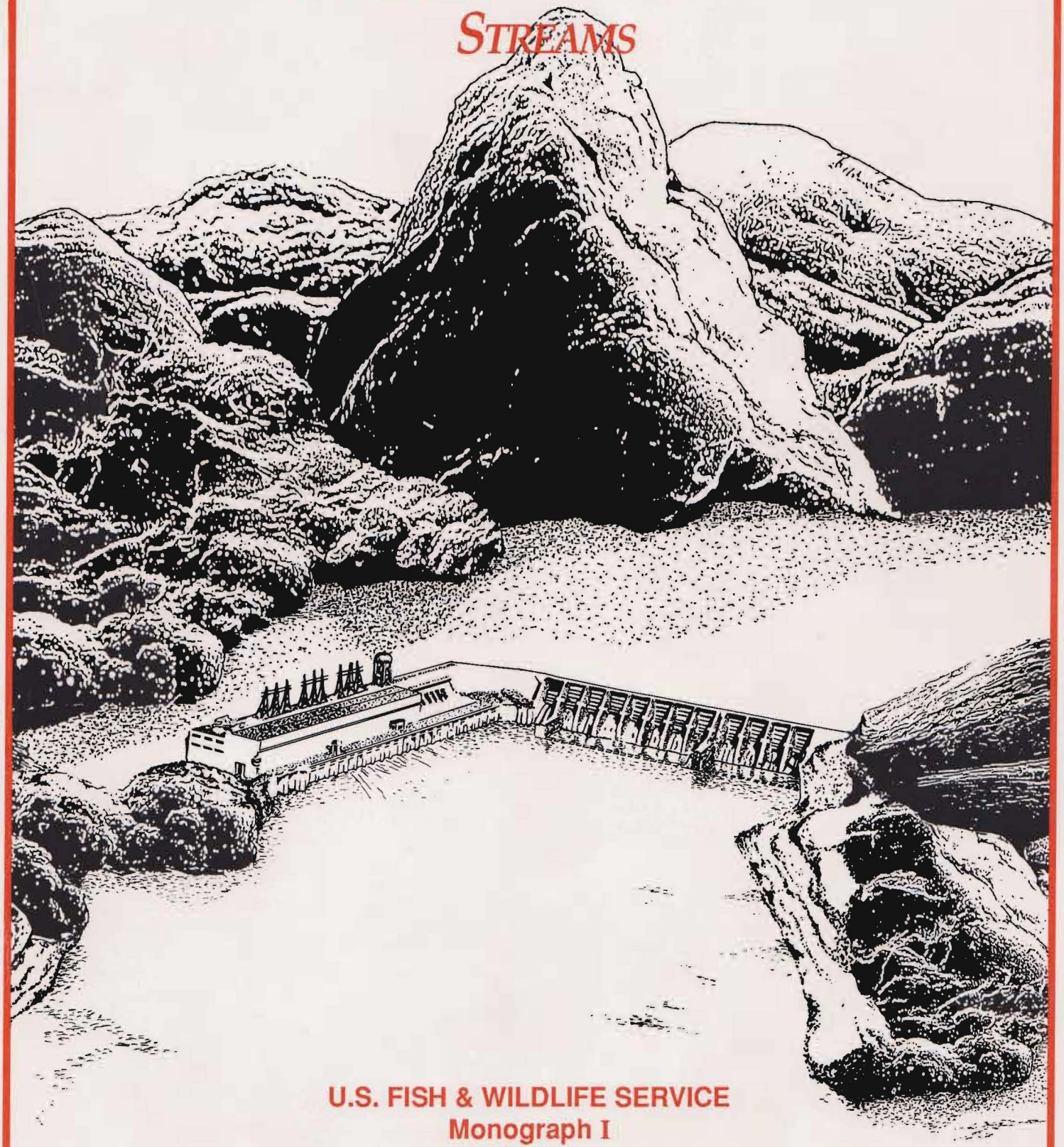
Production and Habitat of Salmonids in Mid-Columbia River Tributary Streams



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The Cover: Fisheries issues are rarely black and white; they are typically colored by the biases of people. Likewise the cover artwork is not what it appears to be. It is in fact a pen and ink drawing of a hydroelectric dam on the mid-Columbia River, but surrounded by a collage of scanning electron photomicrographs arranged by Texas Tech University artist Randy Bouse. The photomicrographs were prepared by Bill Lamoreaux, Memphis State University, from tissues of chinook salmon magnified from 100 to 20,000 times. (Adapted from Fisheries, A Bulletin of the American Fisheries Society, Vol. 14, No. 3, 1989, courtesy Nick C. Parker, Texas Cooperative Fish and Wildlife Research Unit.)

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PRODUCTION AND HABITAT OF SALMONIDS IN MID-COLUMBIA RIVER TRIBUTARY STREAMS

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OVERVIEW

The construction of Grand Coulee Dam (River Mile 597) in 1939 blocked anadromous salmonids from 1,140 mi of the upper Columbia River. To preserve the runs, returning salmon and steelhead were trapped at downstream Rock Island Dam (RM 453) and relocated to upstream tributaries or to the new Leavenworth, Entiat, and Winthrop National Fish Hatcheries. Goals of the Grand Coulee Fish Maintenance Project (GCFMP) were to maintain the production of salmon and steelhead in the mid-Columbia as it existed when Grand Coulee Dam was built. This was to be achieved by restoring natural propagation in the Wenatchee, Entiat, Methow, and Okanogan rivers below Grand Coulee Dam, supplemented with hatchery fish if needed.

In this report we evaluate the GCFM Project. We (1) quantify rearing area and number of chinook salmon and steelhead spawners in the Wenatchee, Entiat, and Methow river drainages; (2) use rearing area and observed standing crop to estimate production; and (3) assess the impacts of settlement on production and habitat.

About half of the area used by anadromous fish in the three drainages was physically measured. Samples were expanded to account for total wetted area (3,702 ac) at low flow in September. We assessed escapements to the Wenatchee, Entiat, and Methow Rivers as the difference between adult counts at appropriate dams. Wild adult escapement equaled interdam count less fish that returned to hatcheries or were harvested. We divided spawner/redd ratios of 2.4 and 3.1 into interdam counts of wild spring and summer/fall chinook salmon, respectively, to account for prespawning mortality. Prespawning mortality of steelhead was estimated at 2.4%. We used an egg deposition of 4,600 eggs per spring chinook salmon female, 5,240 eggs per summer/fall chinook salmon female, and 5,560 eggs per steelhead female. Annual losses of stream salmonids are universally high, and we used 60% overwinter mortality for age-0 fish.

Fish densities were assessed by snorkelers, sodium cyanide census, or both, in 2.1% of the anadromous fish habitat. Non-anadromous headwaters of the Methow River were also sampled. Sampled fish habitat was ranked with the Habitat Quality Index (HQI), which rates late summer flow, annual flow variation, water temperature, food, cover, water velocity, nitrate nitrogen, and

stream width with an index of non-salmonids substituted for bank erosion.

Because temporal and spatial variations in fish abundance confound population estimates based on standing crop, we assessed densities, biomass, growth, and survival of fish spawned and stocked in an Index Area of Icicle Creek, tributary to the Wenatchee River, in 1983 and 1985 to 1989. We also drew on historical records and other evidence, to provide perspective on this and other problems relating to salmon and steelhead abundance and habitat over time.

The Wenatchee, Entiat, and Methow river drainages are in the coldest of 24 western climate zones. The latitude is the same as that of Duluth, Minnesota, and Bangor, Maine. Mean basin elevation is about one mile above sea level. Because the Cascade Mountains wring most of the marine influence out of the air that passes west to east across them, arctic air plays a major role in the climate.

KEY CONCLUSION: Mid-Columbia River tributaries represent harsh environments for fish and should not be confused with the more studied, benign, coastal streams of the Pacific Northwest.

Extrapolating rearing densities for the total drainage rearing areas according to HQI ranking produced estimates of standing crop encompassing temporal and spatial variations in abundance.

KEY CONCLUSION: Mid-Columbia River tributaries exhibited the lowest mean salmonid biomass (2-3 g/m^2) in the western United States.

A mean of 8,432 naturally-produced spring chinook salmon returned to the Wenatchee (4,465), Entiat (1,247), and Methow (2,719) rivers 1967-87. We assumed mean dam loss of 5%, then calculated adult abundance at the Columbia River mouth as 12,600. In-river catch averaged 20%, which increased the estimate of adults to 15,750. A 10% correction for ocean harvest gave a total run size of 17,400. Smolt-to-adult survival ranged from 2.0 to 10.1%.

From 1976 through 1988, the GCFMP hatcheries released 37.1 million (18/lb. or 2.0 million lbs.) yearling spring chinook salmon. A total of 66,836 returned to the hatcheries as adults or 0.18%. Corrected for 5% interdam loss, incidental in-river catch of 8%, and ocean harvest of 10%, total run size was 108,000 fish (1.5 million lbs.) or 0.29% total survival. Smolt-to-adult survival ranged from 0.16 to 0.55%.

KEY CONCLUSION: Smolts of naturally produced spring chinook salmon were 13 to 100 times as viable as hatchery smolts.

Mean escapement for naturally produced summer/fall chinook salmon was 15,497 fish to the Wenatchee (12,012), Entiat (100), and

Methow (3,385) rivers in 1967-87. Corrected for 5% interdam loss, incidental in-river catches of 9%, and ocean harvest of 75% in 1967-84, and more recent harvests of 40%, total run size was about 86,000 naturally-produced summer/fall chinook (Wenatchee - 68,600; Entiat - 570; Methow - 19,350). Smolt-to-adult survival ranged from 2.2 to 8.0%.

Mean smolt-to-adult survival (0.33% - fishery harvest and spawning escapement) ranged from 0.28 to 0.46% for 13.8 million tagged fall chinook salmon, brood years 1978-81, from lower Columbia River hatcheries.

KEY CONCLUSION: Smolts of naturally produced summer/fall chinook salmon from mid-Columbia River tributaries were 8 to 17 times as viable as 13.8 million tagged hatchery smolts released from lower Columbia River hatcheries.

Steelhead differ from Pacific salmon in many ways, but are similar to Atlantic salmon. Steelhead smolts are usually larger (143 to 207 mm) and rear longer in freshwater (up to 7 years) than those of coho and chinook salmon (70-120 mm for those that rear a year of more in freshwater).

KEY CONCLUSION: Unlike salmon, hatchery smolts evidently are as viable as naturally produced smolts (mean, 6.4%; range 1.3-14.3%).

How long wild steelhead stay in mid-Columbia River tributaries is mostly a function of water temperature. Smoltification may occur in 2 years in warmer mainstems or may take 7 years in cold headwaters. This results, together with 1-3 years in the ocean, in as many as 10 overlapping brood years and 16 age classes.

KEY CONCLUSION: Most fish that do not emigrate downstream early in life from the coldest environments are thermally-fated to a resident (rainbow trout) life history regardless of whether they were the progeny of anadromous or resident parents.

O. mykiss is also an extremely adaptable species in much of the developed world where it has been introduced. Many stocks, strains, and life forms are recognized, and the species has become the aquatic counterpart to the white rate in laboratory research.

KEY CONCLUSION: Polymorphism, as applied to arctic char, is equally applicable to summer steelhead in the mid-Columbia River, where distribution ranges throughout thermal bounds.

Estimates of escapement became possible after the completion of Rock Island Dam in 1933. Because only four data points were available before Grand Coulee Dam began reducing smolt survival in 1937, a spawner-recruit curve was not fitted. Annual mean number of steelhead recruits before damming was 14,495, 2.33 times the mean of 6,218 immediately after (1940-43) damming. Recruits at

maximum sustained yield (MSY) and escapement were 19,169 and 7,126 fish, respectively, from 1940 to 1954 according to Beverton-Holt-curve analysis; Ricker curve equivalents were 16,041 and 4,904 fish.

KEY CONCLUSION: In the post-hydroelectric development period (1979-89) wild steelhead have not been able to sustain themselves at any level using sock recruitment analysis. The success of hatchery steelhead, unlike the failed hatchery programs for salmon, which helped insure that wild chinook were not overharvested, surely is partially to blame.

The premise of the GCFMP was that abundance of steelhead was limited by dams in the Wenatchee, Entiat, and Methow rivers.

KEY CONCLUSION: Our stock recruitment curves point to overfishing in the lower Columbia River.

Although salmon are more advanced phylogenetically, the steelhead's life history is more fail-safe when habitat or populations are perturbed. Stochastic effects of environmental variability that would extirpate a salmon population affect steelhead far less.

KEY CONCLUSION: Preserved as headwater rainbow trout, steelhead above Grand Coulee Dam may not yet be extinct.

Low returns of hatchery chinook salmon seem to lie outside the purview of fish health and genetics. Diseases and genetics obviously are important to survival, but various evidence indicates that the behavior of chinook salmon in hatcheries is conditioned differently from that of wild fish.

KEY CONCLUSION: There was little difference in estimated survival of spring chinook salmon from mid-Columbia River hatcheries (0.29%) and 13.8 million tagged fall chinook from lower river hatcheries (0.33%) below most dams.

As with rainbow/steelhead, growth of cutthroat, bull, and introduced brook trout declined with increasing elevation and decreasing temperature.

KEY CONCLUSION: Sizes at given ages of trout species are the lowest ever reported from streams elsewhere.

We estimated maximum annual catches by Indians in the 19th century for the Wenatchee (93,550 fish; 456,250 lbs), Entiat (2,824 fish; 31,938 lbs), and the Methow rivers (21,285 fish; 238,391 lbs). Production of salmonids in these streams is similar--given that the native coho salmon is now extinct, that large numbers of smolts are now lost in turbines of mainstem dams or reservoirs, and that major harvest no longer occurs in natal streams.

KEY CONCLUSION: There is no evidence that historical abundance of salmon and steelhead in the Wenatchee, Entiat, and Methow rivers differed markedly from now.

Additions of hatchery coho salmon juvenile did not negatively affect growth or emigration of juvenile chinook salmon and steelhead in the Wenatchee River and Icicle Creek. Accordingly, we conclude that there are resources available for coho salmon in study streams.

KEY CONCLUSION: Total salmonid production should increase, while single species production should decline, should coho salmon be restored.

Man-made dams and irrigation have reduced anadromous salmonid habitat by 12% for the Wenatchee, 3% for the Methow, and not at all for the Entiat river.

Mining, grazing, logging, and road construction are not widespread problems for salmonids in the Wenatchee, Entiat, and Methow river drainages. Wildfires have been a problem, but occurred naturally before humans became a major factor in the ecosystems. Sediment now delivered to the Wenatchee, Entiat, and Methow rivers from human activities is about 10% above natural background levels. Sediment delivery is too small and stream gradients too high for negative impact on salmonid habitat.

Stream channels are stable, and retain annual peak flows within their banks during most run-off. Extreme floods limit riparian vegetation. Rock riprap is used along streams for flood protection, and provides critical habitat for salmonids.

About 16%, 28%, and 21% of the mean monthly flow is diverted for irrigation in August, September, and October in the Wenatchee River (RM 21.5). Similar values for the Entiat River (RM 0.3) are 5%, 9%, and 8%, respectively. Annual depletion in river discharge from irrigation on the Methow River varies 28% to 79% August to October, depending on reach and return flow. We found no appreciable difference in habitat and salmonid standing crop with irrigation diversion except in grossly dewatered stream reaches. The long-term, 7-day average low flow, with a two-year recurrence interval (Q7 L2), is only 16% (6% to 23%) of the average annual flow, and there is little difference between regulated (17%) and unregulated (16%) streams. Stream organisms live for most of the time at relatively low water velocities and are regularly exposed to very low flows regardless of irrigation diversion. Irrigation, at least at current levels in the Methow River basin, may be more beneficial than detrimental to salmonid habitat because of its positive influence on groundwater.

Water quality of the Wenatchee, Entiat, and Methow rivers is essentially pristine. Moderate amounts of phosphorus and nitrogen

from sewage treatment plants, fish hatcheries, urbanization, and agriculture have probably increased fish production.

Turn-of-the-century sawmill, hydroelectric, and unscreened irrigation diversion dams devastated salmon, but these problems have long been corrected. The only dams affecting the Wenatchee, Entiat, and Methow rivers are on the Columbia River. Dam impoundments contain redside shiners and suckers that use study tributary streams for spawning and rearing, with negative interactions with salmonids. Fishing, changes in habitat, or both have changed the mid-Columbia River fish community to many small to medium sized trophic generalists (e.g., redside shiner) and fewer large piscivores (e.g., bull trout).

Gene-flow from hatchery populations apparently has not functionally affected wild stocks of salmon and steelhead in the mid-Columbia River. Fish hatcheries have had effects that are contrary to management objectives, however.

KEY CONCLUSION: Despite some abuse from recent activities of humans, there appears to be little or no net loss of the functional features of mid-Columbia River tributaries.

In 1987, the Northwest Power Planning Council established an interim goal of doubling salmon and steelhead runs in the Columbia River from 2.5 million to 5 million adult fish. Plans emphasized more hatchery programs. The latest prescription for more hatchery fish calls for supplementation of natural populations of anadromous salmonids with juveniles originating from eggs taken from adult stocks. We demonstrate that mid-Columbia populations are stable, and tributary streams rear salmonids at carrying capacity.

KEY CONCLUSION: Massive enhancement with hatchery fish threatens wild stocks with extirpation or population reduction from such affects as negative interactions, stock mining for eggs, and increased predation (including fish harvest).

By 1967, most of the Columbia River had been turned into reservoirs, of which 163,158 surface ac were accessible to anadromous salmonids--an increase over original river area of 68,516 ac.

KEY CONCLUSION: Mid-Columbia River reservoirs offer unexplored possibilities for anadromous salmonid management.

Perfection of hatcheries and confusion of aims characterizes fisheries management of the Columbia River. Management is cursed by conformity to a past that is dim at best.

KEY CONCLUSION: A new way of seeing and asserting the coherence of the existing Columbia River ecosystem is needed--tributaries as well as mainstem impoundments, anadromous salmonids as well as other fish, wild as well as hatchery fish.

PREFACE

There is little evidence that a reasonable understanding of the Columbia River ecosystem exists. On the whole, the great salmon and steelhead crash in years long past can be more readily explained than the depression in numbers that has followed. This has occurred despite billions of dollars spent on restoration and maintenance programs involving a bewildering grey literature. In response to this issue, we have examined an array of information to increase our understanding of a microcosm of the Columbia River ecosystem that may not apply elsewhere.

All of the hydrologic and physiographic information examined was in English units of measure. This report contains a mix of English and metric systems, depending, generally, upon whether the information pertained to the fish (metric) or to their environment (English). Fish and environmental data were progressively interrelated, rather than entirely compartmentalized, with much of the detail assigned to appendices.

Some of the appendices use methods of attacking estimation problems that have not been employed elsewhere, as far as we know. Other appendices contain historical information of lasting value. These could have been issued as separate reports, but it is both logical and economical to include them in a single publication, where the background need be described only once.

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INTRODUCTION

The Columbia River drains 260,000 mi^2 in Washington, Oregon, Idaho, Montana, Wyoming, Utah, Nevada, and British Columbia. In 1805 Lewis and Clark crossed the continental divide into the Columbia River drainage and revealed runs of about 7.5 million salmon and steelhead (Chapman 1986). For thousands of years these fish supported Indian cultures. Lewis and Clark opened vast new vistas for settling the West. A trickle of fur trappers became a stream of settlers (Chaney 1978).

Emulating their Indian predecessors, non-Indians developed fisheries in the lower Columbia River on what then appeared to be inexhaustible salmon and steelhead runs. The runs were quickly depleted. Concurrently, irrigated farming, logging, grazing, mining, and other impacts of settlement affected salmon and steelhead habitat (Chaney 1978).

The pace of development quickened in the twentieth century. By 1967 the Columbia River was impounded behind a series of dams, except for a 52-mile (Hanford) reach immediately upstream of the confluence of the Snake River.

One of the earliest dams, Grand Coulee, at river mile (RM) 597, blocked anadromous salmonids from 1,140 mi of the upper Columbia River[1] drainage in 1939. To preserve the runs, returning salmon and steelhead were trapped at downstream Rock Island Dam (RM 453), the earliest dam on the Columbia River in 1933, and relocated to upstream tributaries or to the new Leavenworth, Entiat, and Winthrop National Fish Hatcheries (NFHs) (Fig. 1). Goals of the Grand Coulee Fish Maintenance Project (GCFMP) were to maintain the catch and escapement of 79,700 sockeye and 48,600 chinook salmon and 5,000 steelhead from the mid-Columbia as existed when Grand Coulee Dam was built (Calkins et al. 1939; Mullan 1987a). This was to be achieved by restoring natural propagation in the Wenatchee, Entiat, Methow, and Okanogan rivers below Grand Coulee Dam,

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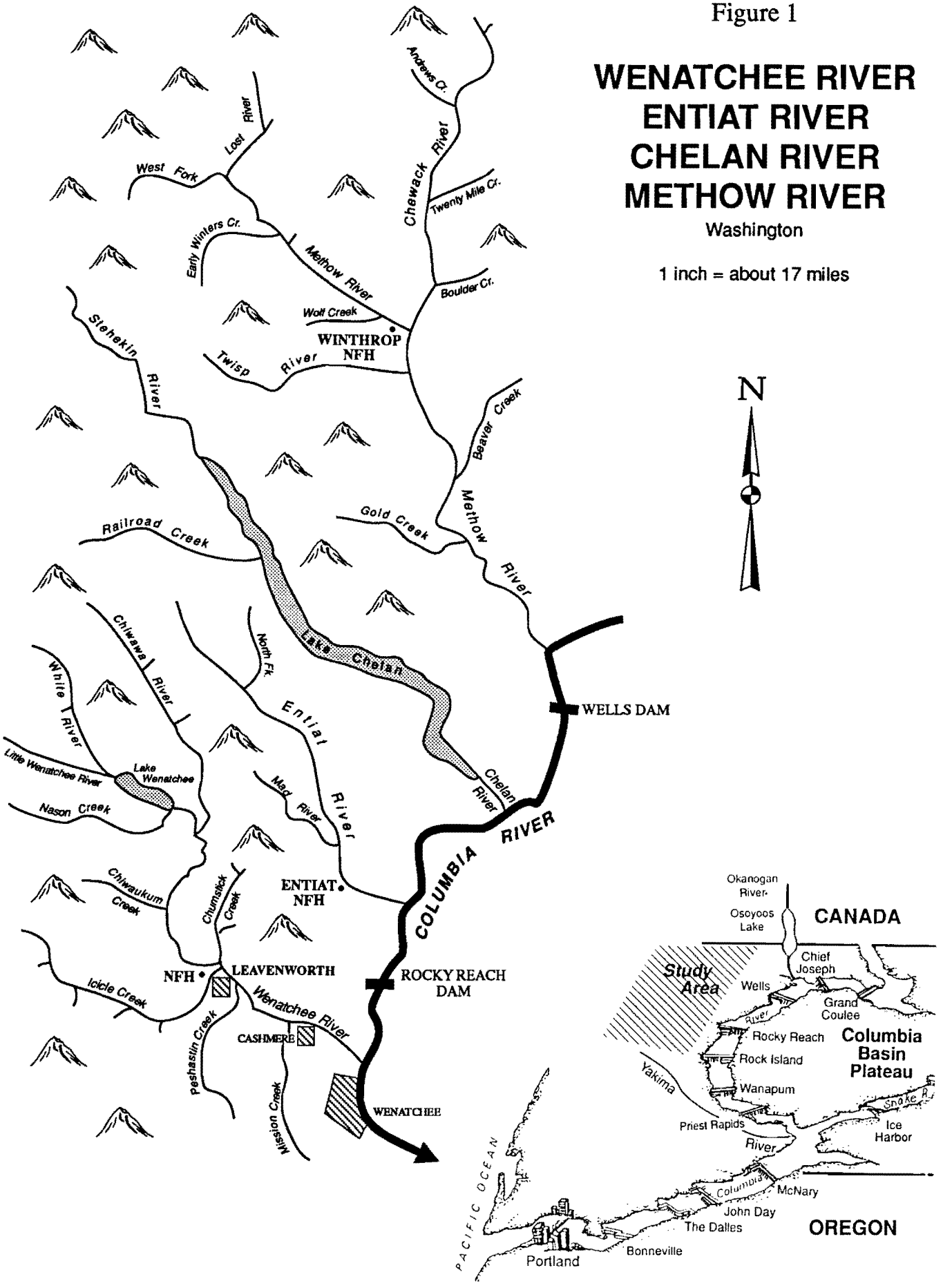
[1]We define the upper Columbia River as the area above Grand Coulee Dam; the middle river, as the area between Grand Coulee Dam and the head of McNary Reservoir (confluence of Snake River); and the lower Columbia River as the area below the head of McNary Reservoir (Fig. 1).

Figure 1

WENATCHEE RIVER
ENTIAT RIVER
CHELAN RIVER
METHOW RIVER

Washington

1 inch = about 17 miles



supplemented with hatchery fish if needed (Calkins 1939 et al.; Fish and Hanavan 1948).

In this report we evaluate the GCFM Project. We (1) quantify rearing area and number of chinook salmon and steelhead spawners in the Wenatchee, Entiat, and Methow river drainages; (2) use rearing area and observed standing crop to estimate production; and (3) assess the effects of settlement on production and habitat.

CHAPTER ONE

STREAMS

Environmental Setting

The mid-Columbia River forms the boundary between the North Cascade Mountains to the west and the Columbia Plateau to the east (Fig. 1). Peaks along the North Cascades vary from 5,000 to 10,000 ft. This mountain range has a complex history resulting in a mix of igneous, sedimentary, and metamorphic rocks. Few major tributaries drain from this once heavily glaciated region. From north to south they include the Methow, Chelan, Entiat, and Wenatchee rivers, with an area of 4,470 mi^2 or 1.7% of the Columbia River Basin.

The Columbia Plateau rises to 2,500 ft and is characterized by basalt beds from lava flows during the Miocene. The area is dry with only a few minor streams.

Between the confluences of the Wenatchee (615 ft elevation) and Methow (789 ft) rivers, the Columbia River is a gorge interrupted in only minor ways by the confluences of major tributaries and side canyons. Toward the north, however, the steep escarpments along the valley walls moderate. These late Wisconsin glacial features are the result of the Okanogan Lobe, a large ice mass that flowed into north-central Washington from British Columbia 20,000 years ago. Local mountain glaciers that developed along the east side of the Cascade Mountains coalesced with the Okanogan Lobe--the most prominent of these being the valley glaciers that carved Lake Chelan (33,104 ac, 1,605 ft deep) and Lake Wenatchee (2,445 ac, 300 ft deep) (Fig. 1).

The contrast in vegetation and physiography bordering the Columbia River between the Methow and Wenatchee rivers is probably greater than elsewhere in the Columbia Basin. High mountains and heavy snowpacks characterize the western portions. Desert conditions prevail among the grass-and-shrub-covered foothills in the eastern portions. Annual precipitation may range from less than 8 to more than 35 in on nearby mountain slopes to the west; the tops of the Cascade Mountains may receive up to 120 in.

The great basin relief (Fig. 2) of the Cascade Mountains profoundly affects stream characteristics. Most ridges and peaks, typically sharp-crested and rugged, are separated by narrow,

Fig. 2. The great basin relief of the Cascade Mountains profoundly affects stream characteristics. Most ridges and peaks, typically sharp-crested and rugged, are separated by narrow, steep-walled valleys whose streams are generally less than 2,000 ft. above sea level, even near their headwaters.

steep-walled valleys whose streams are generally less than 2,000 ft above sea level, even near their headwaters. Relief changes of 6,000 ft may occur in a horizontal distance of 3 mi. Thus, many headwater streams plunge off mountain sides through bedrock-boulder cascades and are not accessible to anadromous salmonids. Similarly, the Chelan River is not accessible to anadromous fish because of impassable falls at the outlet dating to glacial times.

Methods

We used strip aerial photographs (1 in to 2,000 ft) to measure, by computer digitizing (0.9975 planimetric precision, HP9000), surface area of the Wenatchee River. All other streams were measured using range finders, calibrated frequently. We divided streams into homogenous sections for sampling, according to gradient, width, and sinuosity. We field measured 146 stations representing 73 mi and 476 ac of stream, and photo-planimetered 54.2 mi and 1,206 ac of the Wenatchee River (Appendices A and B).

Within each sampling site we measured the pool and riffle (sensu Helm et al. 1985) area, and then calculated a ratio by the number of pools and riffles in a mile of stream. We visually estimated channel substrate composition from three or more random transects per station. We based percent substrate composition on three to five particle sizes: <0.5 ft, 0.5-1.0 ft, and > 1.0 ft in the Wenatchee River drainage; and <0.5 ft, 0.5-1.0 ft, 1.0-1.5 ft, 1.5-3.0 ft, and > 3.0 ft in the Entiat and Methow river drainages. We calculated stream gradient from U.S. Geological Survey (USGS) topographic maps. Stream or river mile (RM) designations are from the River Mile Index (Hydrology Subcommittee 1964) or USGS topographic maps (Appendices A and B).

Because the area of a channel covered by water varies as the volume of flow varies, it was necessary to calibrate the dimensional sampling of streams with average conditions. Surface area in streams decreases much less rapidly than volume of flow (Fig. 3). In September 1986, 6.1 mi (RM 35.8 - 41.9) of the Wenatchee River were measured for ground truth. Area amounted to 178 ac at flow of 600 cfs, which was 86% of the mean September flow (702 cfs, 1912-79, Williams and Pearson 1985).

The photo-planimetered area in the 6.1 mi was 196 ac at a flow of 2800 cfs, which was 123% of the mean annual (base) flow (2273 cfs). Average low-flow area calculated with the photo-planimeter and adjusted with ground truth (178 ac) was similar to the area calculated from ARC-SA = 0.902 + 0.430 ARC-Q (170 acres) (Fig. 3).

Stream discharge was much below average in 1986 and 1987 when streams were measured; some portions of the Methow dried as a result of natural phenomena (Appendix C). We determined expansion factors (1.03 to 1.42) for Methow streams by comparing measurements

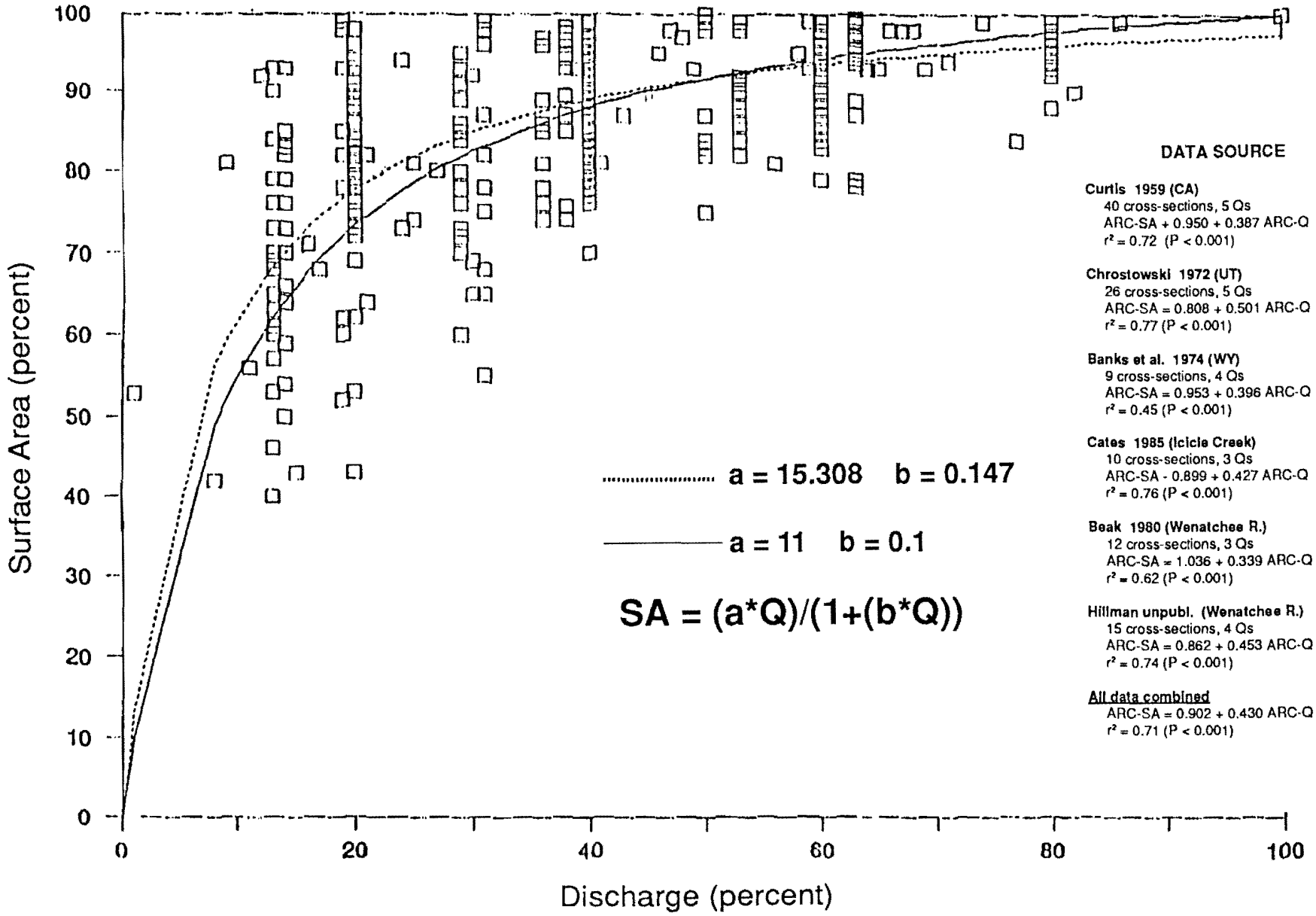


Fig. 3. Relationship between stream wetted area (%) and discharge (%) for data sets on right: Q = discharge; SA = surface area (stream width a surrogate for area); ARC = arcsine sin √ transformation of surface area and discharge; final transformed % data expressed in radians.

of wetted area with normal low-water flow marks. Low-water flow marks included oxidized scale on channel rocks above the normal low water stage. Surface areas--calculated with the regression shown (Fig. 3) at eight stream reaches where widths and discharges were measured coincidentally (USGS)--were consistently in agreement (± 3%) with areas determined with the expansion factors.

We sample-measured tributary streams of the Wenatchee River in fall 1986, when discharge approximated late summer wetted area. We sample-measured the Entiat River drainage in early April 1987 when discharge was similar to long-term August and September flows.

We did not directly measure tributaries not accessible to anadromous salmonids. However, we compiled information on all streams (Appendix D), including the limits of anadromy.

Results

Originally, there were 2,061, 308, and 1,629 ac of streams for spawning and rearing of anadromous salmonids in the Wenatchee, Entiat, and Methow river drainages, respectively. Dams and irrigation have reduced this habitat by 12% for the Wenatchee, 3% for the Methow, but not at all for the Entiat (Table 1). At least another 964 ac of headwater streams in natural or near-natural conditions contain resident salmonids (Appendix D).

River Basins

Wenatchee River originates in Lake Wenatchee (Fig. 1) and glaciation extended only a few miles downstream. The lake is fed by the Little Wenatchee River (15% contribution to Wenatchee River flow) and the White River (25%). Principal tributaries to the Wenatchee River below the lake are Nason Creek (18%), Chiwawa River (15%), and Icicle Creek (20%). Seventy percent of the basin lies upstream of Icicle Creek (RM 25.6) and is heavily forested. Below Icicle Creek the river enters a broader valley used for irrigated fruit growing.

The Entiat River begins as meltwater from glaciers and perennial snow fields 52 mi from the Columbia River. Its major tributaries are the North Fork (20% of flow) and Mad rivers (14%). During the Pleistocene a valley glacier extended downstream to RM 15. Above the resulting terminal moraine, the valley is U-shaped. Below the moraine, the valley and tributaries are V-shaped from stream-cutting (USDA 1979). Only a narrow band of land along the lower river is usable for orchards.

The Methow River basin lies south of the Canadian border between the crest of the Cascade Mountains and the paralleling Okanogan River basin (Fig. 1). Principal tributaries are the Chewack River (23% of flow) and the Twisp River (14%). Unlike the

Table 1. Summary of average surface acres and miles of stream now and originally available to anadromous and resident (above anadromous zones) salmonids in the Wenatchee, Entiat, and Methow river drainages (See Appendixes A - D).

Drainage	Anadromous salmonids				Resident salmonids above anadromous zones	
	Originally		Now		Minimum estimate	
	(acres)	(miles)	(acres)	(miles)	(acres)	(miles)
Wenatchee	2,061	150	1,808	129	379	291
Entiat	308	46	308	46	117	199
Methow	1,629	198	1,586	182	468	373
TOTAL	3,998	394	3,702	357	964	863

sharply incised Wenatchee and Entiat valleys, the Methow Valley is up to a mile wide and the adjoining uplands have been rounded by glaciation. Cattle dominate agriculture, although terraces along the lower valley are also used for orchards. The watershed, like the others, is mostly forested mountains and sparsely inhabited (Highsmith and Kimerling 1979).

Climate

Climate is characterized by great variations in temperature (-14.5 to 43.3° C) and precipitation (8 to 180 in). The highest precipitation and lowest temperatures occur in the highest mountains. Very little of the average precipitation falls from April through September. The mountains receive most of their precipitation as snow, which melts and runs to the streams in late spring and early summer.

Stream Flows

The Wenatchee, Entiat, and Methow rivers have base flows (cfs) of 3,376, 385, and 1,592, respectively. Average values of run-off (cfs) per mi^2 of drainage area are 2.6, 1.9, and 1.1, respectively.

High water results from the melting of the snowpack. Its magnitude depends on the quantity of snowpack and weather prevailing in the spring. For example, above-normal precipitation occurred in the winter of 1947-48, and the snowpack melting was delayed because of colder-than-normal air temperatures. The water content of the snowpack increased during April and early May--contrary to normal trends--followed by sustained above-normal temperatures and rainfall after mid-May. The resulting 500-year flood of May-June 1948 is believed to have been the highest since 1894 (Walters and Nassar 1974).

The low-flow period extends from August through March. Discharges from April through July are usually four or more times those of August through March (Table 2). Lowest summer flows occur in September. Depending on elevation and aquifers, however, still lower flows may prevail October through March (Table 2).

Ground Aquifers

The bedrock of the three drainages is exposed or only thinly covered except beneath or adjacent to the floors of the major valleys. Alluvial and glacial deposits ranging from only a few to several hundred ft in thickness constitute the ground water aquifer. The deposits occur in greatest thickness in the Methow Valley.

Streams flowing over permeable materials lose water to the ground-water aquifer if the stream stage is above the adjacent water table. If the water table is higher than the stream stage,

Table 2. Low-flow characteristics of long-termed (543 yrs of records) gaged streams in the Wenatchee, Entiat, Chelan, and Methow river drainages arranged in descending order of mean basin elevation (data from Williams and Pearson 1985; Copenhagen 1978).

Stream (river mile)	Drainage	Mean basin elevation (ft)	Mean Aug-Mar flow (cfs)	Percent of Apr-Jul mean (high) flow	Mean Sep flow (cfs)	Mean Oct-Mar flow (cfs)	Significant aquifers other than snow pack
Andrews Cr (3.0)	Methow	6300	6	7	10	5	
North Fk (0.1)	Entiat	5823	77	14	86	58	
Phelps Cr (0.1)	Wenatchee	5787	19	14	12	13	
Entiat R (30.0)	Entiat	5594	121	12	140	79	glacier
Icicle Cr (5.8)	Wenatchee	5260	237	18	165	243	glacier
Entiat R (18.1)	Entiat	5230	131	15	122	116	glacier
Stehekin R (1.4)	Chelan	5130	627	21	713	506	glacier
Methow R (40.0)	Methow	5090	392	12	310 *	394	ground
Beaver Cr (6.2)	Methow	5090	8	17	8	8	ground
Twisp R (1.6)	Methow	4957	87	15	66 *	86	ground
Railroad Cr (1.2)	Chelan	4930	88	20	107	67	glacier
Methow R (6.7)	Methow	4780	521	14	491 *	491	ground
Wenatchee R (54.1)	Wenatchee	4720	632	24	375	665	lake
White R (6.4)	Wenatchee	4590	357	22	341	313	glacier
Wenatchee R (46.2)	Wenatchee	4590	1482	23	871	1572	lake
Wenatchee R (21.5)	Wenatchee	4540	1095	24	702	1139	lake
Chiwawa R (6.3)	Wenatchee	4440	176	16	169	163	glacier
Wenatchee R (5.8)	Wenatchee	4440	176	25	961 *	1794	lake
Entiat R (0.3)	Entiat	4390	171	15	152	158	glacier
Mission Cr (7.0)	Wenatchee	3400	9	36	3	11	

* Affected by irrigation diversion.

ground water discharges into the stream channel (Walters and Nassar 1974). This gain and loss in stream flow occurs in many channels of the study drainages. Many small streams flow only during snowmelt and during intense rainstorms in the alluvial fans at their mouths. In the upper Methow River reaches are alternately watered and dewatered during dry summers (Fig. 4).

A better hydraulic connection exists between the Methow River and the ground-water aquifer in the middle river (about RM 50 to 27). Mean low flow is 310 cfs, and the channel does not dry. Minimum-flow indexes (Appendix C) and slope of flow- duration curves indicate that ground water is the primary contributor to stream flow during the low-flow period (Walters and Nassar 1974).

Glacier Aquifers

The greatest melt of glaciers occurs during July and August. By then, the annual snowpack has largely melted, and stream flow from this source is much reduced. The run-off from glaciers most affects stream flows in August and September. This is especially true after a below-average winter snowpack followed by a dry and warm summer.

In 1964, the winter snowpack was above average, the summer was wet and cool, and North Cascades glaciers gained in mass. In 1966, weather conditions were just the opposite, and nearly all glaciers lost mass (Post et al. 1971). The melting of glacier ice contributed only 5% of the August and September flow of the Stehekin River in 1964. In contrast, glacier melt contributed an estimated 27% of the flow in the Stehekin River in August and September 1966, an abnormally dry year (Post et al. 1971).

Late summer flow is more sustained in streams fed by glaciers (Table 2), and water temperature is inversely proportional to discharge in small streams--that is, the smaller the flow, the greater the temperature (Brown 1971). Glaciers contribute substantially to minimum summer flow in some of the study streams (Table 3).

Lake Aquifers

Numerous mountain lakes--only 36 of them lower than 2,500 ft--occur in the study drainages: in the Wenatchee, there are 169 lakes (2,411 ac); in the Entiat, 16 (158 ac); and in the Methow, 120 (876 ac) (Wolcott 1964). Lake Wenatchee is the largest (2,445 ac) lake below 2,500 ft elevation, and makes up 70% of the low elevation lake area. It is also the only lake accessible to anadromous salmonids. Lake Wenatchee tends to equalize flows for the Wenatchee River by allowing more of the annual run-off to occur in the low-flow period,August through March (Table 2).

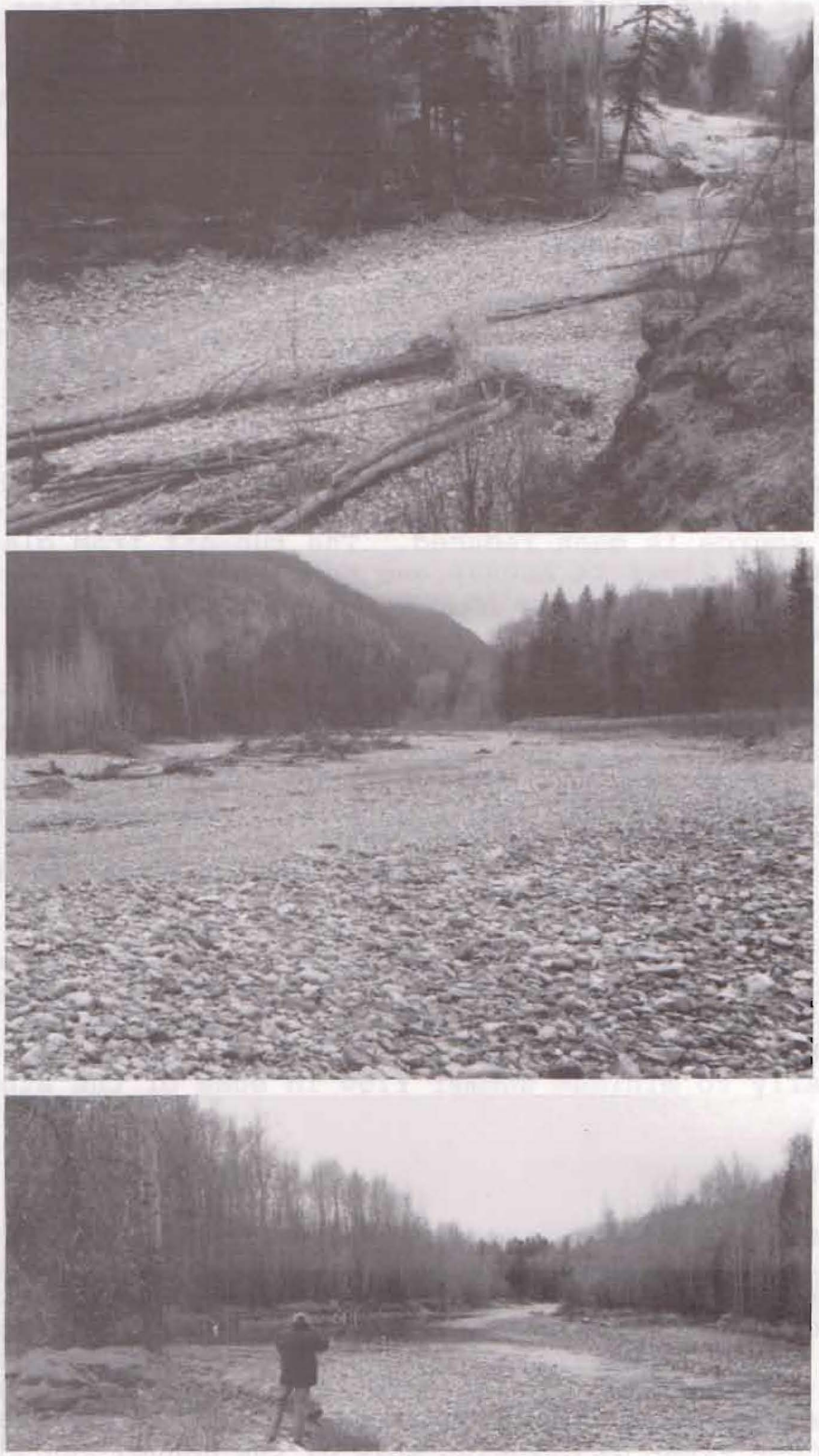


Fig. 4. Reaches of the upper Methow River that periodically dry as a result of natural events. The top two photos are typical of the 10 mile reach that dried in 1987 and the bottom photo where surface flow re-emerged.

Table 3. Estimated contribution of glaciers to minimum flow in the Wenatchee, Entiat, and Methow river drainages (glacier data from Post et al. 1971).

Drainage	Stream	Number of glaciers	Glacier area (acres)	Acre ft of water [a]	Minimum flow (%)	River mile
Wenatchee:	White R.	13	1,928	18,993	42[b]	6.4
	Icicle Cr.	14	420	4,137	21[b]	5.8
	Chiwawa R.	5	173	1,704	10[b]	6.3
	Chiwaukum Cr.	1	25	246	3[c]	0.0
Entiat:	Entiat R.	11	346	3,408	17[b]	18.1
Methow:	Early Winters	7	272	2,679	44[c]	0.0
	West Fork	7	173	1,704		
	Lost River	2	49	483	6[c]	0.0
	Gold Creek	1	25	246		

[a] Assuming an average annual melt of 9.9 acre feet per surface acre of glacier, but that two-thirds of this water is released during August/September in abnormally dry years in computing percentage contribution to minimum flow (Post et al. 1971).

[b] USGS (gauged) mean minimum flows for August and September (Williams and Pearson 1985).

[c] Calculated mean minimum flows for August and September (Lomax et al. 1981).

Unlike glaciers, lakes are heat sinks for solar radiation in summer and tend to moderate extremes in stream temperatures.

Water Quality

The study drainages are Class A or AA, or excellent, for water quality. Oxygen content is normally at or above saturation levels. The waters are usually very clear. They are a dilute calcium-magnesium, carbonate-bicarbonate type, with a conductivity of 56 micromhos, 28 mg/l alkalinity, and 42 mg/l total dissolved solids mean at the mouth of the Wenatchee River. Water in the Methow River is more mineralized (conductivity, alkalinity and TDS values at mouth average 149, 70, and 90, respectively), because the drainage is more arid and the concentration of natural solutes greater (Appendix E).

Water Temperatures

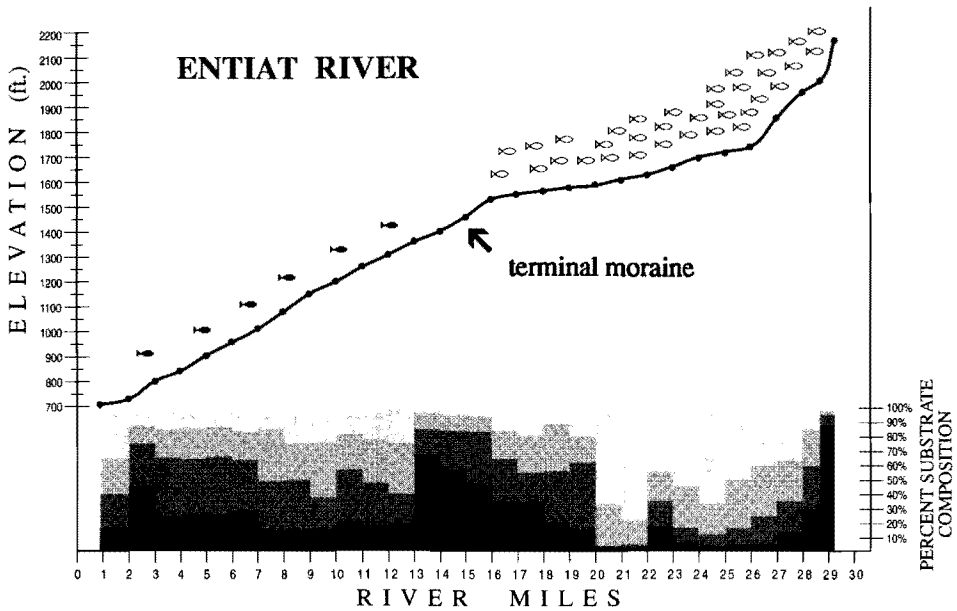
Water temperatures in the lower reaches of the Wenatchee, Entiat, and Methow rivers fluctuate between 0° and 23.5° C. Water temperatures generally remain at or near 0° C November through February. Thermal regimes in upper reaches of the mainstems and in tributaries differ widely with orientation, elevation, and input from rainfall, snowmelt, and aquifers.

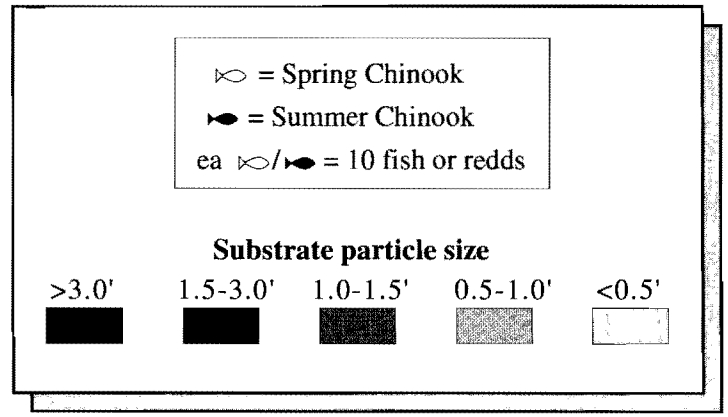
Channel Substrates

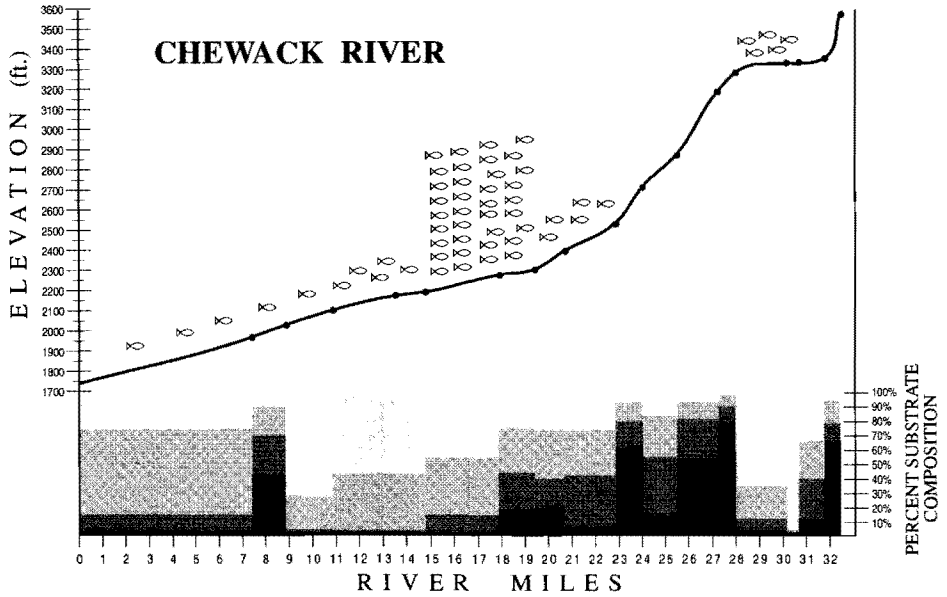
Typically, gravel substrates where salmonids spawn are not evenly distributed in our streams (Fig. 5), but there is no shortage of spawning areas (Bryant and Parkhurst 1950). Our interest in substrate composition was related to cover for juvenile salmonids. Cover is largely supplied by rocky substrate, because banks are swept by currents only during high flow, and there is little woody debris in the mid-channels of the larger streams. Cover is related to gradient. The larger the substrate size, the steeper the gradient; the more pools and riffles in a mile of stream, the steeper the gradient (Appendix B).

Conclusions

Anadromy, like many forms of animal migration, is an evolutionary response for coping with seasonal environments. Streams, unlike oceans, are strongly influenced by the physiography, geology, and climate that surround them. The most striking feature of the study drainages is extreme winter cold caused by latitude, elevation, and continental air mass.







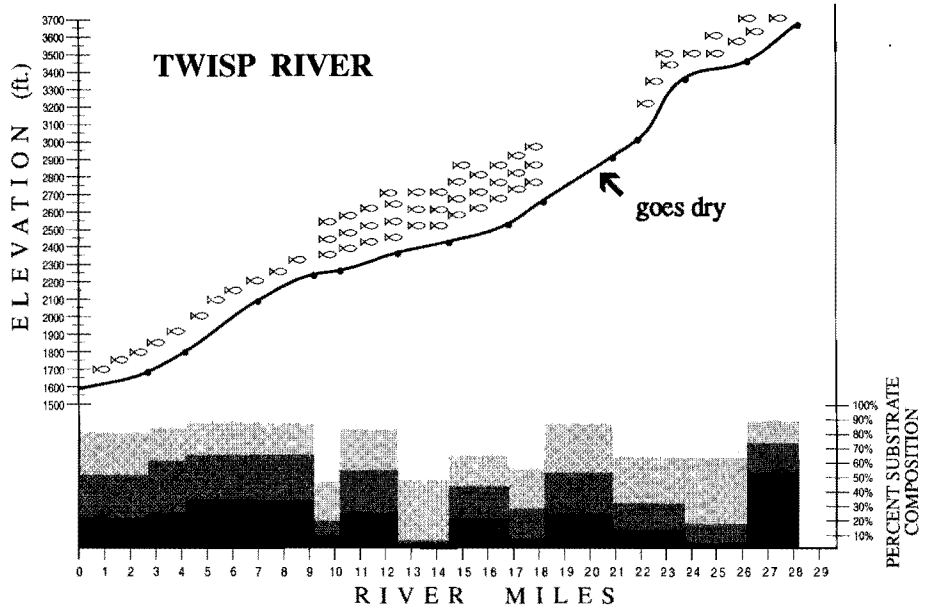


Fig. 5 Relationship between gradient, substrate, and chinook salmon spawning areas (Entiat River, 1957 - 1960, French and Wahle 1965; Chewack and Twisp rivers, Kohn 1987, 1988, 1989).

The drainages are coldest of 24 western climate zones (Williamson et al. 1979). The latitude is the same as that of Duluth, Minnesota, and Bangor, Maine. The mean basin elevation is about one mile above sea level. And because the Cascade Mountains wring most of the marine influence out of the air that passes west to east across them, arctic air plays a major role in the climate.

CHAPTER TWO

SALMON AND STEELHEAD RUNS[2]

Until we understand the structure and function of the undisturbed habitats that produce wild salmonids, and the changes in runs and habitat caused by settlement, our restoration efforts will lack a rational context and effective direction (Sedell and Luchessa 1981). In this chapter we draw on the historical record, as well as on dam counts, to provide perspective on salmonid runs over time.

Methods

Dams have been detrimental to salmon in the Columbia River, but they have served as counting fences. Counting of spawning salmon or redds is a traditional method of establishing an index of abundance. Although the procedure does not give a total count, it is better in some respects than counting at dams: only fish that reach the spawning grounds are inventoried. Because steelhead spawn in the spring during high water when visibility is poor, it has generally not been possible to obtain spawning counts of them.

Single "peak" spawning counts seldom agree with annual dam counts of salmon. About one-third of the fish counted at dams are not accounted for even if peak spawning index counts are doubled to compensate for areas not surveyed (Mullan 1987), for shifts in spawning areas (Lindsay 1981), and for method error (Major and Mighell 1969; Allen and Meekin 1980; Neilson and Geen 1981; Schwartzberg and Rogers 1986). On the other hand, counts throughout the spawning period and the entire lengths of the streams have agreed with dam counts (Meekin 1963; French and Wahle 1965). Recently, Kohn (1987, 1988) accounted for virtually all of the spring chinook salmon counted at Wells Dam in intensive spawning ground surveys of the Methow River drainage. (The 1987 and 1988 Wells Dam count was 5,382, minus 1,921 fish that returned to Winthrop NFH, for a total of 3,461; divided by 1,426 redds, or 2.4 spring chinook/redd.)

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[2]Common names of fish species used throughout this report conform with American Fisheries Society designation (Appendix F).

The disadvantages of counting fish at dams are species misidentification; estimation of total fish passage from sample counts; arithmetic errors; passage of fish through navigation locks (mid-Columbia dams do not have navigation locks); and recounts of fish that fall back over the dam (Bell et al. 1976). However, we believe that dam counts are a more valid assessment of escapement than peak spawning ground surveys for salmon; they are the only method available for counting steelhead. In 1973 and from 1964 to 1967, 94% of the sockeye to the Wenatchee River--based on the difference between counts at Rock Island dam and Rocky Reach Dam--were counted at Tumwater Dam on the Wenatchee River (RM 32.7). Only 58% of those passing Tumwater Dam were found on upstream spawning grounds.

Not all fish counted at dams spawn. Natural mortality, poaching, and other losses are reflected in spawner-to-redd ratios. The larger the spawner-to-redd ratio, the higher the pre-spawning losses, or the higher the number of males in the spawning population.

To estimate pre-spawning loss, we divided spawner-to-redd ratios of 2.4 (Hollowed 1983; Kohn 1987, 1988) and 3.1 (Meekin 1967) into inter-dam counts (subtracting fish that returned to hatcheries or were legally harvested) of spring and summer/fall chinook salmon, respectively. We know of no spawner-to-redd ratios for steelhead trout. Pre-spawning loss of adult steelhead at Wells Dam Hatchery was 1.2% from 1982 to 1990 and we doubled this figure to estimate pre-spawning loss under natural conditions. Pre-spawning loss of spring chinook salmon at Leavenworth Hatchery is about 7% and if this figure is doubled it nears the 17% pre-spawning loss represented by a spawner-to-redd ratio of 2.4.

We estimated egg deposition as 4,600 eggs per spring chinook salmon female (12 year mean, Leavenworth NFH); 5,240 eggs per summer/fall chinook salmon female (Matthews and Meekin 1971); and 5,560 eggs per steelhead female (Wells Hatchery). Fecundity of naturally-produced spring chinook and steelhead in study streams is largely unknown. There was no difference between 21 wild steelhead in the 1930s (WDF 1938) and hatchery females in 1983. Moreover, wild chinook lengths are similar to hatchery fish (Fig. 6) and hatchery fish include small numbers of wild fish.

Egg deposition estimates are notoriously imprecise (Allen 1951; Young et al. 1990) and spawner-to-redd ratios and fecundity for a given year may be much greater or much less than indicated.

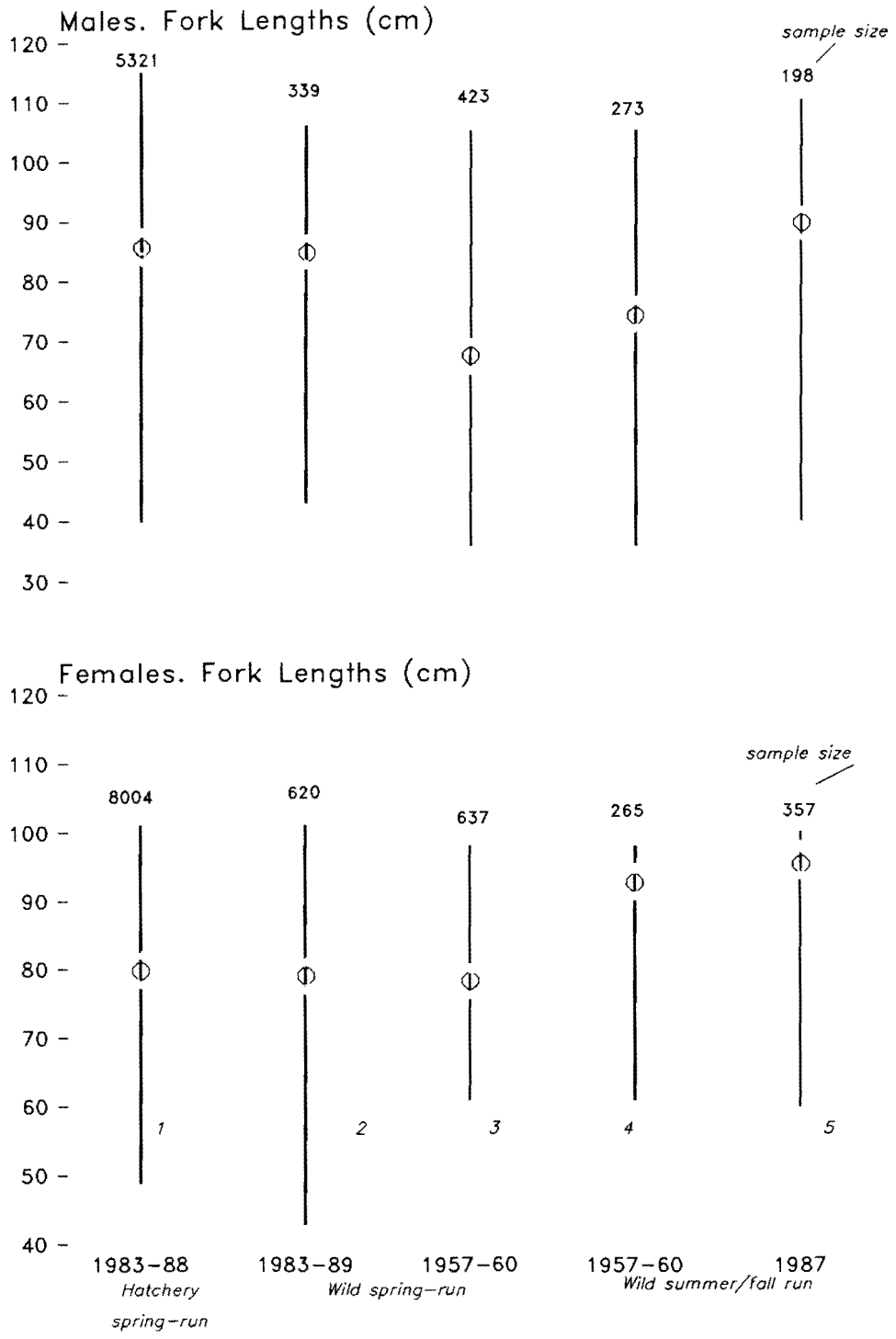

Fig. 6. Mean fork lengths and ranges of hatchery spring-run (1), wild spring-run (2 and 3), and wild summer/fall run (4 and 5) chinook salmon spawners. (1 = Leavenworth and Winthrop NFHs 1983-88; 2-5 = spawning ground carcasses in Fast 1987, French and Wahle 1965, Kohn 1987, 1988, 1989, and unpublished — WDF, PUDs, FWS; mid-eye to end of hypural platte length conversion 1.19.)

Results

Chinook Salmon

Harvest of chinook salmon from the Columbia River peaked at 2.3 million fish in 1883. Yield was about 1.3 million fish a year through the period 1890-1920, followed by a steady decline (Chapman et al. 1982).

Kettle Falls, upstream of Grand Coulee Dam, was the second most important Indian fishing area on the Columbia River before settlement (Chance 1973). As many as 40,000 salmon[3] may have been taken at Kettle Falls during years of large runs in the early 1800s (Chance 1973). Salmon remained abundant in the upper Columbia River until 1878, and virtually disappeared by 1890 (Gilbert and Evermann 1895).

Spring chinook. Lowest spring chinook salmon counts at Rock Island Dam occurred 1935 to 1942, when the commercial catch in the lower Columbia River took up to 86% of the runs. Following reductions in harvest and the relocation of adult spring chinook from Rock Island Dam and releases of hatchery juveniles to the Wenatchee, Entiat, and Methow River 1939-43, counts of returning spring chinook increased at Rock Island Dam. Aside from some initial fluctuation of counts, abundance of wild spring chinook has remained relatively stable from 1960 to 1987 (Fig. 7a) (Mullan 1987).

Summer/fall chinook. The pioneers who chronicled with awe "millions" of salmon ascending Kettle Falls noted a minor peak in June and a major peak in August. They depicted summer chinook as the dominant upstream run of salmon (Gilbert and Evermann 1895; Kennedy 1975;Ray 1977). Reduction of harvest (84% to 47%) in the mid-1940s increased escapement. Abundance of summer chinook salmon increased until 1957, then declined steadily despite little in-river harvest after 1963. Counts of naturally produced summer/fall chinook salmon (total count minus fish that returned to hatcheries or were harvested) at Rock Island Dam reflected the improved escapement of the mid-1940s and the peak in lower river abundance in 1957; but from 1953 to 1987 escapements have remained relatively stable (Fig. 7b) (Mullan 1987).

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[3]Numbers could vary depending on the mix of species caught and their mean weight. In these harvest estimates, we have retained Craig and Hacker's (1940) mean weight of 20 pounds as applied only to chinook salmon, which has been used by all estimators of historical Indian catches.

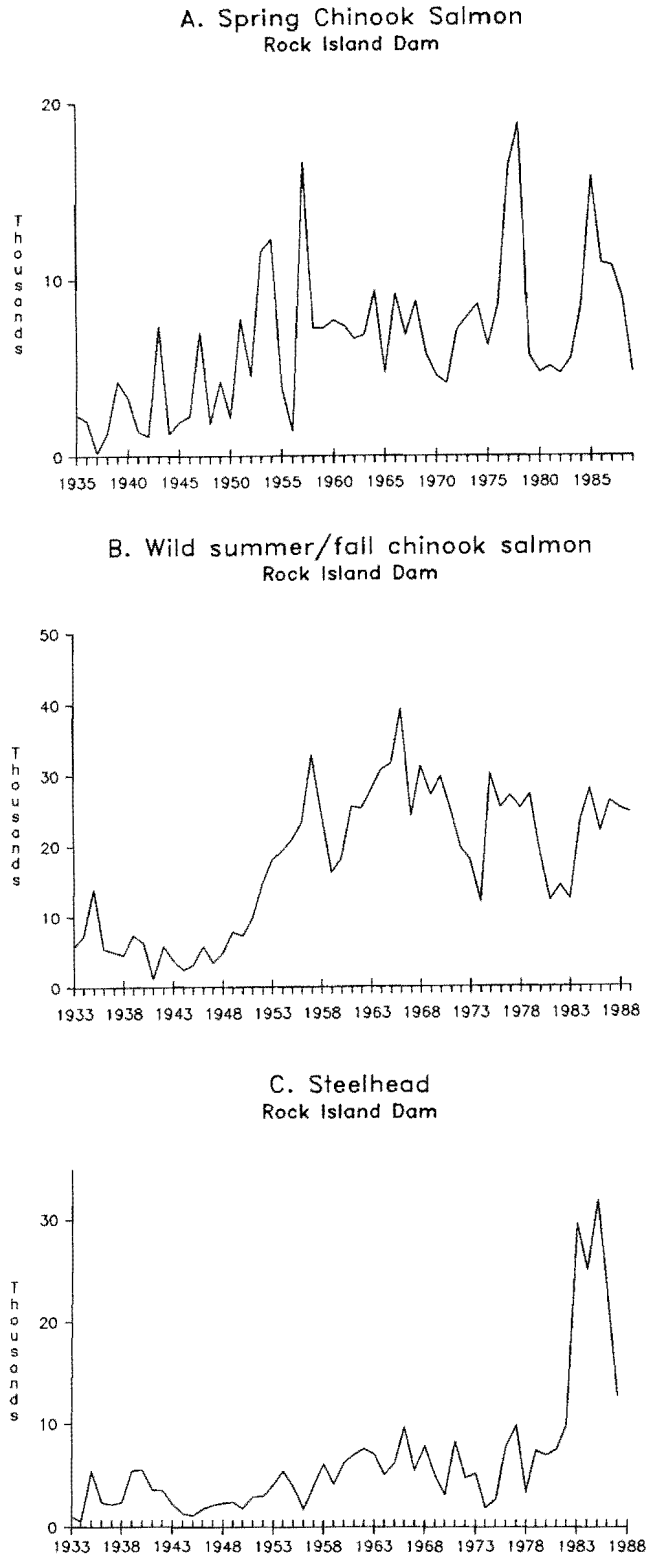


Fig. 7. Annual counts of naturally produced spring (a) and summer/fall (b) runs of chinook salmon and steelhead (c) at Rock Island Dam. (Wild escapement of chinook salmon estimated by subtracting hatchery escapements.)

Coho Salmon

Historical abundance of coho salmon was in lower Columbia River tributaries. Peripheral runs of coho to the mid and upper-Columbia had been largely destroyed before Grand Coulee Dam was built. Only 475 coho salmon were counted at Rock Island Dam from 1933 to 1943 (Mullan 1984). Despite releases of 46 million juveniles by the GCFMP hatcheries from 1942 to 1975, coho salmon were not re-established.

Sockeye Salmon

After blockage of the upper Columbia River by Grand Coulee Dam, rearing for sockeye salmon was confined to Wenatchee and Osoyoos lakes (Fig.1).

Sockeye salmon from the Columbia River rarely are caught in the ocean, and the fishery is confined largely to the lower river. Annual catches ranged from 0.25 to 1.3 million fish before 1900, and from 50,000 to 730,000 fish through the early 1920s (Mullan 1986).

In the 1930s and early 1940s, abundance of sockeye salmon remained depressed compared to annual escapements of 2% to 24% (2,000-20,000 fish at Rock Island Dam). When catch and escapement were brought more nearly into balance beginning in 1945, the runs revived, and abundance maintained until the 1960s. Since then, runs have only occasionally been of the magnitude of 1945-60s.

The early 1900s decline in number of sockeye salmon can be attributed largely to loss of nursery lakes when their access was blocked by dams. Average unit-area smolt production today apparently is similar or has improved slightly compared to the past, but many smolts are lost in mainstem dam turbines or reservoirs (Mullan 1986).

Unexpectedly large runs of sockeye salmon returned in 1984; 160,500 to the Columbia River; 478,000 to Lake Washington; and 5,900,000 to the undammed Fraser River, a record dating to 1904 (IPSPS 1984), indicating the overriding importance of ocean survival.

Steelhead

Steelhead enter the Columbia River in winter and summer, but spawn in spring. Young generally reside for two or more years in streams before migrating to the sea. This extended stream residency prevents steelhead from achieving the abundance of salmon. Steelhead made up only about 5% of the original salmonid abundance in the Columbia River (Chapman 1986).

In contrast to chinook and sockeye salmon catches, steelhead harvest was fairly consistent from 1912 to 1940 at nearly 300,000 fish. From 1938 to 1942, the lower river commercial fishery took an average of 215,000 fish and the escapement averaged 93,000 fish or 31% (Chapman et al.1982). Only about 4% of these fish reached Rock Island Dam for relocation and hatchery propagation as part of the GCFM Project (Mullan 1987).

Steelhead runs above Rock Island Dam increased slowly beginning in the late 1940s, then oscillated widely, followed by dramatic increases in recent years (Fig. 6c). The erratic trend occurred when hatchery steelhead replaced natural production in the early 1960s. Record runs in 1984 and 1985 also occurred in other rivers in Washington--once again indicating the overriding importance of ocean survival for all runs.

Pre-Settlement Indian Harvest

Through thousands of years, the Indian population likely came into balance with its food supply. Population estimates for Indians who relied on salmon for food in the nineteenth century are beset by numerous problems (Appendix G). Considering such problems, we estimated maximum annual catches for the Wenatchee (456,250 lbs), Entiat (31,938 lbs), and the Methow (238,391 lbs) rivers. Just as population size of the individual Indian tribes agrees reasonably well with the size of their territories (Appendix G), the difference in harvest among the three rivers agrees with the amount of habitat available to salmon and steelhead: Wenatchee, 4,506 ac (includes Lake Wenatchee), 101 lbs/ac; Entiat, 308 ac, 104 lbs/ac; Methow, 1,629 ac, 85 lbs/ac.

Run Strength After Completion of Columbia River Dams in 1967

A mean 8,432 wild spring chinook salmon returned to the Wenatchee (4,465), Entiat (1,247), and Methow (2,719) rivers 1967-87. We assumed mean dam loss of 5% (NPPC 1986), then calculated adult abundance at the Columbia River mouth as 12,600. In-river catch averaged 20% (3-39% ODFW/WDF 1988), which increased the estimate of adults to 15,750. A 10% correction for ocean harvest (NPPC 1986) gives a total run size of 17,400.

Mean escapement to the Wenatchee (12,012), Entiat (100), and Methow (3,385) rivers for naturally-produced summer/fall chinook salmon, 1967-87, was 15,497. Corrected for 5% interdam loss, incidental in-river catches of 9%, and ocean harvest of 75%, 1967-84 (NPPC 1986), and more recent harvests of about 40% (Pratt and Chapman 1989), total run size was about 86,000 naturally produced summer/fall chinook salmon (Wenatchee, 68,600; Entiat, 570; Methow, 19,350).

An average of 93,900 sockeye salmon entered the Columbia River, 1967-87 (ODFW/WDF 1988). Harvest in the lower river amounted to 22,900 (24%), and 64,730 (69%) reached Rock Island Dam (loss between dams, 7% total or 1% per dam).

Of the sockeye salmon passing Rock Island Dam, 38% (24,400) turned into the Wenatchee River, and 62% (40,300) moved up the Columbia River. A few of the latter spawn in the Entiat and Methow rivers, but most travel farther upstream, to the Okanogan River, and the young rear in Lake Osoyoos. A few of the sockeye that enter the Wenatchee River, like those in the Entiat and Methow rivers, are fluvial and probably rear in Columbia River impoundments (Mullan 1986).

Unlike salmon counts, steelhead counts at Rock Island Dam show great variability (Fig. 6c) and can be misleading. They represent calendar year designation, not run cycle, and, on average, were about 15% incomplete 1933-62, due to moving uncounted over the dams during winter. Moreover, a steelhead cohort may consist of as many as 10 overlapping brood years and 16 age classes (Appendix H). Reconstruction of Rock Island Dam steelhead counts indicate maximum sustained run size and escapement were 16-19,000 and 4-7,000 adult steelhead 1940 to 1954, compared to mean run size of 24,700 and escapement of 13,700 steelhead 1979 to 1989 (Appendix H).

Egg Deposition

A rough balance of egg deposition from mean salmon and steelhead escapements to the Wenatchee, Entiat, and Methow rivers in recent years does not suggest that they are grossly underseeded (Table 4) as widely believed.

Conclusions

Evidence from the past shows that the middle and upper Columbia River yielded far from regular salmon harvest in the presettlement era (Chance 1973):

> "At the end of August 1811, David Thompson and his men had to subsist on horse flesh at Kettle Falls (Glover 1962:380). That would have been toward the end of the heavy fishing. John Work (1830) makes it very clear that the Kettle Falls fishery during the seasons from 1826 through 1829 only generally yielded enough fish to maintain the people of Fort Colville <u>during the fishing season</u>. In 1828, the men at the fort were relying upon horse meat as early as October (Work 1828). During those years, some Sxoielpi (Indians) starved to death and others ate horses (Heron and Kittson 1831). The total strength of the extra people at the fort during these

Table 4. Mean egg deposition of salmon (1967-87) and steelhead (1982-87) in the Wenatchee, Entiat, and Methow river drainages.

Species	Wenatchee River drainage	Entiat River drainage	Methow River drainage
Spring chinook salmon			
Spawning area (ac)	602	253	980
Number redds/ac	3.1	2.1	1.2
Number eggs/ac	14,216	9,459	5,318
Number eggs/100 m^2	351	234	131
Summer/fall chinook			
Spawning area (ac)	1,206	54	606
Number redds/ac	3.2	0.6	1.8
Number eggs/ac	16,837	3,128	9,442
Number eggs/100 m^2	416	78	233
Steelhead			
Spawning area (ac)	1,801	308	1,586
Number redds/ac	2.2	0.3	2.3
Number eggs/ac	12,059	1,014	9,107
Number eggs/100 m^2	297	36	224
Sockeye salmon			
Rearing area (ac)	2,445[a]	b	b
Number redds/ac	5.0		
Number eggs/ac	13,358		
Number eggs/100 m^2	330		

[a] Lake Wenatchee

[b] Small numbers (< 100-200) of sockeye salmon spawn in the Wenatchee, Entiat, and Methow rivers that are not associated with lakes for rearing

summer seasons amounted to no more than twenty adults and as many children. Salmon, roots, and berries were far from adequate to feed these few people at the fort during the rest of the year. The traders ate horses frequently, and they also had the benefit of crops which had been harvested since 1825. Even with horse meat and crops, the food scarcity at Kettle Falls was still a problem."

and

"In 1826, there was no salmon harvest at all on the Middle Columbia by late July (Black 1826b). In July of 1831, the traders at Fort Walla Walla were eating salmon brought not from Kettle Falls after its abundant catch in 1830, but from Thompson's River (Fraser River system, British Columbia) (McGillivray and Kittson 1831). In July of 1832, John McLoughlin (1832b) decided that Fort Colville should maintain an extra year's reserve of agricultural produce in case there should be further shortages of salmon."

Smith (1983) commented specifically on the middle Columbia:

"The spring of 1811 could not have been an easy season for these groups (Indians). For even in early July when Thompson stopped briefly at the large village at Rock Island, he found the villagers "poor in provisions". Their fisheries were then yielding some salmon, but the catch must have been singularly meager in spite of the fact that the salmon season should have been nicely underway."

and

"In early August 1928, Work reports that along the White Bluffs (Hanford Reach) there were few Indians to be seen and these were starving, for they were catching no salmon. And at Priest Rapids, the salmon seemed very scarce. When, on August 6, he reached Rock Island Rapids, the salmon were found to be very scarce in this area also."

Much of the natural fluctuation common in salmon abundance has been ascribed to variations in survival of the young in freshwater, during either the egg or fry-fingerling states. The historical accounts of feast and famine lie outside of freshwater control. Nickelson (1986) described freshwater control as creating the variability within a generally high or low level of abundance in coho salmon, with the mechanisms playing a secondary role in population regulation. Primary control centers on ocean survival, which we have also suggested as controlling the huge variability in sockeye salmon abundance.

Ocean control seems to operate by producing conditions either favorable or unfavorable, without much gradation (Nickelson 1986). Resident stream trout do not exhibit the wide variation in population size common in Pacific salmon (Hall and Knight 1981). The extremes of temporal variation occur in short-lived (two years) pink salmon (O. gorbuscha). The enormous fluctuations in abundance characterizing this species are widely ascribed to the variable environment in estuarine and marine rearing areas, and not the relatively stable freshwater spawning grounds.

Escapements (inter-dam counts) of summer/fall chinook salmon adults into the Wenatchee River fluctuated from 5,708 in 1967 to 19,696 in 1987. This occurs because of annual differences in such freshwater environmental factors as stream flow, abundance of competitors and predators, and conditions in the ocean environment. For example, the record low escapement in 1967 of 5,708--200 eggs/100 m^2 --resulted four years later in a spawner abundance of 13,076 (1971). The low spawner abundance in 1967, however, was produced by an escapement of 16,283 four years earlier (1963)--564 eggs/100 m^2 (Fig. 6a). This suggests that the habitat was fully seeded even at minimum escapements.

A major problem with stock-recruitment determinations lies in our inability, because of insufficient data, to include fish taken in the ocean in calculating adult escapements (Chapman et al. 1982). Prior to the Pacific Salmon Treaty between the United States and Canada in 1985, three summer/fall chinook salmon were caught in the ocean for every one that escaped to the Columbia River. In contrast, only one spring chinook salmon was caught in the ocean for every nine that escaped to the Columbia River and we can better estimate the relationship between numbers of spawners and progeny produced.

The record low escapement in 1971 of 923 spring chinook salmon--73 eggs/100 m^2--resulted four years later in a total run of 4,580 fish. The lower spawner abundance in 1971 was produced by the 1967 escapement of 1,895 fish. The record total run of 20,023 fish in 1977 was produced by a below average escapement of 3,767 (296 eggs/100 m^2) in 1973.

When optimal flows and ocean conditions optimized steelhead survival during the 1981-82 period, runs to the Methow River increased (particularly the hatchery component) to more than 5 times pre-development run size, albeit at 10 times pre-development smolt numbers (Appendix H). And, the Methow River became the top summer steelhead fishery in the state of Washington--a paradoxical distinction for a river 500 mi from the sea above 9 dams.

In conclusion, natural production of salmon and steelhead smolts now may be similar to historical production in the Wenatchee, Entiat, and Methow rivers. Caveats to this notion are--the native coho salmon is now extinct, that 62% to 71%, on average,

of the smolts are now lost in mainstem dam turbines or reservoirs, and that major harvest now occurs elsewhere. When we include a 13% loss (62%-71% total) of smolts per dam (Mid-Columbia Coordinating Committee 1986) in our estimates of total run sizes of naturally produced salmon and steelhead, we arrive at contemporary estimates of total production (Table 5). If we assume a 33% harvest rate by Indians in the last century (Chapman 1986), we can calculate estimates of production in the pre-settlement era. Admitting that these estimates of primordial abundance are crude and the species composition of the harvest is especially so, they do suggest that production now may not be greatly different than historically (Table 5).

Table 5. Historical (1850s) and contemporary (1967-87) relative abundance of naturally produced salmon and steelhead from the Wenatchee, Entiat, and Methow rivers.

	Wenatchee River		Entiat River		Methow River	
Species	1850s[a]	1967-87[b]	1850s[a]	1967-87[b]	1850s[a]	1967-87[b]
Chinook salmon	41,300	204,800	3,400	9,500	24,200	86,100
Coho salmon	3,900	0	4,500	0	36,000	0
Sockeye salmon	228,100	93,700	0	tr	0	tr
Steelhead	7,300	8,200[c]	500	800[c]	3,600	5,000[c]
TOTAL	280,600	306,700	8,400	10,300	63,800	91,100

[a] Estimated Indian catches (Table 1, Appendix G) multiplied by three (harvest rate 33%) (Chapman 1986). Species composition of Indian catches can only be inferred, so the qualitative catch was likely much different than shown (e.g., see steelhead, Appendix H).

[b] Mean adult run strength corrected for dam loss and harvest and a 13% loss of smolts per dam or reservoir.

[c] For years 1987 to 1989 (calculated from Table 13, Appendix H).

CHAPTER 3

FISH SAMPLES AND HABITAT ATTRIBUTES

To try to understand fish populations outside the ecological setting would be as meaningless as trying to consider habitat without data on the fish that use it (White 1986). In this chapter we describe fish samples and habitat attributes so as to better understand factors affecting the fish.

Methods

We primarily used snorkeling and chemical sampling to define fish populations, while habitat was evaluated according to the Habitat Quality Index (HQI) (Binns 1982).

Snorkeling

Fish densities were estimated by snorkeling observations (Schill and Griffith 1984) at 13 stations (4.1 ac) on tributaries of the Wenatchee River in 1983, 12 stations (16.1 ac) on the Wenatchee River in 1985 (Griffith 1985), 16 stations (21.3 ac) on the Methow River in 1986 (Griffith and Hillman 1986), and 19 stations (6.9 ac) on the Entiat River and tributaries of the Wenatchee River in 1987 (Griffith 1987).

We counted fish in the larger streams under low flow conditions (Wenatchee River, 500 to 800 cfs; Methow, 300 cfs; and Entiat, 100 cfs) during the last week of August. Weather was clear with bright sunlight except for one day with broken overcast. Water clarity ranged from 4 ft to 13 ft. Snorkelers generally could see the river bottom in all portions of a station easily.

Up to eight experienced snorkelers floated downstream through each mainstem section to count fish. In pools, runs, and glides, snorkelers maintained a prescribed spacing from one another by holding onto connected lengths of PVC pipe. In two boulder riffles snorkelers moved feet first and slowly bounced through the riffle (Johnson 1984). Spacing was determined by underwater visibility, measured as the distance at which an object the size of the smallest fish could be recognized clearly. Snorkelers counted only those fish that passed underneath in a lane between themselves and the observer to their left. In pools and glides, the flexible PVC pipe enabled the observers on each end of the counting line to

position themselves about three feet ahead of the others. This facilitated the counting of any fish that moved laterally along the counting line. Fish within 3 ft of each bank were counted by an observer working upstream slowly.

On the smaller streams two snorkelers usually began at the downstream end of a station and proceeded upstream slowly. The station was partitioned into lanes, and each diver counted fish in his lane.

We made separate counts for age-0 (<100 mm) chinook salmon and older juveniles. For rainbow/steelhead trout, three size groups (<100 mm, 100-200 mm, >200 mm) were counted separately. Adult salmon and steelhead were not counted. Juvenile mountain whitefish were differentiated from adults by the presence of parr marks. At a few stations there were too many size/species combinations for observers to tally in a single pass. At these stations we made one pass to count salmonids and a second to count other species.

To assess the accuracy of snorkel surveys, we compared 23 underwater counts of juvenile salmonids in the Wenatchee and Methow rivers with samples taken at the same sites with sodium cyanide the same day or the next morning. Marked hatchery chinook salmon were released in 22 sites as soon as block nets were in place. Recovery efficiency was based on the percentage of marked chinook recovered. We calculated population estimates for chinook and steelhead as follows (Hillman et al. in press):

(1) $N = 100Ns/(6.2t \pm 49.5)$ (age-0 chinook salmon),
(2) $N = 100Ns/(7.3t \pm 53.7)$ (steelhead <100 mm),
(3) $N = 100Ns/(3.5t \pm 29.4)$ (steelhead 100-200 mm),

where N = population estimate; Ns = number of fish counted by snorkeling; and t = water temperature (°C).

Snorkel counts of other fishes were not corrected because in the snorkel/cyanide calibration, we used stations that held insufficient numbers of mountain whitefish, suckers, northern squawfish, and large rainbow (> 200 mm) for meaningful analyses. Snorkel counts of other fish should closely reflect actual abundance (Hillman et al. in press). Because sculpins and dace were noted but not counted at snorkel stations, the average density values from nearby chemical stations were used to complete the species assemblages.

Chemical

We sampled 121 stations (31.8 ac) in late summer, early fall, 1983 to 1989, using briquettes of sodium cyanide (Wiley 1984). Cyanobrik is an effective, controllable, fish toxicant or anesthetic, depending on concentration. It is environmentally non-persistent. Cyanobrik is composed of 99% sodium cyanide and 1% inert ingredients. It is readily soluble in water, forming free

cyanide (CN-ion and molecular HCN). At pH levels and water temperatures in our study streams, at least 96% of the free cyanide exists as HCN. HCN is volatile, lighter than air, and diffuses rapidly into the atmosphere.

We selected stations to encompass a riffle-pool or a series of riffles and pools. We generally attempted to collect fish in about 300 ft of stream length, about the limits of Cyanobrik efficiency downstream from the point of application. Frequently, however, we sampled longer reaches (to 900 ft) by applying additional Cyanobrik at intervals downstream.

In the larger river areas, we selected side-channels or braids passing 10% or less of the mainstem discharge, or sampling sites with flows under 100 cfs, where block nets could be set. A maximum effort was made to recover all fish, with the exception of non-salmonid fry.

To assess the efficiency of cyanide sampling, about 75 (range 46-141) marked hatchery chinook salmon were placed in 24 stations as soon as block nets were in place. Recovery efficiency was 89% (range 66% to 100%). Numbers of other salmon and trout recovered after cyanide application were expanded to compensate for 11% nonrecovery.

Fish collected were measured to the nearest millimeter (fork length) and weighed to the nearest gram or 0.1 gram. One hundred or more fish of each species were measured and weighed in each sampling; if fewer than 100 fish, all were measured and weighed. Through 1987, small fry and fingerlings (<100 mm) were weighed in the aggregate; after 1987 they were mostly weighed individually to 0.1 gram.

Electrofishing

Electrofishing catch depletion estimates (Reynolds 1983) of fish abundance were made at four stations (0.7 ac).

Habitat Evaluation

We ranked fish habitat with Binns' (1982) Habitat Quality Index (HQI), which rates late summer flow, annual flow variation, water temperature, food, cover, water velocity, nitrate nitrogen, and stream width; with an index of non-salmonids substituted for bank erosion. Binns' bank erosion was directed to livestock destabilization and not natural erosion most common along banks in our mountainous streams.

Statistical

We used stepwise multiple regression to test the relationship of HQI variables to salmonid biomass and abundance, running a

separate test for each species in each study drainage. We then used simple linear regression to analyze the relationship of HQI scores with salmonid biomass and abundance in each drainage. For all analyses, we assumed equal variances of dependent variables, uncorrelated errors, low correlation among independent variables, and that dependent variables were linear functions of independent variables. We analyzed data in the HP3000 with the Statistical Package for the Social Sciences (SPSS), Release 6 (Nie et al. 1975) and SPSS update 7-9 (Hall and Nie 1981). We considered tests with values $P > 0.05$ as not significant; $P < 0.05$ as significant; and $P < 0.01$ as highly significant.

Results

Numbers of chinook salmon ($R = 0.45$, $P = 0.00$) and age-0 steelhead ($R = 0.57$, $P = 0.00$) in mid-Columbia tributaries were related significantly to HQI scores (Table 6). We found no relationship between HQI scores and numbers of steelhead parr. Cover and species interaction explained most of the variability in densities of salmon and the smaller steelhead. Cover and interaction, however, explained only about half of the variability in salmon and age-0 steelhead numbers. Relationship between HQI scores and biomass (Table 7) were no better correlated.

The HQI was primarily designed to link biomass of older, larger trout to habitat quality rather than ephemeral numbers of juvenile salmon and steelhead having little biomass. Numbers and biomasses of trout in headwater streams of the Methow River (Table 8), however, were also poorly correlated with HQI attributes. There was no significant relationship (simple linear regression) between HQI and densities of species or pooled densities. HQI explained 15% of the variability of cutthroat trout biomass, but could not account for any variability in the biomass of other species or total (pooled) biomass.

Biomass and density of rainbow trout related significantly (stepwise multiple regression) with stream temperature; but stream temperature explained only a small fraction of the variability (<20%). The sum of temperature, nitrogen, velocity, and cover influenced the biomass of cutthroat trout; only temperature and cover significantly influenced their densities. Temperature explained 12% of the variability in densities of rainbow/cutthroat hybrids; no variables significantly influenced their biomass. Densities and biomasses of bull trout varied independently of the HQI variables. Stream width explained a small fraction (<20%) of the variability in densities and biomass of brook trout. Total salmonid density and biomass varied significantly with food only, and that explained only 10% of the variability.

Table 6. Habitat quality index (HQI) score and densities (number/100 m²) of fish for sampling stations in mid-Columbia River tributaries used by anadromous salmonids.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
						Wenatchee River Drainage							
Wenatchee River													
1.1	S85	24	0.2					0.2	3.7	(2.4)	13.4	0.2+	19.9
1.1 (braid)	C85	17	1.0					1.0		2.4	2.5	68.1	74.0
4.4	S85	26	0.3		0.1	0.1		0.5	0.6	(64.8)	1.7		67.6
4.4 (braid)	C85	44	10.0	5.9	1.7			17.6	8.7	64.8		0.1	91.2
5.2 (braid)	C85	26	1.8	0.6	0.2	0.1		2.7	0.8	15.9	0.1	0.2	19.7
5.3 (braid)	C85	38	5.4	1.9	1.1			8.4	0.5	53.2	4.6		66.7
5.2 (braid)	C85	28	5.5	0.1	0.1			5.7	0.1	5.6	4.6	29.8	45.8
5.2,5.3 (braid)	E,C87	32	3.5	0.8	0.3		62.2	66.8					
6.6 (braid)	C87	53	5.7	0.8	1.0	0.3	20.4	28.2	0.2	(20.5)	0.6	TNC [f]	-
6.6 (canal)	C87	62	15.2	1.2	0.4	0.9	21.3	39.0		321.3	1.1		361.4
6.7	S85	26	1.7	0.2	1.4	0.3		3.6	0.7	(30.2)	1.2	0.1	35.8
10.0	S85	24	9.0	5.9	1.7	0.1		16.7	5.7	(30.2)	6.0	0.2	58.8
12.5	S85	38	2.3	2.4	3.5	0.4		8.6	7.3	(30.2)	15.2		61.3
14.7	S85	38	0.3	1.5	0.2	0.1		2.1	3.3	(30.2)	15.1	0.1	50.8
15.0 (braid)	C86	43	9.2	7.8	4.6	0.1		21.7	3.4	16.6	0.6	0.8	43.1
15.0 (braid)	C87	29	9.1	9.2	2.7	0.1		21.1	1.6	39.8	0.6		63.1
15.6 (braid)	C85	25	2.0	9.4	3.7	0.1		15.2	0.3	36.2	0.1		51.8
16.5	S85	23	0.5	6.7	0.8	0.1		8.1	3.1	(30.2)	4.0	0.1	45.5
18.4 (braid)	C85	47	4.8	16.9	3.9	0.1		25.7	0.3	9.7	0.1		35.8
21.2	S85	17	1.5	3.4	1.5	0.1		6.5	5.2	(23.8)	2.7		38.2
24.5	S85	26	4.2	8.0	5.6	0.9		18.7	3.5	(23.8)	2.8		48.8
26.5 (braid)	C85	36	6.3	12.6	6.8	0.1	0.1	25.9	0.1	23.5			49.5
28.7	S85	28	7.4	9.6	11.2	0.3	0.1	28.6	1.3	(23.8)			53.7
33.8 (braid)	C85	46	6.5	18.0	16.7	0.1	0.2	41.5	0.9	33.5	0.1		76.0
34.0	S85	20	3.2	0.6	1.5	0.1		5.4	1.6	(23.8)			30.8

Table 6 continued.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
37.5	S85	34	2.9	4.1	0.1	0.1		7.2	1.4	(9.3)	0.4	0.2	18.5
38.2 (braid)	C84	23	1.3	4.9	0.7			6.9		9.3			16.2
46.8 (braid)	C84	47	8.7	3.0	1.3	0.3		13.3	0.1	10.7			24.1
49.9 (braid)	C84	32	1.0	1.9	0.2			3.1	0.4	1.1			4.6
Peshastin Cr. (17.9)													
5.3	S83	99	7.8	12.3	40.1	1.7		61.9		(3.4)			65.3
5.3	S87	99	27.9	14.3	6.1	1.5		49.8		(3.4)			53.2
6.6	S87	99	18.5	43.2	57.5	11.0		130.2		(3.4)			133.6
Ingalls Cr. (9.0)													
0.0	S83	90		9.5	35.4	3.2		48.1		(3.4)			51.5
0.0	S87	90	2.3	21.0	101.5			124.8		(3.4)			128.2
9.1	E,S83	99		29.0	102.4	1.0		132.4		3.4			135.8
Icicle Cr. (25.6)													
2.8 (braid)	C86	50	14.7	26.4	0.8			41.9		40.0	5.5		87.4
3.2 (braid)	C85	87	28.9	35.1	3.6		0.3	67.9		11.4	0.3		79.6
3.2 (braid)	C86	87	48.5	55.7	0.7		0.2	105.1		11.3			116.4
3.2 (braid)	C87	87	7.5	96.0	0.7		32.0	136.2	0.9	28.3	0.5		165.9
3.4 (braid)	C85	63	9.5	9.1	0.4			19.0		6.6			25.6
3.4 (braid)	C86	63	27.8	27.1	0.5			55.4		10.9			66.3
3.4 (braid)	C87	71	10.9	43.2			44.7	98.8	2.9	3.2			104.9
3.5 (braid)	C85	75	17.3	8.5	2.2			28.0		10.4	0.5		38.9
3.5 (braid)	C86	63	36.1	16.7	0.8			53.6		12.2			65.8
3.5 (braid)	C87	87	25.3	12.4	2.2		60.4	100.3	4.1	3.4	0.2		108.0
8.6 (braid)	C85	65		17.0	11.7	0.1	0.9	29.7		0.1			29.8

Table 6 continued.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
Chiwaukum Cr. (35.9)													
0.0 (left braid)	C84	12		7.7		0.3		8.0		0.3			8.3
0.0 (right braid)	C84	77	43.6	63.3	5.9		2.0	114.8		4.0			118.8
1.5 (braid)	C85	24	0.9	35.8	6.6		1.9	45.2		14.2			59.4
Beaver Cr (46.7)													
0.0	C85	29	22.0	15.3	0.8		1.2	39.3		0.4			39.7
Chiwawa R. (48.4)													
0.0	C84	22	7.9	1.3				9.2		0.5			9.7
2.1	S87	16	0.2	0.9				1.1	1.7	(4.3)			17.8
6.7	S87	13		0.5	0.3	0.2		1.0		(4.3)			5.3
Meadow Cr. (9.2)													
0.0	C84	27	21.1	17.2	0.4		0.6	39.3		0.3			39.6
9.3	C87	16	3.3	0.8	0.9		3.7	8.7	0.2	5.7			14.6
Chickamin Cr. (13.8)													
0.0	C83	27	15.3		0.5		0.3	16.1					16.1
Rock Cr. (21.3)													
0.6	E84	27			1.2		1.7	2.9		0.5			3.4
21.5	S83	21	9.6					9.6	1.9	(4.2)			15.7
23.9	S87	36	17.7			0.1		17.8	1.5	(4.2)			23.5
27.0	S83	20	2.6					2.6	2.4	(4.2)			9.2
27.1	S87	59	80.9				0.6	81.5	4.8	(4.2)			90.5
28.1 (braid)	C84	60	62.5				2.9	65.4		2.6			68.0
29.7 (braid)	C84	36	25.3			0.8	15.1	41.2		6.9			48.1

Table 6 continued.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
Nason Cr. (53.6)													
0.8	S83	32	3.6	2.1	0.1			5.8	0.9	(7.1)			13.8
0.8	S87	38	0.3	5.8	0.3	0.1		6.5	0.3	(7.1)			13.9
6.7	S83	14	0.5	0.8				1.3	0.1	(7.1)			8.5
6.7	S87	19	3.7	6.4	3.2			13.3	0.2	(7.1)			20.6
8.6	S83	27	7.0			0.1		7.1	0.3	(7.1)			14.5
8.6	S87	61	68.0	46.6	1.0	0.3		115.9	0.5	(7.1)			123.5
13.2	S83	25	4.5	0.3				4.8	0.1	(7.1)			12.0
13.2	S87	41	17.8	1.2				19.0		(7.1)			26.1
Little Wenatchee R (58.6)													
2.0	S83	21	1.3			0.1		1.4		(2.3)			3.7
4.0	C84	36	7.1	0.4	0.1		0.1	7.7		2.3			10.0
7.3	S83	43	14.4	0.1				14.5	0.1	(2.3)			16.9
White River (58.6)													
11.0	C84	38	13.9	0.9			0.7	15.5		20.2			35.7
13.0	C84	18	2.8			0.3		3.1					3.1
13.0	S83	25	0.3	1.5	0.2	0.2	1.5	3.7					3.7
Cougar Cr. (13.1)													
0.0	C84	17		1.7	0.8		2.2	4.7	0.2	6.5			11.4

Table 6 continued.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
						Entiat River Drainage							
Entiat River													
1.2 (braid)	C84	69	8.2	2.7	1.0		0.3	12.2	1.4	10.9	0.9		25.4
3.2	S87	68	22.7	2.5	2.0			27.2	1.3	(2.7)	3.9	0.6	35.7
6.3 (braid)	C84	57	11.6	21.0	0.5			33.1		2.7			35.8
7.0 (braid)	C84	85	5.6	13.9	0.2			19.7		3.4			23.1
Mad River (10.6)													
2.8	C84	37		9.7	3.2			12.9					12.9
13.1a	S87	70	20.7	5.0	11.7	0.2		37.6	1.3		0.6	0.2	39.7
13.1b	S87	62	5.0	1.8	6.6			13.4	1.5		0.1		15.0
16.3 (braid)	C84	49	4.2	6.6	1.7		0.3	12.8					12.8
17.6	S87	29	4.1	1.4	0.4	0.1		6.0	0.3				6.3
20.1	C84	78	12.1	0.6	0.8		0.2	13.7	0.1				13.8
23.4	S87	29	3.0	6.5	0.7			10.2	0.1				10.3
25.2 (braid)	C84	11		0.9		0.6		1.5					1.5
27.5 (braid)	E84	26	4.2	5.2	1.6		0.4	11.4		12.2			23.6
28.0	S87	56	0.6	18.2	2.3	0.3	0.1	21.5	1.0				22.5
						Methow River Drainage							
Methow River													
2.1	S86	25	0.9	0.1	0.2	0.1	0.1	1.4	0.8	(32.9)	1.6	TNC	36.7
3.0	S86	36	0.5	0.1	0.4	0.1		1.1	1.2	(32.9)	2.9	TNC	38.1
5.8	S86	11	3.8	0.2	1.8	0.1		5.9	1.3	(32.9)	1.0	TNC	41.1
7.0 (braid)	C85	74	1.6	8.8	5.5	0.1		16.0		25.9	0.1		42.0
14.0a (braid)	C85	58	6.7	6.6	3.8	0.5		17.6		21.3		1.0	39.9
14.0b (braid)	C85	70	5.3	22.5	6.9	1.1		35.8		25.0	0.5		61.3
14.0a (braid)	C86	86	50.8	2.4	10.2	0.1	0.1	63.6	0.1	75.9	0.2		139.8
14.2	S86	14	3.8	0.1	0.6	0.1		4.6	0.7	(32.9)	1.9	0.1	40.2

Table 6 continued.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
15.6	S86	69	5.4	2.0	20.2	0.5		28.1	1.8	(32.9)			62.8
15.7	S86	69	13.9	5.0	29.4	0.8		49.1	5.0	(32.9)			87.0
17.7	S86	13	1.3	0.1	1.4			2.8	0.6	(32.9)	0.8		37.1
21.2	S86	15	4.7	0.2	1.8			6.7	0.7	(18.0)	1.8		27.2
21.3	S86	37	2.8	0.5	1.2			4.5	3.7	(18.0)	0.3		26.5
23.8	S86	13	1.4	1.1	0.1			2.6	2.8	(18.0)	2.9	0.3	26.6
23.9 (braid)	C85	64	2.4	6.7	0.5			9.6	0.2	18.0			27.8
24.4 (braid)	C85	102	2.3	13.4	1.7	0.1		17.5	0.1	18.9	1.5		38.0
27.2	S86	29	24.9	0.5	7.6	0.1	0.1	33.2	4.0	(18.9)	4.6	0.4	61.1
31.6	S86	30	0.1					0.1	0.5	(18.9)	2.4	0.1	22.0
38.4	S86	37	0.3		1.8	0.2	0.1	2.4	6.3	18.9	0.1	0.3	28.0
41.3	S86	62	0.1	0.1				0.2	3.8	(17.3)			21.3
42.3 (braid)	C85	51	2.3	9.9	0.1			12.3		15.4			27.7
44.3	S86	37	0.0	0.6	1.5	0.1		2.2	2.8	(15.4)			20.4
44.4	S86	30	0.2				0.1	0.3	3.3	(15.4)			19.0
44.8 (braid)	C86	37	0.3	1.5	0.3			2.1		15.4			17.5
50.4	C86	70	7.3	2.1	4.1	0.1	0.1	13.7		17.3			31.0
50.6	C86	62	0.3	1.9	0.6			2.8		22.3			25.1
55.0	C86	16	2.8	1.1	0.7		0.1	4.7		3.9			8.6
60.7	C86	28	13.2	1.2	1.4		0.1	15.9		6.1			22.0
67.4	C86	40	6.1	0.4	1.3			7.8		11.5			19.3
76.4 (West Fork)	C86	46		1.4	5.2		0.3	6.9		3.9			10.8
Gold Cr. (21.8)													
0.8+3.5	C87	63		38.8	36.3	0.3	0.5	75.9		2.8			78.7

Table 6 concluded.

Station and river mile	Method and year [a]	HQI score	Chinook salmon [b]	Rainbow/steelhead y-o-y	Rainbow/steelhead parr	Rainbow/steelhead (>200mm)	Other [c] trout or salmon	Total trout and salmon	White fish	Dace [d] and sculpin	Sucker	Other [e]	Total
Twisp River (40.2)													
0.0	C85	42	4.7	16.3	3.2	0.2		24.4	0.3	3.2			27.9
1.2	E85	61	1.3	9.0	0.9			11.2	0.3	(9.1)			20.6
4.0	C86	82	28.3	7.0	12.4	1.2		48.9		15.0			63.9
11.1	C86	74	19.3	3.2	1.0			23.5	0.1	10.4			34.0
15.6	E85	74	13.6	3.3	2.3	3.0		22.2		(8.2)			30.4
24.4	C87	48	7.7	4.0	13.6	1.7	1.7	28.7		5.4			34.1
27.1	C87	68			6.3	1.3	5.9	13.5					13.5
Chewack River (50.1)													
7.8	C85	52	7.5	20.9	5.1	0.1		33.6		4.3			37.9
14.7	C85	48	6.7	4.5	0.6	0.1		11.9	0.1	4.1			16.1
17.4	C86	24	3.3	0.5	0.1			3.9		7.1			11.0
23.3	C86	45	4.8		3.8	0.1	0.1	8.8		9.3			18.1
Lake Cr. (23.4)													
2.8	C87	46	3.9	2.7	7.2	0.1	0.6	14.5		2.4			16.9
30.8	C87	62	38.0	1.8	13.8	1.1		54.7		15.7			70.4
Wolf Cr. (52.8)													
1.4	C87	47		5.0	29.8		0.3	35.1					35.1
Early Winters Cr. (67.3)													
0.0	C86	43	7.6	0.5	2.0	0.4	2.3	12.8		6.6			19.4
1.5 (braid)	C87	61	11.2	1.5	3.7		0.5	16.9		0.2			17.1
5.0	C86	62	0.2	13.7	5.7	0.7	1.5	21.8		1.1			22.9
Lost River (73.0)													
0.0	C86	34	12.2	0.5	3.3	0.1		16.1		2.8			18.9

[a] Includes C (cyanide), E (electroshocker), S (snorkel); 83 = 1983, etc.

[b] Includes a few yearlings, age 1+

[c] Includes, in order of increasing abundance, cutthroat trout, Eastern brook trout, bull trout, and hatchery coho salmon.

[d] "Estimated" indicated by ( ).

[e] Includes redside shiner, chiselmouth chub, northern squawfish, and threespine stickleback.

[f] TNC = too numerous to count

Table 7. Biomass (g/m²) of fish at sampling stations (same as Table 6) in mid-Columbia River tributaries (anadromous zone).

Station and river mile	Area (m²)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin [a]	Suckers	Other	Total
						Wenatchee River Drainage					
Wenatchee River											
1.1	911	24	tr			tr	3.9	(0.7)	92.0	1.3	97.9
1.1 (braid)	751	17	tr	tr		tr		4.5	17.0	0.5	22.1
4.4	6786	26	tr	tr		tr	1.6	(0.7)	11.4		13.7
4.4 (braid)	428	44	0.5	0.8		1.3	1.0	2.8		tr	5.1
5.2 (braid)	3561	26	0.1	0.2		0.3	0.1	0.2	0.4	0.1	1.1
5.3 (braid)	1291	38	0.3	0.3		0.6	0.2	1.7	29.3	0.1	32.2
5.2 (braid)	5029	28	0.3	tr		0.3	tr	0.2	1.8	0.5	2.8
5.2,5.3 (braid)	5410	32	0.2	0.1	6.2	6.5	-	-	-	-	-
6.6 (braid)	1540	53	0.3	0.6	2.0	2.9		0.2	0.4	2.5	6.0
6.6 (canal)	1766	62	0.7	1.3	2.1	4.1			tr	5.5	9.6
6.7	6867	26	0.1	0.5		0.6	1.1	(0.7)	8.1	0.5	11.0
10.0	2374	24	0.4	0.4		0.8	7.9	(0.7)	41.1	0.8	51.3
12.5	3210	38	0.1	0.9		1.0	10.5	(0.7)	104.2		116.4
14.7	3974	38	tr	0.1		0.1	6.4	(0.7)	86.4+	0.5	94.1
15.0 (braid)	2523	43	0.5	2.3		2.8	0.5	1.4	1.4	0.1	6.2
15.0 (braid)	2360	29	0.5	1.5		2.0	0.1	1.0	tr	tr	3.2
15.6 (braid)	2030	25	0.1	1.5		1.6	tr	3.7	0.3		6.1
16.5	7052	23	tr	0.2		0.2	7.9	(0.7)	27.7	0.5	37.0
18.4 (braid)	1218	47	0.3	1.7		2.0	0.2	0.7	0.8	tr	3.6
21.2	10337	17	0.1	0.2		0.3	10.1	(0.7)	18.7		29.8
24.5	5384	26	0.1	1.6		1.7	9.4	(0.7)	18.9		30.7
26.5 (braid)	1436	36	0.3	1.3	tr	1.6	0.1	2.1		tr	3.8
28.7	3040	28	0.2	1.2		1.4	0.9	(0.7)			3.0

Table 7 continued.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin[a]	Suckers	Other	Total
33.8 (braid)	1779	46	0.3	2.1		2.4	0.4	2.3	tr	tr	5.1
34.0	4968	20	0.1	0.1		0.2	4.3	(0.7)	0.3		5.5
37.5	10397	34	0.1	0.1		0.2	2.5	(0.7)	2.6	0.8	6.7
38.2 (braid)	2389	23	0.1	0.2		0.3		0.5			0.8
46.8 (braid)	1744	47	0.6	0.9		1.5	tr	1.2			2.7
49.9 (braid)	3719	32	0.1	0.1		0.2	tr	0.1			0.3
Peshastin Cr. (17.9)											
5.3	601	99	0.5	7.5		8.0		(2.0)			10.0
5.3	391	99	1.4	3.9		5.3		(2.0)			7.2
6.6	146	99	0.9	23.8		24.7		(2.0)			26.7
Ingalls Cr. (9.0)											
0.0	430	90		9.7		9.7		(2.0)			11.7
0.0	133	90	0.1	19.9		20.0		(2.0)			22.0
9.1	293	99		16.7		16.7		2.0			18.7
Icicle cr. (25.6)											
2.8 (braid)	2604	50	0.9	0.9		1.8		1.1	0.3		3.2
3.2 (braid)	1500	87	1.1	1.3	0.2	2.6		0.4	tr		3.0
3.2 (braid)	1500	87	3.3	0.8	0.1	4.2		0.6			4.8
3.2 (braid)	1500	87	0.5	1.2	1.1	2.8	tr	0.7	0.1		3.6
3.4 (braid)	1639	63	0.4	0.3		0.7		0.1			0.8
3.4 (braid)	1639	63	2.2	0.7		2.9		0.2			3.1

Table 7 continued.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin[a]	Suckers	Other	Total
3.4 (braid)	1639	71	0.6	1.0	1.8	3.4	0.2	0.1			3.7
3.5 (braid)	1473	75	1.0	0.8		1.8		0.4			2.2
3.5 (braid)	1473	63	2.9	0.9		3.8		0.3	tr		4.1
3.5 (braid)	1473	87	1.7	1.0	3.1	5.8	0.2	0.1	tr		6.1
8.6 (braid)	763	65		3.0	0.1	3.1		tr			3.1
Chiwaukum Cr. (35.9)											
0.0 (left braid)	349	12		0.8		0.8		tr			0.8
0.0 (right braid)	202	77	3.4	3.1	0.6	7.1		0.2			7.3
1.5 (braid)	106	24	0.1	2.6	0.2	2.9		1.1			4.0
Beaver Cr (46.7)											
0.0	241	29	1.3	0.7	tr	2.0		tr			2.1
Chiwawa R. (48.4)											
0.0	908	22	0.5	0.1		0.6		tr			0.6
2.1	2310	16	tr	tr		0.1	4.7	(0.2)			4.9
6.7	603	13	tr	tr	tr	0.1	5.3	(0.4)			5.7
Meadow Cr. (9.2)											
0.0	682	27	1.0	0.3	0.1	1.4		tr			1.4
9.3	4418	16	0.2	0.2	0.6	1.0	0.5	0.4			1.9

Table 7 continued.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin [a]	Suckers	Other	Total
Chickamin Cr. (13.8)											
0.0	360	27	0.8	0.1	tr	1.0		tr			1.0
Rock Cr. (21.3)											
0.6	522	27		0.2	1.7	1.9		tr			1.9
21.5	1623	21	0.5			0.5	5.7	(tr)			6.2
23.9	2969	36	0.9	tr		1.0	0.6	(0.2)			1.8
27.0	1032	20	0.2			0.2	7.2	(0.2)			7.6
27.1	309	59	2.3		0.2	2.5	14.5	(0.2)			17.2
28.1 (braid)	384	60	1.6		0.1	1.7		0.2			1.9
29.7 (braid)	245	36	0.7	1.1	0.3	2.0		0.2			2.2
Nason Cr. (53.6)											
0.8	1083	32	0.2	0.1		0.3	0.5	(0.2)			1.0
0.8	2713	38	tr	0.3		0.4	0.3	(0.2)			0.9
6.7	1580	14	tr	tr		tr	tr	(0.2)			0.4
6.7	3411	19	0.1	0.4		0.5	0.5	(0.2)			1.2
8.6	2339	27	0.4	0.1		0.5	0.1	(0.2)			0.8
8.6	921	61	2.0	1.1		3.1	1.6	(0.2)			4.9
13.2	2145	25	0.3	tr		0.4	0.4	(0.2)			1.0
13.2	1211	41	0.5	tr		0.6		(0.2)			0.8
Little Wenatchee R (58.6)											
2.0	2858	21	0.1	tr	0.1	0.2					0.2
4.0	1353	36	0.4	tr	0.1	0.5					0.5
7.3	2089	43	0.8	tr		0.8	0.3				1.1

Table 7 continued.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin[a]	Suckers	Other	Total
White River (58.6)											
11.0	729	38	0.5	tr	tr	0.6		0.5			1.1
13.0	590	18	tr	0.1		0.1					0.2
13.0	724	25		0.3	0.1	0.4					0.4
Cougar Cr. (13.1)											
0.0	648	17		0.2	0.2	0.4	0.1	0.7			1.2
Entiat River Drainage											
Entiat River											
1.2 (braid)	782	69	0.9	5.7	0.4	7.0	1.7	2.8	6.7		18.2
3.2	1419	68	4.5	0.9		5.4	1.6	(2.8)	2.9	0.3	13.0
6.3 (braid)	745	57	1.2	1.8		3.0		0.2			3.2
7.0 (braid)	929	85	0.5	0.8		1.3		0.2			1.5
Mad River (10.6)											
2.8	124	37		0.9		0.9					0.9
13.1a	1373	70	1.6	3.4		5.0	2.7	(0.2)	4.9	1.0	13.8
13.1b	1058	62	0.4	1.7		2.1	2.4	(0.2)	0.7		5.4
16.3 (braid)	635	49	0.3	0.7	0.4	1.4					1.4
17.6	3864	29	0.3	0.2		0.5	0.2				0.7

Table 7 continued.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin[a]	Suckers	Other	Total
20.1	966	78	0.6	0.3	0.2	1.1	0.3				1.4
23.4	3611	29	0.2	0.4		0.6	0.2				0.8
25.2 (braid)	347	11		0.8		0.8					0.8
27.5 (braid)	696	26	0.2	0.8	tr	1.1		0.3			1.4
28.0	1445	56	tr	2.0	0.4	2.4	3.1	(0.3)			5.5
						Methow River Drainage					
Methow River											
2.1	14628	25	0.1	0.1	tr	0.2	2.4	(2.0)	10.7	0.2+	15.5
3.0	4897	36	tr	0.1		0.2	3.0	(2.0)	19.6	1.8+	26.7
5.8	5239	11	0.3	0.6		0.9	2.3	(2.0)	6.8	0.1+	12.1
7.0 (braid)	1889	74	0.1	2.5		2.6		2.2	0.1		4.9
14.0a (braid)	825	58	0.7	2.4		3.1		0.9		0.1	4.1
14.0b (braid)	1528	70	0.1	0.5		0.6		0.2		tr	0.8
14.0a (braid)	825	86	3.8	3.1	0.1	7.0	0.5	4.4	0.8		12.7
14.2	7790	14	0.3	0.2		0.5	2.1	(2.0)	12.8	0.1+	17.5
15.6	3179	69	0.4	6.4		6.8	4.1	(2.0)			12.9
15.7	3093	69	1.0	9.5		10.5	9.1	(2.0)			21.6
17.7	4712	13	0.1	0.4		0.5	1.4	(2.0)	5.7		9.6
21.2	5814	15	0.3	0.5		0.8	1.5	(0.8)	10.2		13.3
21.3	4028	37	0.2	0.4		0.6	12.4	(0.8)	2.2		16.0
23.8	6625	13	0.1	0.1		0.2	8.3	(0.8)	20.2		29.5
23.9 (braid)	1528	64	0.2	0.7		0.9	0.1	1.1			2.1

Table 7 continued.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin[a]	Suckers	Other	Total
24.4 (braid)	2390	102	0.2	2.3		2.5	tr	0.4	tr		3.0
27.2	4146	29	1.8	2.3	tr	4.2	13.5	(1.1)	31.7	0.8	51.3
31.6	5750	30	tr			tr	1.2	(1.1)	16.4	0.2	18.9
38.4	3974	37	tr	0.7	0.2	0.9	21.2	(1.1)	0.4	0.6	24.2
41.3	4288	62	tr	tr		0.1	13.2	(1.1)			14.4
42.3 (braid)	836	51	0.2	0.7		0.9		tr			0.9
44.3	5793	37		0.5		0.5	9.8	(1.1)			11.4
44.4	2123	30		tr	0.4	0.4	11.5	(1.1)			13.0
44.8 (braid)	1211	37	tr	0.1		0.1	tr	1.1			1.3
50.4	4424	70	0.5	1.3	tr	1.8		2.0			3.8
50.6	2243	62	tr	0.2		0.2		2.7			2.9
55.0	3396	16	0.2	0.2	tr	0.4		0.4			0.8
60.7	2801	28	0.9	0.4	0.1	1.4		0.5			1.9
67.4	1237	40	0.4	0.5		0.9		1.2			2.1
76.4 (West Fork)	854	46		2.3	tr	2.3		0.2			2.5
Gold Cr. (21.8)											
3.5	400	63		6.3	0.7	7.0		tr			7.0
Twisp River (40.2)											
0.0	836	42	0.4	2.6		3.0	0.7	0.2			3.9
1.2	980	61	0.1	0.5		0.6	0.9	1.0			2.5
4.0	668	82	1.6	5.4		7.0		1.8			8.8

Table 7 concluded.

Station and river mile	Area (m^2)	HQI score	Chinook salmon	Rainbow steelhead	Other trout and salmon	Total trout and salmon	Mt. white fish	Dace and sculpin[a]	Suckers	Other	Total
11.1	1152	74	0.8	3.1		3.9	tr	0.6			4.5
15.6	603	74	0.7	0.7		1.4		0.4			1.8
24.4	478	48	0.5	4.6	0.7	5.8		0.2			6.0
27.1	1034	68		3.9	0.6	4.5					4.5
Chewack River (50.1)											
7.8	1566	52	0.5	2.2		2.7	tr	1.8			4.5
14.7	1800	48	0.3	0.3		0.6	tr	0.3			0.9
17.4	2121	24	0.2	tr		0.2		0.3			0.5
23.3	1375	45	0.1	1.2	tr	1.2		1.6			2.8
Lake Cr. (23.4)											
2.8	718	46	0.3	1.8	0.1	2.2					2.2
30.8	623	62	1.6	2.0	tr	3.6		0.6			4.2
Wolf Cr. (52.8)											
1.4	339	47		6.8	tr	6.8		0.1			6.9
Early Wntr Cr. (67.3)											
0.0	562	43	0.5	1.0	0.8	2.3		0.7			3.0
1.5 (braid)	869	61	0.4	0.7	tr	1.1		tr			1.1
5.0	824	62	tr	2.1	0.2	2.3		0.1			2.3
Lost River (73.0)											
0.0	1207	34	0.6	0.6		1.2		0.4			1.6

a "Estimated" indicated by ( ).

Table 8. Trout biomass, density, and habitat quality index (HQI) score for Methow River headwater streams, sampled in late summer, early fall, 1988 and 1989.

Sub-basin, stream, and river mile	Order	Elev. (ft)	Mean Jul-Sep water temp (C)	Area (m^2)	Trout biomass g/m^2 Cut-throat	Bull	Brook	Rain-bow	Cutt/ rainbow	Total	No/ 100 m^2	HQI Score
Gold Cr												
S. Fk Gold												
3.8	3	2390	11	183				7.7		7.7	19.7	58
5.9	2	2965	9.8	159				5.3		5.3	16.4	48
13.0	1	4600		11						0	0	
Foggy Dew												
3.4	2	3380	9	273	2.4			2.8		5.2	23.5	48
Crater												
1.9	2	3260	9.2	210	2.6			7		9.6	68.1	48
Beaver Cr												
S. Fk. Beaver												
0.0	2	2747	11.9	247			0.5	2.8		3.3	21	51
3.2	2	3720	10	214			3.7	0.4		4.1	26.7	59
M. Fk. Beaver												
2.6	2	4450	8.5	238			8.5			8.5	45	54
5.2	1	5105	7.3	118			3.3			3.3	20.3	29
Twisp R.												
Little Bridge												
0.0	3	2130	11.6	96				14.2		14.2a	15.3	61
5.2	2	3160	9.4	207				2.8		2.8	20.3	56
W. Fk. Buttermilk												
0.0	3	2865	10	394		0.3				7.2	68.8	72

Table 8 continued.

Sub-basin, stream, and river mile	Order	Elev. (ft)	Mean Jul-Sep water temp (C)	Area (m^2)	Trout biomass g/m^2 Cut-throat	Bull	Brook	Rain-bow	Cutt/ rainbow	Total	No/ 100 m^2	HQI Score
E. Fk. Buttermilk												
0.0	3		10	352		0.3				7.2	68.8	72
1.3	2	2865	9.3	189		0.7				7.8	54.5	52
2.7	2	3560	8.6	259		2.7				6	27.6	62
3.8	2	4440	6.7	390	5.0					5	37.9	59
War												
2.5	3	3200	9.3	555			1.9	1.7	0.2	3.8	7.3	76
South												
0.0	3	3180	9.4	357		tr		3		3.1b	7.6	54
S. Fk. Twisp												
0.0	2	4120	7.4	297	6.1					6.1	15.5	65
1.9	2	4940	5.7	406	4.5					4.5	23.6	47
Chewack R.												
Cub												
3.0	3	2640	12.2	215			6.8			6.8	49.3	63
Eightmile												
8.3	3	3200	9.3	324			4.2	1.2		5.4c	17.6	60
14.6	2	4280	7.1	262			0.2			0.2	1.1	27
Boulder												
5.8	3	3400	8.9	362			5.7			5.7	36.2	67
9.6	3	4640	6.3	286	3.4		4.8			8.2	12.9	49
12.5	1	5700		177						0	0	10
Twentymile												
3.2	3	3730	10	295				3.1		3.1	29.1	48
10.2	2	5840	5.8	334	1.1		0.1			1.2	16.8	23

Table 8 concluded.

Sub-basin, stream, and river mile	Order	Elev. (ft)	Mean Jul-Sep water temp (C)	Area (m^2)	Trout biomass g/m^2 Cut-throat	Bull	Brook	Rain-bow	Cutt/ rainbow	Total	No/ 100 m^2	HQI Score
Andrews												
1.2	3	3600	10.3	306	0.2				4.4	4.6	30.7	56
Goat Cr.												
3.0	3	2800	11.8	419				5.8		5.8d	33.9	61
9.0	2	4680	7.6	242	0.6	0.3			3.4	4.3	12.8	51
Wolf Cr.												
7.2	3	3620	8.4	665	7.1	1.8				8.9	23	113
9.6	3	4520	6.6	514	13.0					13	40.6	85
12.4	2	5690	4.1	211	12.2					12.2	83	53
Early Winters Cr												
Cedar												
1.5	3	3100	9.6	761	3.6	0.2			0.8	4.6	20	66
Early Winters												
8.8	3	3540	8.6	575		2.0 e				2e	6.8	37
12.3	2	4200	7.2	464		2.0				2	7.8	37
Lost R.												
Monument												
0.0	2	3040	9.7	357		0.2		1.7		1.9	31.1	64
Lost R.												
12.7	3	3630	10.2	482	0.7	0.2		0.2		1.1	1	69
W. Fk. Methow R.												
Robinson												
1.4	2	3140	9.8	401	3.6					3.6	13	67
Trout												
0.0	2	2950	9.4	299				2.3		2.3f	9.4	38
W. Fk. Methow												
9.6	3	3670	8.3	706	1.1	0.5				1.6	10.3	45
13.8	2	4385	6.8	546	1.5					1.5	9.5	40

a) 7.9 g/m^2 consisted of hatchery steelhead "smolts"; 13 age-0 chinook and 33 sculpins also collected.

b) 2.6 g/m^2 consisted of hatchery steelhead "smolts"; 1 age-0 chinook and 3 sculpins also collected.

c) 1.2 g/m^2 consisted of hatchery steelhead "smolts."

d) 14 sculpins also collected.

e) 17 sculpins also collected.

f) 2 sculpins also collected.

At this point we suggest that our fish habitat ranking (Table 9) was suspect, as a result of either a lack of data or faulty criteria, and it is most useful to examine whether this was so.

Critical Period Flow (CPF)

The critical period stream flow (CPF) is the late summer mean daily discharge, as opposed to annual mean daily discharge. The most critical period for salmonids in streams is widely believed to occur at low flows in summer, when the volume of water is the least and water temperatures are elevated. Depending on elevation and aquifers, still lower flows may prevail October through March (Table 2). This last point is important because it could well be that winter, not summer, is the true critical period for salmonids in many of the study streams (Fig. 8; also see Hawthorne and Butler 1979).

Nevertheless, we used the period of 1 August to 30 September to represent CPF; lowest summer flows occur in September. A wealth of hydrologic data existed for calculating the index (e.g., Table 2), although reliance was on simulated data in some cases (Appendix C; Lomax et al. 1981).

Annual Stream Flow Variation (ASFV)

Fluctuation in water flow can be an important limiting factor for salmonids, and flow variation and salmonid production are often directly related (Hall and Knight 1981; Binns 1982; Poff and Ward 1988; Wolff et al. 1990). Stable, spring creeks generally are the most productive salmonid streams. Conversely, water courses regularly scoured by severe flooding usually support few salmonids, especially if the floods are separated by periods of sparse base flows (Fig. 4).

The annual stream flow variation (ASFV) ratio of annual peak flow to annual low flow, was designed to evaluate the impact of flow variation on habitat stability. This index presented no problems because of the long-term hydrologic data available (e.g., Table 2).

Water Temperature

Stream temperature, which directly governs the metabolic rate of fish, would ideally be within the range at which fish can feed, swim, and avoid predators at an optimum rate. Fish found in such optimum conditions are functioning within their scope for growth or scope for activity (Fry 1957). As stream temperatures decrease below or above the optimal temperature, the scope for activity decreases.

Temperature acts as either a governing factor, setting the pace of metabolism and, hence, the scope for activity, or as a

Table 9. Habitat Quality Index (HQI) criteria for rating HQI attributes (modified from Binns 1982).

Habitat attribute	0 (Poor)	1 (Fair)	2 (Moderate)	3 (Good)	4 (Excellent)
Late summer stream flow [a]	<10% ADF	10-15% ADF	16-25% ADF	26-55% ADF	>55% ADF
ASFV ratio [b]	>500	100-499	40-99	16-39	0-15
Mean stream temp. Jul, Aug, Sep, C	<5.0 or >21.1	5.1-7.2 or 18.9-21.0	7.3-9.9 or 16.7-18.8	10.0-12.1 or 14.4-16.6	12.2-14.3
Nitrate nitrogen (mg/l)	<0.01 or >2.0	0.01-0.04 or 0.91-2.0	0.05-0.09 or 0.51-0.90	0.10-0.14 or 0.26-0.5	0.15-0.25
Fish food:					
Aquatic vegetation	Lacking	Little	Occasional	Frequent	Abundant
No.invertebrates/ft2	<25	15-99	100-249	250-500	>500
Species interaction: Ratio salmonid density to total fish density (%)	81-100	61-80	41-60	21-40	<20
Water velocity (ft/sec)	<0.25 or >4.0	0.25-0.49 or 3.5-3.99	0.5-0.99 or 3.0-3.49	1.0-1.49 or 2.50-2.99	1.50-2.49
Cover (%)	<10	10-25	26-40	41-55	>55
Stream width (ft)	<2 or >150	2-6 or 75-149	7-11 or 50-74	12-17 or 23-49	18-22

[a] ADF = mean daily flow compared to annual mean daily flow during late summer.

[b] ASFV = annual stream flow variation = ratio of annual peak flow to annual low flow (cfs).

Fig. 8. Typical frazil/anchor ice damming and flooding in areas of the Wenatchee *(above), Entiat (large woody debris in ice), Twisp *(bulldozer), and Methow *(cow) not insulated from arctic cold by surface ice bridging and snow cover (* = photos courtesy of The Wenatchee World, Wenatchee, WA).

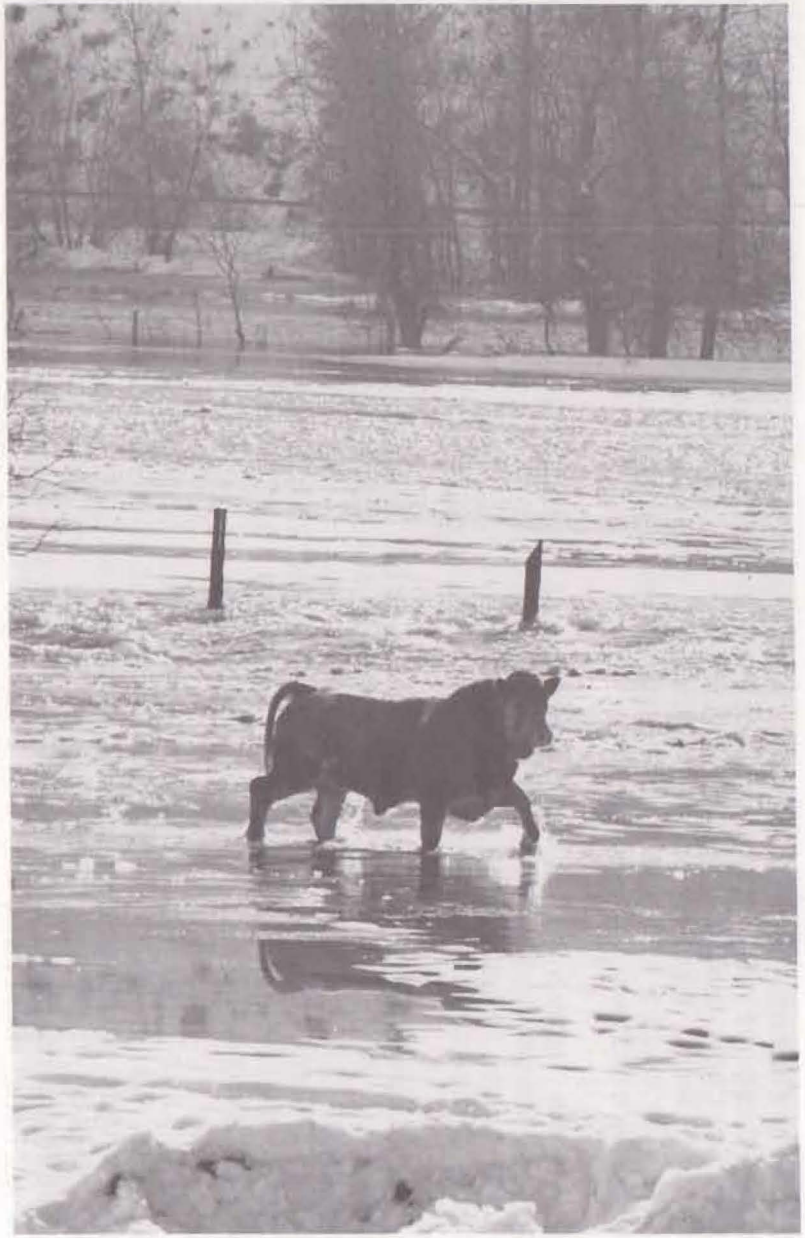


Fig. 8. Concluded

lethal factor (Brett 1952). He determined the lethal limits for the young of all five species of Pacific salmon using a range of acclimation temperatures from 5-24° C (41-75° F). Coho and chinook salmon were the most tolerant of high temperatures, although no species could tolerate temperatures exceeding 25.1° C (77° F) for exposure times of one week.

The upper and lower limits of temperature tolerance in fish can be extended through both adaptation and resistance (Fry 1947). More time is needed for acclimation to low temperatures than to high temperatures (Brett 1952; Doudoroff 1957).

Preference of juveniles of all species of Pacific salmon, despite differences in thermal-acclimation backgrounds, lies between 12 and 14° C (54-57° F). The general avoidance of temperature above 15° C was very definite (Brett 1952). Rainbow trout prefer temperatures between 13° and 22° C; they avoid temperatures under 9° C or above 22° C (Hokanson et al. in press).

Binns' (1982) HQI temperature criteria emphasized lethal limits in summer. Temperatures too cold for optimum growth of salmonids in mid-Columbia tributaries are common. Scarnecchia and Bergenson (1987) found much lower salmonid standing crops than predicted by the HQI in cold (< 10° C) streams, otherwise rated as excellent habitat.

To better reflect thermal regimes in our study streams we realigned ranking with Brett's (1952) Pacific salmon criteria (12.2-14.3° C best; < 5.0 or >21.1° worse, Table 9) and compared mean stream temperatures for July, August, and September.

We used "Datapods" (Model DP112 by Omnidata International, Inc.) in 16 streams to measure daily maximum, mean, and minimum temperatures. We also used other water temperature records (Appendix I). Many were incomplete on an annual basis for one or more reasons, including loss or malfunction of continuous recorders, or partial year use. In all, thermal regime was estimated at 33 stream locations, either continuously through the use of thermographs (55 years of record) or intermittently by thermographs, miscellaneous temperature measurements, or both (Appendix I). We also used regressions to develop a model, so as to characterize water temperature relationships in the Methow River drainage, based on instantaneous water temperatures taken periodically with a hand thermometer at more than 110 stations (Appendix I).

Annual temperature data error was of the order ± 6% and interannual variation +17% to -11% (Appendix I). It is not correct to assume that all salmonid species have the same temperature preferendum as Pacific salmon--for example, rainbow/steelhead do not. Later on, annual temperature units (TUs equal the number of degrees by which the average temperature exceeded 0° C in a 24 hr

period) are used to compare species scope for activity. It is sufficient here to note that Brett's (1952) optimum scope for activity (12.2-14.3° C) corresponds to the "ideal" temperature regime found in most spring creeks (mean 12.8° C; 7.2-18.3° C range; 4,672 TUs).

Nitrate Nitrogen

Nitrogen is the element that transforms organic compounds into the compounds of life. The importance and versatility of nitrogen for the special role it plays in life processes come from several properties. Foremost is the large number of valence states in which this element can exist--from -3 in ammonia to +3 in nitrates (Martin and Goff undated). Nitrate nitrogen (NO_3-N) is the form called for in an HQI evaluation.

Accurate determinations of NO_3-N can be very difficult. Through the U.S. Environmental Protection Agency Storet System we retrieved 948 analyses of NO_3-N for study streams. While these data probably reflect annual nitrate regimes in the streams, they likely underestimate trace amounts present in August and September. Only one-third of the samples were taken in August and September and useable in the rating procedure prescribed by Binns (1982). Furthermore, a majority of the samples were taken on the larger streams (e.g., Appendix E). We augmented these data slightly (N-30), but were forced to turn to other correlates of trophic level in completing some HQI evaluations. Correlates used were conductance (gross ion concentration), total alkalinity, and total dissolved solids (Fig. 9; Ryder et al. 1974).

It long was assumed that in most freshwater the limiting nutrient to productivity was phosphorus. It is now recognized that either nitrogen or phosphorus can be limiting depending on local geochemistry (Martin and Goff, undated).

Soils of the Pacific Northwest are notoriously deficient in nitrogen. More than 90% of the soils of the Wenatchee River basin are deficient in nitrogen but not phosphorous (McColley 1976). Nitrogen is likely the limiting nutrient in Lake Wenatchee (Mullan 1986). Most important are the observations of nitrogen spiralling in the Entiat River drainage (Tiedemann et al. 1978).

Maximum monthly NO_3-N levels in stream flow increased sharply in winter and early spring, reaching peak values just prior to or during peak spring runoff, with a subsequent rapid decline in early summer. The rise in NO_3-N levels in winter and early spring prior to peak flows indicated that moisture from the snowpack transported NO_3-N from the upper soil layers to the shallow ground aquifers and eventually to the streams before the major snowmelt period. Sharply reduced concentration showed that the moisture flux from snowpack to ground water exhausted soil NO_3-N in excess of that retained by an ion exchange (Tiedemann et al. 1978).

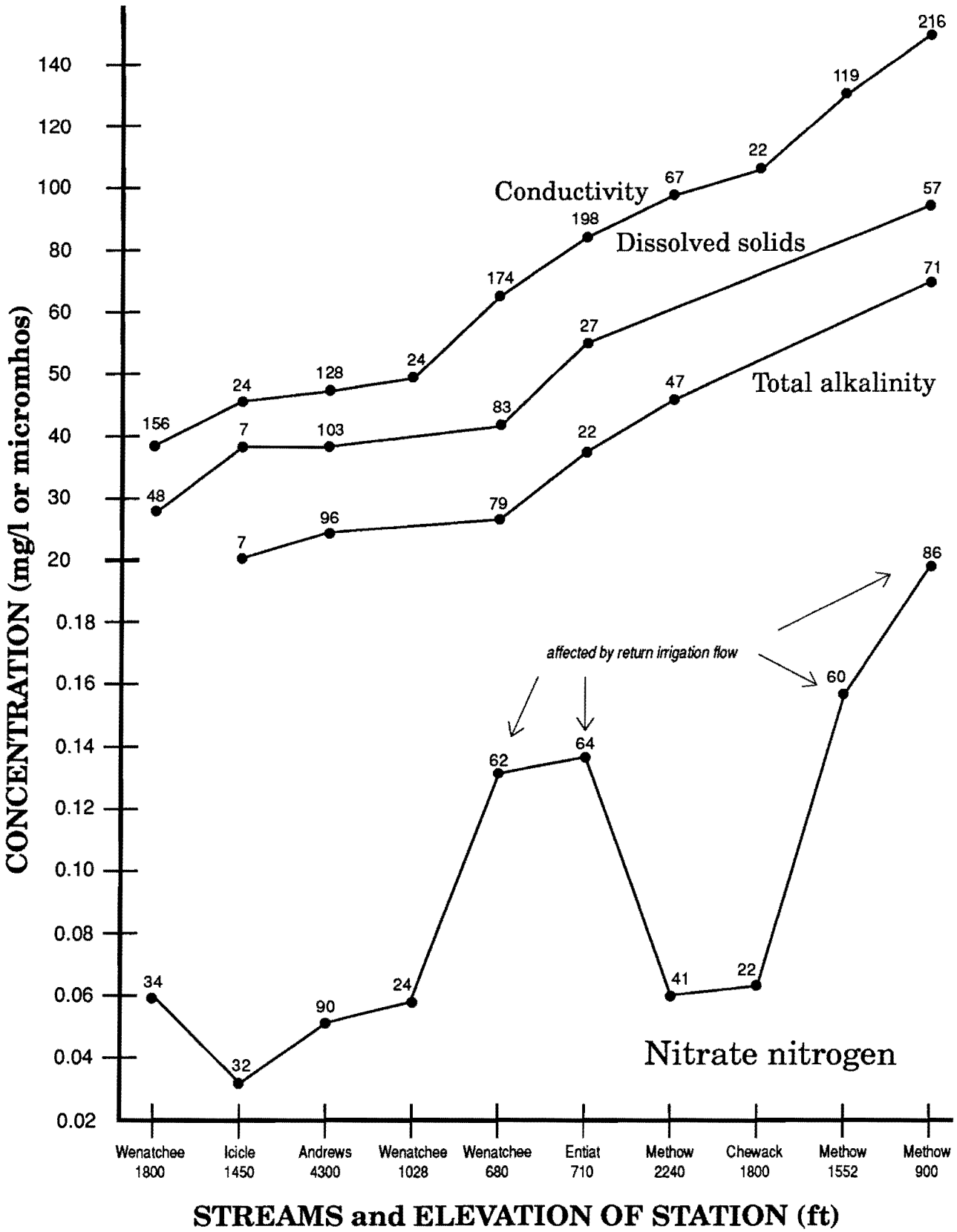


Fig. 9. Mean annual relationship between conductivity, total dissolved solids, total alkalinity, and nitrate in study streams (sample size indicated by numbers above symbols; data from Appendix E.)

Nitrate nitrogen content generally was poor to moderate (<0.1 mg/l) in the Wenatchee and Entiat river systems and moderate to excellent (0.1-0.25 mg/l) in the Methow River system. While content increased in the lower reaches of all three mainstems, the relatively high concentration of NO_3-N in the middle and lower Methow River appeared influenced by ground water.

The occurrence of large amounts of nitrate in ground water is common (Helm 1959; Martin and Goff undated). In some areas these occurrences can be assigned to drainage of water through soil that has been fertilized. High nitrate concentrations also occur in the ground water of areas where an explanation is difficult (Helm 1959; Martin and Goff undated). Relatively high content in the Methow River begins above Winthrop NFH (RM 51.5, 0.395 mg/l NO_3) in the area with little agricultural activity or human settlement below the area that periodically goes dry (Appendix C).

Nitrate is poorly absorbed ionically on cation based soils. Other ions, (i.e., phosphate, sulfate), are better held (Martin and Goff undated). Nitrate is also the most highly oxidized form of nitrogen and the most stable (Helm 1959). We hypothesize that when the annual buildup of nitrate is flushed from the upstream Methow River watershed during snowmelt, some fraction is redeposited in the ground water with recharge.

Fish Food

Because benthic invertebrate occurrence is a function of food and cover, which can be furnished by aquatic vegetation, the assumption is that benthos abundance can be rated by careful observation of vegetation in stream channels (Table 9). To aid in this effort, we collated the results of previous Surber square foot sampling, and we did some of our own (Table 10).

Benthos populations can change with season, year, and other variables. Added to this is the comparatively simple, yet staggering, problem of statistical reliability for samples collected (Needham and Usinger 1956; Chutter 1972). Chutter holds, however, that 3 Surber samples give values within ± 49% of the population mean, 5 samples ± 38%, and 10 samples ± 27%. Our ground truth (Table 10) lies within such approximation.

Ruggles (1959) compared the benthos in the Wenatchee River between the years 1940 and 1955-56 (Table 10). A large decrease was attributed to the grazing activity of a much larger fish population during the 1950s, because of the GCFMP restoring salmon and steelhead populations. This conclusion was almost certainly wrong.

Record drought and low flows occurred in 1940, while 1955 and 1956 were more typical water years. Snowmelt flooding in both 1939 and 1940 was only about half (7,500 cfs) that of 1955 and 1956

Table 10. Density (no./ft²) of macro-invertebrates determined by Surber sampler in Wenatchee and Methow river drainages.

Stream; river mile ( ); mo.& yr. studied	Mean	Range	n	Taxon Percentage Composition: Caddis flies	May flies	Stone flies	True flies	Other
			Wenatchee River Drainage					
3 streams [a]								
8-11/40	233	26-1096	68	33	36	14	11	6
8-11/55	31	4-146	30	15	57	9	12	7
8-11/56	69	2-192	41	13	68	10	7	2
Wenatchee R [a]								
(3.5) 8-11/55-56	34	2-99	19					
(35.6) 8-12/55-56	52	4-140	16					
(44.5) 7-12/55-56	44	8-89	15					
Wenatchee R [b]								
(15.5) 8/80	50	21-123	8	23	48	7	19	4
Nason Cr [a]								
(0.5) 5-11/55-56	52	1-134	16					
Chiwawa R [a]								
(2.0) 5-12-55-56	86	0-192	19					
Rainy Cr [c]								
6-10/75-76	133	81-197	120	12	54	25	5	4
			Methow River Drainage (this report)					
Methow R								
(11.8) 8/85	222	172-401	5	61	25	2	10	2
(54.8) 8/85	99	64-165	5	1	88	5	6	tr
(78.8) 8/89	83	58-117	2	2	66	6	21	5
Beaver Cr								
(1.8) 8/89	824	436-1285	3	10	3	3	44	39[d]
(7.4) 8/89	154	150-187	3	27	43	3	15	12
Twisp R								
(9.2) 8/85	227	154-375	5	3	73	5	13	5
(17.2) 8/89	168	151-185	2	3	71	15	9	2
(27.1) 8/89	153	132-171	3	4	54	14	23	5
Little Bridge Cr								
(1.8) 8/89	192	121-316	3	24	30	7	11	25
(5.2) 8/89	154	95-203	3	6	42	25	25	16
Chewack R								
(15.2) 8/85	177	127-244	5	3	62	13	6	16
(5.2) 8/89	184	433-368	3	7	57	3	26	7
Early Winters Cr								
(0.8) 8/85	72	33-117	5	7	79	1	12	1
(8.8) 8/89	77	48-122	3	9	37	24	29	1
(15.0) 8/89	77	53-121	3	2	44	15	34	5

a) Ruggles 1959; Wenatchee and Chiwawa rivers and Nason Creek. Location of sampling stations in first entry same as shown for individual streams without taxon percentage.
b) Beak Consultants, Inc. 1980.
c) Woods 1977; 9 stations on Rainy Creek subdrainage.
d) Largely beetles (Coleoptera).

(14,000 cfs). The devastating effects of flooding on stream fauna is now well documented (Hynes 1970). Both Ruggles (1959) and Wood (1977) show the trend from lowest benthos densities just after snowmelt in late spring, early summer to highest densities in fall in the Wenatchee River system.

Benthos densities generally were poor-fair ($< 99/ft^2$) in the Wenatchee River system, and moderate ($100-249/ft^2$) in the Methow River system (Table 10), in keeping with the higher fertility of the latter. Exceptions occur in all drainages depending on local conditions. As an example, the fertility of Beaver Creek (RM 1.8) is enriched by agricultural activities along its lower course (Appendix D), and benthos occurrence is excellent ($>500/ft^2$) (Table 10).

Caddisflies (Trichoptera), mayflies (Ephemeroptera), stoneflies (Plecoptera), and trueflies (Diptera) are present at sample sites in all streams (Table 10). Mayflies were generally most abundant, followed by either caddisflies or stoneflies. The exception was Beaver Creek (RM 1.8), which had the highest density and was dominated by diptera and water beetles (Coleoptera) (Table 10).

The problem with relating benthos densities to aquatic vegetation in most streams was its depauperation, at least in late summer, early fall. Where riffles allowed the use of a Surber sampler, field counts underestimated abundance because of the small size of most organisms. Frequently, one might conclude that the bottom fauna was virtually non-existent except that the stomach contents of fish collected did not show this to be true.

Confounding the problem is the question of the importance of the benthos relative to terrestrial insects (not to mention stream drift) as food for salmonids. Salmonids tend to eat whatever they can capture whenever it is available (Hunt 1975). Hunt shows that high annual use of terrestrial insects occurs universally.

Terrestrial organisms made up 78% and 85% of the food present in coho salmon collected by Chapman (1965) in August and September from Deer Creek, Oregon. On an annual basis, terrestrial insects made up 20% of the insects found in 478 rainbow/steelhead from the Wenatchee and Methow rivers; as grasshoppers (Orthoptera) predominated, the proportion by weight would have been even higher (Chapman and Quistorff 1938). A superabundance of hornets (Hymenoptera) occurred in summer, early fall, 1988 and 1989, when Methow River headwater streams were sampled (Table 8). We found larger salmonids gorged with them.

Chapman's (1965) study of production by young coho salmon illustrates the nutritional value of terrestrial food. Coho ate more aquatic organisms than terrestrial organisms during 9 months

of the year, yet food of terrestrial origin supplied 33% of the energy converted to new body tissue.

Periods of peak availability of terrestrial insects coincide with periods of low availability of benthic food in summer (Hunt 1975). Benthic invertebrates in streams are usually more abundant in late fall, winter, and spring. Benthos in Montana streams show a pattern of greatest biomass in spring before snowmelt flooding (Hunt 1975). This could be true also in mid-Columbia River tributaries. Nitrogen content of the streams reach peak values just prior to snowmelt in late spring, and there is coincidental build-up of filamentous Chlorophyceae over the winter.

Because terrestrial food often constitutes a major fraction of the summer diet of salmonids, it has even greater ecological value than its annual contribution to the diet would indicate (Hunt 1975). Benthic food for salmonids in early spring through to snowmelt flooding in late May, early June could also have similar significance. It is during this time when chinook salmon fry emerge from the gravel. Older juvenile chinook and steelhead require a period of rapid growth for smoltification (Wedemeyer et al. 1980). Minor spates, resulting from thawing and freezing of the snowpack, dislodge benthic organisms (Anderson and Lehmkuhl 1968). Water temperatures (Appendix I), while not optimal for growth of salmonids, do not preclude effective metabolism as in winter. Water temperatures are primarily subject to ambient air temperatures and not snowmelt as occurs later. Photoperiod, so important to photosynthetic rates of stream periphyton and drift rates of benthos, increases rapidly (Hynes 1970).

Species Interaction

The competitive exclusion principle holds that no two species that occupy the same ecological niche can exist together indefinitely in the same habitat (Hynes 1970). Extirpation is avoided because similar species usually have different distributions in space or in time.

An important outcome of niche theory (Whittaker et al. 1973) is that the sum of two or more occupied (realized) niches is greater than the sum of one occupied niche, but one niche provides more biomass of an individual or group of similar species (Fig. 10; Carlander 1955). Degree of interaction between species is regulated by the habitat. Each species is genetically programmed to perform within certain limits of temperature, water content of salts and gases, and habitat structure, as well as being influenced by competition for resources and the effects of predators.

Our ratio of salmonid density (excluding mountain whitefish) to total fish density provided a needed linkage between abiotic and biotic features of habitat (Li and Schreck 1982). The species

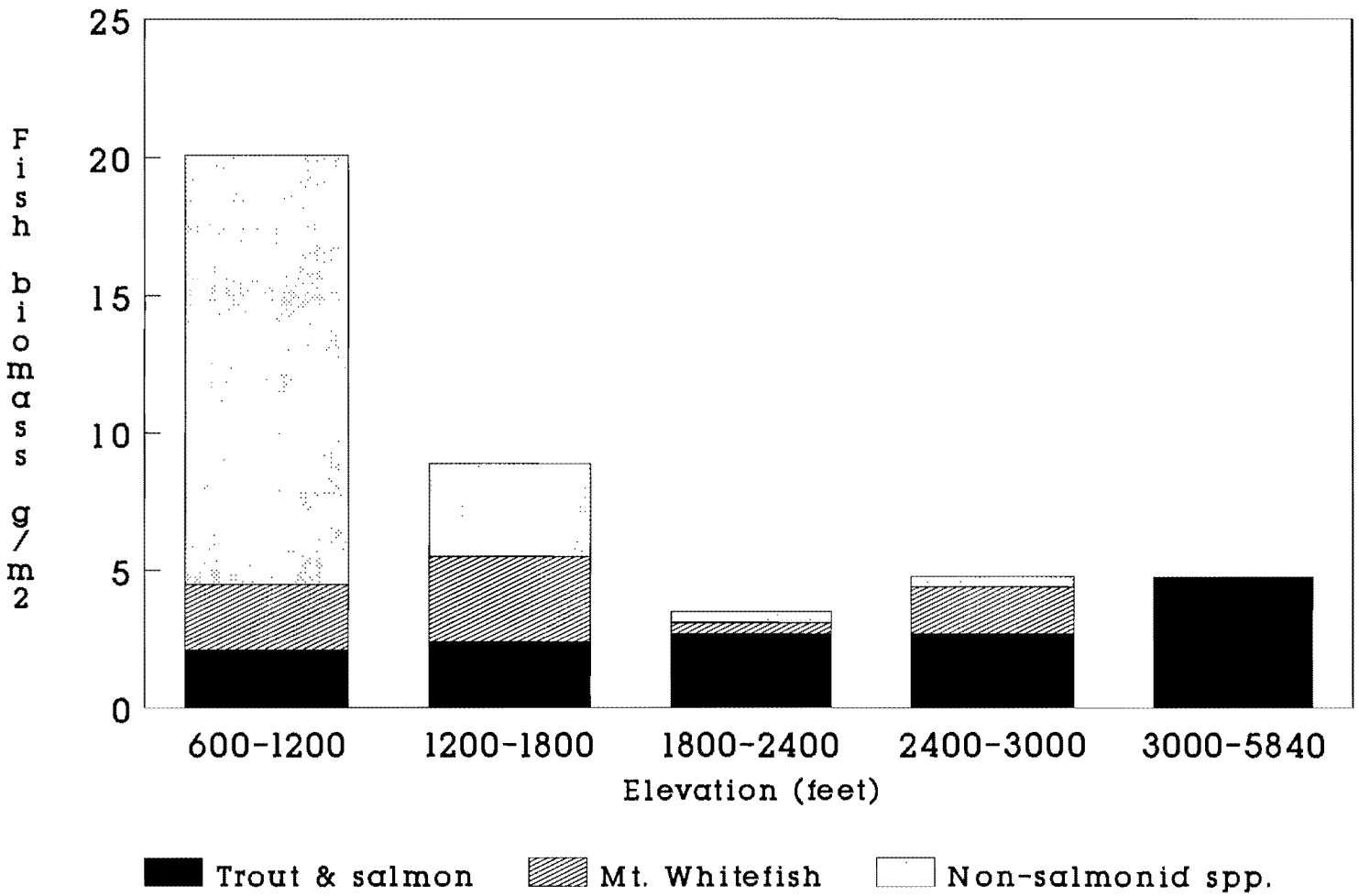


Fig. 10. Trout and salmon, mountain whitefish, and non-salmonid spp contribution to biomass (weighted mean) in the Wenatchee, Entiat, and Methow rivers according to elevation.

interaction ratio was easily generated and explained much of the variability in densities and biomasses of salmonids.

Water Velocity

Current speed exerts major control on fauna in streams (Hynes 1970). Channel suitability for salmonids is often limited by excessive velocity (White 1973).

We measured velocity with dye release as prescribed by Binns (1982). Measurements were adequate for ranking purposes (Table 9, <.25 or >4.0 ft/sec.ft = worse; 1.50-2.49 ft/sec ft = best), but we observed an almost inverse relationship between velocity and salmonid abundance.

We generally found the greatest abundance of salmonids in the slowest moving water--though slow-moving water usually contained abundant cover. Surprisingly, high gradient headwaters, with highest abundance of salmonids (Fig. 10), usually had average water velocities of less than 1 ft/sec. Most frequently they were boulder-filled cascades also containing an abundance of woody debris.

Water velocity does not decrease in a downstream direction, despite reduction in slope, but cover does because of the winnowing effect of increased discharge and increased width (Hynes 1970). This discrepancy goes far towards explaining biotic differences between small and large streams in our watersheds. Suitable water velocities for salmonids probably are affected by water temperature as well as cover, an interaction (Taylor 1988) not recognized in Binns' criteria.

On 19 August 1987 we snorkeled five stations on the Chiwawa River (Appendix D). Weather was hot (26-32° C) with bright sunlight; the water was gin clear with temperatures 10.0-13.3° C. Virtually no juvenile chinook salmon and steelhead (0.0-0.5/100 m^2) were observed in three stations on the lower river. Chinook salmon juveniles were readily observable (8.8-40.5/100 m^2) in the two upriver stations. The upper Chiwawa River is much colder (annual TUs, 1,771; mean Jul, Aug, Sept temp, 9.4° C) than the lower river (annual TUs, 2,447; mean Jul, Aug, Sept temp, 11.8° C). Gradient in the lower river is about double that of the upper river, velocities are higher (1.0 to 2.0 fps vs <1.0 fps), and the dominant substrate is cobble and rubble.

We subsequently snorkeled one of the lower river stations, a boulder-cobble riffle (4,418 m^2) with pocket pools 5-6 ft deep, 7, 15, and 29 September. Essentially no indigenous salmonids were observed in the water column during daylight, except for 70 adult mountain whitefish found 19 August and 7 and 15 September; coho salmon were also present 15 September from a hatchery release (226/100 m^2) the previous day, but not in evidence 29 September.

At dusk, however, we found that the juvenile salmonids emerged from the substrate and fed actively in the water column.

On 30 September we removed the fish population with cyanide and accounted for 145 age-0 chinook salmon, 33 age-0 steelhead, 41 steelhead parr, 144 coho salmon, 5 whitefish, 3 bull trout, 231 sculpins, and 22 dace. Salmonid abundance (8.7/100 m^2) was only a fraction of that observed earlier upriver (17.8-81.5/100 m^2).

Cover

Numerous studies have found that physical habitat characteristics, particularly the many forms of cover, are most closely related to salmonid abundance (Hall and Knight 1981; Fausch et al. 1988). Our study was no exception, as judged statistically and illustrated visually in two parallel but contrasting channels of Chiwaukum Creek (Appendix D). The channel with abundant cover (>55%) (stair-stepped pools and riffles, cobble-gravel substrate, undercut bank, woody debris, average velocity 0.34 fps) contained 114.8 salmonids/ 100 m^2 (7.1 g/m^2) (Tables 6 and 7). The channel lacking cover (<10%) (cobble-boulder chute with only two pocket pools, average velocity 3.2 fps) contained only 8.0 salmonids/100 m^2 (0.8 g/m^2)

A large river presents difficulties in quantifying cover compared to a small stream. In a wadeable stream, there are only so many places that fish can hide, and these can be examined in detail. In a large, deep river, cover relationships are much more difficult to decipher. Then there is always the question of cover for what size fish.

We measured cover as prescribed by Binns (1982), except for mainstem stations sampled by snorkeling. We also relied on two other indicators of cover in completing a ranking.

We believe the key in determining cover lies in knowing the roughness (the friction that results in a head loss) of the channel. The rougher the channel, the higher the cover value. Channels having rougher surfaces or channels with lots of surface area (weeded, stump-filled, boulder-studded) have more resistance to flow than smooth channels resulting in slower velocities (Gebhardt 1986). Ideal cover occurs where water velocity impinges on boulders and woody debris, creating numerious velocity breaks. Such "holding-water" offers protection and concealment from predators, shelter from swift currents, drift food organisms from nearby higher velocity flows, and secure places to rest (Lister and Genoe 1970; Binns 1982; Burger et al. 1983). Our ratio of the number of pools and riffles in a mile of stream, akin to the shoreline development index used in lakes to indicate habitat diversity, also is an indicator of head loss and cover.

All computations involving flow in open channels require an evaluation of Manning's universal roughness coefficient. There are no quantitative relationships available for natural channels similar to those used for flow in uniform pipes for example. Consequently, the ability to evaluate roughness coefficients for natural channels must be developed through experience (Barness 1967).

One means of gaining experience is by examining the appearance of some typical channels whose roughness coefficients are known. For this reason the U.S. Geological Survey published descriptions and color photographs of 50 stream channels for which roughness coefficients had been painstakingly determined (Barness 1967). Three of these channels are in study streams (Mission Creek, Wenatchee River, Chiwawa River); a large number of them are in the Pacific Northwest. Their appearance, geometry, and roughness characteristics are similar to the channel conditions found in study streams. We relied heavily on this photography in ranking cover of the stream reaches sampled by snorkeling.

The problem with deciding on a cover rating does not lie at the extremes of classification (worse = 0, best = 4) regardless of whether channel roughness, measured cover, diversity index, or all three are used. Shallow riffles and exposed pools, with pavement-like substrate, or, at the other extreme, an abundance of undercut bank, aquatic and overhanging terrestrial vegetation, and large boulders or woody debris are obvious. It is the in-between classifications (1 to 3) that are perplexing, especially the monotonous deep river reaches that are difficult to examine. Even though the selection of roughness coefficients is classified as an art, just as measuring cover is, the accuracy of selections can be evaluated statistically. The results of these tests indicate that trained engineers can select roughness coefficients with an accuracy of plus or minus 15% under most conditions (Barness 1967). This suggests that our mid-range classification of cover may have similar accuracy.

Stream Width

The width of a stream is directly related to both fish food (Hynes 1970) and salmonid production (Binns 1979). Small streams generally are more productive of salmonids than large streams because they have more cover or diversity per unit of surface area, lower velocities, greater stability, and higher rates of allocthonous nutrient input (i.e., woody debris, terrestrial insects) per unit of distance. Gowing and Alexander (1980) also document greater efficiency of nutrient cycling, as expressed by production and biomass versus flow or exchange rates, in small versus large streams. Inasmuch as stream widths were measured at fish sampling stations, accuracy was compromised by only small measurement error.

Conclusions

Numerous methodologies have been developed to assess habitat needs of salmonids (Fausch et al. 1988). A basic problem is that no methodology is likely to be successful on a broad scale in precisely defining the actual factors controlling abundance and in understanding their subtle interaction (Behnke 1986; Fryer 1987).

Limitations aside, characterization of habitat in a theoretically sound and consistent manner to a known though low degree of accuracy (± 50%) has merit (Allen 1951). It allows correct rather than precise judgments. For example, total possible HQI score is 335. Average score for 186 stations in the Wenatchee, Entiat, and Methow drainages was 47 (range 11-113) indicating low overall salmonid potential.

CHAPTER 4

BIOMASS AND PRODUCTION

Temporal and spatial variations in fish abundance confound population estimates based on standing crop (Hall and Knight 1981). Here we describe the growth and survival of fish spawned and stocked in a section of Icicle Creek (Appendix D) in 1983 and 1985 to 1989 so as to assess variations in abundance.

Between RM 2.8 and 3.7, Icicle Creek is divided into two channels--the original channel used as an Index Area and a diversion canal (Fig. 11). A dam at the downstream end of the diversion canal provides the head to regulate flow in the Index Area, once used to hold adult salmon for Leavenworth National Fish Hatchery (LNFH). The diversion dam and upstream regulating dam are barriers to upstream migrants, as is the lowermost dam (Fig. 11) on the Index Area except when not racked or at high water. Reduced flows (< 200 cfs) in the channel since LNFH was constructed (1939-40) have resulted in sand deposition. The stream area in the Index Area has declined about 40%-50% to 5.1 ac. This habitat consists of riffles and pools, with cobble, gravel, and sand as substrate.

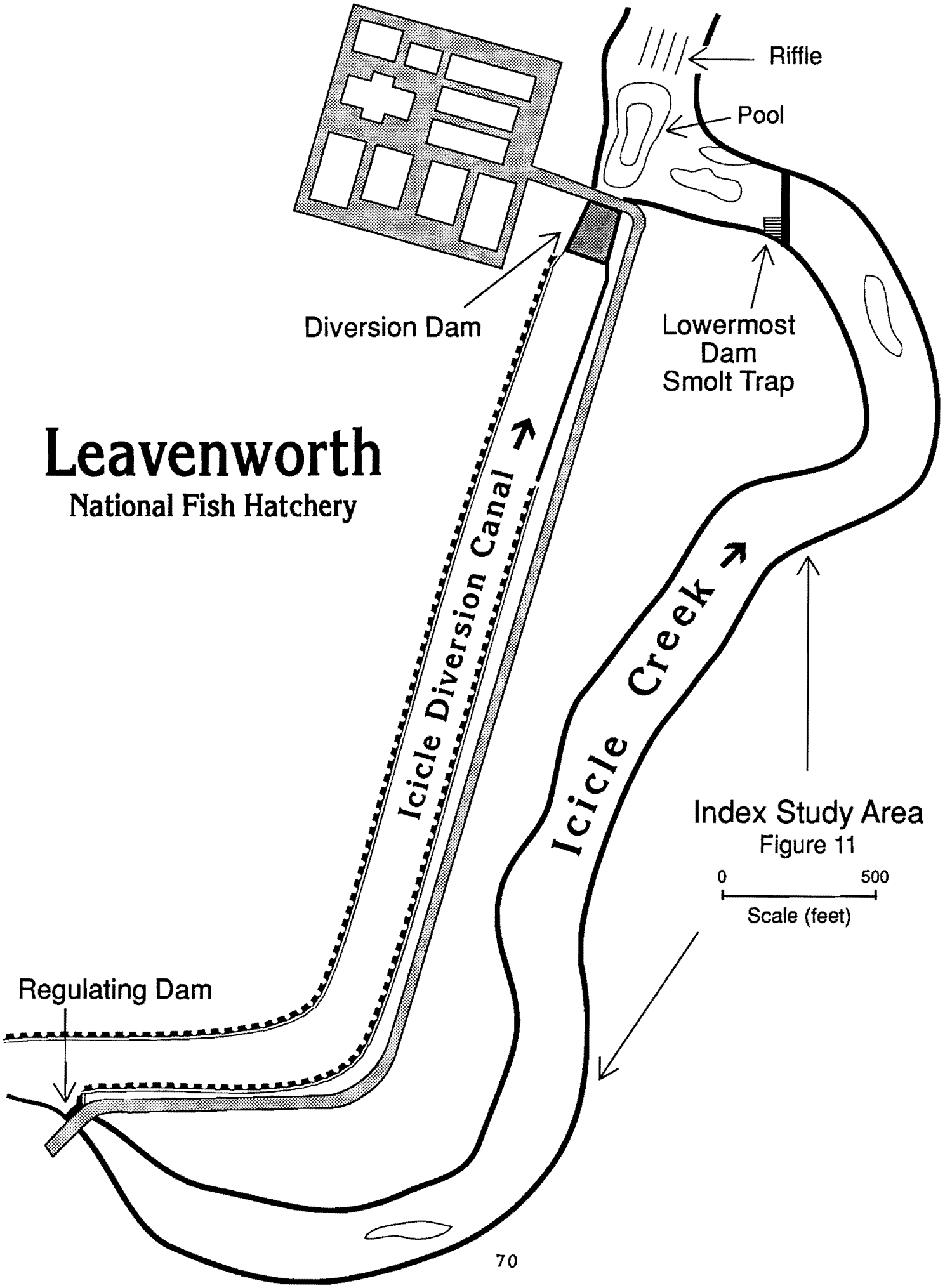
Methods

We released chinook and coho salmon into the Index Area, assessed the abundance and production of fish, monitored migrants, and counted spawning chinook and steelhead and their redds.

Hatchery Releases

Releases of spring chinook salmon totaled 166,600 fingerlings (>40 mm; 5 releases) and 1.39 million fry (< 40 mm; 2 releases); we also released 0.8 million fry below LNFH to observe their dispersal. There were 61,800 fingerling coho salmon in two releases. Releases in the Index Area were below the upstream dam (Fig. 11).

We assumed that hatchery chinook salmon could be separated from naturally produced fish by their larger size. (There are no naturally-produced coho salmon.) To further aid identification, we marked two groups of hatchery chinook; one by fin-clipping and one by fluorescent grit. Adult chinook were excluded from spawning in


Riffle
Pool
Diversion Dam
Lowermost
Dam
Smolt Trap
Leavenworth
National Fish Hatchery
Icicle Diversion Canal
Icicle Creek
Index Study Area
Figure 11
0
500
Scale (feet)
Regulating Dam

the Index Area in 1982 and 1986, so the only juvenile chinook present in 1983 and 1987 were from fry releases.

Population Estimates

Densities of salmonids were estimated by snorkeling in 1983 and with sodium cyanide 1985-1989, as described in Chapter 3. Times and sites sampled were nearly the same each year. Densities of salmonids for sample sites were expanded to the whole Index Area to derive monthly population estimates from July through October. Computation of production followed Chapman (1978) where P = GB (growth x biomass). Population estimates of age-0 salmonids were smoothed by negative exponential curves fitted by least squares regression.

Yield of Juveniles

We defined yield as the number of salmonids that emigrated from the Index Area. The number of migrants was estimated from counts of fish in an inclined plane trap installed in the lowermost dam on the Index Area (Fig. 11), 1987 to 1989. Virtually the entire flow of the Index Area passed through the trap. Releases of known numbers of marked fish indicated close to 100% trapping efficiency. The trap was periodically flooded, however, and non-functional.

Total number of migrants was estimated by multiplying monthly catch by the ratio of the number of days in the month divided by number of days of trap operation. Severe icing and deep snow prevented trap operation in winter.

Natural Spawning

We assumed 4,600 eggs per spring chinook salmon redd and 5,560 eggs per steelhead redd. These are mean hatchery fecundity values discussed in Chapter 2. It would have been spurious to attempt greater precision--illustrated by spawning counts in 1988.

On 25 April 1988, 8 live steelhead males, 8 live females, and 8 redds were counted. On 5 May 1988, 6 green females and 28 males, from LNFH, were released in the Index Area. On 19 May, 9 live steelhead females, 7 live males, and 7 new redds were counted. Accordingly, we estimated steelhead egg deposition as 15 redds x 5,560 eggs.

There was no volitional passage of adult chinook salmon to the Index Area in 1988. On 29 August, 102 female and 44 male adult spring chinook from LNFH were scatter-planted in the Index Area. On 31 August, 41 live females, 21 live males, 30 redds, and 8 carcasses were counted. Four black bears removed carcasses and possibly live fish. On 5 September, 2 live females, 1 live male, 27 old redds, 6 new redds, 2 active redds, and 17 carcasses were

counted. Accordingly, we estimated egg deposition as 35 redds x 4,600 eggs.

Results

Initial Fate of Hatchery Releases

Hatchery chinook salmon fry and fingerlings differed in how long they resided in the Index Area. Most fingerlings emigrated shortly after release while fry did not.

Spring chinook salmon fingerlings. Release of 38,600 fluorescent marked fingerlings (60-72 mm, 3.5 g mean), 9 May 1985: Despite sampling 33% of the Index Area and capturing over 800 juvenile chinook salmon, May through October, only 17 hatchery fish were recovered. No marked fish were captured after July, 1985.

Release of 100,000 fingerlings (94 mm, 6.8 g, unmarked) 20 June 1986: Despite sampling 33% of the Index Area and capturing over 2,200 juvenile chinook salmon, May through October, fewer than 100 hatchery fish were recovered. No hatchery fish were captured after August, 1986.

Release of 20,000 fingerlings (81 mm, 5.9 g, unmarked) 18 May 1987: Hatchery fingerlings were readily differentiated from smaller chinook fry from natural spawning, only beginning to emerge from the gravel. Most hatchery fish (85%) were recovered from the smolt trap within 48 h.

Release of 1,000 fin-clipped fingerlings (84 mm, 6.2 g, unmarked) 28 May 1987: Most (91%) were recovered from the smolt trap within 24 h.

Release of 7,000 chinook salmon fingerlings (95 mm, 9.3 g, unmarked) 25 June 1987: Within 24 h, 2,450 (35%) were recovered from the smolt trap, but only an additional 666 (20%) were subsequently recovered.

Spring chinook salmon fry. Release of 1.3 million fry (37 mm, 0.7 g, unmarked), February 1983: An estimated 6,000 fry were still present 28 July 1983. No chinook salmon spawned in the Index Area in 1982.

Release of 800,000 fry (33-35 mm, 0.5 g, unmarked) to a large pool below LNFH on the mainstem Icicle Creek (Fig. 11), 9 January 1987: Snorkeling revealed that the fry quickly dispersed from strong surface current to the substrate. No fry were observed 500 ft downstream (riffle) in the first 3 hours after release. Subsequent observations showed that the fry dispersed only 1.5 mi in two weeks, and did not reach the Wenatchee River 2.8 mi downstream until early March.

Release of 99,000 fry (35-40 mm, 0.73 g, unmarked) 5 January 1988. Beginning in March, small chinook salmon were observed in quiescent side eddies, backwaters, and channel margins containing vegetative debris on sunny days. An estimated 1,900 (1.9%) were recaptured in the smolt trap March through September, with peak emigration in June (669) and July (892) (Table 11).

Coho salmon fingerlings. Cohos did not quickly leave the Index Area. In 1987, 20,000 (57.6 mm, 2.2 g) and 10,800 (65.2 mm, 3.1 g) coho salmon fingerlings were released on 2 and 19 June, respectively. Only 1.0% emigrated in June; 3.0% in July; and 0.4%, August through November. In 1988, 31,000 (57.5 mm, 2.3 g) were released 3 June. Five percent emigrated in June; 3.4% in July; and 1.0% in August. About 3.4% of both releases migrated as yearling smolts.

Densities, Biomass, Growth, and Migration

Densities of age-0 salmonids varied among months and years (17 to 308/100 m^2), while biomasses were relatively consistent (2.1 ± 2 g/m^2) (Tables 12 and 13). Densities appeared to be related primarily to seeding levels (Table 14) and biomass to survival, growth, and emigration of fish.

Densities. We recorded the highest total salmonid density 308/100 m^2 in July 1987 (Table 12). Density decreased to 136 salmonids/100m^2 in August, and continued to decline through October when it reached a low of 62.6 fish/100 m^2.

Steelhead were the most numerous species in 1987 (Table 12). This brood class originated from 21 redds (567 eggs/100 m^2) (Table 14), close to the maximum of 23 redds in 1986. Next most numerous were hatchery coho salmon (32.0 to 53.5/100 m^2) (150 released/100 m^2). Chinook salmon were least abundant (2.8 to 15.7/100 m^2) and related to only three redds (67 eggs/100 m2) in 1986 (Table 14).

Total salmonid densities followed a similar pattern in other years, with some exceptions (Table 12). In 1985, the lowest density of steelhead was in July (3.7/100 m^2), followed by the highest density in August (35.1/100 m^2). Steelhead spawn in Icicle Creek from March through May. Analysis of length frequencies of steelhead fry indicates that they emerge from the gravel from June through August. In 1985, most steelhead likely had not yet emerged from the gravel at time of the 10 July sampling (Table 12).

Biomass. The most consistently high biomass values (2.8 to 3.7 g/m^2) were recorded in 1987, the same year as maximum densities. Compared to other years, age-0 steelhead were 5-7 mm smaller in September and October 1987 (Fig. 12c). Coho attained a mean length of only 76.8 mm in October 1987, compared to 94.8 mm in October 1988 (Fig. 12a). Growth of chinook was intermediate in 1987 compared to other years (Fig. 12b).

Table 11. Total number of migrant chinook and coho salmon and steelhead trout estimated from an inclined plane trap in the lowermost dam on Icicle Creek Index Area, 1987 to 1989[a].

Month and year	Trap efficiency (%)[b]	Chinook salmon[c]		Coho salmon[d]		Steelhead/rainbow[e]		
		age-1	age-0	age-1	age-0	age-2+	age-1+	age-0
1987								
Apr 17-30	46	570				2	282	
May	20	160				16	129	
Jun	77	46	18		327		156	45
Jul	100		23		995		1	1,286
Aug	100		1		127			544
Sep	90		15		5			600
Oct	53		8		1			39
Nov 1-20	80		3					39
TOTAL		776	68		1,455	18	575	2,553
1988								
Mar 11-31	65	112	37	264		1	79	
Apr	57	39	19	305		12	65	
May	68	24	134	102		21	59	
Jun	80		669	413	1,543		16	1
Jul	97		892	16	1,057	3	11	179
Aug	81		17		312	2		863
Sep	53		142			2		868
Oct 1-7	43				2			3
TOTAL		175	1,910	1,100	2,914	41	230	1,914
1989								
Apr 11-30	71	3	8	530		4	21	
May	73	1	507	481		11	47	
June	27		7,204	2		19	33	6
July	97		1,517			2	9	65
Aug	84		1,612			6		753
Sep	100		454			9	2	347
Oct	90		176	2		9	2	38
Nov	70		555			16	5	65
Dec 1-7	57		14				1	12
TOTAL		4	12,047	1,015		76	120	1,286

a Also recorded were 576 dace, 99 sculpins, 986 age-0 suckers, 5 adult brook trout, 2 adult cutthroat trout, 1 adult bull trout, 764 age-0 mountain whitefish, and 3 mountain whitefish parr.

b Trap efficiency is the percentage of days in a month when the trap was operative.

c Naturally spawned fish except age-0 fish in 1988, which originated with a fry release January 7 (99,000; 0.73g av). Other releases of chinook fingerlings discussed in the text that left shortly after planting are not shown.

d Hatchery releases (20,000, 2.2g av., and 10,800, 3.1g av., June 2 and 19, 1987, respectively; and 31,000, 2.3g av., June 3, 1988).

e Naturally spawned fish.

Table 12. Densities (no/100 m²) of juvenile salmonids in Icicle Creek Index Area (20,639 m²), 1983 and 1985–89. Values are means when more than one station was sampled.

Month and year	Area (m²)	Salmon Chinook 0+	Salmon Coho 0+	Steelhead trout 0+	Steelhead trout 1+	Other [a]	Total
Jul '83	5587 [b]	29.4		1.8	3.2	tr	34.3
Jul '85	847 [c]	16.1		3.7	1.4		21.1
Aug '85	1500 [c]	28.9		35.1	3.6	0.3	67.9
Sep '85	1639	9.5		9.1	0.4		19.0
Oct '85	2803 [d]	9.2		6.8	1.0		17.0
Sep '86	1052 [c]	27.5		78.5	0.3		106.3
Oct '86	1500 [c]	48.5		55.7	0.7	0.2	105.1
Sep '86	1639	27.8		27.1	0.5		55.4
Oct '86	2381 [c]	22.9		12.7	0.5		36.1
		New station replicated 30 d later					
Sep '86	2604	14.7		26.4	0.8		41.9
Oct '86	2604	1.2		14.0	0.1	tr	15.3
Jul '87	1052 [c]	2.8	53.5	250.4	1.5		308.2
Aug '87	1500 [c]	7.5	32	96.0	0.7		136.2
Sep '87	1639	10.9	44.7	43.2			98.8
Oct '87	2381 [c]	15.7	37.4	8.4	0.1		61.6
Jul '88	1052 [c]	4.2	12.2	55.8	0.2	5.6	78.0
Aug '88	1500 [c]	4.2	6.0	45.5	1.1	0.2	57.0
Sep '88	1639	0.6	4.5	14.4	0.2	0.7	19.7
Oct '88	3580 [d]	3.4	16.3	3.6	0.4	tr	23.7
Jul '89	1052 [c]	93.7		90.4	1.4	0.1	185.6
Aug '89	1500 [c]	28.1		23.8	0.8	tr	52.7
Sep '89	1639	2.3		4.2	0.1	0.1	6.7
Oct '89	2381 [c]	17.6		4.7	0.3	0.1	22.7

[a] Eastern brook trout and bull trout
[b] Six stations
[c] Two stations
[d] Three stations

Table 13. Biomasses (g/m²) of juvenile salmonids in the Icicle Creek Index Area, 1983 and 1985–89. Values are means when more than one station was sampled.

Month and year	Area (m²)	Salmon: Chinook 0+	Salmon: Coho 0+	Steelhead trout 0+	Steelhead trout 1+	Other [a]	Total
Jul '83	5587 [b]	2.0		tr	1.2	tr	3.3
Jul '85	847 [c]	0.3		tr	0.1		0.4
Aug '85	1500 [c]	1.1		0.2	1.0	0.2	2.3
Sep '85	1639	0.4		0.2	tr		0.6
Oct '85	2803 [d]	0.5		0.2	0.2		0.9
Jul '86	1052 [c]	1.3		0.2	0.2		1.7
Aug '86	1500 [c]	3.3		0.5	0.3	tr	4.1
Sep '86	1639	2.2		0.6	0.1		2.9
Oct '86	2381 [c]	1.9		0.5	0.1		2.5
		New station replicated 30 days later					
Sep '86	2604	0.9		0.8	0.2		1.9
Oct '86	2604	0.1		0.9	0.1	0.1	1.2
Jul '87	1052 [c]	0.1	2.4	1.1	0.1		3.7
Aug '87	1500 [c]	0.5	1.1	1.1	0.1		2.8
Sep '87	1639	0.6	1.9	1.0			3.5
Oct '87	2381 [c]	1.1	1.9	0.4	0.2		3.6
Jul '88	1052 [c]	0.2	0.5	0.1	0.1	0.1	1.2
Aug '88	1500 [c]	0.3	0.4	0.5	0.2	tr	1.4
Sep '88	1639	0.1	0.4	0.4	0.1	tr	1.0
Oct '88	3580 [d]	0.3	1.8	0.1	0.1	tr	2.3
Jul '89	1052 [c]	2.5		0.2	0.5	0.1	3.3
Aug '89	1500	1.1		0.4	0.2	tr	1.7
Sep '89	1639	0.1		0.1	tr	tr	0.2
Oct '89	2381 [c]	0.9		0.2	tr	tr	1.2

a) Eastern brook trout and bull trout.
b) Six stations sampled.
c) Two stations sampled.
d) Three stations sampled.

Table 14. Seeding levels and mean densities of resident and migrant chinook salmon, coho salmon, and steelhead, Icicle Creek Index Area, 1983 and 1985-89.

Year [a]	Hatchery releases (no/100 m^2)	Natural spawning [b] (eggs/100 m^2)	Mean resident densities (no/100 m^2)	Migrant densities (no/100 m^2)			Survival (%)
				age-0	parr	smolts	
			Chinook				
1983	6310		29.4				0.5%
1985		134	15.9				
1986		223	31.7			3.8	12.4%
1987		67	9.2	0.3		0.8	15.9%
1988	480		3.1	9.2			15.4%
1989		780	35.4	58.4			2.6%
			Coho				
1987	150		41.9	7.1		5.3	12.4%
1988	150		9.8	14.1		4.9	19.0%
			Steelhead				
1986		620	43.5				7.0%
1987		567	99.5	12.3	2.8	0.1	20.2%
1988		405	29.8	9.2	1.1	0.2	10.0%
1989		215	30.8	5.7			17.0%

[a] Year in which eggs hatched, not the year in which they were deposited (brood year).

[b] Assuming 4600 eggs/chinook salmon redd and 5560 eggs/steelhead trout redd.

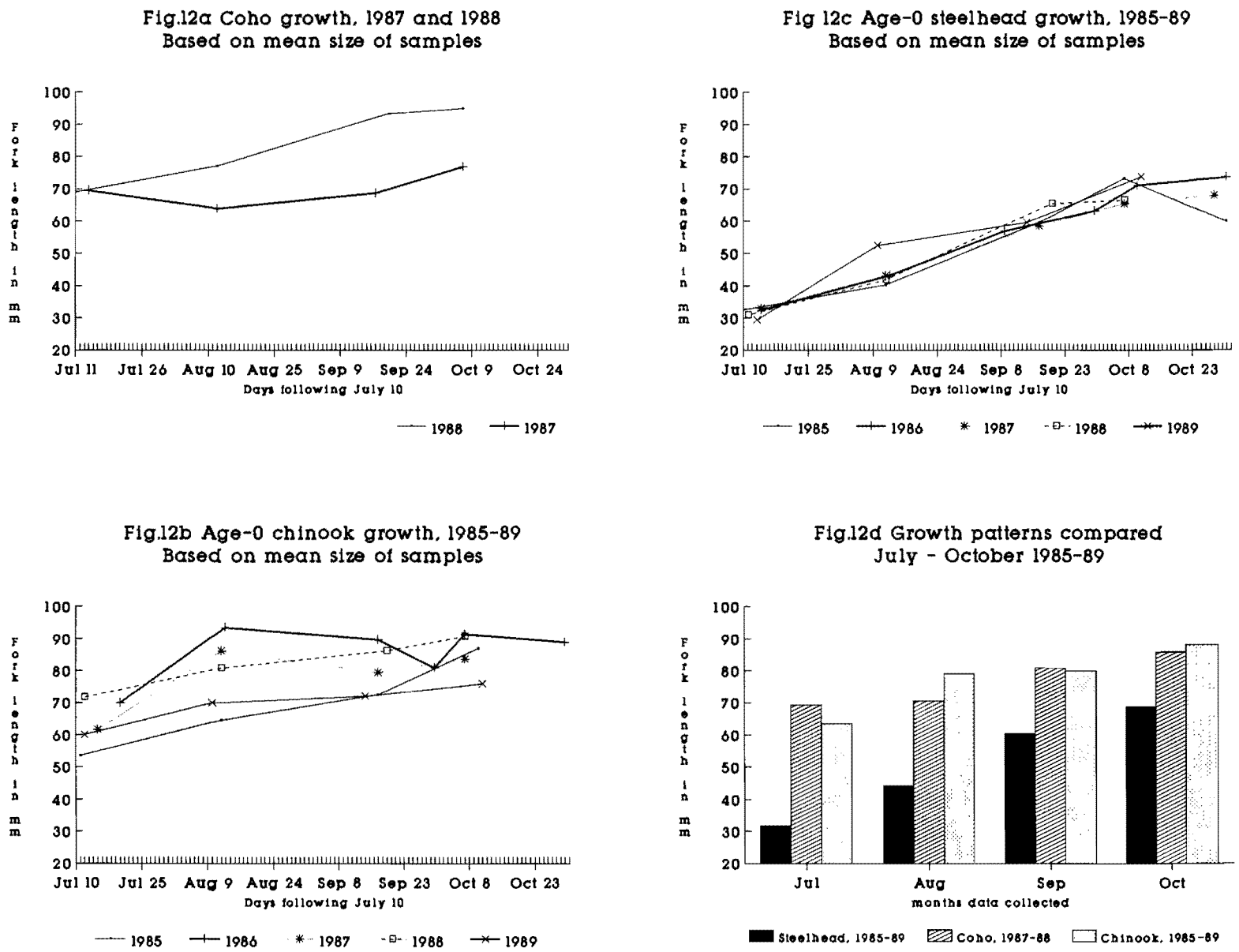


Fig. 12. Average growth of age-0 coho salmon, chinook salmon, and steelhead sampled in Icicle Creek Index Area.

Growth rates of age-0 steelhead, coho salmon, and chinook salmon were not equal because chinook emerge from the gravel first, steelhead last, and, under natural conditions, coho in between. In 1987, however, hatchery coho released in June were larger (mean, 57 mm) than naturally spawned chinook salmon (<50 mm). In July, chinook were smaller (mean, 61.6 mm) than coho (mean, 69.5 mm), but in August, September, and October, chinook were larger (means, 86.1 vs 64 mm; 79.4 vs 68.6 mm, and 83.7 vs 76.8 mm, respectively). In all years, steelhead appeared to grow faster than chinook and coho so the interspecies size discrepancy among age-0 fish decreased rapidly (Fig. 12d). However, the larger fish of all species tended to leave the Index Area (Fig. 13), resulting in underestimation of the growth that actually occurred.

Migration and growth. The proportion of a cohort that migrated downstream at age-0 versus the fraction that migrated as yearlings, and the timing of their migration, depended on the total number of those fish in the Index Area during the first summer and on their growth.

About the same number of similar-sized coho salmon were released in early June 1987 and 1988. Growth was much faster in 1988 than in 1987 (Fig. 12a). Twice the number of age-0 coho salmon left in 1988 (2,912) compared to 1987 (1,455) (Table 11). Chinook salmon were more abundant in 1988 than in 1987. More age-0 chinook salmon left in 1988 than in 1987 (Table 11). And because these hatchery salmon were out of phase with natural hatching and rearing, they were larger and left earlier than wild fish in 1987 (Table 11). However, eleven-fold (12,000) more naturally spawned chinook emigrated in 1989 than in 1988 when growth in spring apparently was similar to 1987, but densities much higher, an anomaly explained later. Emigration of age-0 steelhead was later in 1988 than in 1987, apparently the result of a later emergence in 1988 than 1987 (e.g., 45 alevins June 1987, vs 1 in June 1988) (Table 11). Water temperatures were cooler in spring 1988 than in spring 1987 (Fig. 14).

The gap in the size range between age-0 steelhead and older age-groups closed quickly (Fig.15). In August, when the length of the larger age-0 steelhead began to overlap with the smaller, older trout, fish from separate age-groups were distinguished by samples of otoliths. Despite this precaution, it is likely that steelhead designated as age-0 included small numbers of older fish.

Size and age of steelhead in the Index Area varied greatly (Fig. 15). Of 181 adult steelhead spawned at LNFH from 1988 to 1990, 39 were naturally produced fish. (All hatchery steelhead released to the mid-Columbia River are marked by removal of the adipose fin.) Otoliths showed that these steelhead were about evenly divided between those that spent two or three years in fresh water before migrating to sea, but seven had stayed four to six years (Fig. 15).

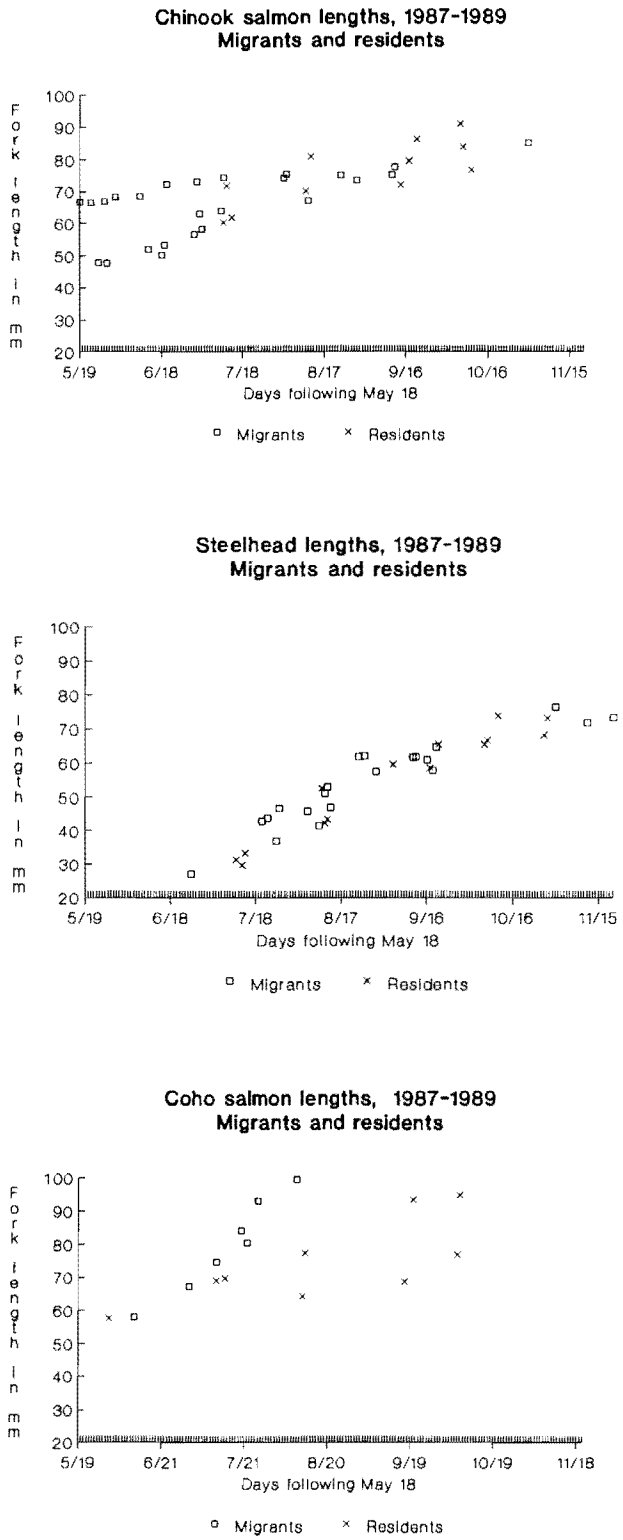


Fig. 13. Relationship between mean lengths (n = ≥20) of age-0 chinook salmon, coho salmon, and steelhead sampled from Icicle Creek Index Area (resident fish) and downstream smolt trap (migrant fish).

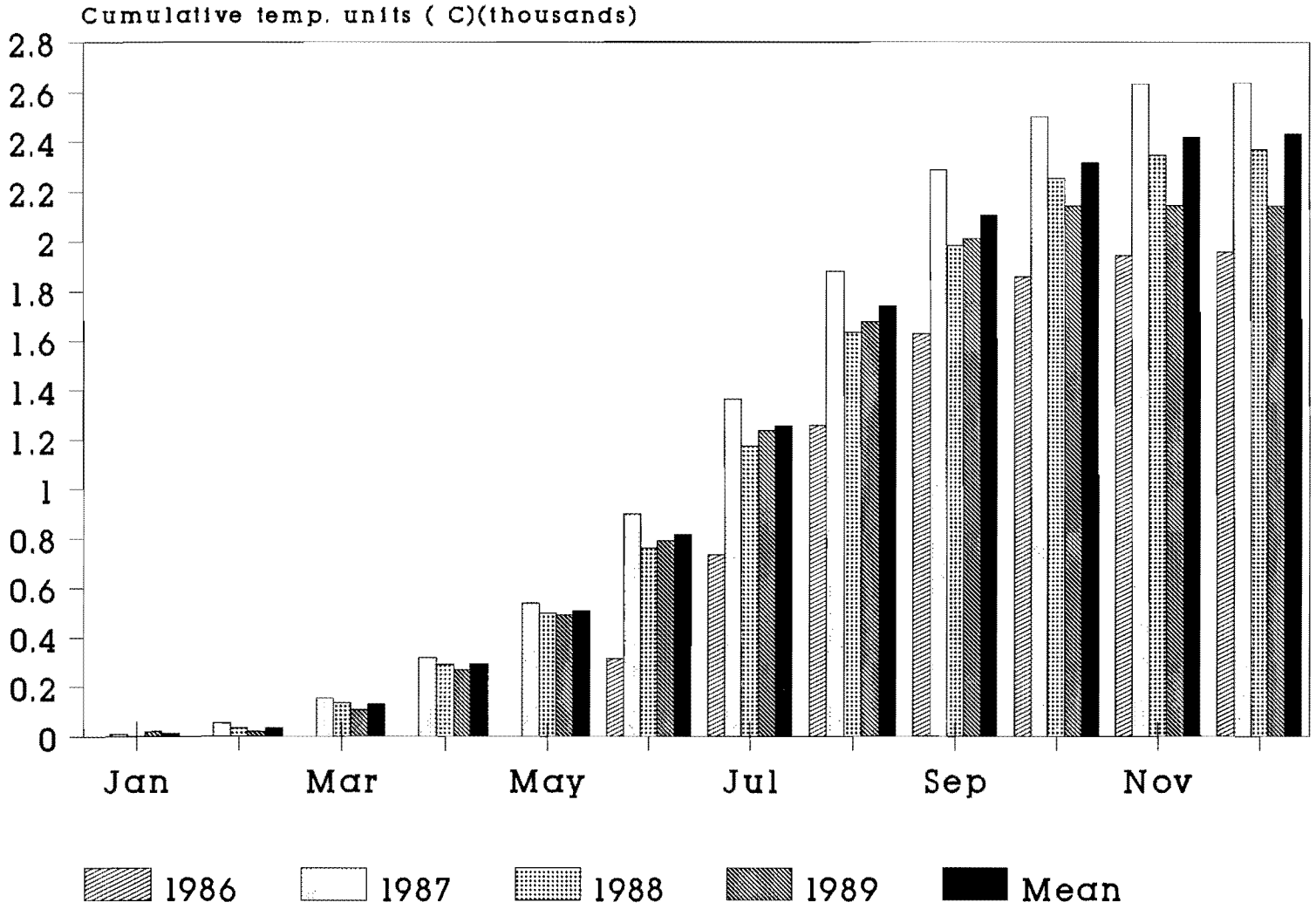


Fig. 14. Cumulative temperature units (TUs equal the number of degrees by which the average temperature exceeds 0 C in a 24-hour period), January through December for the Icicle Creek Index Area.

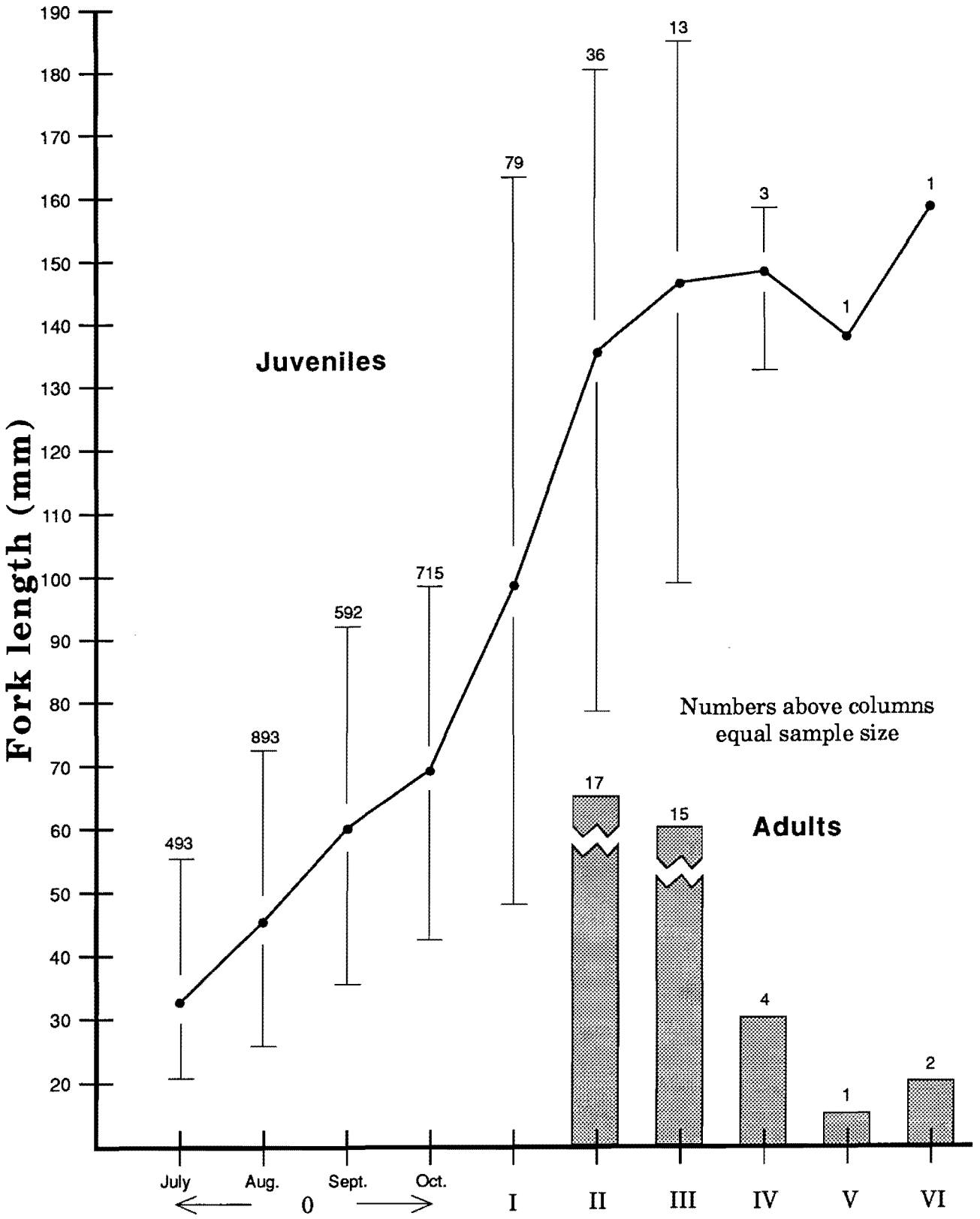


Fig. 15. Top, average fork length (mm) and range at age for steelhead/rainbow trout from Icicle Creek Index Area, 1985 - 89; bottom, number returning adult steelhead examined with corresponding freshwater residency.

Because Icicle Creek contains rainbow trout, it is possible that some fish used to determine age were rainbow trout from headwater areas with very slow growth. Age-0 salmonids dominated the fish population in the Index Area, and numbers decreased exponentially (Fig. 16), suggesting that lethal sampling with cyanide was compensatory. Substituting sampling mortality for natural mortality was perhaps less true for steelhead, which reside two or more years in streams before migrating to sea, unless immigration occurred.

We eradicated the fish population from a station not previously sampled below the Index Area lowermost dam on 30 September 1986, removing 345 age-0 chinook salmon, 620 age-0 steelhead, 18 steelhead parr, 144 juvenile suckers, 815 dace, and 227 sculpins (Tables 12 and 13). We resampled on 30 October and recovered 29 age-0 chinook salmon (8% of original standing crop), 327 age-0 steelhead (53%), 2 steelhead parr (11%), 11 juvenile suckers (8%), 324 dace (40%), and 129 sculpins (57%). The size of the age-0 chinook salmon (mean, 89.9 mm) and steelhead (mean 80.5, mm) was larger than those taken earlier (mean, 80.9 mm for salmon and 63.2 mm for steelhead). Age-0 chinook salmon that remained in the Index Area on 30 October averaged similar in size as those that had moved into the downstream area (90.3 vs 89.9 mm); the steelhead were smaller (60.5 vs 80.5 mm), although similar in size to those initially removed from the downstream station (mean, 60.5 vs 63.2 mm).

We repeatedly observed regularly sampled stations "full" of fish a few days after cyanide treatment in the warmer months of July and August.

Biomass, production, and yield. Salmonid biomass appeared to be mostly constant (1 to 4 g/m^2) (Table 13), and somewhat independent of seeding level (Table 14). Total production varied from 2.0 to 6.0 g/m^2 and was positively related to seeding level. The ratio between biomass and production (P/B) ranged between 1.5 and 2.3. Highest density, biomass, and production, but lowest yield, were associated with highest water temperatures in 1987 (Fig. 14). Yield normally appeared to be about 1.6 g/m^2 (Table 15).

Conclusions

Movement and Migration

Elliott (1986) equated migration with the behavioral movement of population redistribution. He defined four types--random dispersive, dynamic, homeostatic, and social. Random dispersion is one-way transported emigration without control over the end point. Such a definition aptly describes the migration of hatchery chinook fingerlings released to the Index Area. The rate of downstream

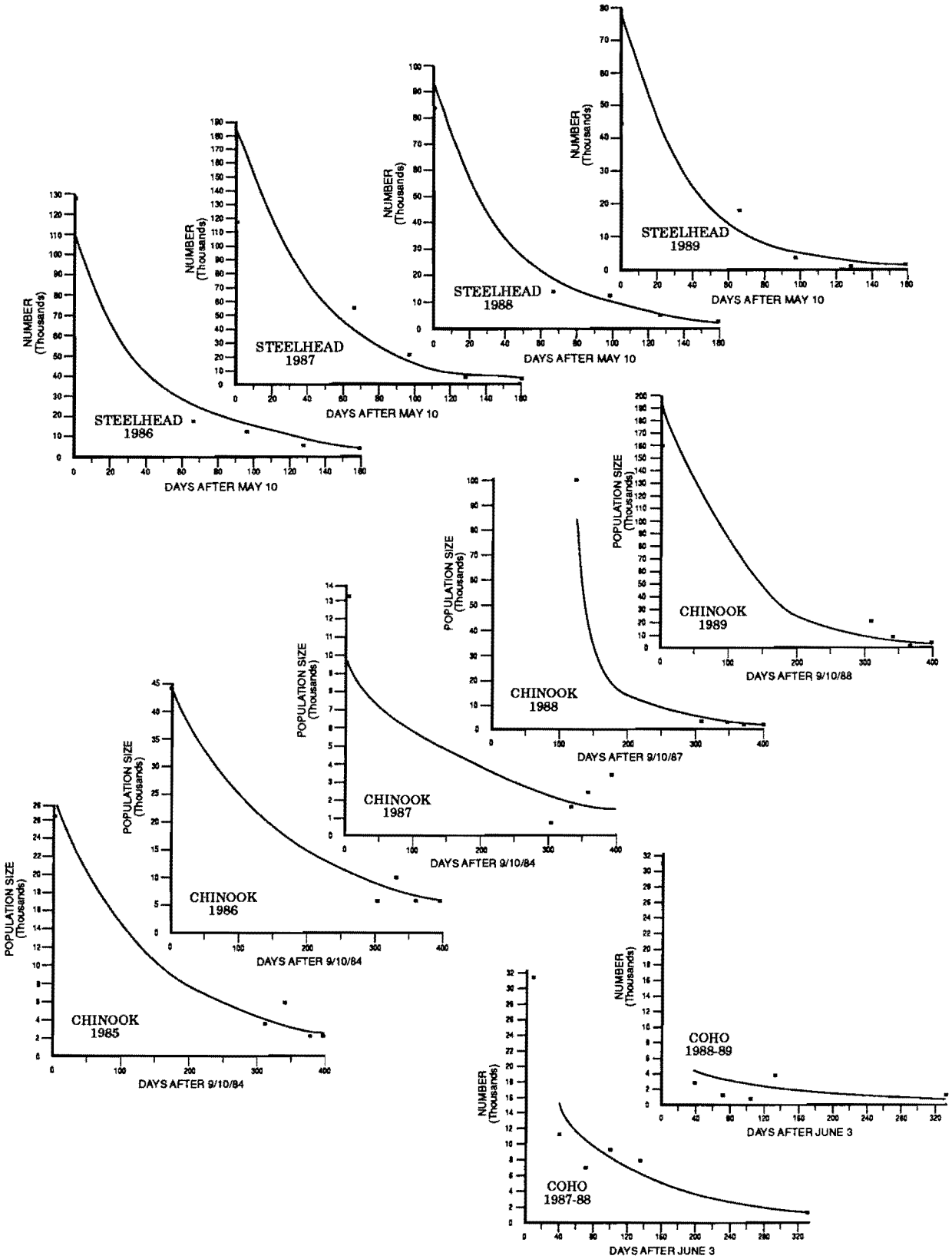


Fig. 16. Population estimates of age-0 salmonids in Icicle Creek Index Area as determined by negative exponential curves fitted by least squares regression (last symbol on coho salmon curves represents numbers of yearling smolts counted in outmigration.)

Table 15. Comparison (g/m^2) of mean biomass, production, and yield of salmonids, Icicle Creek Index Area, 1985-1989.

Chronological year	1985	1986	1987	1988	1989
		Mean biomass (from Table 12)			
Species					
Chinook salmon, age-0	0.6	2.2	0.6	0.2	1.2
Coho salmon, age-0			1.8	0.8	
Steelhead, age-0	0.2	0.5	0.9	0.3	0.2
Steelhead parr	0.3	0.2	1.0	1.1	0.7
Total	1.1	2.7	4.3	2.4	2.2
		Production			
Species					
Chinook salmon, age-0	1.0	2.1	0.7	2.5	0.5
Coho salmon, age-0			1.9	2.5	
Coho smolts				0.1	0.1
Steelhead, age-0	0.4	2.1	3.4	1.1	0.4
Steelhead parr[a]	0.6	0.4	0.2	0.2	1.4
Total	2.0	4.6	6.2	6.4	2.4
		Yield			
Species					
Chinook salmon, age-0			tr	0.4	1.6
Chinook salmon, smolts			0.5	0.1	tr
Coho salmon, age-0			0.2	0.4	
Coho salmon smolts, age-1				0.3	0.7
Steelhead, age-0			0.2	0.2	0.1
Steelhead, parr/smolts			0.1	0.1	0.1
Total			0.9	1.5	2.5

[a] Mean biomass times 2

movement and the behavior of fingerlings were not different from those observed for LNFH yearling smolts (Hillman and Mullan in press). After release, fingerlings and smolts remained at the water surface and drifted downstream in the thalweg, remaining orientated upstream. Hatchery fry, like natural chinook fry, sought quiescent water along stream margins or in channel substrate. This movement is dynamic and actively initiated (Elliott 1986).

The third kind of migration, homeostatic, is a two-way, actively controlled migration,in which navigation is vital and the fish return to their breeding area. Lastly, there is social migration, defined (Elliott 1986) as the movement of individuals within a population, which may include change of dominance or rank, with age, size, or learning.

Salmonid spatial distribution and movements are complex and not easily explained (e.g., Fig. 16, Chinook 1987, chronological sample size: 30, 113, 179, 374). Our observations in the Index Area suggest the following.

The first movement occurs soon after the alevins leave the gravel and start to feed. This is the critical period of the life cycle for population regulation and growth (Allen 1951; Chapman 1965; Elliott 1986). Dynamic movement serves to reduce the clumped distribution of the alevins emerging from redds and to maximize access to available food and space. It is less easy to explain the downstream movement of larger fry and fingerlings that follows.

Through summer, little interspecific interaction was apparent among age-0 chinook salmon, coho salmon, and steelhead. Each species occupied a different microhabitat as a result of differences in size (Hillman et al. 1989a; Spaulding et al. 1989). The Index Area provided habitat for these small salmonids before they reached a size of about 60-80 mm as they attained appreciable densities and growth. With increasing size, however, our observations suggest that this habitat became less suitable for sustaining the production that had occurred.

Stream channels typically have many small hiding niches for small fish, but shelter or microhabitat for larger fish is rarer (White 1986). The primacy of hiding/security cover in streams, and the changes in fish behavior as they outgrow their cover, have been increasingly recognized (White 1986; Hillman et al. 1989a). Cover is largely supplied by rocky substrate in tributaries of the mid-Columbia River. In all but the smaller streams, banks are swept by currents only at flood, and there is little accumulation of woody debris in mid-channels because of flows associated with high gradient (Hillman et al 1989b; Spaulding et al. 1989). Calibration of snorkel estimates with sodium cyanide sampling made clear that juvenile salmonids spend much of their time hiding in interstitial

spaces of rocky substrate, especially when water temperatures are cold (Hillman et al. in press).

Our results seem to confirm that food is rarely a primary limiting factor in streams, but that cover, or closely related food acquisition, most frequently controls salmonid abundance (White 1986). On the other hand, several workers have proposed that fish migrations are almost invariably associated with food supply (Northcote 1978); e.g., initial feeding migration of alevins. Comparison of the growth of age-0 chinook salmon and steelhead in the Index Area with those fed optimum rations at LNFH (Fig. 17) suggests no shortage of food.

Availability of food and size of mouth control what a fish ingests (Williams 1981). Small organisms (e.g., early instar forms of aquatic insects) are the predominant food of small salmonids (Allen 1951; Becker 1973; Alexander and Gowing 1976; Williams 1981). Small organisms are the numerically dominant component of aquatic food webs. Ivlev (1961) showed predators prefer foods of the largest possible size, with morphological features imposing a limiting and optimum size of the principal prey. If fish, as their size increases, are unable to obtain larger food organisms, growth will tend to be asymptotic. And asymptotic growth occurs in the Index Area (Figs. 12 and 15), as well as in most tributaries of the mid-Columbia River (Hillman and Chapman 1989; Chapter 5), indicating that food supply is limited for all but small fish.

We conclude that spatial distribution of salmonids in the Index Area involved social and dynamic movement and was essentially density dependent. Emigration of juvenile salmonids increased also when spawning salmon and suckers were present. On 28 August 1989, 109 ripe chinook salmon were scatter-planted in the Index Area. The next morning 912 juvenile salmonids were in the downstream smolt trap. The prior daily catch--from 1 August to 28 August--had averaged 47 fish; the daily catches on 30 and 31 August averaged 98 fish; and the catch in September declined to only 8 fish per day.

Another instance of density related emigration occurred in June 1989. At this time, 60% (7,200 fish) of the estimated outmigration of age-0 chinook corresponded with a spawning run of bridgelip sucker (800-1,000 fish estimate) that were able to surmount the lowermost dam with floodwater from the mainstem Icicle Creek. In 1988, only 35% (669 fish) of the age-0 chinook outmigration occurred in June; it peaked in July (47%), yet these juveniles were noticeably larger than the 1989 year-class at a corresponding time (Fig. 12b).

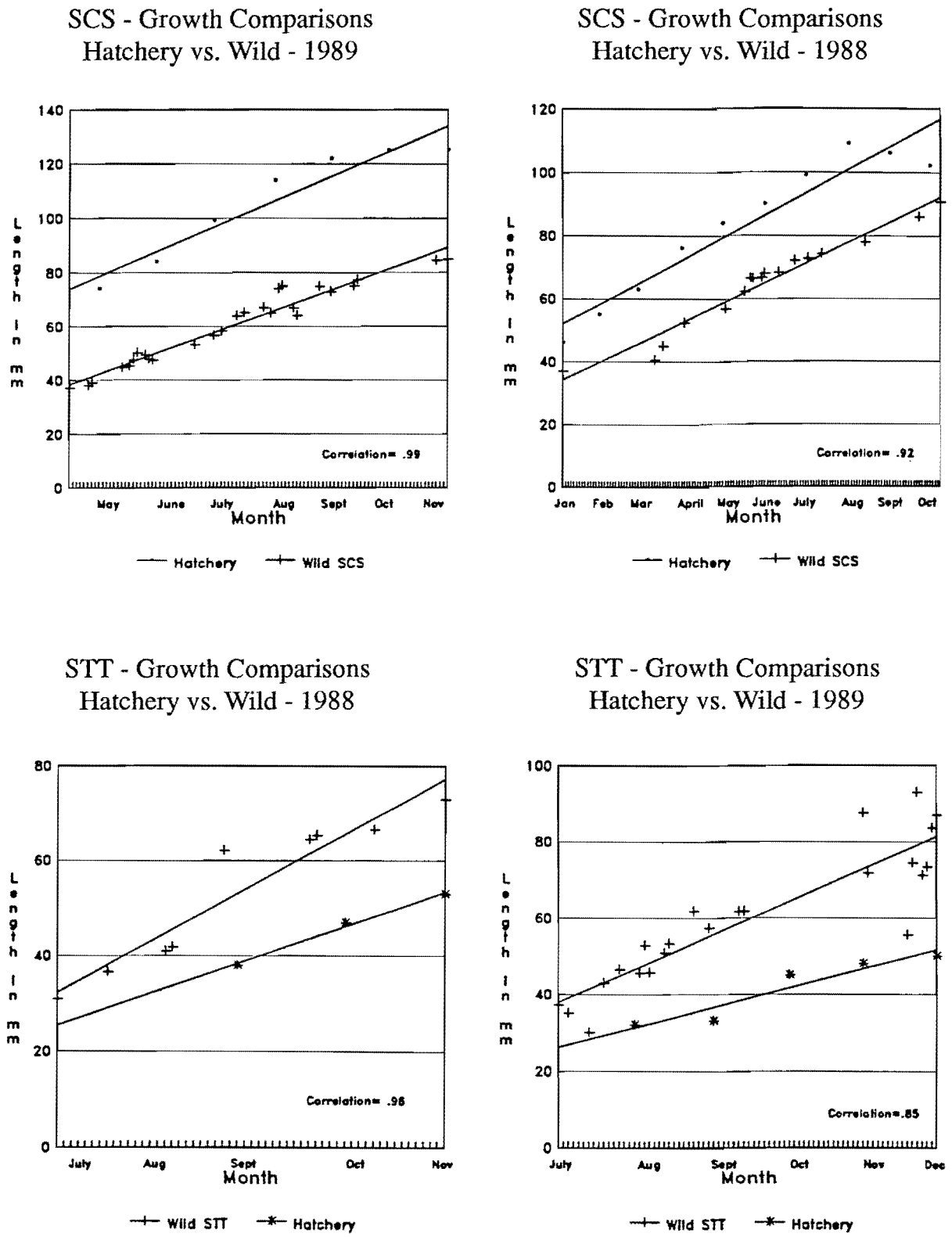


Figure 17. Growth relationships between age-0 chinook salmon (SCS, top) and steelhead (STT, bottom) fed an optimum diet in Leavenworth NFH and wild fish in Icicle Creek Index Area.

Biomass and Production

Allen (1969) conceptualized the relationships between production and biomass:

> Production includes a numerical component determined by reproduction, immigration, mortality, and emigration, and a weight component determined by growth. Stream salmonids are territorial, and this provides a mechanism limiting production since it determines through the size of the territories, the maximum density a stream can support. Fish which are in excess of the number of available territories or which, due to growth, can no longer find territory with suitable characteristics, are displaced from the area and thus cease to contribute to production. Both the average area of the stream channel per fish and the area of the territory increase roughly in proportion to the weight of the fish, and do not differ markedly for different species of salmonids at the same size.
>
> Growth is controlled by the amount of food eaten. The bottom fauna is generally the principal food of stream salmonids and can limit production. The bottom fauna may, in turn, be controlled by the predation of salmonids or other fishes, thus, through competition, providing for stabilizing production. The relationship between size of territory and weight of fish implies that the amount of food available in a given habitat is about proportional to the metabolic rate of the fish. Thus, if fish, as their size increases, are unable to compensate by taking larger food organisms, a greater amount of energy will be expended in feeding. This results in little growth and low production. Because temperature directly governs the metabolic rate of fish, temperature may also exert direct influence on the growth rate and hence on production.

Annual biomass and yield in the Index Area was relatively consistent, at about 2.5 g/m^2 and 1.6 g/m^2, respectively, despite large variations in seeding level (600 to 6,000 fish/100 m^2) and moderate variations in production (2.0 to 6.4 g/m^2) (Table 15). Vital statistics fit well with a compilation of such values (Tables 16 and 17). Biomass was remarkably consistent with values from the Wenatchee, Entiat, and Methow rivers as well as other streams in comparable areas (Table 17).

Fish populations are determined by the biophysiographies of a particular environment (Platts and McHenry 1988). Regionalization allows comparisons, assuming that the streams of concern are roughly similar in geology, climate, and vegetation (Whittier et al. 1988; Gallant et al. 1989).

Table 16. Mean survival rates and yield for juvenile salmonid life–stages in streams.

Stream and location	Spp [a]	Survival rate (%) Egg to alevin	Egg to fry	Fry to fall fing.	Egg to age–1	Fall fing to age–1	Yield No/100 m²	g/m²	Reference
Fall Cr CA	Ch*		14.5 [b]						Wales & Coots 1954
B. Qualicum BC	Ch*		19.8 [b]				30.0	1.2	Lister & Walker 1966
Cowichan R BC	Ch*		12.9 [b]				18.0	0.6	Lister et al 1971
Incubators OR	Ch*	84.0							Smith et al 1985
Icicle Cr WA	Ch		9.8 [b]				14.5	0.7	This report
Yakima R WA	Ch				10.7				Major & Mighell 1969
" "	Ch				6.3				Fast et al 1987
Warm Sprgs OR	Ch				4.6				Lindsay et al 1989
John Day R OR	Ch		20.6 [b]		5.6	29.8			Lindsay et al 1986
Lookingglass OR	Ch		9.5 [b]						Burck 1974
Incubators OR	Ch	63.0							Smith et al 1985
Big Sprgs Cr ID	Ch			23.8					Bjornn 1978
" "	Ch,St						64.5	5.7	" "
" "	St		67.9	9.3		28.4	52.0	3.5	" "
Icicle Cr WA	St		25.8	6.1			11.3	0.3	This report
2 streams WA	St						1.9	0.9	Marshall et al 1980
3 streams BC	St						1.4	0.6	" "
Nuaitch Cr BC	St			23.6		35.3	17.0		Tredger 1980
Incubators OR	St	89.0							Smith et al 1985
Simul/ lab.	St	88.6							Shapovalor 1939
Bothwell Cr ON	St						22.0	3.2	Alexander & MacCrimmon 1974
Platte R MI	St					36.7			Taube 1975
Icicle Cr WA	Co			24.3		19.7	15.7	0.8	This report
Speelyai Cr WA	Co				5.7				Smith et al 1985
Minter Cr WA	Co				3.2				Salo & Baylift 1958
3 streams BC	Co						7.3	3.5	Marshall et al 1980
Big Qualicum BC	Co				9.6		20.0		Lister & Walker 1966
3 streams OR	Co		65.0	19.4	5.2	41.3	46.0	3.4	Chapman 1965
Same (13 yrs)	Co				2.8				Hall & Knight 1981
Incubators OR	Co	80.0							Smith et al 1985
Waddel Cr CA	Co				0.7				Hall & Knight 1981
Platte R MI	Co					60.0			Taube 1975
Cove Br ME	At			10.2		50.3			Meister 1962
Wilfin Beck UK	BT		22.5	17.1	2.0	52.1			Elliott 1987
Black Brows UK	BT**	99.0	7.8	2.0	1.0	47.3			Elliott 1984
Au Sable MI	BT		53.2	2.8	0.7	46.6			Alexander 1979
Average, MI	BT					41.1			" "
Elsewhere	BT					35.1			" "
Au sable MI	EBT		75.0	5.9	2.1	47.9			" "
Average, MI	EBT					23.2			" "
Elsewhere	EBT					33.0			" "

[a] Ch = Chinook salmon, St = steelhead trout, Co = coho salmon, At = Atlantic salmon, BT = brown trout, EBT – Eastern brook trout

* Indicates ocean–type chinook salmon (summer/fall run) that migrate to sea in first year of life; lack of * indicates stream–type (spring–run) that spend one or more years in fresh water before migrating.

** Anadromous brown trout.

[b] A combination of fry and fall fingerlings.

Table 17. Biomass (g/m²) of stream salmonids by geographic area.

Stream(s)	Dominant species [a]	Mean biomass	Standard deviation	n	Reference
		Pacific Forest Ecoregion			
Icicle Cr, WA	Ch, Co, St	2.1	1.2	22	This report
Wenatchee R, WA	Ch, Co, St	2.5	4.4	68	" "
Entiat R, WA	Ch, St	2.3	2.0	14	" "
Methow R, WA	Ch, St	2.2	2.4	49	" "
Methow headwaters, WA	trout	5.2	3.3	40	" "
Various	trout	2.2	2.0	54	Platts & McHenry 1988
Big Qualicum, BC	Ch, St	2.2	1.4	4*	Marshall et al. 1980
25 tribs, Skagit & Sauk Rs, WA	Co, St, Ct	3.9	1.3	4*	R. Cooper, WDW, unpubl.
Gobar Cr, WA	Co, St, Ct	3.1	0.7	6*	" "
Snow Cr, WA	Co, St	3.3	0.7	10*	" "
3 streams, CA	Co, St	2.0	1.0	12	Burns 1971
3 streams, BC	Co, St	1.7	0.8	21	Narver & Anderson in
2 streams, BC	Co, Ct	3.2	1.7	11	Hall & Knight 1981
1 urban cr, WA	Co, Ct	3.5	0.4	2*	Scott et al. 1986
1 pristine cr, WA	Co, Ct	2.0	0.7	2*	" "
24 channelized, WA	Co, Ct	2.6	0.5	44	Chapman & Knudson 1980
same, controls	Co, Ct	3.1	0.5	44	" "
12 grazed, WA	Co, Ct	3.8	0.7	22	" "
same, controls	Co, Ct	3.6	0.9	22	" "
3 streams, BC	Co, Ct	2.2	0.6	7	Glova in Hall & Knight 1981
3 streams, OR	Co, Ct	6.2	1.4	21	Au in Hall & Knight 1981
same	Co only	2.9	2.4	183	Chapman 1965
12 streams, WA	Co	2.2	1.6	21	Flint 1977
2 streams, BC	Ct	3.4	1.3	13	Hall & Knight 1981
3 streams, BC	Ct	1.9	0.7	3	Hall & Knight 1981
		Columbia Forest Ecoregion			
Various	trout	3.8	4.4	42	Platts & McHenry 1988
3 tribs G.Ronde, OR	St	4.7		6	Maciolek 1979
1 trib Umatilla, OR	St	6.3		3	Smith et al. 1985
S.F. John Day, OR	St	2.2		5	" "
3 tribs John Day, OR	St	12.7		14	" "
Nuaitch Cr, BC	St	9.2		4	Tredger 1980
Big Springs, ID	St	3.0	0.8	2*	Bjornn 1978
Big Springs, ID	St, Ch	10.7	1.3	2*	" "
Fish Cr, OR	St, Ch, Co	4.2	0.8	6*	Everest et al. 1987
Warm Springs, OR	St, Ch	1.3		5	B. Cates, USFWS, unpubl.
M.F. John Day, OR	St, Ch	2.2		7	Maciolek 1979
Cape Horn, ID	Ch	5.2	1.3	7	Sekulich 1980
Knap Cr, ID	Ch	0.9	0.2	10	" "
Marsh Cr, ID	Ch	1.8	1.1	20	" "
Tucannon R, WA	Ch	1.1		42	Bugert et al. 1988

Table 17 continued.

Stream(s)	Dominant species [a]	Mean biomass	Standard deviation	n	Reference
		Intermountain Sagebrush Ecoregion			
Various	trout	4.0	3.9	22	Platts & McHenry 1988
Green R, WY	Rt, BT	5.5	1.5	6*	Wiley & Dufek 1986
Three Mile, OR	Rt	24.2			Kunkel 1976
3 streams, OR	Rt	4.6			" "
		Rocky Mountain Forest Ecoregion			
Various	trout	7.7	9.2	62	Platts & McHenry 1988
		Sierra Forest Ecoregion			
Various	trout	8.2	10.6	73	Platts & McHenry 1988
		Great Lakes Ecoregion			
5 streams, MI	St	3.2	1.6	10*	Stauffer 1977
same	St, Co	4.5	1.9	31*	" "
Platte, R, MI					
Above hatchery	St, BT	6.9	1.6	12*	Taube 1975
" "	St, BT	7.1	1.4	12*	" "
Below hatchery	St, Bt	15.1		5*	(our deduction)
" "	St, Bt, Co	17.3	6.0	15*	Taube 1975
Au Sable, MI					
with polution	BT	1.2		5*	Alexander et al. 1979
w/o pollution	BT	2.4		1*	" "
with pollution	BT, EBT, Rt	17.3		5*	" "
w/o pollution	BT, EBT, Rt	12.7		5*	" "
N. Branch					
urbanized 1957-60	BT, EBT	9.0	1.1	8	Alexander et al. 1979
urbanized 1961-67	BT, EBT	8.2	0.0	14	" "
urbanized 1974-76	BT, EBT	12.1	2.7	6	" "
S. Branch	BT, EBT	7.1		4*	Gowing & Alexander 1980
11 streams, MI	BT, EBT	9.4	5.0	46*	" "
Newton Cr, MI					
7" size limit	BT	2.8		3*	Alexander & Peterson 1983
10" size limit	BT	4.7		10*	" "
2 streams, MI	Ch only	0.5	0.3	14	Carl 1984
Lawrence Cr. WI	EBT	8.3	1.7	11*	Hunt in Hall & Knight 1981
Bothwell's Cr, ON	ST	2.5	2.4	30	Alexander & MacCrimmon 1974

Table 17 concluded.

Stream(s)	Dominant species [a]	Mean biomass	Standard deviation	n	Reference
		Eastern Canada			
10 streams, ON	EBT, Rt, BT	3.0	4.0	80	Bowlby & Roff 1986
Miramichi, NB	EBT, At	1.3	0.3	12*	Randall et al. 1989
10 logged, NS	EBT, At	2.4		10	Grant et al. 1986
same, controls	EBT, At	3.0		10	" "
45 streams, PQ	EBT	3.2	1.6	9	O'Connor & Power 1976
		Great Britain			
11 streams	BT	2.8	1.5	67	Crisp in Hall & Knight 1981
2 chalk streams	BT	5.5	1.0	2	Le Cren 1969
Black Brows	BT	4.5	1.4	17*	Elliott 1984
Shelligan Burn	BT	9.7	2.8	9*	Egglishaw & Shackley 1977
3 moorland					
stream A	At	2.8	0.1	4*	Mills 1969
A fertilized	At	4.3		1*	" "
stream B	At	1.2	0.2	6*	" "
stream C	At	1.7	0.4	4*	" "
		Northern Norway			
18 streams	BT, At, char	1.9	1.6	34	Power 1973
		New Zealand			
Horokiwi	BT	22.7	11.4	30	Allen 1951

a) Ch = chinook salmon, Co = coho salmon, St = steelhead trout, At = Atlantic salmon, BT = brown trout, Rt = rainbow trout, EBT = Eastern brook trout, CT = cutthroat trout.

* Generally pooled population estimates over the number of years shown.

Our streams exhibited the lowest mean biomass in the western United States (Table 17). Comparable low biomass primarily occurs in northern Norway. The eastern rim of the North Pacific is formed by high coastal mountains. The streams, except for large rivers (i.e., Columbia), tend to be short and steep, with flooding in late spring, early summer. The lands bordering the North Atlantic are of low relief, except in northern Norway (Allen 1969). Because of lesser elevation and lesser accumulations of ice and snow, the streams have more winter and less spring and summer flooding. Spring and summer flooding is more unfavorable to the feeding and growing stages of salmonids than to the egg and alevin stages (Allen 1969; Miller and Brannon 1982). In the Pacific area, evolutionary response of some species was for very short freshwater residency; pink salmon (O. gorbuscha) and chum salmon (O. keta) hardly rear at all in fresh water.

Summer/fall run chinook salmon that migrate to sea in their first year of life are dominant in the Wenatchee River and of lesser importance in the Methow and Entiat rivers. Juveniles depart these rivers in spring, early summer (Mullan 1987) and are largely not included in our late summer, early fall biomass estimates. Judging from data supplied by Lister and Walker 1966 (1.2 g/m^2), Lister et al. 1971 (0.6 g/m^2), and Carl 1984 (0.5 g/m^2), inclusion of juvenile summer/fall chinook salmon would raise biomass to about that of other streams in the Pacific Forest Ecoregion (3 g/m^2 or 27 lbs/ac) (Table 17).

Streams within the Pacific Forest Ecoregion exhibited a low range of biomass variability (Table 17). Temporal and spatial variations amounts to less than 50% of mean biomass. Here as elsewhere, variations in biomass appeared to be primarily related to edaphic factors (Table 18). Barring nutrient enrichment (sewage, hatchery effluent, urbanization, agricultural fertilizers) or other human activities (channelization, logging, fishing harvest) (Table 17), streams draining softer sedimentary or volcanic formations had higher biomasses than those draining nutrient-poor, granitic rock formations (Northcote and Larkin 1989).

The ratio of production to biomass indicates the efficiency of production. Average P/B ratio for the Index Area was 1.6. Waters (1977) found most values slightly above 1.0 for stream populations of trout and salmon. Generally streams with higher ratios are those with large numbers of young fish (Chapman 1965; Alexander and MacCrimmon 1974; Bjornn 1978; Elliott 1985); those with lower ratios are those with small numbers of old fish (Power 1973; O'Connor and Power 1976; Gowing and Alexander 1980).

Care must be exercised in comparing production ratios between populations that lose large numbers of fish through emigration and resident populations (Chapman 1965). Net production in the Index Area was 2.7 times greater than yield as biomass, a value that

Table 18. Salmonid biomass for selected streams (Tables 7,8,13) draining softer sedimentary or volcanic formations compared to those draining nutrient poor, granitic rock formations.

Soft rock			Hard rock		
Buttermilk Creek	Wolf Creek	Peshastin Creek	West Fork Methow River	Early Winters Creek	Icicle Creek [a]
		Biomass (g/m^2)			
7.2	6.9	8.0	2.3	3	1.1*
7.8	8.9	5.3	2.5	1.1	2.8*
6.0	13.0	24.7	1.6	2.3	2.8*
5.0	12.2	9.7	1.5	2.0	1.5*
		20.0		2.0	1.6*
		16.7			3.1
		Geologic formations and percentage (%) of basin [b]			
Jk (55)	Ku (90)	Tkc (70)	Tg (35) [c]	Tg (40) [c]	Mzg (65)
Mzg (35)	Kc (5)	Ptb (10)	Kl (35)	Ku (35)	Pjse (25)
Tkv (10)	Tkv (5)	Mzg (10)	Ku (30)	Kl (25)	Ptb (10)
		Pjph (5)			
		Qg (5)			

Jk = Sedimentary and volcanic intrusive undivided.
Mzg = Intrusive igneous (granite).
Tkv = Volcanic extrusive igneous.
Ku = Winthrop sandstone, sedimentary (mostly marine).
Kc = Sedimentary (non-marine).
Tkc = Sedimentary sandstone (non-marine).
Ptb = Intrusive igneous.
Pjph = Metamorphic.
Qg = Glacial drift.
Tg = Intrusive igneous (granite).
Kl = Sedimentary (mostly marine).
Pjse = Metamorphic.

[a*] Four or more average values/yr (Table 13) from index study area.
[b] Estimated from Geologic Map of Washington 1961. Washington Dept. of Conservation. Division of Mines Geology.
[c] The upstream intrusive has altered and mineralized the older sedimentary rocks downstream.

appears typical of all but the more benign nursery streams (e.g., Alexander and MacCrimmon 1974). Density-dependent factors are most important in benign environments and density-independent factors in harsh environments in the regulation of salmonid populations (Elliott 1987).

CHAPTER 5

SPECIES' LIFE HISTORIES, ABUNDANCE, AND INTERACTIONS

The environment influences the life history of all species. The purpose of this chapter is to detect, as best possible, the factors that most influence the abundance of fish species found in our streams. Streams are a continuously integrated series of physical gradients and associated biotic adjustments (Minshall et al. 1985). Examination of the reasons why a species (or race) deviates from the behavior of other species present can shed light on the biotic adjustments that occur (Welcomme et al. 1989).

Chinook Salmon

Two behavioral forms account for much of the diversity in the life history of chinook salmon. The stream-type or spring-run (Gilbert 1913), typical of Asian populations, northern-latitude populations, and headwater tributary populations in temperate North America, spend one (produces a stream-annulus on scales) or more years in fresh water before migrating to sea. These fish perform extensive offshore migrations and return to their natal stream in spring, a few months before spawning. Precocious maturation of males in freshwater is common (Healey 1991; Mullan et al. in press).

Ocean-type or summer/fall-run ("sea-type," Gilbert 1913) typifies populations on the North American coast south of 56° N. Ocean-type chinook salmon migrate to sea during their first year of life, spend most of their ocean life in coastal waters, and return to their natal stream in late summer or fall, a few days or weeks before spawning (Healey 1991). One-ocean precocious jacks are more common in ocean-type (>35%) than in stream-type (<13%) chinook salmon (Mullan 1987). Considering the behavioral plasticity of chinook salmon, the above paradigms may not always hold (Reimer and Loeffel 1967; Schleuter and Lichatowich 1977).

In tributaries of the mid-Columbia River ocean-type chinook salmon form one race. Race identifies subdivisions of a species geographically separated to some degree and with reduced gene flow between subdivisions (Ricker 1972). Summer-run and fall-run chinook salmon mix and spawn at the same time (Mullan 1987; Appendix J). If both stream and ocean types of chinook occur in

the same stream, the ocean-type not only spawns later, but also usually downstream of the stream-type (Fig. 5).

Stream-type Chinook

In Chapter 2 we assessed escapements to study streams and found suggestions of an inverse relationship between spawning escapements and total run size four years later (Fig. 18). Extrapolating rearing densities for the total drainage rearing areas according to HQI ranking (Chapter 3) produced a range in late-summer, early-fall population estimates (Table 19). From these data we developed estimates of standing crop covering temporal variations in abundance. If a homogenous reach of stream had an HQI value of, say 20, that rearing area was multiplied by both the "poor" density value (2.5 age-0 chinook/100 m^2) and the "fair" value (3.8 age-0 chinook/100 m^2) (Table 19). Because annual losses of stream salmonids are high universally (Table 16), we assumed 60% overwinter mortality for age-0 chinook salmon. The egg-to-fall fingerling survival of naturally produced, stream-type chinook ranged from 2.7 to 13.3%; and smolt-to-adult survival from 2.0 to 10.1% (Table 20).

From 1976 through 1988, the GCFMP hatcheries released 37.1 million (18/lb. or 2.0 million lbs.) yearling stream-type chinook salmon. A total of 66,836 (0.18%) returned to the hatcheries as adults. Corrected for 5% interdam loss, incidental in-river catch of 8%, and ocean harvest of 10% (the same procedure used to calculate abundance of wild fish, Chapter 2), total run size was 108,000 fish (1.5 million lbs.) or 0.29% total survival. Mean hatchery-to-adult survival ranged from 0.16 to 0.55% (Table 20). Naturally-produced smolts were 13-100 times as viable as hatchery smolts.

Survival rates for naturally produced stream-type chinook salmon (Table 20) agree with those reported by Healey (1991). Major and Mighell (1969) estimated that 5.4 to 16.4% of the eggs deposited by stream-type chinook survived to smolt in the Yakima River (Fig. 1); Fast et al. (1988) estimated 4.2 to 6.5% survival.

Runs of adult stream chinook salmon in the undammed Fraser River average only 19,000 to 31,500 (U.S./Canada 1984), compared to 17,400 for the mid-Columbia. The Wenatchee, Entiat, and Methow rivers contribute less than 2% of the flow to the mid-Columbia River, and there is no evidence that these streams ever produced more fish than they do now.

The universal presence of bacterial kidney disease (BKD) in hatchery stocks is a prime suspect for the poor returns of chinook salmon. Equally obvious is that the behavior of chinook salmon in hatcheries is conditioned differently from that of wild fish. Large age-0 and yearling chinook salmon smolts released to Icicle Creek were not cover-oriented, remained at the water surface and

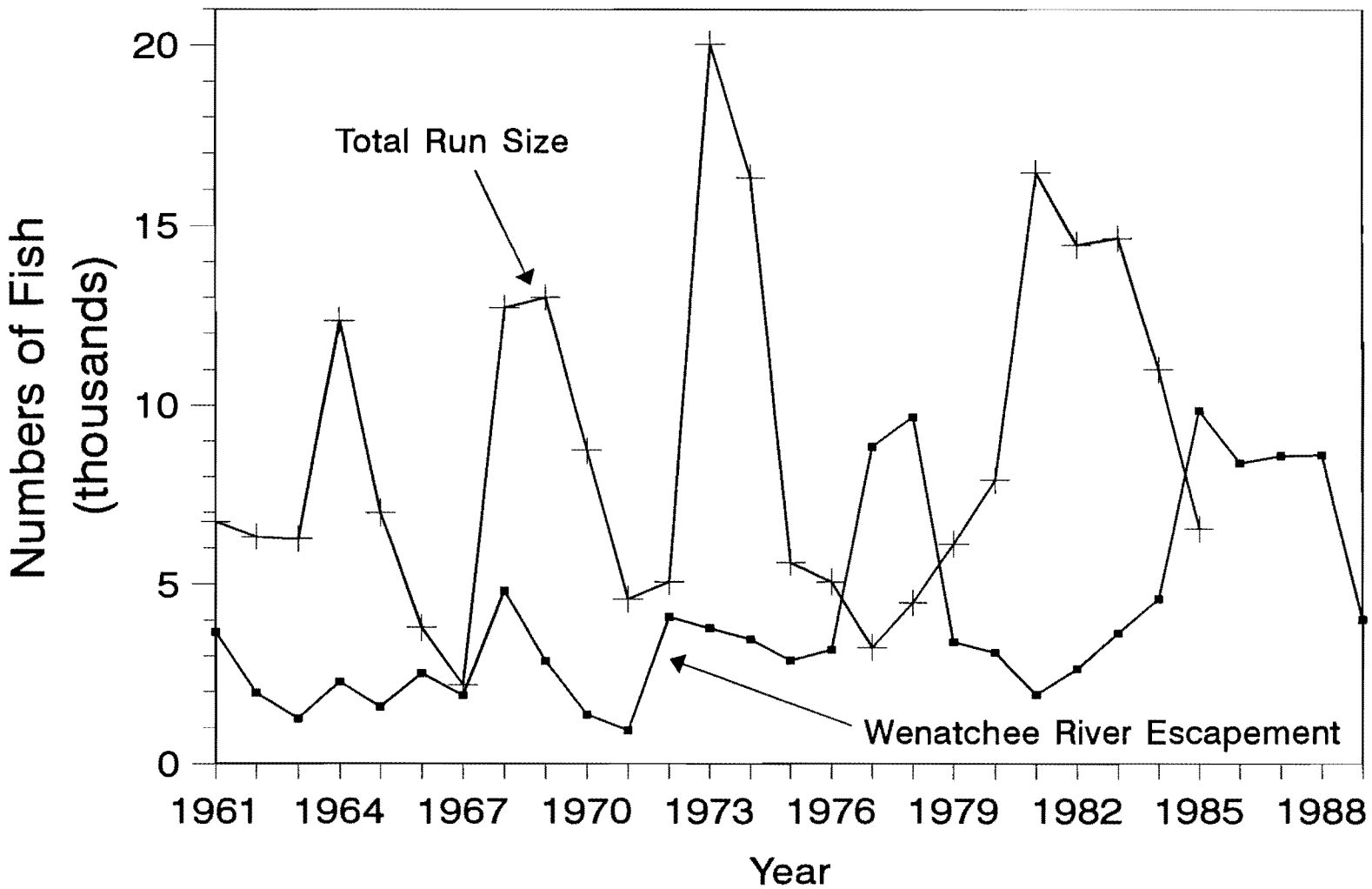


Figure 18. Spawning escapement of naturally produced spring chinook salmon to the Wenatchee river (year N) compared to total run size four years later (Year N-4), 1961-87.

Table 19. Average (weighted) densities (fish/100m^2) of age - 0 chinook salmon, age - 0 steelhead, steelhead parr, and total salmonids (exclusive of mountain whitefish) according to habitat quality indexing (HQI) of poor, fair, average, good, and excellent, for mid-Columbia River tributaries.

				Densities (Fish/100m^2)			
Habitat index	Quality rating	Number of stations	Area (m^2)	Age - 0 chinook	Age - 0 steelhead	Parr steelhead	Total* salmonids
11 - 20	poor	19	65,060	2.5	1.3	1.1	5.4
21 - 40	fair	53	160,897	3.8	2.3	1.3	9.7
41 - 60	average	26	30,239	9.8	8.7	3.6	23.5
61 - 80	good	28	43,908	11.6	8.7	6.2	29.5
81 - 100	excellent	14	12,779	19.9	30.1	9.8	71.4
	TOTAL	141	312,883				

* Includes rainbow/steelhead > 200 mm, cutthroat trout, Eastern brook trout, bull trout, and hatchery coho salmon.

Table 20. Life table for stream-type (spring-run) chinook salmon in mid-Columbia River tributaries.

Item	Wenatchee River drainage	Entiat River drainage	Methow River drainage
Spawning area (ha)	244	102	397
Number of redds/ha	7.7	5.2	2.9
Number eggs/ha	35,088	23,475	13,096
Rearing area (ha)	732	102	642
Number of fall fingerlings (000)	227.7 - 365.3	74.6 - 111.4	302.4 - 690.5
Egg-to-fall fingerling survival	2.7 - 4.3%	3.1 - 4.7%	5.8 - 13.3%
Fall fingerling-to-smolt survival	40%	40%	40%
Number of smolts (000)	91.1 - 146.1	29.8 - 45.6	121.0 - 276.2
Average run size (1967-87)	9,215	2,573	5,611
Smolt-to adult survival	6.3 - 10.1%	5.6 - 8.6%	2.0 - 4.6%
Average hatchery smolt-to-adult survival, 1976 -88 (range)	Leavenworth 0.55% (0.21 - 0.70%)	Entiat 0.16% (0.07 - 0.27%)	Winthrop 0.20% (0.02 - 0.28%)
Viability of naturally produced smolts vs hatchery smolts	14 - 30 X	38 - 80 X	13 - 100 X

drifted downstream in the thalweg regardless of season or time of day, had no apparent social structure, and were hyperactive (Hillman and Mullan in press). Recently hatched fry released to Icicle Creek, by contrast, quickly removed themselves from strong currents and mimicked the behavior of naturally produced chinook (Hillman et al. 1989a, 1989b). Behavior and BKD in hatchery chinook salmon probably is related (Noakes and Grant 1986).

Exceptions to low hatchery returns almost invariably involve chinook salmon with the least exposure to hatchery life. Slow-incubated stream-type chinook transferred to a semi-natural stream fish ladder in November and reared there until March-April have the highest survival (1.63%) of any Columbia River hatchery stock (Lindsay et al. 1989).

Ocean-type Chinook Salmon

Mean escapement to the Wenatchee (12,012), Entiat (100), and Methow (3,385) rivers for naturally-produced ocean-type chinook salmon, 1967-87, was 15,497. Corrected for 5% interdam loss, incidental in-river catches of 9%, and ocean harvest of 75% in 1967-84 (NPPC 1986), and more recent harvests of about 40% (Pratt and Chapman 1989), total run size was about 86,000 naturally produced ocean chinook (Wenatchee - 68,600; Entiat - 570; Methow - 19,350). Although ocean harvest data are not specifically available for all years, it is apparent that the trend in escapements to the Wenatchee River in the past 27 years was relatively stable (Fig. 19). This suggests that the habitat was fully seeded even at low escapements.

We estimated the number of juvenile migrants with three densities (Table 21). Egg-to-migrant survival for wild ocean-type chinook salmon ranged from 4.8 to 15.2%, excluding a 45% aberrant value for the Entiat River (Table 21).

The spawning period of summer chinook in the Entiat River was from early September to late November, with a peak in late October (Burrows 1954). Burrows concluded that the summer chinook run was largely an artifact of hatchery propagation; verified after artificial propagation was abandoned, by the decline in natural spawning (Mullan 1987).

Chinook salmon eggs incubated at temperatures below 5.8° C (42.5° F) from first deposition suffer abnormally high mortalities (Combs and Burrows 1957). Such temperatures prevail in the Entiat River in late October (Fig. 20).

Mean smolt-to-adult survival (fishery harvest and spawning escapement) ranged from 0.28 to 0.46% for 13.8 million tagged ocean-type fish, brood years 1978-81, from lower Columbia River hatcheries (Vreeland 1989). Naturally produced smolts in the mid-Columbia were 8 to 17 times as viable.

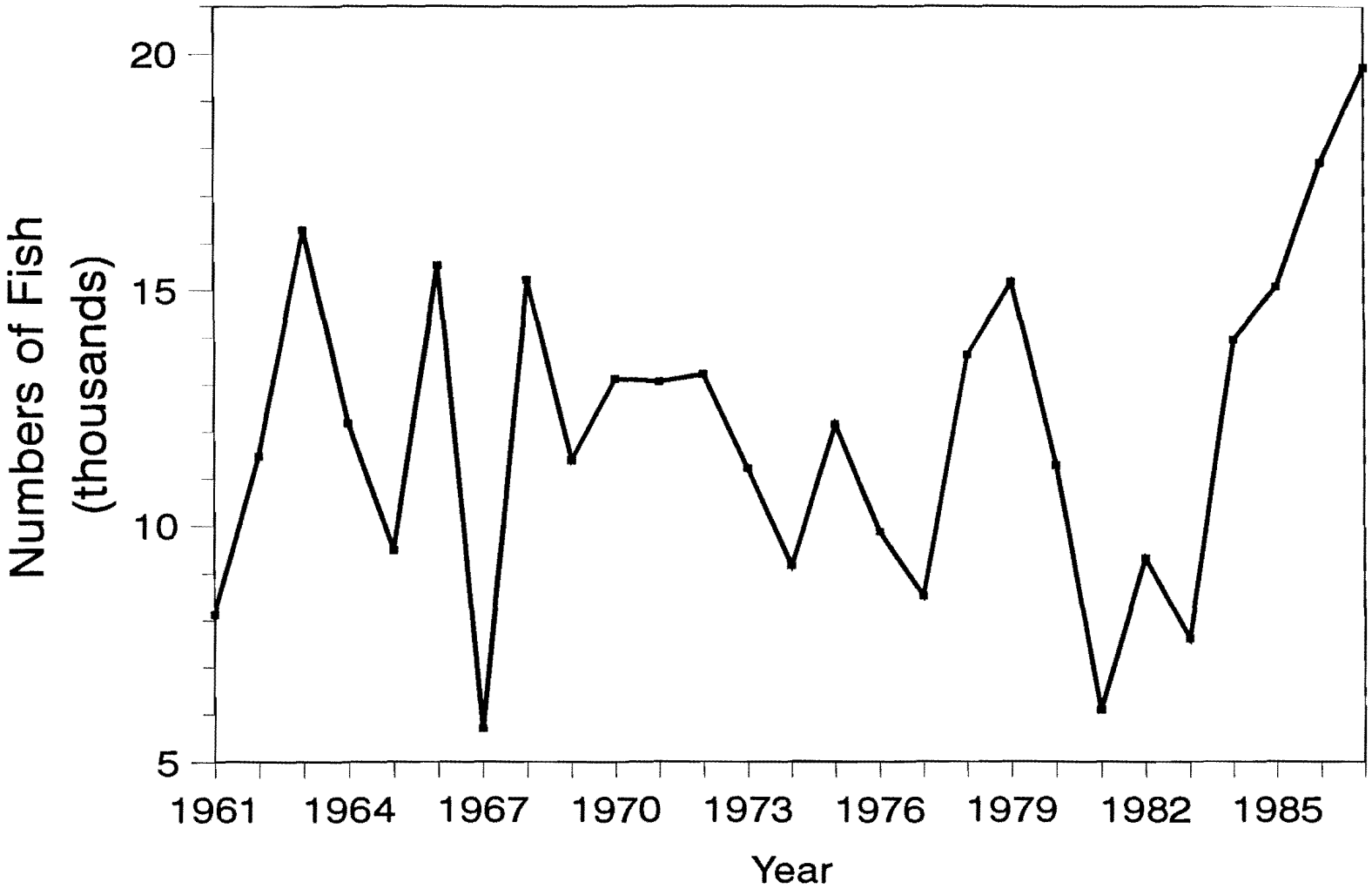


Figure 19. Interdam escapements of naturally produced summer/fall chinook salmon to the Wenatchee River, 1961-87.

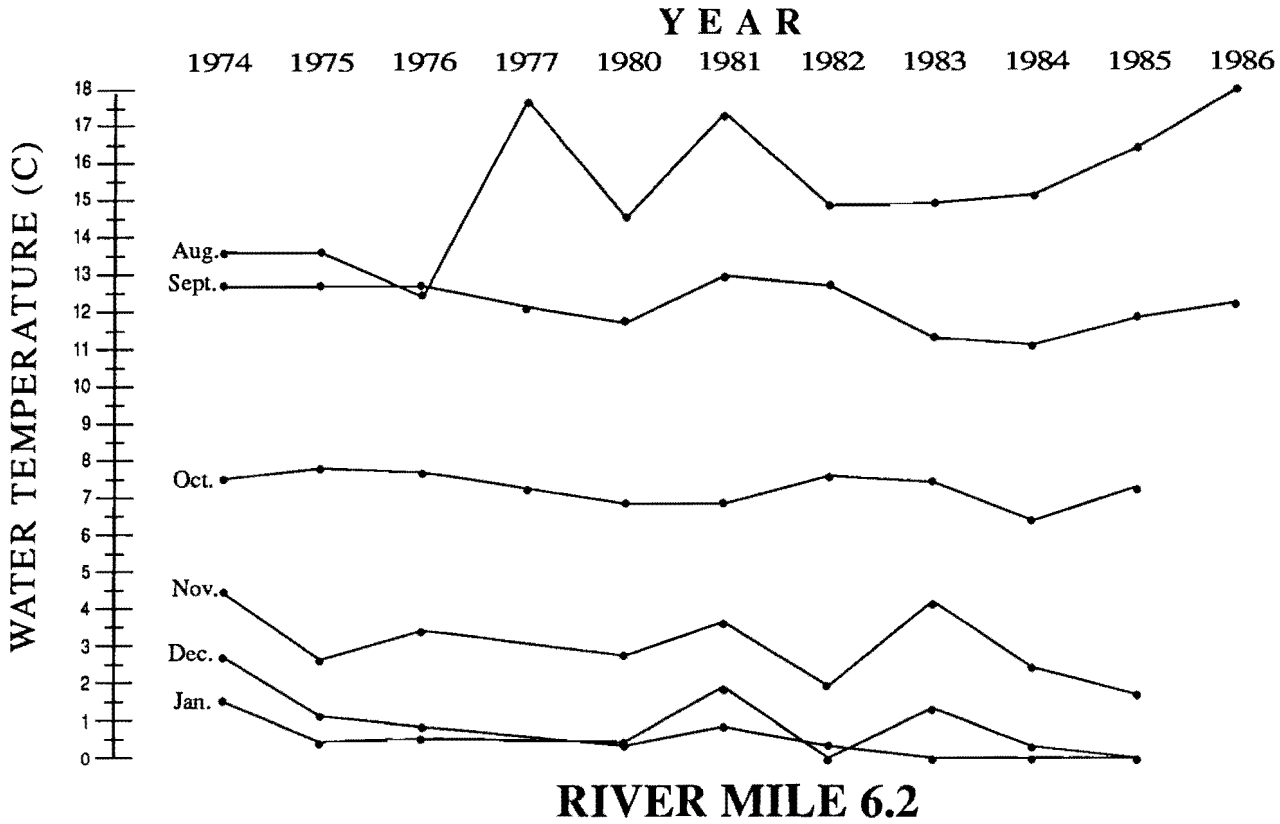
Table 21. Life table for ocean-type (summer/fall run) chinook salmon in mid-Columbia River tributaries with smolt estimates from three sources.

Item	Wenatchee River drainage	Entiat River drainage	Methow River drainage
Average run size (1967-87)	68,600	570	19,350
Spawning area (ha)	448	22	245
Rearing area (ha)	same	same	same
Number eggs deposited	20,300,000	169,000	5,700,000
Number migrants*			
(1 g yield/m^2; 5 g mean wt)	976,500	43,700	490,700
Egg-to-migrant survival	4.8%	25.9%	8.5%
Migrant-to-adult survival	7.0%	1.3%	3.9%
Number migrants**			
(19.9 fish/100m^2)	971,000	43,500	488,200
Egg-to-migrant survival	4.8%	25.8%	8.5%
Migrant-to-adult survival	7.1%	1.3%	3.9%
Number migrants***			
(35.2 fish/100m^2)	1,718,563	76,951	863,556
Egg-to-migrant survival	8.5%	45.5%	15.2%
Migrant-to-adult survival	4.0%	0.7%	2.2%
Summary of above			
Number of migrants (000)	482.4 - 1,718.6	21.6 - 77.0	242.4 - 863.6
Egg-to-migrant survival	4.8 - 8.5%	25.9 - 45.5%	8.5 - 15.2%
Migrant-to-adult survival	4.0 - 7.1%	0.7 - 2.6%	2.2 - 8.0%

* Observed from Icicle Creek Index Area 1986-89.

** Estimated from Table 19, density according to HQI rating of excellent, because most ocean-type chinook habitat while ranking poor to fair in late summer, ranks good to excellent in spring when shoreline vegetation is flooded.

*** Wenatchee R. June densities minus July densities (Hillman and Chapman 1989).



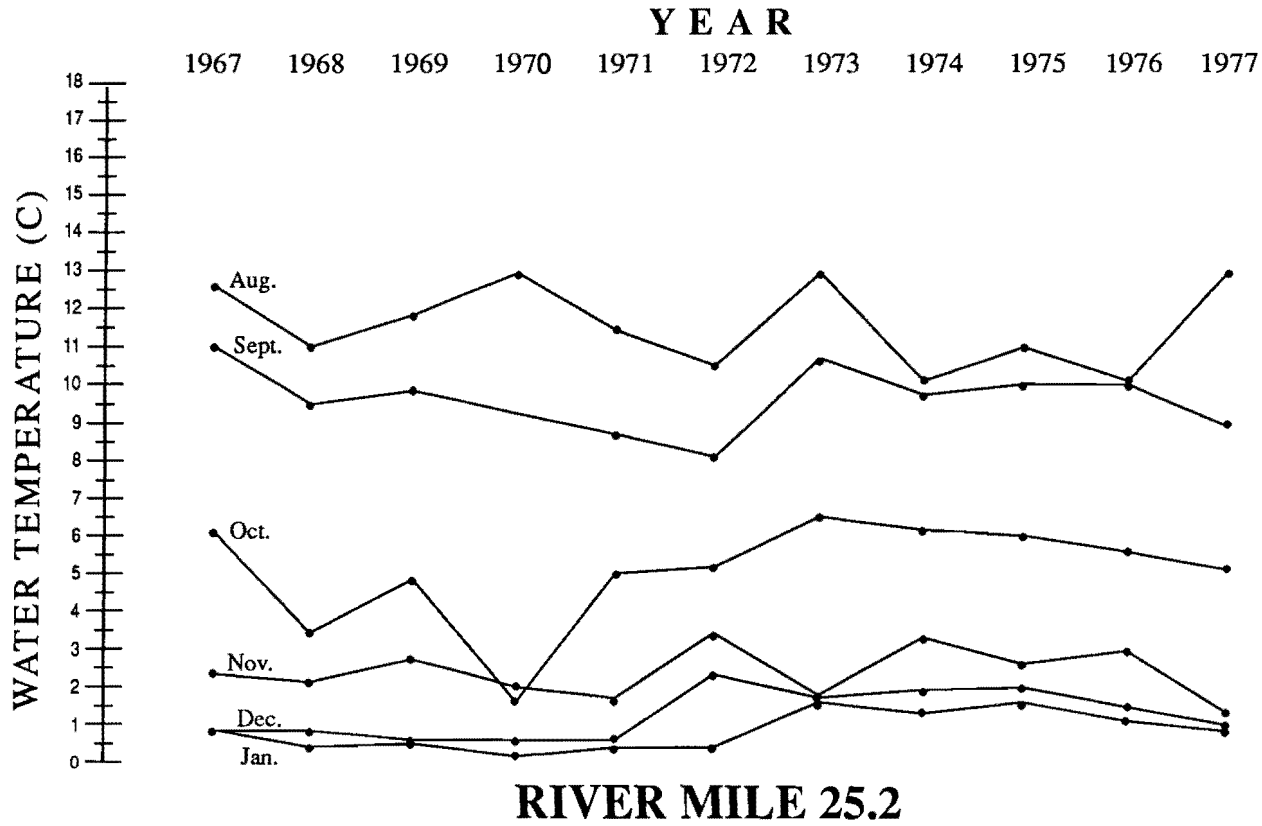


Fig. 20. Mean water temperatures (c) in the lower and upper Entiat River, August through January (see Appendix I for details).

Coho Salmon

Most coho salmon do not migrate far into fresh water to spawn. Historical abundance centered in lower Columbia River tributaries. The farthest cohos are known to have migrated in the Columbia River was to the Spokane River, 700 miles from the ocean (Fulton 1970). Cohos traveled almost as far to reach our streams. All of these runs had been drastically reduced or destroyed prior to completion of Grand Coulee Dam in 1941 by impassible dams, unscreened irrigation diversions, over-harvest, and robbing of millions of eggs for early hatcheries (Appendix J, Craig and Suomela 1941; Bryant and Parkhurst 1950).

In 1940 to 1943, when the GCFMP hatcheries became operational, only 64 native coho salmon were available for spawning, but only 8 females were spawned successfully. While the returns of their progeny showed promise, their unique genetic qualities were subsequently swamped by imported, late, short-run coastal stocks (Mullan 1984). Despite releases of 46 million juveniles during the period 1942 to 1975, and correction of causes of original depletion, naturally reproducing population were not re-established.

It is the nature of animals to penetrate into every habitat where they can eke out a living (Ricker 1972), and it is important to examine why coho salmon were originally abundant in the Methow River (Appendices G and J). Homeostatic migration (Chapter 4) is the movement between reproductive habitat and feeding habitat occurring with regular periodicity (Northcote 1978). Movement at some stage in this cycle is directed rather than a wandering or a passive drift, although these may form one leg of a migration. Production, of course, may be affected by limitations anywhere in the cycle (Northcote 1978).

Salmon are renowned for their homing abilities and the precise timing of their spawning migrations. In essence, a time-window exists for egg deposition in a specific site as water temperatures decrease from upstream to downstream each fall. Thresholds for normal development of chinook salmon eggs are 5.8° C (42.5° F) and 14.2° C (57.5° F) (Combs and Burrows 1957; Garling and Masterson 1985). Similar values for coho salmon are 2.0° C (35.6° F) and 8.0° C (46.4° F) (Tang et al. 1987). Hatching success declines acutely above and below these temperature ranges. Coho show greater tolerance to low incubation temperatures than chinook (Beacham and Murray 1990), which had 100% mortality at 1.7° C (Tang et al. 1987). Lethal temperatures effect the early embryonic stage of salmon eggs before the closure of the blastopore (e.g., 17.5 days at 5.6° C to 7 days at 13.9° C).

Historically, the Methow River primarily supported coho salmon, followed by steelhead, with some chinook salmon (Craig and Suomela 1941). These authors could find no evidence that the

chinook run consisted of anything but spring chinook, though conceding that some summer chinook may have spawned in the lower river. The spawning period for spring-run chinook in the Methow River is August through early September; summer/fall-run chinook spawn downstream October through early November (Fig. 21). Water temperatures in October are adequate for successful development of eggs, but generally too cold in November. On the other hand, apparently native coho salmon spawned successfully November through early December in the middle and upper river influenced by ground water (Figs. 22 and 23).

Addition of hatchery coho salmon juveniles did not negatively affect the growth or emigration of juvenile chinook salmon or steelhead in the Wenatchee River (Spaulding et al. 1989). Results were much the same from releases of coho salmon to the Icicle Creek Index Area (Chapter 4). Accordingly, we conclude that there are resources available for coho salmon in study streams.

Based on geographic distribution of past habitat (Fulton 1979), in terms of stream miles, 6,000-7,000 adult cohos may have originated in the Wenatchee River system; the Entiat, 9,000-13,000; and the Methow, 23,000-31,000 (Mullan 1984). Records of early hatcheries on the Methow River and catch and escapement estimates suggest maximum run size of 15,000-31,000 coho salmon (Mullan 1984; Appendix J). Based on yearling coho production of the Icicle Creek Index Area (216/ac and 199/ac) and rearing area of 1,200 ac within the downstream bounds of probable spawning areas in the Methow River, we crudely estimate smolt production at about one quarter million coho salmon, with smolt-to-adult survival of 6.0 to 12.0%. Naturally produced coho salmon in Oregon are about twice as viable as hatchery smolts (Emlen et al. 1990).

Rainbow/Steelhead (O. mykiss) (from Appendices H and K)

Steelhead differ from Pacific salmon in many ways, but are similar to Atlantic salmon. Steelhead smolts are usually larger (143 to 207 mm) and rear longer in freshwater (up to 7 years) than those of coho and chinook salmon (70-120 mm for those that rear a year or longer in freshwater). Unlike salmon, hatchery smolts evidently are as viable as naturally produced smolts (mean, 6.4%; range, 1.3-14.3%). Releases in recent years of large subyearling steelhead smolts (5-7/lb), with superior total survival, circumvents the high natural mortality of wild juveniles caused by extended freshwater residency.

How long steelhead stay in mid-Columbia River tributaries is mostly a function of water temperature (Fig. 24). Smoltification may occur in 2 years in warmer mainstems or may take 7 years in cold headwaters. This results, together with 1-3 years in the ocean, in as many as 10 overlapping brood years and 16 age classes. Most fish that do not emigrate downstream early in life from the coldest environments are thermally-fated to a resident (rainbow

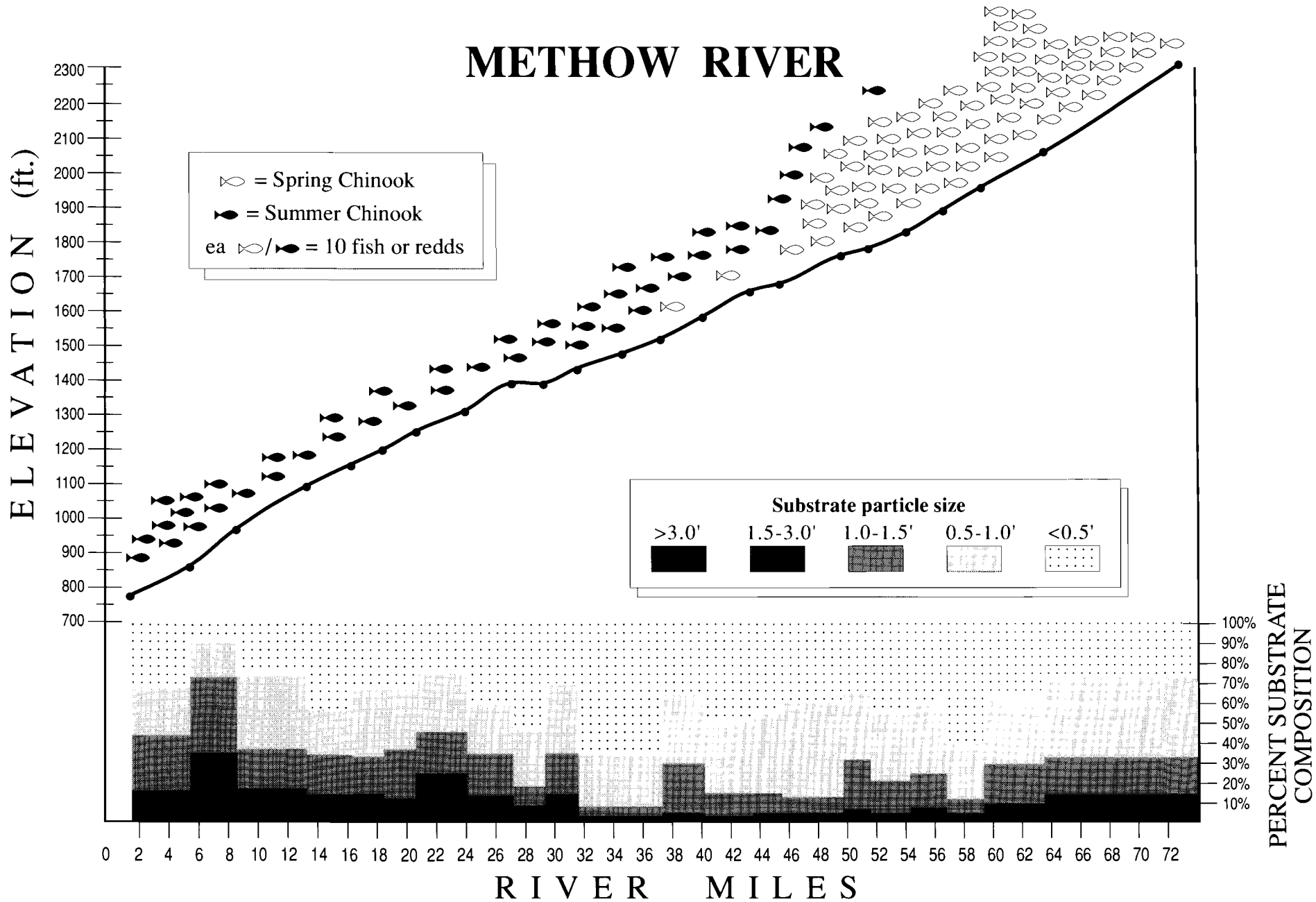


Figure 21. Relationship between gradient, substrate, and chinook salmon spawning (Kohn 1987, 1988, 1989) in the Methow River.

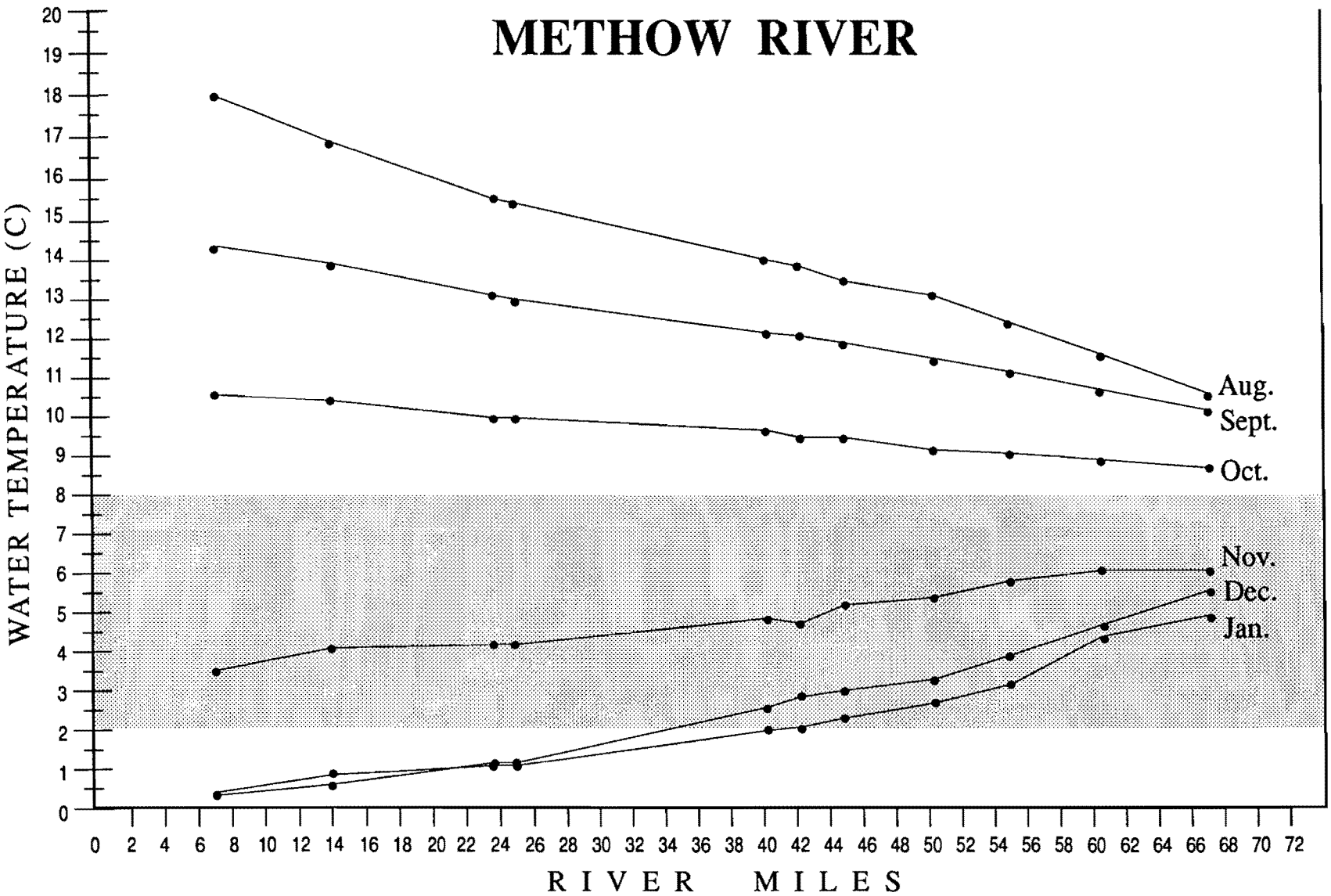


Fig. 22. Mean water temperatures (c) in the Methow River, August through January (see Appendix I for details). Thresholds for normal development of coho salmon eggs - 2.0c to 8.0c - are indicated by shading.

Fig. 23. A seine haul of 255 coho salmon from the Methow River, November 27, 1910. The eggs were hatched in the nearby hatchery at Twisp and the fry released back to the Methow River. Almost 12 million coho eggs were taken 1904 to 1914, representing an average of 360 females per year (3,000 eggs/female). In 1915, a dam without a fishway was constructed in the lower river, and the hatchery moved downstream. Three and one-half million coho eggs were taken from 1915 to 1920. The average of 194 brood females/year suggest a 50% decline in the runs of coho between the periods, 1904 to 1914 and 1915 to 1920. No coho eggs were taken after 1920. (Photo courtesy of Barbara Duffy and Dick Webb and the Shafer Museum, Winthrop, WA).

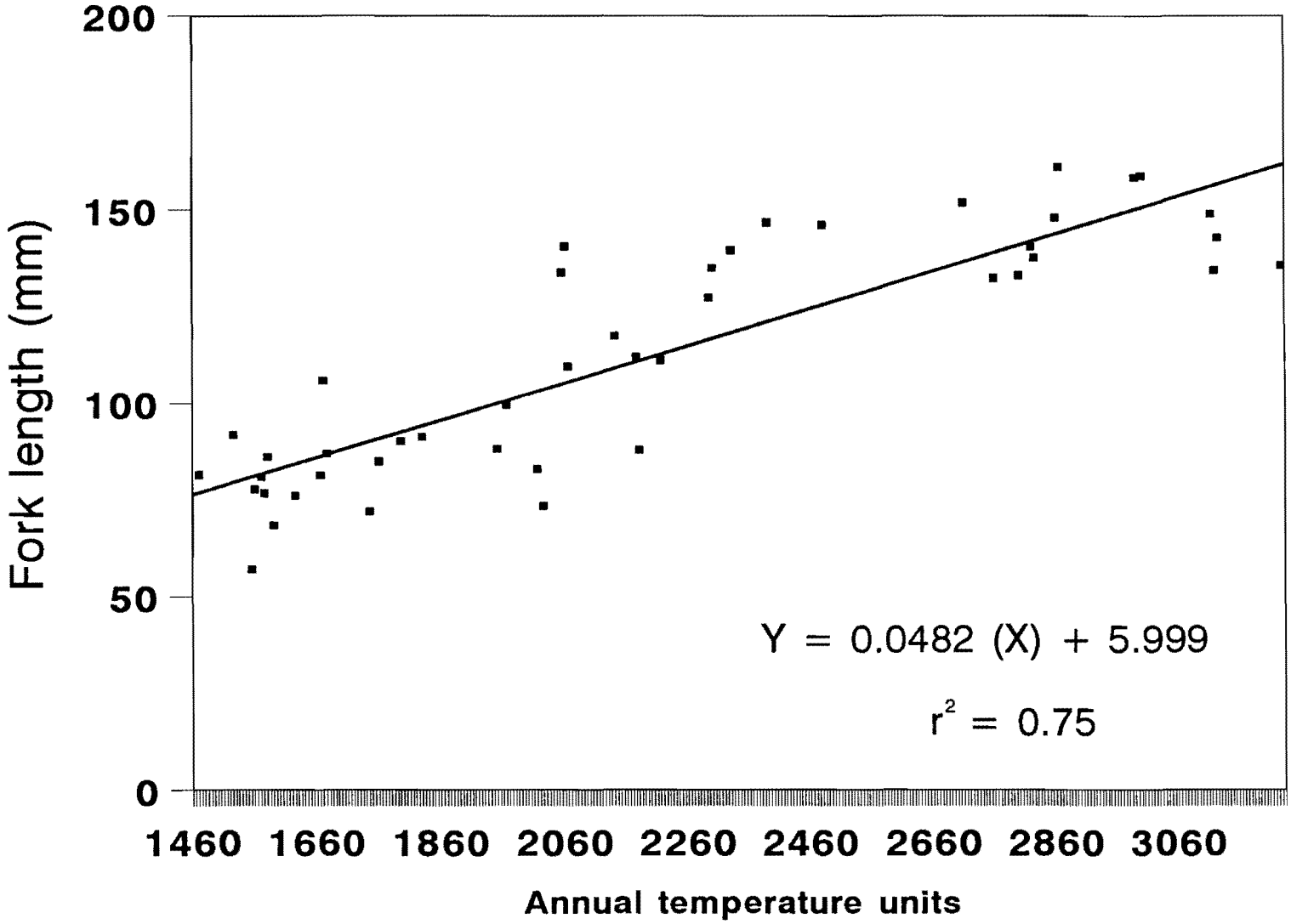


Fig. 24 Annual temperature units compared to length of age - 1+ O. mykiss, Methow River drainage. Age - 1+ fish are used in this comparison because they are nearing the end of their second year of growth and are the first age class that will smolt the following spring if they attain lengths of 143 to 207 mm.

trout) life history regardless of whether they were the progeny of anadromous or resident parents. O. mykiss may hedge its bets also by spawning over a 3 to 4 month period, both before and after spring runoff.

O. mykiss is also an extremely adaptable species in much of the developed world where it has been introduced. Many stocks, strains, and life forms are recognized, and the species has become the aquatic counterpart to the white rat in laboratory research.

Polymorphism, as applied to arctic char, is equally applicable to summer steelhead in the mid-Columbia River, where distribution ranges throughout thermal bounds. Upstream distribution is limited by low heat budgets (about 1,600 TUs). The response of steelhead to these cold temperatures is residualism, presumably because slow growth results in maturity before smoltification for all but a few of the fastest growing individuals. These headwater rainbow trout contribute to anadromy by emigration or displacement to lower reaches where better growth enables some to attain the requisite size for smoltification, while others (virtually all males) retain a fluvial life history regardless of size. Their contribution to anadromy probably is low when steelhead predominate in lower stream reaches and high when they do not. We believe that this life history plasticity explains why headwater populations above a barrier in Icicle Creek since 1940 continue to produce steelhead (Chapter 4); why a 500-year flood (1948) had no discernable effect on subsequent recruitment; and why dam blockage of the Methow River for 14 years exterminated coho salmon but not steelhead.

Although salmon are more advanced phylogenetically, the steelhead's life history is more fail-safe when habitat or populations are perturbed. Stochastic effects of environmental variability that would extirpate a salmon population affect steelhead far less. Indeed, preserved as headwater rainbow trout, steelhead above Grand Coulee Dam may not yet be extinct.

Estimates of escapement became possible after the completion of Rock Island Dam in 1933. Because only four data points were available before Grand Coulee Dam began reducing smolt survival in 1937, a spawner-recruit curve was not fitted. Annual mean number of steelhead recruits before damming was 14,495, 2.33 times the mean of 6,218 immediately after (1940-43) damming. Recruits at maximum sustained yield (MSY) and escapement were 19,169 and 7,126 fish, respectively, from 1940 to 1954 according to Beverton-Holt-curve analysis; Ricker curve equivalents were 16,041 and 4,904 fish.

The premise of the GCFMP was that abundance of steelhead was limited by dams in the Wenatchee, Entiat, and Methow rivers. Our stock recruitment curves point to overfishing in the lower Columbia River. Considering all mortality, escapements of about 0.15 probably were common during the 20 years before the GCFMP.

Ricker's curve B indicates that at an exploitation rate of 0.85, recruit numbers should have stabilized at about one-third of MSY escapement; we show that runs tripled from 1940 to 1954 (Appendix H).

GCFMP translocation and hatchery supplementation failed to increase the number of recruits contrary to common belief. Indeed, the poorest recruitment occurred during the GCFMP. The failure stemmed from high losses of translocated broodstock, both in hatcheries and in streams.

In the post-hydroelectric development period (1979-89) wild steelhead have not been able to sustain themselves at any level using Ricker curve analysis. In the Beverton-Holt model, the same number of steelhead spawners over the lower range of escapements yield a few more recruits. At present, passage and harvest mortalities drive wild steelhead escapements to below replacement levels. The success of hatchery steelhead, unlike the failed hatchery programs for salmon, which helped insure that wild chinook were not overharvested, surely is partially to blame. Since 1987, however, when all hatchery steelhead were adipose-clipped, wild fish have been protected from sport harvest.

Cutthroat, Bull, and Brook Trout (from Appendix K)

Sizes at given ages of Methow River cutthroat, bull, and brook trout are the lowest ever reported from streams elsewhere (Fig. 25). As with O. mykiss, growth declined with increasing elevation and decreasing temperature. Cutthroat, bull, and brook trout spawned upstream of the thermal limits of O. mykiss. Unlike mykiss, cutthroat and bull trout have adfluvial forms, which migrate from natal streams and return when they mature to spawn. In downstream reaches females of all trout species, in all cases, outnumbered males whereas the opposite was true in headwaters. This seems to increase fitness by placing females in the most productive, anadromous or adfluvial-inducing habitat.

Most fish examined had normal body condition factors ($K = W/L^3 \times 100$), ranging from 1.0 to 1.4, and were not starving. Aside from comparable lipid storage, endemic bull and cutthroat trout have lower thermal optima than O. mykiss. Therefore, the path was clear for some anadromous form of these species to penetrate the headwaters of the Columbia Basin in the early Pleistocene, where they endured multiple glacial periods and dispersed widely during post-glacial flooding. Anadromy was not well developed in these species and its loss can be attributed to inter-glacial dominance of O. mykiss which forced retreat of spawning populations to headwaters.

Bull trout diverged from a Dolly Varden type ancestor by evolving into a piscivore. Being the only apex predator in the

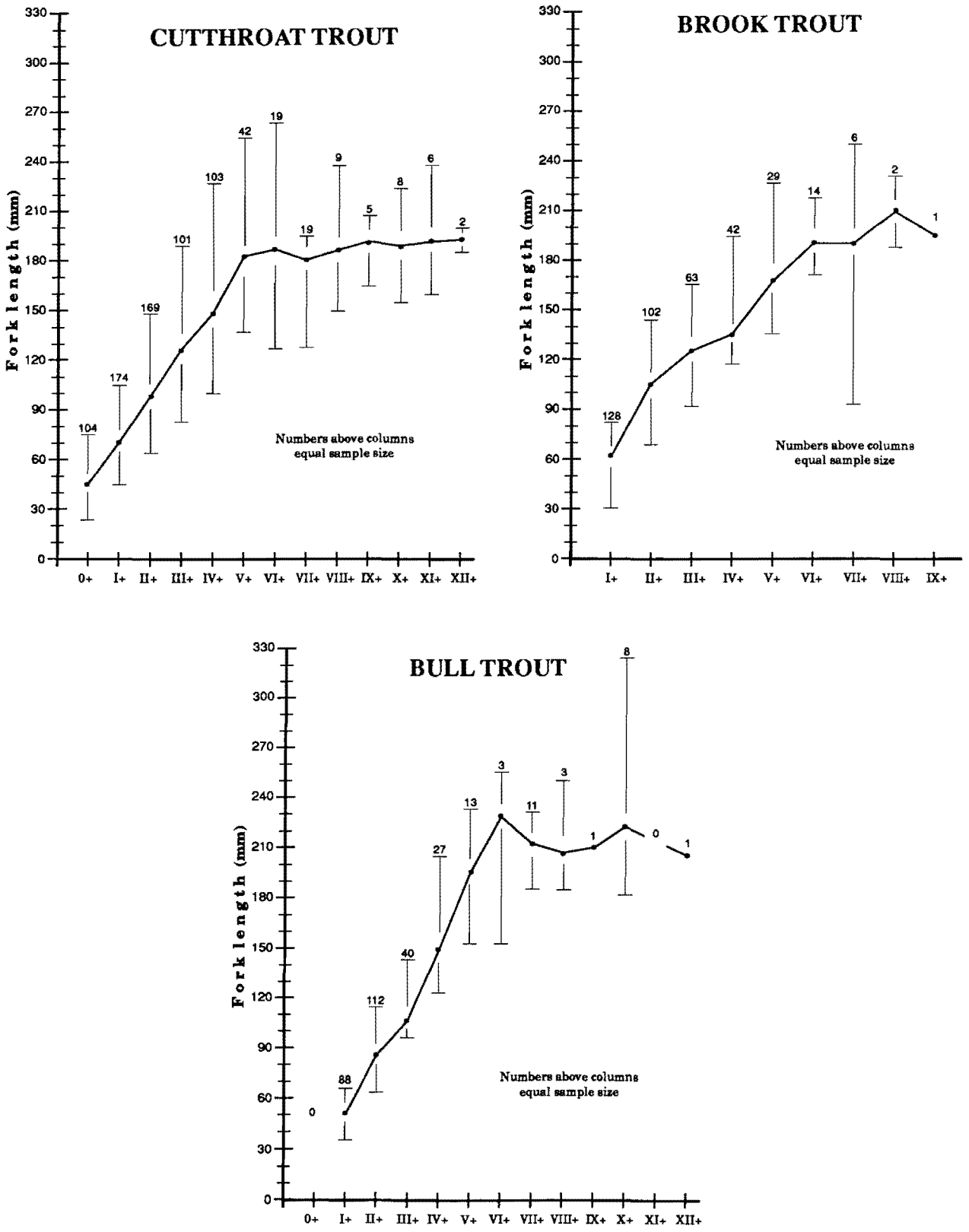


Fig. 25. Mean fork length (mm) and range at age for cutthroat, brook, and bull trout from the Methow River drainage.

fish community likely was an energetic advantage. In isolation from O. mykiss, cutthroat trout evolved into many diverse forms. Specialization always occurred in the absence of O. mykiss and cutthroat almost always disappeared wherever the two species came into contact. More contact occurred in the Wenatchee, Entiat, and Methow rivers. When the land rose following the melting of the ice mass, the resulting barrier falls halted re-intrusions of cutthroat and bull trout. Post-glacial flooding carried upriver populations of cutthroat and bull trout to Lake Chelan and barrier falls at the outlet precluded subsequent invasion of O. mykiss.

Increasing temperatures brought O. mykiss, which displaced cutthroat and bull trout below falls. A few historical notes suggest that some cutthroat did exist in the Methow River in those streams where the falls are found above the thermal minimum for O. mykiss. Stocking of westslope cutthroat in alpine lakes has resulted in the establishment of self-sustaining populations in every major sub-drainage. Bull trout have not been propagated and re-introduced above barrier falls. Eleven breeding populations now occupy only 1.4% (29 ac of stream) of the Methow River watershed. They appear to have disappeared from Lake Chelan in recent years following introduction of kokanee (O. nerka) and O. mykiss in 1917.

Gradient and temperature have been cited as the major factors responsible for longitudinal succession of salmonids. Our results show that O. mykiss excludes the first two or three age classes of cutthroat, brook, and bull trout up to where temperatures decline to about 1,600 TUs, regardless of gradient.

Bull, brook, and cutthroat trout appear to have similar temperature preferences. We suspect that factors other than temperature determine the outcome of their competition. Bull and cutthroat trout evolved together and competition is minimized by ecological segregation. Nevertheless, densities and biomass of allopatric populations of cutthroat in the headwaters of Wolf Creek and the Twisp River were markedly greater than those produced in sympatry with bull trout a short distance downstream (Chapter 3, Table 8).

Brook and bull trout may occupy the same habitat and hybridize extensively, leading to extirpation of bull trout. This may have happened in Eightmile and Boulder creeks in the Methow River, especially considering that bull trout require 6-9 years to reach sexual maturity versus 2-4 years for book trout. Bull trout may require larger streams than brook or cutthroat trout because populations terminated in headwater reaches not blocked by barriers.

Temperature preference for bull trout has not been determined, but it is reasonable from their elevational distribution with brook and cutthroat trout that thermal preferences are similar for all three species. In allopatry they are capable of inhabiting the

entire Methow River watershed, and their confinement to headwaters represents interactive niche compression.

The outcome of interactions apparently is decided within the first few weeks of emergence because fry of the subordinate species are seldom found with the dominant species, though larger individuals occur routinely. Social status, which is nearly always governed by body size, is believed to determine the outcome of competition. Logically, social equality is a requisite for cutthroat-O. mykiss interbreeding, which likely is tied to temperatures favoring neither species. In most watersheds, reaches of thermal neutrality are probably rare, which may answer the question of why O. mykiss and O. c. clarki can maintain species integrity in view of their propensity to hybridize. The narrow zones where bull and brook trout are sympatric with O. mykiss is the analog to the O. mykiss-cutthroat hybridization zone. Preferred temperature may increase with ontogeny of cutthroat and bull trout, which may explain how fluvial and adfluvial fish can live in sympatry with steelhead parr. Achieving critical size from extended rearing in isolation is first required, however.

Replacement of O. mykiss by brook, bull, or cutthroat trout has not been documented to our knowledge. However, the release of cutthroat fry in upper Goat Creek in 1985, led to the replacement of O. mykiss by cutthroat about 1.2 mi downstream of the release site. Although there are no barriers to upstream movement, the cutthroat have not extended their range into the bull trout population upstream. Another example is the convergence of a pure O. mykiss population in Crater Creek with a pure population of cutthroat in Martin Creek at an impassable falls. Successionally, cutthroat dominated for a short distance downstream, succeeded by an equally short hybrid zone, downstream from which only O. mykiss was found. Further, a release of brook trout fry in 1933 apparently caused the elimination of O. mykiss from the Middle Fork of Beaver Creek. Although a proliferation of headwater plants of cutthroat and brook trout in the Methow River has resulted in the contraction of O. mykiss distribution, the net effect has been minimal because temperatures generally favor O. mykiss.

We predict that if stream temperatures rise the projected 4-5° C by mid-21st century, due to global warming, cutthroat and bull trout in the Methow River basin will be replaced by O. mykiss (with trade-offs for mykiss downstream), except for populations above falls.

Mountain Whitefish

Mountain whitefish belong to the subfamily Coregoninae of the family Salmonidae. They are the most abundant salmonid in our streams in terms of biomass (Fig. 10). A large fraction of the whitefish biomass is in slow-growing, older, and larger

individuals, although we aged only a few individuals (Fig. 26). Most large whitefish used large pools, runs, and glides, which we sampled by snorkeling only. Adults observed snorkeling outnumbered juveniles (presence of parr marks) almost two to one (2,852 adults, 1,504 juveniles).

Mountain whitefish spawn in fall and broadcast their eggs (Daily 1971). The eggs are adapted during development to temperatures of 0.6-6.1° C (33-43° F). They hatch in about 5 months at 1.7° C (35° F). Hatching success declines acutely above 6.1° C (43° F) and virtually ceases at 10.0° C (50° F) (Rajagopal 1979). Ideal temperatures for incubation of whitefish eggs prevail in the Wenatchee, Entiat, and Methow rivers.

Stream populations of mountain whitefish are usually considered sedentary, although fish may move into tributary streams from large rivers to spawn (Daily 1971). An exception to this is the Clearwater River, Idaho. Adult whitefish moved 55 mi upstream in spring and early summer, remained in the upper reaches until spawning in November, then moved downstream to overwinter in deep pools of the lower river (Pettit and Wallace 1975).

Fish migrating up the Wenatchee River were counted at Tumwater Dam (RM 32.7) for 15 years between 1935 and 1973. Fewer than 30 mountain whitefish were observed in any year. However, about 2,000 whitefish are harvested each winter in the lower Wenatchee River, some of which are suspected of originating in the downstream reservoir (Mullan et al. 1986). A similar fishery exists on the Methow River, but runs are purported to be much reduced since completion of the receiving Wells Reservoir in 1967 (Williams 1975).

Mountain whitefish and trout and salmon primarily eat aquatic insects (Daily 1971). Whitefish graze the bottom while trout and salmon feed from the drift. Despite such segregation, biomass of trout increases dramatically in headwaters (Fig. 10) when whitefish are excluded because of small stream size.

Other Species

Like most western streams, mid-Columbia River tributaries contain sculpin, dace, sucker, and other fish types, in addition to salmonids. Species diversity increases downstream with increasing stream size and water temperature (Li 1975). This occurs through the process of species addition rather than species replacement, except for trout in headwaters.

Fish with higher metabolic rates are found in the cooler, swifter water upstream and those with lower metabolic rates, downstream (Li 1975). In the mid-Columbia there tends to be three fish zones: (1) the trout zone at high elevations in headwaters,

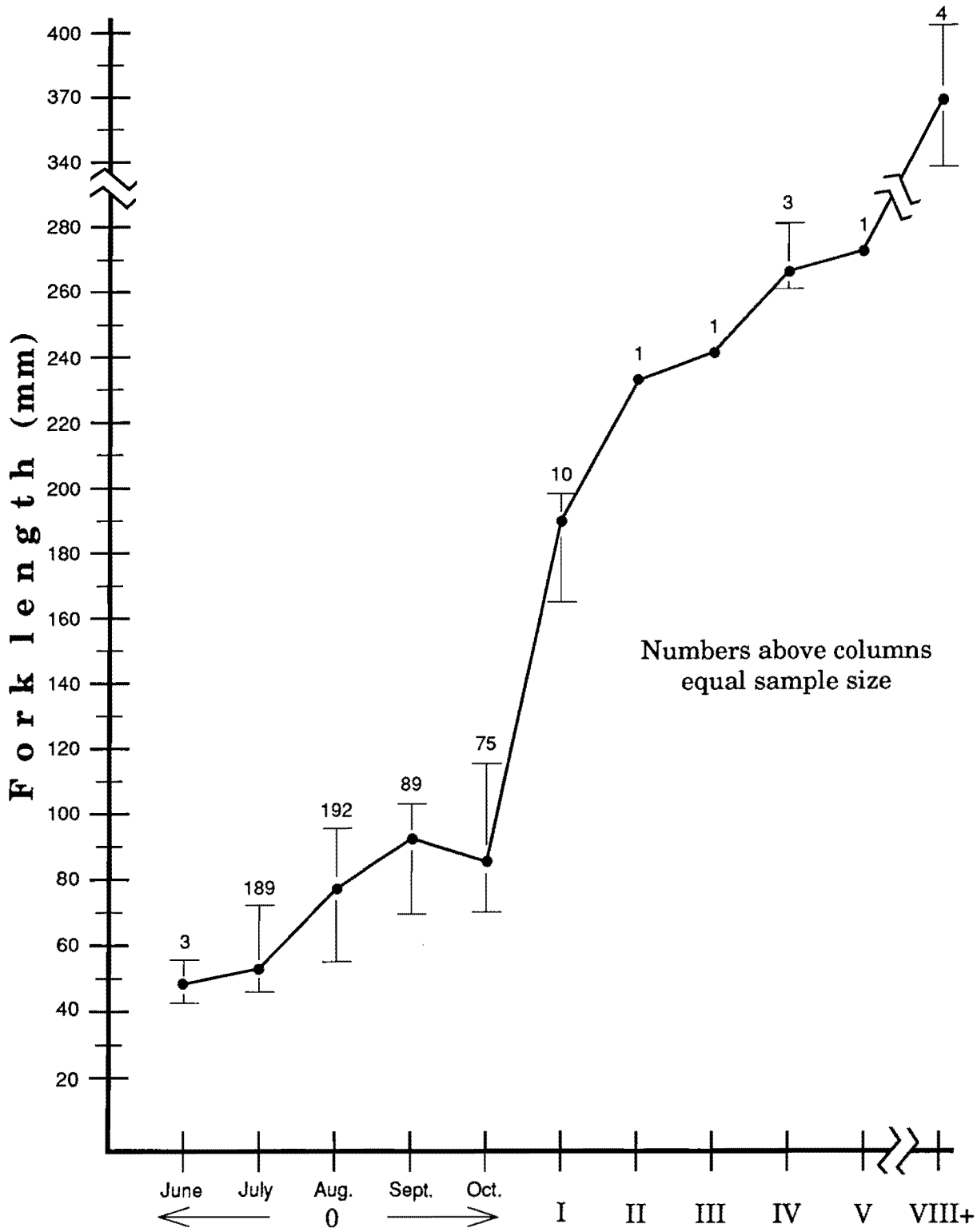


Fig. 26 Mean fork length (mm) and range at age for mountain whitefish. A large fraction of mountain whitefish biomass in study streams is in slow-growing, older, and larger individuals, though we aged only a few fish as shown. Most large whitefish used large pools, runs, and glides, which we mainly sampled by snorkling. Adults (age -3+) observed snorkling outnumbered juveniles (presence of parr marks) almost two to one (2,852 adults; 1,504 juveniles). (Age -0 mountain whitefish shown from Icicle Creek Index Area.)

(2) the salmon-steelhead-whitefish zone in the larger, warmer mid-elevation streams, and (3) the sucker-chub-shiner-squawfish complex of Columbia River impoundments. Fish zones define a particular set of environmental conditions and fish species that are in fact a continuum of change as one goes downstream (Moyle 1975). Because the fish zones are part of a continuum, there are areas of overlap. In particular, rainbow trout, which dominate the lower portion of the trout zone, are also a part of the salmon-steelhead-whitefish zone, and suckers are a component of the lower portion of the salmon-steelhead-whitefish zone as well as mainstem impoundments.

Sculpins up to 152 mm in length are common inhabitants of the salmon-steelhead-whitefish zone and feed particularly on benthic invertebrates (Moyle 1977). They are adept at capturing prey while under rocks, where other fish are excluded (Moyle 1975). Sculpins larger than 85 mm prey heavily at night on small (<55 mm) chinook salmon and steelhead fry in late spring early summer in the Wenatchee River (Hillman 1989). Sculpins also prey on their own young (Chapman and Questorff 1938; Moyle 1975).

Longnose dace as large as sculpins (152 mm) are also ubiquitous in the salmon-steelhead-whitefish zone, but relative abundance is highest in warmer downstream areas. They prefer summer temperatures of 13 to 21° C (Wydoski and Whitney 1979). The larger dace are also adapted to living among rocks on the bottom of swift water, but small juveniles are pelagic and found only in quiet, shallow water (Wydoski and Whitney 1979). Food consists of benthic invertebrates taken by browsing rather than by ambush as in the case of sculpin (Moyle 1975).

Largescale suckers are abundant in deep pools and in higher-velocity runs and riffles in the Wenatchee, Entiat and Methow rivers. There are few suckers under 300 mm and they are commonly in clusters of up to several hundred individuals. These observations, and those of the bridgelip sucker spawning in Icicle Creek (Chapter 4), suggest that many of the suckers may originate in Columbia River impoundments. Suckers graze on algae and detritus (Moyle 1975; Wydoski and Whitney 1979).

Northern squawfish are only occasionally observed, usually as solitary individuals 250-300 mm in length, and frequently in a cluster of suckers. They are a common inhabitant of both Lake Wenatchee and Columbia River impoundments. Squawfish are omnivorous.

Redside shiners are abundant in mid-Columbia River impoundments and immigrate into the lower salmon-steelhead-whitefish zone in summer. They draw upon the same stream resources during the summer as juvenile chinook salmon, and they displace juvenile salmon from rearing space at warm temperatures (>15° C) (Hillman 1991). The maximum length attained by redside shiners is about 178 mm, but most are less than 127 mm.

Conclusions

Factors that regulate populations of stream-dwelling fishes are complex and confusing (Li 1975; Hearn 1987; Fausch et al. 1988). Stream salmonids may be limited at different times by competition, predation, or climatic events such as droughts or floods. When populations are limited by stochastic processes, competition is of little importance or nonexistent (Hearn 1987).

Competition is an important problem given the current emphasis in supplementation of natural populations of anadromous salmonids with hatchery fish, or the reintroduction of coho salmon in study streams.

Because most of the fish species (brook trout are an exception) in our streams evolved in sympatry, we assume that they avoid competition by partitioning resources. What this means is that reintroducing coho salmon will not result in the extirpation of any species; it does not mean there will be no effects. Total salmonid production should increase, while single species production should decline as the result of niche compression (Nilsson 1967).

Each species is best adapted to only a subset of all the conditions within a stream. The total habitat used by a species can be divided into preferred and less preferred areas, the latter being areas used by a species but affording less than optimal conditions (Hearn 1988). Trout and salmon fit into the scheme of resource partitioning by being strongly territorial and aggressive drift feeders. Reintroducing coho salmon, or adding hatchery salmonids, provides a basis for competitive interaction in less preferred habitat areas limiting population densities of the less adapted competitor species.

Moore et al. (1983) depicted niche compression by showing that brook trout standing crops increased after rainbow trout were removed (also, see Appendix K). Seegrist and Gard (1972) showed that winter floods decimated developing eggs of fall-spawning brook trout. Because of reduced competition by young brook trout, survival of fry of spring-spawned rainbow trout increased in years following winter floods. Conversely, spring floods destroyed rainbow eggs, thereby enhancing survival of young brook trout. Conceivably, the periodic fall dewatering of the upper Methow River, where most spring chinook salmon spawn in late summer (Figs. 4, bottom photo, and 21), may confer a recruitment advantage if most chinook eggs survive in under gravel flow areas while resident fishes are decimated.

The role of competition in community organization remains unclear and controversial (Li 1975; Hearn 1988). That little or no effects result from competition strains ecological principles, the progressive replacement of trout species in headwater streams, and

the negative interaction between redside shiners and juvenile salmon. We're not saying that competition is everything. We're saying that it is very definitely something in some situations--like in superimposing hordes of hatchery fish on wild fish, but more on that next.

CHAPTER 6

IMPACTS OF SETTLEMENT ON PRODUCTION AND HABITAT

Streams can be dammed and channelized, their flood plains developed, their waters contaminated, abstracted, and enriched by human activities. In addition, any activity within a drainage basin, as well as deposition of pollutants and radioactivity from the atmosphere, may be reflected in the stream ecosystem. Each impact evokes a unique response. It is difficult to assign a response by the fish in a stream ecosystem to a specific impact because multiple impacts are usually occurring simultaneously.

The purpose of this chapter is to assess the most probable effects of human activity on mid-Columbia watersheds from case histories and related information.

Mining

Numerous mining claims have been located and maintained since the 1870s, but available information suggests minimal production in area drainages. The record is fragmentary but, at most, only temporary effects on a few streams are indicated--e.g., stream bed disruption from placer gold-mining in Peshastin Creek from 1860 to 1940 (NPPC 1986; USFS 1989, 1990). (One exception, the Holden mine in the Chelan River drainage, has left 80 ac of toxic tailings along Railroad Creek, Fig. 2).

Grazing

Grazing on the Wenatchee River drainage was once much more extensive than today. The Little Wenatchee River and Mission Creek watersheds (Appendix D) show the disparity in grazing over time in the high country and in the foothills where homesteaders settled.

The mountainous Little Wenatchee River watershed makes up 7.5% (63,350 ac; 97% USFS) of the Wenatchee River drainage, and it contributes 15% of the Wenatchee River flow. Thirty-four hundred sheep for two months overgrazed 205 ac in the 1930s (Putnam 1936). Even in burned areas below 3,500 ft elevation, sheep grazing caused no apparent damage because vegetation returned rapidly after each fire and stabilized exposed soil. Conditions conducive to

accelerated erosion occurred along sheep trailways in old burns above 3,500 ft. Growing conditions are unfavorable at such elevations and fires are unusually destructive. Areas severely burned were too small and widely dispersed to have perceptibly increased stream sediment loads (Putnam 1936). Today, 61% of the watershed is in wilderness and there is little or no grazing by domestic livestock.

Mission Creek represents the worse scenario for human influence on a subbasin of the Wenatchee River. The watershed of this tributary covers 6% of the Wenatchee drainage, but it contributes less than 1% of the mainstem flow at RM 10.5. However, Mission Creek is one of two major sources that deliver sediments to the Wenatchee River. Geologic and soil conditions in the watershed are extremely unstable because the predominant rock formation is Swauk sandstone (Fig. 27), which is not widespread throughout the Wenatchee River drainage.

The effects of grazing cannot be separated from logging, roading, and other land disturbances associated with early 1900 settlement in the Mission Creek watershed. There is no doubt, however, that grazing was a factor in destabilizing a sensitive watershed. In 1931, 7,200 sheep grazed the watershed and five times this number were trailed through the area (Ciolek 1975).

The first recorded flood to damage the town of Cashmere at the mouth of Mission Creek occurred in 1933 (Fig. 28). The 1933 flood damage was the result of deplorable land use (SCS 1938). Mission Creek was then channelized. Between 1927 and 1946, all but 11,000 ac of the watershed was acquired by the US Forest Service (USFS). In 1953 Mission Creek was chosen as one of 50 in the United States to demonstrate watershed restoration. The program included construction of trail (28 mi) for fire protection; installation of stock fence (10 mi); channel clearing (10 mi); stream bank stabilization (6 mi); roadside erosion control (3 mi); contour furrowing and revegetation (400 ac); 2 fire protection ponds; and closure of 71% of the watershed to grazing (Ciolek 1975). Today, grazing is limited to an occasional urban horse, buffalo, or llama.

The first settlers in the Entiat valley came in 1887 (Kerr 1980). Each settler had a few cattle and horses that were allowed to graze freely. By 1900, hogs grazed in the foothills and sheep at higher elevations. Maximum grazing intensity in the lower valley has been estimated at 1,000 cattle, 400 horses, and 150 hogs (USDA 1979). As many as 13,000 sheep ranged the alpine country.

The first settlers to the Methow Valley and the adjacent Okanogan Valley engaged mainly in livestock grazing. In 1903, the county assessor reported 16,711 cattle (Kerr 1980). Unlike in the sharply incised Wenatchee and Entiat valleys, where less than 20% of the land was suitable for grazing, glaciation smoothed the uplands of the Methow and Okanogan valleys so that half of the area

Fig. 27. Top, geologic and soil conditions in the Mission Creek watershed are extremely unstable because the predominant rock formation is Swauk Sandstone shown in this U.S. Forest Service photo. Bottom, photo by U.S.F.S. showing the erosion of Swauk sandstone soils in the 1933 Mission Creek flood.

Fig. 28. Top, photo by U.S. Forest Service in 1933 showing flood damage of Mission Creek as a result of poor land use in a naturally unstable watershed. Bottom, photo in 1990 of the same area (arrows point to tree and house in both photos) contrasts sharply with that of 57 years ago. Riparian vegetation along creek now obstructs original open vista for camera, while vegetation on hillsides has increased markedly.

could be used as rangeland (PNRBC 1977; USFS 1989). Intensity of grazing--especially sheep--in the Methow and Okanogan valleys has also diminished from earlier years.

Generally, the greater the extent of grazing in a watershed, the greater the potential for adverse fishery impacts. We can surmise that heavy grazing in early years did affect the vegetation, soil, and water, but we cannot assess the extent of the effect. We see little overall damage to streams and riparian vegetation from past or present grazing today. Currently, no rangelands in the Wenatchee and Okanogan National Forests, which comprise 80% of the study watersheds, are classified as being in unsatisfactory condition. In fact, range conditions are regarded as improving and are only 60-70% of authorized stocking (animal unit months) (USFS 1989, 1990). In contrast, about 60% of the private bottomlands used for grazing in the Methow Valley have erosion problems (PNRBC 1977). Stream bank sloughing and cutting was greatest in these cattle-grazed pastures.

Logging and Roads

Logging may impact streams by accelerating soil erosion, increasing nutrients and temperature, decreasing dissolved oxygen, increasing discharge, and altering stream morphology (Everest et al. 1987a; Hartman et al. 1987). The type, intensity, and location of logging determines the extent of impact.

Some 80% of each study watershed is in national forest. From 1910 until about 1955, the common practice was to selectively remove the largest, most valuable trees. Partial cuts of less valuable trees and clearcutting followed. The heaviest logging occurred over the last decade. About 0.06% of the watersheds were logged annually (No-Change-Alternative, Wenatchee and Okanogan National Forest management plans, USFS 1989, 1990).

Investigations throughout the Pacific Northwest show that logging roads are a major contributor of sediments to streams. When the percent of road area in the Clearwater River, Washington, exceeded two mi of road/mi^2 of basin, sediment began to accumulate in streambed gravels (Cedarholm et al. 1980). The Clearwater drainage is characterized by soft rock subject to crumbling under the heavy weights hauled on logging roads. The Wenatchee, Entiat, and Methow drainages have 1.25 mi of road/mi^2 of watershed; 15 to 20% are paved, 30 to 50% have restricted vehicular traffic, and the drainages are characterized by rock not easily pulverized by vehicle traffic (USFS 1989, 1990).

Rainy Creek is a subdrainage (10,733 ac) of the Little Wenatchee River (Appendix D). Between 1953 and 1976, 13.4% of the watershed was logged, or 0.6% annually. There are 10.3 mi of logging roads, or an average of 0.6 mi/mi^2 of basin, of which 80%

closely parallels Rainy Creek. No effects on the benthic macroinvertebrates or on water temperature in Rainy Creek could be detected from logging and logging roads in 1975-76 (Wood 1977). At this time more than 25% of the 1.3 mi^2 area examined had been recently clearcut and it contained over 2.0 mi^2 of logging roads/mi^2 of basin.

Lack of impact in Rainy Creek was attributed to the small area of clearcuts (average, 26 ac; range 1-125), the yarding of felled timber away from the water course, the use of riparian buffer strips, and the high flushing rate of the stream. Although not mentioned as a modifying factor, the soils are coarse and resisted erosion (Putnam 1936; Mullan 1986).

Peshastin Creek is a tributary of the Wenatchee River (Appendix D). Water temperature, turbidity, and sediment production were examined in five logged subwatersheds (85 to 2,422 ac) and a nearby control subwatershed (1,370 ac) during 3 prelogging and 3 postlogging years (1978 to 1983) (Fowler et al. 1988). Area of subwatersheds logged ranged between 22 and 47%. Stream temperatures were relatively unaffected. Stream turbidity and sediment deposition increased during road construction, but declined to near background levels in 2 years.

We performed a Cumulative Watershed Effects Risk (CWE Risk) simulation (Klock 1985) on four watersheds (Appendix L).

About 7.9 mi^2 of the Meadow Crest watershed consist of checkerboard federal, state, and private holdings. It was essentially pristine until the late 1950s. About 70% of the original forest was cut in the next 25 years. CWE Risk was moderate compared to the risk expected from natural hydrologic events. Rapid hydrologic recovery following years of heavy timber harvest and road construction of about 3.4 mi/mi^2 was attributed to stable soils, aggressive reforestation, vigorous natural regeneration, dispersed cutting, and favorable moisture regime (Appendix L).

In the Thompson Creek watershed, private timber had been cut in 39% of upper areas (1.9 mi^2) by 1983. A proposed timber sale at mid-elevations on federal land indicated little CWE Risk until logging on private lands further upstream was factored into the model. If the sale was delayed for four years, the model predicted only moderate accelerated soil erosion. Soils and precipitation were much less favorable to hydrologic recovery of Thomson Creek watershed than of Meadow Crest watershed (Appendix L).

Two subwatersheds, one public and one private, of the Mission Creek drainage, previously described, were also examined. CWE Risk was moderately greater than expected from natural hydrologic events for one year after road construction and for two years after initial harvest on the public watershed (Appendix L). The size of

public unit, winter logging, location of sale relative to topography and drainage boundaries, the eight-year time span between road construction and logging--all were factors contributing to low CWE Risk.

Worst-case risk was predicted for the privately owned subwatershed in the Mission Creek drainage. Harvest re-entry to previously logged areas caused a marked increase in CWE Risk in one year (Appendix L). Quasi-hydrologic recovery required 10 years.

CWE Risk simulation (Appendix L) suggests that the rate of vegetation regeneration is largely a function of precipitation. Precipitation is adequate for rapid regeneration of vegetation in all but the lower-elevation foothills of the Wenatchee, Entiat, and Methow basins where tributary streams are limited and small (e.g., Mission Creek).

None of these data is convincing alone, but together they indicate that short-term habitat damage, such as inflicted by road construction and logging (Hall et al. 1987; Hartman et al. 1987; Watts 1988), has not been a widespread problem for salmonids in area streams. Low impact as a result of low forest cutting gains credence because national watershed areas retain about 38% of their old growth forests (USFS 1989, 1990). Elsewhere in the Pacific Northwest, old growth forests are near the point of vanishing, as recent controversies on the Northern spotted owl have made clear.

Wildfire

In 1970, wildfire destroyed 58,000 ac of vegetation within the Entiat River watershed (Helvey 1980). Although efforts to re-establish vegetation began immediately, high intensity rainstorms in 1972 and 1974 caused massive erosion and flooding. Houses, bridges, roads, irrigation diversions, and fish habitat were destroyed. Large areas of stream bank vegetation and adjacent land were lost. Four people died in one massive mud slide.

Wildfires occurred naturally in north central Washington long before humans became a major factor in the ecosystem (Helvey 1980). Wildfire in 1970, 1976, and 1988 burned 62% of the Entiat River watershed. Although their frequency has decreased with modern fire-suppression efforts, wildfires will continue to destroy vegetation in the Entiat watershed whenever the climatic conditions culminating in past fires are repeated (Helvey 1980). Fire, which destroys ground-stabilizing vegetation, will cause sedimentation of streams in the future.

Naturally evolved plant and fish communities are not delicately balanced; they are quite stable and have much resilience to change. Coho salmon production in streams directly affected by the 1980 cataclysmic eruption of Mount St. Helens, Washington, was

equal to or greater than in unaffected streams three to six years later (Bisson et al. 1988). The Entiat River watershed is well on the road to recovery from effects of the 1970 fire. The drainage of the Mad River (Appendix D), a major tributary of the Entiat, scorched by a catastrophic fire in the 1880s, now reveals only old fire scars and charred wood on the forest floor. The Mad River itself is essentially pristine.

Human influence on the natural fire cycle of the Wenatchee, Entiat, Methow watersheds presents a dilemma. The Indians maintained their berrying and hunting areas by burning encroaching vegetation (Appendix G). In the early 1900s, the Forest Service began suppressing all fires. Increasingly, fire suppression over the past 80 years has excluded wildfire from forested areas that would have otherwise burned. Accumulated fuels have increased and vegetative cover has changed from open stands of fire-tolerant species to dense thickets of less fire-tolerant species (Fig. 29). These changes result in more large, catastrophic wildfires (USFS 1989).

The frequency of wildfire in the Wenatchee NF, which includes the Wenatchee and Entiat rivers, is higher than in the Okanogan NF, which includes the Methow River. There were 167 fires annually from 1960 to 1985 in the Wenatchee NF and 70 fires annually from 1979 to 1988 in the Okanogan (USFS 1989, 1990). Annual area of burn was also higher in the Wenatchee--7,772 ac or 0.35% of the forest--than in the Okanogan NF--1,449 ac or 0.08% of the forest. The Wenatchee NF is wetter than the Okanogan NF and produces more fuel for wildfire but there are also more human caused fires (62%) in the former than in the latter (31%).

The Wenatchee NF has a very complex pattern of fire occurrence. The eastern, most densely populated portions of the Wenatchee, Entiat, and Chelan drainages have more large fires than the rest of the forest. Steep topography, extended dry periods, and strong westerly winds contribute to many large fires in this sagebrush-steppe area (USFS 1990). Prior to the arrival of settlers, fire-return intervals probably were much longer than now (e.g., Whisenant 1990). Cheatgrass, an introduced annual, increases fire frequencies by creating a more continuous and explosive fuel bed.

Sedimentation

"Sediment," as commonly used by fishery biologists, means fine silt and clay particles. Laboratory studies have demonstrated negative effects of sediment on macroinvertebrates, survival and emergence of salmonid embryos and alevins, and growth of fry (Everest et al. 1987). The few studies dealing with the effects of sediment in stream environments are less conclusive, although results from laboratory and field studies agree closely when

Fig. 29. Top, Wenatchee River in Tumwater Canyon as it looked in 1929 at the dedication of the Stevens Pass Highway. Bottom, the same view in 1991. In the 62 years between photos, vegetative cover has changed from open stands of fire-tolerant species to dense thickets of less fire-tolerant species. (Photo courtesy of The Wenatchee World, Wenatchee, WA.)

sediment loading is acute or chronic. There is, however, ample evidence that stable channels containing stored sediment behind obstructions--large rocks, organic debris, bridge abutments, or stream improvement structures--are more productive at every trophic level than either degraded channels largely devoid of sediment or channels that are aggraded and unstable. Thus, there seems to be a broad middle ground between too much and too little sediment in salmonid habitats (Everest et al. 1987a).

Sediment now delivered to the Wenatchee, Entiat, and Methow rivers from human activity is about 10% above natural background levels (USFS 1989, 1990). This is an average, of course, that will vary with the extent of disturbances in a given watershed. Turbidity, a general indicator of sediment transport, is normally very low in area streams. Exceptions inevitably are related to intense wildfire and rainfall events (e.g., Entiat River, Boulder Creek, Appendix E) or to natural mass soil failures (e.g., Mission Creek, Mad River, Appendix E). Acute concentrations of suspended sediments (>20,000 mg/l, Everest et al. 1987a) have killed salmonids in the Entiat River and Mission Creek.

Streams flush out sediment if sediment input rates are less than the stream's ability to transport sediment downstream during normal peak flow. Study streams have high flushing rates related to their high gradient, and aggrading channels are rare (e.g., Icicle Creek Index Area, Chapter 4).

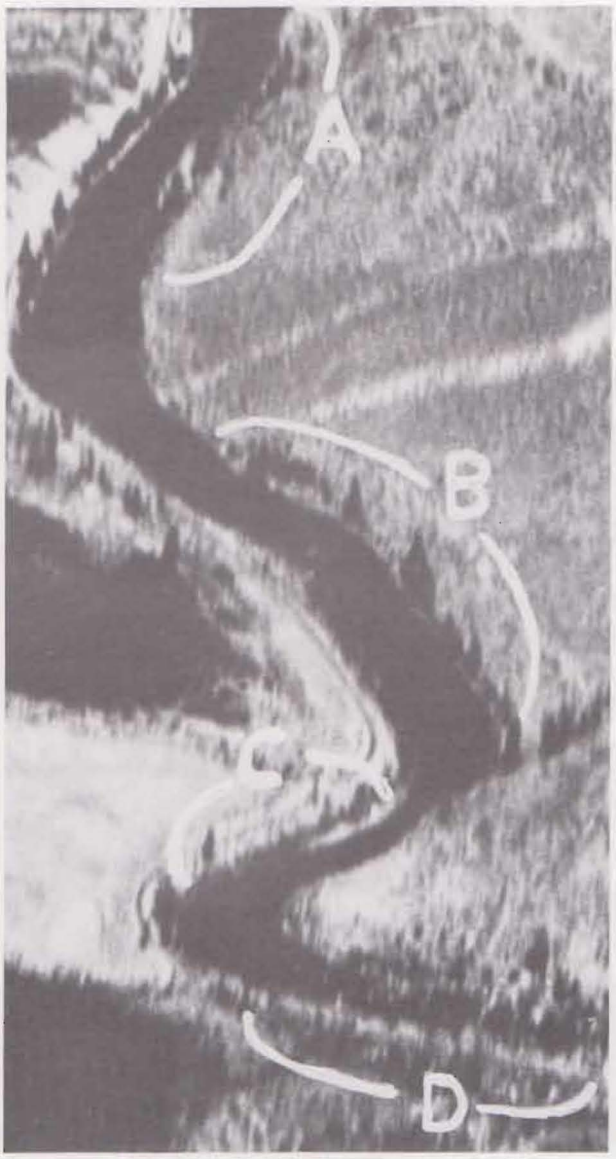
Stream Stability and Riparian Vegetation

A stable stream is one whose channel morphology, roughness, and gradient allows passage of the sediment load contributed from upstream (Leopold and Bull 1979). The balance between the channel's capacity to transport sediment, defined here as silt to large cobble (Everest et al. 1987), downstream and the influx of sediment upstream can be upset by mining, logging, and other human activities.

We used Pfankuch's (1975) criteria for channel stability to subjectively rate 11 reaches (15 transects) of the middle and lower Methow River. Numerical score was 52 (range, 47 to 65) (<38 was excellent; >115 was poor). We also compared photographic enlargements of the 11 reaches from oblique aerial photographs taken in 1932 and controlled aerial photographs taken in 1966 with on-the-ground evaluation of the same reaches in 1990. Channel morphology was similar in 1932, 1966, and 1990, but there was appreciably more riparian vegetation present in 1990 than before (Figs. 30 and 31).

Silt, clay, and glacial flour can be moved by virtually any flow. Normally, water in area streams is very clear and suspended matter at high flows is mostly sand. Large floods cause gravel and

1932 oblique aerial photo



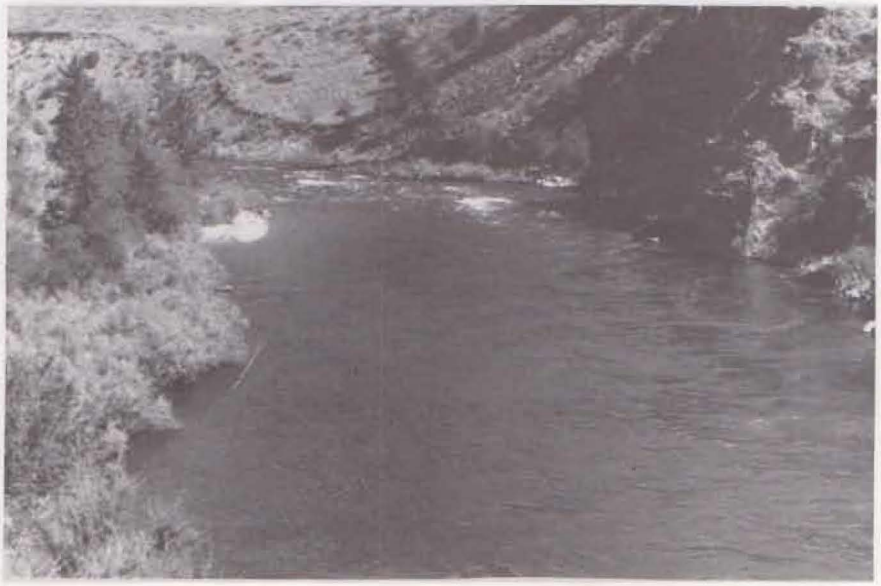
Enlargement of lower portion 1932 photo

1966 aerial photo (enlarged) of same stream reach

Fig. 30. Changes in riparian vegetation along the Methow River (river mile 8.0 to 9.0) over time. Match letters with photos taken 1990 on opposite page with photos on this page. (Note orchards on river terraces).

A. Pine trees shown in 1932 and 1966 photos in 1990.

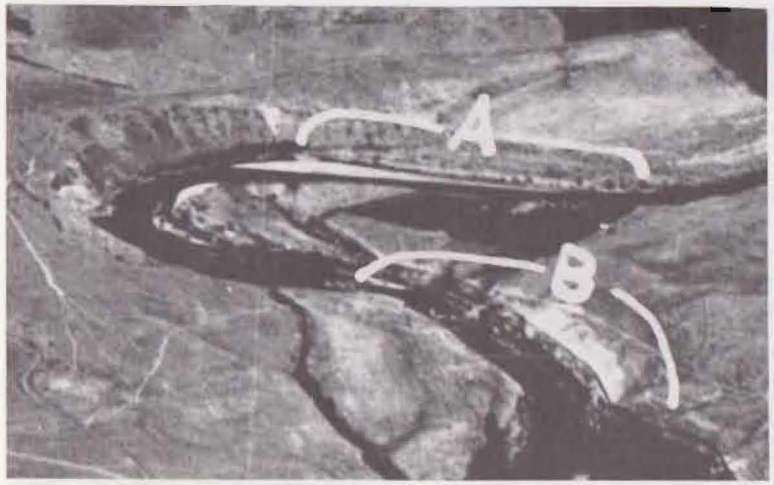
B. Small pine trees that replaced large pine trees shown in 1932 photo, but not in 1966 photo after 500-year flood in 1948.



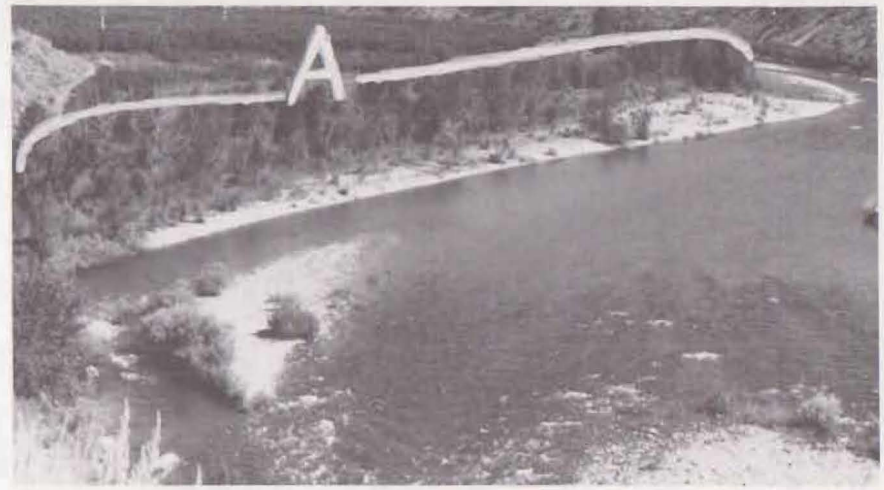
C. Riparian vegetation much more dominant in 1990 photo than in 1932 and 1966 photos opposite page (note eroded bank in background from 1948 flood).

D. Ibid.

Fig. 30. Concluded

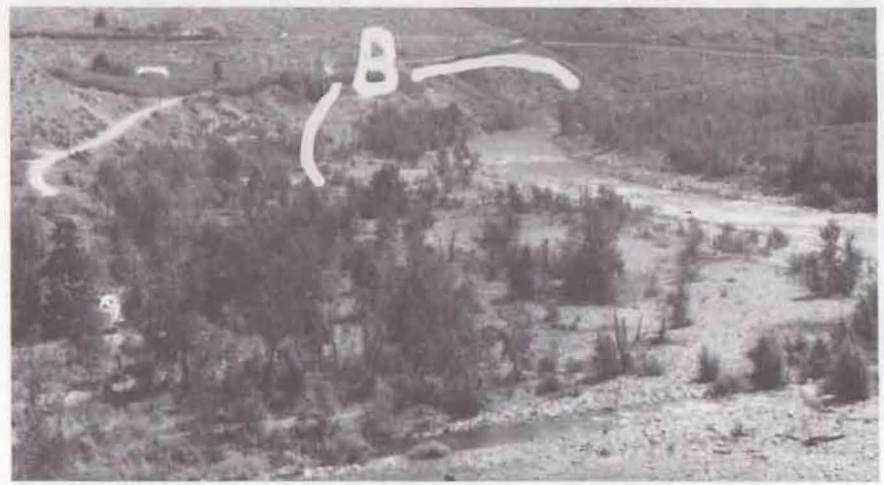


1932 oblique aerial photo (enlarged)



1990 photo

1966 aerial photo (enlarged)



1990 photo

Fig. 31. Increase in riparian vegetation along the Methow River (River mile 3.3 to 4.0) over time. Match letters with photos taken 1990 on right with letters on 1932 and 1966 photos on left. (Note orchards on river terraces).

cobble to roll along the bottom as bedload. This coarse material is molded by streamflow to form the stream bed. In stable channels, annual transport of bed material may cause bars and meanders to shift, but the overall morphology changes little from year to year (Sullivan et al. 1987).

Most sediment in larger streams is deposited as bars--sediment accumulations within the channel that are one or more channel widths long (Sullivan et al. 1987). Bars may grow and shrink seasonally because of imbalances between deposition and erosion. Other than in braided channels, however, bars tend to keep the same location as long as channel boundaries remain intact and bedrock and boulder obstructions remain in place.

Channel obstructions in large, high gradient rivers consist primarily of bedrock and boulders; obstructions of woody debris are uncommon in such rivers, while common in lowland rivers (Sedell and Luchessa 1981). Obstructions help store and sort stream sediment, enhance scour and deposition of bed material, diversify velocity and depth, and fix the position of bars and pools. Stream banks that are bound by vegetation, armored with rock, or both, erode less rapidly and their channel boundaries remain intact over long periods of time (Sullivan et al. 1987). The Methow and Wenatchee rivers have well defined channels that retain annual peak flows within their banks during most run-off.

The Methow flood of 1948 was the highest since 1894. We do not know the extent of damage in 1894. However, we know the 1948 flood destroyed or damaged 6 highway bridges, washed out the valley highway, isolated towns for 11 weeks, destroyed 200 ac of orchards, and inundated 2,500 ac of floodplain (Walters and Nassar 1974). Similar damage occurred in the Entiat and Wenatchee drainages (PNRBC 1971a). Flow in the Methow was 46,700 cfs (500-year flood) or seven times the annual peak flow. Judging from our photo comparisons, the 1894 flood was even more destructive. Riparian vegetation (willow, poplar, cottonwood, pine) was only minimally reestablished by 1932, and moderately reestablished by 1966, compared to 1990 (Figs. 30 and 31). The same sequence to reestablish riparian vegetation occurred along the Wenatchee River on the basis of photographs taken in 1905 and in 1990 (Fig. 32).

The floods of 1894 and 1948 took place over much of the Columbia River basin and were natural events unrelated to settlement (PNRBC 1971a). Floods of this magnitude destroy fish, particularly juveniles, as well as their habitat and food supply (Allen 1951; Gangmark and Bakkala 1960; Elwood and Waters 1969; Seegrist and Gard 1972; Hanson and Waters 1974; Hoopes 1975).

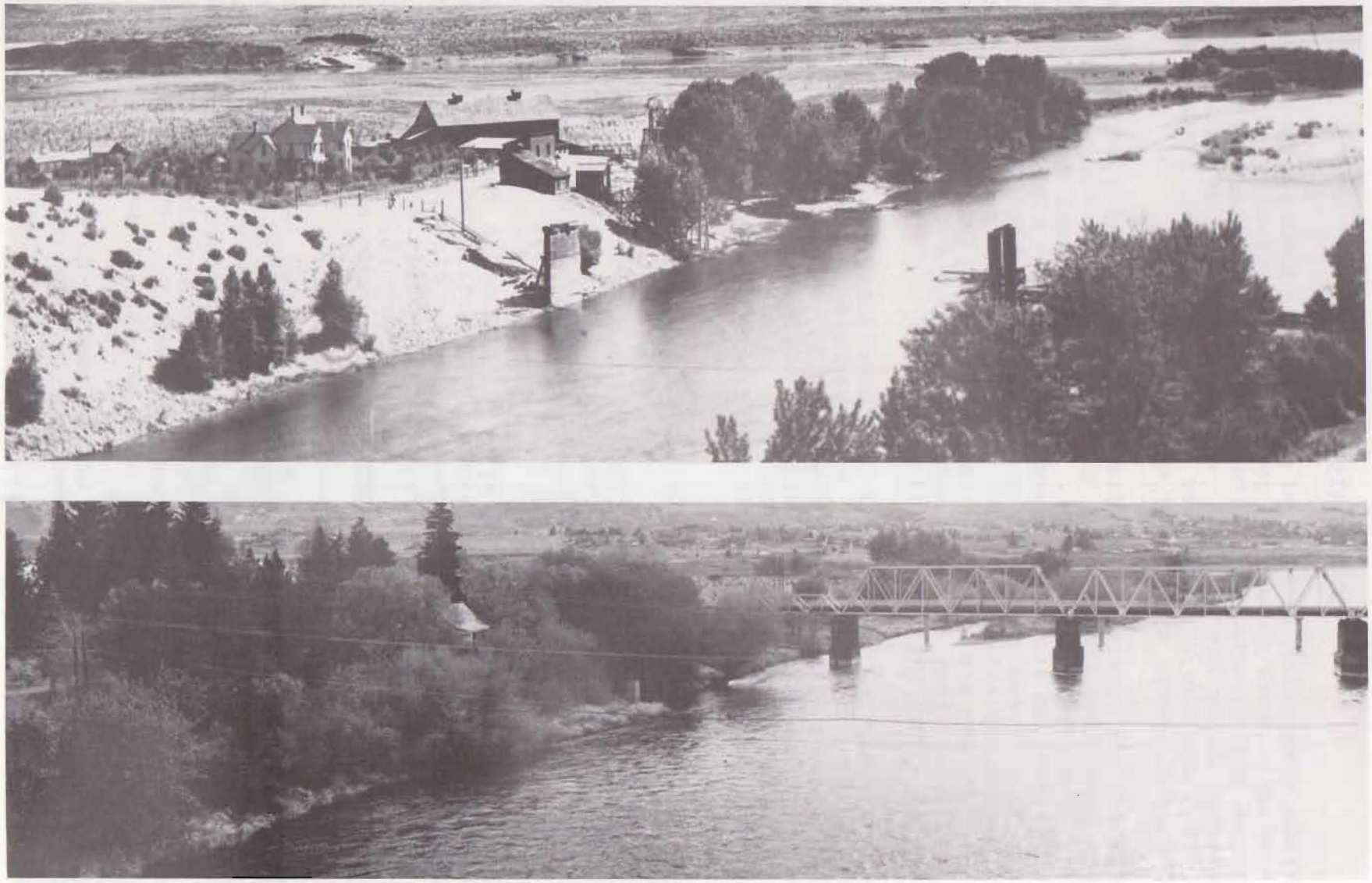


Fig. 32. Top, orchard homestead at the mouth of the Wenatchee River as it looked in 1905. Bottom, the same view in 1990 with vegetation obscuring the homestead. Note that the point bar below the bridge was almost devoid of vegetation earlier, probably a result of the 500-year flood of 1894. (Photos courtesy of The Wenatchee World, Wenatchee, WA).

Stream Alteration

Stream alteration is limited primarily to bank protection for flood control. Rock riprap is common along highways, railroads, and bridges and in urban and farm areas along streams (Fig. 33). The Wenatchee River has 5 mi (5%--one bank only), the Entiat River 2.6 mi (5%), and the Methow River 35 mi (22%) (PNRBC 1971a, 1977; J. Carson, SCS, pers. comm.; our observations).

Nine of ten references in Stern and Stern (1980) depict rock riprap as providing fish habitat along stream banks comparable to, or better than, natural habitat. We found highest densities of juvenile salmon and steelhead associated with rock riprap and large woody debris. Trees and brush growing through boulders with the toe of the riprap extending into the stream was the best habitat (Fig. 33). Salmon and steelhead occur only among boulder riprap in winter, although they may move out of this cover and rest on the substrate at night (Hillman et al. 1989a,b).

Constriction of river length by channelization or highways has been slight in our area because the channels are entrenched with steep banks and confined in narrow valleys. Highway bridges have created downstream pools. Periodic collapses of paralleling irrigation ditches have added boulders, which remain as permanent obstructions, as well as sediment to stream channels.

Agriculture/Irrigation

Irrigation is essential to farming in the Wenatchee, Entiat, and Methow valleys. In 1868, the first settler in the Wenatchee area planted an orchard watered by a simple irrigation system, and most diversions were in place by 1912 (Kerr 1980).

About 3% of the Wenatchee River watershed is farmed--mainly fruit orchards along the lower river. The estimated depletion in river discharge from irrigation reduces stream flow by 298 cfs over a five-month period each year (Appendix D). This amounts to 16%, 28%, and 21% of the mean monthly flow for August, September, and October as measured at RM 21.5 (USGS), below which most irrigation diversion occurs (Appendix D).

Less than 1% of the Entiat River watershed is farmed. From the mouth of the Entiat River upstream about 10 mi, orchards (856 ac) cover a narrow band along both banks. Upstream of the orchards, most of the bottomland is used for pasture (744 ac) (USDA 1979). The estimated depletion in river discharge from irrigation each year is 15 cfs for five months (Appendix D). This amounts to about 5%, 9%, and 8% of the mean monthly flow for August, September, and October at RM 0.3.

About 1.7% (20,000 acres) of the Methow River watershed is farmed. From the mouth of the Methow River upstream to RM 27.4,

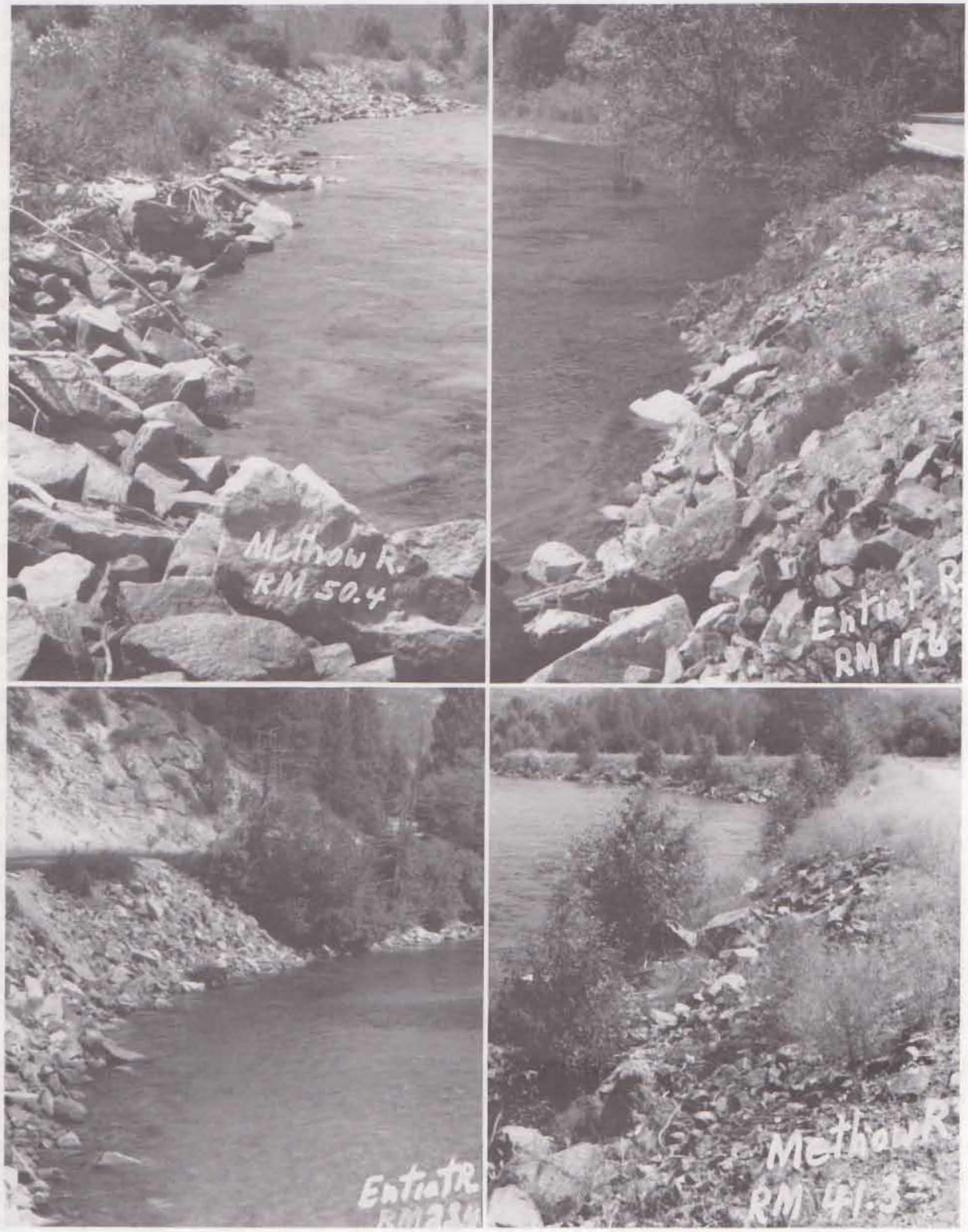


Fig. 33. Rock riprap used along streams for flood protection provides critical summer and winter habitat for salmonids.

practically all of the irrigated land is in orchards. Agricultural use from RM 27.4 to RM 39.4 is about equally divided between orchards and field crops. From RM 39.4 to RM 67.3, most of the irrigated lands are in such forage crops as alfalfa (PNRBC 1977). The estimated annual depletion in river discharge from irrigation varies from 28% to 79% August to October, depending on reach and return flow (Appendix D).

We used the Habitat Quality Index (HQI, Chapter 3) to compare habitat and salmonid abundance in reaches of streams affected by irrigation diversion (Table 22) (Binns and Eiserman 1979). We reasoned that stream flow during late summer would be completely adequate under natural conditions. There was no appreciable difference in habitat and standing crop with irrigation diversion except in grossly dewatered stream reaches (Table 22).

Numerous studies show that stream habitats usually are not drastically altered until base flow is reduced 70%-80% or more (Wesche 1974; Tennant 1976; Newcombe 1981; Fig. 3). The actual quantity of water matters less than how well it fills the channel (Binns 1982). Wetted perimeter decreases much less rapidly than volume of flow (Fig. 3). Changes in depth and area of cross-section in streams closely parallel wetted perimeter in percentage reduction, with flow velocity affected most.

The mean annual flow in our study streams is equalled or exceeded about 32% of the time (Table 23); Hynes (1970) reported 25% for streams elsewhere. More importantly, the long-term, 7-day-average low flow, with a two-year recurrence interval (Q7 L2), is only 16% (6% to 23%) of the average annual flow, and there is little difference between regulated (17%) and unregulated (16%) streams (Table 23). This means that stream organisms live for most of the time at relatively low current speeds and are exposed to very low flows at regular intervals regardless of irrigation diversion. Even when current speed ceases and fish concentrate in isolated pools, the habitat may not be profoundly altered if water temperatures and oxygen content do not become critical. We found highest density, biomass, and production, but lowest yield, of age-0 salmonids in the Icicle Creek Index Area (Chapter 4) associated with highest water temperatures and lowest flows in 1987. For 2 to 3 weeks in August 1987, flow in the Index Area was less than 10% of mean annual flow, though area and depth were much less affected.

Salmonids apparently do little to avoid the consequences of severely declining flows although larger fish are more influenced than smaller fish (Corning 1970; Kraft 1972; Bovee 1978; Randolph 1984). Aside from dynamic migration of fry (Chapter 4), downstream movement of salmonids is almost universally associated with spates and freshets as we observed in Icicle Creek. In the 10 mi section of the upper Methow River that dried in 1987 (Appendix C), we observed large numbers of juvenile chinook salmon, steelhead, and bull trout in pools connected by reduced flows 5-20 cfs on 1

Table 22. Comparison of habitat and salmonid abundance (thousands) in stream reaches with and without irrigation diversion using the Habitat Quality Index (HQI) rating (Table 9).

Stream (river miles)	With irrigation diversion				Without irrigation diversion			
	HQI[a]	Chinook salmon[b] age-0	Steelhead age-0	Steelhead parr	HQI[a]	Chinook salmon[b] age-0	Steelhead age-0	Steelhead parr
Wenatchee R.								
(0.0-27.0)	P/F	64.8-98.5	33.7-59.6	28.5-33.7	no change			
(27.0-35.8)	A/G	47.0-55.6	41.7-41.7	17.3-29.7	no change			
Icicle Cr.								
(0.0-2.8)	F/A	4.9-12.7	3.0-11.3	11.7-47	no change			
Peshastin Cr.								
(0.0-3.8)	P				G/E	9.5-16.3	7.1-24.6	5.1-8.0
Mission Cr.								
(0.0-9.4)	P/F		0.8-1.4	0.7-0.8	A/G	6.0-7.1	5.3-5.3	2.2-3.8
Chumstick Cr.								
(0.0-13.0)	P/F		0.3-0.5	0.2-0.3	F/A	1.5-4.0	0.9-3.5	0.5-1.5
Chiwawa R.								
(0.0-3.6)	P/F	3.1-4.7	1.6-2.8	1.4-1.6	no change			
Entiat R.								
(0.9-16.0)	A/G	58.1-68.8	51.6-51.6	21.4-36.8	no change			
Methow R.								
(1.8-50.1)	F/A	140.5-362.4	85.0-321.7	48.1-133.1	no change			
(50.1-63.3)	F/A	11.8-46.4	6.1-10.9	5.2-6.2	no change			
Chewack R.								
(0.0-8.8)	F/A	7.3-16.6	4.4-16.6	2.5-6.9	no change			
Twisp R.								
(0.0-4.0)	G/E	9.6-16.5	7.2-25.0	5.1-8.1	no change			
Gold Cr.								
(0.0-2.2)	G/E	0.6-0.9	2.1-7.4	1.5-2.4	no change			
Misc.[c]	P/F	4.3-6.6	2.2-4.0	1.9-2.2	F/A	6.5-16.9	4.0-15.0	2.2-6.2

[a] P=poor; F=fair; A=average; G=good; E=excellent.

[b] Steam-type chinook only; ocean-type chinook are not affected by irrigation diversion.

[c] The effects of irrigation diversion on a number of steams (about 42.6 ac) are an enigma, e.g., they flow only during snowmelt and intense rainstorms in the alluvial fans near mouth (Appendix D), and this is an optimistic account of their fisheries value without irrigation diversion.

Table 23. Percentage of time mean annual flow (QAA) is equaled or exceeded and long-term, 7-day average low flow with a two-year recurrence (Q7L2) as a percentage of QAA for unregulated and regulated streams in the Wenatchee, Entiat, Chelan, and Methow River drainages (data from Williams and Pearson 1985).

Steam (river mile)	Drainage	Mean flow QAA (cfs)	Percent of time QAA is equaled or exceeded	Low flow Q7L2 (cfs)	Q7L2 as a percent of QAA
		Unregulated (or no significant irrigation diversion)			
Wenatchee R. (54.1)	Wenatchee	1,317	33	218	17
Wenatchee R. (46.2)	Wenatchee	2,274	33	418	18
White R. (6.4)	Wenatchee	816	28	133	16
Chiwawa R. (6.3)	Wenatchee	488	33	82	17
Icicle Cr. (5.8)	Wenatchee	625	33	104	17
Mission Cr. (7.0)	Wenatchee	13	42	2	14
Entiat R. (18.1)	Entiat	385	25	56	14
Stehekin R. (1.4)	Chelan	1,415	38	212	15
Railroad Cr. (1.2)	Chelan	204	38	29	14
Andrews Cr. (3.0)	Methow	33	25	2	6
Beaver Cr. (6.2)	Methow	21	29	5	23
		Regulated (irrigation diversion)			
Wenatchee R. (21.5)	Wenatchee	3,137	33	548	17
Wenatchee R. (5.8)	Wenatchee	3,375	32	586	17
Entiat R. (0.3)	Entiat	509	25	93	18
Methow R. (40.0)	Methow	1,352	33	205	15
Methow R. (6.7)	Methow	1,612	33	301	19

September. Two weeks later no flow was visible between pools, and the abundance of small salmonids appeared unchanged. By November this reach of stream which was not subject to irrigation diversion had dried (Fig. 4) and an estimated 12,000 to 54,400 juvenile salmonids died.

Salmonid populations are greatest in streams that receive high ground-water input, which stabilizes base flows and water temperatures, and promotes greater water fertility (Hendrickson and Doonan 1972; White et al. 1976; Meisner et al. 1988). In arid regions, riparian vegetation may depend on ground water as well. Evidence is accumulating that irrigation, at least at current levels in the Methow River basin (Appendices C and D), may be more beneficial than detrimental to salmonid habitat because of its influence on ground-water. Vaccaro (1986a, 1986b) calibrated a stream-flow-routing model and a stream-flow temperature model for the Yakima River (Fig. 1) subject to extreme irrigation depletion. A scenario of no reservoir storage, irrigation diversion, or return flows (estimate of natural conditions) produced conditions least favorable for salmon and steelhead.

The Sequim Peninsula in western Washington provides a parallel to the Methow basin. The land has been irrigated since 1898, because precipitation is only 16 in per year. The Dungeness River, which originates in the mountains to the south, flows through the middle of the Sequim Peninsula. In the 1960s, land use began shifting from agriculture to residential, raising concerns about water supplies. Model simulation showed that leakage from irrigation ditches was the major source of recharge to the ground-water aquifer. Termination of irrigation was predicted to lead to several hundred wells going dry (Drost 1989).

Using ground-water sources, rather than surface-water sources, for irrigation in the Methow basin so as to increase stream flows might also disturb thermally segregated water. Under conditions of very limited water supply, it may be preferable on very hot days to actually reduce flows in order to protect cool-water refuges for salmonids (Bartholow 1989).

Contaminants

The state of Washington has classified the Wenatchee, Entiat, and Methow drainages as Class A or AA, or excellent for water quality. Water quality standards for class A and AA water are adequate to protect salmonids (Welch and Perkins 1978). However, the settlers exercised their pioneer right to dispose of sewage in any convenient way and the devil take the man (and he often did) who lived down the creek. Settlers also protected apple trees from codling moths with arsenate of lead. For 50 years the orchards that fringe the lower reaches of the Wenatchee, Entiat, and Methow

rivers were white with the chemical. Livestock died from eating the forage that grew beneath the trees (Kerr 1980).

Risk assessment of contaminants in streams is difficult (Thomson 1987). The most obvious indication that all is not well in a fish community is a history of significant fish kills (Hunn 1988). We know of no fish kills that can be traced to pesticides in the Wenatchee, Entiat, and Methow rivers, despite their widespread use. Elevated levels of arsenic, zinc, and DDT have been reported in bridgelip suckers from the Wenatchee River (Hopkins et al. 1985). Arsenic residues in study streams does not seem to be a problem (Table 24). Unfortunately, there are few data on DDT residues or other pesticides in local fish, which may indicate a lack of a problem. Many of the naturally occurring heavy metals (Helm 1959; USEPA 1986) (chromium, copper, cyanide, lead, mercury, silver, and zinc), however, periodically exceed safe criteria for salmonids (Table 24).

The same contaminants may not bring about similar affects in different streams. The character of the watershed, including soils, vegetation, and land uses; the amount and seasonality of precipitation; the frequency of floods and the amount of erosion; and the nature of the stream banks, bottom materials, and water are all important (Tarzwell and Gaufin 1953; Thomson 1987). The effects of contaminants in aquatic organisms may also be modified, positively and negatively, by antagonism and synergy. Given the characteristics of our study streams and their watersheds--high water quality, high flushing rates, low human development, low accelerated erosion, lack of industrialization, clean water macroinvertebrates--the likelihood that they are long-term toxic dumps (e.g., PCBs in the Great Lakes) is small.

Pesticide use changed in the 1960s. Organochlorine insecticides predominated then (e.g., DDT), but between 1969 and 1972 almost all persistent compounds of that group were legislatively eliminated. They were replaced by the less persistent, biodegradable organophosphorus and carbonate insecticides. Locally, in 1976, 1977, and 1978, 210,300 ac of the Wenatchee National Forest was sprayed with Fenituthion, malathion, and Seven-4-oil to control the spruce budworm. *Bacillus thuringiensis* was sprayed on 50,000 ac in 1987 (USFS 1990). With the wide range of pesticide chemicals used in the post-DDT era, even the most "catastrophic" losses in streams is followed by rapid return of macroinvertebrate populations to normality (Thomson 1987).

Moderate amounts of phosphorus (Table 24) and nitrogen (Fig. 9) from sewage treatment plants, fish hatcheries, urbanization, and agriculture, have not noticeably affected dissolved oxygen levels in the Wenatchee, Entiat, and Methow rivers. Rather, these nutrients have probably increased fish production (Tarzwell and Gaufin 1953). Potential increases of from one-fourth to one-half

Table 24. Toxicity to salmonids (USEPA 1986) of chemicals found in study streams (USEPA Storet).

	Concentration in ug/L							
	Toxicity standard		Study streams			Study control[a]		
Chemical	Acute	Chronic	Mean	Max.	n	Mean	Max.	n
Aldrin	3.0					0.001	0.01	9
Arsenic	360[b]	190[b]	1.1	10.0	151	1.0	3.0	16
Beryllium	130[b]	5.3[b]				0.69	1.0	16
Cadmium	3.9[c]	1.1[c]	0.99	20.0	128	1.1	2.0	16
Chlordane	2.4	0.0043				0.010	0.10	9
Chromium (Hex)	16.0	11.0	1.6	20.0	334	2.7	10.00	15
Copper	18.0[c]	12.0[c]	2.9	140	393	4.9	10.0	17
Cyanide	22.0	5.2	3.2	30.0	25	4.4	30.0	18
Diazinon						0.001	0.01	9
DDD						0.001	0.01	9
DDT	1.1	0.0010				0.001	0.01	9
DDT metabolite (DDE)	1,050[b]					0.001	0.01	9
2,4-D						0.0016	0.01	6
2,4,5-T						0.001	0.01	6
Dieldrin	2.5	0.0019				0.001	0.01	9
Endosulfan	0.22	0.0560				0.001	0.01	6
Endrin	0.18	0.0023				0.001	0.01	9
Ethion			0.001	0.0	6			
Iron		1,000	61.0	440	76	9.8	18.0	16
Heptachlor	0.52	0.0038	0.025	0.1	4	0.001	0.01	9
Lead	82.0[c]	3.2[c]	5.8	170	354	6.8	12.0	17
Lindane						0.001	0.01	9
Malathion		0.01				0.001	0.01	9
Methoxychlor		0.03				0.003	0.01	3
Mercury	2.4	0.0120	0.307	2.7	372	0.15	1.0	19
Mirex		0.0010				0.002	0.01	5
Nickel	1,800[c]	96.0[c]				1.8	6.0	10
Parathion		0.04				0.001	0.01	9
PCBs	2.0	0.0140				0.011	0.10	9
Phosphate			43.0	250	1601	19.0	330	124
Selenium	260	35.0	0.5	3.0	129	0.700	1.00	16
Silver	4.1[c]	0.12[c]	0.27	16.0	129	1.7	16.0	16
Silvex						0.001	0.01	6
Toxaphene	1.6	0.0130				0.142	1.00	7
Zinc	320[c]	47.0	8.2	150	380	7.5	18.0	17

[a] Andrews Creek, containing a flourishing rainbow/cutthroat population (Tables 6 and 7), located in the 824 mi^2 Pasayten Wilderness.

[b] Insufficient data to develop criteria. Value presented is the Lowest Observed Effect Level (LOEL).

[c] Hardness dependent criteria (100 mg/l hardness level used for reported value).

of pristine production seem likely (Table 17, Mills 1969; Taube 1975; Alexander et al. 1979; Scott et al. 1986).

Dams and Diversions

Turn-of-the-century sawmill, hydroelectric, and irrigation diversion dams devastated salmon (Appendix H; Fish and Hanavan 1948; Bryant and Parkhurst 1950). Irrigation diversions have been screened since the 1940s, and early "light bulb" plant and sawmill dams disappeared before 1940.

Dryden Dam (RM 17.6) and Tumwater Dam (RM 32.7) on the Wenatchee River remained major obstructions to upstream passage of adult salmonids until hydroelectric generation was abandoned in 1957. Between 1957 and 1986, when their fishways were modernized, these dams were considered limiting factors to salmon and steelhead production (BPA 1984).

The contention that losses of adult spawners at Dryden and Tumwater dams were much more serious than observed goes against several lines of evidence (Mullan 1986, 1987). For example, in the poor passage years of 1957 to 1986, good numbers of salmon were counted above both dams, and these numbers did not increase after the fishways were rebuilt. As found in analyzing the purported damage to Fraser River salmon runs by the notorious Hell's Gate obstruction of 1913 (Ricker 1987), it is difficult to assess the role of Dryden and Tumwater dams without appearing to be "against the fishways." Indeed, the fishways have done the job they were planned for. The return of adult salmon and steelhead is no longer delayed or blocked, although the number of fish that needed this assistance was probably exaggerated and consisted mainly of weak and injured individuals. Most important, the new fishways insure upstream passage during such extreme drought and low water levels as occurred in 1940 (Fig. 34).

In a similar vein, screens and bypass structures on the older irrigation diversions are now believed to need modernization (WDF 1989). We agree, but not with the deductive leap that loss of juvenile salmon and steelhead in irrigation diversions is a major problem.

Juvenile salmon and steelhead are commonly found in irrigation diversions, both upstream and downstream of rotary-drum screens and bypass structures. Favorable habitat is often created by aquatic and riparian vegetation in irrigation diversions. Consequently, they often have an abundance of young salmonids (e.g., 39.0 fish/100 m^2 and 4.1 g/m^2, Tables 6 and 7, Wenatchee River, RM 6.6, c87). Populations above screens and bypass structures may return to the parent stream when irrigation flow is turned off in the fall, while those below cannot return, hence perish. For the most part juvenile salmonids are not entrained as smolts, but as fry,

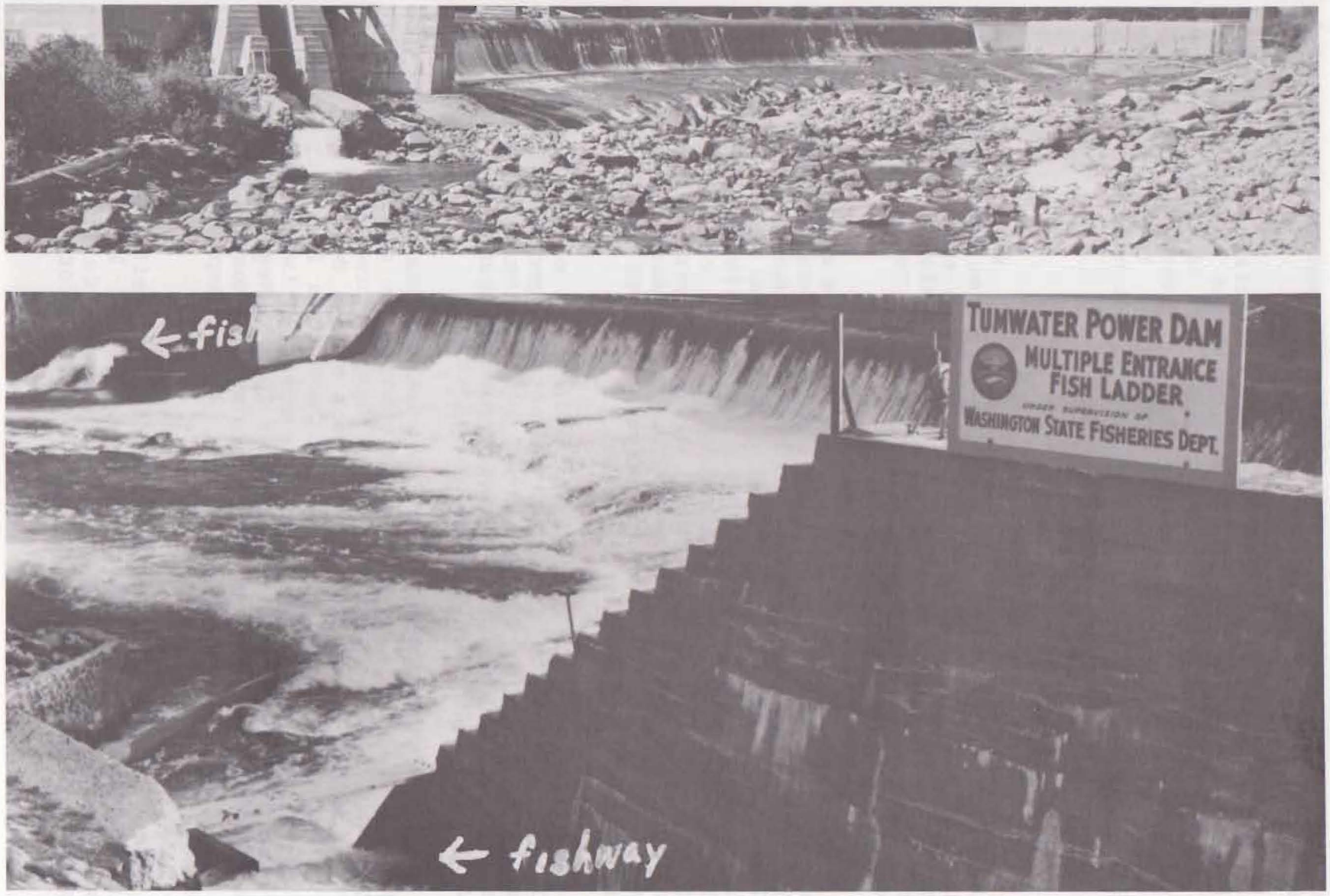


Fig. 34. Top, extreme drought and low water levels as occurred in 1940 at Tumwater Dam on the Wenatchee River (river mile 32.7). Bottom, the fishway that was installed after the above photograph was taken generally did the job it was planned for, particularly following abandonment of hydroelectric generation at the dam in 1957.

largely destined to die (Fig. 16), during the spring when water is turned into the diversions.

Efficiency of even modern, rotary-drum screens is incomplete (97-99%) (Neitzel et al. 1990). Faulty screen seals and rolling over drum screens allow some passage of fry; the mass of larger fish generally prevents their passage. Old screening facilities in our streams are less tight, but absolute loss is probably exaggerated because immigrants colonize vacant habitat.

Impoundments

River log-driving, usually involving splash dams and impoundments, had a short heyday on the Wenatchee and Entiat rivers (Kerr 1980). The only vestiges remaining are sunken logs in the Tumwater Dam impoundment (5-6 ac), Wenatchee River, which provide cover for an above-average abundance of juvenile salmonids (Appendix D, Lake Wenatchee).

The only large impoundments affecting area streams are on the Columbia River (Fig. 1). They form the confluences of the Wenatchee (3,458 [surface] ac Rock Island impoundment), Entiat (9,200 ac Rocky Reach impoundment), and Methow (10,700 ac Wells impoundment) rivers. Small volumes and high flushing rates (1-6 days) place these mainstem impoundments in a riverine category. Reservoirs in the mid-Columbia River function as cold-water tailwaters of Grand Coulee Reservoir (Lake Roosevelt), the only storage reservoir in the United States portion of the river (Mullan et al. 1986).

Impoundments often contain populations of fish that use tributary streams for spawning and nursery grounds (Ruhr 1957; Adams and Moyle 1975; Storck et al. 1983; Swink and Jacobs 1983; Penczak et al. 1984). The most common migrants to our study tributaries are redside shiners and suckers.

Redside shiners draw on the same stream resources during the summer as juvenile chinook salmon, and they displace juvenile chinook salmon from rearing space at temperatures >15° C (Hillman 1989b). Densities of juvenile chinook salmon decline rapidly in their rearing area after redside shiners move in. Not only are redside shiners aggressive toward salmon, the two species use the same resting habitat at night (Hillman 1991). Negative interaction between redside shiner and chinook salmon is most pronounced near the impoundments, where the warmer water temperature (>15° C) favors redside shiner dominance.

A good example of changes in species composition upstream from an impoundment is described by Erman (1973, 1986) for Sagehen Creek, a tributary to Stampede Reservoir, California. Erman compared fish populations in Sagehen Creek before (1952-1961) and

after (1970-1972 and 1982) the reservoir was constructed (1969). By 1982 (Fig. 35):

1) Biomass of trout had declined to less than half at lowest stream elevations; mountain whitefish had disappeared; and sucker biomass had increased to make up the difference in total biomass.

2) Trout biomass at mid-elevations had increased moderately while sucker and other non-game species biomass had decreased significantly.

3) Original brook trout biomass at the upper elevation disappeared.

Trout biomass increased at mid-elevations because large brown trout returned after overwintering in the reservoir. Brook trout disappeared from the headwater because of winter flooding (Erman 1986).

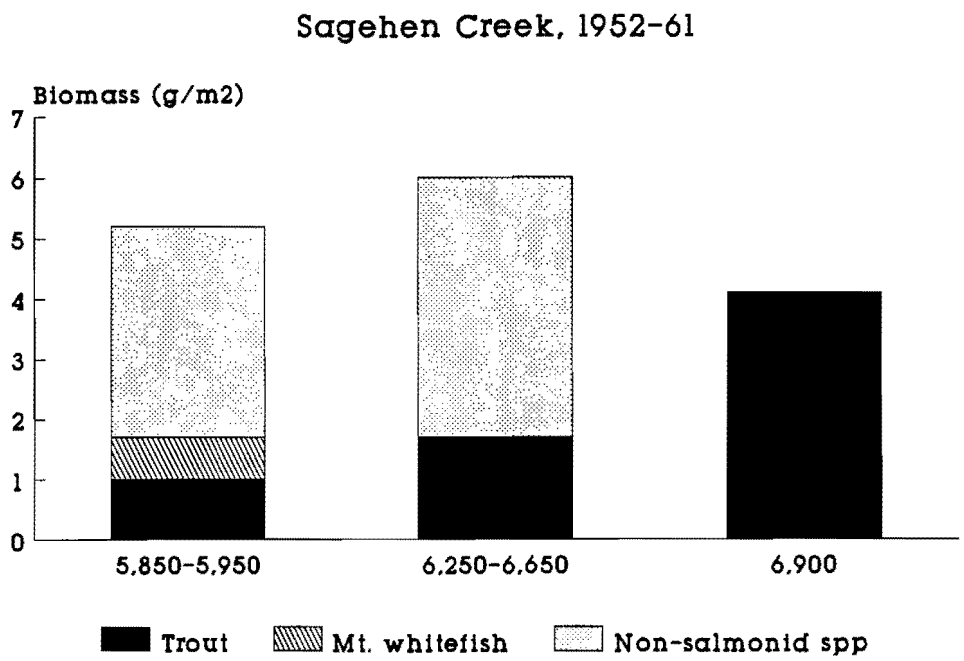
Predation

Can human alterations of streams change the normal interactions of predator and prey fishes? Dams reduce water velocities in rivers and expose downstream migrants to lake-type predators. Hydroelectric turbines damage young fish, leaving them vulnerable to predation. Often overlooked, however, is that mankind is the greatest and most efficient predator of all. Charles Wilson's diary of the survey of the 49th parallel, 1858-1862 (Wilson 1971), is illustrative.

> "At this place we caught an immense number of trout. As soon as the bait touched the water there was a regular rush for it from all sides, grasshopper is their dainty morsel, they will bite greedily at the smallest piece of one; as our rods were simply sticks cut in the wood for the time being with a piece of string tied on to the end for a line, we had not much of the real sport of fishing, but still it was very good fun pulling them out and still better eating them."

And,

> ". . . camped near some promising looking trout holes, which did not disappoint us for they bit most greedily and I caught two dozen off one stone in a very short time. We could only muster three hooks amongst us, but they were all busily employed and did great execution."



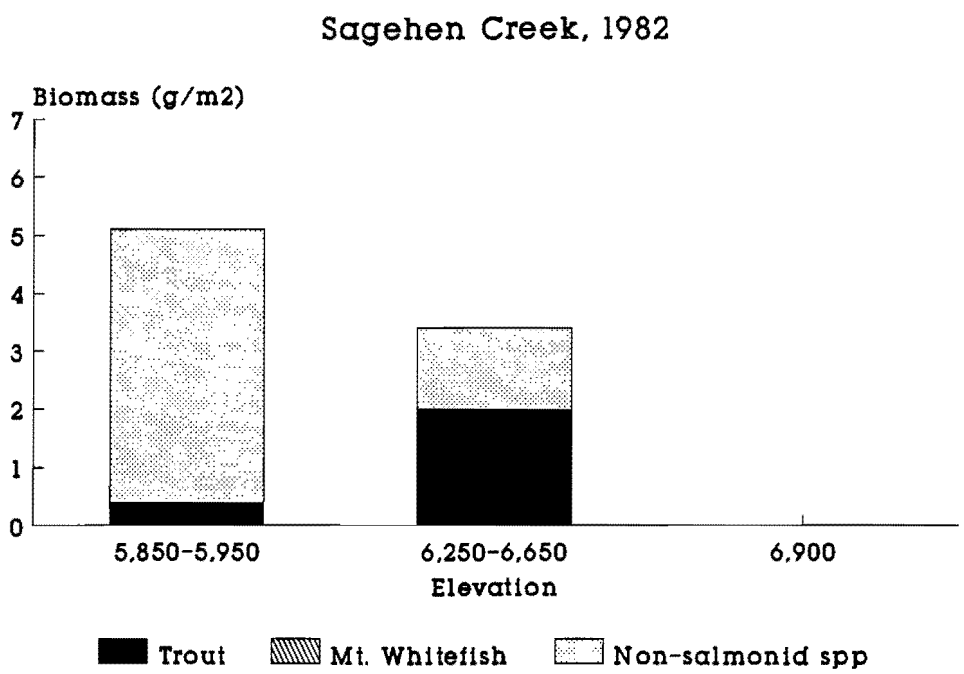


Fig. 35. Biomass of trout, mountain whitefish, and non-salmonid spp by elevation in Sagehen Creek before (1952-61) and after (1982) downstream impoundment of Stampede Reservoir, California. (Data adapted from Gard 1974; Erman 1973, 1986.)

However,

> "During the day we crossed the great watershed of the Columbia and the Pacific and were now robbing Hudson Bay of a mite of the waters which the Saskatchewan after its long wanderings pours into it. We used to think we had capital fishing in the Cascade mountains, but this year has quite beaten anything we have seen before; the [Montana and Alberta] streams are literally alive with the most delicious trout of all weighs, from about 4 oz. to 2 1/2 lbs and they are the most ravenous fish I have ever met with. The greatest catch was made by Dr. Lyall (our surgeon) who caught 9 dozen in about four hours."

Naturally produced trout in readily accessible reaches of the Wenatchee, Entiat, and Methow rivers were being depleted at least by the 1930s. In response to a perceived recreational need, a large trout stocking program evolved that generated further pernicious demand (McFadden 1969). At its peak in the 1960s, the Winthrop NFH was producing up to 9 million rainbow trout annually, mostly of sub-catchable size, and the other GCFMP hatcheries were no less involved.

Hatchery trout stocked in the Wenatchee River attracted anglers that killed 61 to 87% of the wild steelhead larger than 125 mm (Hillman and Chapman 1989b). Anglers harvested 82 to 91% of the hatchery rainbow trout liberated. The high densities of hatchery salmon and steelhead attracts other predators. An estimated 111,750 to 119,250 migrants were consumed by seagulls just below Wanapum Dam in a 25-day period of peak outmigration in 1982 (Ruggerone 1986). The number of migrants consumed by gulls at Wanapum Dam is small compared to the number of wild (440,000[4]) and hatchery-reared (3.7 million[4]) salmonids that passed Wanapum Dam during the 25 d investigation. Nevertheless, the cumulative loss (2.8% + each at up to nine dams) could be important for the greatly outnumbered natural fish, especially considering that flows and ocean conditions optimized survival during 1982 (Appendix H; Fig.

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[4]The estimate of wild salmonid abundance is based on 118,600, 37,700, and 198,600 spring Chinook salmon smolts from the Wenatchee, Entiat, and Methow rivers, with survival rates to Wanapum Dam of 87, 74, and 66% (13% loss per intervening dam), respectively (this report). Similar values for naturally produced steelhead smolts are: 49,146, 9,003, and 47,769, minus mortalities of 13, 26, and 34%, respectively. Outmigration of sockeye salmon at upstream Rock Island Dam 6 April to 28 May, 1982, was about 112,000 smolts (Olson 1983), with a probable survival to downstream Wanapum Dam, in the time-frame 24 April to May 15, of 97,318 fish. Hatchery-reared smolts consisted of 3.6 M spring chinook, 0.617 M steelhead, and 0.429 M coho, adjusted for appropriate loss at intervening dams.

18). Unless hatchery fish satiate the predators, a depensatory mortality as described by Neave (1952) is suggested.

Predation may be more important than interspecific competition in community organization (Li 1975). Pristine fish communities are implicitly structured to allow for competitive and predative processes (Regier et al. 1979). Clearly, the balance between these processes can be shifted by fishing harvest or by altering the habitat so that some species are favored and others are not. The introduced American shad (Alosa sapidissima) has been favored by impoundment of the Columbia River: Run size at Bonneville Dam, 1938-59, was 15,500; 450,600 in 1960-82; and 1.9 million in 1989. Conversely, bull trout were more abundant than at present (Brown 1992) and acted as keystone predators (Paine 1966), tending to reduce competitive interactions at lower trophic levels by holding competitive fishes in check.

Bull trout live 10-20 years, reach a size of up to 20 pounds, are highly piscivorous and mobile if given the opportunity, but are easily caught (Behnke 1980; Brown 1992). Fishing exploitation, changes in habitat, or both, tend to deform a fish community toward dominance by small to medium sized trophic generalists (e.g., redside shiner in mid-Columbia River impoundments) and away from large piscivores (Larkin 1979; Regier et al. 1979).

Genetic Alteration and Loss

Salmonids consist of numerous, more or less reproductively isolated subpopulations, each adapted in varying degrees to their respective environments (Steward and Bjornn 1990). Introduction of exotics or releases of hatchery fish potentially threaten native fish stocks with (1) loss of genetic variation and ability to adapt, and (2) extirpation or population reduction from competitive interactions, increased predation (including fishing harvest), and introduction of disease (Steward and Bjornn 1990). Evidence for adverse genetic effects of hatcheries in the mid-Columbia is fragmentary or lacking.

Coho salmon

Coho salmon runs to the mid-Columbia River were largely destroyed by over-harvest and impassable dams prior to the GCFM Project. Failure to re-establish self-perpetuating populations was related to reliance upon stocks lacking genetic suitability. Although a concerted effort was made to obtain remnant native coho for hatchery propagation (Mullan 1984), only eight females were spawned out of 64 obtained. The returns of their progeny showed promise (Mullan 1984), but they were subsequently swamped from propagation and release of young from late returning, short-run coastal stocks.

Sockeye salmon

Sockeye salmon runs to the mid-Columbia River have persisted in the face of: probable crossbreeding with fish introduced from remote locations; genetic co-mingling, transfer, and introduction for both natural and artificial propagation; blockage by dams of six (201,107 ac) of eight nursery lakes; and commercial harvest up to 98.4% (Mullan 1986). The only explanation for continued persistence is that sockeye salmon and kokanee are forms of the same species, either of which can migrate to sea or mature in fresh water (Mullan 1986). No more than 115 sockeye salmon spawned in the mid-Columbia basin in 1941, producing a run of 10,900 four years later. The latter is improbable unless kokanee contributed as indicated by Mullan (1986).

Chinook salmon

From 1940 to the late 1960s, most chinook salmon juveniles released to the Wenatchee and Entiat rivers and all released to the Methow River from the GCFMP hatcheries descended from co-mingled upriver stocks intercepted at Rock Island Dam. Other releases were juveniles from broodfish obtained in the lower Columbia River (Mullan 1987).

Records from two early hatcheries (1899-1904, 1913-1931) on the Wenatchee River show releases of 9.8 million chinook salmon fry, which largely originated from eggs obtained at hatcheries on the lower Columbia River (Craig and Suomela 1941, Appendix J). Early hatcheries (1899-1931) on the Methow River also received eggs from hatcheries on the lower Columbia River (Appendix J).

A second phase of chinook salmon propagation at Leavenworth NFH began in 1969, following two years when no chinook were reared, and at Entiat and Winthrop NFHs in 1974, following a gap of 8 and 12 years, respectively. The primary stock used was spring-run chinook from Carson NFH on the lower Columbia River, although eggs from the Cowlitz River, and from Little White Salmon and Spring Creek NFHs were used to help establish a continuing egg supply. Carson NFH stock was established from runs of upriver spring chinook trapped at Bonneville Dam (Mullan 1987).

Electrophoresis suggests stocks of stream-type (spring-run) chinook salmon from neighboring streams and hatcheries in the mid-Columbia resemble each other more than they resemble stocks of ocean-type chinook (summer/fall runs) from the same stream (Schreck et al. 1986; Hershberger 1988).

The genetic divergence of hatchery and wild stocks of salmon depends largely on the origin of the hatchery broodstock and the duration and history of their rearing in captivity. Apparently, little (<1%) genetic variability is lost in most salmonid species if the founding population consists of 50 to 200 adults (Steward

and Bjornn 1990). Inbreeding can be ameliorated and genetic drift counteracted by maintaining large population sizes and by the periodic addition of eggs or sperm from wild donor stock. (Steward and Bjornn 1990). Such protocol inadvertently characterized chinook salmon propagation in mid-Columbia River hatcheries (Mullan 1987). But because there was so much mixing, the original gene pool may have been significantly altered.

Trout

The widespread stocking of trout beyond their native ranges including rainbow and subspecies of cutthroat, and the deliberate crossing of rainbow and cutthroat in hatcheries has led to a tremendous decline and even extinction of many forms of western trout (Behnke, in press). Hybrid forms of cutthroat/rainbow/ steelhead were being distributed in the state of Washington almost from the start of hatchery propagation (Cranford 1904).

The number of taxa that compose the native Washington trout has never been determined. Two major species groups--rainbow and cutthroat--are native to Washington; but each of these two groups in turn is made up of distinct subgroups in different geographical regions of the state (R. Behnke, CO St. Univ., pers. comm.).

The rainbow trout in Washington consists of two divergent evolutionary lines. The coastal rainbow trout is native as both resident and anadromous steelhead populations, mainly from the Cascade Mountains to the coast. East of the Cascade Mountains, the native rainbow trout is derived from a diverse group of trout referred to as red-band (R. Behnke, pers. comm., 1990).

Without comprehensive study, most of the taxonomic questions pertaining to the native trout cannot be answered. The only certainties are that some cutthroat trout from the Methow River are hybridized with rainbow trout (R. Behnke, pers. comm., 1990; Table 8), and that exotic brook trout have replaced native trout in some streams (Appendix K).

Steelhead

Steelhead are one form of the polymorphic rainbow trout (Appendix H). The origin of most wild and hatchery steelhead in the mid-Columbia River can be traced to the co-mingled upriver stocks trapped at Rock Island Dam. There is little genetic and meristic difference between steelhead from different natal streams and hatcheries in the mid-Columbia (Loeppke et al. 1983; Schreck et al. 1986; Hershberger et al. 1988), although a recent hatchery import (Skamania) was easily distinguished by electrophoresis as being genetically different from the native group. The lack of electrophoretically detectable variation does not preclude the existence of important differences between closely related populations.

Steelhead spawning at Wells Hatchery, the source of many of the steelhead stocked in mid-Columbia tributaries, has been advanced from spring to winter. Returning adult steelhead originating from hatchery stock that were spawned in winter nevertheless spawn in spring both at Leavenworth NFH and under natural conditions. But, earlier maturation of hatchery steelhead compared to naturally spawned steelhead occurs in broodstock at Wells Hatchery (Table 25). Possible earlier emergence, first claim to microhabitat, and larger size of fry from hatchery steelhead spawning in the natural environment potentially threaten wild fish (Chandler and Bjornn 1988; Noble 1991). Such a hypothesis presumes that hatchery steelhead are inferior to wild fish; this has not been demonstrated in 22 generations of Wells Hatchery steelhead (Appendix H). Hatchery and wild recruits approached pre-development MSY (maximum sustained yield) escapement in 12 of the last 13 years (Appendix H).

Adults for broodstock at Wells Hatchery are randomly collected in the west fishway at Wells Dam, August through early November. There is no significant difference in run timing between naturally spawned and hatchery steelhead. Spawning has been changed from spring to winter by advancing photoperiod and water temperature. A large fraction of the naturally spawned broodstock consists of progeny of hatchery steelhead (Appendix H). Escapements of naturally produced steelhead to the natal Methow River above Wells Dam frequently fell below 20 fish during the early years of Wells Hatchery supplementation. Needless to say, the earlier maturation of hatchery adult females may be an artifact of the initial hatchery environment. On the other hand, the demise of a hatchery stock of salmon on the lower Columbia River did not become obvious until after 90 generations (Nelson and Bodle 1990).

Inherent viability of steelhead has apparently not been affected by hatchery propagation in relation to disease. Virulent epizootics of infectious hematopoietic necrosis (IHN), or "sockeye salmon disease," are common in steelhead at Snake River hatcheries, but not at mid-Columbia River hatcheries. The Snake River was never a large producer of sockeye salmon (Mullan 1986).

Summary

Without intending to understate the gravity of the problem, we conclude, like Steward and Bjornn (1990), that gene-flow from hatchery populations has not produced any obvious effects on remaining wild stocks of salmon and steelhead in the mid-Columbia River. Minimal impact may be attributed to: (1) failure of hatchery programs for salmon but not steelhead (Appendix H), precluding overexploitation in mixed stock fisheries, at least until now; (2) rapid elimination of maladapted genotypes; and (3) robustness and adaptiveness of the wild genome. There is convincing evidence that the adaptation of salmonids, although genetically defined, runs under environmental instruction (Thorpe 1987).

Table 25. Number of hatchery (H) female steelhead and naturally spawned (NS=wild) female steelhead in "ripe" broodstock obtained each week at Wells Dam Hatchery.

Brood year	Class	Number spawned each week beginning first week in January										Number spawned	Number not spawned (green)	Percentage spawned
		1	2	3	4	5	6	7	8	9	10			
1988	H	30	20	36	46	39	51	28	38	8	14	310	9	97
	NS	0	1	1	0	1	6	6	3	3	8	29	30	49
1989	H	43	29	43	56	37	35	23				266	39	87
	NS	0	0	1	0	4	7	3				15	30	33
1990	H	24	28	51	51	57	41	22	20			294	15	95
	NS	0	0	2	4	2	12	5	10			35	13	73
1991	H	35	37	50	57	50	43	37	22			331	51	87
	NS	0	1	1	1	0	6	5	5			19	42	31
Total	H	132	114	180	210	183	170	110	80	8	14	1201	114	91
	NS	0	2	5	5	7	31	19	18	3	8	98	115	46
Percentage naturally spawned		0	1.7	2.7	2.3	3.7	15.4	14.7	18.4	27.3	36.4			

The recent appearance in the Great Lakes of spring-spawning chinook salmon, which developed from fall-spawning chinook, attest to this adaptiveness (Kwain and Thomas 1984), as does the development of even-year runs among pink salmon from an inadvertent odd-year release of 21,000 fry (Kwain 1987). Initial ascendancy of winter-run chinook in the Sacramento River as a result of favorable water temperatures created by Shasta Dam (Slater 1963), and the establishment of a new dominant line in sockeye runs to the Fraser River as a result of selective over-harvest (Ricker 1987) are further examples of the plasticity of Pacific salmon. Another illustration of how environment molds a species' response is the lack of "wildness" in the hatchery progeny of chinook salmon that have survived the rigors of ocean survival. Whether rainbow trout become anadromous (steelhead) or remain fluvial (rainbow) is inextricably related to environment (Appendix H).

Hatcheries

Fish hatcheries have negative effects not limited to possible genetic alteration of salmonid stocks. The most obvious is "mining" of wild populations for eggs. For example, the Wells Dam Hatchery usurped a large portion (94% in 1969) of the summer-run chinook salmon destined for the Methow River and other upstream tributaries (Mullan 1987).

Propagation of fall-run chinook in the Washington Department of Fisheries-Public Utility District (WDF-PUD) Rocky Reach spawning channel (1961-67) resulted in negligible returns (Meekin et al. 1971). Propagation of fall chinook in the downstream WDF-PUD Priest Rapids spawning channel was also ineffective (Allen and Meekin 1973), but effectiveness was increased by conversion to a hatchery (Kaczynski and Moos 1979). Adult fall chinook destined for upriver areas are trapped for broodstock in the fishways at Priest Rapids Dam (Fig. 1). Fall-run chinook that spawned off the mouth of the Wenatchee River, 625 redds in 1961, disappeared coincidental with trapping at Priest Rapids Dam (Mullan 1987).

Difficulties with hatcheries indicate very clearly that effects are frequently contrary to management objectives (Walters 1977; Williams 1990). The naive argument that we learn from our mistakes is a premise that has pervaded a blind faith in hatcheries since the last century (Stone 1872). Continuing disasters at mid-Columbia River hatcheries are common. To list but a few: 3,000 adult chinook salmon died at Leavenworth NFH in 1976 from lethal water temperatures; 952 died at Priest Rapids Hatchery in 1978 from an explosion; 720 died in 1979 at Leavenworth NFH from a lack of dissolved oxygen; hundreds of thousands of juvenile chinook salmon died, 1983-90, at Entiat, Turtle Rock, and Wells hatcheries from various causes when alarm systems failed. Millions of eggs are also routinely destroyed to comply with disease policies. These

"acts of God" are of little long-term consequence unless involving wild fish.

Naturally produced chinook and sockeye salmon sacrificed for artificial propagation in the GCFM Project showed no consistent higher survival over natural recruitment (Mullan 1986, 1987). Today, there is near universal documentation of the superiority of naturally produced salmonids over hatchery fish (Miller 1953; Wales and Coots 1954; Salo and Bayliff 1958; Mason et al. 1967; Flick and Webster 1976; Chilcote et al. 1986; Nickelson et al. 1986; Leider et al. 1989; Emlen et al. 1990). The thousands of coho salmon spawned at early hatcheries on the Methow River, with young released as unfed fry, (Appendix J), doubtless contributed to the species' demise.

Leavenworth NFH was built in 1939-40. At that time the hatchery dam on Icicle Creek became a barrier to anadromous fish. Historically, anadromous salmonids had access to RM 24.0, or about 170 ac of Icicle Creek rather than the 32 ac now available downstream from LNFH. By far, this is the largest fraction of total anadromous salmonid habitat lost to human activity on the Wenatchee and Methow river drainages.

Thinning releases of age-0 chinook salmon at Leavenworth NFH "pulled" 38-78% of wild age-0 chinook salmon and 15-45% of wild age-0 steelhead from stream margins as the hatchery fish moved downstream (Hillman and Mullan, in press). Predaceous rainbow trout (>200 mm) concentrated on wild salmon intermingled with the moving group of hatchery fish. Of 23 observed predatory attacks in mixed groups, piscivorous trout directed only one at a hatchery salmon, and all 23 attacks succeeded. Release of hatchery age-0 steelhead did not pull wild salmon or steelhead from stations.

Conclusions

Despite some abuse from the recent activities of humans, there appears to be little or no net loss of the functional features of mid-Columbia River tributaries. In large part this is a fortuitous outcome from the lack of human interplay, a result of formidable topological and climatic barriers that restrict settlement. To be sure, there are problems in sustaining populations of salmonids, but, for the most part, these are minor, localized, and controllable compared to the mainstem Columbia River (Ebel et al. 1989; Chapman et al. 1991).

CHAPTER 7

WRAP-UP

Often in the past, the interplay between mankind and nature created environments ecologically stable, economically profitable, aesthetically rewarding, and compatible with the reality of civilization (Dubos 1973), and it can do so in the future. Good examples relevant to this study are reservoir tailwater trout fisheries in North America (Mullan et al., 1976; Hudy and Rider 1989), and the positive effect of sewage on striped bass (Morone saxatilis) in the Potomac River, Maryland, (Tsai et al. 1991) and on brown trout in the Au Sable River, Michigan (Merron 1982).

An exploding population in a generally affluent society means more utilization of natural resources. Aquatic ecosystems have some capacity to respond to burgeoning human demands, but compensatory function is limited. Society has always put expedience ahead of environmental protection, and though there are signs of change, there is no room for complacency. Responsible management of renewable resources demands preservation of capital and avoidance of speculative risk (Regier 1978).

In 1987, the Northwest Power Planning Council established an interim goal of doubling salmon and steelhead runs in the Columbia River from 2.5 million to 5 million adult fish. The great loss of salmon and steelhead in the Columbia River can be much more readily explained than how to restore them. And among the problems involved in restoring runs none is more intractable than the changed habitat and changed species composition of the mainstem. Relationships between resident fishes and migratory salmonids have been ignored except for effects of predation on salmonid smolts and vague interest in management of resident species. But, as usual, restoration plans have emphasized more hatchery programs (NPPC 1990).

If history--adaptive management of the Power Council--teaches anything, it teaches that hatchery programs cannot be trusted (Walters 1977; Hilborn 1991). The latest prescription for more hatchery fish calls for supplementation of natural populations of anadromous salmonids with juveniles originating from eggs taken from adult stocks. As we have demonstrated, mid-Columbia populations are stable, and tributary streams rear chinook salmon at carrying capacity. Massive enhancement with hatchery fish

threatens wild stocks with extirpation or population reduction from such affects as negative interactions, stock mining for eggs, and increased predation (including fishing harvest).

As so often emphasized, the collapse in the stock market in 1929 was implicit in the speculation that went before. Current speculation concerning potential enhancement of fish stocks may prove equally unfortunate.

> "Speculation within the Yakima subbasin plan points to historical returns to the Yakima [River] watershed of up to 200,000 fish. Collectively spring production within the other [mid-Columbia] watersheds may have at least equaled that level. It can be inferred that historic abundance levels of spring chinook returning to the upper Columbia watershed numbered in the hundreds of thousands [Integrated System Plan, NPPC 1990]."

Aside from the fact that the Yakima River watershed is much larger (6,585 mi^2) than the Wenatchee, Entiat, and Methow river watersheds combined (3,538 mi^2), there is no evidence that spring chinook salmon runs of this magnitude ever existed. Direct evidence for the abundance of anadromous salmonids that once existed in the Columbia Basin is woefully short in many areas. The contention that 85% of the sockeye salmon in the Columbia River once originated above Grand Coulee Dam is based on an observation of only two sockeye caught at Kettle Falls (the Indians reported many more) and 12 in a tributary to Arrow Lake in 1938 (Chapman 1941).

If we must speculate, let us speculate on a potential with a trifle more substance. The Fraser River--not its sister river, the Columbia to the south--was the largest producer of anadromous salmonids in the world and currently retains that position (Northcote and Larkin 1989). One of the major causes for high production is an abundance of moderately fertile nursery lakes, which produced a return of 15.8 million adult sockeye salmon in 1986.

By 1967, most of the Columbia River had been turned into reservoirs, of which 163,158 surface ac were accessible to anadromous salmonids--an increase over original river area of 68,516 ac. Just as the dams caused problems, they may offer solutions.

Fall chinook salmon that spawn in the Hanford Reach, perhaps the most viable stock remaining in the Columbia River, rear primarily in downstream reservoirs (Mullan et al. 1986; Rondorf et al. 1990). Some sockeye salmon that were introduced to tributaries of the mid-Columbia (1939-43) established stocks that used the reservoirs as nursery lakes (Mullan 1986). Production of up to 1.4 million smolts was estimated, which, however, declined drastically

as the reservoirs aged. Inter-dam escapement of adult summer/fall chinook salmon to Rocky Reach reservoir averaged only a little less (2,808) than escapement above Wells Dam (2,967), 1967 to 1985 (Mullan 1987). Most of these fish cannot be accounted for by numbers spawning in streams tributary to Rocky Reach Reservoir, and presumably they spawn in the reservoir.

Obviously, mid-Columbia reservoirs offer unexplored possibilities for anadromous salmonid management. Loss spawning areas in reservoirs would seem of small consequence, considering current hatchery potential. The relatively benign temperatures in reservoirs would seem suitable for conditioning of hatchery fish to the wild. Competitor and predator fishes could be removed from dam fish ladders during spawning migrations or managed by other means (Mullan et al.1986). It is likely, too, that salmonids spawned in the reservoirs and tributary streams would benefit from reservoir management.

Multispecies understanding of Columbia River fish populations is incomplete. Perhaps an understanding of the mechanisms that control and adjust the system will never exist, and not be missed. If so, however, the promise of Columbia River hatchery programs could remain unfilled. As pointed out by Li (1975) and others before him, you cannot understand the fish until you understand the world--or worlds in the case of salmon and steelhead--in which it swims.

Resource decisions are value judgments consisting of trade-offs between opposing options. Options for the management of salmonids are complete dependency on natural reproduction, intensive and extensive use of hatchery fish, or the judicial use of hatchery fish both numerically and geographically (Wagner 1977). We opt for the latter even though such a compromise may be the most difficult socially and biologically. The harvest of hatchery fish and not the muscle of wild fish is a particularly vexing problem with this option.

A balance between what an altered ecosystem can provide naturally in the way of fish and what can be stocked safely and cost effectively does not rest with projections of historical fancy. The past is irretrievable. What commands our attention is a new way of seeing and asserting the coherence of the Columbia River ecosystem as it exists now, tributaries as well as mainstem impoundments, salmonids as well as other fish, wild as well as hatchery fish.

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