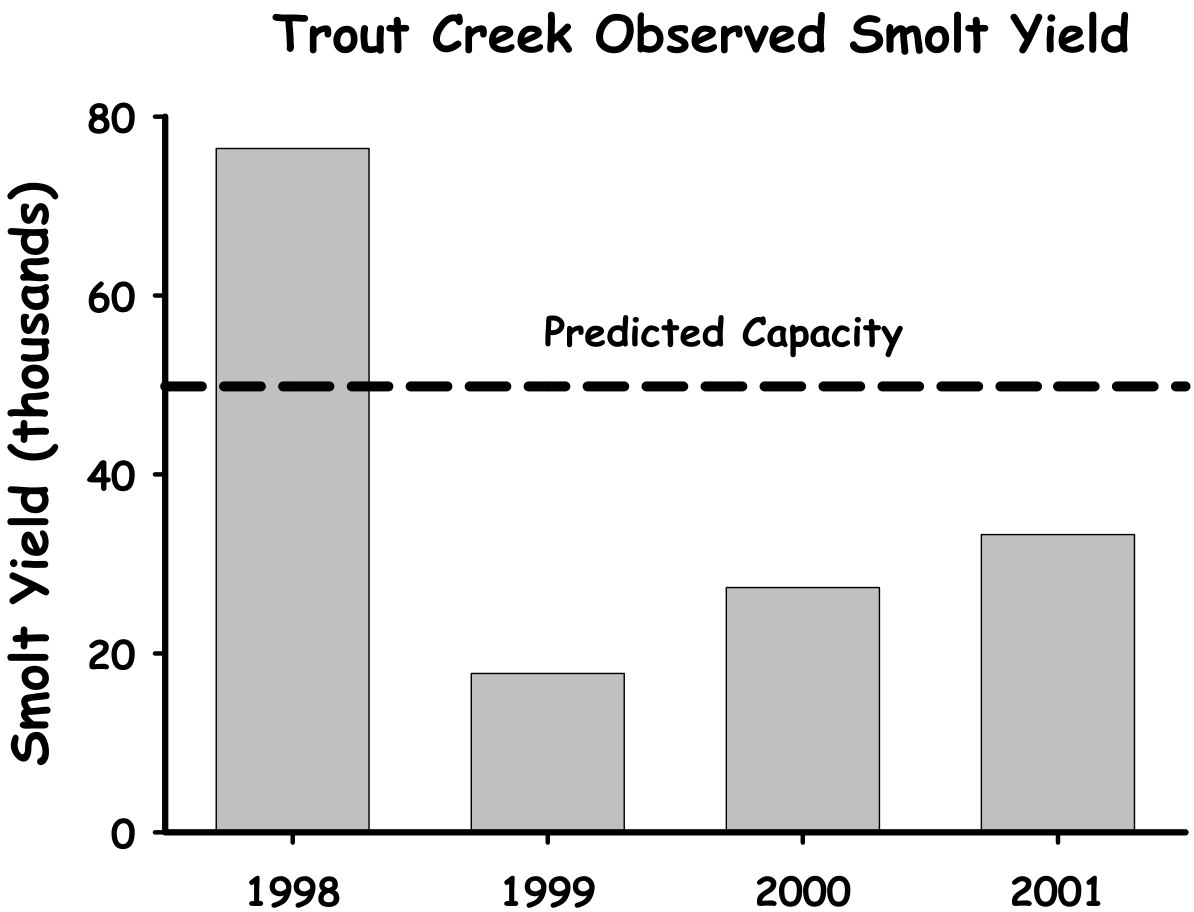


Figure 3. Estimates of steelhead smolts emigrating from Trout Creek, Deschutes Basin, each year, 1998-2001, compared with watershed carrying capacity estimated using the Unit Characteristic Method. Smolt passage estimates from Personal communication, Tom Nelson, ODFW, Madras.

We can compare estimates of rearing capacity to the density of spawners in selected section of Trout Creek (Table 1). This comparison by stream reach depicts that full rearing capacity is unlikely in any one year because full seeding must be achieved in each reach every year. Table 1 shows that adult recruits varies substantially between reaches each year. Low flows in 2002 impaired access to highest reaches in the watershed. A comparison of spawning densities between 2001, a normal water year, and 2002 shows that spawner density dropped in tributaries and the upper reaches of Trout Creek mainstem in 2002, but increased in most of the lower reaches of Trout and Ward creeks (Figure 4). This highlights that environmental and random variation in biological events at the reach level can be substantial and that observed variation in smolt output from the watershed probably reflects variation in the number of reaches filled to rearing capacity. Such events as droughts will cause variation from year-to-year in which reaches are seeded with spawners or retain sufficient flow in summer to support parr. Thus, smolt production at a 40-60% of capacity for the whole watershed would typically indicate that a watershed is rather well seeded.

Table 1. Parr capacity estimated by Ackerman and Cramer (2002) for specific reaches of the Trout Creek watershed (Deschutes Basin) compared to observed densities of steelhead spawners in 2001 and 2002. Spawning data from ODFW (T. Nelson, Madras, pers. comm.).

Stream	River Miles	Parr Capacity/mile	Redds/mile 2002	Redds/mile 2001
Amity Creek	0 - 0.03	384	0	--
Antleope Creek	0 - 5.4	1085	1	--
Augar Creek	0 - 3.6	296	24	10
Big Log Creek	0 - 2.75	223	15	9
Board Hollow Creek	0 - 0.9	384	0	--
Cartwight Creek	0 - 1.25	197	7	2
Cartwight Creek	1.25 - 2.35	277	0	--
Dutchman Creek	0 - 1.75	243	18	13
Dutchman Creek	1.75 - 2.55	254	6	--
Foley Creek	0 - 1.7	640	36	20
Opal Creek	0 - 2.5	309	18	15
Potlid Creek	0 - 0.5	241	24	18
Potlid Creek	0.5 - 2.6	330	1	--
Trout Creek	1.4 - 2.3	2710	23	--
Trout Creek	2.3 - 6.3	2332	9	9
Trout Creek	6.3 - 9.3	2332	15	7
Trout Creek	9.3 - 12.4	1784	6	34
Trout Creek	12.4 - 13.4	1536	13	36
Trout Creek	13.4 - 14.6	1536	19	32
Trout Creek	14.6 - 16.8	1536	20	32
Trout Creek	16.8 - 20.1	1312	18	32
Trout Creek	33.5 - 34	294	8	24
Trout Creek	36.3 - 38.3	294	11	--
Trout Creek	38.3 - 40.5	294	25	19
Trout Creek	40.5 - 42.5	294	20	19
Trout Creek	42.5 - 45.9	294	27	19
Trout Creek	45.9 - 46.3	294	24	--
Trout Creek	46.3 - 47.5	294	10	--
Trout Creek	47.5 - 48.0	294	4	--
Ward Creek	0 - 6.2	1083	4	9
Little Trout	0-1	367	--	0

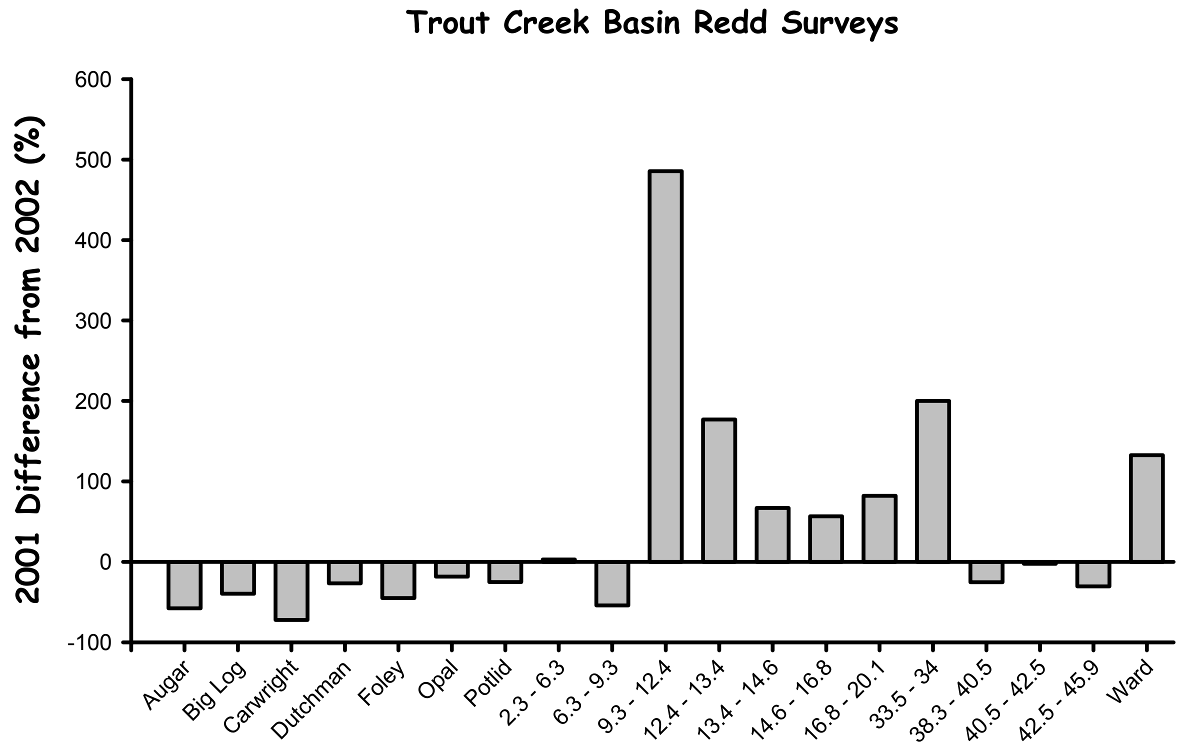


Figure 4. Relative difference in steelhead spawning density between 2001 and 2002 for various reaches of Trout Creek, Deschutes Basin. Spawning data from ODFW (T. Nelson, Madras, pers. comm.).

The above information supports our contention that each subbasin and each reach within a subbasin will have a unique carrying capacity that is determined by available habitat, and that capacity will influence abundance trends. We will also present available information on carrying capacity and density-dependent survival as we describe abundance trends for the major subbasin in the ESU.

2.2 Abundance Trends of Major Populations

During the status review under the ESA, the Biological Review Team (BRT) appointed by NMFS was concerned about the widespread declines in abundance of summer steelhead, and declining abundance was cited as a primary reason for the continuing the listing status (WCSBRT 1999). Those trends have reversed in recent years.

Abundance of steelhead spawners is monitored in the Deschutes, John Day, Umatilla, Walla Walla and Yakima rivers by state and federal resource agencies and tribes. We have compiled data from these surveys and other unpublished data for the major watersheds in the Middle Columbia ESU. The recent 2001-2002 Columbia River steelhead run was the largest return of steelhead since counts have been conducted at Bonneville Dam in the late 1930's (ODFW and WDFW 2002). This includes both wild and hatchery origin steelhead. Steelhead abundance patterns, where monitored in the ESU, are presented below.

2.2.1 Yakima River

O. mykiss are distributed throughout the Yakima River basin (Figure 5) in nearly all mainstem and tributary reaches. A substantial population of resident *O. mykiss* are found in the mainstem Yakima River above the city of Yakima (WDFW et. al. 1993). Access for anadromous steelhead to portions of the headwaters of the Yakima River basin is blocked by dams, and access to some tributaries is also precluded by passage barriers. However, steelhead and rainbow trout are widely distributed in the Yakima subbasin, but the anadromous steelhead cannot access the entire watershed.

Steelhead represent less than 1 percent of the *O. mykiss* spawners in the upper Yakima River above Roza Dam (Pearsons et al. 1998), but nearly 100 percent of the *O. mykiss* in Satus and Toppenish creeks in the lower Yakima subbasin (Hubble 1992). Steelhead are produced almost entirely from the lower Yakima Basin, especially in Satus, Creek, Toppenish Creek, and the lower Naches River. Radio-telemetry studies conducted in the Yakima River basin by NMFS in 1989-1993 (Hockersmith et al. 1995a) identified steelhead spawning areas. Fish were radio tagged in the lower river in the summer, and then tracked to their spawning areas the following winter and spring. Spawning distribution of these tagged fish in brood years 1990-1992 was 48% in the Satus Basin, 32% in the Naches Basin, 11% in the Toppenish Basin, 2% in the Marion Drain, 4% in the Yakima River mainstem below Roza Dam, and 3% in the Yakima River or tributaries above Roza Dam. Within the Naches Basin, most steelhead spawning (85%) occurred in the Naches River mainstem, primarily from river mile 2.7 (Cowiche Creek confluence) to the Little Naches River, with the remainder distributed in lower reaches of the Bumping River, Little Naches River, and Rattlesnake Creek. The few steelhead spawning upstream of Roza Dam were spread among Roza Canyon, the upper Yakima mainstem, and in several tributaries. The low numbers of steelhead returning to the upper Yakima River are enumerated more recently by fish ladder counts at Roza and Prosser dams. During 1995-2002, an average of only 5.3% of fish passing Prosser Dam also passed Roza Dam (Table 2).

Table 2. Adult Steelhead passing Prosser Dam and Roza Dam in the Yakima River, 1995-2002. Yakima Nation unpublished data.

Year	Steelhead Passing Prosser Dam	Steelhead Passing Roza Dam	% Passing Roza Dam
1995	925	23	2.5
1996	505	92	18.2
1997	1,106	79	7.1
1998	1,113	34	3.1
1999	1,070	21	2.0
2000	1,500	105	7.0
2001	2,845	135	4.7
2002	4,255	216	5.1
Total	13,319	705	5.3

Although the upper Yakima River above Roza Dam currently supports few steelhead, rainbow trout are abundant there. Pearsons et al. (1998) found that resident rainbow were numerous in the mainstem and were also the most abundant and widely distributed salmonids at index sites in tributaries to the upper Yakima River. WDFW has labeled the upper Yakima River trout fishery “Blue Ribbon” and it is considered some of the finest trout water in Washington State (WDFW 1993).

Recent studies from the Yakima Basin indicate that resident and anadromous forms of *O.mykiss* interbreed and share a common gene pool in the upper Yakima River basin (Pearsons et al. 1998). In fact they are not only capable of interbreeding, but also of having offspring that express the alternate life history form; that is, anadromous fish can produce nonanadromous offspring, and vice versa (Shapavalov and Taft 1954; Burgner et. al., 1992).

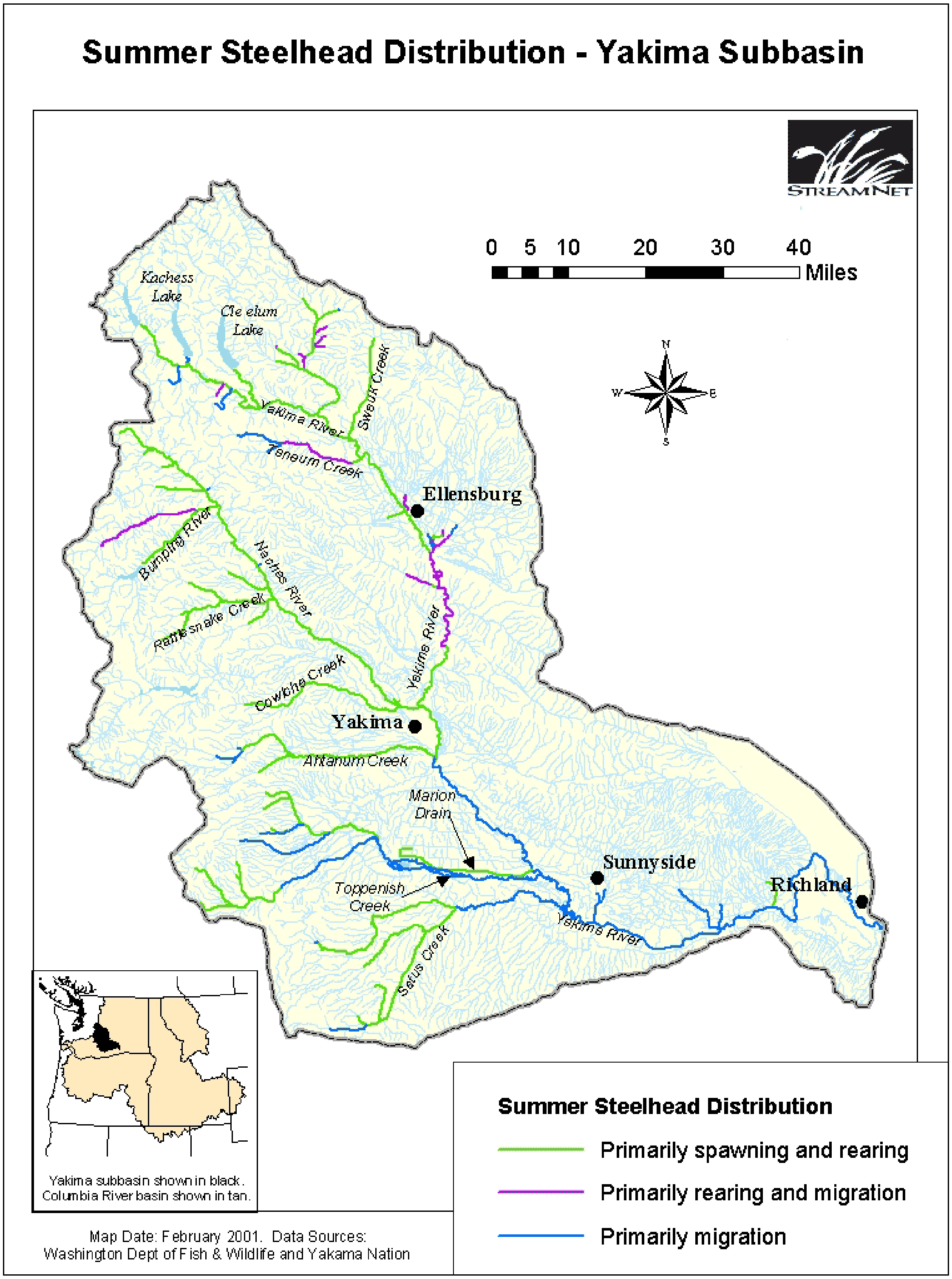


Figure 5. Map of steelhead distribution in the Yakima Basin.

Distinct estimates of hatchery and wild adult steelhead entering the Yakima River began in 1980. However hatchery steelhead were stocked prior to 1980. The first years of estimates (1980-1981/1983-1984) were derived from sport catch surveys, and surveys may have underestimated the total run size. Estimates for the 1984-1985 run and thereafter are from counts at Prosser Dam.

Estimated wild steelhead run size increased from 204 in 1980-81 to 2,601 in 1987-88, declined to as low as 451 fish in the mid-1990's, and subsequently recovered to a run of 4,463 fish in 2001-02 (Figure 6). Increased escapements of wild spawners during the 1980's were due in part to lower sport harvest in the Yakima Basin as a result of reduced daily catch limits starting in 1984 and prohibition of all wild steelhead harvest starting in 1986 (WDF et al. 1993). Harvest rates were quite high (66-69 %) in the early 1980's, and dropped to less than 10% of the run by the late 1980's (Table 3).

The abundance of wild steelhead has been increasing since 1996, and in both 2001 and 2002 exceeded the highest levels observed since counts of wild fish began (Figure 6). Hatchery produced steelhead are less than 10% of returns (note the difference in scales on Figure 6).

Data suggests density-dependence is a significant depressing factor on steelhead productivity in the Yakima subbasin (Table 4 and Table 5). Figure 8 shows a significant negative relationship of smolt recruitment rate as a function of parent spawners. Further, smolt to adult survival shows a negative relationship to smolt abundance (Figure 7). A reduction in smolt survival for smolts as abundance increases may reflect density dependent growth that results in smaller smolts when they are more abundant. Satus and Toppenish creeks have limited carry capacity which strongly reflects density-dependent control factors.

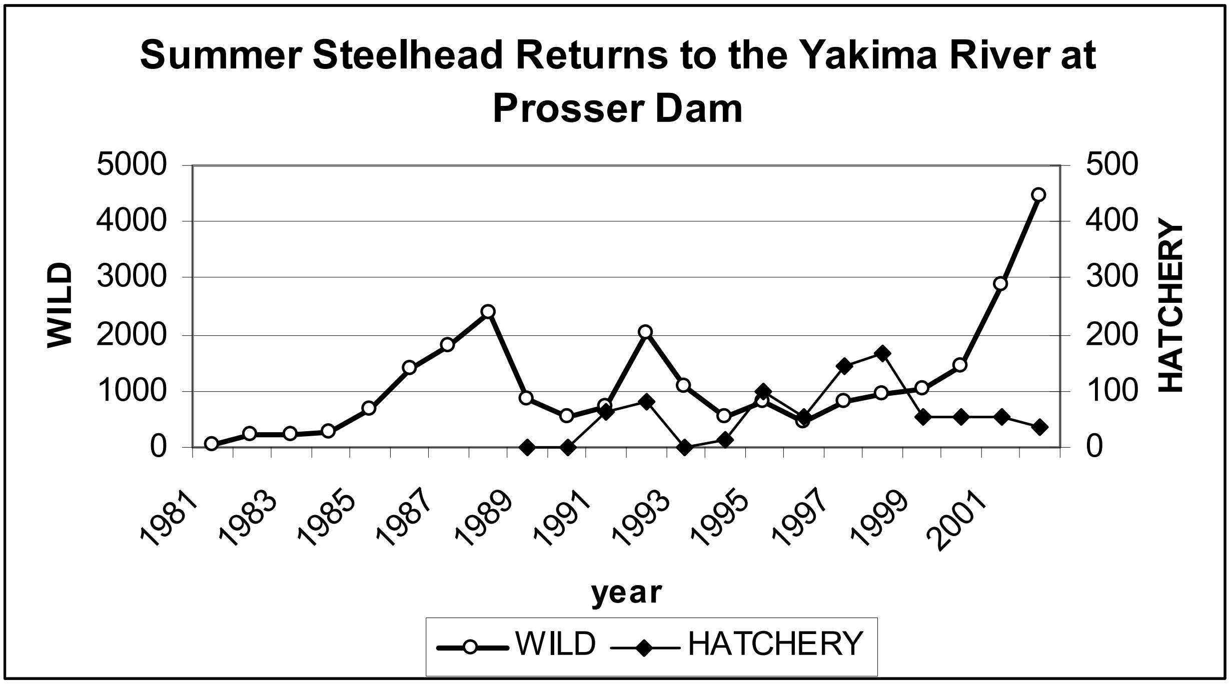


Figure 6. **Yakima River steelhead returns, for both wild and hatchery fish, 1981-2002. Please note there are different scales on the Y –axis for wild and hatchery fish. Hatchery returns to the Yakima River have never exceeded 200 fish, while wild runs have fluctuated between fewer than 500 fish to over 4,500 in recent years.**

Table 3. Estimated run size, harvest, broodstock collection and spawning escapement of wild and hatchery produced summer steelhead in the Yakima River, 1980-2002.

	Run Size(2)			Net Catch Above Prosser		Sport Catch		Hatchery Broodstock		Spawning Escapement		
Run Year	Wild	Hatchery	Total	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Total
1980-81	204	\\\\(3)	204	\\\\	\\\\	140	\\\\	0	0	64	\\\\	64
1981-82	699	\\\\	699	5	\\\\	484	\\\\	0	0	210	\\\\	210
1982-83	734	\\\\	734	21	\\\\	483	\\\\	0	0	230	\\\\	230
1983-84	911	\\\\	911	22	\\\\	603	\\\\	0	0	286	\\\\	286
1984-85	2194	\\\\	2194	21	\\\\	1481	\\\\	0	0	692	\\\\	692
1985-86	2235	\\\\	2235	0	\\\\	702	\\\\	120	0	1413	\\\\	1413
1986-87	2465	\\\\	2465	6	\\\\	514	\\\\	123	0	1822	\\\\	1822
1987-88	2601	239	2840	0	0	156	239	80	0	2365	\\\\	2365
1988-89	1066	96	1162	3	0	46	96	153	0	864	0	864
1989-90	727	87	814	40	5	39	82	109	0	539	0	539
1990-91	730	104	834	0	0	0	28	9	15	721	61	782
1991-92	2014	251	2265	0	0	0	146	0	22	2014	83	2097
1992-93	1104	80	1184	0	0	0	72	15	8	1089	0	1089

Table 3 Continued. Estimated run size, harvest, broodstock collection and spawning escapement of wild and hatchery-produced summer steelhead in the Yakima River, 1980-2002.

	Run Size(2)			Net Catch Above Prosser		Sport Catch		Hatchery Broodstock		Spawning Escapement		
Run Year	Wild	Hatchery	Total	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Total
1993-94	540	14	554	0	0	0	0	0	0	540	14	554
1994-95	820	98	918	0	0	0	0	0	0	820	98	918
1995-96	451	54	505	0	0	0	0	0	0	451	54	505
1996-97	816	145	961	0	0	0	0	0	0	816	145	961
1997-98	948	165	1113	0	0	0	0	0	0	948	165	1113
1998-99	1018	52	1070	0	0	0	0	0	0	1018	52	1070
1999-00	1448	52	1500	0	0	0	0	0	0	1448	52	1500
2000-01	2885	54	2939	0	0	0	0	0	0	2885	54	2939
2001-02	4463	34	4497	0	0	0	0	0	0	4463	34	4497

1 Run size and harvest data for 1980-81 to 1983-84 run years are from 1992 Washington State salmon and steelhead stock inventory, Appendix 3 (WDF and WDW 1993). Run size data for 1984-85 and later are from Yakima Subbasin Summary (1984-85 to 1999-00) and unpublished Yakama Nation data (2000-01 and 2001-02). Harvest and broodstock statistics are from WDF and WDW (1993) and unpublished Yakama Nation Data.

Table 4. Estimated smolt production, adult returns from that production, and smolt-to-adult survival of wild Yakima River summer steelhead, 1985-1997. Data from Berg (2001; Table 5)

Migration year	No. of smolts	Adult return	Smolt-to-adult survival (%)
1985	65,735	2,249	3.42
1986	120,591	1,858	1.54
1987	109,934	879	0.80
1988	70,961	925	1.30
1989	26,620	1,040	3.91
1990	23,075	1,697	7.36
1991	22,983	845	3.68
1992	36,225	661	1.82
1993	17,339	657	3.79
1994	18,738	630	3.36
1995	17,715	881	4.98
1996	45,814	996	2.17
1997	69,450	1,215	1.75

Table 5. Estimated smolt production and smolts per spawner relative to parent spawners, wild Yakima River summer steelhead, 1985-1997. Data from Berg (2001; Table 5)

Brood year	Adult escapement	Smolt estimate	Smolts per Spawner
1985	689	107,329	155.8
1986	1,408	101,232	71.9
1987	1,822	39,168	21.5
1988	2,496	31,330	12.6
1989	864	22,654	26.2
1990	539	31,169	57.8
1991	782	20,054	25.6
1992	2,095	16,824	8.0
1993	1,089	20,017	18.4
1994	551	30,115	54.7
1995	918	63,729	69.4
1996	485	108,036	222.8
1997	961	91,962	95.7

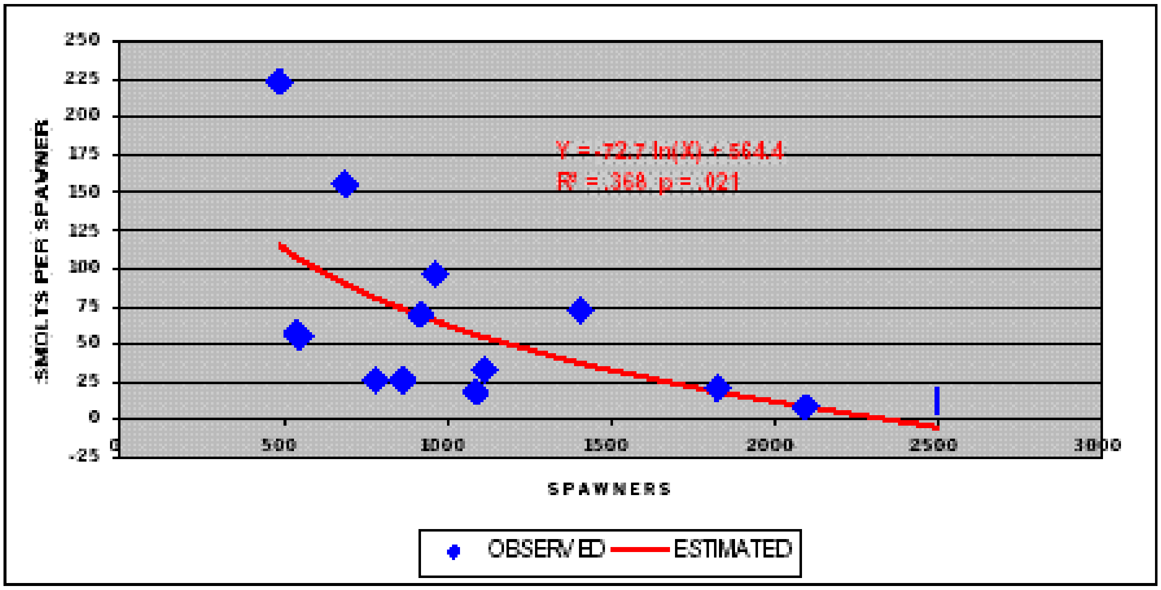


Figure 7 **Estimated smolt production and smolts per spawner relative to parent spawners, wild Yakima River summer steelhead, 1985-1997. Figure from Berg (2001)**

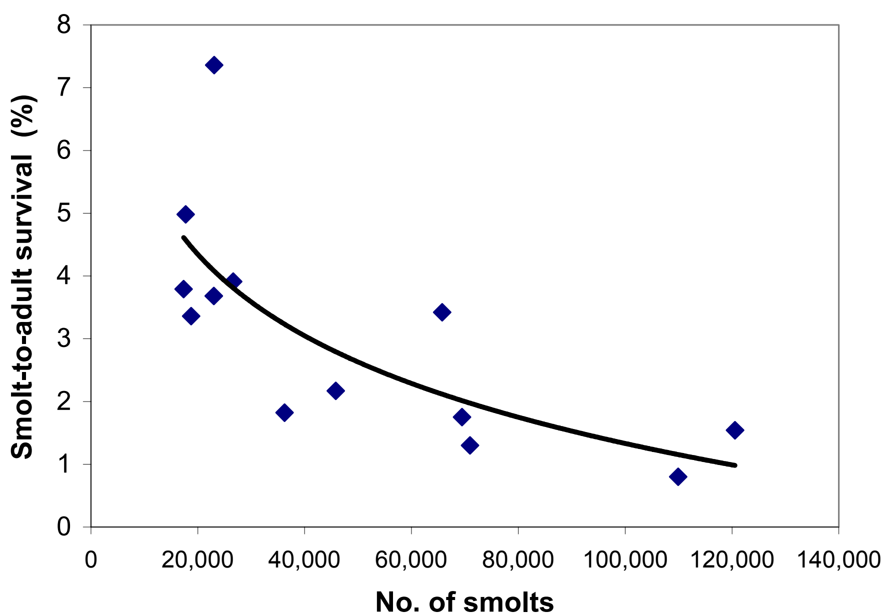


Figure 8. **Smolt-to-adult survival relative to numbers of migrating smolts, wild Yakima River summer steelhead, 1985-1997 smolt migration years. Based on data from Berg (2001) Table 5.**

2.2.2 Walla Walla River

The Walla Walla River subbasin originate in the Blue Mountains of southeastern Washington and northeastern Oregon and enters the Columbia River upstream of McNary Dam near Wallula. About 73% of the drainage lies in Washington and the remainder in Oregon. There are approximately 340 miles of streams supporting summer steelhead spawning and rearing (Figure 9) (Subbasin Plan 1990).

Most summer flow in the basin originates in the East Fork Touchet River, Mill Creek and the South Fork Walla Walla River (Table 6). Mean flow in August at the USGS gage on these three streams is 44 cfs, 31 cfs, and 109 cfs, respectively. Most to all of streamflow is diverted during summer from the lower portions of the Touchet River, Mill Creek and Walla Walla River, so only the upper portions of these streams are suitable for steelhead spawning and rearing (Figure 9).

Table 6. Drainage area and run-off of major tributaries in the Walla Walla subbasin (U.S. Army Corps of Engineers 1997).

Drainage	Drainage Area Square Miles	Drainage % of Subbasin	Average Annual Run-off (Acre/feet)	Runoff % of Subbasin
SF Walla Walla	163	4	139,000	30
NF Walla Walla	55	2	39,200	8
Mill Creek Walla Walla	96	4	69,073	15
Touchet (Bolles)	581	22	180,300	40
Other Tributaries	1,775	66	37,500	8
Total	2,667	100	462,000	100

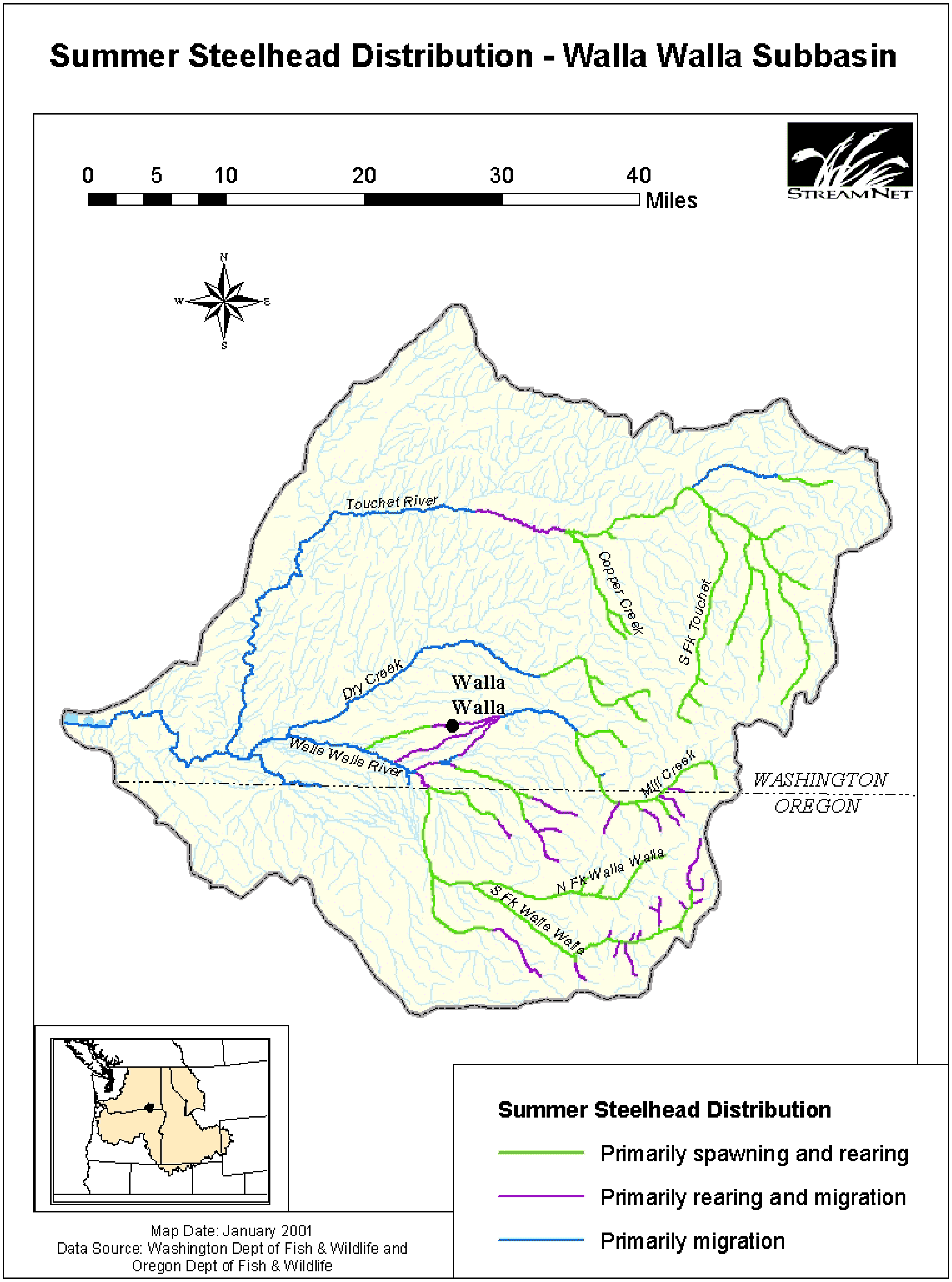


Figure 9. Map of summer steelhead distribution in the Walla Walla subbasin.

The Touchet River Basin is managed with hatchery supplementation, while the upper Walla Walla Basin was managed for wild fish only until returns in 2001.

Steelhead escapement into the Oregon portion of the Walla Walla subbasin has been monitored since 1992 as fish pass through a trap and ladder at the Nursery Bridge in Milton Freewater. ODFW manages the Oregon portion of the basin for wild steelhead and uses the Nursery Bridge trap to exclude hatchery fish from the basin. A nominal number of hatchery fish do enter the basin because some steelhead are able to pass the Nursery Bridge site during high water without using the ladder. Trapped steelhead are marked and the total escapement above the trap is estimated based on the ratio of marked and unmarked kelts when they arrive back downstream at the trap. The proportion of kelts found to be unmarked has ranged from 10 to 30% since 1992 (Draft Subbasin Plan 2001). Based on counts at Nursery Bridge trap, the number of adult steelhead returning to the Walla Walla in Oregon declined during the early 1990's, but sharply increased after 1999 (Table 7). In general, the largest escapements (ie. 815 in 1993) have led to smallest returns four years later, and smallest escapements (ie., 279 in 1999) have led to largest returns four years later (Table 7).

Table 7. Estimated number of adult steelhead escaping upstream of the Nursery Bridge Trap in the Walla Walla Subbasin, Oregon (Data from Oregon Department of Fish and Wildlife, Pendleton). Does not include hatchery fish entering the trap that were removed from the stream.

Brood Year	Wild	Hatchery	Total
1993	815	2	817
1994	535	1	536
1995	430	5	435
1996	358	7	365
1997	292	5	297
1998	378	3	381
1999	279	1	280
2000	514	13	527
2001	744	36	780
2002	1,205		
AVG	483	8	491

Steelhead return to Oregon after two years in the ocean which is not typical for many Columbia and Snake River steelhead populations. Most steelhead populations in the Columbia and Snake River spend only one year in the ocean (Table 8).

Table 8. Analysis of scales collected from adult summer steelhead trapped at Nursery Bridge Dam on the Walla Walla River (Oregon Department of Fish and Wildlife data).

Life History Pattern	Percent		
	1992-1993	1993-1994	1994-1995
2/1	24.0	21.0	13.6
2/2	63.0	56.0	63.6
2/3	2.6	0.1	3.0
3/1	2.6	6.9	9.1
3/2	7.8	14.0	10.6
2/4	0.0	2.0	0.0
1 salt	26.0	27.8	22.7
2 salt	71.0	68.7	74.2
3 salt	3.0	1.7	3.0
4 salt	0.0	1.7	0.0
Repeat Spawners	8.0	3.5	9.1

The escapement of steelhead into the Touchet River is estimated from redd counts in index areas of the subbasin. Additionally, the ratio of hatchery and wild fish is determined from fish trapped at the steelhead acclimation pond in Dayton, Washington Escapement estimates are made by expanding redd counts from index surveys and assigning the relative percentage of wild and hatchery fish from steelhead enumerated at the trap. Numbers of hatchery fish have been low and natural fish generally compose more than 90% of the run. Adult returns have ranged from 184 to 1,006 fish since 1987, with no apparent pattern. The large run of 1,006 fish in 1988 led to one of the smallest runs of 193 fish 4 years later. The smallest runs have each led to runs about double that size 4 years later (Table 9).

Table 9. Steelhead escapement estimates for the Touchet River upstream of the Dayton Acclimation Dam trap site. (G. Mendel, WDFW, Dayton , pers. comm.)

Year	Natural	Hatchery	Total	% Natural
1987	334	29	363	92
1988	1,006	88	1,094	92
1989	214	19	233	92
1990	332	29	361	92
1991	193	17	210	92
1992	374	32	406	92
1993	484	36	520	93
1994	358	19	377	95
1995	388	96	484	80
1996	no information			
1997	no information			
1998	474	53	527	90
1999	271	46	317	87
2000	217	56	273	80
2001	253	56	309	82

2.2.3 Umatilla River

A large portion of the Umatilla basin is low elevation and with less than 10 inches of rain annually (James et al 2001), so much of the stream flow comes from a small part of the basin at high elevation. The North Fork and South Fork Umatilla River merge at RM 91.3 and Meacham Creek then enters at RM 80.9 (Hollis 1966). The watersheds of these three tributaries compose about 14% of the Umatilla Subbasin area, but supply 40% to 50% of the average flow. The other major tributary that has steelhead spawning and rearing habitat is Birch Creek which enters the Umatilla River at RM 49.7 (Figure 10).

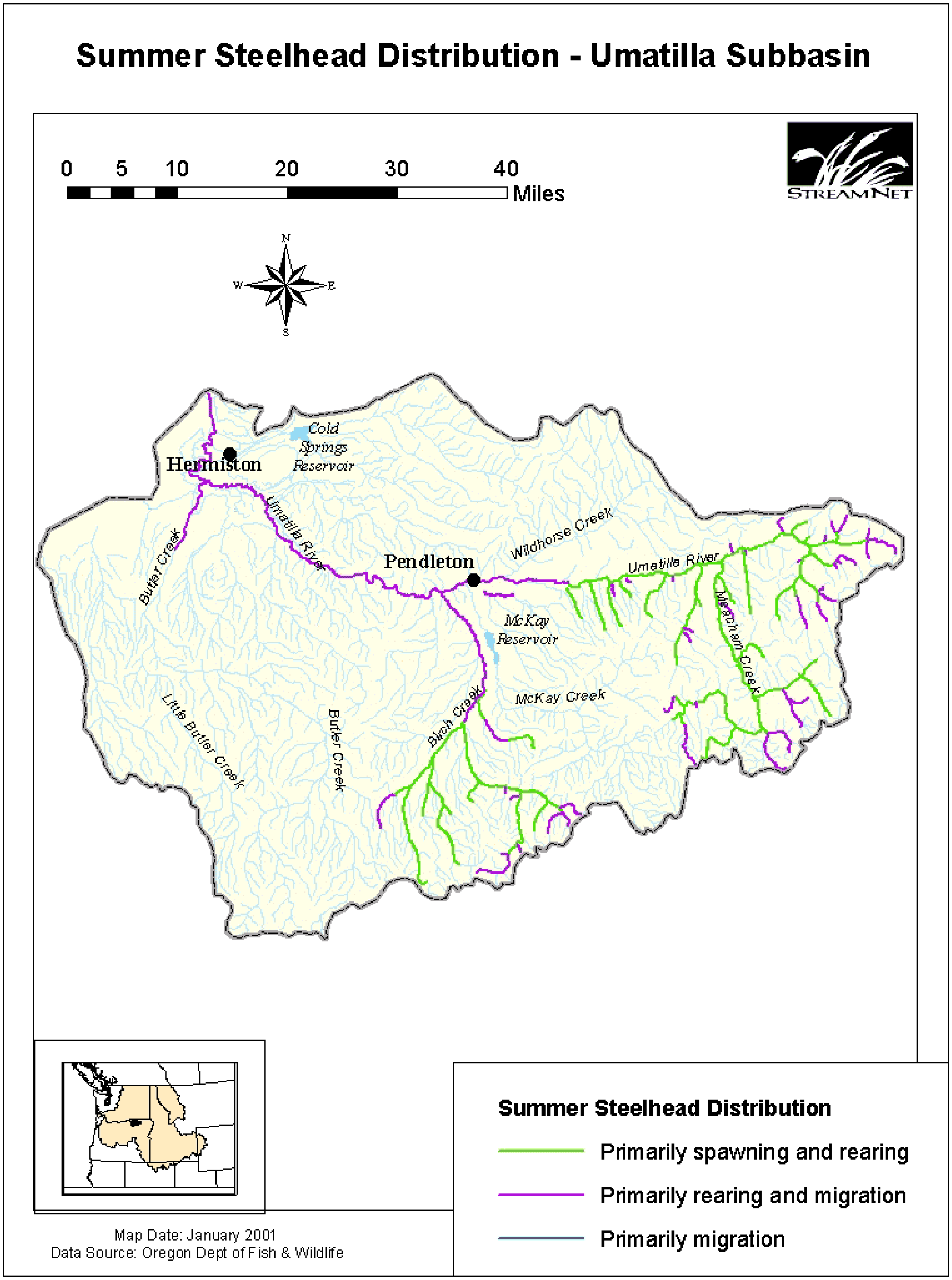
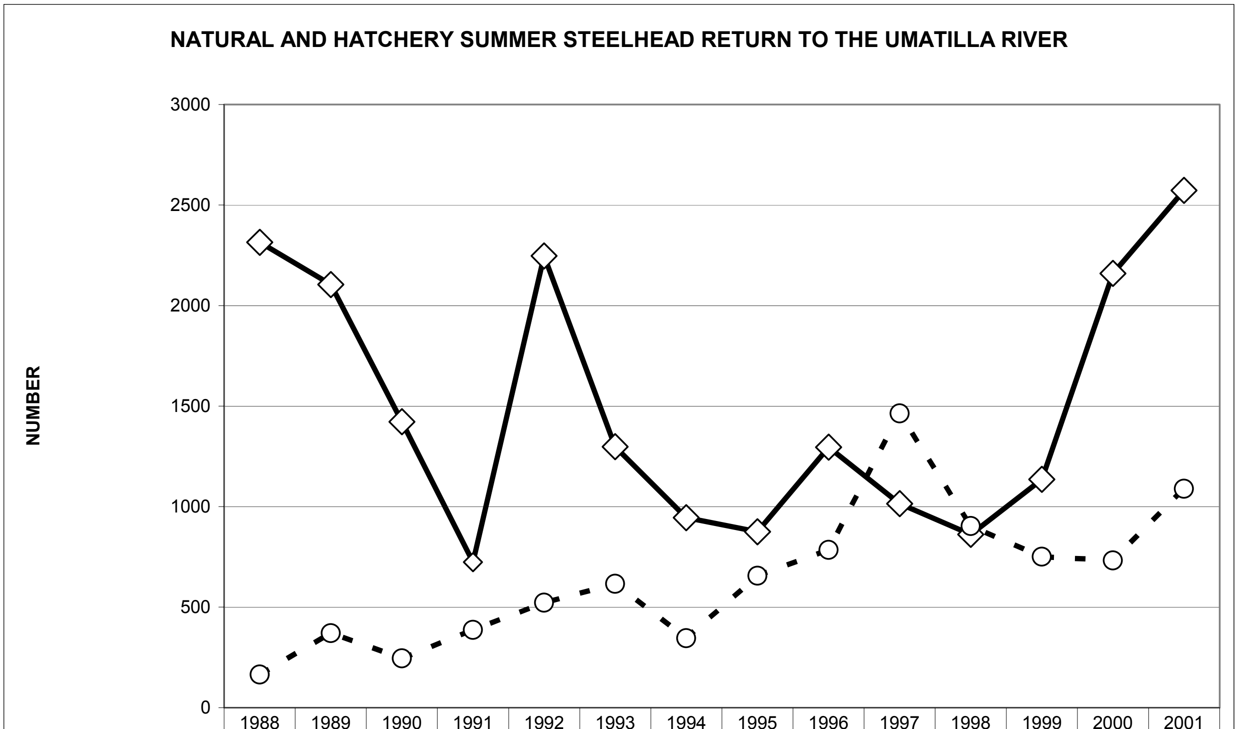


Figure 10. Map of Umatilla Basin and key spawning areas for steelhead.

Umatilla River summer steelhead are counted as they pass Three-Mile Dam, located near the confluence of the Umatilla and Columbia rivers. Spawning and rearing areas a well upstream of Three-Mile Dam. Populations of naturally produced steelhead have fluctuated between 724 – 2,573 fish, while hatchery returns are generally less abundant, ranging from 165 – 1,463 fish for the period of record Figure 11.



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
NATURAL	2315	2104	1422	724	2247	1298	945	875	1296	1014	862	1135	2160	2573
HATCHERY	165	370	245	387	522	616	345	656	785	1463	903	751	732	1089

RETURN YEAR

Figure 11. Hatchery and wild summer steelhead returns to the Umatilla River (Paul Kissner, CTUIR unpublished data).

The Umatilla Hatchery is the central production facility for Umatilla subbasin hatchery steelhead, and an integral part of the hatchery program includes satellite facilities at Bonnifer and Minthorn Springs. Bonnifer is on the main stem of the Umatilla River, and the Minthorn Springs facility is on lower Meacham Creek. Most steelhead smolts have been released in the vicinity of these facilities, and none have been released in the North Fork Umatilla or Birch Creek. The program has been releasing about 150,000 smolts per year with an ultimate goal of returning 1,500 hatchery steelhead to the mouth of the river (draft Subbasin Plan 2001). Eggs for hatchery production are taken from predominantly wild broodstock collected each year at Three-Mile Dam.

The disposition and hatchery:wild composition of adult steelhead is monitored at Three-Mile Dam. Some steelhead are taken for hatchery broodstock, some are caught in tribal and sport fisheries, and some spawn naturally (Figure 10). It is impossible to estimate the number of steelhead, wild or hatchery, that spawn naturally. Of the steelhead passed at Three-Mile Dam, some fish may die before spawning and others may be wanderers that return downstream to migrate elsewhere for spawning. However, our data indicate that the number of naturally-produced fish available as spawners have increased steadily (Figure 10). Also, the percentage that hatchery fish compose of available spawners has ranged from roughly 25 to 60% during the last decade.

Table 10. The number and percent of Steelhead available to spawn naturally that were of hatchery origin; Umatilla River, 1988-1999. From Draft Subbasin Plan 2001.

	RUN YEAR													
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Natural at Three Mile Dam	2315	2104	1422	724	2247	1298	945	875	1296	1014	862	1135	2160	2573
Hatchery at Three Mile Dam	165	370	245	387	522	616	345	656	785	1463	903	751	732	1089
Percent Hatchery at Three Mile Dam	6.7	15.0	14.7	34.8	18.9	32.2	26.7	42.8	37.7	59.1	51.2	39.8	25.3	29.7
Hatchery Caught below Three Mile Dam							14	40	35	66	89	54	74	
Percent straying at Three Mile Dam			3.96	7.76	2.82	8.05	3.16	15.56	16.13	14.74	20.69	4.4	16.36	
Natural Mortalities at Three Mile Dam	20	12	25	2	3	0	0	0	8	5	2	1	0	2
Hatchery Mortalities at Three Mile Dam	5	17	143	50	112	70	51	33	73	95	70	75	42	97
Natural Taken for Brood Stock	151	160	106	99	237	125	92	86	105	97	86	111	115	106
Hatchery Taken for Brood Stock	0	0	0	103	95	91	42	68	26	10	30	15	15	10
Natural Harvested above Three Mile Dam-CTUIR						5	5	5	0	0	5	5		
Hatchery Harvested above Three Mile Dam-CTUIR						25	20	20	39	33	33	39		
Natural Harvested above Three Mile Dam-ODF&W								0	0	0	0	0		
Hatchery Harvested above Three Mile Dam-ODF&W						22	5	21	25	24	12	47	4	
Natural Available to Spawn*	2144*	1934*	1290*	623*	2007*	1165	847	784	1186	909	769	1019		
Hatchery Available to Spawn*	160*	353*	102*	234*	315*	407	227	514	617	1301	758	575		
Redds Observed in Index Reaches	138	77	High Water	High Water	135	High Water	64	74	119	138	126	218	238	383
Index Reaches Miles Surveyed	18.5	20	High Water	High Water	21.4	High Water	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4
Redds Per Mile in Index Reaches	7.5	3.9	High Water	High Water	6.3	High Water	3.0	3.5	5.6	6.4	5.9	10.2	11.1	17.9
Percent Hatchery Available to Spawn	6.9	15.4	7.3	27.3	13.6	25.9	21.1	39.6	34.2	58.9	49.6	36.1		

* Harvest not determined Assumes that harvest is 50% females and 50% males
No adjustments made for hook and release mortality
Index reaches are in Squaw, NF Meacham, Buckaroo, Camp, and Boston Canyon Creeks and the SF Umatilla River

Abundance and distribution of spawners is determined from annual surveys to count redds in key spawning areas. Few live fish are observed during these surveys, but the data show a high correlation of run size to redd counts. Steelhead escapement to the spawning grounds has steadily increased in the Umatilla River since 1994 (Figure 12), ranging from a low of 3.0 redds per mile in 1993-94 to a high of 17.1 redds per mile during 2000-01.

It is particularly important to look at trends for spawners in tributaries least likely to be affected by supplementation from hatchery releases. These streams include Birch Creek and the North Fork Umatilla. Spawning surveys have only been occasionally in streams not expected to benefit from supplementation, but a survey in East Fork Birch Creek in 2000 showed that redd counts were up sharply, consistent with the trend throughout the basin (Appendix 1).

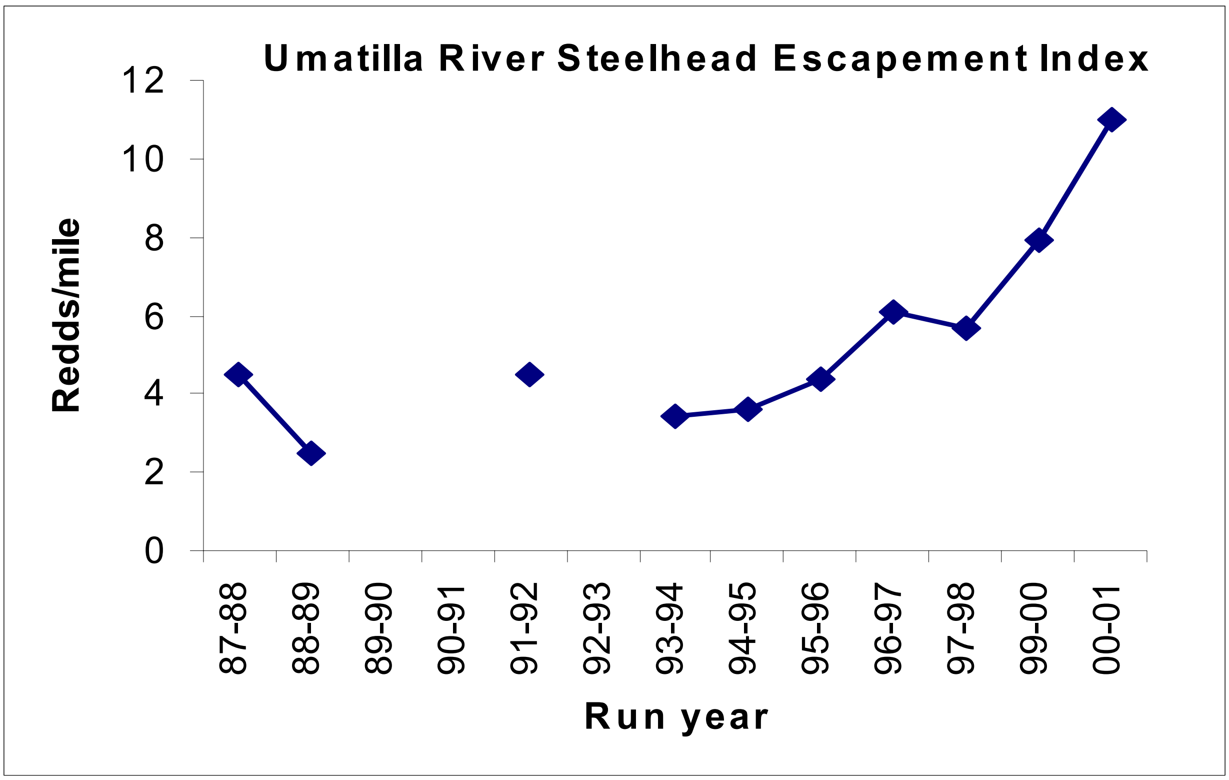


Figure 12. Steelhead escapement index for the Umatilla River. Index areas are monitored for redds, but in some years high water makes accurate redd counts impossible (Paul Kissner, CTUIR unpublished data).

In addition to steelhead counts and broodstock collection at Three-Mile Dam, adult steelhead are counted at Birch Creek trap (Table 11). The trap is located in a fish ladder at a diversion dam ¼ mile downstream of the confluence of the East and West forks of Birch Creek. Approximately 60% of the steelhead jump the diversion dam and are not counted in the ladder. It was estimated from a mark/recapture study in 1995-96 that approximately 30% of the wild steelhead counted at Three-Mile Dam were accounted for in Birch Creek that year.

It is notable that, in addition to a large share of the basin's wild steelhead passing up Birch Creek, the percentage of steelhead that were hatchery fish entering Birch Creek in never exceeded 5% in 4 years of trapping. This percentage stands in sharp contrast to the estimated percentage that hatchery fish composed of steelhead available to spawn naturally above Three Mile Dam, which in those same years ranged from 34.3% to 58.9% (Table 10). This evidence indicates the same thing is happening in the Umatilla Basin that happened in the Deschutes Basin; that is, hatchery fish spawning naturally do not fully intermix with wild fish, and key wild spawning areas have few hatchery fish.

The low percentage of hatchery fish found in the primary wild spawning tributary of the Umatilla Basin is again clear evidence that assumptions employed Chilcote (2001) about mixing of hatchery and wild fish when he estimated the probability of extinction for steelhead in the Umatilla Basin are false. Chilcote (2001) found there was a high probability of extinction in the Umatilla Basin, and that estimate of low viability for this population was driven by his assumption that addition of hatchery fish reduced productivity of wild fish. See the detailed discussion of Chilcote (2001) for the Deschutes Basin.

Table 11. Adult summer steelhead collected at the fish trap on Birch Creek (T. Bailey, ODFW, Pendleton, pers. comm..).

	Wild	Hatchery	% Hatchery	Total
1995-96	143	6	4%	149
1996-97	109	6	5%	115
1997-98	85	1	1%	86
1998-99	73	0	0%	73

Carrying capacity of the Umatilla Basin has been estimated based on habitat quality and observed emigration of smolts. According to Northwest Power Planning Council methodology, the smolt capacity in the Umatilla basin is 60,900. However, in 1977, 107,500 smolts were captured at the Westland trap located in the lower Umatilla subbasin. Smolts trapped at Westland was the basis for calculation of steelhead carrying capacity in the US vs Oregon reports (ODFW 1987). CTUIR believe the 107,500 capacity is still low and does not represent full seeding. Present estimated adult steelhead carrying capacity is 4,787 which is the estimated spawning population required to produce 107,500 smolts (Subbasin Plan 1990). Returns of naturally produced steelhead to the basin since 1988 have ranged from 724 to 2,573, and show no consistent trend up or down. Thus, observed run sizes of wild fish alone have typically been 20-60% of predicted capacity.

2.2.3 John Day River

The John Day Subbasin supports one of the largest wild runs of summer steelhead in the Columbia River basin. An undetermined, but relatively low, number of hatchery steelhead stray into the John Day subbasin.

Fishery managers have divided the John Day subbasin into four major watersheds; the North Fork, Middle Fork, Upper John Day and Lower John Day. The largest tributary in the John Day subbasin is the North Fork which enters the mainstem at RM 184. The North fork flows westerly for 117 miles. The North Fork supplies approximately 60% of the water to the John Day subbasin. The Middle Fork flows 75 miles and enters the Mainstem at RM 32. The South Fork flows 60 miles and enters the Mainstem at RM 212. Other major Mainstem tributaries are Rock Creek which enters at RM 22 and Canyon Creek which enters the Mainstem at RM 248 (Subbasin Plan 1990).

The John Day River supports a population of wild steelhead as there have been no hatchery steelhead released in the John Day River subbasin since the late-1960's (Draft Subbasin Plan 2001). Straying of hatchery steelhead into the John Day River is estimated to be less than 10%. (ODFW 2001).

Spawning and rearing habitats for steelhead are widely distributed throughout the John Day subbasin. Of some 508 streams and 9,603 miles of stream in the John Day subbasin, summer steelhead use approximately 2,780 miles or 28% of the total stream area (Figure 13)

Abundance of steelhead in the John Day River is monitored by conducting annual redd surveys on approximately 77 miles of index areas throughout the watershed. Redd survey data from index areas, combined with habitat data and within-basin harvest information was used to estimate the escapement of steelhead to the John Day River (ODFW 2001). Escapement estimates range from a low of 2,685 when only 1.0 redd/mile was observed in 1979, to a high of 47,642 fish when 16.0 redd/mile were observed in 1966 (Figure 14). Error associated with estimates of adult production was not discussed.

Spawning densities of steelhead have exceeded threshold levels determined necessary to maintain viable steelhead populations, and thresholds determined critical to maintain steelhead production (Table 12). Chilcote (2001) evaluated six subpopulations of summer steelhead within the John Day subbasin to determine their risk of extinction. Chilcote (2001) found that there was no risk of steelhead extinction for at least 90 years. Chilcote (2001) estimated that probability of extinction in any of the six areas is essentially 0 if harvest rate is under 20%, and only exceeds 5% when harvest rate reaches 35% or greater. Chilcote (2001) assumed none of the spawners in the John Day were hatchery fish, so pitfalls of his assumptions regarding hatchery produced steelhead did not affect his analysis steelhead populations in the John Day River.

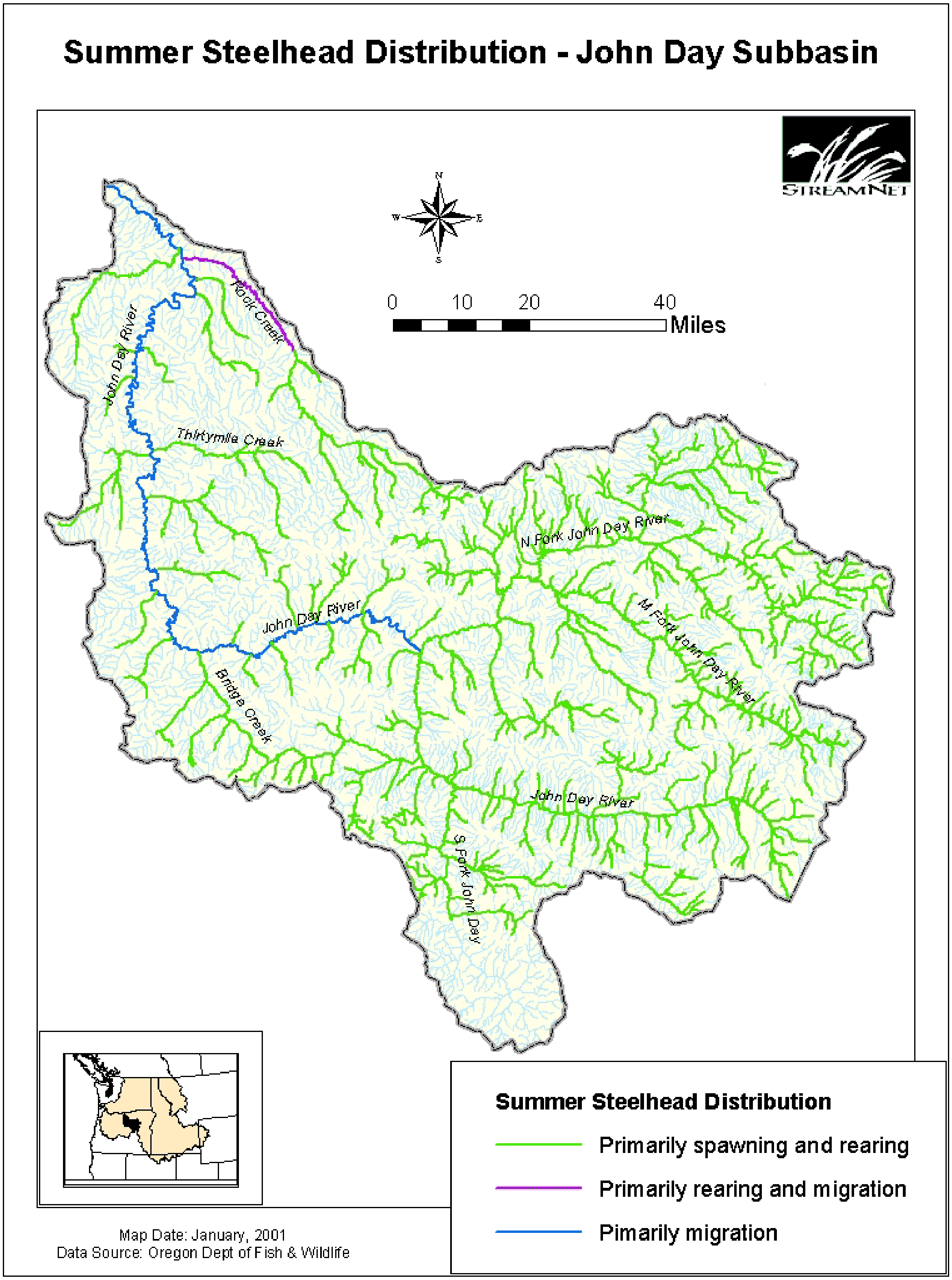


Figure 13. Map of summer steelhead distribution, John Day Subbasin.

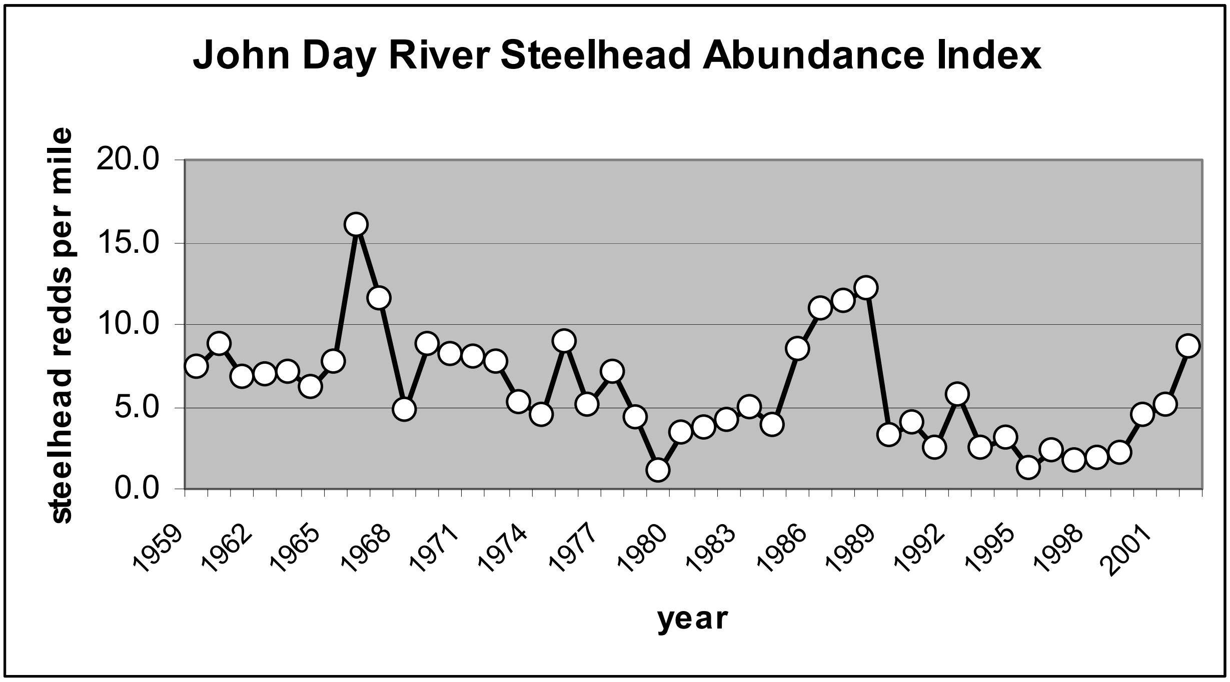


Figure 14. John Day River steelhead abundance index, expressed as steelhead redds per mile. Data for years 1959-2000 (ODFW, 2001), data for 2001-02, unpublished ODFW.

Table 12. Observed 6-year average of wild steelhead abundance, and conservation abundance thresholds for John Day River sub-populations estimated by Chilcote (2001). Abundance expressed as spawners per stream mile.

Sub-Population	Observed Abundance	Viable Threshold	Critical Threshold
Lower John Day	2.7	0.8	0.2
Lower NF John Day	2.6	0.9	0.2
Upper NF John Day	3.0	0.5	0.1
MF John Day	4.8	2.2	0.8
S. Fork John Day	2.6	1.7	0.6
Upper John Day	2.6	1.5	0.5

We agree with Chilcote (2001) that steelhead populations will not go extinct in the near future in the John Day subbasin. However, we believe that stray hatchery steelhead do spawn in the John Day subbasin, and these fish may reduce production of natural steelhead through density-dependent impacts.

Deschutes River Steelhead

Summer steelhead spawn in mainstem lower Deschutes River below the Reregulating Dam and in most tributaries below the dam (Figure 15). Significant steelhead tributary spawning systems in the lower Deschutes River include the Warm Springs River, White River, Shitike Creek, Wapinitia Creek, Eagle Creek, Nena Creek, Trout Creek, Bakeoven Creek, Buck Hollow Creek and other small tributaries. Spawning in White River is limited to the two miles below White River Falls. The upstream distribution of steelhead spawning in Nena Creek is limited by a natural barrier. Spawning in the mainstem lower Deschutes River accounts for 30 to 60% of the recent natural production of steelhead in the Deschutes River basin (ODFW 1987, 1997). Historically, steelhead were found in the Deschutes River above the present site of Round Butte Dam in the mainstem up to Big Falls, Squaw Creek, Crooked River, and possibly the Metolius River (Nehlsen 1995). Anadromous fish cannot currently pass the Pelton Reregulating dam (RM 100). There is a trap on the right bank below the Reregulating Dam where steelhead may be collected.

Mitigation agreements between fisheries agencies and Portland General Electric (PGE) provided for 1,800 hatchery steelhead in lieu of naturally produced fish above the Pelton/Round Butte project. From 274 to 1,619 adult steelhead were caught in the upstream migrant trap at Round Butte Dam when the project was under construction from 1957 through 1965 (Korn et al. 1967). Most of the spawning and rearing of steelhead found in the 1950’s above Lake Billy Chinook occurred in the lower 15 miles of the Squaw Creek (Nehlsen 1995). In the 1950’s and early 1960’s, the number of steelhead counted in Squaw Creek (trapped at a weir located 16 miles upstream of the mouth and in the 16 miles below the weir) ranged from 62 to 619. When the Oregon State Game Commission began surveys in 1951, no steelhead were observed spawning in the upper mainstem Deschutes, but a few steelhead were trapped at Steelhead Falls in 1953, 1954, and 1955, suggesting the potential for steelhead spawning up to Big Falls. Steelhead spawning and distribution in the Crooked River basin were not systematically documented until after the construction of Bowman, Pelton, and Round Butte dams, and the numbers of fish counted in the 1950’s were small (Montgomery 1952; Montgomery 1953; Montgomery 1954).

Steelhead may have been present in the Metolius River, but in small numbers (Fies et al. 1996). Most historical accounts indicate no steelhead were present, although there are occasional reports of fish identified as steelhead (Nehlsen 1995). Resident rainbow were abundant, and remain so today. Oregon Department of Fish and Wildlife (ODFW) records do not indicate the presence of steelhead in the Metolius River and elders from the Confederated Tribes of Warm Springs Reservation of Oregon do not believe that steelhead were native to the Metolius River (Fies et al. 1996).

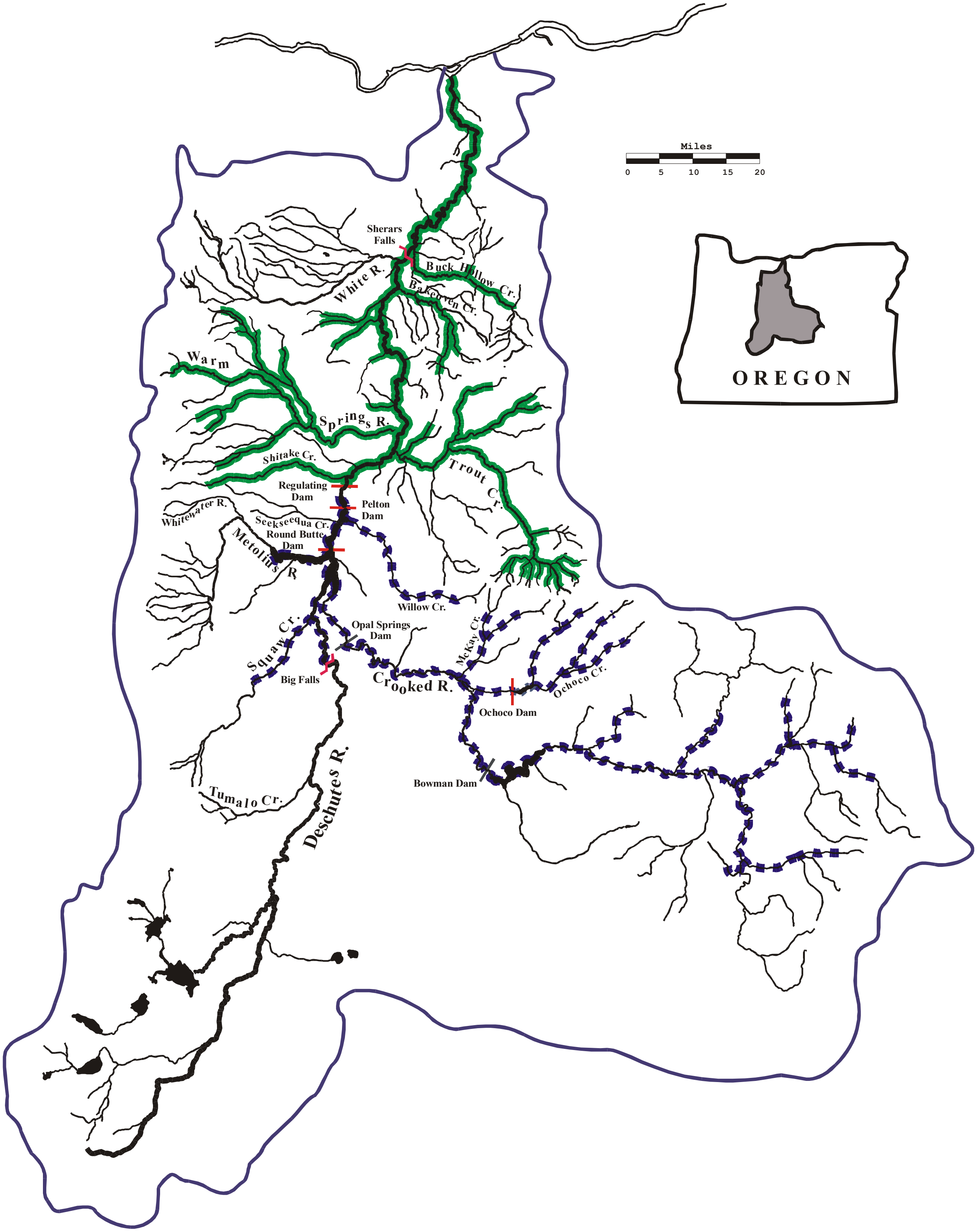


Figure 15. Current (green) and historic (yellow) distribution of steelhead in the Deschutes River Basin (Nehlsen 1995, Lichatowich 1998).

Adult abundance is monitored at Sherars Falls, Pelton Regulation Trap, Warms Spring Hatchery, and spawning ground surveys in the Deschutes Basin. Most spawning and rearing of steelhead occurs above Sherars Falls and a variable portion of the steelhead that pass Sherars Falls are wanderers that later leave the basin to spawn elsewhere. Steelhead returns to the Deschutes River are broken into three components: wild origin fish, Deschutes Subbasin hatchery fish (Round Butte), and stray hatchery fish from outside the Deschutes Basin (Figure 16). During the period of record, wild steelhead returns to the Deschutes have ranged from fewer than 500 fish in 1994-95, to in excess of 9,000 fish in the mid-1980's. The 2001-02 return of 8,985 wild fish was the second largest run since counts began in 1977. Counts of wild fish at Sherars Falls have increased steadily since the smallest run in 1994-95.

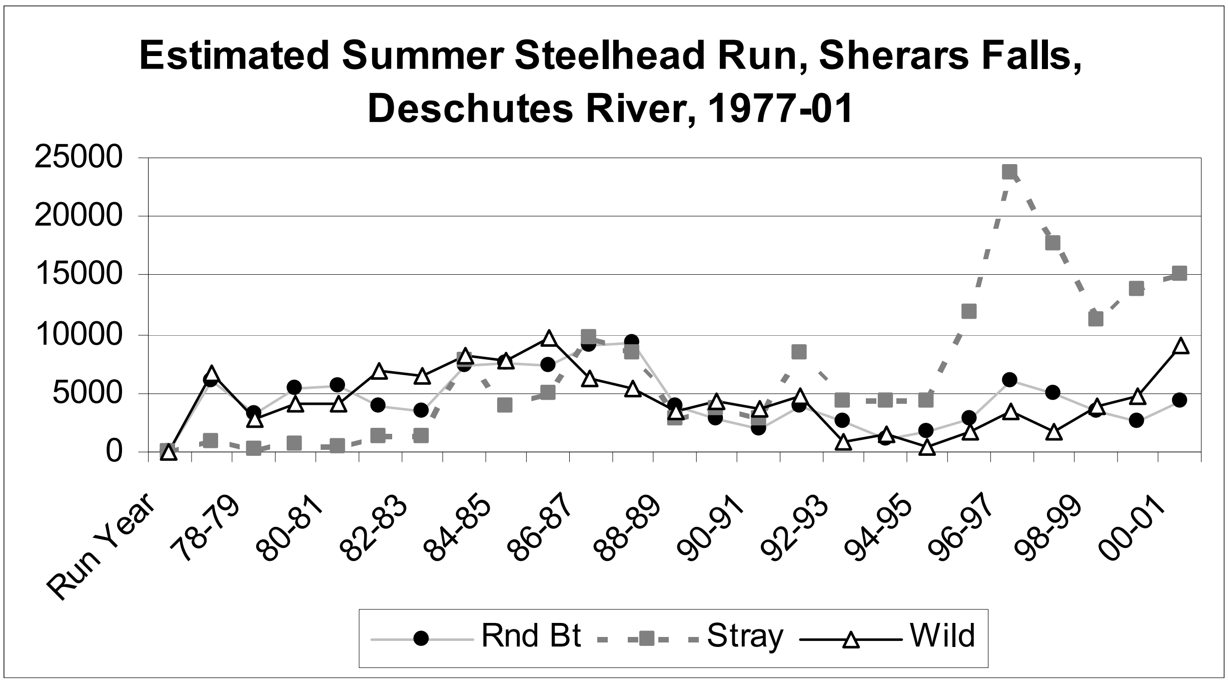


Figure 16. Estimated summer steelhead reaching Sherars Falls on the Deschutes River, Oregon (ODFW, unpublished data). Data is partitioned in to wild fish, Round Butte Hatchery (Rnd Bt) fish which originate from within the Deschutes Basin, and stray hatchery fish from hatcheries outside of the Deschutes Basin. No correction for fall back.

Recent unpublished data from adult tracking studies conducted by Peery and Keefer at the University of Idaho suggests that significant numbers of hatchery steelhead move into the Deschutes River temporarily, then return downstream to the Columbia and continue to other watersheds. In 1996, 1997 and 2000 they collected steelhead at Bonneville Dam and outfitted them with transmitters. These fish were later detected at fixed receiver sites near the Deschutes River mouth (RM 0.3) and 1.6 miles below Sherars Falls (RM 43). Approximately 60 – 70% of steelhead detected within the mouth of the Deschutes were later detected in other watersheds, and 30-40% of steelhead detected near Sherar's Falls were later detected in other watersheds (Table 13 and Table 14). Up to 25% of radio-tagged steelhead known to have traveled upstream in the Deschutes River as far as Sherars Falls were later found in the Snake River. Fallback rates at Sherars Falls were estimated at 44% in an unpublished 1996 ODFW study cited by Chilcote (MS 2002). The percentage of steelhead detected at RM 0.3 site on the Deschutes River and then recorded in the Snake was higher, ranging from 37 to 44.6% (Table 10). Recoveries of coded-wire tag from adult steelhead at Round Butte and Warm Spring hatcheries reveals that most stray hatchery steelhead recovered in the Deschutes River originated from smolt releases at hatcheries participating in the Lower Snake River Compensation Program.

Table 13. Subsequent detections of radio-tagged steelhead first detected at RM 0.3 in the Deschutes River. Information provided by C. Perry and M. Keefer (University of Idaho, Cooperative Fish and Wildlife Research Unit, Moscow)

Year	N	% last detected in Deschutes River	% last detected in Snake River
1996	219	39.3	37.0
1997	231	28.6	42.0
2000	231	30.7	44.6

Table 14. Subsequent detections of radio-tagged steelhead detected near Sherars Falls. Information provided by C. Perry and M. Keefer (University of Idaho, Cooperative Fish and Wildlife Research Unit, Moscow)

Year	N	% last detected in Deschutes River	% last detected in Snake River
1996	58	63.8	24.1
1997	60	63.3	25.0
2000	45	71.1	22.2

Chilcote (2001) developed an accounting for the number of stray hatchery steelhead that presumably spawned naturally in the Deschutes subbasin by starting with steelhead counts at Sherars Falls, and subtracting the numbers accounted for by fallback, harvest, and hatchery collections. The findings, shown in Figure 17, indicate that potential stray spawners are reduced compared to counts at Sherars Falls shown in Figure 16. Estimates of wild spawners, after adjustments, show returns in 2001 and 2002 were the second and third highest in the data series (Figure 17). The percentage of hatchery fish that could have spawned in the Deschutes subbasin is described next.

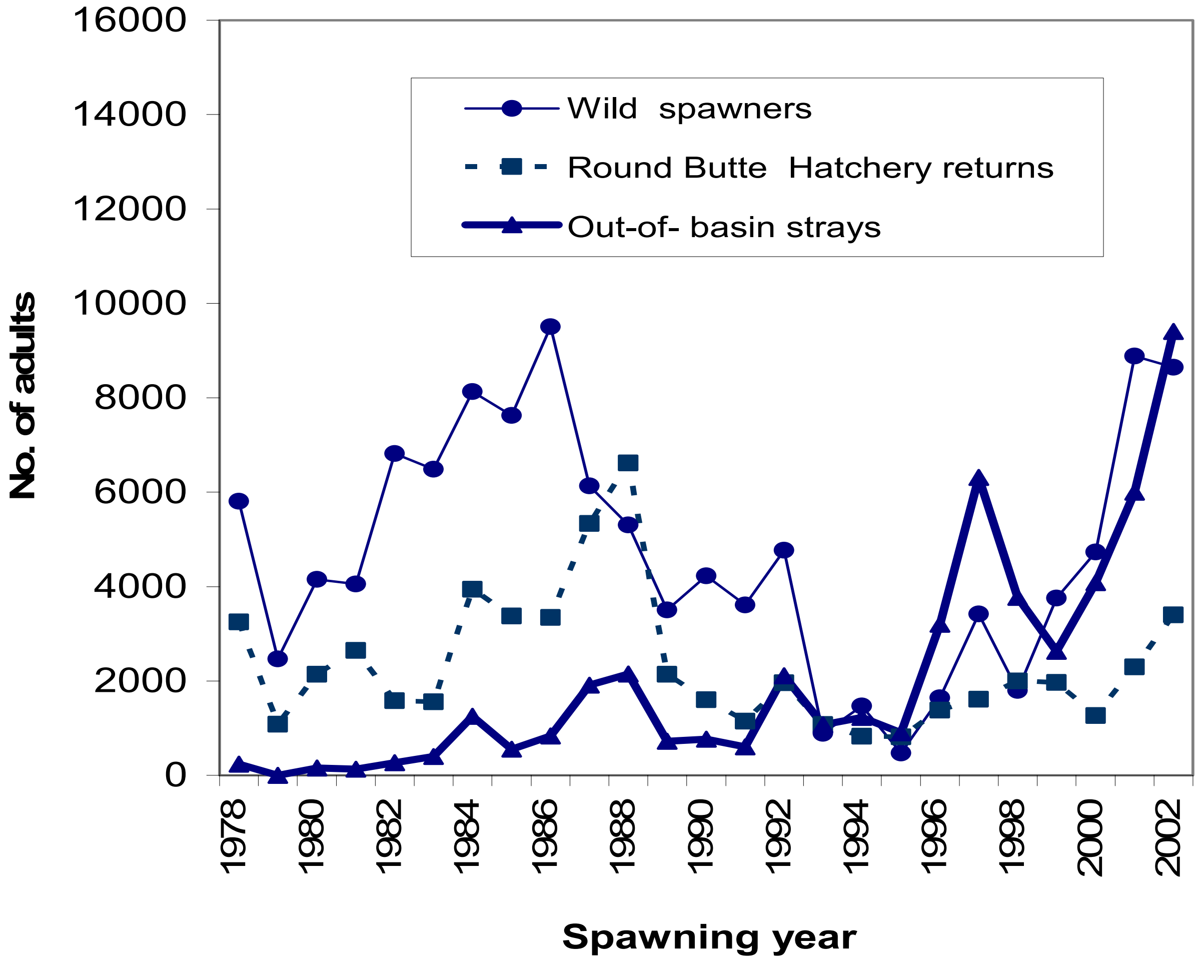


Figure 17. Estimated wild and hatchery adult steelhead that spawned naturally above Sherars Falls, Deschutes River Data for 1978-2002. Data for 1978-2000 from Chilcote (2001). Data for 2001 and 2002 from M. Chilcote ,ODFW, Portland, pers. comm.

Although large numbers of stray hatchery steelhead passed Sherars Falls and entered hatcheries (Round Butte and Warm Springs), surveys in the primary spawning areas indicate that most steelhead spawning in the Deschutes in recent years are natural rather than hatchery fish. ODFW conducts spawning surveys annually in Bakeoven and Buckhollow creeks where they record the number of spawners with and without adipose fins for those fish they could get a clear look at. Some hatchery fish were present, but in much lower proportions than observed at Sherars Falls (Figure 18; Table 15).

Hatchery steelhead composed a substantial proportion of spawners in the mid-1990's when the number of total spawners was low, but as the number of wild spawners increased in the last three years, the percentage of hatchery fish remained lower. Large numbers of unknown origin steelhead may bias the information because it is more difficult to assess steelhead without adipose fins than steelhead with adipose fins (personal communications, Steve Pribyl, ODFW January 2003).

The trend in steelhead escapement and redd counts in Trout Creek, an important steelhead spawning tributary in the Deschutes subbasin, has increased sharply (Figure 19) despite a history of hatchery steelhead strays in the area.

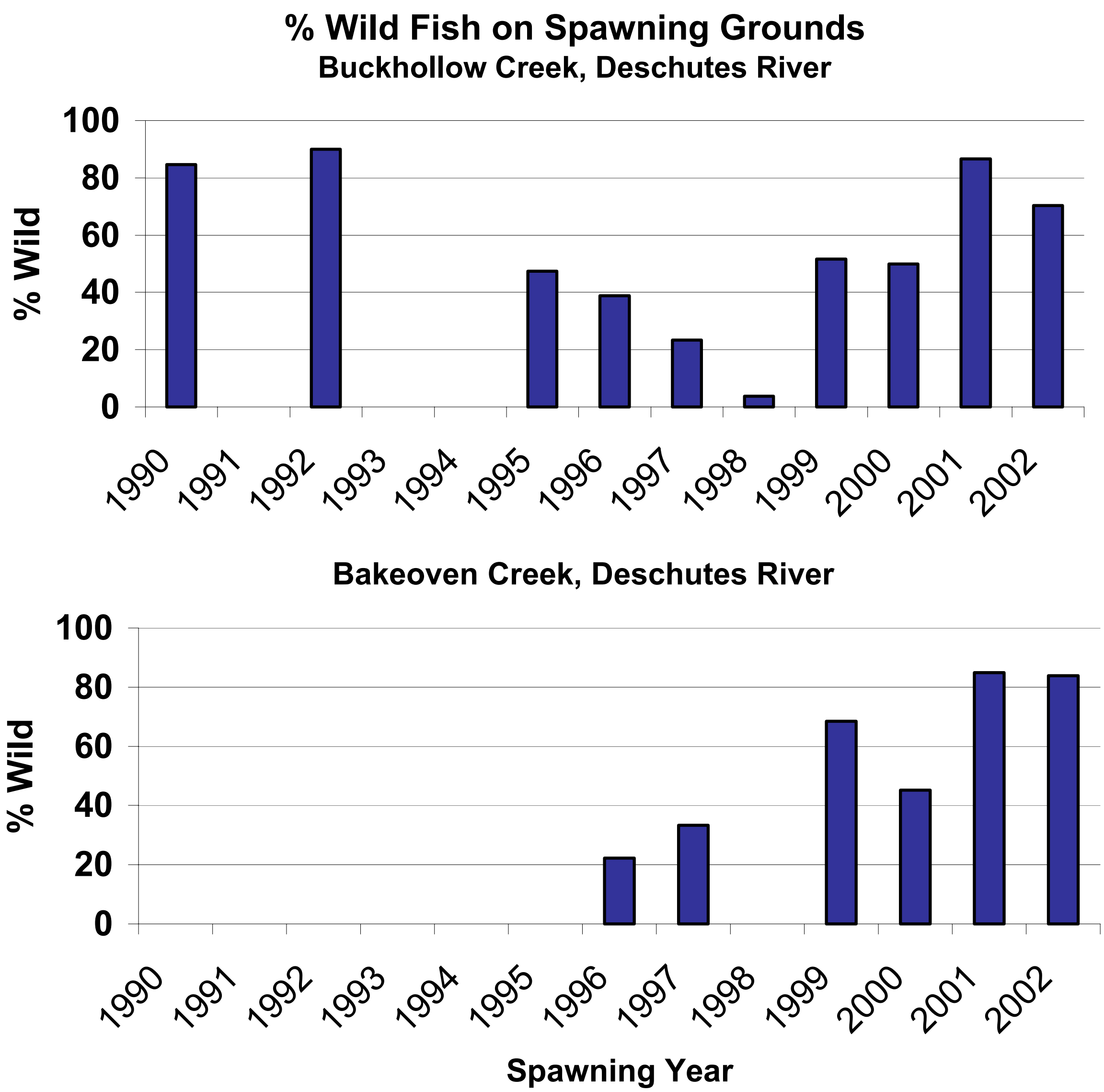


Figure 18. Proportion of wild fish observed on spawning beds in two Deschutes River tributaries. Data from Table 15. Years with only five or less fish observed are not plotted.

Table 15. **Steelhead redd counts and numbers of steelhead spawners identified as being of wild or hatchery origin in Deschutes River tributaries, Bakeoven and Buckhollow creeks, 1990-2002 spawning years. Data from Pribyl (2002) and French and Pribyl (2002b).**

Spawning Year	Bakeoven Creek			Buckhollow Creek		
	Redd Count	No. of spawners identified by origin[a]		Redd Count	No. of spawners identified by origin[a]	
		Wild	Hatchery		Wild	Hatchery
1990	24	0	1	85	11	2
1991	8	5	0	72	3	1
1992	9	0	0	34	9	1
1993	21	2	3	48	1	1
1994	13	0	0	8	1	1
1995	20	1	3	69	9	10
1996	35	2	7	65	7	11
1997	57	4	8	136	7	23
1998	68	3	2	179	1	26
1999	89	13	6	152	15	14
2000	83	14	17	110	8	8
2001	480	158	28	445	91	14
2002	214[b]	52	10	221[b]	38	16

[a] Number of live spawners that could be visually identified as being of wild or hatchery origin (adipose fin clip) during spawning surveys.
[b] Spawner access to upper reaches restricted by low stream flows.

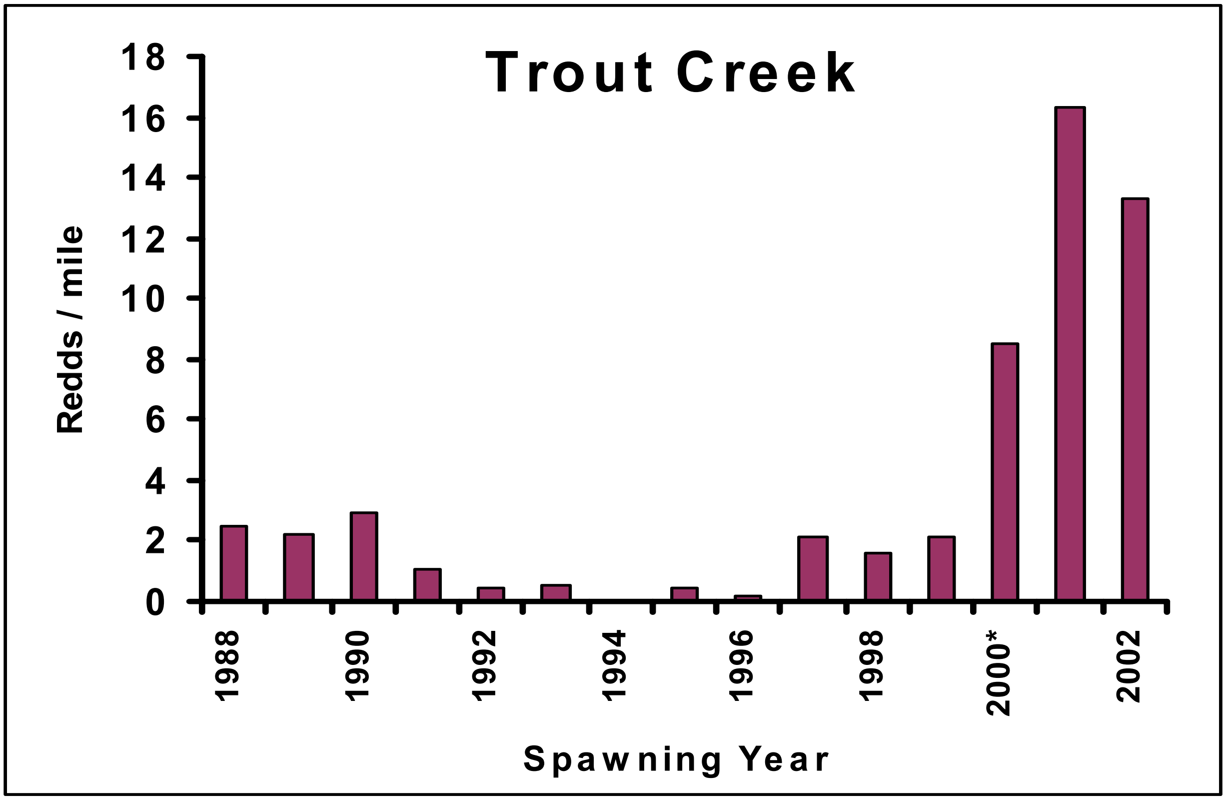


Figure 19. Annual density of steelhead redds counted in Trout Creek, tributary to the lower Deschutes River. Data from T. Nelson, ODFW, Madras, pers. comm.

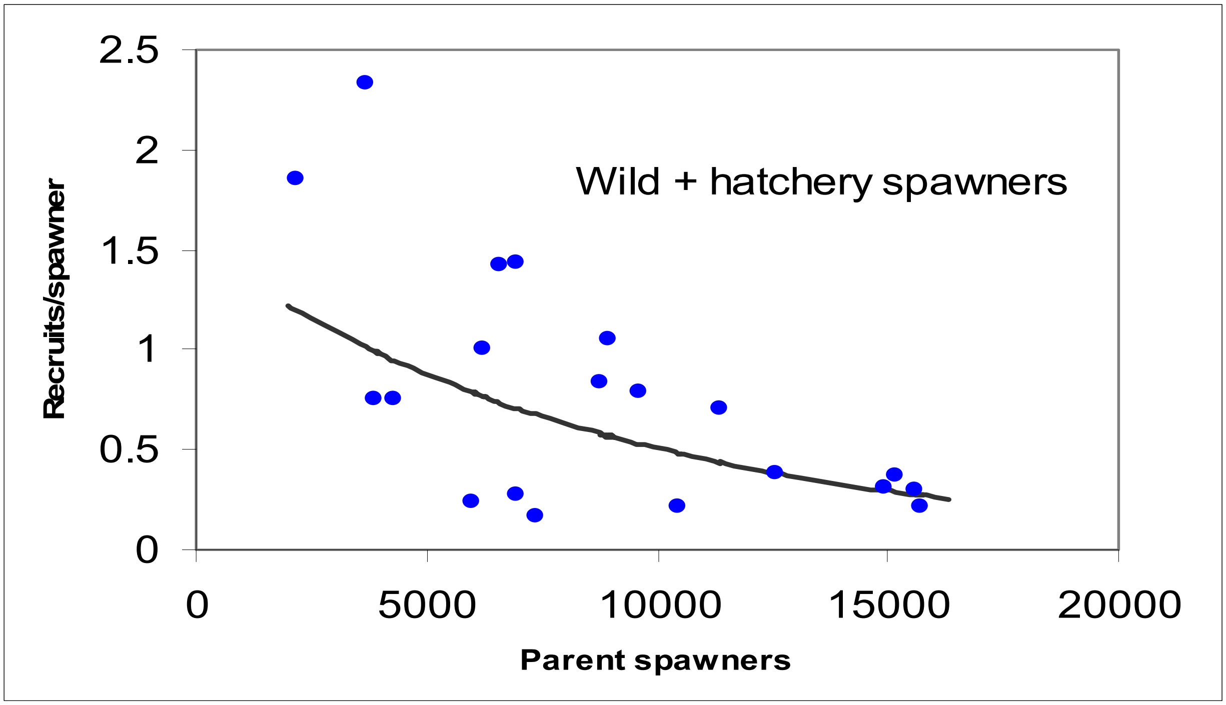
Data obtained from actual spawning surveys, and not from fish passing Sherars Falls, are the most appropriate for assessing intermixing of hatchery and wild fish. Surveys in the spawning streams show that the percentage of stray hatchery steelhead in the main spawning tributaries is presently below levels cited by NMFS as a cause for alarm in their listing decision and below the percentages assumed by Chilcote (2001) in his analysis of extinction risk.

Return rates of adult steelhead to the Deschutes show strong indication of density-dependent survival. Chilcote (MS 2002) used the data set on run size and age composition to estimate the number of spawners and subsequent adult recruits from each brood (methods described more fully in Section 3.2 of this report). Regardless of the unaccounted hatchery fish above Sherars Falls, there is a strong negative trend in recruits per spawner (Figure 20). Observations that hatchery steelhead generally composed 15% or less of spawners in Trout, Bakeoven, and Buckhollow creeks in recent years (except 30% in 2001 in Buckhollow Creek) demonstrate that all unaccounted hatchery steelhead above Sherars Falls (over 50% in recent years) should not be counted the same as wild spawners when developing stock-recruitment relationships for wild steelhead. Thus, the upper graph in Figure 20 depicts a worstcase scenario for recruitment rate while the lower graph depicts a best-case scenario. Observations of spawning fish indicate the best-case is closer to actual reality.

There were relatively high rates of recruitment per spawner during the 1993-1997 brood years despite a high proportion of hatchery spawners in the basin (Table 15). These data indicate there is a strong compensatory survival response at low wild spawner levels in the Deschutes Basin or that hatchery spawners have a higher recruitment per spawner when populations are low. The data suggests that recruitment will drop below the replacement level (one recruit per spawner) when the abundance of spawners reaches 5-6,000 fish (Table 16). This capacity level is similar to one estimated by ODFW (1987) for the lower Deschutes River and tributaries based on available habitat, habitat condition, average fecundity, and egg-to-smolt survival rates. ODFW (1987) estimated the basin below Round Butte is capable of producing an annual spawning population of approximately 6,600 steelhead adults from 147,700 smolts per year. Both the data presented in Table 16 and the capacity estimate by ODFW suggest that wild spawner escapement in 2001 and 2002 exceed capacity of the basin.

Table 16. Wild adult steelhead recruits per spawner relative to total parent spawners and wild parents only for 4 brood years of low wild fish spawning escapements, Deschutes River, 1993-1997 brood years.

Brood year	No. of parent spawners		Wild recruits per spawner	
	Total (wild and hatchery)	Wild only	From total spawners	From wild spawners only
1993	3868	894	0.75	3.22
1994	4279	1472	0.75	2.19
1995	2194	476	1.86	8.58
1996	6222	1642	1.00	3.80
1997	11344	3417	0.70	2.32



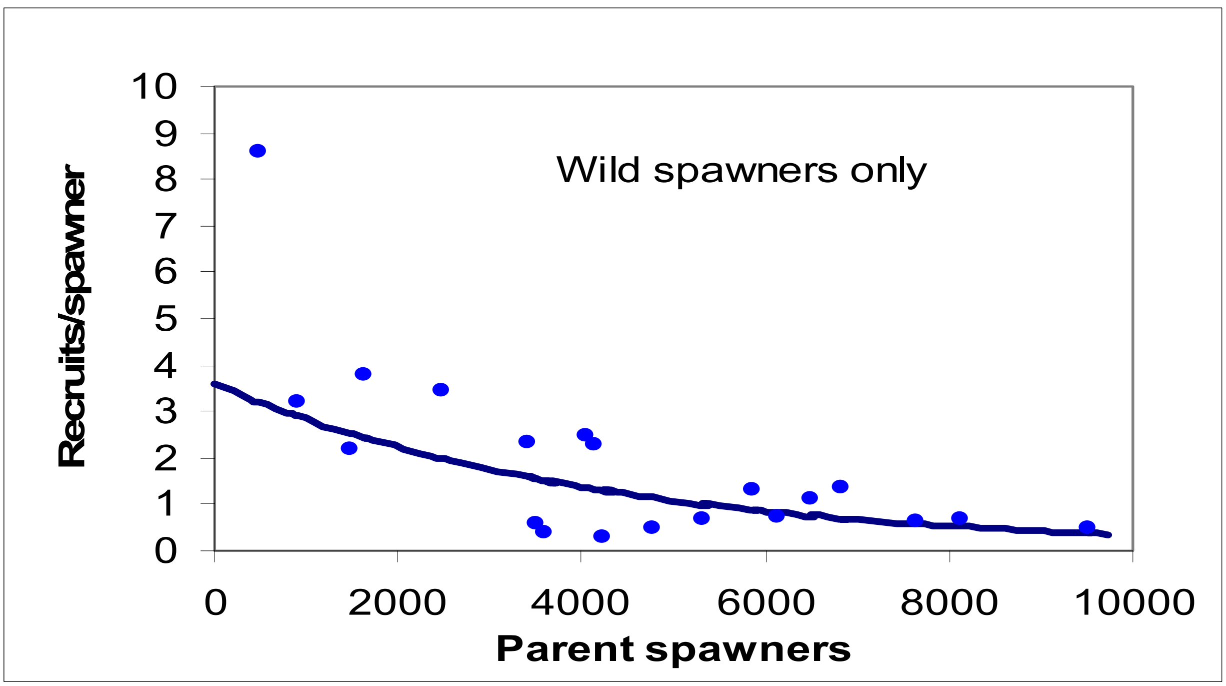


Figure 20. Wild adult recruits per parent spawner above Sherars Falls relative to parent spawners, based on total wild and hatchery spawners (upper graph) and wild spawners only (lower graph), Deschutes River steelhead, 1978-1997 brood years. Lines are regression fit of Ln(recruits/spawner) vs spawners, as is typically used to estimate parameters of the Ricker curve. Data for 1978-1994 broods from Chilcote (MS 2002). Source of 1995-1997 data is described in Section 3.2.

2.3 Historical Abundance of Steelhead in the Middle Columbia Region

NMFS often compares historical abundance information to current abundance information as an indicator of population status. NMFS (Busby et al. 1996) suggested the Middle Columbia ESU historically produced about 300,000 steelhead on an annual basis, based on another estimate that about 100,000 steelhead were thought to return to the Yakima River. However, this is a misinterpretation of earlier work, and probably does not reflect the historical abundance of steelhead in the Middle Columbia ESU. We explain here our best reconstruction of how the misrepresentation occurred.

Washington Department of Fisheries (WDF) et al. (1993) suggested Smoker (1956) estimated the historical abundance of steelhead in the Yakima River. Their report states the Yakima may have produced historical runs of 100,000 steelhead. The suggestion that 100,000 steelhead returned to the Yakima River, based upon Smoker's analysis, is not the correct interpretation of Smoker's work. Smoker did not develop historical steelhead population abundance estimates for the Yakima River, and Smoker did not conclude historical steelhead runs in the Yakima amounted to 100,000 fish. In fact, Smoker (1956; p. 8) determined that the Yakima Basin could potentially produce 700,000 pounds of steelhead for commercial and recreational fisheries, if the Yakima Reclamation project implemented certain fish passage and instream flow changes.

Smoker's (1956) estimate that the Yakima could produce 700,000 lbs. of steelhead was converted to numbers of steelhead assuming an average steelhead weight of 7 pounds (Bruce Watson, Yakama Nation, pers. comm) and then it was concluded the Yakima historically produced 100,000 steelhead. The Yakama Nation (Watson, Yakama Nation, pers. comm.) provided this estimate to WDF (1992), and it was incorporated in to the Salmon and Steelhead Stock Inventory report.

A careful reading of Smoker's original report shows that it does not give estimates of historical steelhead production. Rather, Smoker's estimate of steelhead production potential appears in a table on p. 9 under the column heading: "Original production pounds." This column heading could be confusing and may have been misinterpreted to mean historical production of Yakima River steelhead.

Busby et al. (1996) used the WDF (1992) report as a basis for developing an historical abundance estimate for steelhead in the entire Middle Columbia Region. They noted the Middle Columbia region was roughly 3 times the size of the Yakima Basin, and could therefore have produced about three times the estimated historic production of the Yakima. Thus, the suspect estimate for the Yakima River was extrapolated to represent the entire Middle Columbia region, to develop the estimate that 300,000 steelhead returned there.

Two sources exist for estimating the historic abundance of steelhead in the Yakima Basin. Kreeger and McNeil (1993) developed an historic estimate of steelhead based upon harvest statistics for the Columbia Basin, and the amount of area the Yakima watershed occupies within the Columbia Basin. They estimated the historic run of steelhead to the Yakima River was about 20,800 adults. Another recent effort (Yakima Subbasin Summary 2001), based upon the calibration of an Ecosystem

Diagnostic Treatment and Planning Model (EDT), was recently completed. Using this model, it was estimated that the Yakima River, at historic equilibrium abundance, produced 42,931 steelhead.

Chapman (1986) examined Columbia River harvest records during the peak of the commercial fisheries in the late 1800's and early 1900's. By assuming exploitation rates were at the level of maximum sustainable yield, Chapman concluded the historical salmon and steelhead production of the Columbia Basin was about 8.5 million fish. Of this, the steelhead component was about 554,000 adults for the entire Columbia Basin. Clearly, Chapman's estimate of steelhead for the entire Columbia Basin would equate to far less than 300,000 steelhead from the Middle Columbia ESU.

These various estimates suggest the historical production of steelhead in the Yakima Basin was less than 50,000 fish, rather than the 100,000 fish number used by Busby et al. (1996).

3.0 Effects of Hatchery Steelhead on Productivity of Naturally Spawning Steelhead Populations in the Middle Columbia ESU

3.1 Background

In the initial status review of west coast steelhead, the possibility that hatchery-produced steelhead could negatively affect wild populations was considered to be a potentially significant factor in viability of Middle Columbia steelhead (Busby et al. 1996). Concern regarding hatchery fish continued to be evident in the status review update completed by National Marine Fisheries Service (NMFS) in 1999 (WCSBRT 1999). These assessments were developed in a situation of declining or low abundance of wild steelhead and increasing abundance of hatchery steelhead. Since that time, however, wild steelhead abundance has rebounded despite the continuing presence of hatchery steelhead. This recent development calls into question the conclusions of earlier status reviews on hatchery-wild steelhead interactions. We re-examines the evidence for reduced steelhead population productivity attributable to presence of hatchery-produced spawners. We present this information in the traditional scientific format by first describing our methods, results, and finally our discussion of findings.

3.2 Analytical Approach and Methodology

The ESA is concerned about the abundance and viability of wild steelhead populations. This analysis examines recruitment rates of wild steelhead based on wild spawner abundance. Presence of hatchery steelhead is assumed to be one factor in the "environment" of wild steelhead. Earlier spawner recruit analyses of Oregon steelhead (Chilcote 2001; MS 2002) were based on the assumption that wild and hatchery spawners were present, and the two groups can be treated as a mixed population. In this analysis we also compare steelhead recruitment rates for wild spawners with rates calculated for total spawners (wild and hatchery fish) in the escapement.

We emphasize comparisons between steelhead populations in the Middle Columbia ESU which have high and low proportions of hatchery fish. We examine population productivity (adult recruits per parent spawner) and abundance trends. We used geometric mean and median numbers of wild recruits per parent spawner as two measures of productivity. These measures were favored over the arithmetic mean because measures of survival and productivity tend to be lognormally distributed with a small number of high values that can bias estimates of the mean (Peterman 1981). Steelhead recruitment over time was standardized so that populations could be compared on the same scale. For each population, the average number of wild adult recruits was calculated for the period being analyzed. Annual numbers of wild recruits to each population were then expressed as a ratio of the average recruitment to that population, i.e., number of recruits per average recruitment.

The terms "wild" and "hatchery" steelhead are used here to identify adult steelhead that have resulted from natural production and artificial propagation, respectively. It is recognized that the wild population may include first generation progeny from matings of hatchery-origin spawners or hatchery and wild spawners.

Steelhead abundance data for Oregon populations were obtained from Appendix 2 of Chilcote (2001) which included data up to and including the 1999-2000 run year. Data for the two most recent years, 2000-2001 and 2001-2002, were obtained from unpublished Oregon Department of Fish and Wildlife (ODFW) records for the John Day (T. Unterwegner, ODFW, John Day, pers. comm.) and Umatilla (T. Bailey, ODFW, Pendleton, pers. comm.) populations. Steelhead redd counts and estimates of wild and hatchery spawner proportions in two Deschutes River tributaries, Bakeoven and Buckhollow creeks, were also used in the analysis. These data, which included the 1990-2002 spawning years, were obtained from ODFW reports (French and Pribyl 2002b; Pribyl 2002). Adult recruits by brood year were estimated from Deschutes population age composition data (Chilcote 2001).

In the case of the Deschutes, the data set was a refinement of ODFW Sherars Falls population estimates (French and Pribyl 2002a) corrected to account for angler harvest and hook-and-release mortality of wild steelhead above Sherars Falls, removals of hatchery steelhead at Pelton and Warm Springs hatchery traps, and fallback of hatchery strays (M.W. Chilcote, ODFW, Portland, (pers. comm.).

Spawner-recruit data for the three Oregon populations include brood years or spawning years 1978 to 1994, were obtained from Table A.1 of Chilcote (MS 2002). The absence of pre-1978 observations in the Deschutes data set precluded use of earlier John Day and Umatilla data. While Chilcote's Table A.1 provided data on wild recruits, the abundance of parent wild spawners had to be calculated from the table's statistics relating to total spawners (wild and hatchery) and proportion of hatchery fish in each population. For the three most recent broods (1995-1997), we estimated wild and hatchery parent spawning escapements and wild recruits from data in Appendix 2 of Chilcote (2001), and data obtained from Unterwegner and Bailey for the 2000-2001 and

2001-2002 adult returns. Redd counts per stream mile for the John Day Basin were expanded to total numbers of spawners using the method described by Chilcote (MS 2002). We assigned adult returns to brood year based on average age composition data for each population presented in Appendix 2 in Chilcote (2001).

Steelhead run size (Prosser Dam counts) and spawning escapement data for the Yakima population (1985-2000 spawning years) were obtained from the August, 2001 draft of the Yakima Subbasin Summary report (Berg 2001). Run size and escapement statistics for the two most recent years, 2000-2001 and 2001-2002, were from unpublished Yakama Nation data. Adult returns to Prosser Dam on the lower Yakima River were corrected upwards to account for Columbia River mainstem harvest in the Zone 6 commercial fishery (ODFW and WDFW 2002). Adult wild steelhead returns were assigned to brood years based on the average age composition data presented in Berg (2001).

3.3 Incidence of Hatchery Steelhead in the Populations

Hatchery-produced summer steelhead have been documented in varying proportions in the Deschutes, Umatilla and Yakima rivers (Figure 21). Relatively small numbers of stray hatchery steelhead, resulting from smolt releases at out-of-basin facilities, have also been observed in the John Day River (ODFW 2001), but monitoring in the John Day Basin, in contrast to the Deschutes and Umatilla Basins, is limited to spawning areas rather than in the migration corridor. While there has not been a continuing hatchery supplementation program at Yakima River since 1980, wild adults (9 to 153) were collected annually during 1986-1993 as broodstock to support research on effects of hatchery smolt releases on wild salmonid juveniles (McMichael et al. 2000). Returns of adult hatchery steelhead, produced from native stock, have been present since 1988 at Three-Mile Dam on the Umatilla River. Trends in hatchery fish composition have been similar between streams even though the percentages differ between streams (Figure 21). The peaks in percentage of hatchery fish have coincided with years when returns of wild fish were lowest. Thus, hatchery returns have been more stable than wild returns, so the percentage that hatchery fish represent is highest when numbers of wild fish are lowest. However, the fact that the percentage of hatchery fish dropped as soon the numbers of wild fish increased indicates that abundance of hatchery and wild fish are independent (ie. hatchery spawners should not be counted as parents of the next generation of wild fish).

Observations of hatchery:wild composition in spawning areas indicates most of the stray hatchery fish either leave before spawning or spawn in areas not used by wild fish. We interpret Figure 21 to indicate that the percentage of hatchery fish, whether wanderers or strays, will rise and fall as the abundance of wild fish rises and falls. The numbers of hatchery fish in 2001 and 2002, but the change in those years was the increase in numbers of wild fish in the run. Wandering (not spawning) hatchery fish should not be used as a measure of their spawning interaction with wild fish.

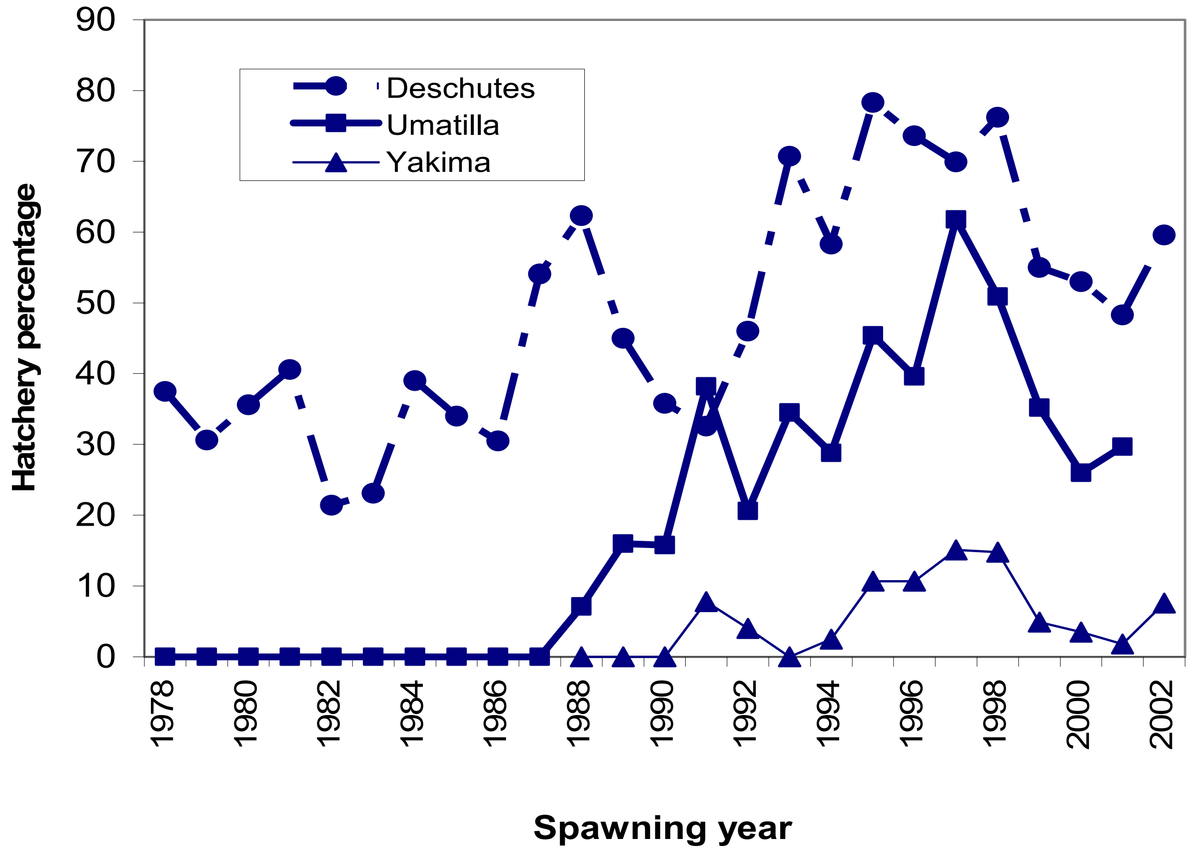


Figure 21. Percentage of hatchery-produced adults in spawning escapements of three major steelhead populations, Middle Columbia ESU, 1978-2002.

3.4 Productivity Comparisons Among Populations

Recruitment rates (recruits per parent spawner) of wild adult steelhead have fluctuated considerably in all four major steelhead populations (Deschutes, John Day, Umatilla, Yakima) in the Middle Columbia ESU (Figure 22). While year-to-year differences among populations are evident, all populations followed a general pattern of high recruitment rates from brood years in the early 1980's, declining to low recruitment rates in the late 1980's and early 1990's, with a marked recovery in recruitment rates for broods in the mid-1990's.

We compared two different measures of natural recruits per parent spawner: (1) a spawning population comprised of wild and hatchery spawners, and (2) a population of wild spawners only (excluding hatchery fish from the parent spawner count). Geometric mean numbers of wild recruits per spawner were greatest when only wild fish were included in the parent spawner population (Table 17). This was most pronounced in the Deschutes population where recruits per spawner from wild parents averaged over twice the rates calculated for mixed wild and hatchery spawner populations.

Comparison of median adult recruits per spawner, based on the same data set used for Table 17, shows Deschutes wild spawners with a higher recruitment rate than the John Day and Umatilla populations over the 1978-1997 brood years, but similar recruitment rates for these populations when only the 1985-1997 brood years are considered. Unlike the geometric mean, the median statistic is not influenced by the markedly higher recruitment rates exhibited in the 1993-1997 brood years (Figure 22).

Graphs of Deschutes wild steelhead recruits per spawner, relative to parent spawners, illustrate that calculated productivity falsely appears much lower when hatchery fish are counted as part of the spawning population (Figure 20). As described previously, only 13-30% of steelhead spawning in tributaries were hatchery fish, although more than 50% of steelhead passing Sherars Falls were hatchery steelhead in 2001 and 2002. Based on Ricker's ***a*** parameter, [equivalent to ln(recruits/spawner) at low population size], productivity from wild spawners only (3.60) substantially exceeds calculated productivity of a composite wild-hatchery population (1.52). The large difference in these two calculated values of ***a*** would produce dramatic differences in the probability of extinction predicted by a life-cycle simulation as described by Chilcote (2001).

The recruitment rate for wild steelhead in the Yakima (mean of 1.30 recruits/spawner) exceeded the Deschutes, John Day, and Umatilla populations in average and median recruitment rate calculated for wild fish only from the 1985-1997 brood years (Table 17). The years 1985-1997 was a period of generally low productivity for all populations, with recruits per spawner below replacement level for 8 of 13 brood years (1985-1992).

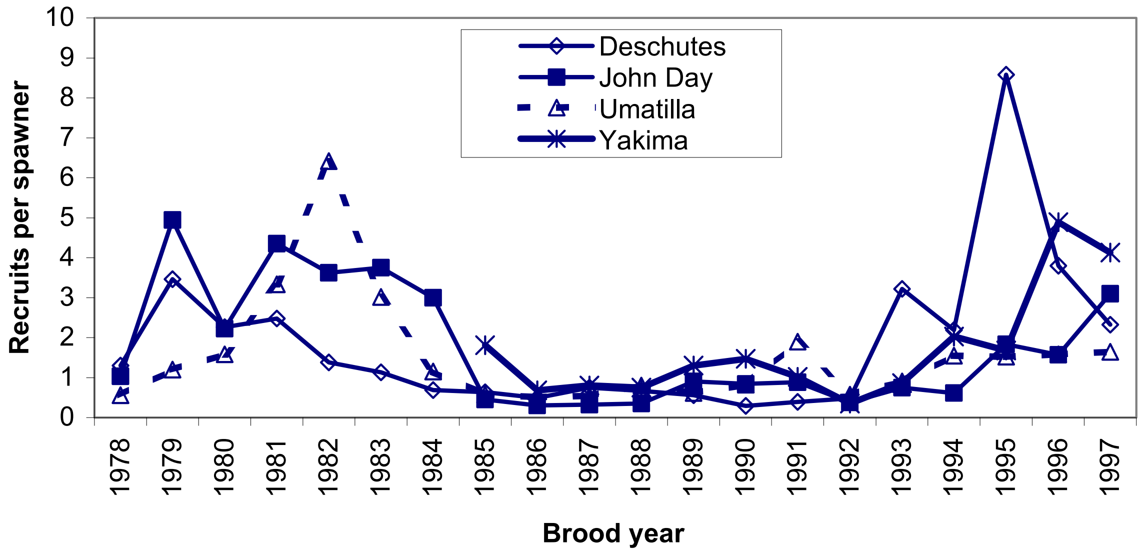


Figure 22. Wild adult steelhead recruits per wild parent spawner in four major steelhead populations, Middle Columbia ESU, 1978-1997 brood years. Data for 1978-1994 from Chilcote (MS 2002) and Berg (2001). Source of 1995-1997 brood data is described in Section 3.2 See Appendix 2.

Table 17. Median and Geometric means for adult wild recruits per parent spawner in four steelhead populations and two periods. Reliable data for Yakima population were not available before the 1985 brood.

Population	Wild recruits / spawner (wild and hatchery)				Wild recruits / spawner (wild only)			
	Median	Geometric Mean	SD	Range	Median	Geometric Mean	SD	Range
1978-1997 brood years (N=20)								
Deschutes	0.73	**0.58**	2.20	0.17-2.33	1.22	**1.24**	2.50	0.29-8.85
John Day	0.92 [a]	**1.13**[a]	2.57	0.29-4.69	0.97	**1.19**	2.58	0.3-4.94
Umatilla	0.89	**1.00**	2.03	0.46-6.42	1.18	**1.18**	2.01	0.51-6.42
1986-1997 brood years (N=20)								
Deschutes	0.71	**0.42**	2.06	0.17-1.86	0.75	**1.08**	2.88	0.29-8.85
John Day	0.70 [a]	**0.69** [a]	2.06	0.29-2.95	0.82	**0.73**	2.07	0.30-2.95
Umatilla	0.70	**0.72**	1.39	0.46-1.22	0.82	**0.93**	1.64	0.51-1.64
Yakima	1.3	**1.25**	2.00	0.34-3.51	1.3	**1.30**	2.05	0.35-4.89

[a] Although the John Day steelhead population has not been subjected to a hatchery program, it has been assumed that stray hatchery-produced steelhead from other subbasins comprise 5% of spawning population (Chilcote MS 2002).

3.5 Population Abundance Patterns

Wild steelhead recruitment to the three Oregon populations, Deschutes, John Day and Umatilla, the Deschutes and Umatilla with wild and hatchery spawners and the John Day with essentially wild spawners, followed similar patterns of abundance over the 1978 to 1997 brood years (Figure 23). Differences among populations were evident, however, when swings between high (early 1980's) and low (early 1990's) abundance are compared. Relative recruitment of wild fish was greatest for the John Day in the early 1980's, but that population also exhibited the most pronounced recruitment decline between that period and the low point in the early 1990's. Wild fish recruitment was most stable in the Umatilla population.

The population of wild steelhead in Warm Springs River, a Deschutes tributary without hatchery steelhead, serves as a reference for the Deschutes River with its mix of wild and hatchery spawners. Fish entering the Warm Springs River must pass a weir where hatchery and wild steelhead are sorted and hatchery steelhead are removed by the U.S. Fish and Wildlife Service. Given that only wild steelhead spawn in the Warm Springs River, the abundance of naturally produced steelhead returning there provides a reasonable “control” experiment for comparison to other parts of the Deschutes Basin to determine if the intermixing of hatchery and wild spawners reduces productivity. As in the previous comparison among river basins, both the Warm Springs and Deschutes populations follow similar patterns in abundance of returning wild adult steelhead (Figure 24). This comparison shows no indication that production has been diminished in the Deschutes river by the presence of hatchery fish.

The pattern of wild steelhead recruitment over time to Buckhollow and Bakeoven creeks, Deschutes River tributaries, shows a recovery of the population during the mid-1990’s in a similar trend to wild populations in the John Day and Yakima rivers where incidence of hatchery spawners is considered to be low (Figure 25). Increased natural population productivity in these Deschutes tributaries during the mid-1990’s occurred even though the significant percentage of hatchery-origin steelhead unaccounted for above Sherars Falls remained high (Table 15).

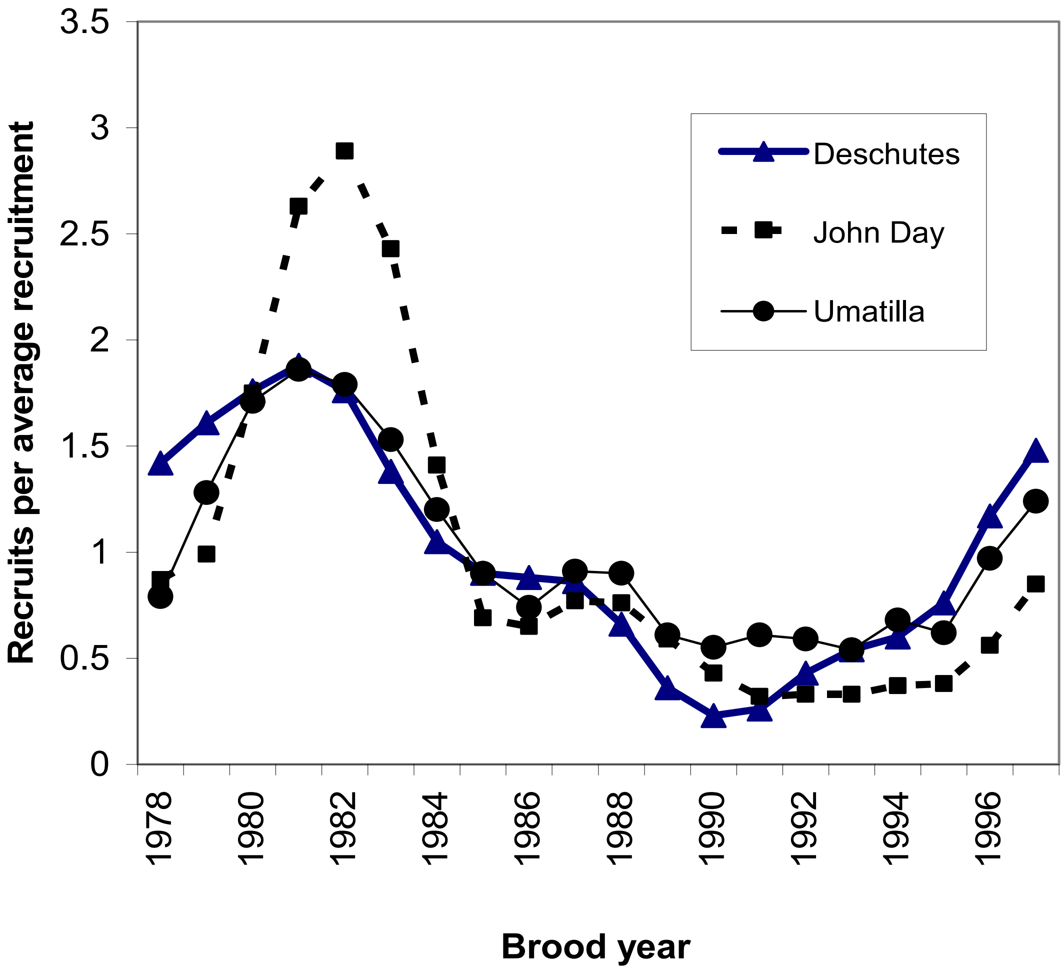


Figure 23. **Relative recruitment of wild adult steelhead to spawning populations including wild and hatchery fish (Deschutes and Umatilla) and wild fish only (John Day), 1978-1997 broods.**

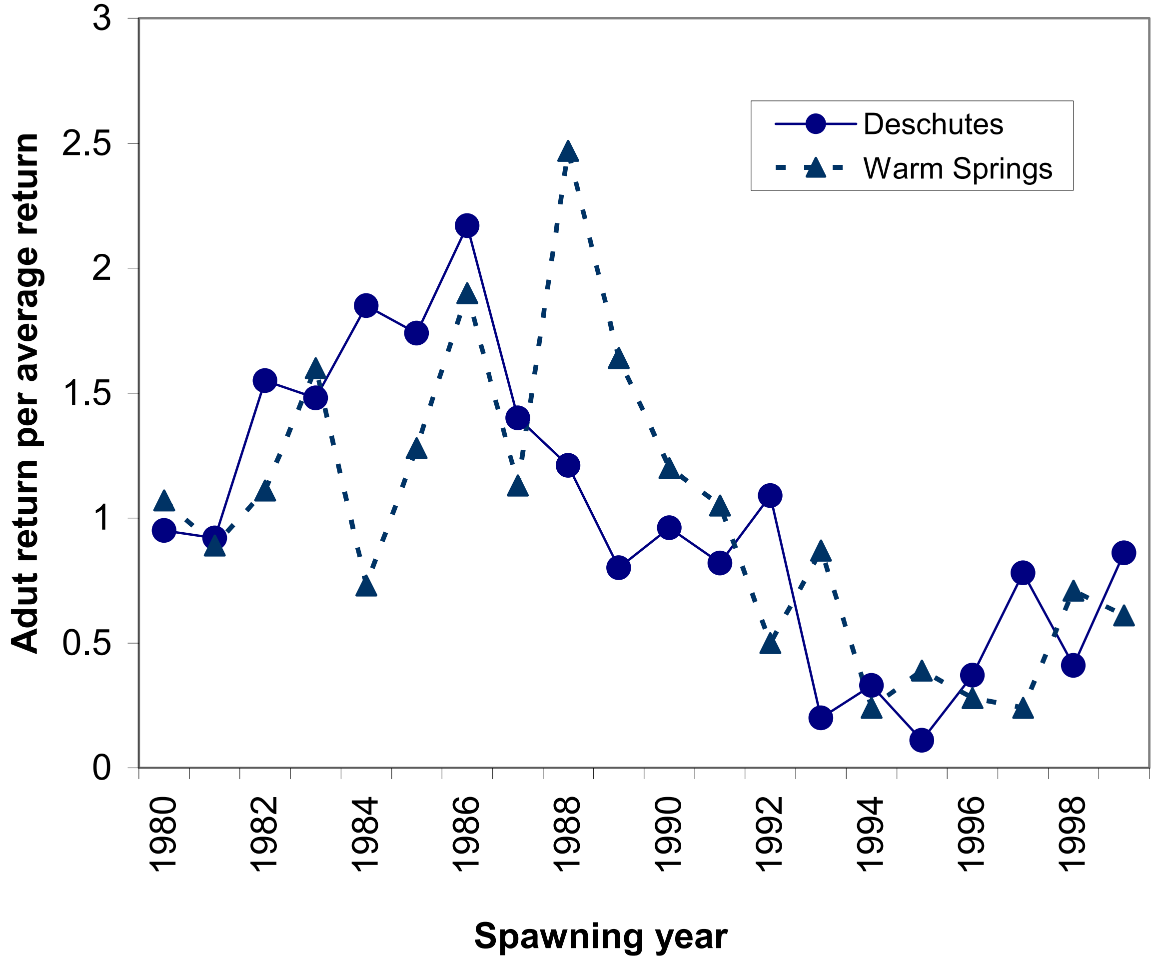


Figure 24. Relative abundance of wild adult steelhead returns (escapement + harvest) in Deschutes (wild + hatchery) and Warm Springs (wild only) populations. 1980-1999.

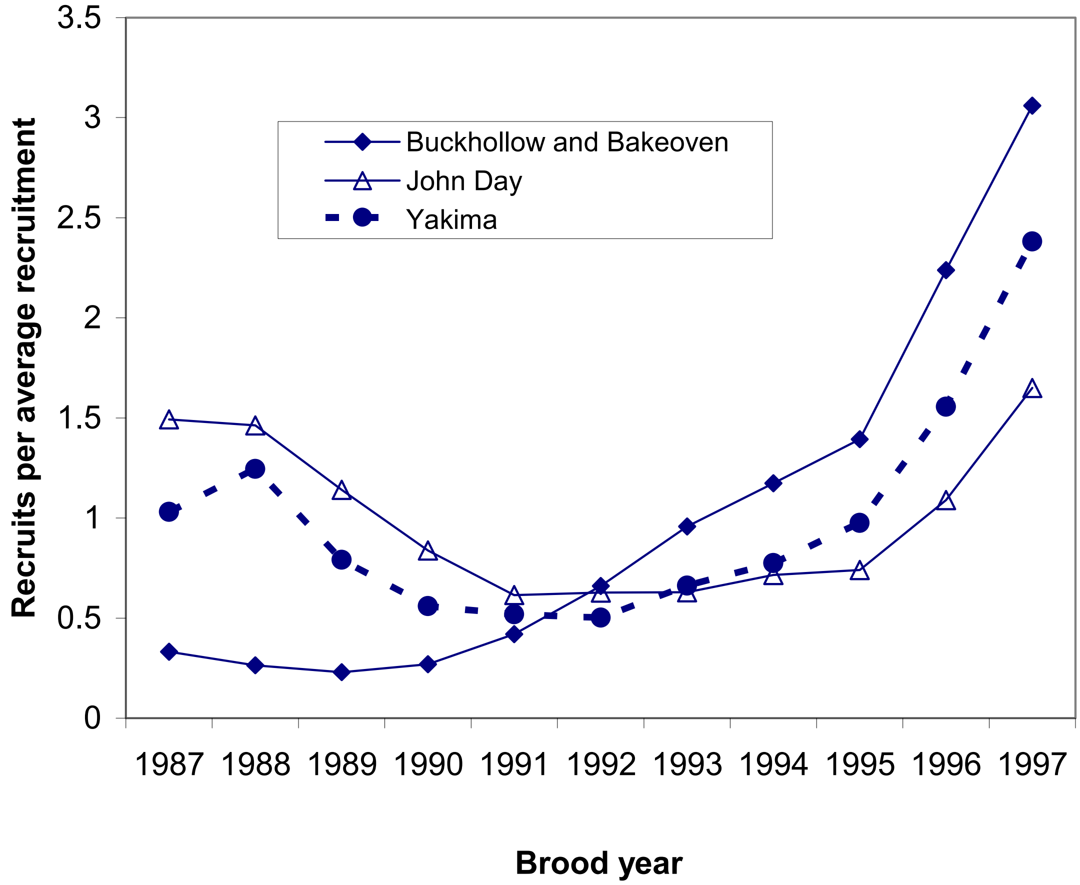


Figure 25. ***R*elative recruitment of wild adult steelhead to Deschutes River tributaries, Buckhollow and Bakeoven creeks (wild and hatchery spawners), and the John Day and Yakima populations (principally wild spawners), 1987-1997 brood years.**

3.5 Effects of Hatchery Strays on Risk of Extinction

The most comprehensive viability analysis of mid-Columbia steelhead populations was performed by Chilcote (2001). Chilcote concluded that the probability of extinction was high for the Deschutes and Umatilla populations, but low for populations in the Warm Springs River and six different subbasins in the John Day Basin. Chilcote's work provides important insight into regional factors that influence population trends of steelhead, but we show here that assumptions he made regarding hatchery fish in the Deschutes Basin turned out to be in error. Chilcote used available data from each subbasin and for the entire ESU to estimate age composition, hatchery:wild composition, harvest rates, run sizes, and recruit per spawner rates for steelhead spawners in each Oregon basin. Because Chilcote (2001) provides the most recent and complete viability analysis of Middle Columbia steelhead, we carefully examined his work, and we provide new information which tests some of his assumptions. In particular, Chilcote (2001) notes that his assumptions about hatchery fish spawning in the wild have a dramatic effect on the estimated probability of extinction. Chilcote assumed, when he estimated recruits per spawner, that naturally spawning hatchery fish should be assigned equal value with wild fish as parent spawners. We found additional evidence to test that assumption in the Deschutes Basin, and it clearly establishes that Chilcote made the wrong assumption on this facet of his analysis. The consequence of making that wrong assumption was that Chilcote substantially over-predicted the probability of extinction for steelhead in at least the Deschutes Basin.

Before examining the evidence to test Chilcote's (2001) assumption about spawning contribution of hatchery fish, it is important that one understand the assumption and its impact on estimation of population viability. Chilcote assumed that naturally spawning hatchery and wild steelhead intermixed at spawning and that recruitment was determined by the total number of hatchery and wild fish in that mix (Chilcote (2001). Chilcote (2001) states:

> *"Regardless of the mechanism, when hatchery fish mix with wild fish in natural production areas, the overall productivity of the population declines. In effect the freshwater habitat becomes less efficient in producing steelhead. Not only does this mean that natural production goals are compromised, it means that the population's vulnerability to extinction is increased. " (p.35)*

He used this assumption in calculating the parameters of the Ricker stock-recruitment function that drove his prediction of future population trends. In particular, Chilcote's assumption influences the estimate of the Ricker α parameter that expresses the maximum recruits per spawner the population is capable of producing. If naturally spawning hatchery fish are counted equivalent to wild spawners, but they contribute few recruits, then their inclusion reduces the estimate of the α (recruits/spawner) parameter. This assumption is important because future spawning runs are predicted by multiplying the number of spawners times the expected recruits/spawner. The effect of Chilcote's treatment of hatchery spawners as intermixed parents with wild fish is that any reduced contribution to recruitment by hatchery spawners (compared to wild fish) functions as though it were stealing productive ability from wild fish. For example, if 500 wild steelhead in a basin produce 1,500 recruits, and another 500 hatchery fish spawning in the same basin produce no recruits, then the 1,500 recruits are really produced by 500 parents. However, Chilcote's analysis would assume that 500 wild and 500 hatchery fish each produced half of the 1,500 recruits, and that the population now requires twice the number of spawners to produce the same number of recruits. This creates an analytical problem if hatchery fish contribute natural recruits at a lower rate than wild fish, because the reduced overall recruits per spawner will predict that both wild and hatchery fish are less productive and less able to sustain harvest or low ocean survival.

For the following discussion, we need to distinguish between the Ricker ***a*** value and the Ricker α. The Ricker stock-recruitment function is:

Recruits = α**•Spawners•e**$^{(-B \cdot Spawners)}$

The parameters of this function (α and ***B***) are usually estimated by rearranging the equation into the form of a linear regression as follows:

ln**(Recruits/Spawners) = *ln*** (α) **- *B*•Spawners**

For simplicity of expression, the value of ***ln*** **(**α**)** is often labeled simply as ***a***. Thus,

a* = *ln **(**α**)**

Given that the units of α are recruits/spawner, then the units of ***a*** are ln(recruits/spawner). Chilcote (2001) uses Ricker ***a*** values (ln(recruits/spawner)) throughout his analysis.

Chilcote (2001) makes his assumption about intermixing of hatchery and wild spawners explicit, when he gives the following method for calculating the Ricker a parameter for a mixed population:

"theoretical relationship between the overall productivity of a population and the proportion of hatchery fish in the population was represented by:

$$\boldsymbol{a} = P_w(\boldsymbol{a}_{wild}) + P_h(\boldsymbol{a}_{hatchery}) \qquad \text{Equation 4}$$

where ***a*** is the Ricker recruitment parameter calculated for the population at a particular time interval, P_w and P_h are the respective proportions of wild and hatchery fish in the natural spawning population, $\boldsymbol{a}_{wild}$ is the recruitment parameter that would have been estimated for this population were the only spawners wild fish, and $\boldsymbol{a}_{hatchery}$ the recruitment parameter for a spawning population consisting only of hatchery fish."(p. 14)

This method says that productivity in a given basin will be the average of the productivities for hatchery and wild fish. However, it can be shown analytically that Equation 4 will only be true if the populations completely intermix and share production of offspring. If the reproduction of hatchery and wild fish functions independently, then equation 4 is incorrect, as demonstrated by Cramer and Neeley (1993).

Cramer and Neeley (1993) present modeling results to demonstrate that productivity of independent populations with differing productivities cannot be averaged. Cramer and Neeley (1993) showed that four hypothetical populations of Snake River spring chinook having Ricker α values of 4, 6, 10, and 14 would respond quite differently to an improved survival rate past dams. These subunits were assigned different capacities according to the estimated capacity of habitat in the Snake River

Basin that was estimated as poor, fair, good, or excellent. Cramer and Neeley (1993) found that a 20% increase in survival affecting all four populations would cause their sum to increase 60% above that for baseline conditions, the population subunit with α **= 4** would still go extinct, and the subunit with α **= 6** would still decline. Only with a 40% increase in survival would the subunit with α **= 6** begin to slowly increase, and with a 75% increase in survival, that subunit would increase to produce about five times as many adult fish as the subunit with α **= 14**. These simulations demonstrate that averaging the estimate of productivity for populations that operate largely independently will give an erroneous prediction of their future performance.

As we show in this report, the evidence from ratios of hatchery to wild fish on the spawning grounds in the Deschutes Basin indicates that hatchery and wild fish are generally not spawning in the same areas, and productivity of the wild populations does not show impairment from hatchery fish. Thus, application of equation 4 by Chilcote would lead to an erroneous assessment of population productivity in at least the Deschutes Basin and most likely in the other Mid-Columbia subbasins. We conclude that hatchery and wild populations should be modeled separately.

Chilcote fully acknowledged that his assumptions regarding hatchery and wild intermixing were both tenuous and highly impactful to his findings. Chilcote (2001) makes the following point.

> *"In particular, model runs for the Deschutes and Umatilla populations were extremely sensitive to how much reproductive discounting was applied to naturally spawning hatchery fish. Regardless, using the standard discounting approach described in the methods section, the results of supplemental PVA model runs suggested that if the future proportion of naturally spawning fish in the Deschutes and Umatilla populations was reduced by approximately 1/3, the probability of extinction would decrease to less than 0.05."*

As we have shown, the proportion of hatchery fish spawning with wild fish in the tributaries is far below the proportions estimated at Sherars Falls. Appendix 3 of Chilcote shows that the 7-year rolling average for proportion of hatchery fish among natural spawners in the Deschutes Basin was assumed to range from 32% to 50%. Data we present for Bakeoven and Buckhollow creeks shows that the true 7-year rolling average would be 10% to 20%, which is much greater reduction than the 1/3 that Chilcote says would reduce the extinction risk to less than 0.05. It is clear that Chilcote would have concluded the Deschutes population had little risk of extinction had he used spawning area data rather than escapement at Sherars Falls.

Chilcote (2001) applied a large "discounting" to the productivity of natural populations which included hatchery fish. Chilcote found by calculating the Ricker ***a*** value for 15 populations of steelhead in Oregon with varying proportions of hatchery fish among the spawners, that there were statistically significant decreases recruits per spawner as the percentage of hatchery fish increased. He interpreted this to mean that presence of the hatchery fish impaired the productivity of wild fish, rather than that hatchery fish were producing poorly. His regressions indicated that recruitment rate dropped from Ricker ***a*** of 2.0 for a wild population to Ricker ***a*** of 0.5 when 40% of spawners were hatchery fish. The Ricker ***a*** value corresponds to the natural logarithm of recruits per spawner at low population size. So, the antilogs of the Ricker ***a*** values of 2 and 0.5 indicates that the predicted drop in productivity would be from 7.4 recruits/spawner down to 1.6 recruits/spawner. This analysis accounts for a 79% reduction in productivity. It is clear that Chilcote's assumptions regarding the impact of hatchery fish is driving his estimates of extinction risk. Chilcote acknowledged this by stating:

> *"For nearly all of the time intervals evaluated, it appears that when the proportion of hatchery fish exceeds 60%, the population can no longer replace its self, even at very low densities where the recruitment function would predict that survival would be at its greatest." (p. 33)*

We point out again that if wild fish are reproducing independently from hatchery fish, their production would continue as has been observed in Deschutes tributaries and the above conclusion by Chilcote would not apply.

3.6 Discussion

When compared on the basis of wild adult recruits per wild parent spawner, steelhead populations comprised of wild and hatchery-origin spawners (Deschutes and Umatilla) exhibited similar productivity to populations of predominantly wild spawners (John Day and Yakima). Comparability in productivity of hatchery-wild and wild populations was further evidenced by similarities in population abundance and recruitment patterns since 1978.

In an analysis of 12 Oregon steelhead populations, Chilcote (MS 2002) demonstrated a significant negative relationship between an index he derived for population productivity and proportion of hatchery-origin spawners. He concluded that hatchery steelhead productivity (adult recruits per spawner) approximated 30% of wild steelhead productivity. While Chilcote's findings certainly establish the importance of further testing the effects of hatchery programs, our analysis shows that few hatchery fish showed up in the areas where most wild fish spawned, at least in the Deschutes River tributaries. Thus, Chilcote's finding was a reflection of low contribution by the hatchery spawners. We agree with McClure et al. (MS 2002) who noted in their population viability assessment of Columbia River salmon and steelhead, that adjusting for the effects of hatchery fish on population productivity may correspond to *"--- an accounting problem rather than a negative ecological or genetic effect of hatchery fish."*

Low productivity of hatchery fish is not the same as impaired productivity of the wild fish in the same basin. None of Chilcote's analysis includes details of where hatchery strays spawn in a basin relative to where wild fish spawn, and poor survival of hatchery strays is probably amplified by their spawning in sub-optimal areas.

Chilcote (2001) predicts grave effects in streams with high percentages of hatchery fish. Hatchery steelhead production, especially in the Columbia Basin, has been established to mitigate for habitat losses related to development.

Hatchery adults tend to increase in years of poor wild survival because hatchery outputs are relatively constant. For example, the number of steelhead smolts released from hatcheries into the Deschutes River since 1980 has been essentially constant ranging between 150,000 to 180,000 (ODFW data). Thus, the fraction of hatchery fish in the run was often greater during years when wild production was poor, but that outcome was a result rather than a cause of poor natural production. In subsequent years, when wild production is better, the proportion of wild fish observed compared to hatchery fish increases. This phenomenon is evident in recent data showing that the percentage of wild fish in two Deschutes tributary spawning areas has rebounded dramatically since Chilcote formulated his model (see Figure 25). In fact, the backdrop at the time of development of his model was one of very low proportions of wild fish compared to previous or subsequent years.

Genetic evidence consistently indicates that interbreeding of wild and hatchery populations in the same stream is far less than expected based on their relative abundance. Sharpe et al. (2000) found biochemical evidence that wild steelhead from the Kalama River had retained a genetically distinctive identity in a comparison with the stock of hatchery fish that has been present in the Kalama basin in high numbers since the early 1970s. Further, evidence suggests that productivity of the wild populations remains high after consistent exposure to hatchery fish spawning in the same basin. Again, in studies of steelhead in the Kalama River in Washington, wild fish retained more than a 10-fold advantage in their productivity even though hatchery fish have been present and naturally spawning for over 20 years within the study area (Chilcote et al 1986, Leider et al, 1990, and P. Hulett, personal communication as cited by Chilcote 2001).

4.0 Factors Affecting Resident and Anadromous O. mykiss Distribution—Examples from Selected Streams

We present evidence here that these have two very different life histories because they spawn and rear in different areas that correspond to habitat characteristics that favor either one or the other life history. Another accounting problem for estimation of spawners and recruits among Middle Columbia steelhead populations comes from the co-occurrence of resident and anadromous life histories within the same sub-basins. Evidence shows that resident and anadromous *O. mykiss* compete directly with one another, so the presence of one form reduces the basin capacity for rearing of the other if access to the ocean is available. In this section of the report we examine how factors such as elevation, stream flow, water temperature, and other habitat features may influence how steelhead and rainbow trout partition their use of habitat in the Middle Columbia ESU.

4.1 Literature Review

Separation of resident and anadromous *O. mykiss* within the same basin occurs where there are strong differences in temperature regime. Resident rainbow are commonly found in areas that are cooler in spring and summer than where anadromous steelhead occur. The spatial patterns of stream temperature in basins where both the resident and anadromous forms are abundant are consistent with the theory that resident populations will prevail in streams where summer conditions are consistently favorable for growth and survival. The theory is that resident trout larger than steelhead parr will competitively displace juvenile steelhead (Thorpe 1994). Thorpe (1994) concluded: *"When the animal's needs are being met, it stays where it is; when they are not, it moves until it finds appropriate conditions for its current demands."*

At a finer scale than large river basins, observations indicate that the anadromous life history is able to exploit stream sections that are likely to have summer temperatures exceeding optimal levels, or have low flows that constrain growth opportunities for fish that prefer deeper and faster water as they increase in size. Thorpe (1994) also noted, *"When conditions are relatively predictable, even when predictably extreme, different successful strategies may evolve to allow species to exploit the limited possibilities open to them."*

Within the Mid-Columbia steelhead ESU, significant populations of resident *O. mykiss* are common in the Yakima and Deschutes rivers. Tracking of radio-tagged adult steelhead by Hockersmith et al. (1995) indicated that 57% of steelhead entering the Yakima Basin spawned in the two lowermost tributaries, Satus and Toppenish creeks, even though those streams constituted a small proportion of the basin. Toppenish and Satus creek watersheds are substantially lower in elevation with greater variation in runoff and temperature than major tributaries upstream in the Yakima Basin. Much of the Yakima Basin upstream of those tributaries supports healthy populations of resident rainbow trout. Shapovalov and Taft (1954) found for *O. mykiss* in Waddel Creek off the central California coast, *"The majority of the resident fish are in the upper reaches of the streams, where cooler temperatures prevail, while the majority of the sea-run fish and offspring of sea-run fish are in the lower reaches of the streams where the water is warmer."* Zimmerman and Reeves (1999) found that *O. mykiss* in Nena and Tenmile creeks, tributaries to Deschutes River, were exclusively steelhead, while age 0+ and 1+ *O. mykiss* in margins of the Deschutes main stem were dominantly resident. Laboratory tests by Zimmerman and Reeves (2000) with Deschutes rainbow and steelhead fry showed that rainbow trout were significantly less aggressive than were steelhead, with rainbow trout preferring calmer water and remaining at higher densities than steelhead. Steelhead fry remained close to the substrate and preferred riffle-like units. However, juvenile steelhead from intermittent tributaries such as Tenmile Creek experience greater growth than those in the mainstem and may, therefore, experience a competitive advantage as they shift from tributary environments to the mainstem (Zimmerman and Reeves 2000).

Recent studies on the introduction of hatchery steelhead to the upper Yakima Basin where resident trout are abundant have indicated that competition between resident rainbow and steelhead can be intense, and that victory in a competitive interaction generally goes to the larger fish. McMichael et al. (1999) reported from studies in the Yakima River that agonistic interactions were substantial between individual *O. mykiss*, regardless of whether they were resident or anadromous, and that the larger individuals were behaviorally dominant in over 80% of contests observed, regardless of resident or anadromous origin. The agonistic interaction was so strong where hatchery steelhead were stocked that in years of high temperature, the contact interactions appeared to be the cause of 32% of hatchery fish and 17% of wild fish having visible infections of *Saprolignia* fungus (McMichael et al. 1999). Given that larger fish are the predominant winners of behavioral interactions, then streams where summer conditions are consistently favorable for growth and survival of rainbow trout are likely to develop populations of resident trout that are larger than juvenile steelhead, and will displace juvenile steelhead.

Radio-telemetry studies conducted in the Yakima River basin by NMFS in 1989-1993 (Hockersmith et al. 1995a) identified steelhead spawning areas. Principal steelhead spawning areas were Satus Creek, Toppenish Creek, and the Naches River mainstem and tributaries. Within the Naches Basin, 88% of steelhead spawning occurred in the Naches River mainstem, primarily above river kilometer 24, with the remainder distributed between Bumping River, Little Naches River, and Rattlesnake Creek. Steelhead spawning upstream of Roza Dam occurred in Roza Canyon, the upper Yakima mainstem, and in several tributaries. Spawning distribution in the Yakima River basin for brood years 1990-1992, as determined through radio-telemetry studies, was 48% in the Satus Basin, 32% in the Naches Basin, 11% in the Toppenish Basin, 2% in the Marion Drain, 4% in the Yakima River mainstem below Roza Dam, and 3% in the Yakima River or tributaries above Roza Dam. The low numbers of steelhead returning to the upper Yakima River have been confirmed more recently by fish ladder counts at Roza and Prosser dams. During 1991-1998, an average of only 4.7% of the Yakima River basin steelhead run returned to the upper Yakima River (Yakama Nation unpublished data).

Attempts to establish steelhead in streams with strong populations of resident rainbow have failed. For example, the ODFW attempted to establish steelhead in the McKenzie and Middle Fork Willamette basins for two decades, but ODFW has recently dropped the program due to the lack of natural reproduction from these fish. Both of those streams continue to support acclaimed rainbow trout fisheries that are supported by natural production. Similarly, attempts to establish steelhead in the upper Yakima Basin have failed. McMichael et al. (1999) found that 26 to 39% of hatchery steelhead smolts released in the upper Yakima River did not emigrate even from the study area in the Teanaway River (a tributary of the Yakima River) during the first month after release. Stream temperatures some years did not exceed 8°C until June 1, and these low temperatures may have suppressed migratory tendencies (McMichael et al 1999). Only 1.9 to 2.6% of smolts released were estimated to have passed Prosser Dam (234 km downstream) in 3 of the 4 years studied, while a high of only 24.9% passed Prosser Dam in 1993. Snorkeling observations revealed that the stocked steelhead behaviorally dominated and often displaced the typically smaller wild juvenile trout.

McMichael et al. (1999) found that competition between fish in the Yakima Basin was strongest between individuals of the *O. mykiss* species, but competition of steelhead with juvenile chinook and coho was negligible. These observations suggest that steelhead did not compete with chinook which may explain why anadromous spring chinook are able to remain established in each of the streams (Table 18) where *O. mykiss* are not anadromous.

Table 18. Examples of portions of basins where resident and anadromous *O. mykiss* occur in separate, but ocean-accessible portions of the same basin. Areas where portions meet or overlap will produced mixed rainbow-steelhead populations.

Basin	Resident Rainbow Portion	Steelhead Portion
Willamette River	McKenzie R. & Middle Fork Willamette R.	Calapooia, Santiam, Mollala, Clackamas subbasins,
Yakima River	Basin above Yakima	Basin below Yakima
Deschutes River	Metolious River	Crooked River, Squaw Creek, Trout Creek
Sacramento River	Main stem above Redding	Main stem and tributaries below Redding

Each of these examples is consistent with the hypothesis that streams with non-stressful temperatures during the summer low flow period, and sufficient growth opportunity to produce a 12-14 inch trout at first maturity, will tend to produce resident trout, while those streams where growth opportunities during summer are constrained will produce anadromous steelhead. A key part of the growth opportunity includes the downstream reaches where parr, migrating from a habitat constrained stream, would rear to complete their freshwater rearing. We note that in examples of rivers with separate strong populations of steelhead and resident rainbow trout, the resident life history is tied to a large river channel with summer temperatures generally < 15°C. Without this large channel having cool summer temperatures, migratory parr (present in both resident and anadromous populations), will eventually be stimulated to also migrate from the large channel when temperatures climb beyond the optimal range. Thus, a small cool-water stream where rearing space for rainbow > 150 mm is constrained will generally support a fluvial population if the stream connects to a large cool river (e.g. McKenzie River basin), but will support an anadromous population if the stream connects to a large channel in which summer temperatures often exceed the optimum range (e.g. lower Yakima Basin). This deduction includes the supposition that the anadromous life history of *O. mykiss* is driven by the probability of <u>suboptimal</u> rearing conditions (temperature and space) in freshwater, while resident populations are driven by the probability of <u>optimal</u> rearing conditions in freshwater. As Thorpe (1986) deduced, migration reflects avoidance of a limiting condition to search for a better condition elsewhere. Thus, an increase in stream temperatures where resident rainbow existed might alter natural selection in that population to favor anadromy, and a reduction of summer stream temperatures into the optimal range might alter natural selection in that population of steelhead to favor resident rainbow.

In order to model the conditions that would dictate whether an *O. mykiss* population would be resident or anadromous in a particular stream reach, both the temperature regime and space limitations must be considered. Data on relationships of growth to temperature and on observed parr migrations give us clues on what the environmental threshold might be. The data we reviewed to determine the relationship between growth and temperature indicated that optimum growth rates in a natural stream setting were generally found when temperatures were 11-15°C. Further, observations of rainbow trout behavior in a stream where a continuous temperature gradient occurred showed that trout would move to cooler areas when temperature exceeded 18°C (Baltz et al. 1987). The combination of these observations indicate that streams with temperatures consistently averaging 11-15°C during summer and rarely exceeding 18°C would give *O. mykiss* little reason to migrate, and a resident life history would be the expected outcome. In streams where temperatures are consistently above or below the 11-15°C during the summer, *O. mykiss* would be stimulated to eventually migrate in search of better growth opportunities. That migration could end in a larger river channel if temperatures there were within the optimum range, or would end in the ocean and an anadromous life history if optimal conditions were not consistently found downstream in freshwater.

These deductions relative to temperature are supported by the difference in observed temperature regimes between the resident and anadromous zones for *O. mykiss* production in basins where the two types occur (Figure 26). In these example basins, the resident type always occurs upstream of the anadromous type, temperatures rarely exceed the optimum growth range within the zone used by the resident type, and temperatures often exceed the optimum range during mid summer in the zone used by the anadromous type (Figure 26).

In addition to the consideration of temperature regime as a stimulus to migrate, the size of stream also plays a role in the stimulus to migrate. For example, the studies by Leider et al. (1986) of Gobar Creek and by Bjornn (1978) of Big Springs Creek demonstrated that most smolts resulting from spawn in those streams actually completed their rearing in a larger channel downstream. Low flows in summer were typically about 300 cfs in the Kalama River where parr from Gobar Creek grew to be smolts. If we look at examples of resident trout streams for the minimum stream size in which fluvial adults typically reside, we find such streams as the North Fork of the Middle Fork Willamette River and Salt Creek of the Middle Fork Willamette River where low flows are typically about 190 cfs and 120 cfs, respectively. However, streams of this size within the anadromous access zone, only appear to have resident populations when connected to a still larger river (> 1,000 cfs low flow) with temperatures not exceeding the optimum range.

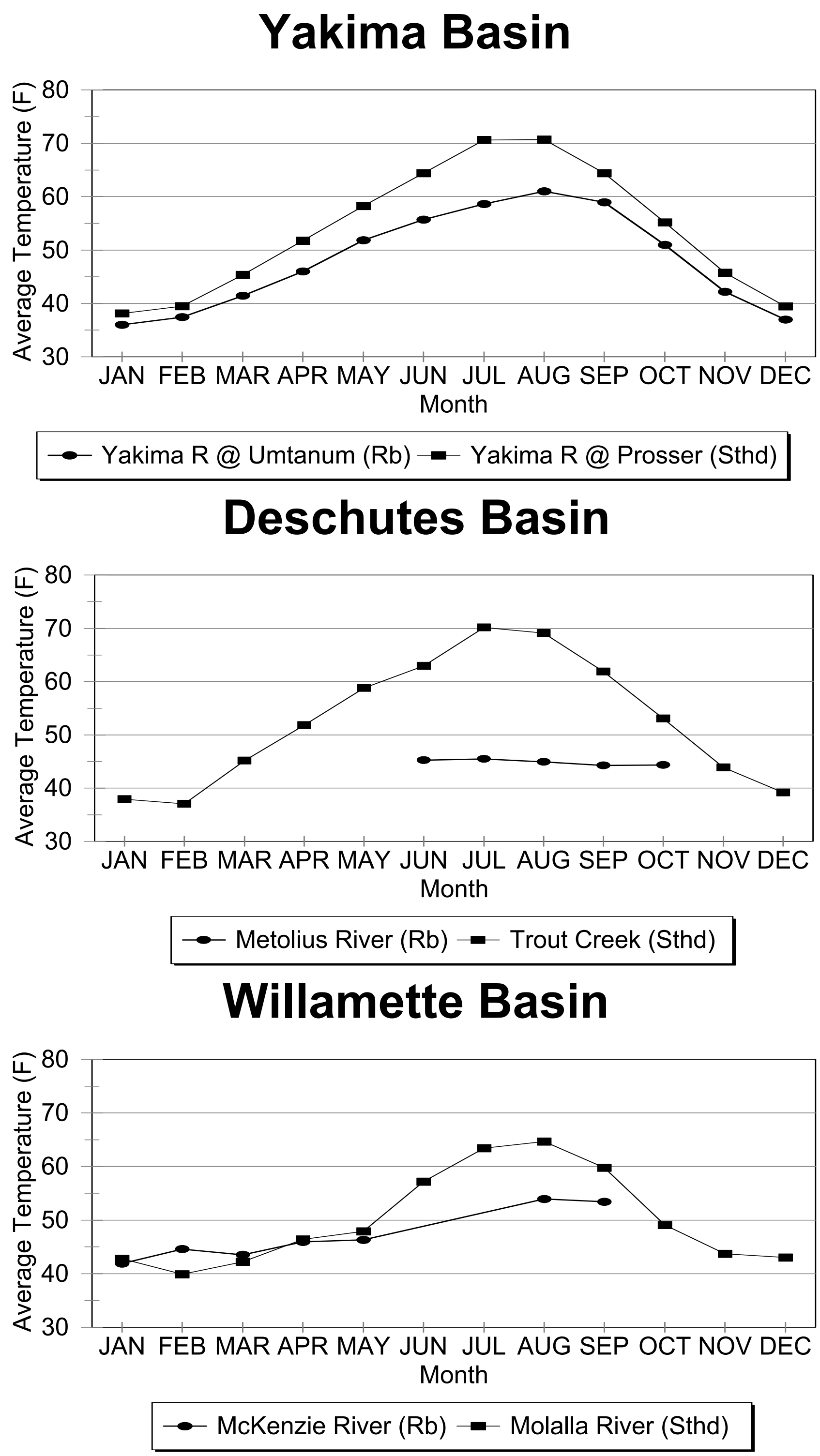


Figure 26. Temperature regimes for the separate zones of anadromous and resident types of *O. mykiss* within the Yakima, Deschutes and Willamette river basins.

In addition to the influences of flow and temperature on selection for residency or anadromy of *O. mykiss*, the biological setting within rearing areas and the survival costs of anadromous migration would also influence the balance of selection. Substantial competition for rearing space with other species or in-basin populations of rainbow may increase selection favoring anadromy. This may be a factor in the mainstem Deschutes where large populations of resident rainbow and whitefish are well established, and these fish may be formidable competition for juvenile *O. mykiss* that migrate out of tributaries (e.g. Trout Creek) into the Deschutes main stem. High survival costs of anadromy, such as passage through the 200 miles of Willamette River, may increase selection against anadromy for *O. mykiss* from streams such as the McKenzie and Middle Fork Willamette rivers.

Table 19. Habitat factors which influence steelhead and rainbow trout production.

Stream Key for Anadromy or Residency
Resident *O. mykiss* streams: Streams draining to a river with summer base flow 500-1,000 cfs and mean August temperature of 10 - 15ºC. Migratory habits of rainbow in the tributary network of the main river would be expected as follows: A. Tributaries with August temp > 15ºC . Rainbow fluvial to main river B. Tributaries with summer base flow < 150 cfs. Rainbow fluvial to main river C. Tributaries with August temp <15ºC, and summer base flow > 150 cfs. Rainbow rearing through adulthood, with some fluvial to main river. D. Tributaries with August temp >15ºC or flows < 150 cfs may produce steelhead if abundance of competitors in main stem is high and average survival during smolt migration to the ocean is high. **Anadromous *O. mykiss* streams:** All other streams, most with mean August temperature > 15ºC Theoretically, there could be a zone of overlap between resident and anadromous populations, but environmental gradients are sharp enough that we found no clear examples of zones where both types were common.

4.2 Suitability of Flow Regimes for Resident Trout

In order to determine whether flow regimes in major sub-basins of the Mid-Columbia region would support rainbow trout or steelhead, we compiled mean monthly stream flow data from 43 stream gages in five major rivers of the ESU. These rivers include the Deschutes, John Day, Umatilla, Walla Walla, and Yakima Rivers. The point of the analysis was to determine if there were reaches within each of the basins that summer flows were sufficiently high and temperatures sufficiently low to support a resident rather than anadromous population of O. mykiss.

We examined the downstream accumulation of flow in the rivers during August, September, and October. These were the months of lowest flow (hereafter called baseflow). We examined full historical and the last 10-year periods of record, to see if here were major changes in flow regimes, but our findings remained the same for all periods.

We also calculated an index of flow variability in each basin, as follows:

$$\frac{\text{Q (highest monthly flow), cfs}}{\text{Q (lowest monthly flow), cfs}}$$

All months of the year were included. This index value increases as the relative difference in high and low flow increases, so a lower value indicates greater stability of flow across seasons.

Flow records showed large differences in the baseflow regimes of these systems. The Deschutes River, which has a large population of resident rainbow trout, sustains far more baseflow (3,000-5,000 CFS) than the John Day (150-300 CFS), Umatilla (25-100 CFS), and Walla Walla (30-100 CFS) rivers (Figure 27, Figure 28, Figure 29). Reduced flow in the mid section of the Deschutes reflects irrigation diversion during summer. The Yakima River represents an intermediate flow regime, with baseflows of 1,000-1,500 CFS, still much larger than in the John Day, Umatilla, and Walla Walla. Baseflows in both the Deschutes and Yakima rivers are great enough to satisfy the depth and velocity preferences of large rainbow trout. Water temperatures in large sections of these two rivers also do not exceed 16°C. Further, the flow variability in these two rivers is much less (Figure 30) than in the John Day, Umatilla, and Walla Walla rivers. Conditions in the Deschutes and Yakima upper main stems and tributaries are well suited to production of resident rainbow trout, but similar conditions do not exist in other rivers of the Middle Columbia ESU.

The geology and elevation of the Deschutes River headwaters, and its large drainage area, account for its high sustained baseflow. Much of the Deschutes headwater area is composed of fractured, highly permeable volcanic lithologies, which in the High Cascade Mountains have a tendency to produce high storage capacity, abundant spring flow, and high sustained baseflow. The Metolius River, which flows into Lake Billy Chinook above Round Butte Dam, is an example of a stream with these characteristics, and naturally favors the production of resident *O. mykiss*. In contrast, flow regimes of the John Day, Umatilla, and Walla Walla reflect lower elevation headwaters, smaller drainage areas, and a higher proportion of flow diversion in lower mainstem reaches. The flow regimes of these systems, and their temperature regime in the lower mainstem, would naturally favor anadromy for *O. mykiss*, although small resident populations co-inhabit some headwater areas of these watersheds.

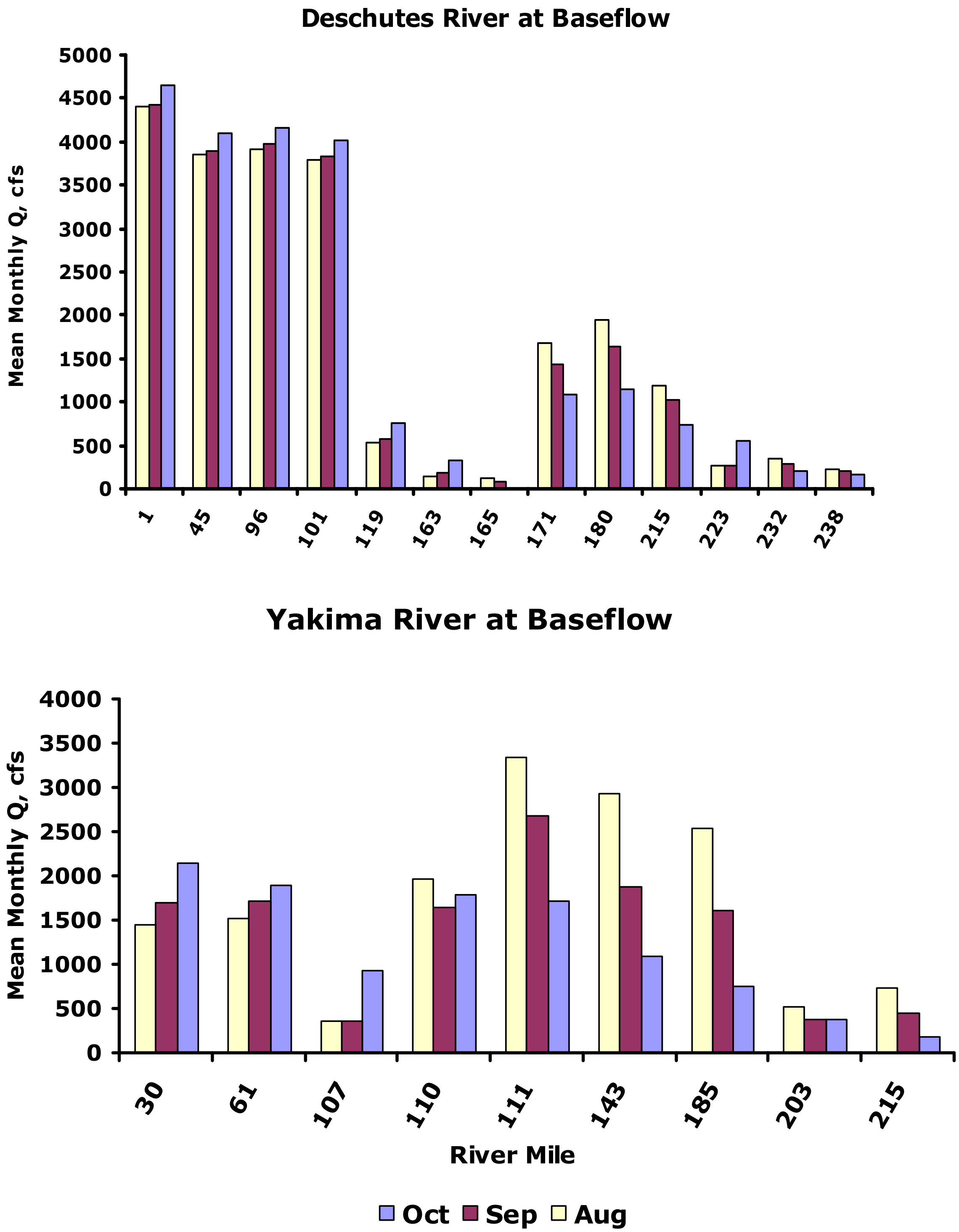


Figure 27. Downstream hydrograph during summer low flow in the Deschutes and Yakima basins. Monthly means calculated from full period of record at USGS gages proceeding up the largest gaged channel.

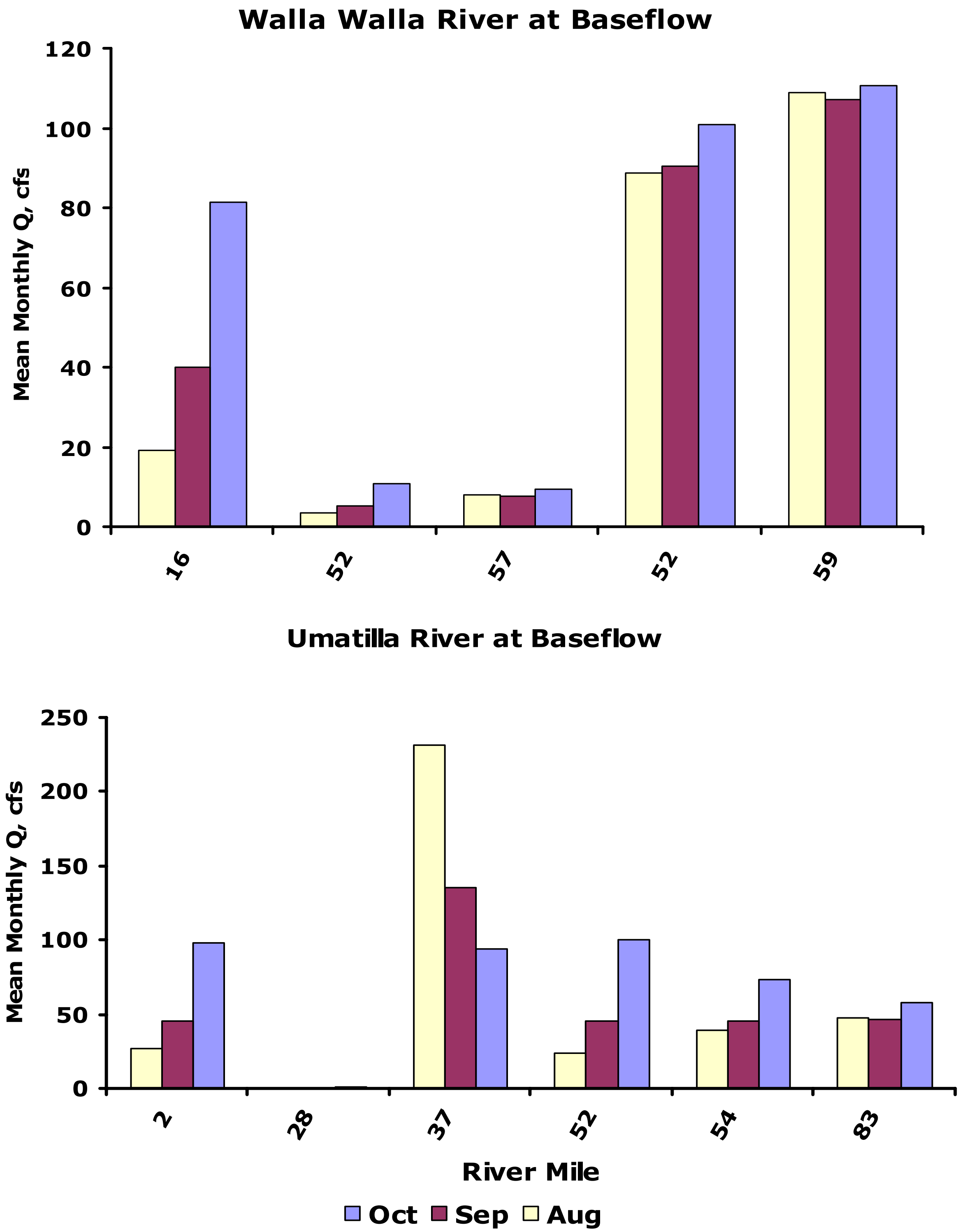


Figure 28. Downstream hydrograph during summer low flow in the Walla Walla and Umatilla basins. Monthly means calculated from the full period of record at USGS gages proceeding up the largest gaged channel.

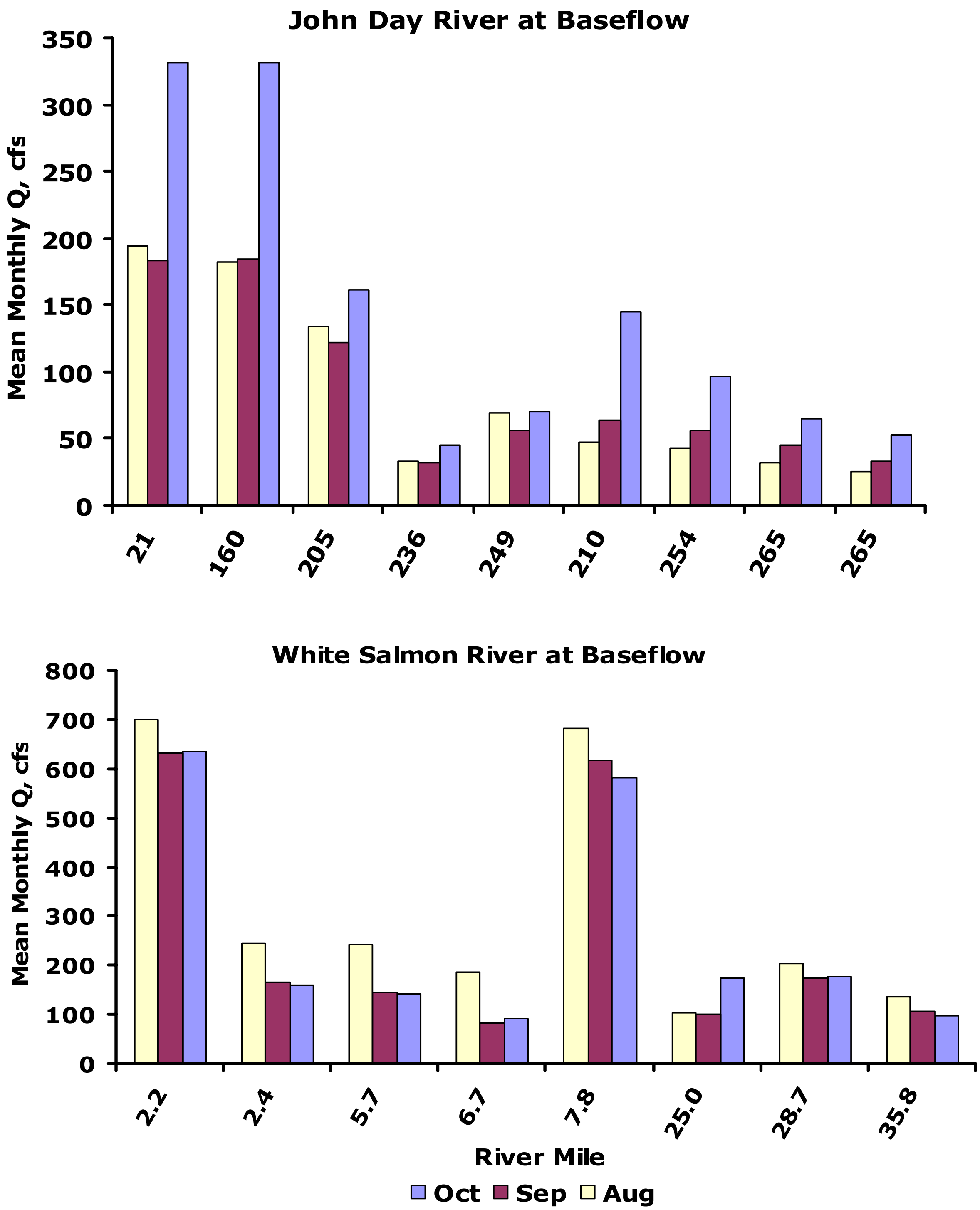


Figure 29. **Downstream hydrograph during summer low flow in the White Salmon and John Day basins. Monthly means calculated from the full period of record at USGS gages proceeding up the largest gaged channel.**

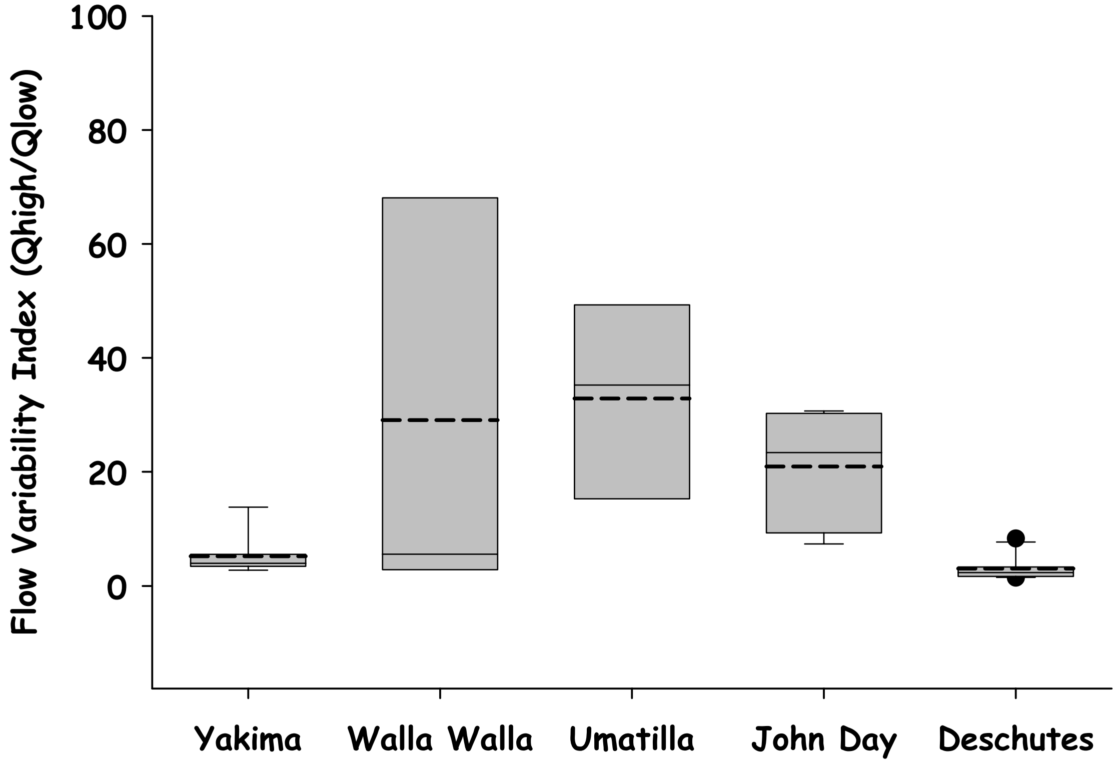


Figure 30. Index of flow variability for Middle Columbia streams. The Deschutes and Yakima rivers are watersheds that produce runs of steelhead as well as premier rainbow trout fisheries, while the Walla Walla, Umatilla, and John Day rivers support primarily steelhead and other anadromous fisheries. Dashed line represents mean. Whiskers represent 10th and 90th percentiles. Top and bottom of box represent 25th and 75th percentile. Solid mid-line represents the median.

5.0 Steelhead Population Viability Analysis

Cramer and Beamesderfer (2001) developed a life cycle model to synthesize the available information on Deschutes River steelhead and to systematically explore the potential for successful reintroduction into the upper basin based on our understanding of steelhead population dynamics and limiting factors. We prepared the stochastic form of this model to estimate the magnitude of risk for extinction of Deschutes steelhead. The model projects future steelhead numbers based on reproduction and survival rates estimated from run reconstructions of the lower Deschutes River steelhead population, capacity estimates derived from habitat assessments, and conservation actions. The model is based on best available data for survival rates, harvest rates and age composition of Deschutes River steelhead, and incorporates both compensatory and depensatory mortality into a Beverton-Holt stock recruitment function.

Accurate risk assessments require stochastic population models which can incorporate variability in survival rates and uncertainty in parameter estimates in addition to traditional stock-recruitment and other life cycle processes (Brown and Patil 1986). “Population Viability Analyses” based on stochastic population models are a widely-applied tool to assess risks of extinction and probabilities of recovery for threatened species (Burgman et al. 1993). Analyses have recently been applied to several salmonid populations including Snake River spring chinook salmon (Emlen 1995), Oregon coho salmon (Chilcote 1998a, Nickelson and Lawson 1998) and Oregon steelhead (Chilcote 1998b).

The model breaks the steelhead life cycle into different stages so that the effects of specific activities and limiting factors can be evaluated (Figure 31). The model also simulates a hypothetical resident trout population and it’s interaction with steelhead. basin-specific data is available on fecundity, age at smoltification, in-basin fishing mortality, etc. Values of other attributes are less certain but reasonable ranges can be identified based on a review of other Northwest steelhead stocks. For instance, the potential range of egg to smolt survival rates in other steelhead populations can be used to identify typical rates for unproductive, average, and productive stocks.

The stochastic portions of the steelhead reintroduction model were adapted from a population viability model developed for ODFW assessments of fishing risks for Willamette spring chinook (Beamesderfer 2001).

The difference equations which comprise the model are solved at annual intervals. Number of fish is tracked by year and cohort from spawning and freshwater rearing through smolt migration, ocean rearing, fisheries, and freshwater migration of adults back to the spawning grounds. Number of eggs produced was estimated as the product of spawner number, sex ratio, and fecundity, Wild parr numbers (pre-smolts) were estimated from eggs based on a stock-recruitment function. All density-dependent mortality for steelhead was thus assumed to occur during the freshwater rearing stage. The model also provides options for steelhead and trout interactions in the parr stage.

The model calculates survivors beginning migration, passing Columbia River mainstem dams to reach the ocean, recruiting to maturity in the ocean, escaping mainstem freshwater fisheries, passing Columbia River dams as adults, returning to the Deschutes Basin, escaping Deschutes basin fisheries, and surviving to spawn. Adult recruits produced by each year-specific spawning cohort included adults returning at several ages. Adults returning to freshwater in year 0, spawned in year 1. Offspring of those adults migrate seaward in the spring at least one year following spawning at freshwater ages 1+ to 4+. Adults mature and return to freshwater after 1 to 3 years in the ocean. Thus each brood year of spawners can contribute recruits to multiple run. Ages of migration and return were based on age composition data for the Deschutes basin.

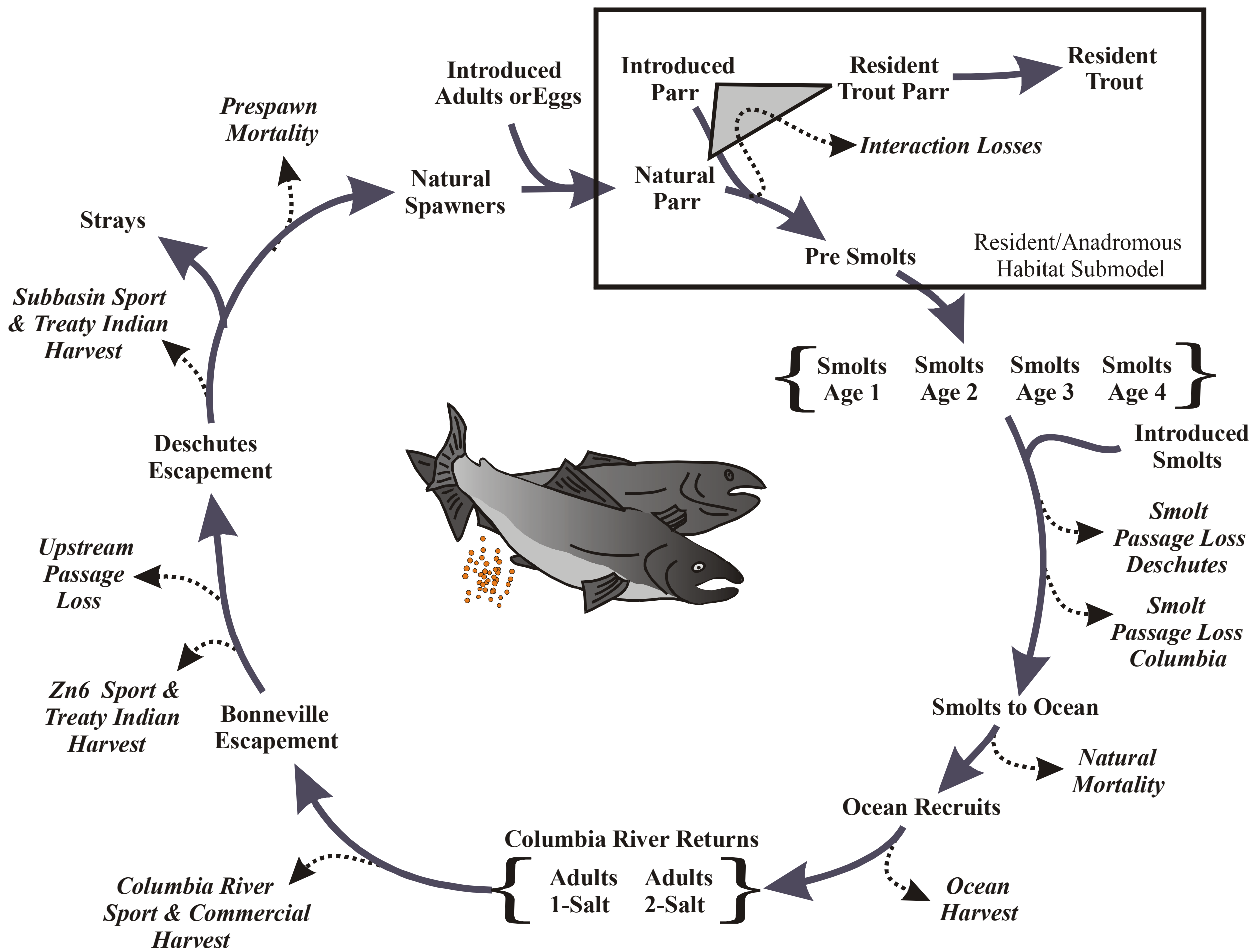


Figure 31. Diagram of steelhead and trout life cycle components represented in model.

5.1 Model Inputs

5.1.1 Natural Production

Estimates of natural production start with eggs produced by female spawners. Spawner numbers are based on escapement past Sherars Falls minus prespawning mortality. Some adult steelhead die of natural causes during the extended period of freshwater holding before spawning. Olsen et al. (1991) reported a 9.2% average prespawning mortality rate of 1973-1989 brood years of hatchery steelhead held at Round Butte Hatchery after collection at the Pelton Ladder Trap. The NPPC (1989) used a value of 10% prespawning mortality in their System Planning Model for steelhead. Similar values have been estimated for spring chinook salmon based on egg retention in carcass samples (Beamesderfer et al. 1997). Based on these observations, we used a 10% prespawning in simulations.

Total eggs are the product of spawners, the percentage of spawners that are females, and female fecundity. Female sex ratio and fecundity were estimated from data for the wild lower Deschutes steelhead population. Average values were used for all simulation years. The average fecundity of 5,200 eggs per female was based on 50 wild steelhead sampled in 1970 and 1971. This estimate is similar to a fecundity of 5,130 used by Olsen et al. (1987) to estimate production capacity in the lower Deschutes basin. The female sex ratio (66%) was the average for wild steelhead from the Pelton Ladder and Warm Spring National Fish Hatchery traps from 1972 to 1994 (Olsen et al. 1991, ODFW 1996).

5.1.2 Habitat Condition

In the framework of this life cycle model, habitat condition affects steelhead through quality and capacity effects. The model relates habitat quality and capacity to density-dependent survival of eggs through some point in the freshwater juvenile stage. We generically denote this stage as parr. Increases in the quality of a given area of habitat, through habitat improvement activities for instance, can be expected to increase productivity of the population which the model expresses as an increase in egg-to-parr survival rates for a given density of eggs or spawners. Increases in quantity of habitat, as where removal of a passage barrier opens up new production areas, increase the carrying capacity which the model expresses as the maximum number of parr which could theoretically be supported by the available habitat. The habitat condition scalar input for the model affects the habitat capacity parameter of the density-dependent egg-to-parr survival rate equation but does not affect the habitat quality parameter.

Stock Productivity

Various indices of population productivity have been described including the intrinsic rate of increase used by the NMFS cumulative risk initiative for listed stocks and stock-recruitment relationship parameters favored by many fishery biologists.

We defined stock productivity based on density-dependent egg-to-parr survival rates. We used a multistage function described by Moussalli and Hilborn (1986) which allowed us to emulate a Beverton-Holt stock-recruitment relationship. Moussalli and Hilborn (1986) demonstrated that a single Beverton-Holt curve could be used to describe a series of life stages with density dependent survival, or conversely, that density-dependent functions could be disaggregated into separate functions for each stage. Similar functions have been widely validated as underlying constraints to salmonid population dynamics and provide for realistic models of population behavior over a broad range of population sizes (NPPC 1986; Byrne et al. 1992). The function includes productivity (p) and capacity (c) parameters:

$$\text{Parr} = (\text{Eggs} * p) / \{1 + [(\text{Eggs} * p) / c]\}$$

Capacity (c) is the asymptotic maximum number of parr which can be produced by the habitat and productivity (p) is the maximum egg-to-parr survival rate which would be expected to occur at low densities. This approach results in egg-to-parr survival rates which decrease as habitat capacity is approached. All density-dependent freshwater rearing effects are thus represented in the egg-to-parr stage. Density dependent survival for steelhead is typically modeled between spawning and juvenile rearing.

We based simulations on average, low, and high productivity values for other steelhead populations in the region because of limitations of the current data on the lower Deschutes steelhead population. We were unable to derive suitable estimates of inherent stock productivity from run reconstructions of Deschutes River steelhead, primarily because of the confounding effects of an increasing contribution of hatchery strays and recent poor ocean conditions. Run reconstructions provided snap-shot estimates of recruitment rates but rates could not be related to density. Run reconstruction data was also heavily influenced by recent poor ocean conditions and thus does not reflect expected long term cycles.

Chilcote (1998) summarized recent stock-recruitment data for 26 steelhead populations in the Columbia River and Oregon coast. The maximum Beverton-Holt recruit per spawner value (ß) corresponding to Chilcote's Ricker curve fits averaged 4.5 and ranged from 2.1 to 8.2 for summer steelhead. Values for winter steelhead averaged 2.5 and ranged from 1.3 to 4.4. Chilcote's productivity estimates are heavily weighted for conditions in the recent period which may not reflect the long term average expectation based on ocean productivity patterns. Byrne et al. (1992) assumed a predevelopment steelhead productivity for Clearwater River (Idaho) summer steelhead equivalent to a maximum of 20 recruits per spawner. We represented a reasonable potential range of steelhead stock productivity using values of 2, 5, and 20 for the maximum spawning recruit per spawner parameter (ß). Thus, ß = 2 in a hypothetical stock of low productivity, 5 in a hypothetical stock of average productivity, and 20 in a hypothetical stock of robust productivity.

The value of α = 5 for recruits/spawner at zero population density is reasonable choice for the Deschutes given that the geometric mean of observed recruitment rates from 1978 to 1997 (excluding hatchery fish) was 3.45 recruits/spawners (exp (1.24) from Table 15) in the Deschutes River, and 3.3 recruits/spawner (exp (1.19) in the Warm Spring River. These means would have included recruitments when spawning was near capacity.

Adult spawner-recruit equation parameters were transformed into corresponding egg-to-parr equation parameters based on egg production and estimated rates of survival from parr through returning spawners. A general formulation of the life cycle model is:

$$R = P\,(pf)\,(F)\,(S_e)\,(S_p)\,(S_m)\,(S_s)\,(S_a)$$

where,

R = number of recruits spawning in the next generation,
P = number of spawners in current generation,
pf = percent of spawners that are female,
F = average fecundity per female,
S_e = survival rate from egg to parr,
S_p = survival rate from parr to smolt,
S_m = survival rate of smolts during migration to the ocean,
S_s = survival rate in the ocean from smolt to adult,
S_a = survival rate from adult in the ocean to spawning (includes fishing and conversion).

Thus, the egg-to-parr equivalent of average, low, or high adult recruits per spawner can be estimated by solving:

$$S_e = (R / P) / [(pf) (F) (S_p) (S_s) (S_m) (S_a)]$$

where

$$R / P = ß$$

These calculations indicate that the maximum egg-to-parr survival rates corresponding to adult recruit per spawner rates of 2, 5, and 20 are 0.0260, 0.0515, and 0.2060, respectively. Corresponding parr-to-spawner relationships based on an arbitrary 80,000 parr capacity assumption are depicted in Figure 32.

In this approach, the assumed stock-recruitment relationship provides a useful means of calibrating net survival rates so that uncertainties in egg-parr, parr-smolt, or smolt-adult survival rates did not compound to produce unrealistic model results. Estimates of survival at each life partition net survival from egg to adult rather than independently deriving adult numbers from the net effect of each component survival rate.

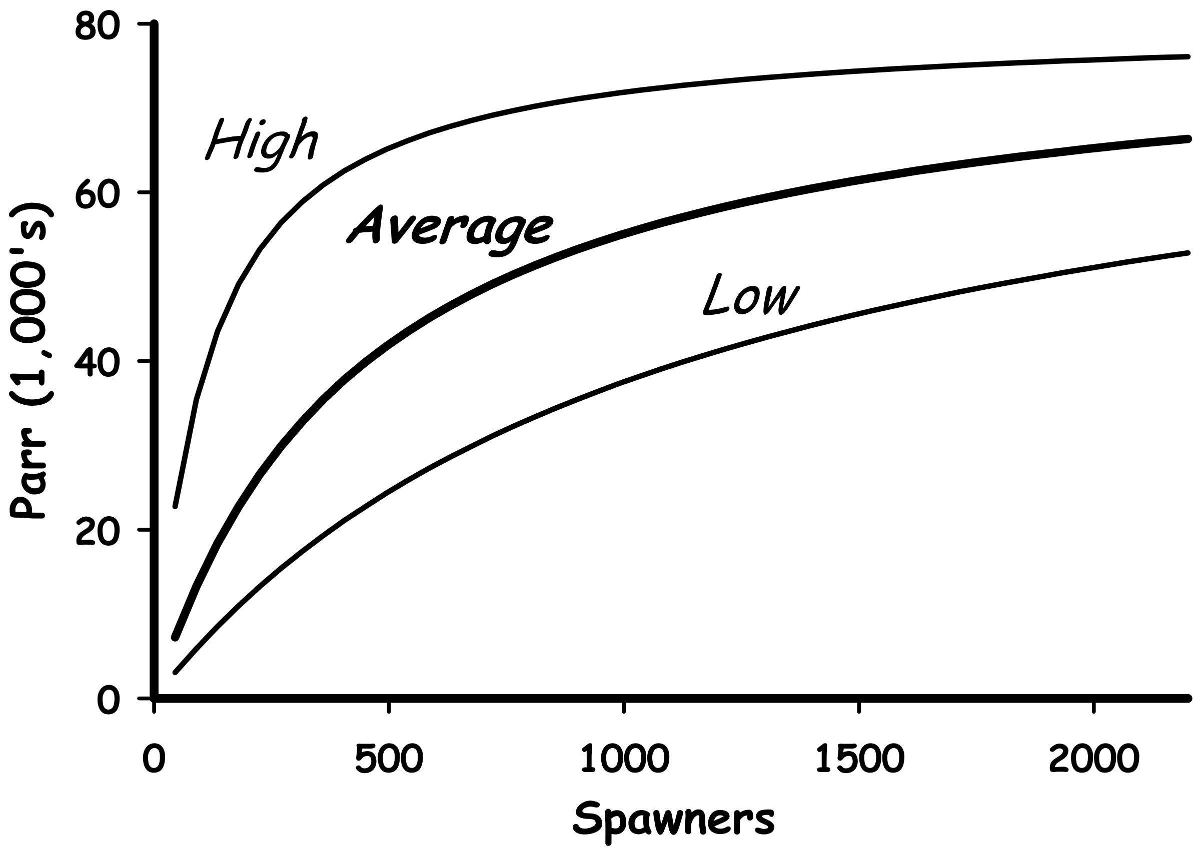


Figure 32. Parr per spawner production curves based on different productivity assumptions and a hypothetical parr capacity assumption of 80,000.

5.1.3 Freshwater Carrying Capacity

The model defines freshwater carrying capacity at the parr stage based on the hypothetical maximum number of parr which the habitat will support. This asymptote parameter is input as the rearing capacity in the Beverton-Holt egg-to-parr survival equation. The baseline parr capacity estimate corresponding to the 6,600 adult spawner capacity estimated by ODFW (1987) was selected by iterative use of the model – parr capacity values were revised until the model forecast an equilibrium steelhead spawner number of 6,600 based on current survival rates, average productivity rates, and no mortality associated with Pelton-Round Butte passage. The implicit assumption is that the basin could produce 6,600 spawners per year on average under current conditions if passage, habitat quality, and competition with trout were not limiting. The resulting asymptotic parr capacity was 223,293 for the 6,600 spawner baseline.

5.1.4 Depensation

Options are included in the model to allow depensation at low spawner escapements. Depensation is the reduced production or survival which may occur at low spawner numbers. The traditional stock-recruitment function calculates ever-increasing recruitment rates at low spawner numbers such that theoretical populations based on these relationships are unrealistically difficult to extirpate and assessments overestimate stock productivity. In practice, the traditional stock-recruitment begins to fall apart at low population sizes as a result of the loss of genetic diversity which helps maintain the stock over a wide range of habitat and environmental conditions, inbreeding depression which increases chances for expression of deleterious recessive traits, demographic problems such as difficulties in finding a mate, and predator or competitor traps. Low population processes are often referred to as "Allee effects" (Hilborn and Walters 1992, McElhany et al. 2000).

Depensation options include "low" depensation where parr per egg survival rates are fixed at spawner numbers less than a designated threshold and "high" depensation where parr per egg numbers incrementally decline to zero at spawner numbers less than the designated threshold (Figure 33). Various threshold levels have been identified (McElhany et al. 2000, Beamesderfer 2001). For sensitivity analyses in this assessment, we used a threshold of 300 spawner consistent with the Oregon Department of Fish and Wildlife Wild Fish Policy. This threshold should be considered a benchmark for comparative purposes rather than a hard-and-fast limit.

Simulation with depensation can be used to provide more conservative assessments of reintroduction prospects. Depensation options are primarily used in stochastic simulations of low population risks. Depensation options also provide an avenue of exploring the potential effects of competition with trout where more specific information on the mechanics of the interaction are unknown.

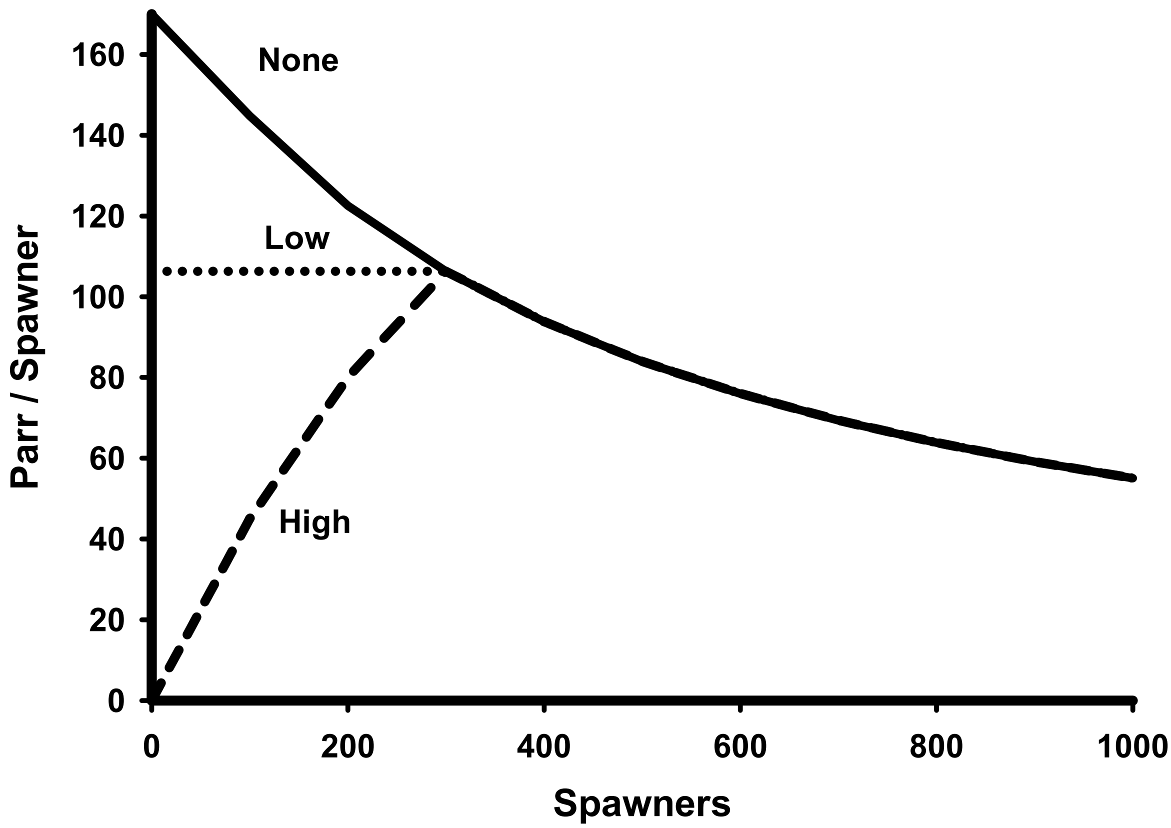


Figure 33. Effects of depensation options on parr versus egg relationships.

5.1.5 Parr to Smolt Survival and Smolt Ages

The model estimates smolt numbers as the product of parr and a density-independent parr-to-smolt survival rates. This quantity allows us to partition juvenile mortality into a density-dependent component which we represented in the egg-to-parr stage and a density-independent component which we represented in the parr-to-smolt stage. We used a parr to smolt survival rate of 50%. This parr to smolt survival rate was based on values reported for other steelhead populations. Wild steelhead studies in Idaho estimated that parr-to-smolt survival averages 50% (Cramer et al. 1997). A 50% parr-to-smolt rate is comparable to the a 0.75% egg to smolt survival rate applied by Olsen et al. (1987) to estimates of lower Deschutes steelhead smolt capacity when egg-to-parr survival rate is 1.5%. A 1.5% egg-to-parr survival rate is similar to that derived from stock-recruitment parameters described above for average productivity and spawner numbers equal to half of the equilibrium abundance.

Numbers of smolts produced by a brood-year cohort of spawners are distributed among different out-migration years consistent with observed smolt ages reported for the lower Deschutes River steelhead population. We used a multi-year average for all cohorts. Thus, 29%, 55%, 14%, and 2% of smolts migrated at ages 1, 2, 3, and 4, respectively.

5.1.6 Resident Trout Interactions

The model currently includes hypothetical relationships for trout populations and steelhead-trout interactions which can be used to explore sensitivity to competition. The strength of the competitive interaction, trout parr numbers, and trout adult numbers are explicit model inputs. The strength of the competitive interaction identifies a reduction in steelhead parr carrying capacity which results from the input parr number. For instance, an input of 20% will reduce the habitat capacity parameter in the egg-to-parr survival rate curve by 20%. The model calculates a trout-steelhead competition coefficient based on the competitive interaction input and applies which it applies to future steelhead and trout numbers:

coefficient = [(parr capacity) * (competitive interaction)] / (number of trout parr)

The future capacity of the habitat for steelhead parr is reduced proportional to the product of future trout parr numbers and this competition coefficient. Future trout numbers are reduced proportional to the product of steelhead parr numbers and this competition coefficient. Future trout adult numbers are estimated based on trout parr numbers and a pseudo trout parr to adult survival rate based on the ratio of input parr and adult numbers.

Smolt Passage Survival

Downstream passage survival rates of smolts in mainstem Columbia River dams are a particularly controversial subject. Accurate estimates have only recently been made possible by the development and application of PIT tag technology although substantial uncertainties remain in the interpretation of these PIT tag estimates. Per-project survival rates of hatchery steelhead at Snake River dams were estimated to average 88 to 92% per year based on PIT tag studies (NMFS 2000). The 1995 biological opinion by the National Marine Fisheries Service for operation of the Federal Columbia River hydropower system described survival rates for Snake River spring/summer chinook and steelhead which were between 40 and 60%. A net survival rate of 50% past 8 dams translates into a per dam survival rate of $(0.50)^{1/8}$ or 0.917. We used a per dam mortality rate of 10% for each of The Dalles and Bonneville dams, consistent with PIT tag study results and assumptions of the biological opinion. We used this rate ($0.9^2 = 0.81$) for all years because we lack reliable year-specific rates. Estimates may be regarded as approximate minimum estimates because they do not include delayed or latent mortality related to mainstem dam passage. Additional mortality is likely to be much less significant for the Deschutes steelhead stock than for far-migrating steelhead stocks from the Snake and upper Columbia river basins.

5.1.7 Ocean Survival

The model estimates the number of steelhead recruiting to adulthood in the ocean as the product of the number of smolts surviving to reach the ocean and a smolt-to-adult survival rate. No smolt-to-adult survival estimates are available for wild Deschutes River steelhead. Estimates for wild steelhead are rare because of the difficulty of estimating wild smolt numbers. Estimates of smolt to adult survival rate are available for hatchery smolts but wild smolts typically survive at a greater rate. Reported smolt-to-adult survival rates for various Northwest steelhead populations including Deschutes hatchery fish average 5.4% and range from 1% to 12%, although survival rates since 1985 are typically less than average (Table 20). Reported rates include ocean and freshwater, natural and human-caused mortality factors.

For wild origin smolts, we modeled smolt-to-adult ocean survival rates in the absence of human-caused mortality at an average 10% rate based on a review of literature values used in other Columbia River modeling efforts. This estimate is comparable to the 6% smolt-to-adult survival rate that included dam effects and poor ocean conditions suggested by Olsen et al. (1987) for lower Deschutes River wild steelhead.

Recent experience has demonstrated that ocean survival rates can be highly variable. The log-normal coefficient of variation for Deschutes River hatchery steelhead was slightly greater (29%) than the average (19%) for 8 other Northwest steelhead populations (Table 20). Survival rates are also autocorrelated among years because of overlapping generations and periodic ocean regime shifts which result in extended sequences of poor or good survival years (Beamish and Boullion 1993). We used the observed variability in the lower Deschutes River hatchery steelhead survival to represent the expected variation in wild steelhead. The model provides options for random normal variation in ocean survival and for autocorrelated variation in ocean survival. We applied the hatchery survival coefficient of variation to the assumed average 10% natural smolt survival rate in random normal simulations. In autocorrelated simulations, we used a sequence of scalars derived by dividing annual hatchery survival rates by the average for all years. Scalars were used in order starting with one selected at random. After the last scalar in the sequence, the model jumps to the beginning of the time series and continues until every scalar is used. The cycle then started again with a new random selection. This ensures that all years of data are weighted equally.

5.1.8 Adult Age Composition

Adult steelhead in the ocean are apportioned between return years based on observed frequencies of one- and two-salt fish for lower Deschutes River steelhead (Olsen et al. 1991). Thus 53% return after 1 year in the ocean and 47% return after 2 years in the ocean. No three-salt fish steelhead were reported by Olsen et al. for wild Deschutes River steelhead. The model did not provide for repeat spawners because of a low reported incidence in the Columbia River steelhead populations. Ages of adult maturation are applied independent of ages of smoltification.

Table 20. Reported smolt-to-adult survival rates for various Northwest steelhead populations.

Smolt Year	Deschutes Summer Hatchery	Eagle Crk. Winter Hatchery	Kalama Winter Hatchery	Kalama Summer Hatchery	Up. Col. Summer Hatchery	Umpqua Summer Hatchery	Snow Crk. Winter Wild	Queets Winter Wild	Keogh Winter Wild
1965	--	--	--	--	2.0%	3.6%	--	--	--
1966	--	--	--	--	2.1%	3.9%	--	--	--
1967	--	--	--	--	1.6%	6.4%	--	--	--
1968	--	--	--	--	1.0%	8.0%	--	--	--
1969	--	--	--	--	1.4%	5.8%	--	--	--
1970	--	--	--	--	1.9%	4.8%	--	--	--
1971	--	--	--	--	1.4%	4.3%	--	--	--
1972	--	--	--	--	1.4%	2.1%	--	--	--
1973	--	--	--	--	0.1%	1.7%	--	--	--
1974	--	--	--	3.1%	0.8%	2.2%	--	--	--
1975	--	--	0.5%	6.0%	1.9%	3.5%	--	--	--
1976	8.1%	--	2.4%	5.4%	2.0%	3.7%	--	--	
1977	2.4%	--	0.5%	4.0%	0.2%	4.8%	--	--	15.2%
1978	10.0%	--	1.3%	18.1%	1.5%	2.7%	6.5%	--	7.4%
1979	8.6%	--	1.5%	16.0%	1.2%	3.7%	10.7%	--	15.2%
1980	7.7%	--	0.8%	9.6%	1.4%	1.2%	5.6%	--	8.4%
1981	1.4%	--	0.6%	2.9%	0.7%	1.4%	2.2%	--	25.4%
1982	14.5%	--	1.7%	4.9%	5.3%	3.1%	6.1%	--	26.1%
1983	6.9%	2.4%	1.5%	8.0%	2.9%	5.3%	10.5%	--	15.5%
1984	11.7%	2.3%	3.0%	12.4%	4.5%	5.6%	4.8%	17.3%	18.3%
1985	11.9%	1.2%	1.2%	8.0%	1.9%	7.7%	3.5%	11.4%	25.3%
1986	6.2%	0.8%	1.6%	6.2%	1.3%	6.3%	7.1%	13.5%	10.0%
1987	4.2%	0.6%	2.0%	7.8%	0.7%	4.7%	1.3%	9.8%	13.3%
1988	3.5%	1.2%	1.3%	6.1%	0.7%	3.4%	1.7%	17.7%	6.7%
1989	1.6%	0.9%	1.8%	4.9%	0.7%	3.7%	1.6%	13.0%	15.4%
1990	4.6%	1.7%	2.4%	13.7%	1.3%	1.3%	3.0%	11.7%	6.3%
1991	1.8%	1.0%	1.2%	6.2%	0.8%	1.4%	2.1%	16.1%	3.6%
1992	0.3%	0.7%	0.4%	3.6%	0.3%	1.2%	1.6%	8.6%	3.0%
1993	3.3%	0.7%	0.5%	1.6%	0.7%	2.0%	2.8%	7.7%	3.3%
1994	3.5%	0.2%	2.0%	4.5%	0.5%	4.9%	6.6%	7.9%	2.6%
1995	4.8%	--	--	1.9%	1.1%	2.9%	--	12.1%	4.0%
1996	4.5%	--	--	0.7%	--	--	--	--	--
1997	2.4%	--	--	--	--	--	--	--	--
1998	1.8%	--	--	--	--	--	--	--	--
Averages									
All years	*5.5%*	*1.1%*	*1.4%*	*6.8%*	*1.5%*	*3.8%*	*4.6%*	*12.2%*	*11.8%*
pre 1985	*7.9%*	*2.3%*	*1.4%*	*8.2%*	*1.8%*	*3.9%*	*6.6%*	*17.3%*	*16.4%*
1985-pres	*3.9%*	*0.9%*	*1.4%*	*5.4%*	*0.9%*	*3.6%*	*3.1%*	*11.8%*	*8.5%*
CV[1]	*29%*	*14%*	*13%*	*26%*	*18%*	*16%*	*21%*	*13%*	*32%*

[1] *Coefficient of variation (standard deviation / mean) based on Ln(SAR).*

5.1.9 Adult Passage Mortality

Adult steelhead are subject to mortality associated with upstream passage of dams. Passage mortality rates for adults at mainstem Columbia River dams were modeled at 5% per dam. More precise estimates cannot be derived because of uncertainties in dam counts, tributary turnoffs, and fishing impacts. Pratt and Chapman (1989) concluded that 5%/dam was a reasonable estimate for steelhead based a review of the available data on interdam loss of adults. The *U. S. v. Oregon* Technical Advisory Committee is also using a 5% standard in run reconstruction calculations of fishery impacts.

5.1.10 Fishing

Steelhead harvest or fishery impact occurs in Columbia River sport fisheries, Columbia River Treaty Indian gillnet fisheries, Columbia River Treaty Indian subsistence fisheries, Deschutes River sport fisheries, and Deschutes River Treaty Indian subsistence fisheries. Coded wire tag analyses indicate that steelhead are not taken in significant numbers in any ocean fishery, apparently because of an offshore, high-seas distribution pattern. Non-Indian commercial fisheries for steelhead in the Columbia River have been prohibited beginning in 1975 and incidental impacts of non-Indian commercial fisheries for other species are minimal because no significant fisheries occur in the group A migration time frame.

Columbia River sport fisheries above and below Bonneville Dam keep only marked (hatchery) fish since the late 1970's. Deschutes-origin steelhead are taken in lower Columbia River mainstem sport fisheries primarily during July and early August when the majority of these group A steelhead pass through the lower river. Harvest rates on Group A hatchery steelhead have averaged 3.7% and ranged from 2.0% to 4.8% per year since 1984 when hatchery and wild run size estimates became available. Impacts to wild Deschutes steelhead are limited to catch and release mortality which is believed by the *U. S. v. Oregon* Technical Advisory Committee to be about 10% based on a review of the available literature data. The projected annual impact on wild Deschutes steelhead in the lower Columbia River sport fishery would be less than 1% if catch and release mortality was 10% and wild fish were handled at a similar rate to hatchery fish. We modeled future Deschutes wild steelhead impacts in this fishery at 1%.

Significant sport fisheries for steelhead between Bonneville Dam and the Deschutes River occur primarily from July through September when fish seek refuge from warm Columbia River temperatures in cool tributary mouths, primarily in Bonneville Reservoir. Catch estimates of steelhead in Zone 6 sport fisheries are based primarily on catch record cards returned by anglers. Recent biological opinions by the National Marine Fisheries Service for listed wild steelhead stocks have limited mainstem non-Indian fishery impacts to 2%. We modeled future Deschutes wild steelhead impacts in the Zone 6 sport fishery at 1% which is equivalent to the 2% limit less the 1% impact in the lower Columbia River. This impact is consistent with a 10% catch and release mortality and a 10% handle rate.

Steelhead are taken by treaty Indian fisheries in the Columbia River mainstem primarily in Fall gillnet fisheries which target chinook salmon from late August through

October. Harvest rates on group A steelhead have averaged 13% for wild fish and 14% for hatchery fish from 1984-1999. Rates have been declining during that period as more weak stock protection measures were implemented to protect the listed stocks. Current steelhead harvest rates in fall treaty Indian fisheries are limited by the NMFS to not more than 15% although actual harvest rates have averaged only 9% in 1995-1999. Harvest rates during fall gillnet fisheries are limited by the use of large mesh gillnets to target the larger fall chinook. Small numbers of steelhead are also taken in various ceremonial and subsistence fisheries during the remainder of the year. These fisheries primarily occur by hook-and-line or from platforms with dip nets. Treaty Indian fisheries occur from Bonneville to McNary dams but most of the effort is between Bonneville Dam and the Deschutes River mouth. We modeled future treaty Indian fishery impacts on wild Deschutes steelhead at 80% of 9% for fall fisheries plus a 1% impact in other ceremonial and subsistence fisheries for a total annual rate of about 8%.

Steelhead harvest or fishery impact also occur in Deschutes basin sport and tribal dipnet fisheries. The Deschutes River supports a very popular sport fishery for steelhead. The bag limit has been restricted to the harvest of marked (hatchery) steelhead since 1979. The fishery occurs primarily from the river mouth to Sherars Falls and the majority of the catch is of non-local steelhead which have sought refuge in the cooler Deschutes before continuing their migration up the Columbia River. The required release of wild fish, catch of many non-local fish, and the reliance on catch record card data for catches above Sherars falls makes estimation of fishery impacts on wild Deschutes River steelhead difficult. We estimated wild steelhead impacts in the Deschutes sport fishery based on a run reconstruction using Sherar's escapement estimates, reported wild releases from creel surveys in the lower Deschutes, proportional wild handle above Sherars Falls from catch record card data, and an assumed 10% catch and release mortality rate. We also assumed that only 20% of the wild handle below Sherars was local-origin based on relative Deschutes and Bonneville Dam wild numbers and observations that most of the upriver steelhead run enters the Deschutes. We modeled future impacts on wild Deschutes River steelhead in Deschutes basin sport fisheries at 4% based on a recent year average impacts estimated in this run reconstruction. This estimate appears to be inflated by the use of catch record cards and creel survey data for reported releases.

Tribal fisheries in the Deschutes River occur primarily with dipnets in the area immediately below Sherars Falls in years when fall salmon runs are significant. Recent catches are relatively small and typically do not exceed 100 steelhead. Currently, wild steelhead caught in the tribal fishery are released. For modeling purposes, we considered tribal fishery impacts in the Deschutes basin to be included with sport fishery impacts at the 4% rate.

5.2 Calibration and Validation

5.2.1 Productivity and Capacity Assumptions

To explore whether the model provides realistic results, we examined model sensitivity to alternative assumptions of population productivity and habitat capacity. These simulations started with deposition of 500,000 eggs per year for 10 years. Low, medium, and high capacity values correspond to 40,000, 80,000, and 160,000 parr. Low, medium, and high productivity values correspond to maximum egg-to-parr survival rate parameters of 0.0206, 0.0515, and 0.2060.

Simulated future spawner numbers increased rapidly for all capacity and productivity assumptions in these simple deterministic simulations. Spawner numbers reached or exceeded equilibrium within 10-20 years in all except the low productivity, low capacity case where equilibrium was reached after about 30 years.

Equilibrium spawner numbers were determined by the combination of egg-to-parr productivity and capacity parameters rather than just the capacity parameter alone. Higher or lower capacities resulted in higher or lower equilibrium levels when productivity was constant. Higher or lower productivities also resulted in higher or lower equilibrium levels even where the capacity parameter was constant. This seemingly counterintuitive result is explained by the effects of density-dependent survival rates. Even though more spawners produce more parr until the hypothetical habitat capacity is reached, density-dependent reductions in survival rate at high spawner numbers mean the increase in parr number is not enough to replace the spawners that produced them. The capacity parameter input value becomes a hypothetical limit and the realized carrying capacity is defined based on the equilibrium level. Figure 34 illustrates the relationship between capacity and productivity parameters and equilibrium spawner number using spawner-recruit curves corresponding to different combinations of input values. Thus, the realized capacity of the habitat depends on the actual parr capacity and the combination of survival rates throughout the steelhead life cycle. Changes in survival rates anywhere in the life cycle will affect the apparent carrying capacity of the system for steelhead.

5.2.2 Simulated Versus Actual Recruitment Rates

To examine whether model results were consistent with recent performance of summer steelhead in the Deschutes basin, we compared recruitment rates in model simulations under various productivity and capacity assumptions with rates estimated in steelhead run reconstructions. We used average number of spawning recruits produced by parent spawners as an index of stock productivity. Ratios greater than 1 generally indicate a productive or increasing stock and ratios less than 1 indicate a decreasing stock.

All productivity and capacity assumptions used in simulations result in recruitment rates considerably greater than those observed during the recent period of poor ocean conditions. Recruits per spawner for natural steelhead in the lower Deschutes River ranged from 0.16 to 1.84 and averaged 0.47 (geometric mean) for 1978-1995 brood years. Simulated spawner per spawner rates averaged 1.04 to 1.19 over the 50-year simulation period. Average spawner:spawner rates during the first 10 years of simulations ranged from 1.43 in the low production, low capacity case to 2.73 in the medium production, high capacity case Recruitment rates during the first 10 years were greater than the 50-year results because fewer years were included where spawner numbers near equilibrium produced recruitment rates of 1.0. A similar effect explains why average 10-year recruitment is greater for the medium productivity examples than for high productivity examples at a given capacity. The high productivity pushes the population to equilibrium more quickly and results in more 1:1 stock recruitment rates within the initial 10 year period.

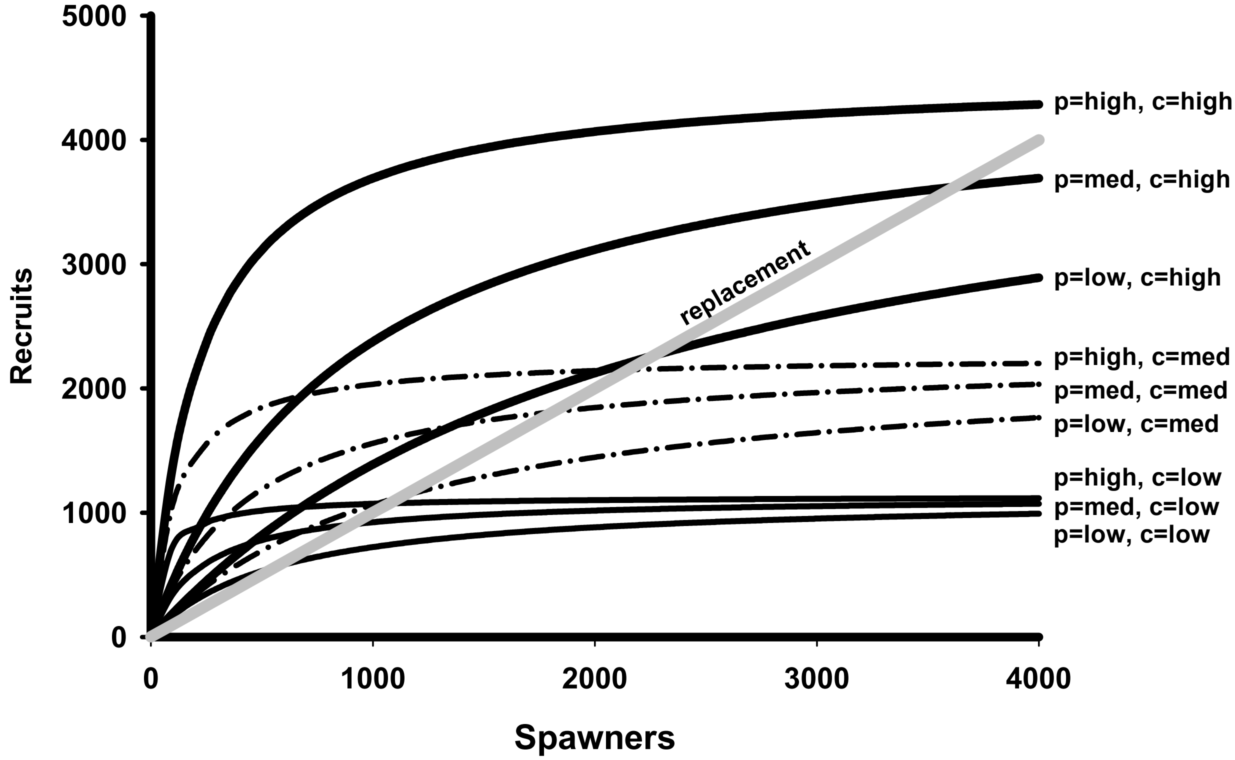


Figure 34. Stock-recruitment curves (recruits at spawning) for different productivity and capacity assumptions.

5.2.3 Comparison to Post-impoundment Counts

To examine whether model results were consistent with historic declines in summer steelhead to the upper Deschutes basin following Pelton Round Butte project development, we compared actual Pelton trap counts with model-predicted counts. The model steelhead population was initially set at 1,600 adults based on average productivity and capacity assumptions, and an assumed greater fishing mortality rate which resulted in the desired equilibrium escapement. The juvenile migrants were then subjected to a 65% mortality rate in the Deschutes basin to yield the population trajectory in Figure 35. Actual and model-predicted population trajectories were very similar. Input numbers used in this exercise were somewhat arbitrary but the result does demonstrate the abrupt effect of large increases in passage mortality on adult steelhead escapement.

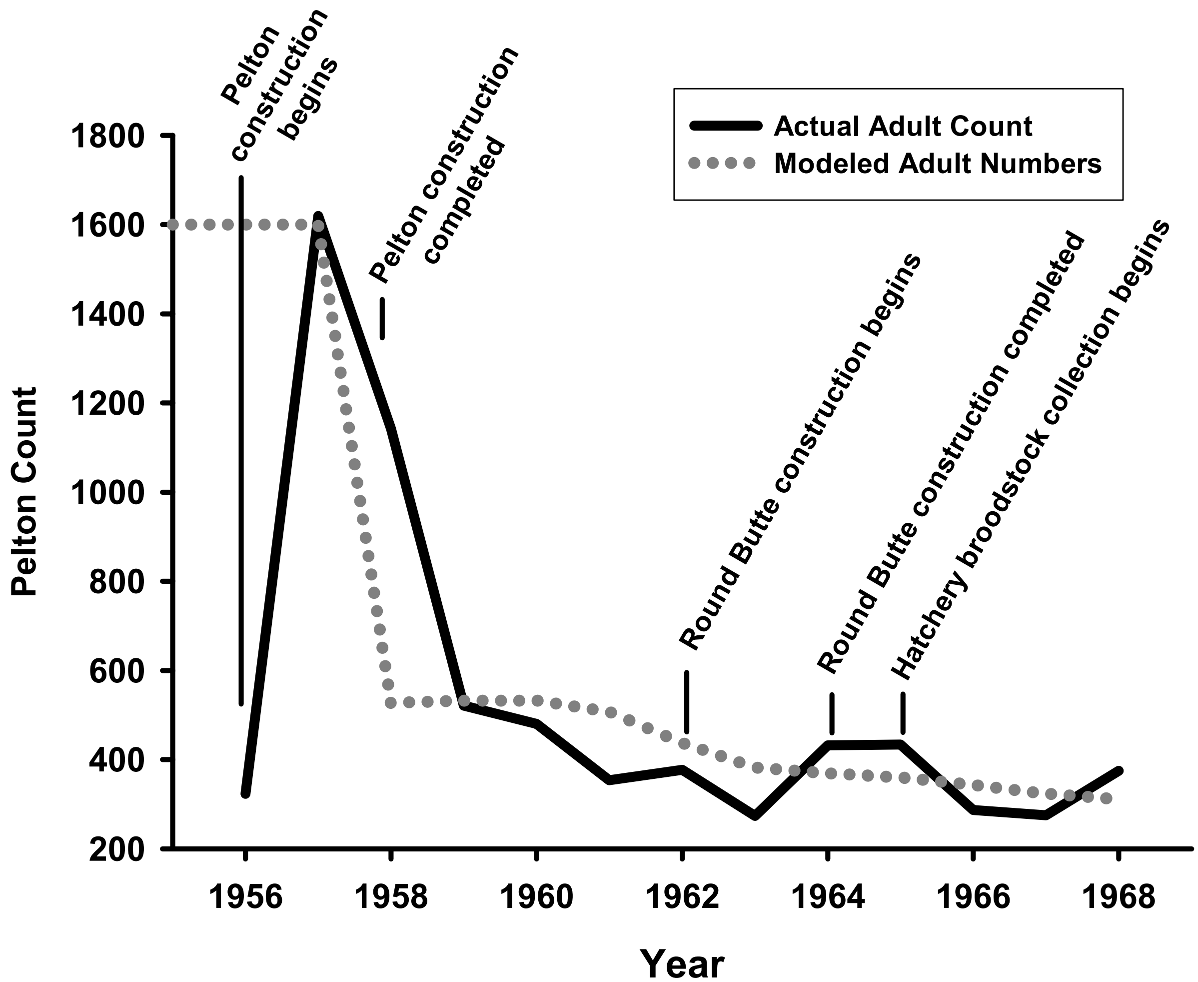


Figure 35. Comparison of the observed and simulated response of the steelhead population upstream from the Pelton-Round Butte projects following completion of Round Butte Dam. Population was initialized at 1,600 then subjected to an additional 65% juvenile mortality rate during Deschutes migration.

5.2.4 Simulations Results

In order to run stochastic simulations, we had to assign a variance comparable for Deschutes River steelhead. We assembled estimates of productivity parameters and their standard deviations calculated Chilcote (1998) for Mid Columbia Steelhead populations. Variance was greatest for Deschutes populations, because Chilcote (1998) included large number of hatchery fish in his estimates of productivity. All other Mid Columbia populations included few hatchery fish, so we believe those estimates of variance are more appropriate to represent wild steelhead in the Deschutes. Accordingly, we used the average variation for the Umatilla and John Day populations, which gave a coefficient of variation of 51% (Table 21). Accordingly, we used the coefficient of 50% in our simulations.

Table 21. Observed variation in estimates of productivity parameters for Mid Columbia Steelhead. From Chilcote 1998.

Population	*a*	s	Coefficient of variation
Deschutes	1.043	1.413	1.355
JD Below PG	1.236	0.998	0.807
Jd Above PG	1.167	0.763	0.653
NFJohn D	1.398	0.515	0.368
MF John D	1.426	0.548	0.384
SF John D	1.028	0.552	0.537
Umatilla	1.713	0.559	0.326
	Average		**0.513**

We simulated 500 runs of 100 years each and varied harvest rates to explore their effects on extinction probability. We calculated the probability that the run size would drop below 300 fish during any year of simulation. The simulation showed that even with harvest rate nearly 80%, the probability of run size dropping below 300 was less than 10% (Table 22). This result suggests the population is substantially robust than predicted by Chilcote (2001). However, our results should be regarded as optimistic because we treated variation in recruitment as random, rather than following a pattern of regimes. If we have temped to mimic variability caused by ocean regime changes, the population would have dropped below 300 more frequently during sequential low years of survival.

Table 22. Results of stochastic simulations with 500 runs of 100 years each. Parameters set to represent Deschutes Wild Steelhead.

Harvest Rate		**Popluation**		**Probability**
Columbia	**Deschutes**	**Average**	**Maximum**	**< 300**
10%	8%	4,626	12,445	0.00%
10%	20%	3,885	10,431	0.00%
10%	30%	3,228	8,753	0.12%
10%	40%	2,599	7,181	0.22%
10%	50%	1,955	5,592	0.42%
10%	60%	1,333	4,882	1.22%
10%	70%	724	3,088	6.20%

6.0 References

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Appendix 1. Peak counts of redds and fish in steelhead (STS) spawning areas of the Umatilla Basin. Data from P. Kisner, CTUIR, Pendleton, pers. Comm.

	South Fork Umatilla				North Fork Umatilla				Meacham Creek			
Year	Redds	STS	Miles	Survey	Redds	STS	Miles	Survey	Redds	STS	Miles	Survey
1985									0	0	1.5	1
1986									49	2	6.4	1
1987	3	0	3.0	1	6	2	2.5	1	49	0	9.0	3
1988	5	1	2.0	1	1	0	2.5	1	51	1	9.0	1
1989*	7	0	2.0	1	3	0	1.5	1	24	0	9.0	1
1990	High Water				High Water				High Water			
1991	High Water				High Water				High Water			
1992	15	9	4.2	2	17	3	2.5	2	120	39	18.0	2
1993*	8	4	4.2	1					6	5	15.8	1
1994	8	0	4.2	1	4	0	4.0	3	40	5	18.2	1
1995**	4	2	3.2	1	1	1	2.0	1	12	5	3.1	1
1996	3	3	5.0	1				0	6	4	high	Incid
1997	9	2	3.2	2	High Water				High Water			
1998	7	2	3.2	3	5	0	3.0	1	65	7	9.8	2
1999	34	3	3.2	5								
2000	34	5	3.2	3					69	6	9.8	1
2001	48	4	3.2	2								
2002	28	0	3.2	1								

	Ryan Creek				Minthorn Springs			
Year	Redds	STS	Miles	Survey	Redds	STS	Miles	Survey
1985	2	0	2.0	1				
1986	13	0	2.0	1				
1987	10	0	2.0	1				
1988	9	0	2.0	1				
1989*	16	0	3.0	1				
1990	High Water				High Water			
1991	High Water				High Water			
1992	3	0	2.0	1	5	0	.2	1
1993*								
1994	3	0	3.0	1	1	2	.2	1
1995**								
1996					2	5	.2	1
1997					2	1	.2	1
1998								
1999	1	0	3.0	1	23	11	0.5	4
2000					12	10	0.5	2
2001								
2002								

	Pearson Creek				West Birch				East Birch			
Year	Redds	STS	Miles	Survey	Redds	STS	Miles	Survey	Redds	STS	Miles	Survey
1985												
1986												
1987	22	0	6.0	1					11	0	5.5	1
1988	15	13	6.0	1	2	0	2.0	1	39	10	11.0	1
1989*												
1990	High Water				High Water				High Water			
1991	High Water				High Water				High Water			
1992	1	1	6.0	2	0	0	3.3	1	4	0	1.0	1
1993*	3	5	8.0	1	3	0	4.5		11	2	4.5	
1994	31	9	5.0		20	5	6.0		61	9	7.0	
1995**	8	1	2.0						31	5	6.5	
1996	11	1	4.0									
1997												
1998												
1999	17	1	5.8	1					18	0	4.5	1
2000	86	20	5.8	2					67	14	4.5	2
2001												

Appendix 2. Data used for time series of spawners and natural recruitment of steelhead in the Deschutes, John Day, Umatilla, and Yakima basins.

Brood Year	Deschutes Summer Steelhead					John Day Summer Steelhead				
	Spawners		Recruits			Spawners		Recruits		
	SpTot	SpW	RecW	R/S Tot	R/S W	SpTot	SpW	RecW	R/S Tot	R/S W
1974						11706	11121	9535	0.81	0.86
1975						24041	22839	10210	0.42	0.45
1976						14882	14138	12693	0.85	0.9
1977						16208	15398	12709	0.78	0.83
1978	9584	5875	7633	0.79	1.3	12500	11875	12209	0.98	1.03
1979	3695	2490	8603	2.33	3.46	2941	2794	13801	4.69	4.94
1980	6615	4154	9391	1.42	2.26	11593	11013	24438	2.11	2.22
1981	6976	4053	10048	1.44	2.48	8921	8475	36842	4.12	4.35
1982	8953	6822	9440	1.05	1.38	11763	11175	40448	3.44	3.62
1983	8783	6491	7356	0.84	1.13	9535	9058	33949	3.56	3.75
1984	15146	8133	5607	0.37	0.69	6910	6564	19718	2.85	3
1985	12539	7636	4818	0.38	0.63	22836	21694	9677	0.42	0.45
1986	14913	9515	4690	0.31	0.49	31360	29792	9067	0.29	0.3
1987	15561	6131	4603	0.3	0.75	35528	33752	10827	0.3	0.32
1988	15718	5313	3541	0.22	0.67	31407	29900	10603	0.34	0.35
1989	6958	3507	1947	0.28	0.56	9648	9166	8263	0.86	0.9
1990	7375	4233	1224	0.17	0.29	7603	7223	6074	0.8	0.84
1991	5967	3610	1403	0.24	0.39	5352	5084	4461	0.83	0.88
1992	10459	4769	2302	0.22	0.48	12471	11847	4557	0.37	0.38
1993	3868	894	2882	0.75	3.22	6395	6075	4566	0.71	0.75
1994	4279	1472	3230	0.75	2.19	8905	8460	5181	0.58	0.61
1995	2194	476	4082	1.86	8.58	3084	2930	5363	1.74	1.83
1996	6222	1642	6234	1.00	3.8	5289	5025	7901	1.49	1.57
1997	11344	3417	7942	0.70	2.32	4056	3853	11962	2.95	3.1

SpTot = total wild and hatchery-origin spawners;
SpW = spawners of wild origin;
RecW = wild adult recruits from natural spawning;
R/S Tot = wild adult recruits per parent spawner of both wild and hatchery origin (SpTot);
R/S W = wild adult recruits per parent wild spawner (SpW).
Age composition of recruits for Deschutes, John Day, and Umatilla River taken from Chilcote (2001), Yakima taken from Berg (2001)

Brood Year	Umatilla Summer Steelhead					Yakima Summer Steelhead				
	Spawners		Recruits			Spawners		Recruits		
	SpTot	SpW	RecW	R/S Tot	R/S W	SpTot	SpW	RecW	R/S Tot	R/S W
1974	2350	2350	2950	1.26	1.26					
1975	1932	1932	2445	1.27	1.27					
1976	2255	2255	1767	0.78	0.78					
1977	1120	1120	1216	1.09	1.09					
1978	2741	2741	1540	0.56	0.56					
1979	2080	2080	2486	1.2	1.2					
1980	2107	2107	3320	1.58	1.58					
1981	1084	1084	3606	3.33	3.33	64	64	2512	39.25	39.25
1982	541	541	3473	6.42	6.42	210	210	2814	13.40	13.40
1983	982	982	2966	3.02	3.02	230	230	2865	12.47	12.47
1984	2013	2013	2319	1.15	1.15	286	286	2275	7.95	7.95
1985	3062	3062	1744	0.57	0.57	692	692	1254	1.81	1.81
1986	2788	2788	1426	0.51	0.51	1413	1413	966	0.68	0.68
1987	3263	3263	1769	0.54	0.54	1822	1822	1458	0.80	0.80
1988	2309	2161	1736	0.75	0.8	2365	2365	1763	0.75	0.75
1989	2255	1926	1182	0.52	0.61	864	864	1120	1.30	1.30
1990	1521	1302	1069	0.7	0.82	539	539	793	1.47	1.47
1991	964	620	1175	1.22	1.9	782	721	735	0.94	1.02
1992	2472	2007	1145	0.46	0.57	2097	2014	711	0.34	0.35
1993	1709	1160	1042	0.61	0.9	1089	1089	938	0.86	0.86
1994	1151	844	1312	1.14	1.55	554	540	1097	1.98	2.03
1995	1445	789	1199	0.83	1.52	918	820	1381	1.50	1.68
1996	1981	1196	1885	0.95	1.58	505	451	2204	4.36	4.89
1997	2369	906	2396	1.01	1.64	961	816	3371	3.51	4.13

SpTot = total wild and hatchery-origin spawners;
SpW = spawners of wild origin;
RecW = wild adult recruits from natural spawning;
R/S Tot = wild adult recruits per parent spawner of both wild and hatchery origin (SpTot);
R/S W = wild adult recruits per parent wild spawner (SpW).
Age composition of recruits for Deschutes, John Day, and Umatilla River taken from Chilcote (2001), Yakima taken from Berg (2001)