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Feasibility of Reintroduction of Anadromous Fish Above or Within the Hells Canyon Complex

James A. Chandler
Editor

Technical Report
Appendix E.3.1-2

Hells Canyon Complex
FERC No. 1971

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Estimators of Potential Anadromous Fish Smolt Yield

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Chapter 7

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In this chapter, we develop several estimators of smolt productivity in tributaries upstream of Hells Canyon Dam:

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Our purpose in examining these methods was to estimate smolt outputs from the main Snake River and its subbasins under the following six possible scenarios:

- Passage provided at each individual dam in the Hells Canyon Complex (HCC)
- Scenario 1 plus passage at Swan Falls Dam
- Scenario 2 plus passage at C.J. Strike Dam
- Scenario 3 plus passage at Bliss Dam
- Scenario 4 plus passage at Lower and Upper Salmon Falls combined
- Scenario 5 plus passage into and from subbasins now blocked by manmade obstacles not owned by Idaho Power Company (IPC)

Our specific task was to estimate potential smolt yield from each subbasin under the foregoing scenarios. This chapter provides detailed descriptions of the methods for estimating smolt yield from individual subbasins. In Chapter 8 of this report (Chapman and Chandler 2001a), we present the results from applying these methods to individual subbasins.

1.1. Definitions

We define a spring/summer chinook (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), or sockeye (*O. nerka*) smolt as a migrant leaving a subbasin just after the overwintering phase.[1] We assume that overwintering occurs in the subbasin. For example, smolt yield from Pine Creek is estimated as the number of juveniles leaving the Pine Creek basin and entering the Snake River in the spring. Likewise, we consider sockeye smolt yield from Big Payette Lake to be the number of smolts that arrive at the outlet of the lake in spring.

We call fall chinook juveniles "smolts," while recognizing that these subyearling migrants rear as they move down the Snake River. We consider the output of smolts in this case to be the numbers of subyearlings that leave a portion of the Snake River. For example, output of the area between upper Swan Falls reservoir and C.J. Strike Dam is the number of juveniles that arrive at upper Swan Falls reservoir. Output from the area between upper Bliss Reservoir and Lower Salmon Falls Dam is the number of juveniles that arrive at upper Bliss Reservoir.

1.2. Available Data

For subbasins upstream of the HCC, we found few estimates of fish habitat surface areas. The Northwest Power Planning Council (NPPC) provides the StreamNet database on its Web site (http://www.nwcouncil.org). As a part of the council's System Planning Model (SPM), this database contains estimated smolt output and stream surface areas for habitat units in the Snake River basin downstream of the HCC. However, it lacks such estimates for areas upstream of Hells Canyon Dam.

Because we lacked estimates of surface area in most subbasins, we approached smolt yields from other directions. We considered smolt outputs in relation to watershed areas, stream miles (mi) (or kilometers [km]), and stream order. In the next section, we develop estimates of smolt output in relation to basin area.

2. SMOLTS PER UNIT OF EFFECTIVE BASIN

2.1. Snake River

Not all portions of subbasins in the Snake River Basin can produce anadromous fish, especially stream-annulus salmon and steelhead. It is possible that some stream portions of the various

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[1] We recognize that presmolts can depart tributary basins in the fall and then overwinter in larger tributaries or in the mainstem Snake River. However, the subbasin approach has attractive simplicity. We found no information that permitted us to assign different overwinter survival rates to presmolts that might spend the winter in tributary basins and those that might overwinter in the mainstem Snake River.

subbasins never produced stream-annulus fish because of their high summer water temperatures. We believe appropriate examples of these nonproductive stream sections include the mainstem Clearwater River downstream of Lowell, Idaho; the mainstem Salmon River below Salmon, Idaho; and the mainstem Snake River. While the latter stream segment was an important producer of fall chinook, it was probably always too warm in summer for spring chinook and steelhead. This is not to say that juvenile spring chinook and steelhead were never found in these warm mainstem areas. They likely used short, localized segments downstream of the mouths of tributaries or springs for temporary rearing areas. Some chinook and steelhead probably overwintered in mainstem reaches.

We use the term "effective basin" for drainage areas used by stream-annulus salmon and steelhead for spawning and rearing in subbasins[2] (as introduced in Chapter 1 [Chandler and Radko 2001]). The effective basin consists of the area that lies upstream of the beginning of excessively high summer water temperatures. We assumed that the summer maximum weekly average temperature (MWAT) in the unuseable low-elevation stream reaches was and is 22 °C and higher. That opinion is supported by information in Hicks (1998). McCullough (1999) noted that maximum temperatures of about 22 to 24 °C set the downstream limit for salmonids, and specifically for chinook salmon. These maxima would correspond to a somewhat lower MWAT. McCullough (1999) suggested that the optimum temperature for growth, about 15.6 °C, should be the temperature standard for stream management. However, if we adopted this standard, we must then eliminate from our estimates of smolt yield upstream of the HCC many stream reaches that chinook juveniles might use for rearing. A downstream habitat boundary formed by an MWAT of 22 °C does tend toward overestimating the habitat available to rearing salmon and steelhead. However, for our purposes it provides an appropriate limit.

To begin our estimates, we first used U.S. Geological Survey (USGS) water resource data on basin areas downstream of the HCC to develop estimates of effective basin area (Table 1). We used both judgment and our knowledge of fish presence or absence to set the downstream distribution limit of stream-annulus salmon and steelhead.[3]

Next, we selected a historical scenario in which we could relate estimated smolt output at Ice Harbor Dam, under prehatchery conditions and conditions of full seeding by the parents, to upstream effective basin area available then. Raymond (1979) provided estimated smolt outputs for the early 1960s. We used Raymond's estimates to calculate smolt outputs in relation to effective basin area (Table 2). In 1964 and 1965, 14,201 square miles (mi^2) of effective basin area yielded an average of about 2.6 million chinook per year at Ice Harbor Dam, and 20,209 mi^2 of effective basin yielded an average of just over 1.4 million steelhead per year.[4] A negligible

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[2] The effective basin concept was also used to estimate the potential yield of chinook salmon and steelhead smolts from the Lake Chelan basin (Hillman et al. 2000).

[3] The Grande Ronde River is an exception. With extensive temperature data, we were able to develop a regression of MWAT on elevation, and then use a geographic information system (GIS) to determine naturally useable stream lengths and basin areas.

[4] Beginning in the smolt migrations of 1967, Rapid River Hatchery for spring chinook and Pahsimeroi Hatchery for summer steelhead began to influence smolt numbers. Therefore, we confined our examination to the first two years (1964 and 1965) of Raymond's (1979) smolt estimates.

number of these fish originated upstream of the HCC (see Raleigh and Ebel 1968). We consider it conceptually appropriate to use the figure of 20,209 mi^2 for the area that produced steelhead. However, spring/summer chinook production in the Clearwater River system was almost nonexistent in the early 1960s, largely because Lewiston Dam prevented passage of adult salmon, but not steelhead.[5] Thus, only 14,201 mi^2 of effective basin could produce chinook salmon. We did not include Panther Creek in our effective basin totals. By the early 1960s, salmon and steelhead there had been decimated by mine-caused toxicity.

An important question arises in this scenario. Did adult salmon and steelhead fully seed the Snake River basin in the early 1960s? Escapement of steelhead to the Snake River in 1962–1963, which produced the 1965 outmigration, was the largest (106,322 fish at Ice Harbor) in the 22-year period from 1962 to 1984. Steelhead escapement at McNary Dam in 1961–1962, which produced the 1964 outmigration, was the ninth-largest (102,267 fish) in the 30-year period from 1954 to 1984. No count is available at Ice Harbor Dam in 1961–1962. The Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) report that the escapement goal for upriver summer steelhead is 75,500 wild/natural fish passing Bonneville Dam, with an expectation that 30,000 wild/natural fish should pass Lower Granite Dam (ODFW/WDFW 1998). This escapement goal was exceeded by three-fold in 1962. Using the ratio of the Ice Harbor Dam count to the McNary Dam count in 1962 (106,322 IceHarbor/160,769 McNary = 0.66, ODFW/WDFW 1998), we calculate that escapement to the Snake River in 1961 was about 67,500, more than twice the escapement goal. Therefore, we conclude that the Snake River basin was fully seeded by steelhead in the years that yielded smolts at Ice Harbor Dam in 1964 and 1965.

For spring/summer chinook, the escapement issue is more problematic. The ODFW and WDFW escapement goal for spring chinook at Lower Granite Dam is 25,000 wild/natural fish (ODFW/WDFW 1998). Escapements of spring chinook in 1962 and 1963 exceeded that goal. There is no escapement goal for summer chinook in the Snake River. Escapement of summer chinook was 30,600 in 1962 and 20,900 in 1963. It seems reasonable to assume that the basin was fully seeded with spring/summer chinook adults in the brood years that produced the 1964 and 1965 outmigrations. Figures 2 and 3 from Hassemer (1993) (see our Figures 1 and 2) support that assumption.[6] Wild spring/summer chinook very likely seeded rearing areas fully in the first half of the 1960s.

The difference between the numbers of smolts that arrived at Ice Harbor Dam and the numbers derived from the upriver effective basin estimates is mortality during the migration. Raymond

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[5] Because Dworshak Dam had not been completed yet, the North Fork Clearwater River was still producing wild steelhead.

[6] We do not regard the 1957 escapement for “summer chinook” areas to be typical. The high escapement resulted from the largest summer chinook run to the Columbia River since 1938 and from the closure of The Dalles Dam (and the resultant flooding of Celilo Falls). In the Celilo Falls area, the tail end of the runs of Snake River spring/summer chinook and ocean-annulus summer/fall chinook of the middle Columbia River were fished especially hard. The 1957 escapement, the largest on record since 1938, very likely constituted an overescapement in terms of spawners required to fully seed rearing areas. The 1957 brood did not replace itself in 1961 and 1962, either in total upriver run or in escapement.

(1979) estimated the survival rates of juvenile chinook salmon migrating between scoop traps placed in the Salmon River near Riggins and Ice Harbor Dam in 1966, 1967, and 1968. The respective estimates equaled 0.85, 0.88, and 0.95, which average to 0.89. We use a survival estimate of 0.85 from subbasins to Ice Harbor Dam to account for the fact that many subbasins are farther from Ice Harbor Dam than is the trap location near Riggins. Thus, estimated smolt yield from effective drainages would equal 180/0.85, or 212 chinook salmon. It seems appropriate to use the same correction for steelhead, as other work by Raymond (1979) shows similar mortality rates for salmon and steelhead during the downstream migration. Thus, estimated steelhead yield from effective basins would be 70/0.85, or 83 smolts.

2.2. Checks on the Effective Basin Paradigm

Buckman (1990) applied a concept somewhat similar to the effective-basin paradigm for estimating the smolt yield of eastern Oregon streams. He estimated, using the upper John Day River as a model, that 1,000 mi^2 of basin in Oregon (Pine and Eagle creeks and the upper Malheur River) could produce 219,000 spring chinook smolts and 91,000 steelhead smolts. This equates to a production rate of 219 chinook and 91 steelhead per square mile of basin.[7] These figures comport fairly well with the empirical yields of smolts per unit of effective Snake River basin, based on Raymond (1979), of 212 chinook and 83 steelhead per square mile of effective basin.

Petrosky (1990a) estimated potential smolt output from Idaho tributaries upstream of the HCC, including the Wildhorse River and associated small tributaries and the Weiser, Payette, and Boise rivers. He applied SPM estimates of smolt yield per unit of surface area to his estimated surface areas for the foregoing streams. However, he did not specify how the estimated stream surface areas were calculated. He estimated yields for fully seeded habitat as follows:

River	Spring chinook	Steelhead
Payette	1,360,000	294,000
Boise	1,514,000	290,000
Weiser	274,000	104,000
Wildhorse (and adjacent tributaries to the Snake River)	26,000	70,000

We can compare yields calculated on the basis of estimated smolt production in the SPM (Petrosky 1990a) by estimating effective basin areas in pertinent Idaho subbasins that are upstream of the HCC and that are included in his estimates. We provide total basin and effective

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[7] Buckman (1990) noted that the areas that he included in the 1,000 mi2 habitat potential for salmon and steelhead constituted only parts of the basins of the Malheur River, Pine Creek, and Eagle Creek. Other habitat in those drainages could support anadromous fish, but they had no potential for collecting smolts as they moved downstream. When we consider potential yields from areas opened up by passage at all manmade obstacles, we assume that passage for adults and juveniles is assured in all areas (see Paradigm 1 in Table 15).

basin areas of the Payette River; the Middle, South, and North forks of the Boise River; and the Weiser and Wildhorse rivers in Table 3.

Using Buckman's (1990) estimators of 219 chinook per square mile of basin, we can estimate the total yield of Idaho tributaries above the HCC as about 1.5 million chinook smolts from the effective basin areas shown in Table 3. Employing the smolt yields of 212 chinook per square mile (from Raymond 1979) in the Snake River above Ice Harbor Dam in the early 1960s, one can estimate the total yield of Idaho tributaries upstream of Hells Canyon Dam (Wildhorse, Weiser, Payette, and Boise rivers) as 1.45 million chinook[8]. Petrosky (1990a) estimated a total output from the same subbasins as 3.174 million chinook, or about twice the yields based on Buckman (1990) and Raymond (1979).

We also applied the effective basin approach to the upper Columbia River for comparison with the results derived for the Snake River (Hillman et al. 2000). To estimate smolt output for the upper Columbia River, we relied substantially on Raymond (1988), Mullan et al. (1992), and Schaller et al. (1999).

Schaller et al. (1999) estimated maximum sustained population (MSP) escapements of adult wild spring chinook at 4,808, 496, and 1,379 in the Wenatchee, Entiat, and Methow rivers, respectively. Therefore, the total MSP in the upper Columbia River would equal 6,683 adults. Escapements exceeded this figure in 1960, 1961, 1964, 1966, and 1967–1969 (ODFW/WDFW 1998:237–238). Smolt progeny of those years (Table 4) averaged 668,714. The median progeny yield equaled 690,000 for the 7 years of data.

Mullan et al. (1992) estimated optimum production of steelhead from the upper Columbia River subbasins as 231,898 smolts. This number substantially exceeds the maximum numbers of wild steelhead smolts estimated by Raymond (1988) to pass Priest Rapids Dam in 1962–1970. Nonetheless, we used the estimate provided by Mullan et al. (1992).

We can roughly estimate effective basin areas in the middle Columbia River region as follows:

Drainage	**Effective Basin (mi^2)**
Wenatchee River	1,412
Entiat River > RM 16[9] + Mad River	295
Methow River tributaries	1,701
Total	**3,408**

Therefore, we estimate that the effective basins upstream of Rock Island Dam could produce, at full seeding, about 690,000 spring chinook (or 202 spring chinook smolts per square mile of

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[8] Raymond's smolt estimates exclude the area upstream of the HCC because stream-annulus smolt yields there had reached remnant status by 1964.

[9] See Mullan et al. (1992:16).

effective basin) at the first dam downstream of productive subbasins. We adjusted this number by accounting for a 10% loss between the subbasin and the first dam. Therefore, we arrived at an estimated output of 224 spring chinook per square mile of effective basin[10]. Mullan et al. (1992) prepared their estimate of optimum steelhead smolt output based on habitat quality in the subbasins of the upper Columbia River. Their estimate converts to a smolt output of 68 smolts per square mile of effective basin. A higher estimate for 1986–1990 smolt output equaled 265,000 smolts at Rock Island Dam (see bottom of Table 8 in Mullan et al. 1992:H-297). This figure converts to approximately 294,000 smolts leaving the mouths of tributary subbasins if we assume a 10% loss between the subbasins and Rock Island Dam. In turn, that estimate converts to 86 smolts per square mile of effective basin area.

Smolt outputs per unit of effective basin in the upper Columbia River and in the Snake River comport reasonably well (224 v. 212 chinook and 86 v. 83 steelhead). Therefore, we believe it is appropriate to use the effective basin concept as a means of estimating smolt output from some subbasins upstream of the HCC. However, later in this chapter we suggest that the concept may not apply to subbasins with low water yields, such as the Owyhee and Bruneau rivers and Salmon Falls Creek.

2.3. Checks on the SPM-Based Smolt Output

Using Petrosky's (1990a) smolt yields, together with estimated effective drainage sizes, we calculated example smolt yields per unit of area for SPM-based estimates. For example, the Boise River above Arrowrock Dam (effective basin of 2,210 mi^2, including North, Middle, and South forks) would, with the SPM estimators, yield 685 chinook and 131 steelhead per square mile. The Weiser River, if we assume an effective basin of 1,550 mi^2, would yield 177 chinook and 67 steelhead smolts per square mile. If we assume a probably more realistic effective basin of only 605 mi^2, the area would yield 453 chinook and 172 steelhead smolts per square mile. The Wildhorse River (with an effective area of 177 mi^2) would yield 147 chinook and 395 smolts per square mile. The yields per unit of area, particularly for chinook, tend to exceed those estimated for Oregon streams by Buckman (1990) and for the Snake River basin if we use the effective basin paradigm based on Raymond (1979). The apparently high estimates led us to attempt additional checks of SPM-estimated smolt yield.

A first empirical check on the SPM-based estimate of Petrosky (1990a) employs smolt yields from the Wildhorse River. This check is feasible for chinook only, as Petrosky (1990a) included Indian Creek and several small independent streams that drain into the Snake River in his "Wildhorse River and associated tributaries" grouping. However, in that grouping, only the Wildhorse River would produce chinook salmon. Petrosky (1990a) estimated on the basis of the SPM that the Wildhorse River should yield 26,000 chinook. But when Bell (1961) reported results of trapping in the Wildhorse River during 1958, 1959, and 1960 (Table 5), he estimated that 83% of the downstream-migrant chinook and 57% of the steelhead migrants from the

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[10] We adjusted for a 10% loss in the upper Columbia River area, rather than the 15% loss used in the Snake River, because the subbasin confluences with the Columbia River lie closer to the first dam when compared with the distance between the subbasin confluences in the Snake River and Ice Harbor Dam.

Wildhorse River were trapped, based on the percentage of the river strained by the trap in various time periods.

The highest reported yield of chinook smolts (3,365) occurred in calendar year 1958 (Bell 1961). However, the progeny of a given brood year of spring chinook leave the natal stream as presmolts in the fall and as spring smolts. Therefore, the "migration year" yield is a more important statistic than the calendar-year yield. Even if we use the calendar-year statistic, the output of the Wildhorse River equals only 12.9% of the estimate derived with the SPM by Petrosky (1990a) (Table 5).

The 1958–1959 migration-year yield of chinook smolts in Snake River tributaries was derived from the record high escapement above Zone 6 of 99,500 spring chinook of the 1957 brood (ODFW/WDFW 1998). That high escapement resulted from the flooding of Celilo Falls by The Dalles Dam in 1957. No escapement since then at McNary Dam has exceeded this level. The smolt output in the 1958–1959 smolt migration year is more likely to have resulted from full seeding than that of any other year of recorded McNary Dam escapements. Yet smolt output, including presmolts in fall, was only 8.5% (2,208 smolts) of the SPM-predicted yield for the Wildhorse River at full seeding (Table 5).

We assume that Bell's (1961) expansion of smolt trapping information to total smolt yield is reasonable. Escapements at McNary Dam lead us to assume that the 1957 and 1958 brood years of spring chinook returned in sufficient numbers to fully seed the Wildhorse River. However, we have no way to verify either assumption. At smolt-to-adult returns (SARs) of 4%, the smolt outputs assessed by Bell (1961) for the Wildhorse River convert to an estimated 88 spring chinook and 516 steelhead returning to the Columbia River. A footnote in Chapter 6 (Chapman and Chandler 2001b) describes how we adjusted Brownlee trap numbers for spring chinook by using Bell's data. In that adjustment, we calculated backward from smolt yield to the numbers of 1957-brood year adults that produced the outmigration. This calculation resulted in an estimate of 28 chinook salmon in the escapement of the 1957 brood. The estimate of 88 spring chinook returning to the mouth of the Columbia River comports fairly well with the escapement estimate of 28 fish, given that we estimated an inriver fishing rate in Zones 1 through 5 of 0.47 and total interdam losses of about 0.14.

Taken at face value, the foregoing empirical check on the SPM-based estimate of smolt output of the Wildhorse River indicated to us that the SPM overestimates smolt output. The tendency to overestimate smolt potential might also be the case for the other tributaries upstream of the HCC. The empirical data in Bell (1961) also serve as a check on the smolt output calculated with the effective basin concept, which would predict an output of about 37,524 chinook (212 smolts/mi^2 × 177 mi^2) and 14,514 steelhead (83 smolts/mi^2 × 177 mi^2). The actual output of chinook and steelhead smolts equaled 5.9% and 87%, respectively, of the chinook and steelhead estimates derived from the effective basin concept. The steepness of the Wildhorse River, better suited to steelhead than chinook, possibly contributed to the discrepancy between empirical data and model estimates.

We also checked SPM output estimates against empirical data for the Tucannon River. The SPM estimated the potential yield of spring chinook and steelhead from the Tucannon River as 275,300 and 49,032 smolts, respectively. Kelley and Associates (1982) censused chinook and steelhead abundance in the Tucannon River. They stated: “In the upper and cooler reaches, the salmon and steelhead populations were as dense as one might expect in fully seeded high quality salmon and steelhead streams. Growth was rapid and the fish appeared in good condition.” They estimated total populations of juvenile chinook salmon and yearling steelhead as 170,000 and 111,000, respectively. These numbers do not represent smolt output, as they were obtained in the summer preceding the spring of seaward migration for chinook and most steelhead.

One can estimate smolt yield for the Tucannon River by multiplying chinook fingerling numbers by a conservatively high survival factor of 0.4. We base this multiplier on 1) detection rates at Lower Granite Dam for chinook PIT-tagged the previous summer in Oregon tributaries to the Snake River (Achord and Sandford 1996) and 2) spill and fish guidance efficiencies at Lower Granite Dam (see Chapman et al. 1991, Petrosky and Schaller 1996).[11] Steelhead smolt conversion from yearling stage is more problematic, but a conservatively high 0.5 multiplier can be used. These factors result in an estimated smolt output of 68,000 chinook (25% of the SPM estimate [170,000 × 0.4]/275,300) and 55,500 steelhead (13% over the SPM estimate [111,000 × 0.5]/49,032). While the steelhead smolt output comports well with the SPM smolt yield, the chinook estimate does not. Even the young-of-the-year numbers for chinook are 38% less than the SPM smolt output.

2.4. Checks on Estimates of Petrosky (1990a) and Buckman (1990) with Adult Returns

As a possible evaluation of numerical estimates in Petrosky (1990a) and Buckman (1990), one can examine total smolt yield obtained from only those streams that were available to, and used by, anadromous fish in the late 1950s, and that lie upstream of the Oxbow trap.[12] That total then can be used to estimate adult returns possible with survival rates appropriate for that time. Effective drainages available for chinook salmon upstream of the Brownlee trap at the time included only Eagle Creek, the Wildhorse River, and the Weiser River. Petrosky (1990a) estimated potential smolt output as 274,000 spring chinook from the Weiser River and 26,000 from the Wildhorse River.

Buckman (1990) did not separate the potential output of Eagle Creek from the total area that included high-elevation portions of the Malheur River system (unused by salmon and steelhead in the mid-1950s). However, one can do so by teasing out drainage areas. Buckman (1990) estimated about 1,000 mi^2 of drainage in combined areas of Eagle Creek, Pine Creek, North Fork Malheur River, and Middle Fork Malheur River. Eagle Creek has a drainage area of about 183 mi^2. If 1,000 mi^2 would produce the 219,000 spring chinook estimated as smolt yield of the combined Eagle Creek, Pine Creek, North Fork Malheur River, and Middle Fork Malheur River drainages, then the yield of the Eagle Creek drainage, based on Buckman’s (1990) application of

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[11] The Tucannon River lies well downstream of Lower Granite Dam, but we wanted to obtain a survival estimate to the first dam in this case.

[12] The Oxbow trap captured the spring chinook runs of 1959–1960. The Brownlee trap was replaced by the Oxbow trap in June 1958.

smolt yield estimates extrapolated from the John Day River basin, would be 40,077 spring chinook.

Totaling the estimated potential spring chinook smolt output of the Weiser River (274,000), Eagle Creek (37,000), and Wildhorse River (26,000) based on Buckman (1990) and Petrosky (1990a) yields a sum of 337,000 spring chinook. That estimate may be evaluated with approximate mid-1950s survival rates. Raymond (1979) estimated smolt survival rates to adult return in the early 1960s from Ice Harbor Dam as 4 to 6%, including returns harvested in Zones 1 through 6 in the Columbia River. Those survival rates should provide a reasonable surrogate for mid-1950s rates.

The estimate most appropriate for returns to the HCC in the mid-1950s for smolts produced in the Weiser River, and in Eagle Creek and Wildhorse River (the drainages that produced spring chinook upstream of the Oxbow trap), may be the SAR of about 4% for chinook.[13] This estimate would include fish harvested in the Columbia River. Returns of spring chinook from 1958–1960, before most effects of the Brownlee Project became apparent, and after flooding of Celilo Falls, averaged only 1,557 spring chinook. As noted in Chapter 6 (Chapman and Chandler 2001b), this escapement represents an estimated 4,098 adults at the mouth of the Columbia River. This estimate constitutes a SAR to the mouth of the Columbia River of 1.2% of the Petrosky/Buckman output of 337,000 smolts. At a more realistic (then) 4%, adult numbers at the mouth of the Columbia River, estimated on the basis of Petrosky/Buckman, should have been about 13,480. The Petrosky/Buckman estimate appears nearly three times too high. The apparent overestimate may result from excessively high output estimates. It could also result from underescapements of spring chinook in the Wildhorse and Weiser rivers and in Eagle Creek in 1954–1956.

As an alternative, one can estimate the total spring chinook run from the mean spring chinook escapement of 1,557 at Oxbow trap by using our Chapter 6 (Chapman and Chandler 2001b) estimate of recruitment. We estimated recruitment of 4,098 fish to the Columbia River.

There are at least three explanations for the discrepancy between the estimates based on Petrosky (1990a) and Buckman (1990) and the numbers derived from other estimators. First, the total smolt output projected in Petrosky (1990a) and Buckman (1990) was too high. Second, the drainages were not producing smolts at maximum yield for the available habitat quality (insufficient seeding in the 1954–1956 adult brood years that produced the 1958–1960 progeny returns). Third, the actual SAR was much lower than that calculated in Raymond (1979). We consider the first two explanations to be more likely than the third.

One cannot eliminate the possibility that the drainages were underseeded in brood years 1954−1956. No redd counts are available in the Weiser and Wildhorse rivers in those years. Counts in the Weiser River began in 1957 (Welsh et al. 1965). Redd counts in Eagle and Little

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[13] Raymond (1979) accounted for fishery harvest in his SARs. Adult returns were allocated by brood year, sometimes on the basis of incomplete information. While Raymond's SARs are the only early 1960s estimates available, they should be viewed as approximations and in the context of the techniques available at the time.

Eagle creeks in 1954, 1955, and 1956 equaled 1, 16, and 24, respectively.[14] By comparison, the redd count in the same areas in Eagle Creek in 1957 equaled 411 (Haas 1965). Redd counts in the Little Weiser, West Fork Weiser, and Weiser rivers equaled 50, 85, and 246, respectively, in 1957 (Welsh et al. 1965). Escapements in 1957 probably constituted more than full seeding. Thus, 792 redds represent about 1,900 adult chinook at 2.4 fish per redd (Mullan et al. 1992), and about 3,100 adults if one assumes 2 fish per redd and a 50% prespawning loss (Chapman et al. 1991). Thus, apart from the Wildhorse River, the 1957 brood in the Weiser River and Eagle Creek might have yielded about 127,000 smolts (calculated as 792 redds × 4,000 eggs × 0.04 survival rate from egg to smolt). We can add 2,208 smolts for the output of the Wildhorse River, as calculated earlier for the 1957 brood. The calculated total smolt output for the three drainages is about 38% of the smolt yield predicted by Petrosky and Buckman.

The foregoing check on estimates of Petrosky (1990a) and Buckman (1990) is inconclusive. It does not rule out the possibility that their estimates of potential yield may have been too optimistic in the aggregate. However, examining the foregoing material and recalling that the empirical data for the Wildhorse and Tucannon rivers suggest much lower production of smolts than the SPM-based estimates offered by Petrosky (1990a), we believe the estimates based on the SPM are likely too high, particularly for chinook salmon smolts.

2.5. Yields Estimated with Effective Basin Areas

We believe that smolt yields estimated from effective basin sizes offer a useful tool for predicting smolt outputs from several subbasins upstream of the HCC. The estimate based on smolt abundance at Ice Harbor Dam (Raymond 1979) integrates conditions extant in the early 1960s, including effects of roading, mining, logging, grazing, and irrigating. Our Chapters 3 (Chapman 2001) and 4 (Chandler and Chapman 2001) and knowledge of conditions in the effective basins available in the early 1960s downstream of the HCC, lead us to conclude that habitats in most Snake River subbasins downstream of the HCC were in better condition, on average, than those in the subbasins upstream of the HCC. For example, although irrigation diversions depleted flows in segments of the upper Grande Ronde and Imnaha rivers, and some tributaries to the upper Salmon rivers, most other subbasins downstream of the HCC were free from the intensive irrigated agriculture and livestock production extant in most subbasins upstream of the HCC. The upstream area also has lower rainfall, particularly in the southern subbasins, than do the central Idaho, Blue, and Wallowa mountains. An indication of the difference can be seen in USGS streamflow data (Table 6)

Fish habitat availability and fish densities, as dependent variates, respond to climatic and hydrographic factors. Platts and McHenry (1988) provided pertinent analyses, reporting mean density of trout by ecoregion in the western United States. The Intermountain Ecoregion (Great Basin south of the line of the Boise Front, with low precipitation) supported a mean of 4 trout per 100 square meters (m^2) (39 sites), while the Columbia Ecoregion to the north (generally

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[14] Not all redd counts in all areas occurred on the same date.

northward from the line of the Boise Front, and with higher precipitation)[15] supported a mean density of 22 trout per 100 m^2 (43 sites).

We believe that it is reasonable to apply smolt yields calculated from effective basin size, whether based on Buckman (1990) or our adaptation of Raymond (1979), to the following drainages: Pine and Eagle creeks and the Powder, Burnt, Weiser, Payette, and Boise rivers. For the Owyhee and Bruneau rivers and Salmon Falls Creek, we believe other estimators better apply (e.g., smolt yields/km, or yields/km by stream order). Because Buckman (1990) used the concept for the North and Middle forks of the Malheur River, we apply it there, also, for comparative purposes. However, the Malheur River has low water yield per unit of area, making it resemble the more-southerly subbasins (Owyhee, Bruneau, and Salmon Falls). Because of the configuration of the Wildhorse River subbasin, we question whether the effective-basin model should apply there, although we later use it as a conservatively high estimator.

3. PRODUCTION ESTIMATES BASED ON STREAM MILES OF HABITAT

3.1. Adults Produced per Lineal Unit of Habitat

The Pacific Fishery Management Council (Table 1 in PFMC 1979:3) estimated that, in the 1970s, 4,182 mi of habitat remained for chinook salmon in the Snake River drainage. That total excluded the North Fork Clearwater River upstream of Dworshak Dam and the Snake River and its tributaries upstream of Hells Canyon Dam. PFMC (1979) also estimated that that amount of natural Snake River habitat produced 113,000 fall and spring/summer chinook (including escapement and adults harvested in ocean and river fisheries). This estimate converts to 27 chinook salmon adults per habitat mile. Production “formerly” amounted to an estimated 181 chinook salmon per mile in 7,739 mi of habitat (PFMC 1979).

The PMFC (1979) estimates of 1970s salmon habitat and production are of interest primarily because they represented the opinion of experts from several agencies about the productivity of the available habitat and corresponding survival rates. At that time, there were eight dams on the Snake and Columbia rivers downstream of the HCC, and habitat conditions likely did not differ markedly from those currently extant.

The PFMC (1979) estimates of miles of habitat can be compared to drainage areas downstream of the HCC (Table 7). Using the mean miles of habitat per square mile of effective area obtained from the drainages of the North Fork Clearwater, Grande Ronde, Salmon, and Imnaha rivers (0.27), we can convert the PFMC (1979) information as follows: 6,833 mi^2 of effective basin in

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[15] The Malheur River subbasin has elements of both ecoregions. Higher elevations of the Middle and North forks have characteristics more like the Columbia Ecoregion, while lower elevations of the basin and the South Fork Malheur River fall within the Intermountain Ecoregion.

Idaho tributaries upstream of the HCC (Boise, Weiser, Payette, and Wildhorse rivers; Table 3) that were included by Petrosky (1990a) as potential producers of salmon should contain about 1,845 mi of spring chinook habitat. The Oregon tributaries mentioned as potential fish producers by Buckman (1990) amount to 1,000 mi^2, which we can estimate to contain 270 mi of chinook habitat. The 2,397 total mi of spring chinook habitat upstream of Hells Canyon Dam and in subbasins included in Petrosky (1990a) and Buckman (1990)[16] could be estimated, on the basis of PFMC (1979), to produce about 27 chinook per mile. That production rate totals 64,719 adults (before exploitation), if conditions in that area were equal to those incorporated in the PFMC (1979) estimates developed in the 1970s.

PFMC (Table 1 in PFMC 1979:3) estimated that the escapement to fill the 4,182 mi of habitat for natural spawning in the Snake River would require 124,000 fish.[17] That number included escapement needed in the Clearwater River to fill the habitat then remaining there (excluding the North Fork Clearwater River, which was extirpated by Dworshak Dam). By the 1970s, the fall chinook run to the Snake River was negligible because of the loss of the area upstream of the HCC. Rounding down to an escapement of 120,000 seems reasonable, accounting for an escapement of 4,000 fall chinook. The escapement goal for spring chinook at Lower Granite Dam is 25,000 wild/natural fish (ODFW/WDFW 1998). No escapement goal has been set for summer chinook (stream-annulus) in the Snake River. Spawning-ground index counts for "spring" and "summer" chinook trend areas in the late 1950s and early 1960s (Figures 1 and 2) lead us to suggest that the escapement of "summer" chinook may reasonably and conservatively[18] equal the goal for wild/natural spring chinook. Thus, we assume that the total escapement needed for wild/natural spring/summer chinook spawners equals about 50,000 fish.

One might conclude that 1) the PFMC (1979) goal was too high, 2) 50,000 escapees at Lower Granite Dam is insufficient, or 3) the estimate of 124,000 escapees above fisheries needs to be adjusted to account for interdam losses and tributary turnoff to make the goal comparable to the goal at Lower Granite Dam. To adjust for interdam losses between the McNary Dam tailrace and Lower Granite passage, consistent with the date of the PFMC work, we can multiply by a factor of 0.77. Assuming no adjustment for sport or Native American fishing upstream of Lower Granite Dam, one would adjust the PFMC (1979) escapement to 120,000 × 0.77, or 92,400.

Escapements past fisheries or at Lower Granite Dam do not equal spawning abundance. Chapman et al. (1991) estimated that prespawning losses in spring chinook in the Snake River amounted to over 50%. Thus, the escapement requirement of PFMC (1979), adjusted to Lower Granite Dam, of 92,400, and the escapement of 50,000 that we offered earlier (based on

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[16] This figure excludes the Bruneau River, as well as Salmon Falls, Rock, Cedar Draw, and Billingsley creeks, all of which PFMC (Table 5 in PFMC 1979:20) did not include as lost salmon habitat. This figure also excludes the Owyhee River, which PFMC (1979) did include.

[17] PFMC (1979) defined escapement as the number of fish allowed to escape for natural spawning in recent years and the number needed to fully use the present habitat. Escapement should thus be assumed to be escapement past fisheries.

[18] "Conservatively" here means a probable overestimate of full seeding requirements.

the spring chinook escapement goal of 25,000 and an estimated summer chinook goal of 25,000), would be reduced by prespawning losses to 46,200 and 25,000, respectively. Assuming that half of the escapement would consist of females, we can calculate egg depositions of 23,100 females × 4,000 eggs per female = 92.4 million eggs, and 12,500 females × 4,000 eggs per female = 50.0 million eggs for the respective escapements. Using the previously mentioned 4% egg-to-smolt survival rate, these depositions convert to smolt outputs of 3.7 million and 2.0 million by stream-annulus fish.[19] Adjusting for a 15% loss in smolts between subbasins and the site of Ice Harbor Dam, so that we can compare the smolt numbers with those in Raymond (1979), we reduce these outputs to 3.1 million and 1.7 million smolts, respectively.

PFMC (1979) did not include miles of habitat lost in the Bruneau River and Salmon Falls Creek, or in small streams tributary to the Snake River. The latter omission is understandable because PFMC (1979) did not evaluate steelhead habitat losses. However, spring chinook did once use the Bruneau River, Salmon Falls Creek, and Rock Creek.

We lacked information on the methods used by PFMC (1979) to estimate miles of lost habitat in each subbasin. In Chapter 4 of this report (Tables 5 and 6 in Chandler and Chapman 2001), we use data from a Geographic Information System (GIS) to estimate stream kilometers of useable habitat (within the Effective Useable Basin) by summing kilometers of streams of greater than second order and with less than 10% gradient and summing kilometers of streams greater than third order with less than 10% gradient. The following table compares basins reported in PFMC and our estimates:

River	PFMC (1979) estimates of lost habitat (km)	Our estimate of useable habitat (km) for >3rd order and < 10% gradient	Our estimate of useable habitat (km) for >2nd order and < 10% gradient
Burnt	224	37.4	107.5
Powder	320	545.6	1,184.4
Weiser	409.6	657	1,182.3
Payette	752	769.5	1,322.9
Boise	832	1,147.9	1,806.1

In all comparisons, except that in the Burnt River, our estimates of useable habitat exceed the estimates offered by the PFMC (1979), with km of stream greater than third order and less than 10% gradient being the closest approximation.

3.2. Smolts Yield per Lineal Unit of Habitat

The subbasin outputs of 3.7 million and 2.0 million chinook salmon smolts given in Section 3.1 lead to an estimated smolt output in 4,007 habitat miles (after the subtraction of 175 mi of mainstem Snake River fall chinook habitat) of 923 and 499 smolts per mile (574 and

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[19] Failure to adjust for the escapement to the Tucannon River causes a negligible error in these estimates.

310 smolts/km, respectively). These figures would be considered maximum output of fully seeded habitat in the Snake River, exclusive of the area upstream of the HCC and Dworshak Dam.

Using the range of estimates (574 and 310 smolts/km) that we calculated from PFMC (1979) would carry an underlying assumption that the quality of habitat in the Snake River basin upstream of the HCC equals that in the basin downstream of the HCC. We believe that much habitat in the Clearwater, Imnaha, Wenaha, and Minam rivers, and in many parts of the Salmon River, probably should be classed as “good.”[20] “Poor to fair” probably applies to habitat quality in the Tucannon River and much of the main Grande Ronde River and tributaries (exclusive of the Minam and Wenaha rivers and Lookingglass Creek). As we noted in Chapters 3 (Chapman 2001) and 4 (Chandler and Chapman 2001), we believe that the overall quality of habitat upstream of the HCC should be considered as “poor.” Some portions of the Boise, Bruneau, Middle Fork Weiser[21], and upper Malheur rivers may deserve to be classed as “fair” or even “good.” However, irrigation water withdrawals, mining, channelization, and grazing degraded proportionally much more of the habitat upstream of the HCC than they did in the Snake River basin downstream of the HCC.

PFMC (1979) estimated that extirpated salmon habitat in systems upstream of Hells Canyon totaled about 2,276 mi. Of this total, 1,791 mi (2,882 km) lie in the Powder, Burnt, Weiser, Payette, Boise, and Malheur rivers.[22] Using the estimated smolt outputs in the previous paragraph, one would calculate that this extirpated habitat might produce 893,000 to 1.65 million smolts. This estimate assumes that habitat in the area upstream of the HCC could produce stream-annulus smolts as effectively as the habitat downstream of the HCC. That assumption probably leads to an overestimate of smolt yield.

Hurley (1995a,b) estimated redband densities[23] in tributaries to the Weiser River (Table 8). For five portions of the Middle Fork Weiser River that averaged 8.62 m in width, mean redband

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[20] Effective basin areas applied to the data of Raymond (1979) did not include streams that no longer produced salmon, such as Yankee Fork and Panther Creek.

[21] Data in Hurley (1995a,b) provide a check. In five reaches with mean width 8.62 m, redband density equaled 7.36 “parr” per 100 m^2 (Table 8). This converts to 634 parr per km. Conservatively assuming a smolt:parr conversion rate of 0.40, and using redband parr as surrogates for steelhead parr, we estimate a potential steelhead smolt output of 254 per km. “Good” habitat 10 m wide should yield 600 smolts per km. Either the Middle Fork Weiser River was not fully seeded by redband in the broods that made up densities in Hurley’s work, or the habitat there should not be considered “good.” It is possible that Hurley assessed populations reduced by drought that extended from 1986 to 1994.

[22] We have not included the Owyhee River in this total because we wanted to compare outputs of smolts from PFMC (1979) stream miles with outputs based on effective drainage area. The Owyhee River has a very low runoff per unit area, and the effective basin concept may not apply there.

[23] Hurley (1995a,b) did not regard his snorkel-based densities as population estimates. However, our reading of his methods indicates that he emphasized pool habitats, probably because snorkeling in very shallow riffles and glides is less practical than snorkeling in pools. We would expect higher densities per unit area in pools than in glides and riffles; hence, his estimates likely were higher than would be the case if all habitats were sampled with equal emphasis.

density equaled 634 parr per kilometer. At a smolt:parr conversion rate of 0.4, and with the assumption that redband densities could be completely converted to steelhead densities, one can estimate the steelhead smolt yield of the Middle Fork Weiser River as 254 smolts per kilometer.[24] Further assuming that Raymond's (1979) ratio of chinook to steelhead at Ice Harbor Dam provides a reasonable estimate of subbasin relative yields, one can estimate that chinook smolt output would equal 653 smolts per kilometer.

Based on drainage area rather than river miles, 11,166 mi^2 of effective (Table 4 in Chapter 4 [Chandler and Chapman 2001]) basin that includes the Powder, Burnt, Weiser, Payette, Boise, and Malheur rivers can be estimated to produce 2.37 million chinook smolts at 212 smolts per square mile. This estimate exceeds the estimate range (0.89 to 1.65 million) developed from PFMC (1979) stream kilometers. At a minimum, these exercises do not indicate that the effective basin concept underestimates smolt output.

4. SMOLTS PER STREAM SURFACE AREA

Rich et al. (1992) estimated the probable carrying capacity of habitat in the upper Salmon and the Middle Fork Salmon rivers at 108 chinook parr per 100 m^2. Scully and Petrosky (1991) estimated the same carrying capacity at 85 chinook parr per 100 m^2. If we apply to these estimates a conservatively high 0.4 conversion efficiency from parr to smolt, we arrive at estimated smolt carrying capacities of 43 and 34 chinook smolts per 100 m^2, respectively.

The estimates for the upper Salmon and Middle Fork Salmon rivers were based on stream habitats where the percentage of surface sand did not exceed 35%. Therefore, the data excluded Bear Valley Creek sections with high surficial sand. We believe that these estimates can be applied to habitat considered to be "good" or "excellent," but not to most habitats upstream of the HCC.

Marshall et al. (1980) examined the available literature on the yield of chinook smolts. The data came from four streams, two of which (Big Springs Creek, in the Lemhi River basin, and Deadman River, British Columbia) produced stream-annulus chinook. The average smolt yield equaled 45 smolts per 100 m^2 in the Lemhi River (11 years of data from Bjornn 1978) and 41 smolts per 100 m^2 in the Deadman River (output estimated by Marshall et al. 1980). These averages amount to 5,000 and 3,100 smolts per kilometer, respectively. Stream widths in Big Springs Creek and Deadman River averaged about 11 m and 7.6 m, respectively (Marshall et al. 1980). Marshall et al. (1980) noted that smolt yield might be proportional to total dissolved solids (TDS).

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[24] If we use the same surrogate approach, including 35 stream sites examined by Hurley (1995a,b), 30 of them with lesser stream widths, we find that median redband trout density equaled only 106 parr per kilometer, which would convert to only 42 steelhead smolts per kilometer. We suspect that drought may have influenced the density of redband in smaller streams more than in the Middle Fork Weiser River.

The smolt yields in the foregoing paragraph are considerably lower than those in the SPM. Big Springs Creek (a tributary to the Lemhi River) could be considered as “good,” or even “excellent” habitat. Smolt yields in the SPM equal 90, 64, 37, and 10 smolts per 100 m^2 for “excellent,” “good,” “fair,” and “poor” habitat, respectively, with “excellent” and “good” outputs 100% and 42% higher than empirical outputs in the Lemhi River.

Steelhead smolt yield is proportional to stream area, length, and TDS (Marshall et al. 1980). In three interior streams—the Lemhi River (TDS = 300 milligrams/liter [mg/l]), Criss Creek (British Columbia, TDS = 160 mg/l), and Deadman River (TDS = 200 mg/l)—smolt yield equaled 15.1, 11.6, and 6.2 smolts per 100 m^2, respectively. The Lemhi River, the only stream for which smolts per kilometer were estimated, yielded 1,680 smolts per kilometer. The areal yields in Marshall et al. (1980) tend to be higher than those in the SPM (10, 7, 5, and 3 smolts/100 m^2 in “excellent,” “good,” “fair,” and “poor” habitat, respectively).

Mullan et al. (1992) estimated the steelhead smolt output of the middle Columbia River region (Wenatchee, Entiat, and Methow rivers). Mullan et al. (Table 8 in Mullan et al. 1992:H-297) offered an estimate based on a Habitat Quality Index (HQI). They estimated an optimum steelhead smolt yield of 231,898 from all three subbasins combined. Other estimates of potential output of steelhead in the middle Columbia River region noted in the table range from 232,000 to 299,503. The SPM estimate for the same tributaries was 396,162, or 32% higher than the highest alternative estimate, and 70% greater than the HQI-based estimate.

We also examined chinook salmon parr densities in Mullan et al. (1992). The data were obtained in measured surface areas by snorkeling, electrofishing, or using cyanide. We were interested in years and basins that must have been fully seeded by the adult brood. In the Wenatchee River in 1987, parr resulted from an escapement of 21,000 adults at Rock Island in 1986. Mullan et al. (1992) calculated 7,629 wild fish to the Wenatchee River (accounting for both fishing and escapement to Leavenworth), more than full escapement.[25] Excluding data for the main Wenatchee River below Icicle Creek, which would likely involve summer/fall fish (subyearling migrants), we found that the average parr density was 18.9 fish per 100 m^2 ($n = 15$, range = 0−81, median = 10.9). If we include the data for the entire river, we get 16.7 parr per 100 m^2 ($n = 19$).

In 1995, 4,066 wild spring chinook escaped to the Methow River (Mullan et al. 1992). This also must have been full seeding. The Methow River upstream of Twisp, including tributaries, had a mean parr density in 1986 of 6.24 parr per 100 m^2 ($n = 17$, range = 0–28.3, median = 3.3) (see Table 6 in Mullan et al. 1992:35).

In Icicle Creek, a Wenatchee River tributary, seeding should have been more than adequate in 1986 and 1987. The combined mean density in the following years (1987 and 1988) was 24.4 parr per m^2 ($n = 7$). Some hatchery fry might have been involved.

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[25] Referenced in section 2.2, Schaller et al. (1999) estimated maximum sustained population escapements at 4,808, 496, and 1,379 wild spring chinook in the Wenatchee, Entiat, and Methow rivers, respectively.

It appears that fully seeded spring chinook production areas in the upper Columbia River can support a high-end average parr density of about 20 to 25 parr per 100 m^2. Assuming a 40% overwintering survival rate, we estimate a maximum output of about 8 to 10 smolts per 100 m^2.

Are empirical data obtained in upper Columbia River subbasins pertinent to predictions of smolt output from the area upstream of the HCC? They are indeed useful. They provide one more check on SPM estimates of smolt output. Mullan et al. (1992) offer chinook *parr* densities in "excellent," "good," "average," "fair," and "poor" habitat as 20, 12, 10, 4, and 2.5 fish per 100 m^2, respectively. The SPM predicts chinook *smolt* outputs of 90, 64, 37, and 10 smolts per 100 m^2 for "excellent," "good," "fair," and "poor" habitat, respectively. If we adjust the Mullan et al. (1992) parr densities by a multiplier of 0.4 to account for overwinter losses, the disparity between empirical data and the SPM estimates increases.

The SPM estimates of chinook smolt output again appear to be too high. Rich et al. (1992) came to a similar conclusion for tributaries to the Salmon River. They stated:

The NPPC file rates each EPA reach as being poor, fair, good, or excellent habitat for rearing chinook and steelhead smolts. Respective NPPC smolt densities in number/100 m^2 are 10, 37, 64, and 90 for chinook and 3, 5, 7, and 10 for steelhead. The NPPC smolt density ratings provide a consistent, though subjective, assessment of habitat quality and smolt carrying capacity within Idaho subbasins. Based on parr densities from this project[26] and 50% parr-to-smolt survival, or less (Kiefer and Forster 1991), we believe that NPPC smolt densities are good approximations for steelhead, but overestimate capacity for chinook in Idaho streams. NPPC steelhead smolt capacity in excellent habitat (10/100 m^2) and 50% parr-to-smolt survival imply a parr density of 20/100 m^2, the same as defined by Petrosky and Holubetz (1988) based on empirical data. NPPC chinook smolt carrying capacity in excellent habitat (90/100 m^2) and 50% parr-to-smolt survival imply a parr density of 180/100 m^2, which is 67% higher than defined by Petrosky and Holubetz (1988) based on empirical data and fry stocking experiments. We adjusted the NPPC smolt density ratings to parr carrying capacity assuming that excellent steelhead habitat would support 20 parr/100 m^2 and excellent chinook habitat would support 108 parr/100 m^2. We also assumed the same relative density proportions between the NPPC habitat classes of poor, fair, good, and excellent. Thus, respective parr carrying capacity ratings for the four habitat classes were: 6, 10, 14, and 20/100 m^2 for steelhead; and 12, 44, 77, and 108/100 m^2 for chinook.

Although this quote appears to be reasonable, the SPM probably overestimates steelhead smolt output in all habitats. Smolt yields are derived from parr densities. The assumed conversion rate of 50% from parr to smolt is probably too high. Thurow (1987) found that parr of ages 2 and 3 dominated in his samples in the South Fork Salmon River. Thus, a conversion factor of 0.5 from parr to smolt would overestimate smolt yield because many age-1 parr must pass through two winters rather than one. Parr of age 1 may spend one or two winters in natal streams before smolting. Parr of age 2 may spend one or two winters. Age-3 parr that migrate as age-4 smolts, although in the minority, spend one winter before smolting. The net effect of these time lags to smolting is to decrease the parr-smolt conversion from the assumed 0.5 to some lower figure.

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[26] "This project" refers to data and analyses in Rich et al. (1992).

WDFW (1999) estimated a conversion efficiency of about 0.17 in the Wenatchee River, where more than half of parr smolt at age 3 or older.

4.1. Possible Reasons for Overestimates in the SPM

The NPPC presence/absence database assumes that mainstem rivers produce spring/summer chinook and steelhead at what appear to be rather high rates per unit of area. For example, the database shows a production rate of about 39 chinook smolts per 100 m^2 in the main Imnaha River between the mouth of the river and Cow Creek (4.3 mi, 65 ft wide). The Middle Fork Salmon River between Soldier Creek and Brush Creek (5.6 mi, 120 ft wide) is estimated to yield 18 smolts per 100 m^2. The main Snake River between the mouth of the Salmon River and Deep Creek is assumed to yield 6.8 smolts per 100 m^2. This relatively warm reach has strong populations of smallmouth bass, channel catfish, and abundant cyprinids.

In addition to the systemic overestimates of chinook smolt yield (Rich et al. 1992), errors may easily arise because the quality of habitat in each stream reach is overestimated. For example, erroneous classification of “good” instead of a more realistic “fair” causes an overestimate in the NPPC SPM of 73%. An overly optimistic “fair” instead of “poor” causes a 3.7-fold overestimate.

4.2. Estimates of Habitat Area in Streams Upstream of the HCC

A report by the Idaho Department of Fish and Game estimated anadromous fish habitat in various subbasins (Table 7 in IDFG 1985:31). For the Salmon River, total habitat amounted to 56 million m^2 in 4,805 stream kilometers, which translates to an estimated stream width of 11.7 m. The tabulated information assumes that too much of the main Salmon River is useable habitat. However, for the Middle Fork, South Fork, and Salmon River upstream of Yankee Fork, total habitat estimates may prove useful in our efforts to provide checks on other width-based estimates. Total habitat in those three areas was estimated at 21.2 million m^2 in 2,238 stream kilometer, or 9.47 m^2 per stream meter.

Moore (1986) offered estimates of coldwater habitat available in various drainages of interest to our study. Table 9 summarizes key assessments that we extracted from them.

The Boise River, from Table 9, would provide 7,662,214 m^2 of coldwater habitat. The Weiser River, excluding the mainstem area from Galloway Dam to Cambridge[27], would provide 2,286,622 m^2. The Payette River, excluding the reach from Black Canyon Dam to Banks, would provide 7,328,706 m^2. In Table 10, we tabulated smolt outputs from these drainages, using NPPC smolt yields from “fair” and “poor” habitat qualities, as adjusted by Rich et al. (1992).

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[27] Moore (1986) notes that this area supports rainbow trout and smallmouth bass. We consider this reach to be unsuitable for rearing by steelhead parr, even though it supports some resident rainbow trout.

We attempted to determine whether the information in Table 10 overstates habitat available to anadromous fish. Moore's (1986) habitat estimates were intended to quantify coldwater habitat, not anadromous fish habitat. Thus, it might be assumed that his estimates of total coldwater habitat include reaches that would support resident redband trout but not steelhead or chinook salmon (e.g., the North Fork Payette River and tributaries upstream of Big Payette Lake, second-order tributaries, and areas upstream of natural migration barriers).

To evaluate Moore's (1986) potential over-inclusion, we examined his estimates with respect to stream miles of coldwater habitat per unit of drainage area. We were interested in this check as a comparison with our earlier estimate of about 0.27 lineal mile of salmon habitat per square mile of effective drainage. We estimated that the effective drainages of the Boise, Payette, and Weiser rivers equaled 2,210, 2,245, and 605 mi^2, respectively. The latter figure for the Weiser River includes only the area upstream of Cambridge. Inclusion of all effective basin areas defined by the MWAT would increase the Weiser River area to 1,550 mi^2. Moore's (1986) estimates of stream miles in each basin equaled 496, 502, and 265 mi, respectively (excludes the mainstem river from Galloway to Cambridge). Therefore, the ratios of habitat miles to effective drainage areas equaled 0.22, 0.22, and 0.17. The mean of these ratios equals 0.20, lower than the mean ratio of 0.27 that we estimated from mileages in PFMC (1979) in relation to effective drainage areas. We suggest from this comparison that Moore's calculations of coldwater habitat do not seriously overestimate habitat that anadromous fish might use.

In Table 10 we compared the estimates based on Moore (1986) with those of Petrosky (1990a), who estimated that the Boise, Payette, and Weiser rivers would produce 1,509,430, 1,360,000, and 274,000 chinook salmon smolts, respectively. We believe that the habitat in those basins should be considered "poor" for the most part, although we show paradigms for smolt output for "fair" habitat as well in predictions in Chapter 8 (Chapman and Chandler 2001a). In considering whether we are too conservative in using the "poor" habitat rating, we believe it is important to remember our definition of a smolt as the juvenile salmon or steelhead leaving the subbasin after overwintering in the subbasin. This means that the successful presmolt must pass from rearing areas through mainstem river segments. The presmolts must overwinter in the subbasin.

We calculated, from estimates in Moore (1986) and our assessments of effective basin areas, the square meters of habitat available per square mile of effective basin. We found that each square mile of effective basin in the Payette (2,245 mi^2), Weiser (605 mi^2), and Boise (2,210 mi^2) rivers contained estimated coldwater habitat areas of 3,265, 2,149, and 3,467 m^2, respectively. When we included the entire effective basin of the Weiser River (1,550 mi^2), we calculated that each square mile of the Weiser River basin supported an estimated 1,475 m^2 of coldwater habitat.

5. SMOLTS PER LINEAL DISTANCE

Platts (1974) censused fish populations in 1971 and 1972 in the drainage of the South Fork Salmon River. He used primacord explosives and a block net downstream to capture all fish in 291 stream sections, each 15.24 m long. Platts (1974) stated: "Explosive primacord assured collection of 100 percent of the fish population within each sample area." Platts et al. (1983) described methods for the use of primacord in fish censuses.

The South Fork Salmon River is a “summer” chinook subbasin. “Summer”[28] chinook salmon escapements into the Snake River at Ice Harbor Dam in 1970 and 1971, the parent brood years, were 16,400 and 23,500 adults, respectively. The South Fork Salmon River was the destination for the majority of these fish. While there is no stated escapement goal for “summer” chinook in the Snake River, the 1971 escapement is the second largest on record since Ice Harbor Dam was completed. Some “summer” chinook destined for the South Fork Salmon River undoubtedly were counted as “spring” chinook. Escapements of the spring component of the spring/summer chinook in 1970 and 1971 were 44,900 and 28,900 adults, respectively.

Hassemer’s (1993) Figure 3, reproduced in this report as Figure 2, shows that redd counts in wild trend areas in 1970 and 1971 were much reduced from those in the first half of the 1960s. It appears unlikely that rearing streams used by summer chinook were fully seeded. Platts (1999, pers. comm.) believed the streams that he studied and reported on in his 1974 paper were underseeded. We assume, therefore, that Platts (1974) censused salmon juveniles in underseeded conditions.

Summer steelhead escapements at Ice Harbor Dam equaled 51,556, 49,011, and 63,790 in the return years 1969, 1970, and 1971, respectively. These escapements were well above Snake River escapement goals. Thus, it seems more likely that the South Fork Salmon River was fully seeded by adult steelhead in the years that produced rainbow/steelhead censused by Platts (1974).

We believe that the data offered by Platts (1974) are useful for our predictions primarily as illustrations of the relative densities of juvenile salmonids in various stream orders and gradients.

Platts (1974) related numbers of parr per station (50-ft length) to a number of variables. He found that stream depth and width and the elevation of the channel were the most important of these variables. All these variates should correlate with stream order: stream depth and width, positively; the elevation, negatively. In fact, stream order strongly and positively correlated with the numbers of salmon and steelhead parr per stream mile (Figure 3). No chinook used first- or second-order streams. Platts (1974) found very slight use by chinook (32 parr/mi) of third-order streams. Chinook used fourth- and fifth-order streams at higher rates: 243 and 866 parr per mile, respectively. Rainbow/steelhead did not use first-order streams, and used second- and third-order streams at low rates (53 and 74 parr/mi, respectively). They were more abundant in fourth- and fifth-order streams, numbering 285 and 1,151 parr per mile, respectively.

Brown (1988) also examined the relationship between stream order and fish density in the basin of Redwood Creek, California. He found that gradient and barrier frequency decreased with increasing stream order. Seventy-one percent of the streams in which gradient formed a barrier were third order or smaller. The mean relative abundance of anadromous salmonids in tributaries to Redwood Creek increased from a value of 0 for first- and second-order streams to almost 4 for fifth-order streams and 5 for a single sixth-order tributary.

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[28] We use quotation marks here because Chapman et al. (1991) considered the spring and summer chinook runs as a continuum and termed these fish “spring/summer” chinook. The South Fork Salmon River is considered to support the later-migrating “summer” chinook component of the continuum.

Data provided in Platts (1974) and Brown (1988) provide convincing evidence that first- and second-order streams in the area upstream of the HCC would not support rearing by juvenile chinook salmon. Platts (1994) had no way to determine whether the rainbow trout that he censused were steelhead or resident rainbow trout. The few rainbow trout found in second-order streams would consist wholly of resident fish.

From Platts (Table 32 in Platts 1974:174), we found that stream orders 3, 4, and 5 (and > 5) held spring/summer chinook and steelhead at densities shown in Table 11. The ratio of chinook density in stream order 3 to that in orders greater than 3 equaled 0.028. The ratio of rainbow/steelhead in stream order 3 to that in higher orders equaled 0.05. Some rainbow/steelhead in stream order 3 would not go to sea (see earlier text). We concluded that we can safely confine estimates of spring/summer chinook and steelhead yields to stream orders greater than 2. We arbitrarily estimated that stream orders 3, 4, and 5 (or > 5) should be considered to have widths of 2.5, 5.0, and 10.0 m, respectively.

Therefore, we believe that the area upstream of the HCC could produce anadromous fish in stream orders 3 and greater. We assume that stream order 6, if of suitable temperature, would support no more fish per unit of length than would stream order 5 (based on the opinion of W. Platts, pers. comm. 1999).

Platts (Table 26 in Platts 1974:163) found no chinook salmon juveniles in stream reaches with gradients greater than 10%. He found few rainbow trout at gradients greater than 11%. The few rainbow trout found at gradients of 18 to 24% almost certainly consisted of resident fish only, not steelhead. We consider stream reaches with gradients greater than 10% as nonproductive rearing areas for anadromous salmonids.

A sustained gradient of 20% constitutes a formidable barrier. An example may be found in Napias Creek, a tributary to Panther Creek. There a gradient greater than 20% extends for about 200 m. This gradient blocks anadromous entry into the upper watershed (Welsh et al. 1965). Therefore, we defined the upstream migration limit for adult salmon and steelhead as either an impassable falls or a sustained 20% gradient. We consider areas upstream of such blockages to be naturally inaccessible.

When taken together, the information in the foregoing two paragraphs means that anadromous salmonids could successfully pass a gradient of up to 19% and find some upstream areas of less than 10% gradient to support spawning and rearing. However, even areas of low gradients with satisfactory rearing conditions would be unuseable if they lie anywhere upstream of a 20% gradient or an impassable falls. As a practical matter, most salmon spawning and rearing probably take place at gradients of less than 6% (Table 26 in Platts 1974:162).

WDFW (1999) developed a steelhead parr production model called Gradient Area Flow Methodology (GAFM). GAFM uses the following equation to estimate parr abundance based on streamflow in late summer and on gradient percentages:

$$Y = a(X_1^{-0.25})\, X_2(e^{-bX2})$$

where

Y = parr/100 m^2

X_1 = late summer discharge, cubic feet per second (cfs)

X_2 = percent gradient

$a = 26.335$

$b = 0.1447$

The model, based on empirical data, has an $R^2 = 0.93$, significant at $p < 0.001$.

The GAFM model yields an estimate for the Wenatchee River basin of 372,073 steelhead parr. Parr in the Wenatchee River can spend from 1 to 7 years before migrating as smolts, with most smolt ages being 2+ (43%) and 3+ (46%). Age-4+ and older smolts made up 9.6% of the smolts in the GAFM model. The average age of steelhead smolts that passed Rock Island Dam equaled 2.65 years. WDFW (1999) therefore corrected parr yield by annual survival rates to arrive at smolt yield from parr numbers in a given year.[29] They estimated the Wenatchee subbasin smolt yield at 62,167, which converts to 184 smolts per mile (114 smolts/km). That estimate may be appropriate for Idaho habitats as well because the waters draining subbasins of the upper Columbia River have low conductivities, as do waters draining the central Idaho and Blue mountains.

Parr (older than age 0) in the South Fork Salmon River included ages 1 (41%), 2 (51%), and 3 (8%)[30] in 1984, and ages 1 (36%), 2 (72%), and 3 (13%) in 1985 (Thurow 1987). Inasmuch as Thurow (1987) censused densities in summer, it appears that many juvenile steelhead do not smolt until age 3. WDFW (1999) assumed the average survival rate was 40% from one age to the next. Age-1 parr that smolt at age 2 would suffer only one such overwinter loss, with 40% surviving to smolt. But age-1 parr that smolt at age 3 would suffer two such losses. Therefore, they would survive at a rate of 16% to smolt. The effect of this concept on calculations of smolt yield from parr numbers is to reduce the parr-smolt conversion rate from the 40% used by Thurow (1987). In the Wenatchee River, an estimated parr population of 372,073 would yield not 372,073 × 0.4, or 148,829 smolts, but rather 372,073 × 0.16, or 59,532 smolts because of the age and mortality adjustment (WDFW 1999).

Thurow (1987) extensively investigated steelhead in the South Fork Salmon River, providing useful information on parr abundance in 1984 and 1985. ODFW/WDFW (1998) provided estimates of wild Group-B escapements past Zone 6 as 16,100 and 12,400 in the respective years. It is probable, however, that escapements in 1981–1983 that parented the parr present in 1984 and 1985 did not fully seed the subbasins and the mainstem of the South Fork Salmon River in those years. The minimum run size for Group-B steelhead in 1981−1983 was considerably lower than in 1984 and 1985. Thus, we believe that Thurow's (1987) density data may not represent fully stocked habitat. However, he estimated the potential (fully seeded)

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[29] A multiplier of 0.5 is probably sufficient in Idaho and Oregon tributaries where parr smolt at age 2+. In waters where many fish do not smolt until > age 3+, a best guess might place the average conversion at 0.25 to 0.35.

[30] Based on average densities in 21 transects, each 50 to 150 m long and covering the full stream width.

density in "restored habitat" as 15 parr per 100 m^2 (range = 10–20 parr/100 m^2). He reviewed literature on smolt output and concluded that smolt output would be 30 to 40% of the parr density, or 3 to 8 smolts per 100 m^2. He concluded that 4 smolts per 100 m^2 was a reasonable estimate of smolt output in "restored habitat." He noted that the output of smolts could be proportional to TDS. A reasonable output for streams with TDS of 60 to 80 mg/l appears to be 3 to 4 smolts per 100 m^2 (Marshall et al. 1980). For our purposes, we can use Thurow's (1987) paradigm for "restored habitat" as appropriate for "good" or even "excellent" habitat. It would not be appropriate for habitat in "fair" or "poor" condition.

One problem with Thurow's smolt conversion is that he assumed that all rainbow trout between 70 and 250 millimeters (mm) were steelhead parr when found downstream of migration barriers. This assumption would lead to an overestimated steelhead smolt output. We believe that not all parr between 70 and 250 mm were steelhead and that some parr larger than 200 mm would not smolt. Thurow (1987) assumed that rainbow parr larger than 250 mm were nonsmolting residual steelhead or resident rainbow. However, for these fish to be present, some smaller and younger parr in the area downstream of migration barriers must replace them over time.[31] This means that not all parr between 70 and 250 mm could be steelhead. We believe it appropriate to use 3 smolts per 100 m^2, the lower end of Thurow's (1987) estimated range, as the potential smolt output from "restored habitat."

IDFG (1985) estimated that the South Fork Salmon River contained 515 mi of habitat (829 km), or 9.8 million m^2 of habitat. This estimate converts to a mean stream width of 11.8 m. It also converts, at 3 smolts per 100 m^2, to 357 smolts per kilometer. One should be cautious about this estimator, however, for it represents output of what Thurow (1987) called "restored habitat." We use the estimate of 357 smolts per kilometer as reasonable for "good" habitat, and 157 smolts per kilometer as more suitable for "poor" habitat.[32]

As a check on the foregoing exercise, we examined redband densities in various drainages upstream of the HCC. In 67 sites in the Owyhee and Bruneau rivers and Salmon Falls Creek (Table 12), we found a median population density of 289 redband per kilometer. For simplicity, if we assume that the entire population can be considered surrogates for steelhead parr and that 40% would survive to smolt[33], then smolt output would be estimated as 116 smolts per kilometer. The introduction of steelhead would not eliminate all redband, so some of the resident "parr" cannot be considered as surrogates for steelhead. Thus, 116 smolts per kilometer must be considered a conservatively high maximum estimate. Population assessments based in many cases on one-pass electrofishing may be considered to be minimum estimates. Some sites also

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[31] Large parr downstream of migration barriers are unlikely to have originated upstream of the barriers because they could not return to natal stream reaches to spawn. Thus, downstream movement past the barrier would be maladaptive.

[32] This adjustment uses the NPPC SPM smolt output in "poor" to "good" habitat as a ratio (6:14).

[33] Investigators assessed redband densities in summer. Thus, if redband serve as surrogates for steelhead parr, the "parr" would have to pass through a minimum of one winter before they become "smolts." It is likely that many age-1 "parr" would spend two winters before reaching the "smolt" stage.

contained brook trout (*Salvelinus fontinalis*), but we have not included their density as a factor affecting potentially introduced steelhead.

Some stream sections do not support redband at all. In the Bureau of Land Management's (BLM) Owyhee Resource Area (ORA)[34], for example, 14 of 63 censused sites held no redband in one or more years. We believe it is reasonable to conclude that many other sites would not support steelhead rearing.

In the Blue Mountains, minimal estimates of density in 46 sites were 215 redband per mile, or 134 redband per kilometer, which converts to 54 smolts per kilometer if redband are assumed to offer a surrogate for steelhead densities at full seeding. The estimates are likely lower than they should be because they derive from one-pass electrofishing (Moore et al. 1991a,b).

Hurley (1995a,b) snorkel-censused redband in 35 sites in the Weiser River drainage (21 in the Middle Fork Weiser River, 14 in the East Fork Weiser River), on U.S. Forest Service (USFS) lands. Higher densities were found from the USFS boundary upstream in the wider streams. Median density equaled 106 fish per kilometer. In the highest 50% of the densities, redband numbers averaged 492 per kilometer. In 10 sites with width greater than 5 m, mean parr density equaled 561 per kilometer. If we assume a 40% overwinter survival rate and consider redband trout as surrogates for steelhead parr, smolt densities would equal a respective 42 per kilometer, 197 per kilometer, and 224 per kilometer. Hurley (1995a,b) sampled systematically and did not consider his snorkel census as a population estimate. However, he reported his data as fish densities per unit of area. He snorkel-censused more intensively in pools. Therefore, he may have tended to overestimate average population density in all habitats taken together.

6. U.S. V. OREGON METHOD APPLIED FROM THE GRANDE RONDE RIVER

ODFW estimated production statistics for spring chinook salmon and steelhead in subbasins of the Columbia River upstream of Bonneville Dam, pursuant to management goals required under U.S. v. Oregon. DeShazo et al. (1987a,b) prepared the U.S. v. Oregon subbasin report for the Grande Ronde River. We used their approach, based on the concept of full seeding and certain assumptions about fish per redd, fecundity, and egg-to-smolt survival, to offer another paradigm for smolt yield estimates.

Unfortunately, "full seeding" is an elusive and possibly misleading parameter. The full-seeding concept developed within a management atmosphere is strongly influenced by stock-recruitment models. These models rely on past performance. They relate known numbers of brood-year progeny to the abundance of the parents. The general concept holds that biological compensation at low escapements produces relatively high numbers of smolts per parent, and very high

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[34] The former Owyhee Resource Area is now encompassed by the BLM's Owyhee Field Office, which also manages a portion of the lands that were within the former Bruneau Resource Area.

escapements yield relatively few numbers of smolts per parent. The models indicate that intermediate spawning escapements maximize either sustainable yield or the numbers of returning adults (managers may seek either, depending on social goals). Stock-recruit models rely on past data. Although they accommodate stochastic variability, they assume no long-term trend in productivity of environments in which salmon and steelhead must live. We do not exaggerate when we say that fishery managers who rely on stock-recruit models tend to think that they should avoid "overescapement." The sport and commercial fishing industries, and the communities that depend on them, tend to pressure managers to harvest potential "overescapement" (Wright 1981). Yet salmon and steelhead evolved with frequent "overescapements." Low harvest rates by humans very likely were common before the mid-1800s (Chapman 1986). Fishery managers did not consider the role of marine-derived carcass nutrients in maintaining stock productivity (Cederholm et al. 1999). Nor did they consider the adaptive benefits associated with the intense competition of females for optimal spawning sites, and of males for females.[35] In the discussion that follows, we are forced by the inadequacy of the information base to ignore them as well.

DeShazo et al. (1987a) estimated spring chinook smolt yields in the Grande Ronde subbasin on the basis of full seeding. They estimated a capacity of 3,662 redds. At 2.4 fish per redd, fecundity of 3,940 eggs, and a 3% egg-to-smolt survival at full seeding, they calculated a smolt yield of 432,848. That smolt output would consist of 179,309 wild fish and 253,535 "natural" ones (strongly influenced by hatchery fish that spawn in the wild). To produce that smolt output, escapement to the wild production areas (Minam and Wenaha rivers) would have to equal 3,641 fish; to all other areas, 5,148 fish, a total spawning escapement (at the time of redd construction) of 8,789. Chapman et al. (1991) estimated that the prespawning mortality of spring chinook in the Snake River basin amounted to roughly 50%. Therefore, we estimate, albeit roughly, that over 17,000 spring chinook would have to escape to the basin. DeShazo et al. (1987a) noted that an estimated 12,200 spring chinook escaped to the Grande Ronde River in 1957[36]. However, that brood year failed to replace itself in that basin, unlike most other subbasins within the Columbia River system. The construction and operation of dams on the mainstem Snake River would not explain that failure. Ice Harbor Dam did not become operational until 1961, two years after the smolt progeny of the 1957 brood migrated downstream. Nor were any new Columbia River dams constructed in the interval. No data exist to allow one to evaluate whether marine productivity and survival were lower for the 1961 and 1962 brood years than they had been for the 1957 brood.

DeShazo et al. (1987a) stated that the Grande Ronde basin contained 157.8 mi of spawning habitat, 288,684 square yards (yd^2) of spawning gravel, and 2,860,000 yd^2 of pool habitat. Of the total area of spawning gravel, 33% was considered to be "good" and the remainder "marginal." PFMC (1979) estimated that the Grande Ronde River contained 647 mi of salmon habitat. Taken at face value and together with DeShazo et al. (1987a), this estimate suggests that rearing habitat

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[35] The current thinking in fishery management continues to include "harvesting the surplus" without regard to these factors and their role in maintaining both ecological productivity and stock viability.

[36] The escapement of the 1957 brood year resulted in large part because of the flooding of Celilo Falls by The Dalles Dam pool, eliminating both the obstacle and fishing there.

for chinook salmon is much more abundant than spawning habitat. That inference seems reasonable.

For steelhead, DeShazo et al. (1987b) used 1.67 fish per redd, 4,340 eggs per redd, and an egg-to-smolt survival rate of 0.75% at full seeding. They estimated 351 mi of wild spawning area and 889 mi of natural spawning area: a total of 1,240 mi. Wild-production areas were confined to the Wenaha and Minam rivers and Joseph Creek.[37] Output at full seeding was estimated as 91,400 wild and 231,495 natural smolts: a total of 322,896. Full seeding for steelhead is more difficult to assess than it is for spring chinook. A redd count of over 8 per mile was noted in the Grande Ronde River basin in three years (1966, 1967, and 1985). DeShazo et al. (1987b) used 8.0 redds per mile to estimate carrying capacity. However, maximum redd counts may not indicate carrying capacity. It is legitimate to examine whether the broods that spawned at this density replaced themselves. Redd counts per mile four and five years after 1966 and 1967 equaled 3.5 and 2.7, respectively. Unfortunately, mainstem dams were coming on line in that interval, diminishing the utility of the brood replacement evaluation.

We can develop a rough check on the estimated escapement requirement for the Grande Ronde River from our earlier estimates of effective basin area in the Snake River. The escapement goal for spring chinook at Lower Granite Dam is 25,000 wild and natural fish (ODFW/WDFW 1998).[38] No escapement goal is stated for spring/summer chinook, but we estimated earlier that a goal of 25,000 was reasonable for these later-running fish. The steelhead escapement goal is 75,000 wild and natural[39] fish. If we allocate these fish on the basis of available effective basin areas in the Snake River, but downstream of the HCC, and account for the loss of the North Fork Clearwater River to Dworshak Dam (about one-third of the available Clearwater River effective basin area), roughly 18.4% of the escapement of steelhead would have gone to the Grande Ronde River (3,720 mi^2/20,209 mi^2) in the late 1950s. That calculation allocates 13,800 steelhead to the basin. DeShazo et al. (1987b) estimated a full-seeding escapement requirement of 16,566.

The presence of spring/summer chinook in the Snake River basin somewhat complicates a similar rough check on spring chinook escapements. However, if we remove the Imnaha and South Fork Salmon river drainages, which make up the majority of the productive area for “summer” chinook, the effective basin area available for spring chinook becomes about 11,920 mi^2 (excluding the Clearwater River). The Grande Ronde would make up about 31% of that area, so we would allocate 31% of the spring chinook spawning goal, or about 7,800 fish, to the Grande Ronde basin. DeShazo et al. (1987a) estimated a full-seeding escapement requirement of 8,789. Our rough check again suggests that their estimate was somewhat optimistic, although not excessively so.

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[37] Much of the mainstem of Joseph Creek warms too much in summer to provide suitable salmonid habitat. Most tributaries to the stream offer suitable temperatures for rearing.

[38] As stated elsewhere, we assume that the agencies responsible for setting escapement goals aimed to assure maximum sustained yield in the context of stock-recruit models.

[39] “Natural” here means the progeny of hatchery fish, or their progeny lineage in subsequent generations, that spawn in the wild.

We see at least one difficulty in developing a paradigm for smolt output applicable to habitat upstream of the HCC that relies on the U.S. v. Oregon assumptions used in the Grande Ronde River. We have no estimates of "spawning habitat" in streams in the latter area upstream of the HCC. If we use "spawning area" and "rearing area" synonymously, we would estimate chinook and steelhead smolt outputs as 1,704 and 162 per kilometer, respectively. If we use the PFMC (1979) estimate of 647 mi of salmon habitat in the Grande Ronde River (1,041 km), the chinook smolt yield drops to 416 per kilometer.

We can compare smolt outputs of DeShazo et al. (1987a,b) per unit of watershed area with those that we developed earlier in this chapter. We assumed that the 4,070-mi^2 Grande Ronde basin contains 3,720 mi^2 of effective basin. Thus, the U.S. v. Oregon smolt outputs convert to an effective-basin output of 116 chinook per square mile and 87 steelhead per square mile. This estimate for chinook is only 55% of our estimate of 212 smolts per square mile for effective basins throughout the Snake River that we developed earlier from Raymond (1979). The steelhead estimate comports rather well with the estimate of 83 smolts per square mile that we developed from Raymond (1979) and that Buckman (1990) developed from data obtained in the John Day River.

As an alternative, we could apply the DeShazo et al. (1987a,b) smolt estimates to the total watershed area of the Grande Ronde River (4,070 mi^2). That process results in a paradigm of 106 chinook smolts per square mile and 79 steelhead smolts per square mile of Grande Ronde River basin. To use this paradigm upstream of the HCC, we would have to assume that the basin to which we applied it had similar habitat quality and quantity per square mile.

DeShazo et al. (1987a) stated that six major factors had affected spring chinook habitat in the Grande Ronde basin:

- Livestock overgrazing
- Mountain pine beetle damage
- Limited rearing habitat
- Low streamflows
- Logging activities
- Unscreened diversion ditches

They stated that much of the riparian habitat had been destroyed on the upper Grande Ronde River, the Wallowa River, and tributaries to Catherine Creek. Pine beetles destroyed riparian habitat. The channelization of the Wallowa River and its tributaries substantially reduced available rearing habitat. Losses in rearing habitat reduced the total capacity of many streams to support spring chinook. DeShazo et al. (1987a) reported that the ODFW estimate of juvenile production capacity had been reduced by 30% in the upper Grande Ronde River and Sheep Creek, by 20% in the Lostine River and Bear Creek, and by 70% in the Wallowa River and Hurricane Creek.

DeShazo et al. (1987b) note that only the Minam and Wenaha drainages remained relatively unaltered. Steelhead habitat problems in the basin included, in ranked order:

- Degraded riparian habitat
- Lack of rearing habitat
- Inadequate screening at screened and unscreened diversions

Livestock overgrazing had “extensively impacted” riparian habitat. Riparian and/or instream rehabilitation was deemed necessary in 436 mi on 64 tributaries. Logging and road construction caused further degradation on private land. Summer flows were deemed to be naturally low and further depleted by irrigation withdrawals.

DeShazo et al. (1987b) stated that water temperatures in the upper Grande Ronde River and smaller tributaries often exceed 80 °F (26.6 °C). A review of Watershed Sciences (2000) suggests that a MWAT of 22 °C in the main Grande Ronde River is strongly affected by flows from the Wenaha River and Lookingglass Creek, both of which enter the main river well down in the Grande Ronde River basin. The entry of very cool water from major tributaries low in the basin is uncommon in the area upstream of the HCC. The Minam, Lostine, East Fork Grande Ronde, and Wallowa rivers appeared to lie above the MWAT upper boundary of 22 °C, as did Bear Creek and most of Indian Creek (except for the lowest 5 km). Most of the following creeks had relatively high temperatures: Joseph (except for 10 to 15 km between river kilometer [RKM] 30 and RKM 55), Meadow (the lowest 15 km), McCoy (lowest 12 km), Fly (lowest 17 km), Chesnimnus (lowest 15 km), and Sheep (lowest 8 km).

Relatively poor habitat for chinook in many segments of the Grande Ronde River basin might explain why smolt yield per unit of effective basin is lower than that calculated for the Snake River as a whole. We suggest that the poor habitats upstream of the HCC will also yield fewer smolts than the Snake River as a whole.

We think that the summary of habitat conditions for the Grande Ronde River drainage in DeShazo et al. (1987a,b) reasonably describes conditions prevailing in most drainages upstream of the HCC (see Chapters 3 [Chapman 2001] and 4 [Chandler and Chapman 201] and Section 8 of this chapter). We conclude that a paradigm that uses the DeShazo et al. (1987a,b) approach has sufficient merit to warrant inclusion in an array of paradigms. If nothing else, it permits a comparison of the various estimators. We show the results of using the U.S. v. Oregon paradigm for several drainages, but we suggest that the paradigm may best serve for the Burnt, Powder, and Weiser rivers and serve less well for Pine Creek; Wildhorse River; Indian Creek; and the Boise, Malheur, Owyhee, and other systems that enter the Snake River higher upstream of Swan Falls Dam.

7. SOCKEYE SMOLTS PER LAKE SURFACE AREA

Lacking data on smolt output from Payette Lake, one can use indirect estimators. One of these indicators is smolt output from Redfish Lake. Limited information is available on smolt yields per unit of Redfish Lake surface area. This 1,500-acre lake yielded 14,422 to 50,521 sockeye smolts (mean = 26,292), or 9.6 to 33.7 smolts (mean = 17.5) per surface acre in 1979–1988 (Bjornn et al. 1968, Chapman et al. 1990). The two largest egg depositions, brood years 1981 (198,652 eggs) and 1982 (191,363 eggs), yielded, respectively, the lowest (14,422) and highest (50,521) numbers of smolts. Kokanee (*O. nerka*) progeny made up about 75% of the smolt output (Chapman et al. 1990). We did not include kokanee egg deposition in the foregoing egg totals.

One can use smolt output per acre at Redfish Lake as an estimator for smolt output per acre for Payette Lake, another glaciated, granitic basin. That model would estimate a yield of 48,000 to 168,500 sockeye smolts from Payette Lake (estimated mean = 87,500). We assume that the area and productivity of the lake, not spawning area, would limit the smolt output. An annual rise in lake level caused by a dam at the lake outlet has partially destroyed the spawning area of the North Fork Payette River. Roughly 3 km of original spawning area is inundated. Fine sediments have deposited on the gravels that once existed in this area. The remaining available spawning area is probably sufficient to fully seed Payette Lake. However, small kokanee use it extensively for spawning. The degree to which kokanee might reduce potential sockeye output is uncertain. Using the Redfish Lake smolt output eliminates some of that uncertainty because kokanee were present in Redfish Lake in the 1980s when Bjornn et al. (1968) assessed smolt output.

Lake trout (*S. namaycush*), which are exotic to Payette Lake, have established themselves there. Though their effect on the potential output of sockeye from the lake is unclear, we doubt that lake trout would reduce sockeye output substantially. Payette Lake is an oligotrophic body of water. Anthropogenic nutrients entering the lake from surrounding developments might partially offset the lack of fertilization once provided by sockeye carcasses. In fact, artificial fertilization is always a possibility for promoting sockeye production in the lake. However, as at Redfish Lake, fertilization with inorganic nutrients to jump-start sockeye production might not find much favor in the local community, which is heavily oriented to the recreational use of the lake.

As we noted earlier in Chapter 6 (Chapman and Chandler 2001b), proportionalized estimates of Redfish Lake sockeye returns to the mouth of the Columbia River, based on lake area, equal 14,400 to 57,400 adults. This estimate of pristine production of adult sockeye does not comport with the smolt output estimated on the basis of smolt yield from Redfish Lake. A smolt output of 48,000 to 168,500 (estimated mean = 87,500) cannot produce an adult run to the Columbia River of 14,400 to 57,400. The discrepancy may be caused by the following:

Relatively higher productivity of sockeye lakes in the upper Columbia River**—**A simple area-proportionalized estimate would therefore overestimate Payette Lake sockeye production.

Inappropriate time window for estimation of Redfish Lake productivity, used as a surrogate for smolt yield per acre**—**Sunbeam Dam, near Clayton, denied sockeye access to Redfish Lake from 1910 to 1934. The Redfish Lake basin was not fertilized by marine nutrients during this period. Kokanee likely reestablished sockeye runs after the dam was breached. Smolt yield in the 1980s may not have reached pristine numbers or potential.

One can divide proportionalized adult returns to the Columbia River by 0.04 to obtain an estimated smolt output from Payette Lake of 360,000 to 1.44 million. Confidence limits, if they could be calculated, would be wide around these estimates. We tend to favor the lower number because of the inherent low nutrient recruitment in the granitic basin of the North Fork Payette River and Payette Lake.

8. HABITAT QUALITY UPSTREAM OF HELLS CANYON DAM

As we noted earlier, appellations of “fair” or “poor,” with their respective smolt yields, sharply reduce smolt output per unit of area (or per unit of stream length) from yields estimated for “excellent” or “good” habitat. When applying paradigms based either on stream surface area or stream length, one must decide how to characterize habitat quality. After preparing Chapters 3 (Chapman 2001) and 4 (Chandler and Chapman 2001) on the history and status of habitat upstream of the HCC, examining data on redband densities, and applying our personal acquaintance with the area, we believed it was appropriate and reasonable to consider all habitat upstream of the HCC as “poor,” unless we found reasons to upgrade the designation to “fair” or “good.” Pine, Rock, and Salmon Falls creeks and the Powder, Burnt, Malheur, Owyhee, lower Bruneau, Boise, Payette, and Weiser rivers are all diverted extensively for irrigation. The main Snake River receives large inputs of fine sediment, inorganic nutrients, and organic matter. Many subbasin stream reaches have been channelized, and many have been placered, dredged, or both. Fine sediments from anthropogenic activities have degraded most of these reaches. Livestock have degraded stream habitat and riparian communities in most subbasins.

A few areas and systems remain in “good” or “fair” condition. Parts of the Middle Fork Weiser River, South Fork Boise River, and portions of the upper Bruneau and the North Fork and Middle Fork Malheur rivers offer examples. High-elevation lands within wilderness areas or other protected designations also remain in good condition. Those lands most often lie upstream of the zones used by salmon and steelhead. However, we recall our definition of smolt yield as the subbasin output of juvenile salmon and steelhead after fish overwinter in the subbasin. Fish produced in high-elevation habitats must move downstream into stream reaches that usually lack the complexity and substrate quality needed for good winter habitat. In subbasins with irrigation storage, juveniles produced upstream must pass through reservoirs that usually contain predator species. If they successfully pass through the reservoirs, they find downstream habitats dewatered in fall and winter as water managers retain the water in storage. Even in drainages that lack mainstem reservoirs, diversions reduce instream flow in summer and fall. Because the streams have lost robust riparian communities that shade them, their summer temperatures have increased. Also, warmwater and coolwater competitors and predators have been introduced. These factors influenced our thinking about overall habitat quality upstream of the HCC.

9. INTERACTIONS OF REINTRODUCED STEELHEAD AND INDIGENOUS REDBAND TROUT

Behnke (1992) recognized rainbow, or redband, trout native to the Columbia River basin east of the Cascades and to the upper Fraser River basin—including Kamloops trout, resident stream forms, and steelhead—as *O. mykiss gairdneri*. Most steelhead that originally ascended the Columbia River must have been redband steelhead. Redband trout are found in the headwaters of most major river systems in the area upstream of the HCC. Populations in the tributaries of these headwaters are usually isolated both from each other (Allen et al. 1997) and from access to the mainstem Snake River by dams and stream sections that have high summer water temperatures.

The reintroduction of anadromous fish upstream of Hells Canyon should be examined from the standpoint of effects on resident rainbow, or redband, trout. Reisenbichler (1984) reviewed how outplanting hatchery-reared salmonids affects resident fish. He used a simple genetic model (one gene locus with two alleles) to incorporate gene flow and density-dependent mortality. Computer-based simulations showed that density-dependent mortality and gene flow are "... a potent force for eliminating advantageous alleles and, by inference, for effecting other potentially damaging genetic change in wild fish populations."

Currens (1987) examined biochemical and meristic evidence to determine ancestry for a wild population of rainbow trout in the upper Metolius River, Oregon. Hatchery-produced rainbow trout have been stocked in the Metolius River since at least 1934. Currens (1987) felt that interbreeding of nonnative and native rainbow trout explained much of the meristic and biochemical differentiation of Metolius River rainbow trout he documented. Native Metolius rainbow trout had characteristics typical of inland rainbow. Nonnative hatchery strains that were examined were typical of coastal rainbow. Many established strains of hatchery rainbow have a common origin in coastal streams, especially the McCloud River (Busack and Gall 1980). Currens (1987) found convincing evidence of gene flow from nonnative hatchery fish to wild rainbow trout. He suggested the possibility that interbreeding with nonnative trout reduced the fitness of the wild population.

The reintroduction of steelhead in the White Salmon River upstream of the site of Condit Dam concerned the USFS. Deibel (1995) examined the potential for damage to resident rainbow. He summarized genetic considerations by noting the following:

- Wild rainbow are genetically distinct from the hatchery fish in Northwestern Reservoir (upstream of Condit Dam) and may have subpopulations in the wild population.

- Lower White Salmon River steelhead are more closely associated with inland stocks of steelhead (*O. mykiss gairdneri*).

- Steelhead could be present already in the White Salmon Wild and Scenic River, a result of either fish escapement from a winter steelhead net pen or by resident rainbow consisting of "landlocked" steelhead.

- Spawning periods of resident rainbow and steelhead overlap.
- Distribution of suitable spawning habitat limits the magnitude of potential interbreeding of resident rainbow with steelhead.

Deibel (1995) discussed the potential for anadromous fish to introduce new pathogens to the resident rainbow population. However, many pathogens of concern probably already occur in the White Salmon River rainbow population, although no current data on this point are available.

Deibel (1995) examined literature on interactions of rainbow, coho (*O. kisutch*), and chinook. He concluded that the numbers of resident rainbow in the White Salmon River would decline if steelhead became established. The amount of the decline and the effect on resident trout, particularly numbers of large resident fish, depend on several factors:

- Genetic makeup of resident trout affecting behavior in sympatry with steelhead
- Mortality affecting age-2+ trout recruitment to the age classes that support the resident trout trophy fishery for fish 16 to 24 inches long
- Future densities of steelhead juveniles in habitat in the White Salmon River
- Productive capacity of the White Salmon River to support high numbers of juvenile fish

Bjornn (1978) showed that the densities of introduced rainbow trout affected the numbers of resident rainbow. Numbers of rainbow trout greater than 30 centimeters (cm) long declined after extensive introductions of steelhead in Big Springs Creek (a Lemhi River tributary). Before introductions of steelhead, age-2+ fish accounted for 44% of the rainbow population. By 1970, after steelhead introductions, age-2+ fish made up less than 10% of the rainbow/steelhead population. The mean numbers of rainbow greater than 30 cm long declined from about 430 in 1962 to an average of 133 in the period 1963–1974 (range = 66–265).

Deibel (1995) summarized his opinion of carrying capacity and production with reintroduction:

- Coho and chinook salmon would have little effect on resident trout.
- Numbers of resident rainbow would decline if steelhead became established.

The magnitude of the decline would be moderated by the following:

- Habitat segregation
- Genetic control of behavior of resident fish in sympatry with steelhead
- Habitat preference of trophy trout for large, deep pools not typically used by age-2 or younger steelhead
- Potential benefits from increased nutrient availability from an increased prey base (greater numbers of young anadromous fish) and from carcasses

One might argue with item 3. The habitat preference of large fish for large, deep pools would not eliminate the competitive interaction of younger age classes. Recruitment of large fish would have to come from those younger fish. Spawning and rearing to age 2+ in tributaries is a common phenomenon in the Intermountain West, with age-2+ fish migrating to main rivers after extended rearing in tributaries. In these tributaries, competition with young steelhead could be of considerable concern.

Allendorf et al. (1980) used electrophoretics to examine the protein makeup of 218 rainbow trout from 6 sampling locations in the Kootenai River basin. They determined that large allelic differences existed within a small geographical area. Two samples shared close affinity to other inland rainbow trout and were very different from hatchery stocks released in the area. The authors concluded that populations of native and introduced rainbow trout, and their hybrids, exist in the sampled area.

Wishard et al. (1984) evaluated genetic relationships among redband trout in Owyhee County tributaries to the Owyhee River, a former steelhead-producing basin. They reported that the allelic frequencies

> ... in general typify all other rainbow trout-like populations of the upper Columbia River and Fraser River basins examined to date.… [M]ajor features include high frequencies of the LDH-4 variant allele and the SOD common allele.... These inland populations...collectively have widely differing life history patterns and occupy highly diverse habitats, but all fall into Behnke's broad concept of redband trout.

The Owyhee County trout were more similar to other interior populations of rainbow trout than to coastal or hatchery trout. Wishard et al. (1984) did not recommend treating redband trout of interior basins as a separate species, although subspecies recognition would not be excluded. They suggested that management of rainbow trout native to arid regions of the western United States would focus on physiological attributes, with particular attention to identification, habitat requirements, and population dynamics. They stated: "Any cultural or transplantation projects involving these populations would include identification and consideration of relationships among populations prior to any poolings or transplantations."

Ricker (1972) suggested that an introduced stock is unlikely to alter the genotype of a native population significantly through hybridization because natural selection strongly favors the native genotype. Allendorf et al. (1980) believed this thesis to be untrue. They believed that once hybridization occurred, the action of chromosomal recombination makes recreation of the original native trout genotype through the process of selection essentially impossible. Also, they thought that the overall adaptive superiority of the native stock might not be reflected in the action of natural selection. Allendorf et al. (1980) stated that "[f]or example, the introduced stock may outcompete and thereby greatly reduce the native stock in an early stage of the life cycle so that the advantage of the native stock will never be realized. This situation is thought to occur in at least one instance with the rainbow trout" (Allendorf and Utter 1979).

Moreover, the continued stocking of hatchery fish may swamp the native stock by numbers alone, even if the native fish have a strong and effective selective advantage.

That native, persisting, redband trout are an important genetic resource is reinforced by a comment of Behnke (1992):

> In the Oregon desert basins and in the arid regions of the Owyhee drainage...of southern Oregon, western Idaho, and northern Nevada, the redband trout has evolved adaptations to live in extremely harsh environments characterized by great extremes of water temperature and flow. In most of these situations, hatchery strains of rainbow trout are not effective predators or competitors.... The arid-lands redband trout, mainly known from the Owyhee and Malheur river drainages, possesses the hereditary basis to function at high temperatures. As discussed, I have caught the native redband trout in Chino Creek, Nevada, by fly-fishing in waters of 28.3 °C. I also caught the same form of trout under similar conditions in Swamp Creek, Oregon, in intermittent, stagnant pools.

Wild redband trout live in lower Salmon Falls Creek, downstream of Salmon Falls Dam. At the most downstream site sampled by Warren and Partridge (1995), the MWAT equaled 22.6 °C. Redband density was only 3.2 fish per 100 m^2. However, both juveniles and adults were present, along with smallmouth bass. Redband trout were more abundant farther upstream and closer to Salmon Falls Dam, where, presumably, water temperatures were lower because the stream originated as flow from the substrate around the dam.

In tributaries to the Owyhee and Bruneau rivers, and in Salmon Falls Creek, electrofishing data of the Nevada Division of Wildlife (NDW), USFS, BLM, and IDFG permit one to calculate adult and juvenile densities of redband trout (Table 13). Redband densities averaged 9.8 fish per 100 m^2 (range = 0–111.9 fish/100 m^2). For 68 streams with available abundance data per mile (including the aforementioned streams with area information), we found an average of 384 trout per kilometer (size or age was not distinguished). The median number per kilometer equaled 289 fish. If we conservatively assume that 40% of the redband (surrogates for steelhead parr) survive to smolt, the smolt yield equals 3.92 fish per100 m^2.

Similar density calculations for 36 streams in the ORA (Table 14) yield a median density[40] of 18 redband per 100 m^2 (range = 0.3–120 fish/100 m^2). This density converts, at a 40% survival rate, to a surrogate smolt yield of 7.2 fish per 100 m^2. If we include the ORA streams with no redband, and all years at every site[41], the mean density equals 19.1 fish per 100 m^2 ($n = 92$), which converts to surrogate smolt yields of 7.6 fish per 100 m^2.

The NPPC presence/absence database shows a steelhead smolt output of 6 to 20 smolts per 100 m^2, with the output within that range dependent on habitat quality of “poor” to “excellent.” This smolt output roughly converts to 15 to 50 presmolts (overwinter survival rate of 0.40). Therefore, the total (minimum) densities of about 19 redband per 100 m^2 (roughly indicative of presmolt capacity) do not suggest that steelhead habitat quality in redband streams would be better than “poor.” Again, we assumed that redband were occupying habitat at carrying capacity.

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[40] Where data were obtained at one site for more than one year, we averaged the densities.

[41] Includes two dry sites in the Little Owyhee River in 1995 and one on Reynolds Creek in 1994.

The densities do not fully incorporate newly emerged redband fry because these small fish are not as vulnerable to the electrofishing gear. However, the NPPC presmolt estimates do not include redband fry either. As we noted in our discussion of Thurow's work (1987), not all parr in the South Fork Salmon River migrate to sea. Thus, even the surrogate estimate of 3.92 smolts per 100 m^2 is too high.

The numbers in Table 13 represent minimum density estimates because technicians obtained them with one pass of the electrofishing gear through short stream sections. The data for Salmon Falls Creek are an exception because the technicians used multiple passes there. We assumed that redband trout adjusted their numbers to the available habitat. We also assumed that redband trout would be fully adapted to the conditions in which they were living. Whether steelhead could displace redband trout wholly or partially in habitat occupied by redband depends on many factors. These factors include egg size and female fecundity (greater in steelhead), intraspecific resistance offered by the better-adapted redband trout, and the ability of steelhead to cope with degraded habitats, especially high summer water temperatures.

Applying the available experience and information to the reintroduction of steelhead upstream of the HCC, one can conclude the following:

Redband trout present in many tributaries upstream of the HCC very probably were closely related to, or of the same genetic makeup as, native steelhead. Some isolated populations may have drifted genetically away from steelhead.

Redband trout remaining in tributaries upstream of the HCC have had at least 50 years to drift genetically or to adapt to local conditions. In some cases, redband populations likely had up to 100 years to drift genetically. An example might be redband trout in portions of the Bruneau River and in the upper Malheur River drainage.

Notwithstanding numbers 1 and 2, steelhead transferred out of the Hells Canyon area are probably related fairly closely to redband trout remaining in tributaries upstream of the HCC. Niagara Springs Hatchery, where the transferred stock is reared, would likely be a prime source of steelhead for reintroductions upstream of the HCC. However, Behnke (1992) warned: "These interior runs have dwindled and many local races are extinct because of dams, irrigation, and land use practices. Although hatchery propagation of middle Columbia basin redband steelhead occurs on a massive scale, hatcheries can neither maintain the genetic diversity of wild stocks nor recreate the diversity of extinct stocks."

It is likely that if steelhead were reintroduced with persistent, sustained liberations of hatchery stocks in streams where redband trout are present, the introduced steelhead could overwhelm redband adaptations. However, refugia upstream of barriers might maintain local redband characteristics.

Fishery managers could reserve certain known redband trout habitat for the resident rainbow form. That reservation may occur automatically for habitat where extensive and severe transportation difficulties make steelhead establishment uneconomic or socially unacceptable.

10. ADDITIONAL COMMENTS ON EFFECTIVE BASINS

Because we lacked detailed information—and, in most cases, any information—on stream surface areas in various parts of the Snake River basin upstream of Hells Canyon Dam, we resorted to various tools for developing paradigms for potential smolt yield. As noted earlier, we set the downstream limit of stream-annulus salmonid spawning—and, perhaps more importantly, rearing—by estimating the point at which the MWAT reaches 22 ºC. We developed regressions of MWAT on elevations at which MWATs were recorded. Appendices 1 through 7 in Chapter 4 (Chandler and Chapman 2001) provide regressions for each stream for which we found sufficient data to develop the regressions. The elevations at which the MWAT reached 22 ºC varied by subbasin. For example, in Pine Creek, the regression predicted that the MWAT limit would occur at about 2,700 ft mean sea level (MSL). In the Malheur River, the MWAT limit was predicted at about 4,600 ft MSL. We found little data for some basins and in those cases used regressions for adjacent basins, plus judgment and information from the literature, to estimate the downstream elevation at which the MWAT limit should occur.

We assume that, in the predevelopment era, subbasin tributaries were cool enough to support stream-annulus salmonids all the way to their junctures with the Snake River. Those tributaries should have supported dense riparian vegetative communities. They had not yet been affected by irrigation water withdrawals and returns. Thus, limited exposure of the surface and substrate to the sun should have helped to keep temperatures low.

To provide some area-related information on subbasin tributaries, we modified lineal smolt densities from various sources by considering stream order. As noted earlier, stream order correlates negatively with gradient and positively with stream width (Platts 1974). Fish density correlates positively with stream order, as suggested by the smolt estimators in the NPPC SPM and as shown by data in Platts (1974) (Figures 3 and 4) and in Brown (1988)[42].

This information led us to assume that juvenile chinook and steelhead would not use streams of order 2, but would use stream order 3 at very low densities, stream order 4 at considerably higher densities, and stream orders of 5 and greater at high densities. We assumed that the mean widths of stream orders 3, 4, and 5 (or higher order) equaled 2.5, 5.0, and 10 m, respectively.

We used a GIS to quantify stream kilometers in each stream order within defined conditions (Tables 5 and 6 in Chandler and Chapman 2001). The most critical quantification for our purposes tabulated stream kilometers by stream order between the downstream bound of 22 ºC MWAT and the upstream migration limit defined by a stream gradient of 20% or impassable falls.

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[42] We have not included figures or tables on density data as a function of stream order for Redwood Creek (Brown 1988) because the data derive from an ecoregion very dissimilar to the Snake River Plain and its associated tributaries.

11. SUMMARY OF PARADIGMS

Table 15 summarizes paradigms that may be useful in predicting smolt yields of subbasins upstream of Hells Canyon Dam. The paradigms vary in their inherent utility as methods and in their applicability to various subbasins. For example, the applicability of paradigms 10 through 15 in Table 15 depends on an assumption that, since the 1950s, the quality of fall chinook spawning and rearing habitat in the main Snake River has not changed enough to render the estimators inappropriate.

To provide a comparative context, we tabulated smolt potential for several streams included in the NPPC SPM database (Table 16). The Pahsimeroi River had the lowest estimates. The Middle Fork Salmon River had the highest densities, as one would expect, inasmuch as the SPM assumes much higher smolt yields from habitat in excellent condition.

We also summarized redband densities, placing them in Table 17 as “parr,” together with steelhead smolt estimators in some of the various paradigms, to provide a ready check for readers.

We note that in the various paradigms surrogate smolt yields estimated from redband densities tend to be lower than estimators for steelhead. This may be due in part to the small width of some sites censused by various investigators who contributed to data used in the last three rows of the table. The snorkel data for 10 sites with widths greater than 5 m in the Weiser River (last row in Table 17), and 3-pass electrosampling estimates in Salmon Falls Creek, would suggest so, although relatively wide channel width in the latter site likely also contributed to higher fish density per lineal distance. Use of single-pass electrofishing in the Owyhee and Bruneau rivers and in the Blue Mountains may have contributed to lower numbers in those sites. The data suggest that if redband trout provide formidable resistance to establishment of steelhead, and live sympatrically with steelhead, redband would substantially reduce the ability of streams upstream of the HCC to yield steelhead.

11.1. Assumptions Inherent in Paradigms Used to Estimate Potential Smolt Yields

Every paradigm for estimating smolt yields embodies assumptions. The following list may not include all of these assumptions, but it helps to emphasize that we consider calculations of potential yield as reconnaissance-level estimates. Refinement would require field inventories and measurements in each subbasin. The numbers listed below correspond with the paradigm numbers shown in Table 15.

- All paradigms (1–15) assume full seeding.
- In paradigms 3–6 and 8, we assume habitat quality in the area upstream of the HCC is, on average, “poor” or “fair.” We base this opinion on Chapters 3 (Chapman 2001), 4 (Chandler and Chapman 2001), and 5 (Chandler et al. 2001) of this report.

- We assume that steelhead would fully replace redband where the latter reside, and that eastern brook trout would not interactively depress spring/summer chinook salmon densities or growth.
- In paradigms 7 and 8, we assume that the ratio of steelhead to chinook salmon would equal 0.3915, from Raymond (1979) and the appropriate effective basin sizes.
- In paradigms 3–9, we assume that screens in all water diversions prevent entrainment of juvenile salmon and steelhead in diversions.
- In paradigm 1, we assume that diversion screens are emplaced and operative to the same degree as they were in the John Day River system when Buckman (1990) developed his smolt yield model.
- In paradigm 2, we assume that habitat degradation, water diversions, and diversion screening upstream of the HCC are similar to conditions extant in the portion of the Snake River basin downstream of the HCC in the early 1960s, the period pertinent to smolt yields estimated by Raymond (1979).
- In paradigms 10–14 we assume that habitat quality and quantity per unit length in the main Snake River upstream of the HCC do not differ from conditions extant in the 1950s.
- In paradigms 18 and 19, we assume that redband numbers per unit area or length offer surrogates for steelhead parr numbers, and that we can expect about 40% of “parr” to survive to “smolt.”

11.2. Assumptions Inherent in Applying Yield Paradigms

In applying yield paradigms, we made the following assumptions:

1. Spring chinook and steelhead could rear only in stream areas upstream of the point at which the MWAT reaches 22 ºC. In other words, this MWAT sets the downstream boundary of the effective basin.
2. The upstream limit for adult migration of spring chinook and steelhead is either an impassable falls or a gradient of 20%.
3. Spring chinook and steelhead do not rear in gradients greater than 10%.

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Table 1. Effective basin areas estimated for subbasins of the Snake River downstream of the HCC.

Basin	Effective basin area[a] (mi^2)
Grande Ronde River	3,720
Imnaha River	980
Major Clearwater River fish tributaries[b]	6,008
North Fork	
Lochsa River	
Selway River	
Lapwai Creek	
Lolo Creek	
Major Salmon River tributaries	8,444
East Fork	
Middle Fork	
North Fork	
South Fork	
Lemhi River	
Little Salmon River	
Pahsimeroi River	
Upper Salmon River	
Chamberlain Creek	
Minor Snake River tributaries	1,057
Slate Creek	
Whitebird Creek	
Asotin Creek	
Chamberlain Creek	
Bargamin Creek	
Tucannon River	
Total[c]	**20,209**

[a] Estimated for most subbasins from basin areas and either personal knowledge of fish distribution or literature on presence/absence. Note that the mainstem Clearwater River downstream of Lowell and the mainstem Salmon River downstream of Clayton are not considered rearing areas for stream-annulus fish. Effective basin area for the Grande Ronde River was calculated from topographic maps and MWAT regressions on elevation.

[b] We did not include the South Fork Clearwater River because a dam near Harpster prevented anadromous fish passage in the early 1960s.

[c] Only 170 mi^2 of Asotin Creek and 200 mi^2 of the Tucannon River are included in this total. These portions are assumed to have suitable temperatures for stream-annulus fish. Kelley and Associates (1982) are the source for the Tucannon River assumption.

Table 2. Smolt yields at Ice Harbor Dam (Raymond 1979), effective basin areas, and smolt yields per mi^2 in the Snake River upstream of Ice Harbor Dam.

Statistic	Chinook	Steelhead
Smolts at Ice Harbor Dam (1964)	2,915,000	1,668,000
Smolts at Ice Harbor Dam (1965)	2,197,000	1,167,000
Mean number of smolts	**2,556,000**	**1,417,500**
Effective basin area (mi^2)	**14,201**	**20,209**
Smolt yield per mi^2 at Ice Harbor	**180**	**70**
Smolt yield per mi^2 at subbasin[a]	**212**	**83**

[a] Adjusted for an 85% survival rate from subbasins to Ice Harbor Dam.

Table 3. River subbasins for which Petrosky (1990a) estimated chinook smolt yields upstream of Hells Canyon Dam, with maximum basin area and estimated effective basin areas.

River segment	Maximum basin area (mi^2)	Effective basin area (mi^2)
Payette River	3,310	2,211[a]
Weiser River	1,686	**1,532**[b]
Boise River	4,031	**2,914**[c]
		Subtotal = 6,657
Wildhorse River	177	**176**
		Totals = 6,833

[a] Excludes 725 mi^2 above Big Falls (natural barrier).

[b] Later in this chapter, we separately estimate smolt yields for effective basin sizes of 1,532 and 605 mi^2. The 605 mi^2 represents effective basin above Cambridge, Idaho. We believe little habitat for salmon lies downstream of Cambridge, although steelhead could persist in some tributaries. Mann Creek is an example, even though it flows intermittently in summer. We would expect steelhead to use upper portions of the drainage (cf. Welsh et al. 1965).

[c] We later estimate yield from both 2,914 and 2,210 mi^2. The 2,210 mi^2 represents effective basin above Arrowrock Reservoir. We doubt that the Boise River could produce salmon and steelhead downstream of Arrowrock Dam, a belief apparently shared by Petrosky (1990a).

Table 4. Years of probable full seeding of spring chinook spawning areas in the upper Columbia River, with Raymond's (1988) estimated wild smolt progeny outputs.

Brood year	Smolt year	Numbers of smolts passing first dam
1960	1962	833,000
1961	1963	200,000
1964	1966	769,000
1966	1968	1,117,000
1967	1969	642,000
1968	1970	690,000
1969	1971	430,000
		Mean = 668,714
		Median = 690,000

Table 5. Weir catches and estimated total yield of chinook salmon and steelhead smolts from the Wildhorse River in two migration years (from Bell 1961), and percentage that estimated yield makes up of SPM estimate of Petrosky (1990a).

Species	Brood Year	Migratory Year[a]	Weir Catch	Estimated Yield from River	% of SPM
Chinook	1957	1958–1959	2,039	2,208	8.5%
	1958	1959–1960	887	1,110	
Steelhead	1956	1958–1959[b]	10,656	12,898	
	1957	1959–1960	5,861	11,577	

[a] Only through June in 1960. Large catches of migrants were made in July–December, mostly in September–December, in 1958 and 1959. The fall catches likely would consist of presmolts seeking overwintering areas downstream in the Snake River. Thus, 1960 catches must be considered to be incomplete.

[b] Does not include 14 and 74 juveniles trapped in July and August of 1958 and 1959, respectively.

Table 6. Subbasins in the Snake River basin, drainage areas, and runoff per unit area.

Drainage	Area (mi^2)	Annual runoff (acre-feet)	Runoff/mi^2 (acre-ft/mi^2)
Upstream of HCC[a]			
Weiser River above Cambridge	605	457,900	756
Boise River above Boise	2,680	2,201,000	821
Malheur River above Vale	3,880	208,800	54
Malheur River above Warm Springs Reservoir	1,100	136,900	124
Noth Fork Malheur River above Beulah	440	104,500	238
Eagle Creek above Skull Creek	156	229,600	1,471
Owyhee River above Rome	8,000	704,100	88
Bruneau River above Hot Springs.	2,630	281,200	107
Salmon Falls Creek above Hagerman	2,120	115,900	55
Downstream of HCC			
Grande Ronde above Troy	3,275	2,241,000	684
Clearwater River above Spaulding	9,350	11,180,000	1,195
Salmon River above Riggins	13,550	9,103,000	671
Imnaha River above Imnaha	622	373,200	600
Tucannon River above Starbuck	431	123,800	287

[a] No useable information is available for the Burnt or Powder rivers.

Table 7. Subbasins, effective basin areas, and habitat miles in subbasins downstream of the HCC.

Subbasin	Effective basin area (mi^2)	Habitat miles	Miles of habitat per mi^2
North Fork Clearwater	1,360	627	0.461
Grande Ronde	3,720	647	0.173
Salmon	8,501	1,834	0.216
Imnaha	980	223	0.228
			Mean: 0.27

Table 8. Redband trout densities in Weiser River (WR) drainage (MF and EF = Middle and East forks), from Hurley (1995a,b). Gradients are observed except where shown as taken from map. Fish densities were obtained with snorkeling and systematic sampling. Each fifth pool and every tenth of other habitat types were snorkeled. Hurley (1995a,b) did not regard the densities as population estimates.

Stream reach/tributary	Length (km)	Width (m)	Gradient (%)	Fish per 100 m^2
MFWR near USFS boundary	4.6	9.6	3.8	9.5
MFWR upstream Warm Springs Creek in B channel	3.1	7.5	4.8	7.0
MFWR upstream Warm Springs Creek in A channel	1.1	9.1	2.0	10.2
MFWR above Cabin Creek, ends Mica Creek	1.8	8.6	4.7	4.1
MFWR above Mica Creek, ends 325 m above Corral Creek	2.6	8.3	8.0	6.0
MFWR above 25 m above Corral Creek, ends Jungle Creek	3.25	2.9	5.5–12.2	3.6
MFWR Jungle Creek to No Business Creek	0.6	1.0	8.3	2.1
MFWR No Business Creek to Granite Creek	2.11	2.1	6.5	0.2
MFWR Granite Creek to tributary below Road 245 crossing	2.03	1.8	8.6	0
MFWR below Road 245 crossing to bedrock cascade	1.17	1.6	7.0	0
MFWR Fall Creek	3.25	2.9	5.5–12.2	19.5
MFWR Warm Springs Creek	2.11	2.1	8.7	16.5
MFWR Boulder Creek	2.03	1.8	3.0–9.0	19.0
MFWR Cabin Creek	1.17	1.6	7.0	32.0
MFWR Mica Creek	3.87	2.3	4.5–22.0	5.0
MFWR Big Creek	3.17	2.8	3.5–13.7	3.0
MFWR Little Creek	0.72	1.9	5.9 (map)	13.0
MFWR Jungle Creek	2.36	2.8	4.3–12.0	3.0
MFWR Crystal Creek	0.69	2.1	7.5 (map)	10.0
MFWR No Business Creek	2.86	3.1	2.8 (map)	0
MFWR Granite Creek	3.33	2.4	2.8 (map)	0
EFWR Weiser River to Fourth Gulch	4.27	5.8	3.0 (map)	11.5
EFWR Fourth Gulch to Shingle Creek	2.83	62	4.0	10.8
EFWR Shingle Creek to Cold Springs Creek	4.81	5.7	4.0	8.7
EFWR Cold Springs Creek to start B channel above slump	1.62	5.2	5.3	5.9
EFWR above slump end to Dewey Creek	2.23	5.7	4.0	3.7
EFWR Dewey Creek	4.02	1.5	5.0	0.2
Upper EFWR above Dewey Creek	3.54	3.6	3.1 (map)	1.0
Upper EFWR at small north tributary	1.51	3.0	4.7 (map)	0.2
Upper EFWR above spring to A channel	1.04	2.7	4.5	0
Upper EFWR A channel	2.14	2.5	5.8 (map)	0.3
Upper EFWR transition A channel to B channel	0.94	2.6	3.0 (map)	0
Upper EFWR C channel	1.03	2.7	2.6 (map)	0
Upper EFWR B channel	0.83	2.3	3.8 (map)	0
Upper EFWR A channel riparian opening to top of steep cascade	0.62	2.4	6.1 (map)	0

Table 9. Estimated coldwater habitat in various subbasins upstream of the HCC (from Moore 1986).

Stream	Mi	Km	M^2 per km	Total m^2	Mean width m
Bruneau River—ID only, excluding lowest "too warm" 10 mi	250	400	6,333	2,533,200	6.3
Owyhee River—ID only	495	825	4,010	3,308,574	4.0
Jordan Creek	35	58	3710	215,159	3.7
Boise River					
South Fork	105	168	13,339	2,240,952	13.3
Middle Fork	411	658	8,239	5,421,262	8.2
Payette River					
Black Canyon to Banks, including tributaries	47	78	28,516	2,232,805	28.5
Squaw and Willow creeks	71	118	6,089	718,557	6.1
South Fork below Big Falls[a]	26	43	28,348	1,218,964	28.0
Middle Fork with tributaries	23	38	22,435	852,526	22.4
Clear Creek	22	37	6,416	235,459	6.4
North Fork, Banks to Cascade	152	253	8,793	2,224,686	8.8
North Fork above Tamarack Falls-McCall	24	40	29,127	1,165,105	29.1
No. Fork above Big Payette Lake	34	57	2,219	125,848	2.2
Gold Fork with tributaries	49	82	4,870	397,840	4.9
Lake Fork	37	62	4,408	271,993	4.4
Boulder Creek	17	28	4,160	117,728	4.2
Weiser River					
Above Cambridge, including tributaries	196	327	3,976	1,300,152	4.0
Galloway–Cambridge mainstem	24	40	24,662	986,480	24.0
Galloway–Cambridge tributaries	69	115	8,578	986,470	8.6

[a] Area upstream of Big Falls omitted, and Moore's (1986) areas adjusted to lowest 26 mi of South Fork Payette River.

Table 10. Smolt yields from subbasins listed in Table 9, calculated with “poor” and “fair” habitat estimators, and as estimated in Petrosky (1990a).

Drainage	Habitat (m^2)	Chinook SPM		Petrosky (1990a) chinook	Steelhead SPM		Petrosky (1990a) steelhead
		Fair 18/100 m^2	Poor 4.8/100 m^2		Fair 4/100 m^2	Poor 2.4/100 m^2	
Boise River	7,662,214	1,379,199	367,786	1,509,430	306,488	183,893	290,000
Payette River	7,328,706	1,319,168	351,778	1,360,000[a]	293,148	175,889	294,000[b]
Weiser River	2,286,622	411,953	109,758	274,000	91,465	54,879	104,000

[a] Petrosky (1990a) assumed modification of Big Falls to enable fish to reach the upper South Fork Payette River.

[b] See previous footnote.

Table 11. Average densities of juvenile spring/summer chinook and rainbow/steelhead in various stream orders in the South Fork Salmon River (from Platts 1974).

Species	Stream Order			
	2	3	4	5
Chinook	0	0.3	2.3	8.2
Rainbow/steelhead	0.5	0.7	2.7	10.9
Reaches sampled	43	134	87	21

Table 12. Rainbow (rb) and brook trout (bt) numbers per mile in the Owyhee, Bruneau, and Salmon Falls drainages. "One-pass" electrofishing predominated as the fish census tool. ORD = Owyhee River drainage; EF, SF, WF = forks; BD = Bruneau River drainage; SFD = Salmon Falls drainage. "Miles" column indicates length of reach over which population data were obtained in short sample sections.

Drainage	Stream	Reference	Species	Fish per mile (year)	Miles
EFORD	Riffe Creek	NDOW 1978	rb	264 (1978)	3.0
ORD	California Creek	NDOW 1991	rb	738 (1953)	7.0
				low (1991)	
ORD	South Fork California Creek	NDOW 1991	rb	170 (1953)	
				370 (1991)	
ORD	North Fork California Creek	NDOW 1991	rb	341(1953)	
				0 (1991)	
EFORD	Mill Creek	NDOW 1987	rb	773 (1986)	3.4
EFORD	McCall Creek	NDOW 1987	rb	717 (1986)	6.3
EFORD	Trail Creek	NDOW 1987	rb	789 (1986)	10
			bt	285 (1986)	10
EFORD	Van Duzer Creek	NDOW 1987	rb	272 (1986)	7.4
			bt	228 (1986)	7.4
EFORD	Cobb Creek	NDOW 1987	rb	535 (1986)	4.3
			bt	60 (1986)	4.3
EFORD	Lime Creek	NDOW 1987	rb	39 (1986)	2.0
			bt	32 (1986)	2.0
EFORD	Springs Creek	NDOW 1987	rb	26 (1986)	2.5
			bt	53 (1986)	2.5
EFORD	Hutch Creek	NDOW 1987	rb	89 (1986)	1.5
			bt	193 (1986)	1.5
EFORD	Timber Gulch Creek	NDOW 1987	rb	90 (1986)	2.0
			bt	83 (1986)	2.0
EFORD	Sheep Creek	NDOW 1987	rb	2,162 (1986)	1.4
			bt	19 (1986)	1.4
EFORD	Wood Gulch Creek	NDOW 1987	rb	1,251 (1986)	3.7
EFORD	Road Canyon Creek	NDOW 1987	rb	211 (1986)	2.7
EFORD	Gravel Creek	NDOW 1987	rb	46 (1986)	2.6
EFORD	Badger Creek	NDOW 1987	rb	2,232 (1986)	7.5
EFORD	Beaver Creek	NDOW 1987	rb	1,401 (1986)	9.3

Table 12. (Cont.)

Drainage	Stream	Reference	Species	Fish per mile (year)	Miles
EFORD	Fawn Creek	NDOW 1987	rb	1,508 (1987)	6.9
EFORD	Deep Creek	USFS 1978a	rb	924 (1978)	1.5
EFORD	Middle Fork Deep Creek	USFS 1978a	rb	528 (1978)	1.8
EFORD	South Forth Deep Creek	USFS 1978a	rb	290 (1978)	2.9
SFORD	Mill Creek	USFS 1978b	Rb	515 (1978)	3
			bt	158 (1978)	3
SFORD	Burns Creek	NDOW 1985	rb	1,866 (1985)	6.3
SFORD	Marsh / Miller Creek	USFS 1978c	rb	616 (1978)	2.9
SFORD	Jack Creek	USFS 1978d	rb	2,125 (1978)	4.5
			bt	317 (1978)	4.5
SFORD	Chino Creek	BLM 1977	rb	759 (1977)	5.0
SFORD	Snow Canyon Creek	USFS 1978e	rb	607 (1978)	4.6
			rb	1,161 (1956)	?
SFORD	Waterpipe Canyon Creek	BLM 1954	rb	260 (1954)	5.0
			bt	1,890 (1954)	
SFORD	Indian Creek	NDOW 1987	rb	337 (1987)	4.1
SFORD	Winters Creek	NDOW 1987	rb	581 (1987)	5.4
SFORD	Mitchell Creek	NDOW 1987	rb	158 (1987)	3.6
SFORD	Wall Creek	NDOW 1987	rb	616 (1987)	2.0
SFORD	Silver Creek	NDOW 1987	rb + bt	1,200 (1987)	3.2
SFORD	Breakneck Creek	NDOW 1987	rb	211 (1987)	2.8
SFORD	Columbia Creek	NDOW 1987	bt	465 (1987)	5.7
SFORD	Blue Jacket Creek	NDOW 1987	rb	238 (1987)	4.1
			bt	824 (1987)	4.1
SFORD	Boyd Creek	USFS 1978f	rb	1,320 (1978)	4.5
SFORD	Doby George Creek	NDOW 1987	rb	1,320 (1987)	4.3

Table 12. (Cont.)

Drainage	Stream	Reference	Species	Fish per mile (year)	Miles
SFORD	Capp Winn Creek	NDOW 1987	rb	417 (1987)	4.8
SFORD	Burns Creek	NDOW 1985	rb	1,866 (1985)	6.3
BRD	Bruneau River	NDOW 1990	rb	40 (1990)	22.0
BRD	Badger Creek	NDOW 1990	rb	528 (1990)	0.5
BRD	Coon Creek	NDOW 1990	rb	602 (1990)	8.8
BRD	Copper Creek	NDOW 1990	rb	466 (1990)	6.5
BRD	Cottonwood Creek	NDOW 1990	rb	172 (1990)	1.8
BRD	Deer Creek	NDOW 1990	rb	53 (1990)	0.5
BRD	Hicks Creek	NDOW 1990	rb	79 (1990)	1.8
BRD	Little Coon Creek	NDOW 1990	rb	282 (1990)	3.3
BRD	McDonald Creek	NDOW 1990	rb	381 (1990)	9.3
BRD	Meadow Creek	NDOW 1990	rb	528 (1990)	1.3
BRD	Miller Creek	NDOW 1990	rb	623 (1990)	3.6
BRD	Rattlesnake Canyon Creek	NDOW 1990	rb	18 (1990)	2.5
BRD	West Fork Jarbidge River	NDOW	rb	978 (1985)	18.1
		1985	bt	74 (1985)	18.1
BRD	Cougar Creek	NDOW 1993	rb	158 (1992)	3.9
BRD	Dave Creek	NDOW 1993	rb + bt	211 (1992)	2.8
BRD	Jarbidge River	NDOW 1993	rb + bt	317 (1992)	13.5
BRD	Fall Creek	NDOW 1993	rb + bt	145 (1992)	3.8
BRD	Robinson Creek	NDOW 1993	rb	475 (1992)	6.2
BRD	Slide Creek	NDOW 1993	rb + bt	185 (1992)	5.4
BRD	Indian Johnnie Creek	NDOW 1989	rb	160 (1989)	5.1

Table 12. (Cont.)

Drainage	Stream	Reference	Species	Fish per mile (year)	Miles
BRD	Little Telephone Creek	NDOW 1989	rb	766 (1989)	1.8
BRD	Meadow Creek	NDOW 1989	rb	264 (1989)	?
BRD	Sand Creek	NDOW 1989	rb	95 (1989)	6.6
BRD	Seventy-six Creek	NDOW 1989	rb	313 (1989)	9.1
BRD	Telephone Creek	NDOW 1989	rb	148 (1989)	7.6
BRD	Willow Creek	NDOW 1989	rb	959 (1989)	7.2
SFD	Sun Creek	NDOW 1997	rb	634 (1996)	?
SFD	Canyon Creek	NDOW 1997	bt	4,309 (1996)	?
SFD	Wilson Creek	NDOW 1996	rb	972 (1995)	?
SFD	Salmon Falls Creek—Lily Grade	Warren and Partridge 1995	rb	274 (1994)	
SFD	Salmon Falls Creek above Cedar Creek	Warren and Partridge 1995	rb	129 (1994)	
SFD	Salmon Fals Creek near Hollister	Warren and Partridge 1995	rb	965 (1994)	
			bt	88 (1994)	
SFD	Salmon Falls Creek below SF Dam	Warren and Partridge 1995	rb	2,155 (1994)	
			bt	5,297 (1994)	

Rainbow

n = 67

Used latest value if more than one.

Median = 475 per mi or 285 per km

Table 13. Trout densities in streams draining Blue Mountains. Based on one-pass electrofishing without blocking nets, the estimates are minimums. PR = Powder River (1990); BR = Burnt River (1990); SR = Snake River (1990); EF, NF, SF = forks. Stream sections with illegible data or missing segment lengths were omitted from the table.

		Juveniles		Adults						
Drainage Stream	**Ref. No**	**Fish per mi**	**m^a**	**Fish per mi**	**m^a**	**Width m**	**Slope %**	**Dens. Juv./ 100 m^2**	**Dens. Adults/ 100 m^2**	**Land Use**
PR Eagle Creek	ODFW 1990	215	60	54	60	8.6	2.0	1.44	0.36	CA
PR Eagle Creek	ODFW 1990	134	100	81	100	12.2	2.0	0.41	0.25	CS
PR Eagle Creek	ODFW 1990	—	86	6	86	10.5	1.5	0	0.22	SG
PR EF Eagle Creek	ODFW 1990	154	63	51	63	7.3	1.0	0.65	0.44	LG
PR EF Eagle Creek	ODFW 1990	254	82.5	78	82.5	5.4	3.0	2.9	0.89	MT
PR Grave Creek	ODFW 1990	0	8.3	0	8.3	1.1	3.0	0	0	SG
PR Jim Creek	ODFW 1990	326	39.5	122	39.5	1.6	4.0	12.6	4.7	SG
PR Little Eagle Creek	ODFW	810	19.9	891	19.9	5.2	3.5	9.7	10.6	LG
PR Little Eagle Creek	1990	475	37.3	86	37.3	2.4	2.0	12.3	2.2	LG
PR Long Creek	ODFW 1990	496	32.5	0	32.5	0.94	4.0	32.7	0	LG
PR Paddy Creek	ODFW 1990	197	57	56	57	2.9	3.0	4.2	1.2	SC
PR Spring Creek	ODFW 1990	361	58	56	58	1.06	3.0	21.1	3.25	SC
PR Summit Creek	ODFW 1990	0	27.1	60	27.1	2.5	1.5	0	1.5	CA
PR Trout Creek	ODFW 1990	762	31.7	0	31.7	0.92	1.0	51.4	0	CA
PR WF Eagle Creek	ODFW 1990	372	64.9	25	64.9	3.59	5.5	6.4	0.43	SG
BR Alder Creek	ODFW	665	29.1	-	19.9	1.16	1.5	35.5	0	SC
BR Alder Creek	1990	0	13.5	0	13.5	2.07	1.0	0	0	AG
BR Antler Creek	ODFW 1990	150	53.6	0	53.6	0.67	1.0	12.3	0	HG
BR Barney Creek	ODFW 1990	70	46	35	46	1.48	20	2.7	4.0	LG

Table 13. (Cont.)

		Juveniles		Adults						
Drainage Stream	**Ref. No**	**Fish per mi**	**m^a**	**Fish per mi**	**m^a**	**Width m**	**Slope %**	**Dens. Juv./ 100 m^2**	**Dens. Adults/ 100 m^2**	**Land Use**
BR Bear Creek	ODFW 1990	244	33	0	46	0.66	2.5	21.9	0	LG
BR Beaver Creek	ODFW 1990	162	19.9	0	19.9	0.8	2.0	10.5	0	HG
BR Big Creek	ODFW 1990	68	47	0	47	1.34	1.0	3.6	0	HG
BR Bullrun Creek	ODFW 1990	102	47.5	68	47.5	2.73	2.0	1.75	1.24	LG
BR Camp Creek	ODFW 1990	245	52.6	0	52.6	1.48	1.0	12.75	0	LG
BR Camp Creek		40	40	0	40	1.02	1.0	4.95	0	AG
BR China Creek	ODFW 1990	181	44.5	0	44.5	1.42	1.0	7.1	0	HG
BR EF Camp Creek	ODFW 1990	187	60.3	0	60.3	0.86	2.0	11.7	0	LG
BR Elk Creek	ODFW 1990	297	52	27	52	2.79	3.0	7.6	0.69	LG
BR Geyser Creek	ODFW 1990	1075	9	0	9.0	1.7	1.0	23.9	0	MI
BR Greenhorn Creek	ODFW 1990	1261	17.9	0	17.9	1.3	1.5	39.5	0	SG
BR King Creek	ODFW 1990	107	45	0	45	0.3	1.0	0.22	0	LG
BR Last Chance Creek	ODFW 1990	147	55	29	55	2.4	2.5	4.4	0.88	LG
BR Last Chance Creek		222	50.7	63	50.7	0.92	2.0	15.0	4.3	LG
BR Lawrence Creek	ODFW 1990	287	45	0	45	4.0	1.0	4.4	0	LG
BR Lawrence Creek		236	75	22	75	3.5	1.0	4.2	0.38	LG
BR Lawrence Creek		387	50	64	50	2.5	2.0	9.6	1.6	SG
BR Lookout Creek	ODFW 1990	79	15	0	15	2.5	3.0	6.7	0	SC
BR Manning Creek	ODFW 1990	550	37.5	100	37.5	1.2	3.0	24.4	4.4	HG
BR Manning Creek		243	39.8	0	37.5	0.45	1.5	33.5	0	LG
BR Middle Burnt	ODFW 1990	117	55	0	55	0.40	1.0	18.0	0	HG
BR Middle Willow	ODFW 1990	859	55	29	55	1.0	1.0	9.0	1.8	HG
BR NF Dixie Creek	ODFW 1990	0	56.5	86	56.5	1.19	1.0	0	4.4	HG
BR NF Dixie Creek		0	194	8	194	1.36	1.0	0	0.38	LG
BR NF Dixie Creek		131	159.5	10	159.5	0.29	1.0	6.3	2.1	LG
BR NF West Camp Creek	ODFW 1990	180	89.7	0	89.7	2.36	2.0	4.7	0	LG

Table 13. (Cont.)

Drainage Stream	**Ref. No**	**Juveniles**		**Adults**		**Width m**	**Slope %**	**Dens. Juv./ 100 m^2**	**Dens. Adults/ 100 m^2**	**Land Use**
		Fish per mi	**m^a**	**Fish per mi**	**m^a**					
BR North Burnt	ODFW 1990	232	55.5	0	55.5	0.95	1.0	15.2	0	SG
BR SF Camp Creek	ODFW 1990	424	49.5	0	49.5	1.38	1.0	26.3	0	?
BR Sisley Creek	ODFW 1990	0	32.3	498	32.3	2.42	1.5	0	12.8	AG
BR Sisley Creek		288	61.5	210	61.5	1.75	1.5	10.2	7.4	SG
BR Sisley Creek		1116	13	992	13	1.7	1.0	40.7	36.2	SG
BR Sisley Creek		532	51.5	63	51.5	0.31	1.5	106.5	3.9	SG
BR Snow Creek	ODFW 1990	144	33.5	0	33.5	0.81	3.0	11.0	0	SC
BR Spring Creek	ODFW 1990	0	60	0	60	0.7	3.5	0	0	CC
BR Stevens Creek	ODFW 1990	191	42.3	0	42.3	0.75	3.0	16.9	0	LG
BR Thornton Creek	ODFW 1990	176	18.3	0	18.3	0.42	2.0	26.0	0	SG
BR Trout Creek	ODFW 1990	524	27.7	0	27.7	1.0	1.0	32.5	0	LG
BR Trout Creek		270	23.9	0	23.9	0.65	1.0	25.6	0	HG
BR WF Burnt Creek	ODFW 1990	265	30.5	0	30.5	1.36	1.0	12.1	0	HG
BR WF Burnt Creek		81	40	0	40	0.8	2.0	2.5	0	HG
SR Fox Creek	ODFW 1990	105	15.3	0	15.3	1.31	4.0	0.5	0	LG
						n = 46				
						Total redband per mi = 215 or 129 per km				

[a] Length of stream segment sampled in meters. This length used to estimate fish per mile.

Table 14. Streams and sites in streams with and without redband trout in the Owyhee Resource Management Area (Table FISH-4 in BLM 1999), and fish densities (Table FISH-3 in BLM 1999).

(1) Streams and sites lacking redband, with river mile and year of observation	(2) Streams with redband, with river mile and year of observation	(3) Redband/100 m^2 in Column (2)
	Boulder Creek 8.0 (1996)	7.3
	Boulder Creek 9.8 (1977)	1.0
	Boulder Creek 12.6 (1993)	7.8
	Boulder Creek 14.8 (1977)	54.0
	Cabin Creek 3.4 (1977,1996)	29.2
	Castle Creek 23.4 (1976, 1977)	23.5
	Combination Creek 3 (1976, 1977)	44.0
	Corral Creek 1.2 (1977)	1.0
	Cow Creek 32.8 (1977, 1996)	66.1
Deep Creek 34.4 (1993, 1997)	Deep Creek 34.4 (1976, 1977)	18.0
Flint Creek 3.9 (1993)	Flint Creek 3.9 (1977, 1993, 1997)	51.9
	Jordan Creek 67.7 (1996)	0.3
	Jordan Creek 70.8 (1977, 1993)	1.25
	Jordan Creek 75.9 (1997, 1993, 1997)	6.9
	Jordan Creek 87.7 (1977, 1993)	0.75
	Jordan Creek 88.3 (1976, 1993, 1997)	11.9
	Jordan Creek 95.4 (1976, 1993, 1997)	22.1
	Jordan Creek 97.9 (1996)	18.9
Josephine Creek 0.6 (1996)		
	Jump Creek 5.6 (1994)	58.0
	Jump Creek 5.9 (1994)	17.3
	Jump Creek 10.2 (1977))	120.0
	Juniper Creek 2.0 (1991, 1996)	4.1
	Juniper Creek 2.8 (1991)	1.0
Little Owyhee River 0.2 (1995) (dry)		
Little Owyhee River 13.0 (1995) (dry)		
Little Squaw Creek 0.2 (1997)		
Macks Creek 0.2 (1997)		
McBride Creek 10 (1996)		
	Nip & Tuck Creek 3.0 (1993)	102.0
	North Fork Castle Creek 3.7 (1996)	18.0
North Fork Owyhee River 11.8 (1997)	North Fork Owyhee River 11.8 (1991)	1.0
	North Fork Owyhee River 14.4 (1991, 1996)	1.2
	Owyhee River 184.0 (1995)	0.32
	Pickett Creek 10.2 (1976, 1996)	19.1

Table 14. (Cont.)

(1) Streams and sites lacking redband, with river mile and year of observation	(2) Streams with redband, with river mile and year of observation	(3) Redband/100 m^2 in Column (2)
Red Canyon Creek 13.5 (1993)	Red Canyon Creek 0.1 (1997)	5.7
	Red Canyon Creek 2.0 (1991, 1993)	19.2
	Red Canyon Creek 13.4 (1991, 1993)	1.3
	Red Canyon Creek 13.5 (1991)	23.0
Reynolds Creek 2.8 (1994), 6.6 (1994) 23.7 (1994) (dry)	Reynolds Creek 6.6 (1997)	19.7
	Reynolds Creek 23.7 (1976, 1977, 1997)	14.7
	Rock Creek 3.7 (1996)	1.0
	Salmon Creek 0.6 (1997)	110.7
	Scotch Bob Creek 0.7 (1997)	2.0
	S. Boulder Creek 1.6 (1996)	47.6
	S. Boulder Creek 11.2 (1977)	63.0
	Sinker Creek 7.6 (1977)	34.0
	Sinker Creek 8.1 (1976)	21.0
	Sinker Creek 16.0 (1997)	18.3
	Sinker Creek 17.6 (1977)	4.0
	S. Mountain Creek 6.6 (1977, 1996)	63.0
South Fork Owyhee River 3.0, 19.0, 29.0 (1995)		
Squaw Creek (N) 4.8, 8.7 (1997)		
Squaw Creek (S) 0.0 (1976)		
	Succor Creek 54.1 (1976)	30.0
	Williams Creek 3.1 (1976, 1977)	28.0
	Williams Creek 7.0 (1976)	4.0
	Williams Creek 7.9 (1977)	6.0
		Median **18.0**

Table 15. Summary of paradigms of possible use in estimating smolt output from subbasins upstream of the HCC.

Paradigm	Spring/summer chinook smolts			Steelhead smolts			Fall chinook smolts
	Fair	All	Poor	Fair	All	Poor	
1. Smolts per mi^2 of effective drainage		219			91		n/a
Calculated from Buckman 1990[a]							
2. Smolts per mi^2 of effective drainage		212			83		n/a
Calculated from Raymond 1979[b]							
3. Smolts per 100 m^2	18		5	4		2.4	n/a
NPPC database[c]							
4. Smolts per km, > 10 m wide	1,800		500	400		240	n/a
NPPC database[d], assumed stream order 5 or greater							
5. Smolts per km, 5 m wide	900		250	200		120	n/a
NPPC database[e], assumed stream order 4							
6. Smolts per km, 2.5 m wide	117		33	52		31	n/a
Assumed stream order 3.	13% of order 4 (see Table 32 in Platts 1974)			26% of order 4 (see Table 32 in Platts 1974)			
7. Smolts per km, all widths		310–574			121–225		2,715
PFMC (1979)[f, g]							
8. Steelhead smolts per km	912		401	357		157	n/a
Adjusted from Thurow (1987)[h]							
9. Smolts per km		674[j]			264		n/a
Adjusted from GAFM (WDFW 1999)[i]							
10. Smolts per km, Snake River		n/a			n/a		31,786
							NPPC database
11. Smolts per km, Snake River		n/a			n/a		31,248
Homedale to Swan Falls Dam							Petrosky (1990b)
12. Smolts per km, Snake River		n/a			n/a		11,974
Upper Brownlee Reservoir to Swan Falls Dam							adjusted from Petrosky (1990b)[k]
13. Smolts per mi, Snake River		n/a			n/a		19,957
Upper Brownlee Reservoir to Swan Falls Dam							adjusted from Petrosky (1990b)[l]
14. Smolts per km, Snake River		n/a			n/a		31,248
Upper Swan Falls Reservoir to C.J. Strike Dam							Petrosky (1990b)
15. Smolts per km, Snake River		n/a			n/a		31,248
Upper C.J. Strike Reservoir to Bliss Dam							Petrosky (1990b), adjusted to 15,624 in uppermost 19.2 km

Table 15. (Cont.)

	Spring/summer chinook smolts			Steelhead smolts			Fall chinook smolts
	Fair	**All**	**Poor**	**Fair**	**All**	**Poor**	
16. Smolts per mi^2 of watershed		106			79		n/a
Based on U.S. v. Oregon method as applied in Grande Ronde River							
17. Smolts per mi^2 of effective basin in Grande Ronde River and U.S. v. Oregon smolt output		116			87		n/a
18. Redband "smolts" per km surrogate, 10 sites in Weiser River > 5 m wide		579 [m]			224		n/a
19. Redband "smolts" per km surrogate, 67 sites in Owyhee River, Bruneau River, Salmon Falls Creek[n]	291 (all sites) 559 (Salmon Falls Creek)			114 (all sites) 219 (Salmon Falls Creek)			n/a

[a] See earlier text.

[b] See earlier text.

[c] Adjusted for chinook to Rich et al. (1992).

[d] Adjusted for chinook to Rich et al. (1992) and an assumed 40% parr-smolt survival.

[e] Adjusted for chinook to Rich et al. (1992).

[f] PFMC (1979) estimated full seeding would require 124,000 chinook salmon adults in the 1970s. See Section 3.2 for necessary adjustments to arrive at 310–574 smolts per km.

[g] Steelhead numbers derived from ratio of 83 steelhead to 212 chinook, per Paradigm 2. See description in Section 2 of effective basin paradigm.

[h] Width of habitat in South Fork Salmon River equals 11.9 m, calculated from IDFG (1985). Chinook based on ratio of chinook to steelhead 212/83; see Section 2.

[i] Gradient 0 to 10%.

[j] Estimated from ratio of 212 chinook smolts to 83 steelhead smolts, per Paradigm 2. See Section 2.

[k] Assumes, in accord with Petrosky (1990b), that 89% of all spawning downstream of Swan Falls Dam would occur between Givens Hot Springs and Swan Falls Dam (41 mi). Thus, total yields calculated by Petrosky (1990b) would be prorated as 41/107 to the reach between upper Brownlee Reservoir and Swan Falls Dam (107 mi).

[l] Assumes that virtually all spawning would occur between Givens Hot Springs and Swan Falls Dam (41 mi). Thus, yields calculated by Petrosky (1990b) would be prorated as 41/107 to the reach between upper Brownlee Reservoir and Swan Falls Dam (107 mi).

[m] Chinook smolts based on ratio of 212 chinook to 83 steelhead. Also see Table 17.

[n] See footnote *m*. Census data for Owyhee and Bruneau rivers are based on single-pass electrofishing. Small size of streams should lead to high first-pass proportion of population in sites. Four sites in Salmon Falls Creek had three-pass census.

Table 16. Smolt yields per mi^2 of subbasin, estimated with the SPM in subbasins downstream of the HCC.

	Chinook smolts per mi^2	Steelhead smolts per mi^2	Fall chinook smolts per mi^2
Full Imnaha River drainage (NPPC database)[a]	806	212	n/a
Full Pahsimeroi River basin (NPPC database)[b]	187	36	n/a
Little Salmon River (NPPC database)[c]	449	204	n/a
Full Middle Fork Salmon River drainage (NPPC database)[d]	958	290	n/a

[a] Total smolt yield summed for all streams in Imnaha River basin from NPPC, adjusted as per Rich et al. (1992). Basin area from Interior Columbia Basin Ecosystem Management Project and S. Fletcher (Wallowa-Whitman National Forest, pers. comm.).

[b] Pahsimeroi River basin, 825 mi^2, considered “fair” habitat (Class 3) by IDFG (1991). Chinook yields adjusted as per Rich et al. (1992). The river disappears into the substrate for part of its length.

[c] Habitat rating by NPPC Class 3 in mainstem; Class 1 in Rapid River > hatchery weir; Hazzard, Hard, Boulder creeks Class 1; other tributaries Class 2.

[d] Middle Fork Salmon River (considered pristine, Class 1) area of 1,490 mi^2 includes all basin upstream of and including Loon Creek. The yield of chinook adjusted as per Rich et al. (1992).

Table 17. Steelhead smolts per kilometer from selected parameters, compared with redband densities as surrogates for steelhead parr.

Steelhead paradigm	**Estimator smolts per km**
Smolts per km, 10 m wide	240 to 400
NPPC database	(midpoint 320)
Smolts per km, 5 m wide	120 to 200
NPPC database	(midpoint 160)
Smolts per km, 2.5 m wide	31 to 52
NPPC database	(midpoint 41.5)
Smolts per km	157 to 357
Adjusted from Thurow (1987)	
Smolts per km, adjusted from GAFM (WDFW 1999).	264
Smolts per km, adjusted from PFMC (1979)	121 to 225

Redband “smolts” as steelhead surrogates	**Parr and “smolts”**
67 sites in Owyhee and Bruneau rivers and Salmon Falls Creek[a]	Parr median 289 = 116 smolts
4 sites in Salmon Falls Creek (included in the 67 sites)	Parr mean 384 = 154 smolts
	Parr mean 547 = 219 smolts
46 sites in Blue Mountains	Parr median 351 = 134 smolts
35 sites in Weiser River[b]	Parr median 106 = 42 smolts
Among the 35 sites, 10 sites > 5 m wide	Parr mean 561 = 224 smolts

[a] Population estimates in Salmon Falls Creek were based on 3-pass electrofishing.
[b] Based on systematic sample census with snorkeling.

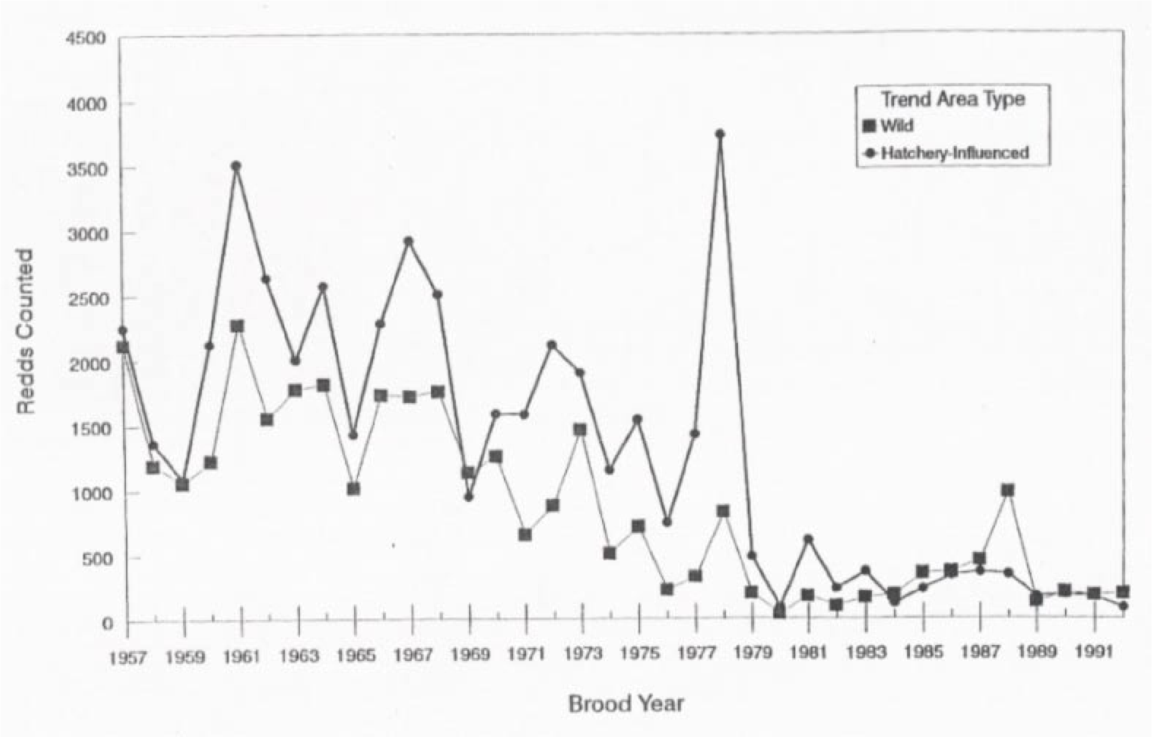

Figure 1. Numbers of spring chinook salmon redds counted in Salmon River drainage wild and hatchery-influenced areas, 1957−1992. Hatchery influence began in 1981 at the Sawtooth Hatchery weir and in 1984 at the East Fork Salmon River weir (reprinted from Figure 2 in Hassemer 1993).

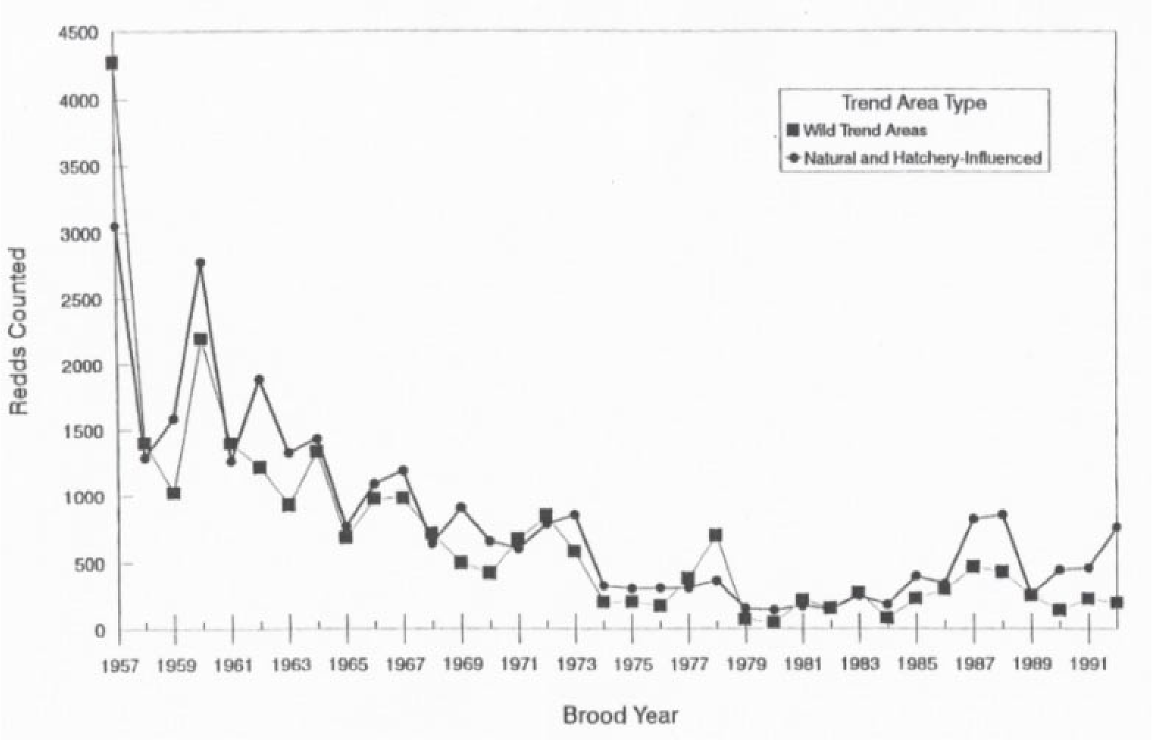

Figure 2. Numbers of summer chinook salmon redds counted in Salmon River drainage wild, natural, and hatchery-influenced trend areas, 1957–1992. Hatchery influence began at the South Fork Salmon River weir in 1980 (reprinted from Figure 3 in Hassemer 1993).

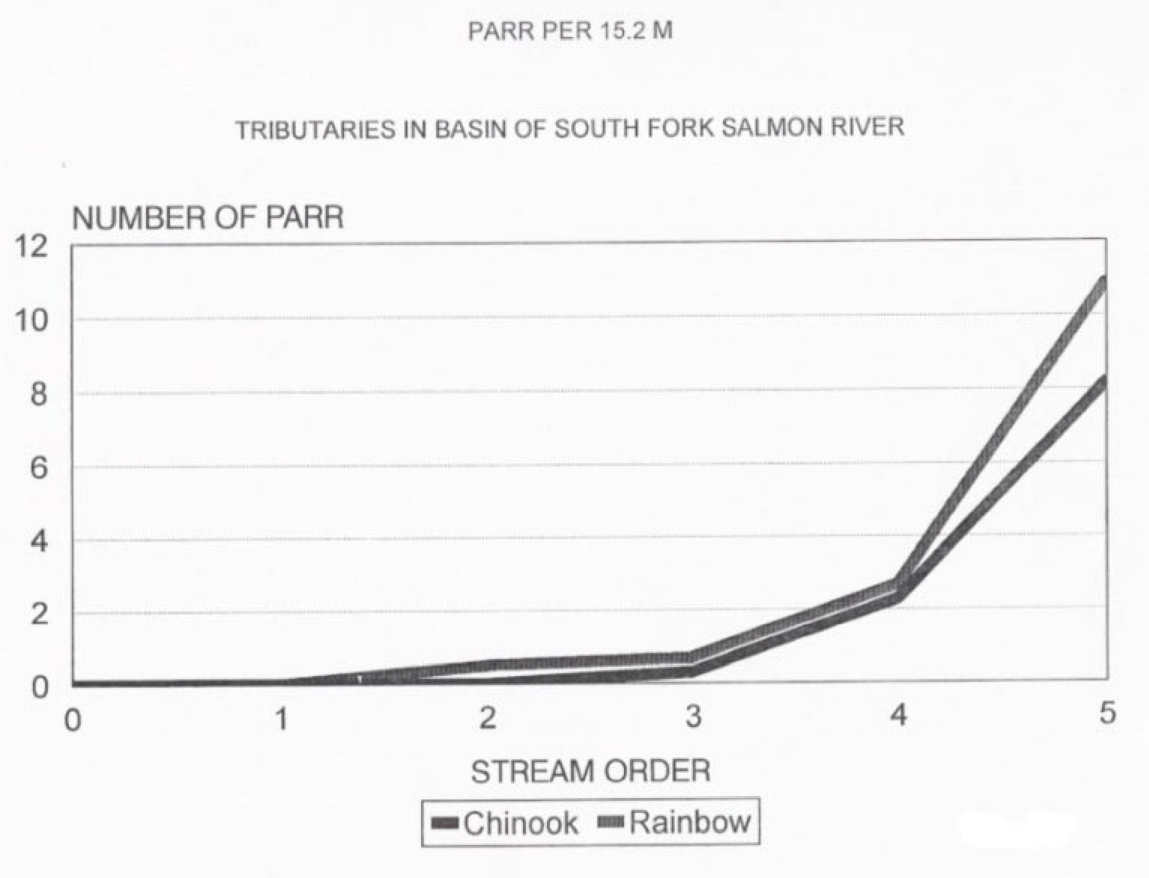

Figure 3. Number of Parr per 15.2 m relative to stream order for chinook salmon and rainbow trout in South Fork Salmon River basin tributaries (reprinted from Platts 1974).

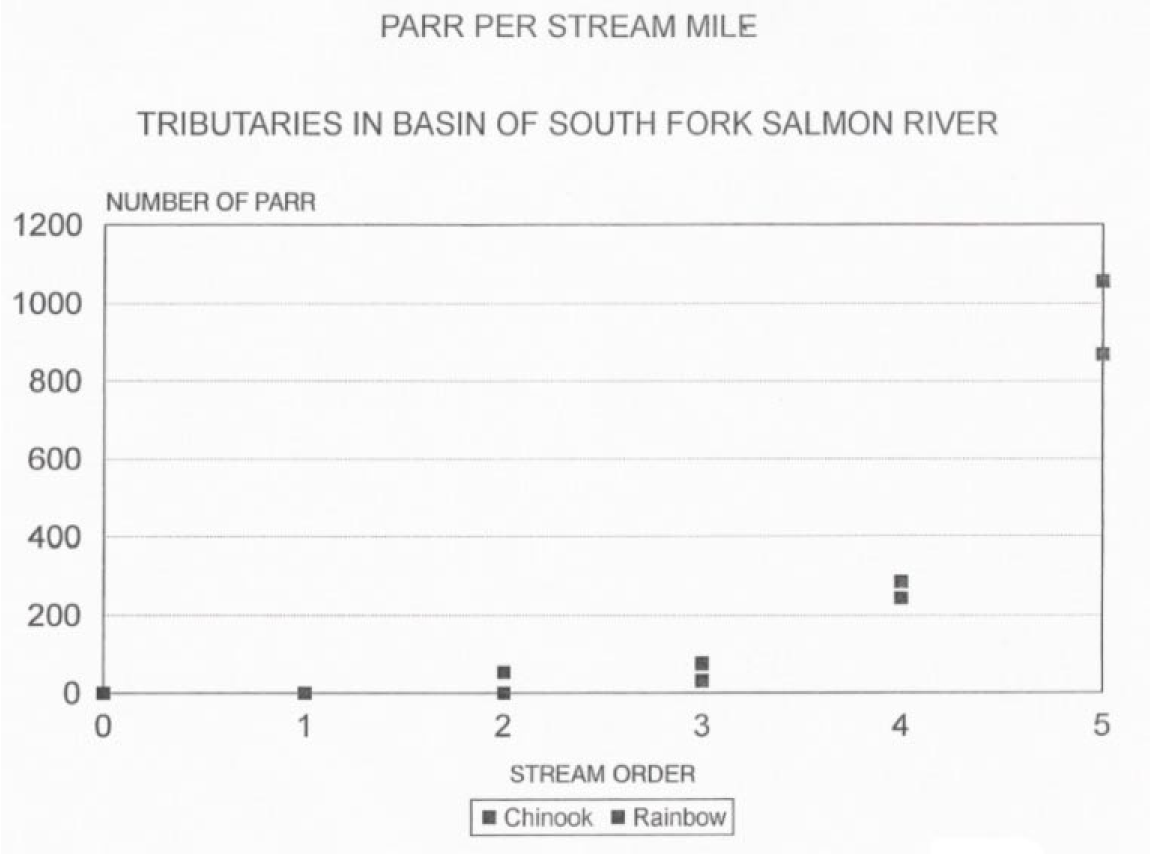

Figure 4. Number of parr per stream mile by stream order for chinook salmon and rainbow trout in South Fork Salmon River basin tributaries (reprinted from Platts 1974).