AN ABSTRACT OF THE THESIS OF

David M. Price for the degree of Master of Science in Fisheries Science presented on November 30, 1998. Title: Multiscale Habitat Electivity and Movement Patterns by Adult Spring Chinook Salmon in Seven River Basins of Northeast Oregon.

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Abstract approved: ______

Hiram W. Li

I examined habitat electivity and movement patterns of adult spring chinook salmon at microhabitat and channel unit spatial scales, and seasonal to annual temporal scales in seven streams in the Grande Ronde, John Day, and Imnaha basins. The objective was to compare habitat use and availability among streams, channel units, and microhabitats, and to assess chinook salmon fidelity to those habitats using radio-telemetry. The analyses showed that habitat quality and availability in the seven study streams varied. Each stream posed different physical constraints on adult chinook salmon habitat; this was reflected by the differential use of habitat by salmon among streams. Salmon elected pools almost exclusively in the John Day Basin, whereas pools and riffles were elected in near equal proportion in the Grande Ronde and Imnaha basins. Within streams, use was similar between years. Almost all salmon were observed in association with cover, but the type of cover largely reflected availablity. Chinook salmon elected the deepest depths within channel units (microhabitat scale), but not necessarily the deepest channel units among streams (channel unit scale). Chinook salmon did not elect cooler stream temperatures within channel units in any study stream, except the Middle Fork John Day River. Radio-tagged chinook showed a high fidelity to habitats, except when stream temperatures approached lethal limits. Due to stream specific differences in habitat availability and use, multiscale habitat assessments for individual streams are recommended to increase the success of watershed restoration activities.

Multiscale Habitat Electivity and Movement Patterns by Adult Spring Chinook Salmon in Seven River Basins of Northeast Oregon.

by

David M. Price

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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David M. Price, Author

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INTRODUCTION

Pacific salmon stocks (*Oncorhynchus spp.*) are depressed throughout the Columbia River basin (NMFS 1996). As a result, spring chinook salmon (*Oncorhynchus tshawytscha*) in the Snake River basin are now listed for protection under the federal Endangered Species Act (US Congress 1973). Although discussions on the decline of salmon populations have centered on the impact of hydropower systems, habitat degradation and elevated temperature regimes also have contributed to the regional decline of salmon (Nehlsen et al. 1991). Reduced and degraded riparian habitat, diminished water quality and quantity, decreased channel complexity, increased fine sediment, and barriers to migration are the major habitat impediments to salmonid productivity (Meehan 1991, Peterson et al. 1992, Spence et al. 1996). The severity of the decline of salmonids and the complexity of degraded habitat features mandates immediate preservation and restoration actions (NMFS 1996). However, attempts to restore habitat often have failed to increase salmon abundance (Beschta et al. 1991, Reeves et al. 1991). Reeves et al. (1991) proposed that failure to consider habitat factors that limit salmonid production specific to individual streams may prevent successful salmonid restoration.

Several studies provide useful insight into the habitat selection of stream-dwelling salmonids. For example, Grossman and Freeman (1987) documented differential use of water column depth and small substrate by rainbow trout

(*Oncorhynchus mykiss*) in a small reach of a North Carolina stream. Heggenes et al. (1991) observed strong habitat election by cutthroat trout (*Oncorhynchus clarki*) for deep water and overhead cover in a small British Columbia stream. Indeed, optimal temperature regimes, depth, overhead cover, velocity refuge and substrate characteristics are vital components of salmonid habitat, yet the relative importance of each habitat component appears to vary by stream (Gorman and Karr 1978, Johnson and Kucera 1985, Moyle and Vondracek 1985, Baltz et al. 1987, Cunjak and Power 1987).

Most recent salmonid habitat electivity literature concerns resident trout and juvenile salmon. Very little research has addressed habitat characteristics of adult salmon in freshwater habitats. For example, Berman and Quinn (1991) documented thermoregulatory behavior by adult chinook salmon in the Yakima River, Washington, but they failed to report habitat use beyond "pool," "island," and "bank" descriptions. Although data are scarce, pools have been described as a vital component of freshwater habitat to adult salmon. For example, pools have been reported as important resting habitat for adult salmonids (Bjornn and Reiser 1991), and as refugia from large-scale disturbance such as drought and fire (Sedell et al. 1990). Pools also may be important to adult salmonids because of the relative depth they provide as protection from terrestrial predators (Bisson et al. 1982, Bjornn and Reiser 1991, and Nakamoto 1994). Perturbations from land management activities may have reduced pool availability from historical numbers. McIntosh (1992) recently described the loss of large pools in the Grande Ronde basin from 1941 to 1991 due to land management history. Large pools

(> $20m^2$ x > 0.9m deep) decreased from 6.1 pools / km in 1941 to 2.1 pools / km in 1991, a 57% reduction of large pool habitat (McIntosh et al. 1994).

In addition to habitat configuration, adequate stream temperature regimes are a vital element to adult salmonid habitat. The upper incipient lethal temperature (UILT) for adult salmon is 25°C (Brett 1952, Coutant 1970, Bell 1986, Armour 1991). Indeed, most salmonids risk death when stream temperatures exceed 23 - 25°C (Bjornn and Reiser 1991). Current stream temperature regimes on the Middle Fork John Day River may represent a substantial increase from historical accounts, and may be limiting salmonid habitat to upstream reaches (Torgersen 1996).

Although habitat association studies of stream dwelling fishes provide useful insights for population ecology, they may have narrow application because of their limited spatial scale. For example, many studies of habitat associations have focused on microhabitat selection of single species within single streams (Baltz et al. 1987, Shirvell 1989, Bozek and Rahel 1992, Shirvell 1994). Yet, physical characteristics such as climate, topography, geology, vegetation, valley form and channel morphology combine to form differing stream systems that constrain fish habitat availability (Poff and Ward 1990, Frissell et al. 1986). Nevertheless, specific species and life histories often are assumed by researchers to elect similar habitat conditions among streams (Shirvell 1994). For example, habitat models for monitoring and assessment often have used precise habitat definitions, rather than the range of conditions under which species occur (Reiser et al. 1989). One such model is the Instream Flow Incremental Methodology (IFIM) where minimum instream flow needed to support fish is predicted from stereotyped habitat variables (Bovee 1982). Comprehensive studies examining multi-scale habitat selection of salmonids among different stream systems appears lacking.

The use of available habitat by stream fishes may be a product of selection at scales ranging from microhabitat to drainage basins (Schlosser 1991). Further, assessments of fish habitat should be done in a hierarchical order to detect the influences of multi-spatial scale selection (Johnson 1980, Gregory et al. 1991). The choice of scale is important because the role of habitat refugia during disturbance may function at variable scales in individual streams (Sedell et al. 1990). For example, drought and subsequent stream temperature rises may serve as a form of natural and anthropogenic disturbance (Resh et al. 1988, Sedell et al. 1990). In response to increasing stream temperatures, adult spring chinook salmon were observed using stream habitat units with cooler temperatures than were available in adjacent channel units in the Yakima River, Washington (Berman and Quinn 1991). Other studies found the scale of thermoregulation to occur at microhabitat scales for adult steelhead (Nakamoto 1994), and rainbow and brown trout (*Salmo trutta*) (Matthews et al. 1994) in northern California streams (i.e., within channel units). However, Torgersen et al. (in press) showed that thermal refugia for adult chinook salmon may occur at multiple spatial scales, primarily at the reach level, in the John Day River, Oregon. Currently, no study has examined habitat electivity of adult salmon across both multiple spatial and temporal scales. In this study, I examined habitat use by adult spring chinook salmon at channel unit and microhabitat spatial scales, and at hourly to between-season temporal scales in seven streams of northeast Oregon.

The goal was to characterize summer habitat of adult spring chinook salmon and identify whether habitat factors may affect their survival in the John Day, Grande Ronde, and Imnaha River basins. The objectives of this study were: (1) to describe the basin-wide habitat available to adult chinook salmon in the John Day, Grande Ronde, and Imnaha rivers; (2) to describe the habitats and microhabitats elected by adult salmon in these watersheds; and (3) to determine the seasonal and annual variation in multi-scale habitat electivity by adult salmon.

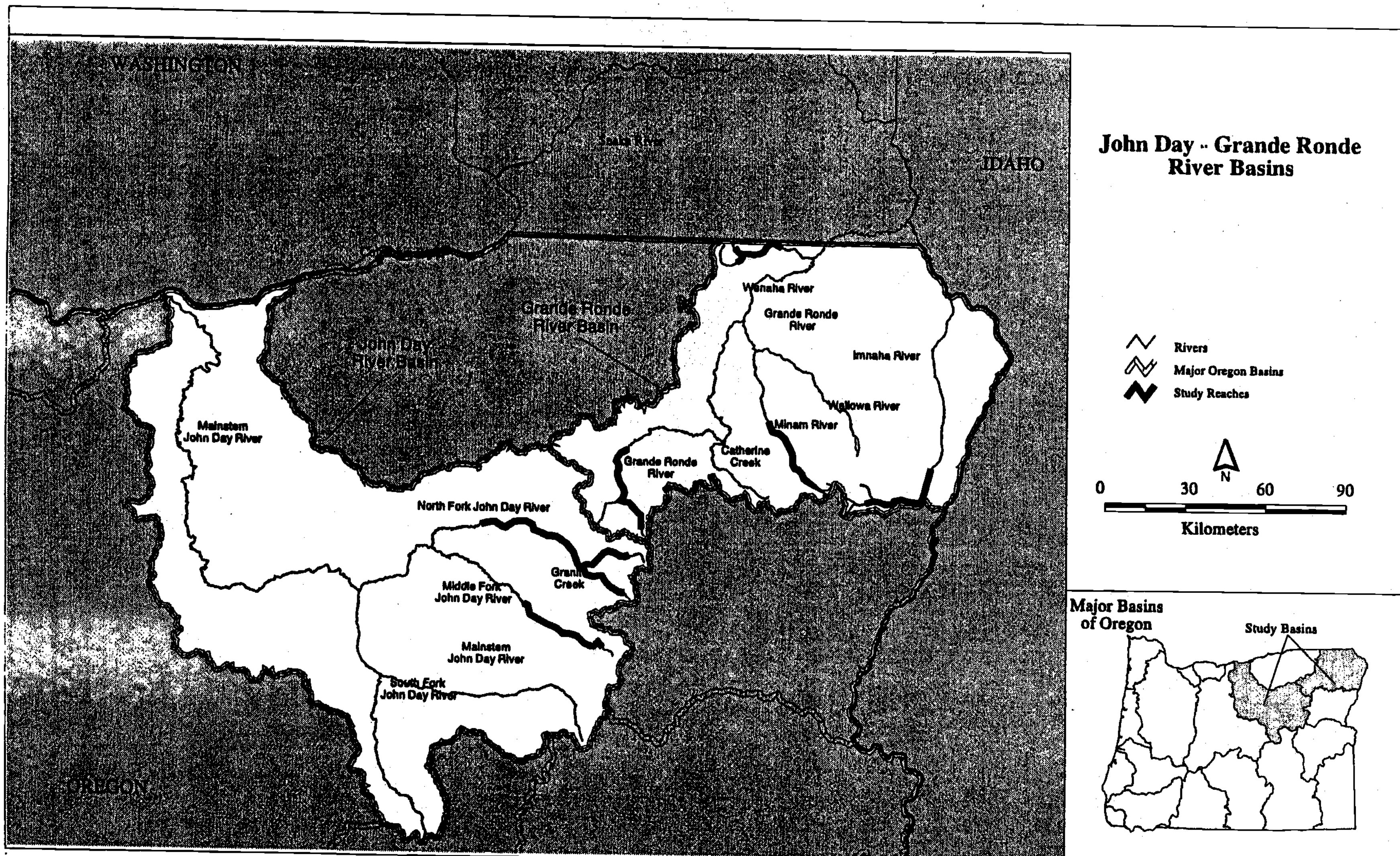
METHODS

Study Area

The Blue Mountains of Northeast Oregon and Southeast Washington cover a vast area and contain the Ochoco, Aldrich, Strawberry, Greenhorn, Elkhorn, and Wallowa ranges. Elevations range from 275 m in valley bottoms to 3,050 m in the highest peaks of the Wallowa Mountains. Collectively, these ranges form the headwaters that contain some of the strongest and weakest runs of spring chinook salmon in the Columbia River basin. Our study addresses the use of habitat by adult spring chinook salmon in tributaries of the John Day, Grande Ronde, and Imnaha rivers within the Blue Mountain physiographic province (Figure 1). The seven sub-basins selected for this study encompass a wide variety of land use histories and vary significantly in habitat condition. Four study streams flow through wilderness areas and two are privately managed for livestock and timber production.

The John Day basin drains roughly 20,300 km^2 in east central Oregon. The two primary tributaries are the North Fork (188 km) and Middle Fork (121 km). The study areas are confined to headwater reaches on the North Fork John Day River (NFJD), Granite Creek (a tributary of the North Fork John Day River), and the Middle Fork John Day River (MFJD). Anecdotal data were collected above Prairie City on the mainstem John Day River. These are the major holding and spawning streams of adult chinook salmon in the John Day River system (Howell et al. 1985, Lindsay et al. 1986).

Figure 1. John Day and Grande Ronde River study basins.



Subbasins within the John Day drainage basin vary widely in land use and habitat conditions. The North Fork John Day River had intensive mining activity until the 1940s (Oregon Water Resources Department 1986), and it lies partially in the North Fork John Day Wilderness. Habitat conditions include abundant large wood, healthy riparian forests, and relatively cool water. The North Fork John Day study area contains two distinct sections. The lower section lies outside of wilderness designation and is geomorphically unconstrained. The upper section is highly incised and is entirely within the North Fork John Day Wilderness. The Middle Fork John Day River also had intensive mining activity that ended in the 1940s, but unlike the North Fork John Day River, logging, road construction, and livestock grazing continue to be dominant sources of disturbance (Oregon Water Resources Department 1986). The Middle Fork John Day River is characterized by having low gradient, unconstrained alluvial valleys throughout much of its course.

The Grande Ronde River flows 342 km from its source to the confluence with the Snake River in northeast Oregon. The Grande Ronde River drains approximately 9,900 km^2 in the Blue and Wallowa Mountains. The study areas are in the upper reaches of the Wenaha (18 km), Minam (19 km), and upper Grande Ronde (37 km) rivers. These streams contain the majority of holding and spawning reaches in the Grande Ronde River basin (Thompson and Haas, 1960, and Jeff Zakel, Rich Carmichael, Oregon Department of Fish and Wildlife Biologists, pers. comm.).

The Wenaha and Minam rivers are wilderness streams with few anthropogenic influences. The Wenaha River flows easterly from headwater springs. It is constrained by steep canyon walls throughout much of its course with intermittent alluvial terraces. The Minam River flows northerly from headwaters originating in the western Wallowa Mountains and enters the Wallowa River, the largest tributary of the Grande Ronde River. The Minam River is characterized by high gradient, incised reaches that contain three distinct unconstrained sections. The upper Grande Ronde River experienced intensive mining activities, livestock grazing, splash dams, logging, and road construction which have contributed to high sediment yields (USDA 1994 and Wissmar et al. 1994) and elevated stream temperature regimes (Bohle 1994). The upper Grande Ronde River features relatively low gradient reaches that contain short sections of constrained valleys.

The Imnaha River drains approximately 2,380 km^2 from the eastern Wallowa Mountains and the Hells Canyon Plateau. The river flows northerly 129 km to the Snake River. The upper portion of the 30 km study reach is located in Wilderness designation and the lower reaches are owned and maintained by the US Forest Service and managed for low intensity recreation. The upper Imnaha River habitat conditions have been described as "good to excellent" (USDA 1992), and are characterized by high channel complexity and relatively cool stream temperatures flowing through broad, U-shaped valleys.

Field Surveys

Habitat surveys in each of the seven study streams were conducted to characterize habitat available to adult chinook salmon. Fish surveys using snorkeling techniques were conducted to record the habitat used by adult salmon, and their spatial extent and distribution. While conducting fish surveys, we concurrently collected random microhabitat availability data to determine whether or not salmon were selecting microhabitats randomly. To assess the consistency of habitat selection within relatively constant physical constraints, we selected four streams to examine habitat use between years.

Movement patterns of salmon were determined using radio-telemetry from spring through the end of summer. These data were used to examine fidelity to diel and seasonal habitats, and responses to changing environmental cues.

Habitat Surveys

Surveys were conducted to assess habitat available to adult chinook salmon in each of the seven study streams. Surveys of the Imnaha, Wenaha, Minam, upper Grande Ronde, and Middle Fork John Day River were conducted in 1993, while surveys of Granite Creek and the North Fork John Day River were conducted in 1994. Surveys began approximately 5 km below the lowest known extent of the adult salmon holding distribution and continued through the upper extent. Stream lengths sampled ranged from 14 to 72 km (Table 1). Due to limited access to private property, the Imnaha River survey began approximately 5 km above the lowest known extent of holding salmon distribution (Brad Smith, Oregon Department of Fish and Wildlife Fisheries Biologist, pers. comm.).

Table 1. Fish and habitat survey lengths, and number of adult salmon observations in Granite Creek, and the Imnaha, Middle Fork John Day (MFJD), Minam, North Fork John Day (NFJD), Wenaha, and upper Grande Ronde (UGR) rivers.

Stream	*Survey length (km)*	*Total salmon observed 1993*	*Microhabitat observations 1993*	*Total salmon observed 1994*	*Microhabitat observations 1994*
Granite Cr.	14.3	100	20	55	25
Imnaha R.	30.2	[a]	25	62	60
MFJD R.	42.2	68	35	92	55
Minam R	19.3	24	24	[b]	[b]
NFJD R.	72.3	[c]	[c]	302	133
Wenaha R.	18.3	23	23	17	17
UGR R.	36.8	32	7	1	1

[a] Total salmon observed in the Imnaha River was not accurately quantified in 1993.
[b] Minam River was not sampled in 1994.
[c] North Fork John Day River was not sampled in 1993.

Habitat surveys were conducted (Hankin and Reeves 1988) by classifying five channel unit types (Bisson et al. 1982: pool, glide, riffle, rapid, and cascade). For each channel unit, the following data were collected: unit type, length, mean width, mean depth, maximum depth of pools, valley constraint (constrained vs. unconstrained), quantity and size of woody material, substrate composition, dominant cover type, and the percent of channel unit area available as cover. Channel units were considered constrained if the valley width was estimated to be less than twice the active channel width.

Woody material was quantified relative to type (single piece or jam), volume, distribution, and potential use as salmon cover. The minimum size requirement for a wood piece was 2 m in length and 10 cm in diameter (Bilby and Ward 1989). I estimated length and diameter of all wood pieces meeting the minimum size requirement. Dimensions of woody debris were verified by measuring the length and diameter of about 10% of single pieces (Hankin and Reeves 1988). Wood jams were defined as aggregates of five or more pieces of woody material. In cases where wood occurred as jams, total volume (length x width x height, including interstitial spaces) and the number of pieces meeting the minimum size requirement were estimated. The distribution of woody material in wetted and active channel zones was determined, based on the method used by Robison and Beschta (1990). Only woody material in the wetted channel was assessed for its potential use as cover for adult salmon.

Substrate type was recorded in seven size classes based on diameter. Substrate size classes included: organic debris, sand and mud (< 2 mm), small gravel (2 - 9.9 mm), large gravel (10 - 99 mm), cobble (100 - 299 mm), boulder (≥ 300 mm), and bedrock.

The dominant, or most abundant, instream cover type was recorded for each channel unit during habitat surveys. Cover types included woody debris, boulders, undercut banks (≥ 1 m long and ≥ 0.5 m wide), turbulence, overhead and aquatic vegetation, and depth (≥ 0.8 m). Total cover available to adult salmon was recorded as an estimated percentage of area in each channel unit. Cover was considered to be available to adult salmon if it was within 0.5 m above the wetted channel (Brown and Mackay 1995) and when stream depths were > 10 cm. We assumed that depths < 10 cm would be unoccupied by adult salmon because about half of their body would be exposed.

Fish Surveys

Fish surveys were conducted throughout the study reaches of each stream to examine the distribution and habitat used by adult spring chinook salmon. Fish surveys were conducted using snorkeling techniques, 22 July to 13Aug, 1993 and 12 July to 15 Aug, 1994. Streams were surveyed once. Observations were completed between 0900 and 1700 hours. In most cases, one snorkeler per reach conducted surveys in an upstream direction, usually making a single pass through a channel unit. Snorkelers reported fish numbers, locations, and habitat use data to bank observers.

Adult salmon were observed for habitat use at channel unit and microhabitat scales. Channel unit habitat variables included: unit type, fish position in the channel (mid-channel or bank association), dominant substrate type, and total number of adult chinook observed in the channel unit. Microhabitat variables included: focal (fish snout location) and thalweg temperature, focal depth and total depth (depth of the water column at the focal point location), focal substrate type and cover type used. All observed fish were counted, but only non-moving fish maintaining their position in the channel (i.e., apparently undisturbed) were observed for microhabitat use data. Detailed sketch maps were drawn by bank observers of channel units containing fish to provide a context of habitat availability and specific focal habitat locations.

Stream temperatures were measured with hand-held digital thermometers (± 0.1°C). Focal temperature measurements were collected within 1 m of the head of each fish. Thalweg temperature measurements were taken in the main stream flow, laterally adjacent to each fish.

Cover categories were matched to those in habitat surveys. In 1993, each fish was recorded as using a dominant cover type. In 1994, each cover type was categorized as either being used or unused by each salmon observed.

Microhabitat Availability Surveys

After recording data on undisturbed fish, we conducted a survey to compare microhabitat use to availability; habitat availability was determined from random samples within a given channel unit containing salmon. We selected two random locations per microhabitat observation to obtain random depth, stream temperature, cover type, and substrate type availability. A random sample point, one each upstream and downstream of each fish, was used to represent availability at the microhabitat scale. Cover was considered randomly available if it was within a 0.5 meter radius of sample points.

Movement Patterns

Movement patterns of 20 adult salmon were monitored in 1994. Salmon were caught while migrating on the Middle and North Forks of the John Day River 5 km below known holding reaches. Passive wire-mesh weir traps and dip nets were used. Fish were quickly transferred to a 100 liter fiberglass tub containing 50 mg/l of anesthetic (tricaine methane sulfonate, MS-222). Once a fish was anesthetized, a temperature sensitive Lotek™ radio-transmitter (149.358 - 149.719 mHz, 16.4g) was inserted orally into the gut. Fish length, sex and physical condition were recorded before release in the stream. The process of capture and recovery lasted about 5 minutes.

Salmon migration was monitored using radio receivers operated from the air (fixed-wing aircraft) or on the ground (truck or on foot) until all fish began holding. Once salmon stopped migrating, their use of habitat was monitored throughout the summer. Seasonal movement patterns were monitored after upstream migrations had ceased for one week. Fish were tracked at least twice per week.

Seasonal Movement of Radio-Tagged Salmon

Precise locations of salmon were determined from the ground using precision control adjustments on the telemetry receiver and by triangulation. Use of specific habitat features could be estimated within 0.5 meters in the Middle Fork John Day River and within 3.0 meters in the North Fork John Day River. Habitat data collected on holding radio-tagged salmon included the following variables: focal temperature (obtained through the telemetry receiver), thalweg temperature, channel unit type, position in the channel, dominant substrate, cover type, and river kilometer (rkm). Radio-tags were calibrated relative to hand-held thermometers after field data were collected. Detailed sketch maps of each channel unit containing tagged salmon were drawn to provide a reference for future locations and to track the seasonal and daily movement patterns of salmon.

Daily Movement of Radio-Tagged Salmon

Daily activity patterns of radio-tagged salmon were assessed in the Middle Fork John Day River on five occasions to observe behavior during times of high stream temperature, and to determine the home range size and fidelity to holding habitats. Five radio-tagged salmon were monitored on several occasions at 10 - 60 minute intervals for periods extending to 24 hours in July, 1994. Cover use was described during daylight hours, and movement patterns, focal temperatures, and thalweg temperatures were recorded day and night. Detailed sketch maps were drawn to record precise salmon locations and a context for movement patterns.

Stream Temperature

Temperature data provided information on the thermal patterns to which salmon were exposed. Stream temperatures were recorded in all study streams to provide temporally continuous thalweg temperatures. Temperature monitors (HoboTemp™) were deployed within well-mixed riffles at the lowest known extent of adult salmon holding habitat in all study streams (n=7 HoboTemp loggers). HoboTemp loggers were programmed to collect stream temperature data at 30 minute intervals (± 0.1°C) during the period of 1 June to 30 September in 1993 and 1994. Post-study calibration experiments indicated that all monitors were accurate to within ± 0.2°C.

Data Analyses

Adult salmon habitat electivity was analyzed at two spatial scales. The channel unit scale addresses habitat available and habitat used by salmon within individual streams and among channel units. The microhabitat scale addresses habitat electivity among other microhabitat features within channel units. All statistical significance values were tested at the $\alpha < 0.05$ level.

Channel Unit Scale

Channel unit area available was established as the measure to gauge electivity by adult salmon at the channel unit scale. Channel unit areas were corrected for estimator bias (Hankin and Reeves 1988). For each stream, areas were summed for each channel unit type then divided by survey length to obtain the total area available to adult salmon by channel unit type. Rapids and cascades were included in the riffle category during analysis because habitat estimators were inconsistent among streams when categorizing high gradient channel units. Channel unit availability and use by salmon was compared for each stream (Chi Square analysis). Similarly, the use of channel units among years was compared within streams (Chi Square analysis).

Habitat use was compared to that available at the channel unit scale for substrate and total cover. Availability was determined by multiplying the percentage of each substrate size class and cover type by channel unit area. The resulting area was then summed within each stream and divided by 100 to obtain a percentage of each substrate size class and cover type. We compared the use and availability of substrate size classes (Kolmogorov-Smirnov two-sample tests). Similarly, the use of substrate size classes was compared between years (Kolmogorov-Smirnov two-sample tests). Kolmogorov-Smirnov two-sample tests also were used to determine if the use of specific cover types differed from availability, and whether or not the distribution of cover types used by salmon were similar between years.

Total depth of locations occupied by salmon was compared among streams (ANOVA). Similarly, we compared focal depths (surface to snout) among streams (ANOVA). Focal depths and total depths were compared between years in the Wenaha, Imnaha, and Middle Fork John Day rivers, and Granite Creek (two-tailed t-tests).

Microhabitat Scale

Microhabitat scale analyses included the comparison of fish survey data and microhabitat availability surveys. Variables analyzed included temperature, depth, and cover. Microhabitat availability was determined from random coordinates within channel units containing salmon. We examined whether or not salmon were found in stream areas with lower temperatures than were available randomly or in the thalweg (one-tailed, paired t-tests). We assessed if depths elected by salmon were deeper than those randomly available (one-tailed, paired t-tests). Cover use was compared with availability to determine whether salmon were using cover in greater frequency than would be randomly available.

RESULTS

Across seven streams in the Blue Mountain physiographic province, a total of 233 river kilometers were assessed for fish use and fish habitat availability. In 1993, 247 adult chinook salmon were observed in the Imnaha, Middle Fork John Day, Minam, upper Grande Ronde, and Wenaha rivers and Granite Creek (table 1). In 1994, 529 fish were observed in the Imnaha, Middle Fork John Day, North Fork John Day, and Wenaha rivers and Granite Creek.

Channel Unit Scale

Channel unit types were not available to salmon in equal proportions. In all study streams, riffles were the dominant type of channel unit available to fish, ranging from 55-85% by area. In comparison, pools ranged from 10-38% of the available habitat in all study streams. Glides were uncommon, except in the Middle Fork John Day River (20%).

Differences between channel unit use by adult salmon and availability was found for all streams. Pools were the dominant channel unit used by adult salmon in 1993 and 1994 in the John Day watershed (figure 2; i.e., NFJD, MFJD, and Granite Cr.). The use of pools ranged from 97% in Granite Creek to 83% in the North Fork John Day River in 1994. Channel unit use in the Wenaha, Minam, and Imnaha River streams, however, was more evenly divided between pools and riffles. The use of pools ranged from 35% in the Wenaha River to 85% in the upper Grande Ronde River in 1993. Glides were used infrequently in all streams, and were the least frequent unit type available.

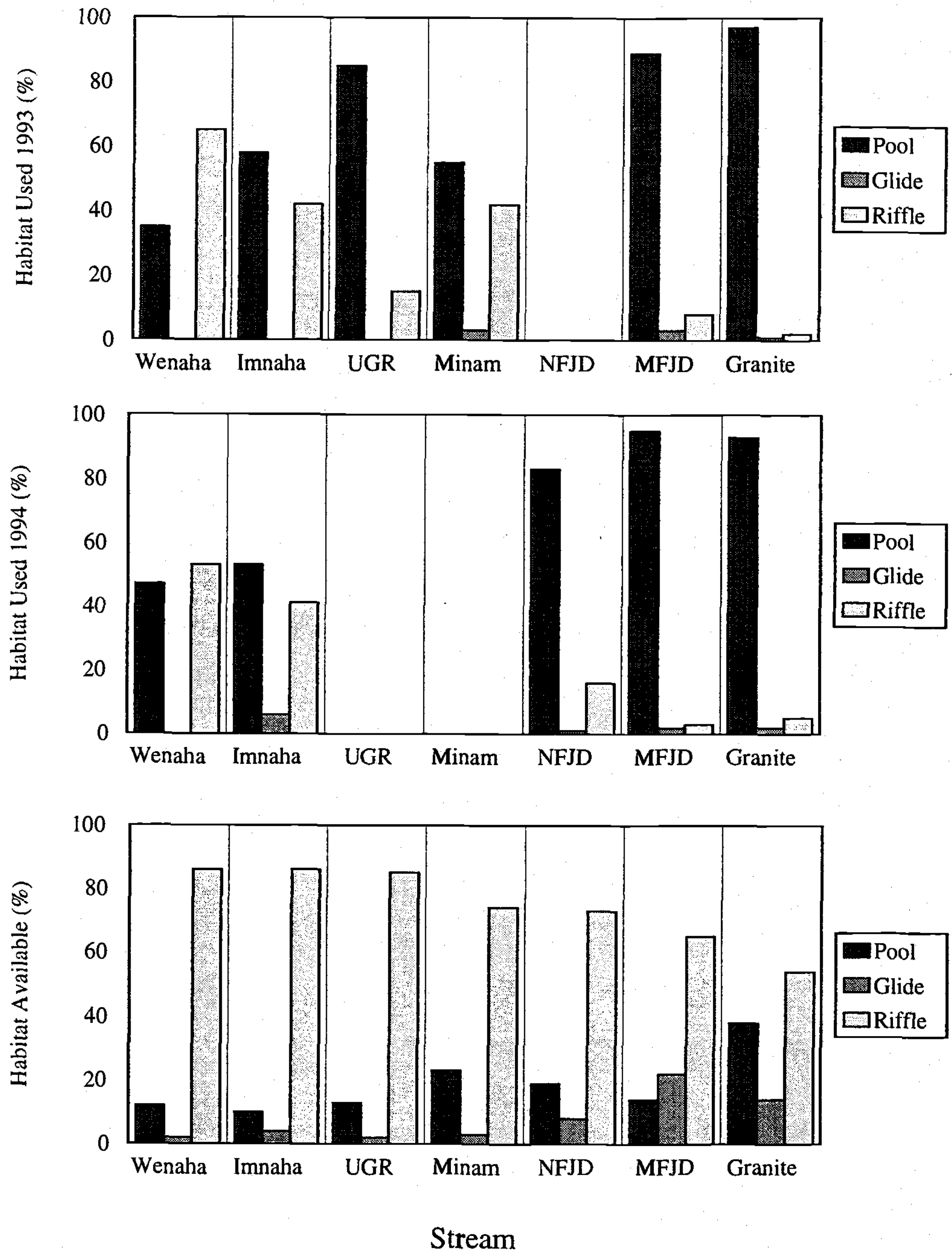


Figure 2. Habitat electivity of adult chinook salmon in the Wenaha, Imnaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek in 1993 and 1994.

Channel unit use was not different between 1993 and 1994 within the Wenaha ($p = 0.084$), Imnaha ($p = 0.054$), and Middle Fork John Day rivers ($p = 0.263$), and Granite Creek ($p = 0.427$).

Cover appeared to be an important component of habitat for adult chinook salmon. In 1994, almost all fish observed in wilderness streams used cover. In 1993, 9% of fish in the Wenaha River were not associated with cover, but in all other wilderness streams sampled during the 1993 population census, fish were always observed in association with cover. In the Middle Fork John Day River, 8% and 15% of fish were not using cover in 1993 and 1994, respectively. In 1993 and 1994 Granite Creek surveys, 5% and 4% of fish were observed without cover, respectively.

Stream temperature profiles differed widely among streams and years. Stream temperatures recorded on the Middle Fork John Day River in 1994 were the highest observed throughout the study. In 1994, maximum stream temperatures exceeded the reported upper incipient lethal temperature (UILT) for chinook salmon (25°C; Brett 1952, Bell 1986, and Armour 1991) for 43 consecutive days beginning on 8 July (figure 3). Maximum summer stream temperatures peaked on 23 July at 30.0°C. Maximum stream temperatures exceeded 25°C on 9 consecutive days on the North Fork John Day River and on 7 days on Granite Creek. Stream temperatures on the Minam, Imnaha, and Wenaha rivers rarely exceeded 20°C in either year, and never approached 25°C.

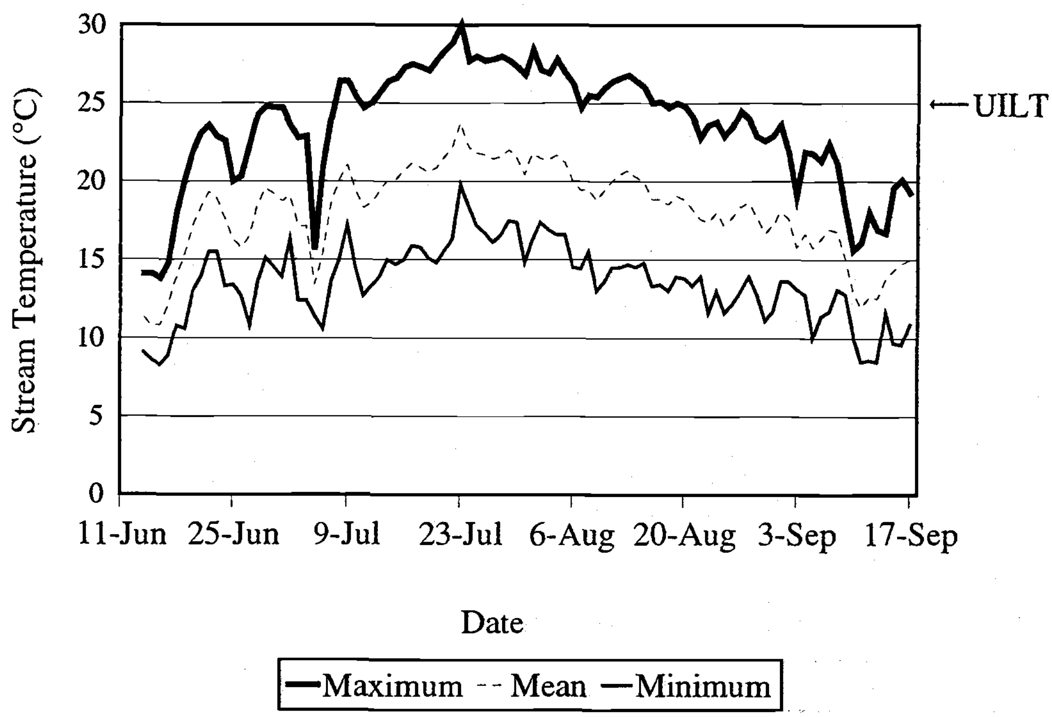


Figure 3. Maximum, mean, and minimum daily stream temperatures in the Middle Fork John Day River at Big Creek in 1994. The upper incipient lethal temperature (UILT) is reported at 25°C (Brett 1952, Bell 1986, and Armour 1991).

Microhabitat Scale

Stream temperatures occupied by holding salmon were not lower than thalweg temperatures in any stream in either 1993 or 1994. Differences were observed between focal and mean random temperatures in the North Fork and Middle Fork John Day rivers and Granite Creek in 1994. Differences appeared most pronounced when stream temperatures exceeded 20°C on the Middle Fork John Day River, although this pattern was not apparent in the North Fork John Day River and Granite Creek (figure 4).

Adult salmon were closely associated with the bottom of the stream channel. In 1994, mean distances above the substrate (substrate distance) were lowest in Granite Creek (0.08 m) and highest in the Imnaha River (0.26 m; table 2). Conversely,

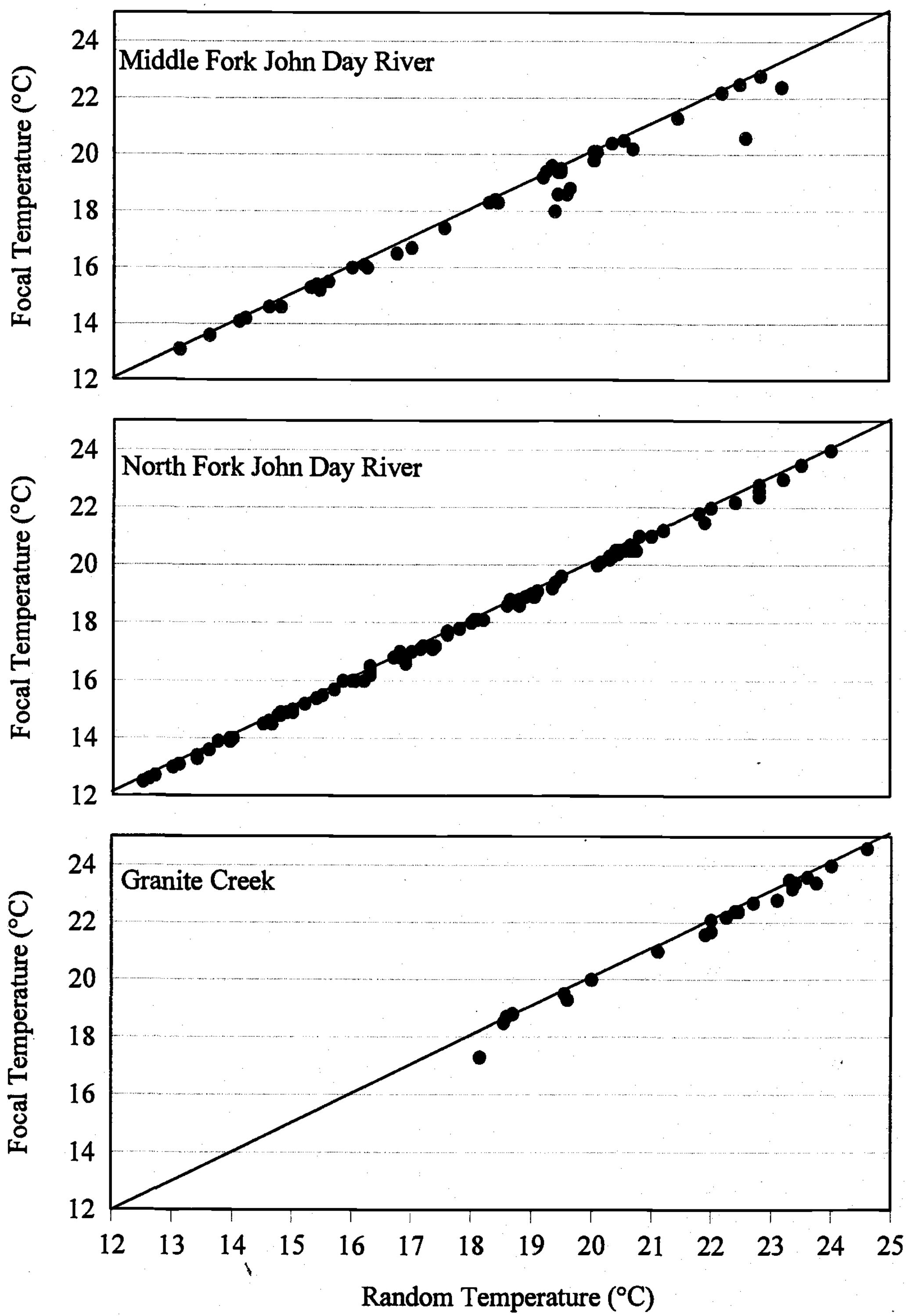


Figure 4. Focal temperature of adult chinook salmon versus mean random stream temperature during fish surveys of the Middle Fork and North Fork John Day rivers and Granite Creek in 1994. Data points below the line represent electivity for cooler stream temperatures than available randomly.

in 1993, substrate distances were highest in Granite Creek (0.38 m) and lowest in the upper Grande Ronde (0.09 m) (table 3).

Table 2. Focal, total, and random depths and distance above the substrate (±SE) of adult chinook salmon in Granite Creek, and the Imnaha, Middle Fork John Day (MFJD), North Fork John Day (NFJD), and Wenaha rivers in 1994.

Stream	*Focal depth*	*Total depth*	*Substrate distance*	*Random depth*
Granite Cr.	0.90 (0.11)	0.97 (0.11)	0.08 (0.01)	0.80 (0.09)
Imnaha R.	0.63 (0.05)	0.88 (0.07)	0.26 (0.04)	0.54 (0.04)
MFJD R.	0.47 (0.05)	0.57 (0.04)	0.10 (0.01)	0.45 (0.04)
NFJD R.	0.78 (0.04)	0.93 (0.04)	0.16 (0.01)	0.52 (0.05)
Wenaha R.	0.61 (0.13)	0.79 (0.15)	0.17 (0.02)	0.38 (0.04)

Table 3. Focal, total, and distance above the substrate (±SE) of adult chinook salmon in Granite Creek, and the Imnaha, Middle Fork John Day (MFJD), Minam, Wenaha, and upper Grande Ronde (UGR) rivers in 1993.

Stream	*Focal depth*	*Total depth*	*Substrate distance*	*Random depth*
Granite Cr.	0.90 (0.20)	1.35 (0.20)	0.38 (0.08)	[b]
Imnaha R.	0.62 (0.07)	0.75 (0.07)	0.13 (0.02)	[b]
MFJD R.	0.61 (0.05)	0.72 (0.05)	0.11 (0.02)	[b]
Minam R.	0.69 (0.07)	0.81 (0.07)	0.16 (0.02)	[b]
Wenaha R.	0.62 (0.06)	0.82 (0.07)	0.20 (0.03)	[b]
UGR R.	0.62 (0.08)	0.71 (0.08)	0.09 (0.03)	[b]

[b] Random depths were not sampled in 1993.

Focal depths were not different in streams with paired data among years. Mean focal depths were not different in the Imnaha ($p = 0.74$), Wenaha ($p = 0.14$), and Middle Fork John Day ($p = 0.26$) rivers and Granite Creek ($p = 0.09$) between 1993 and 1994. However, mean focal depths were different among streams in both years. Mean focal depths were shallowest in the Middle Fork John Day River in both 1993 and 1994.

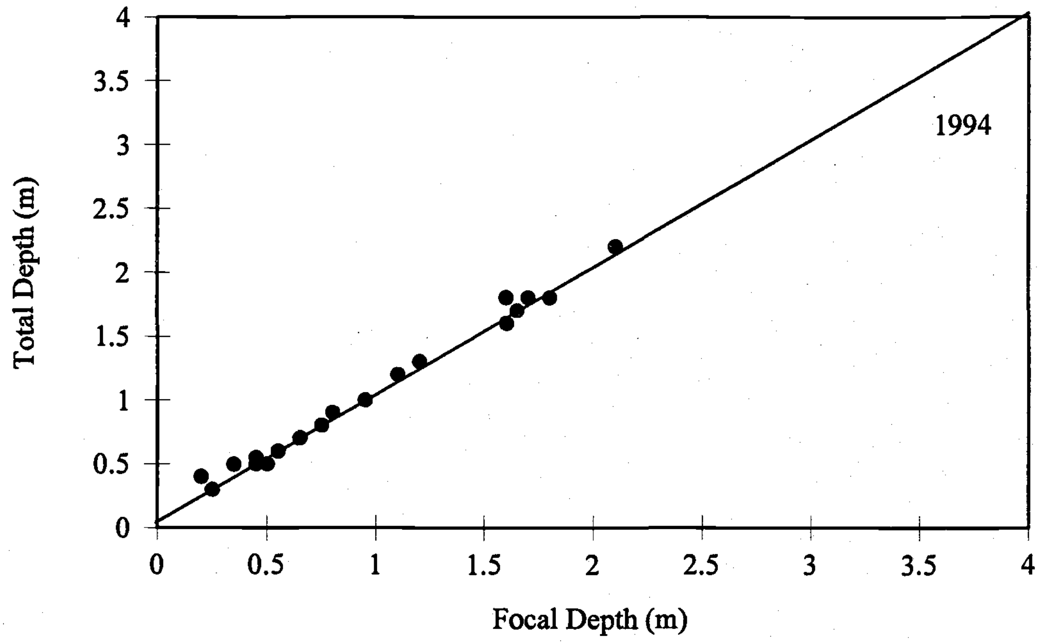
Although the depth of sites occupied by adult salmon differed among streams, they were similar between years. Total depths did not differ between years in Granite Creek ($p = 0.08$; figure 5), and the Imnaha ($p = 0.29$; figure 6) and Wenaha ($p = 0.82$;

figure 7) rivers. In the Middle Fork John Day River (figure 8), total focal depth was different between years ($p = 0.04$).

Adult salmon were rarely found in focal depths < 0.25 m. In 425 microhabitat observations, 17 fish (4%) were observed holding in depths < 0.25 m. Fish were never observed at depths < 0.18 m during population surveys.

Total focal depths were compared to random depths to determine whether salmon elected depths deeper than might be available within channel units. Total focal depths were deeper than mean random depths in four of five streams during the 1994 fish survey (Imnaha, $p < 0.0005$; Wenaha, $p = 0.002$; Middle Fork John Day, $p = 0.005$; and North Fork John Day, $p < 0.0005$; Granite Creek, $p = 0.105$). Random depths were not sampled in 1993.

The electivity of substrate types varied among streams in both years. Use and availability of substrate size classes by adult salmon was different in 1993 and 1994 in Granite Creek (figure 9) and the Wenaha River (figure 10). Distributions were not different in the Imnaha River (1993 and 1994) (figure 11), the Minam River (1993) (figure 12), or the North Fork John Day River (1994) (figure 13). The proportion of substrate size class use was different in the Middle Fork John Day River in 1993, but not in 1994 (figure 14). Differences in the distribution frequencies of substrate sizes used by salmon between years were not different in the Imnaha ($p = 0.474$), Wenaha ($p = 0.369$), and Middle Fork John Day ($p = 0.211$) rivers and Granite Creek ($p = 0.111$).



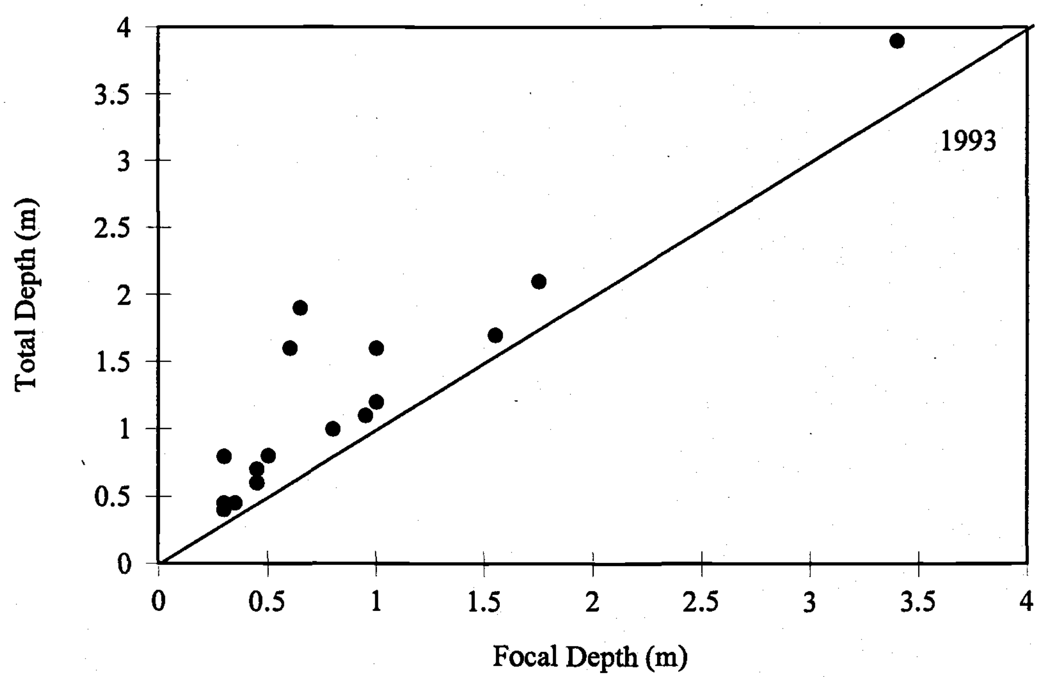
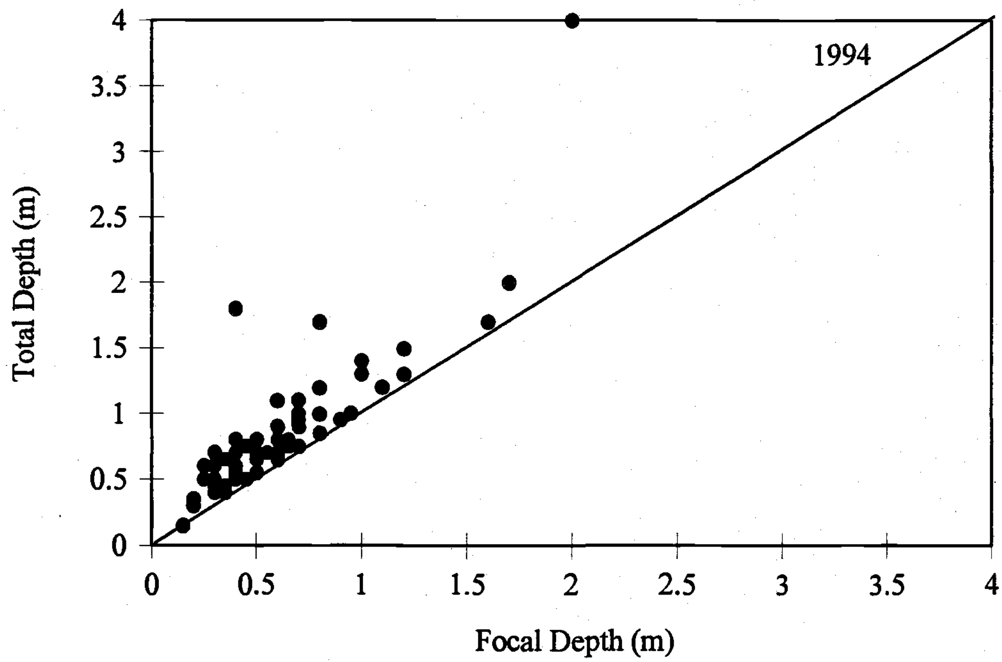


Figure 5. Focal depth of adult chinook salmon as a function of total depth during fish surveys of Granite Creek.



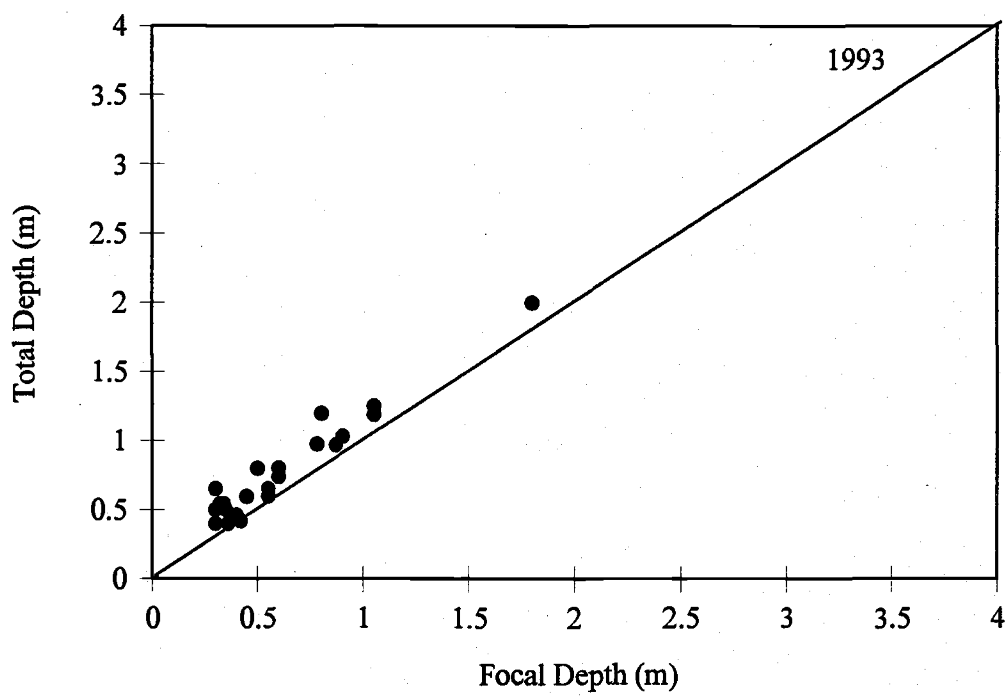
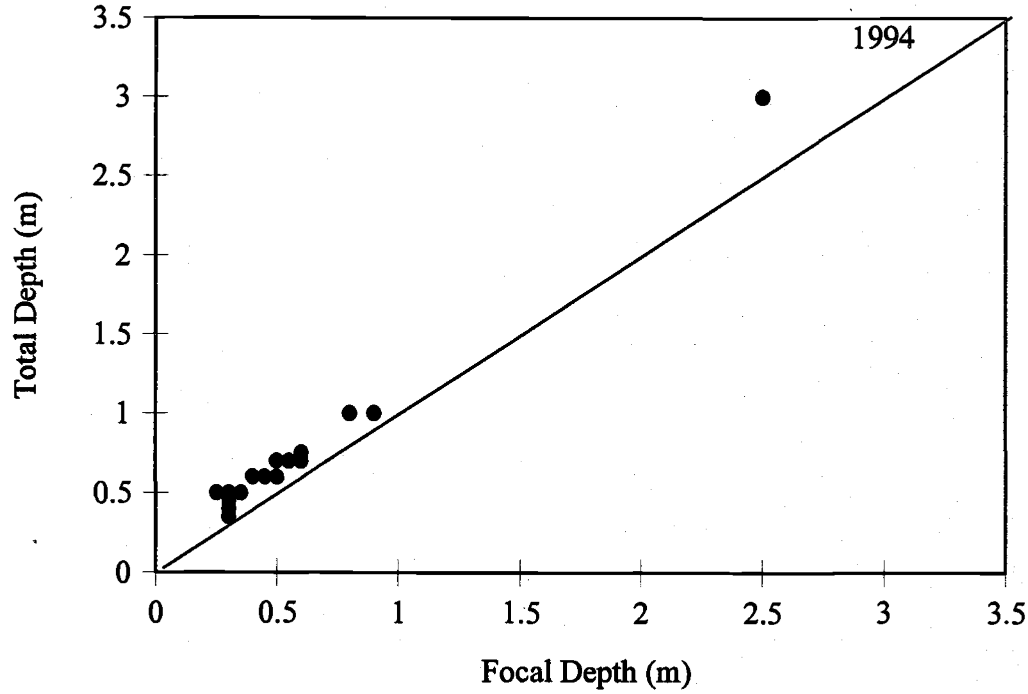


Figure 6. Focal depth of adult chinook salmon as a function of total depth during fish surveys of the Imnaha River.



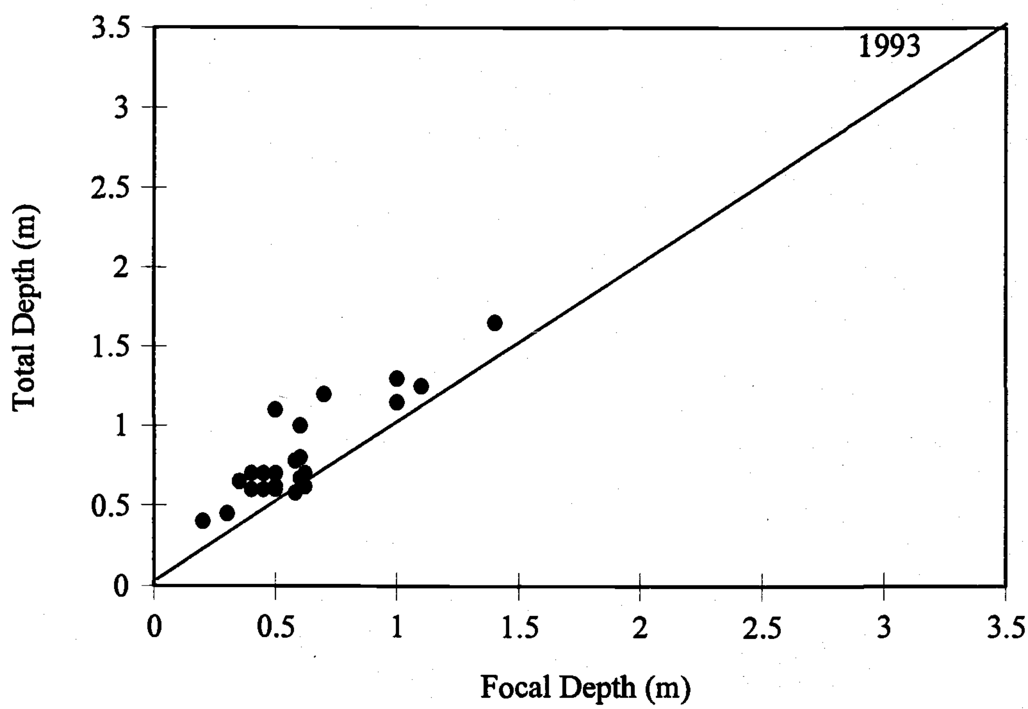


Figure 7. Focal depth of adult chinook salmon as a function of total depth during fish surveys of the Wenaha River.

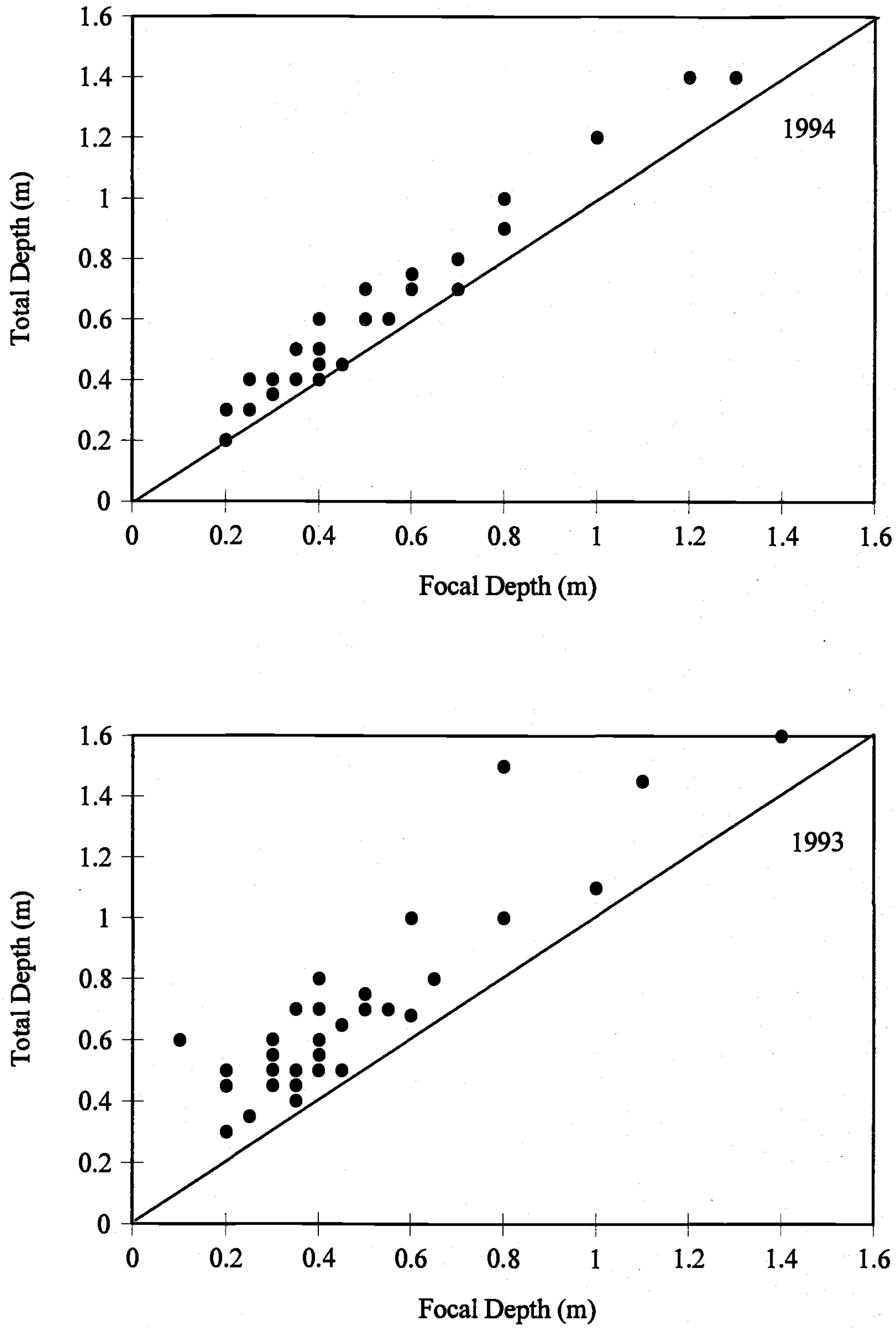


Figure 8. Focal depth of adult chinook salmon as a function of total depth during fish surveys of the Middle Fork John Day River.

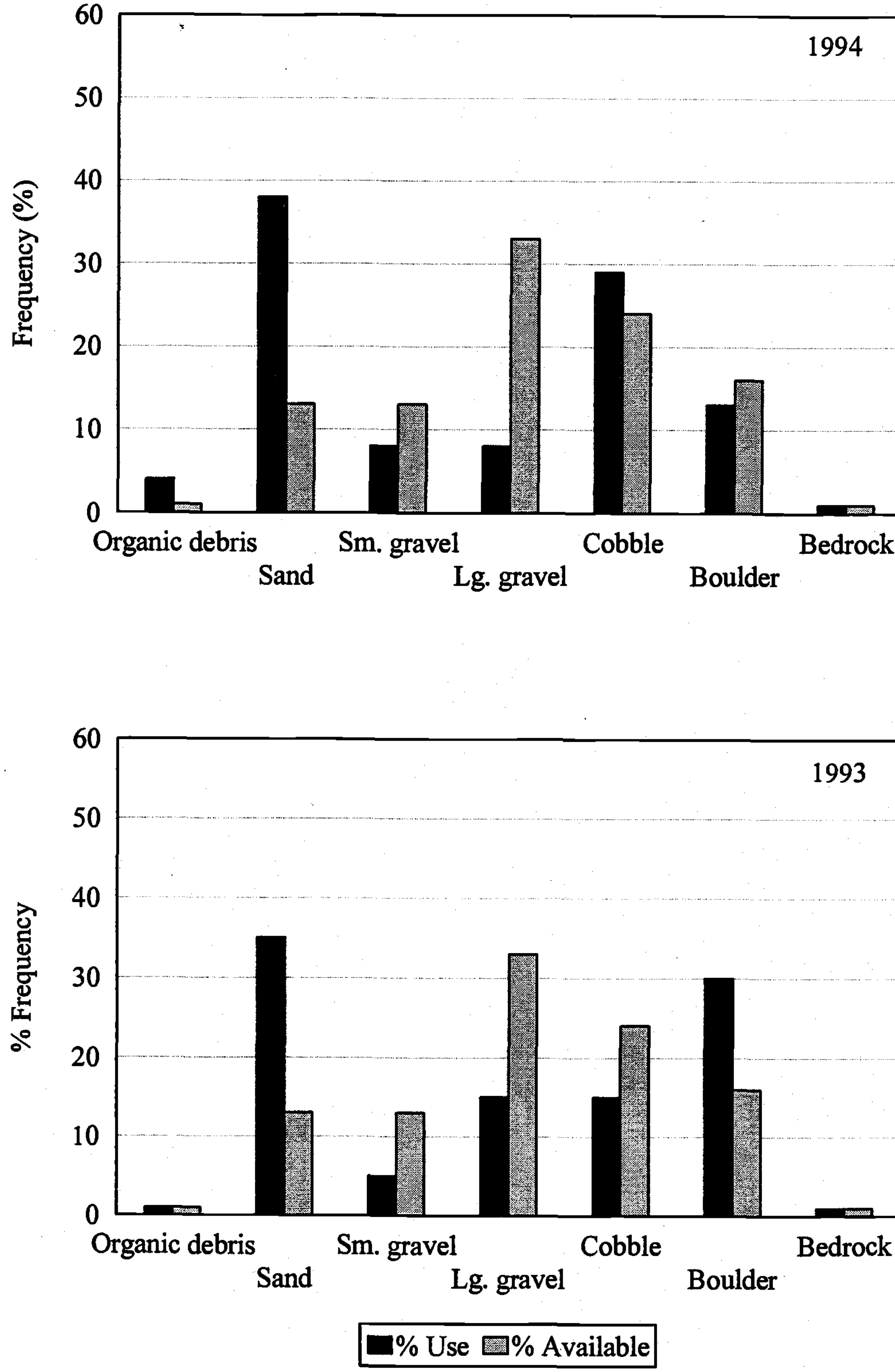


Figure 9. Substrate selection of adult chinook salmon in Granite Creek in 1993 and 1994.

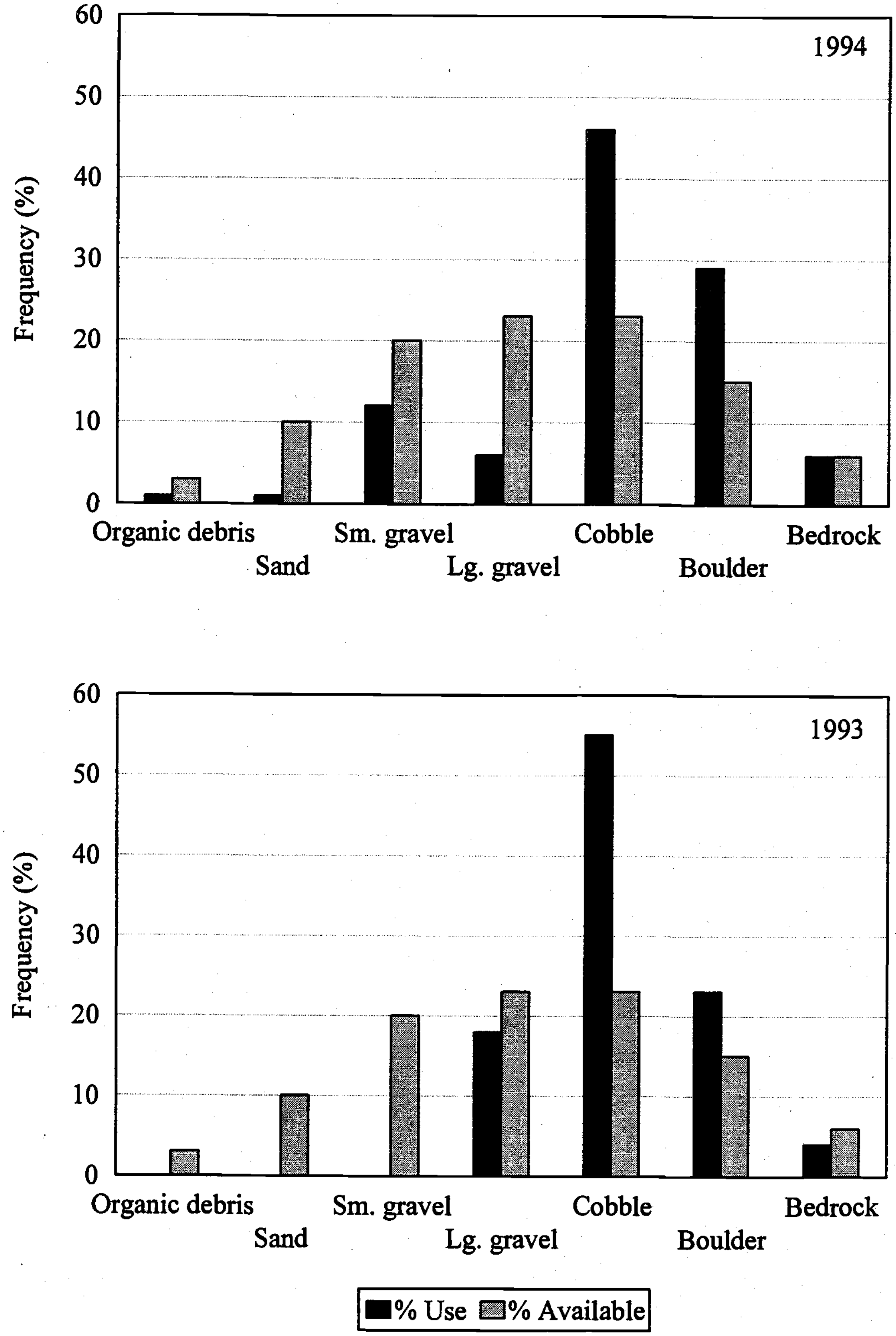


Figure 10. Substrate selection of adult chinook salmon in the Wenaha River in 1993 and 1994.

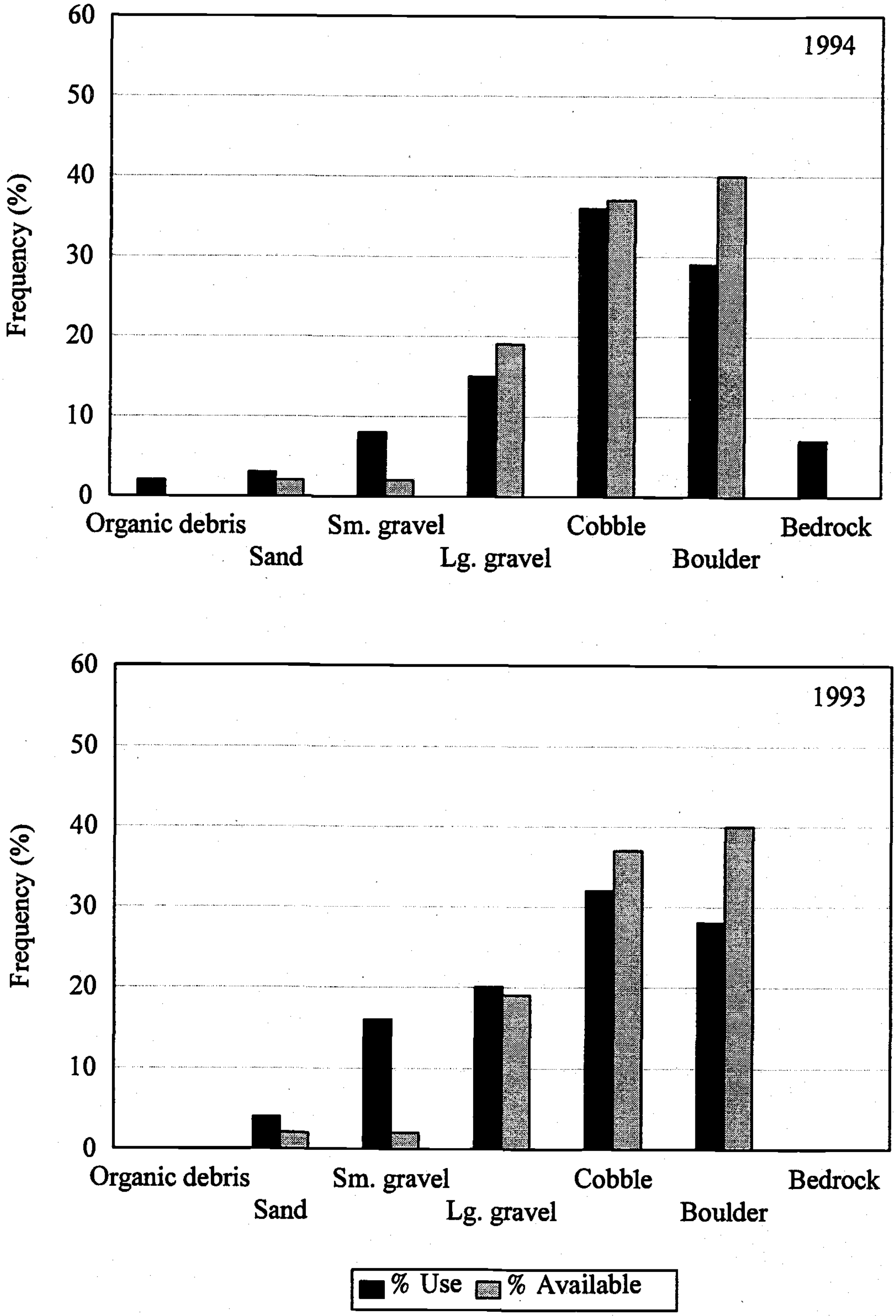


Figure 11. Substrate selection of adult chinook salmon in the Imnaha River in 1993 and 1994.

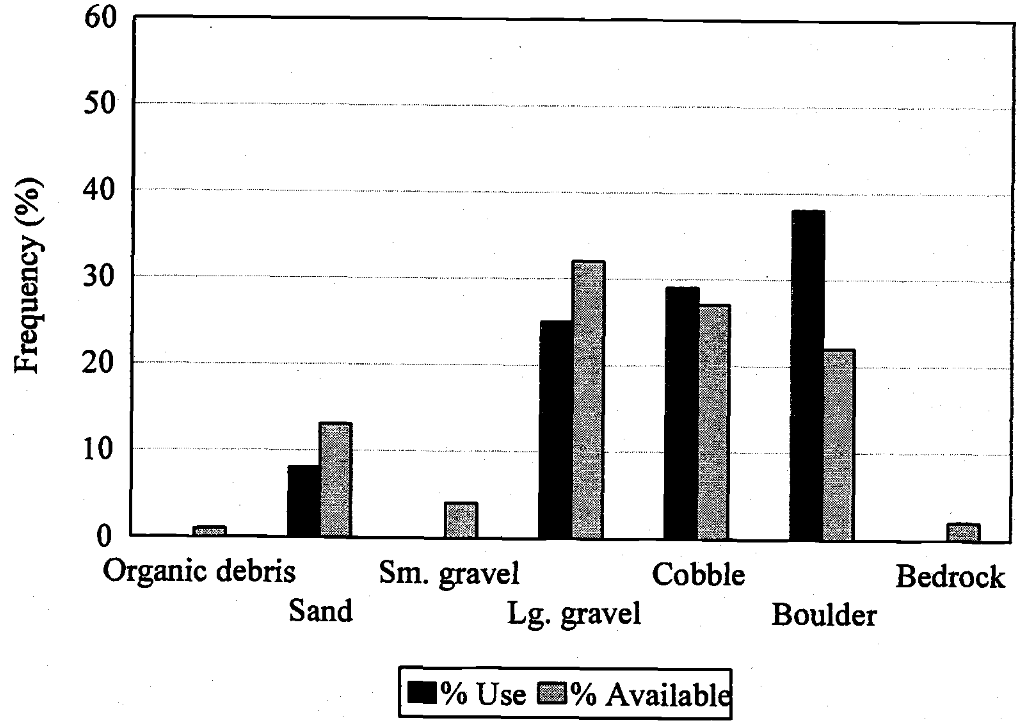


Figure 12. Substrate selection of adult chinook salmon in the Minam River in 1993.

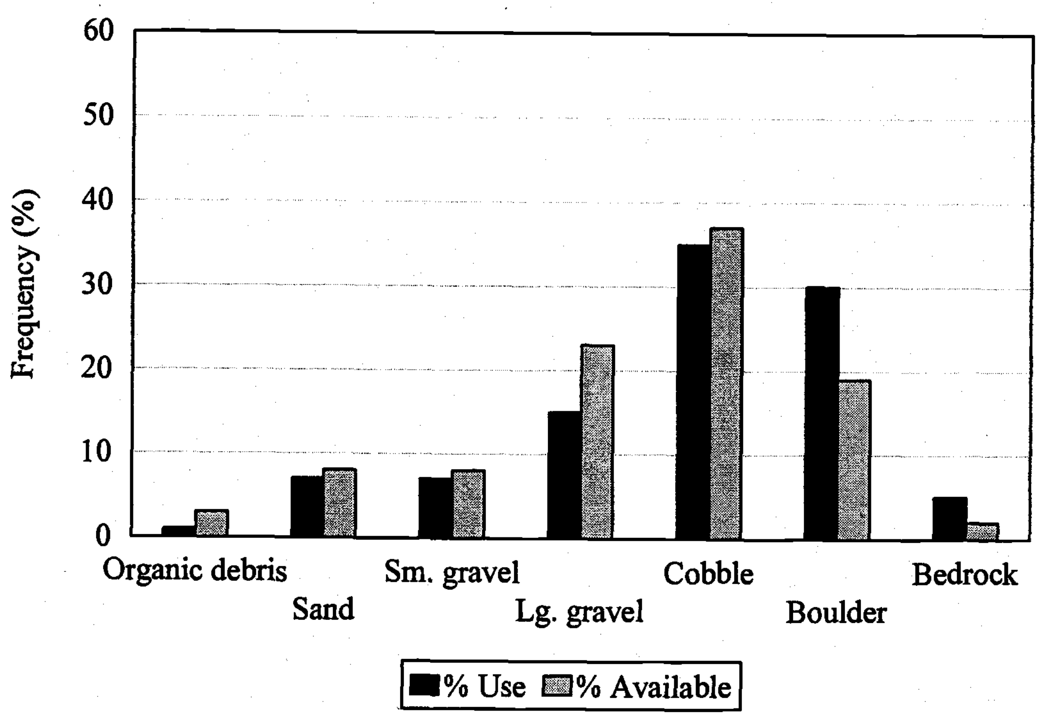


Figure 13. Substrate selection of adult chinook salmon in the North Fork John Day River in 1994.

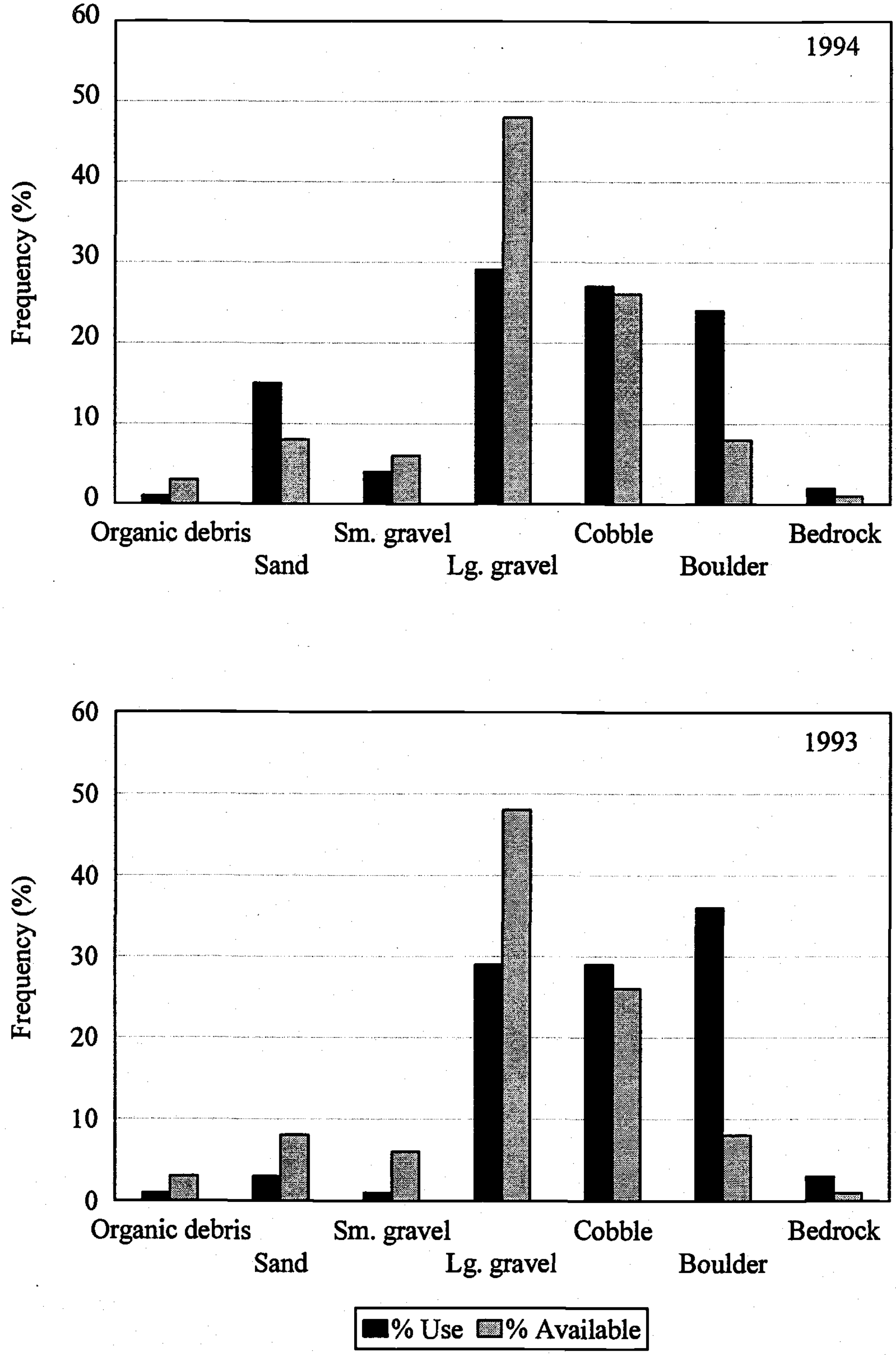


Figure 14. Substrate selection of adult chinook salmon in the Middle Fork John Day River in 1993 and 1994.

The type of cover used between years was different in the four streams with paired data. For example, the use of woody debris decreased 28% in the Imnaha (figure 15) and 20% Middle Fork John Day (figure 16) rivers, and Granite Creek (9%) (figure 17) from 1993 to 1994. Woody debris increased 6% in the Wenaha River (figure 18). The use of mid-channel cover types increased from 1993 to 1994. An increase in the use of depth (≥ 0.8 m), for instance, was observed in all streams. Similarly, the use of turbulence increased in the Imnaha, Wenaha, and Middle Fork John Day rivers, but decreased slightly in Granite Creek.

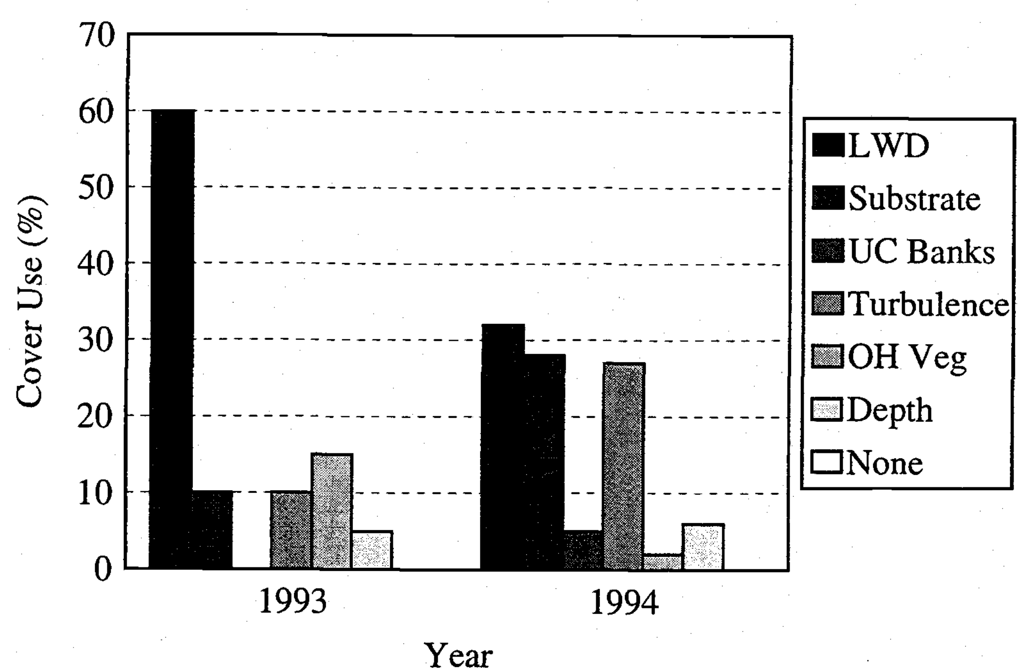


Figure 15. Frequency of cover use in the Imnaha River in 1993 and 1994.

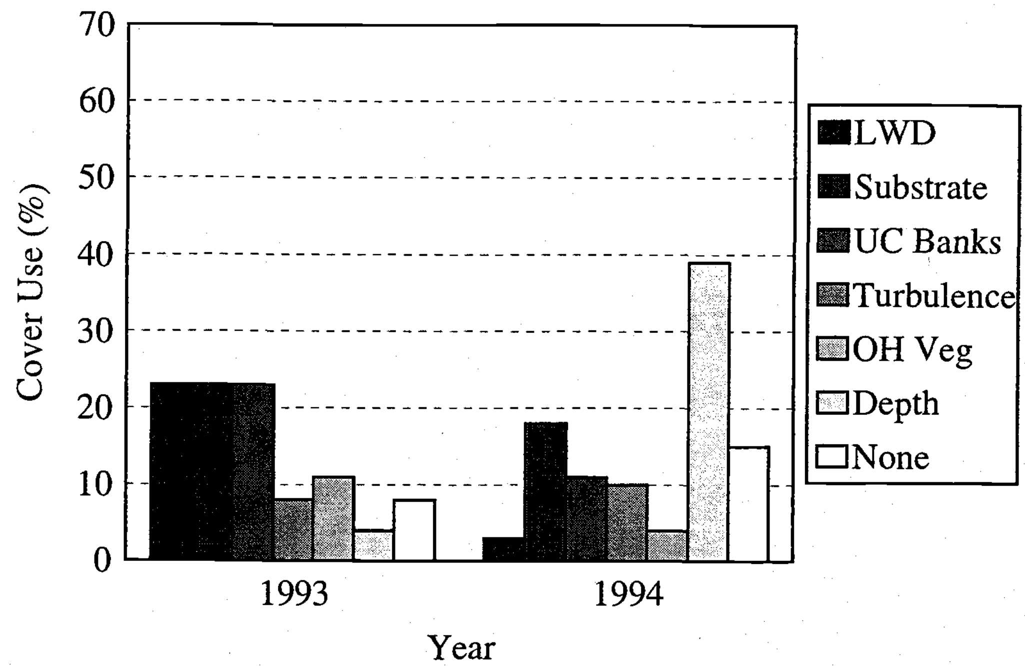


Figure 16. Frequency of cover use in the Middle Fork John Day River in 1993 and 1994.

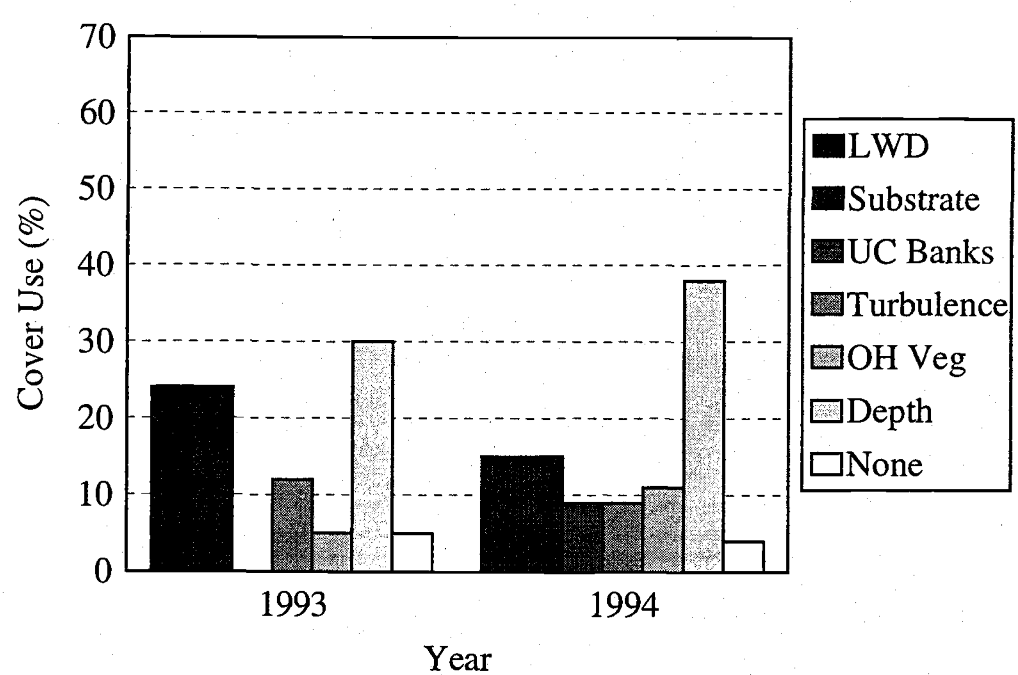


Figure 17. Frequency of cover use in Granite Creek in 1993 and 1994.

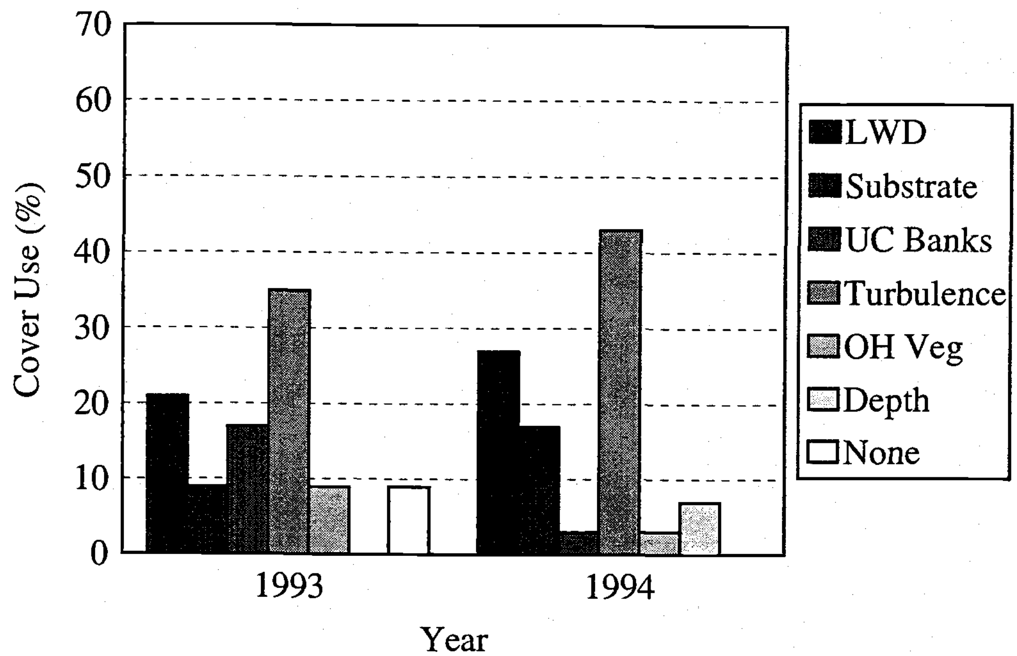


Figure 18. Frequency of cover use in the Wenaha River in 1993 and 1994.

Movement Patterns

Salmon were tracked one to six times weekly during routine surveys of the Middle Fork and North Fork John Day rivers in 1994. All tagged salmon ceased migration by the third week of June. In the Middle Fork John Day River, three tagged fish in the upper reaches of holding distribution moved less than 40 meters through the summer. Six fish in the lower reaches of distribution held in defined locations until stream temperatures approached lethal limits in mid-July.

Seasonal Movement of Radio-Tagged Salmon

Seasonal movement patterns among radio-tagged fish varied with both stream reach and stream temperature in the Middle Fork John Day River (figure 19). Radio-tagged salmon began holding from 12 June to 22 June when a rapid rise in maximum stream temperature approached 20-25°C. All but one tagged fish showed limited seasonal movement from mid-June through mid-July. Salmon in the upper reaches of the Middle Fork John Day River remained at their holding locations throughout the summer (i.e., home range < 40 m). Three of four fish observed near the lowest extent of distribution (river kilometer 82) moved upstream eight kilometers to river kilometer (rkm) 90 during peak summer temperature dates in July to hold in a pool where many untagged fish were observed holding. Thermal infrared videography indicated that this reach (rkm 90) may be a relatively cool reach of stream (Torgersen 1996). Seasonal movement patterns showed no direct relationship with stream discharge.

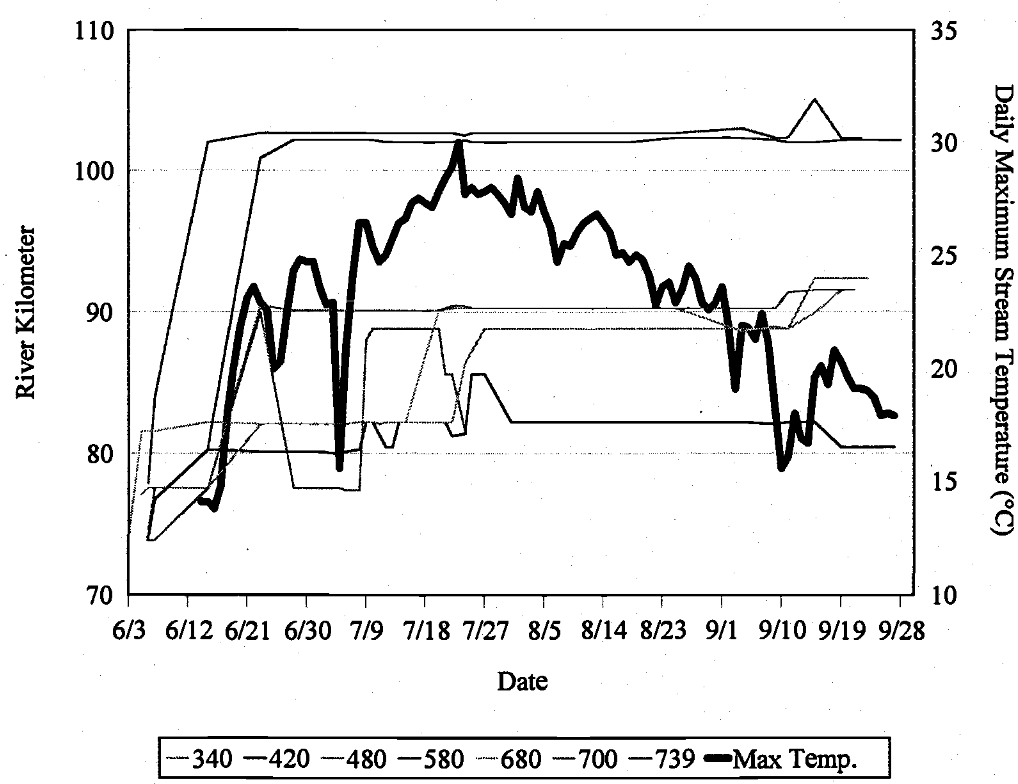


Figure 19. Seasonal movement patterns of radio-tagged adult chinook salmon with respect to maximum stream temperature.

All adult salmon maintained a home range of less than 100 m after 1 August and prior to spawning migrations in mid-September. Radio-tagged fish began spawning on the Middle Fork John Day River when stream temperatures dropped sharply after 5 September. All tagged salmon spawned within three distinct reaches and within two kilometers of their August holding locations (figure 19). Two fish (#580 and #739) spawned at rkm's 102 and 103, respectively. Three fish (#680, 340, and 480) spawned at rkm 91. These two stream reaches may be areas with substantial ground water influence (Torgersen 1996). Although several of the radio-tagged fish had held within the same pool throughout much of the summer, none of them were observed spawning with each other. The spawning distribution of radio-tagged salmon closely resembled the spawning distribution of non-tagged salmon.

Daily Movement of Radio-Tagged Salmon

Daily movement patterns of adult chinook salmon displayed a trend of high fidelity to holding locations in the Middle Fork John Day River during July of 1994. Fish #340 was tracked three times during the month of July (figure 20). During all intensive tracking observations, it returned to its original holding location despite frequent wanderings. Similarly, fish #680 moved at irregular intervals but returned to within seven meters of its original location during tracking observations on 20 and 21 July (figure 21). In clear representation of fidelity to a holding site, fish #420 moved two kilometers downstream on 2 July and held for six days before returning to its exact microhabitat location on 8 July (figure 22).

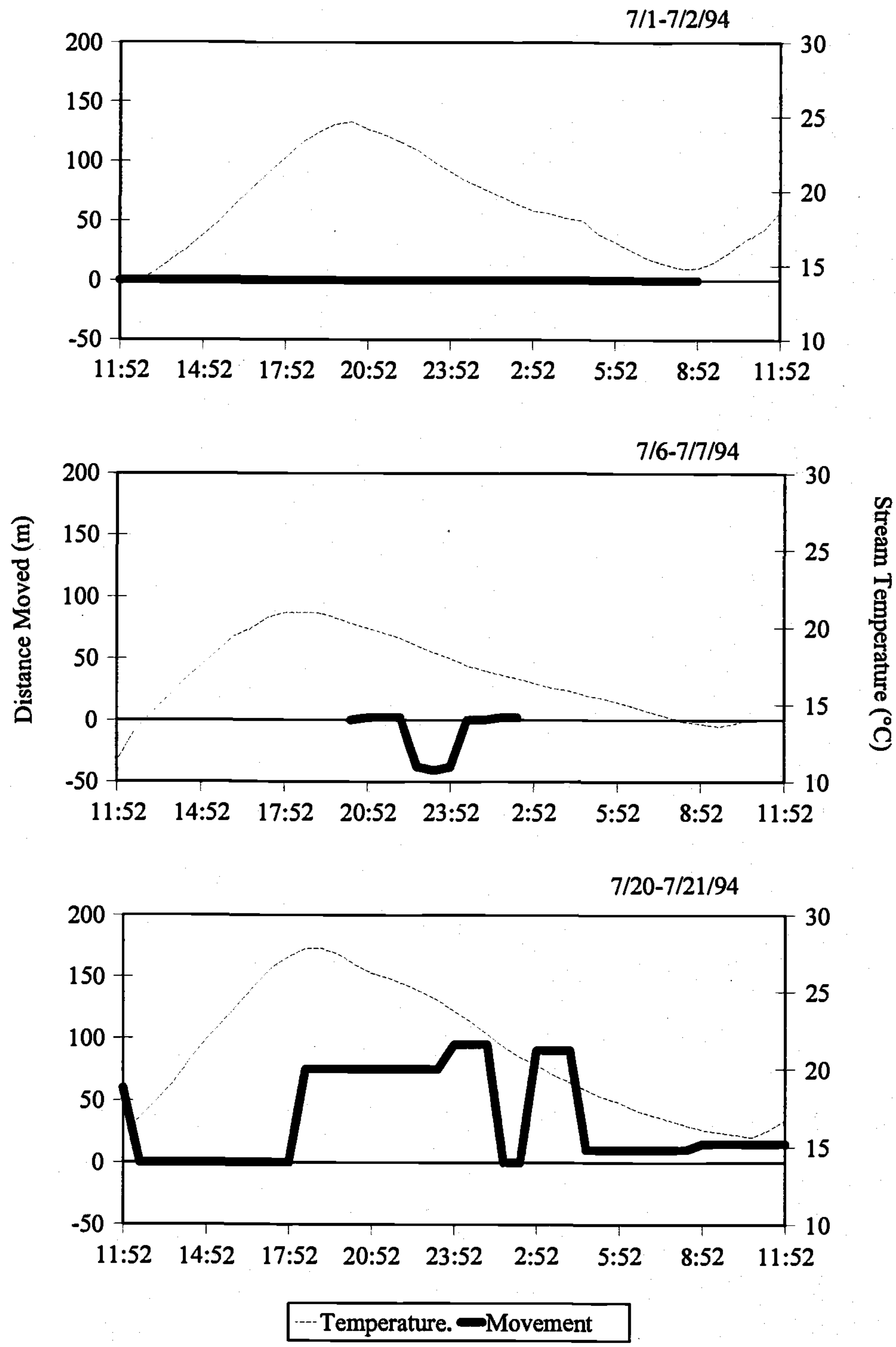


Figure 20. Movement patterns at one hour intervals of a radio-tagged chinook salmon on three occasions with respect to stream temperature. The origin on the movement axis indicates the predominant location occupied prior to intensive monitoring; positive values indicate upstream movement and negative values indicate downstream movement.

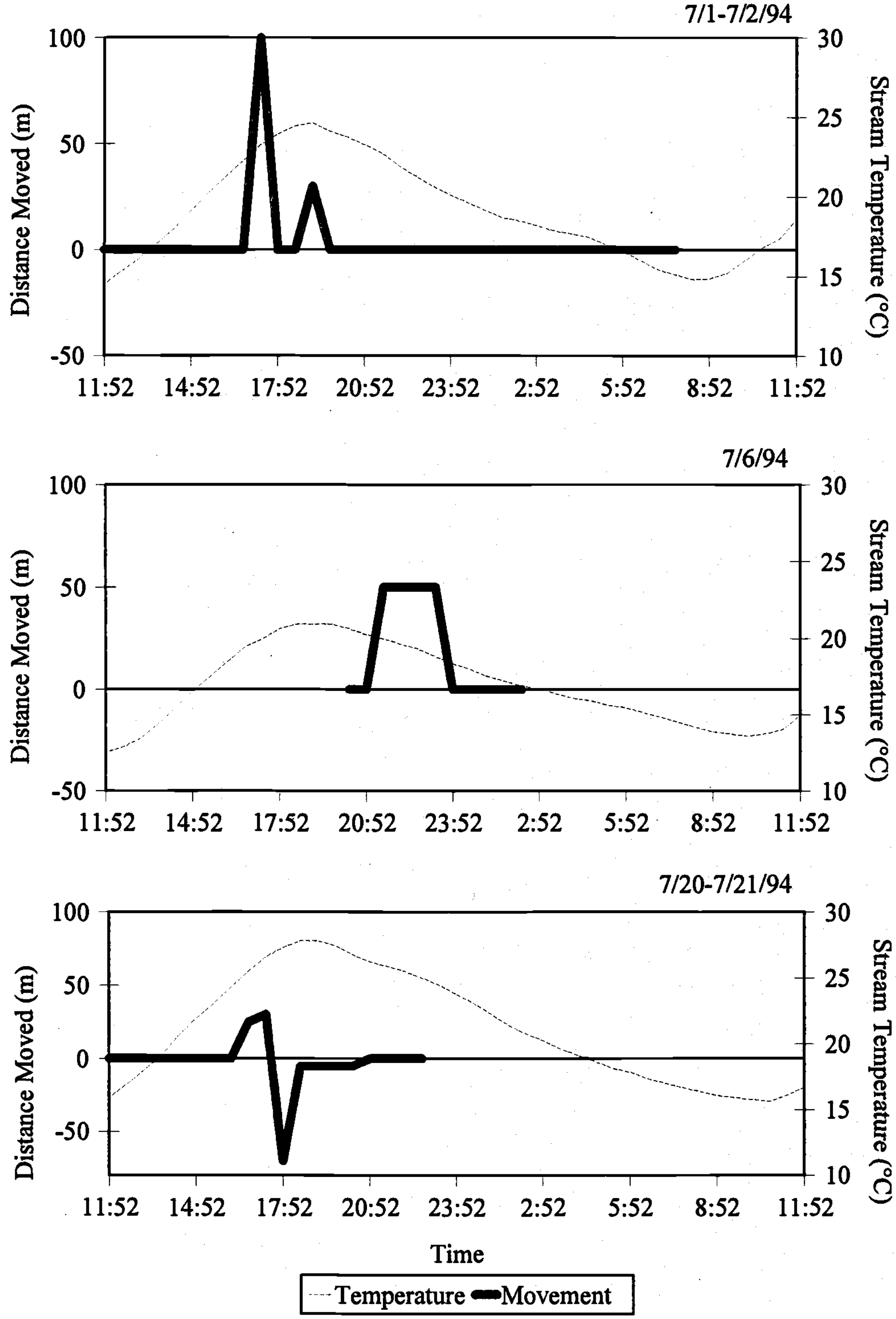


Figure 21. Movement patterns at one hour intervals of a radio-tagged chinook salmon on three occasions with respect to stream temperature. The origin on the movement axis indicates the predominant location occupied prior to intensive monitoring; positive values indicate upstream movement and negative values indicate downstream movement.

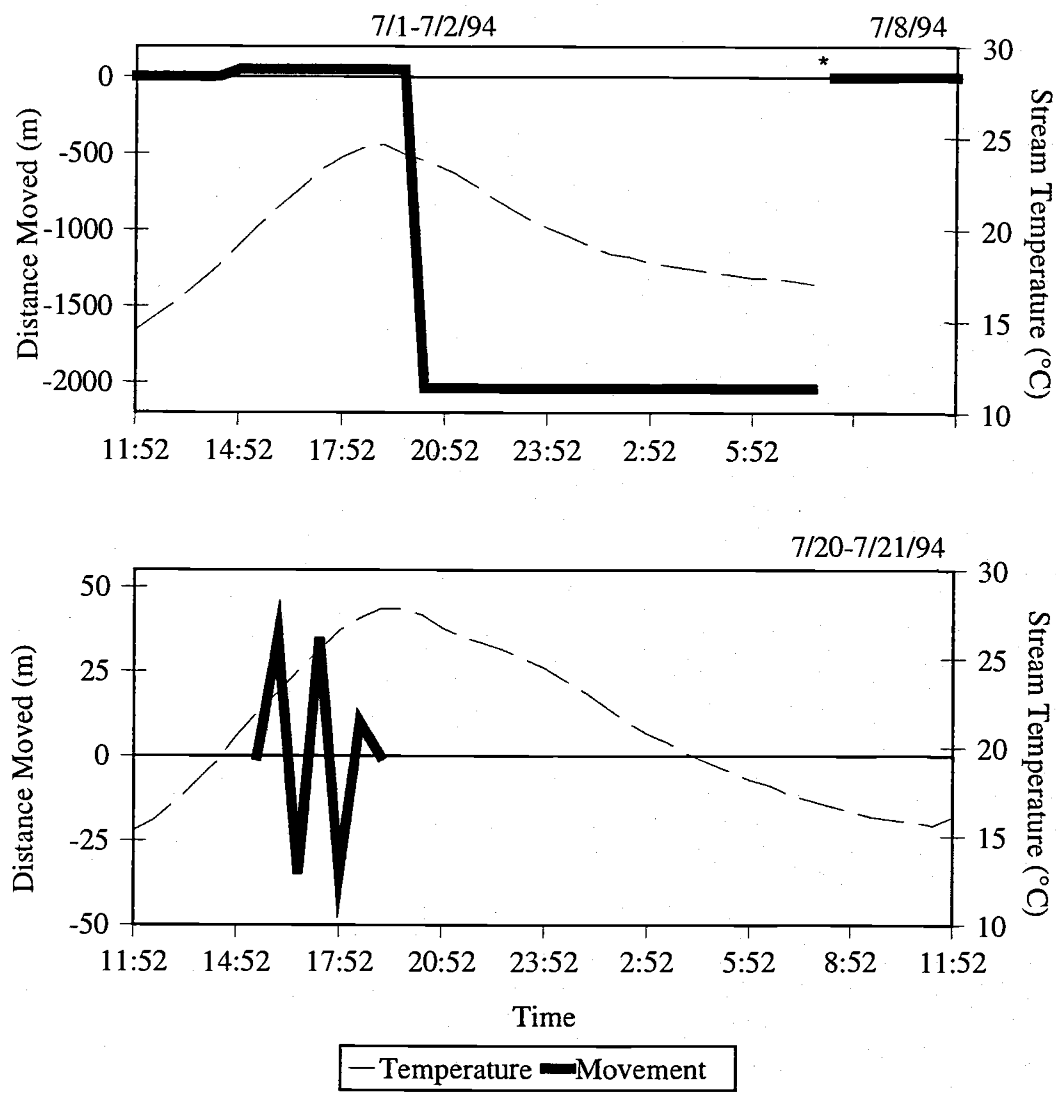


Figure 22. Movement patterns at one hour intervals of a radio-tagged chinook salmon on two occasions with respect to stream temperature. The origin on the movement axis indicates the predominant location occupied prior to intensive monitoring; positive values indicate upstream movement and negative values indicate downstream movement. * Fish returned to original holding location after six days.

Daily movement patterns of radio-tagged salmon reflected no clear relationship with stream temperature or the diel cycle. Salmon #340 displayed movement at peak stream temperatures and on a declining thermal profile. Salmon #680 showed movement during the rise and fall of the thermal profile and did not move during intensive tracking on 1 July. Fish #420 showed repeated 35 m movements upstream and downstream during peak stream temperatures on 20 July, but movement two kilometers downstream on 1 July showed no clear relationship with stream temperature.

All fish displayed variation in the length of time they stayed in any location. Fish #340 stayed two hours at a site 50 m upstream of its original location on 6 July, but during short excursions on 1 July and 20 July, the length of stay was less than one hour. Fish #680 moved upstream 90 m on 20 July and held for periods exceeding five hours yet also had stays of less than one hour. The length of stay for fish #420 ranged from five minutes on 20 July to six days beginning on 1 July.

DISCUSSION

My analyses show that the quality and availability of habitat in the Blue Mountain physiographic province varied among the seven study streams. Each stream posed different physical constraints on holding adult chinook salmon. Accordingly, use and selection of habitat by salmon was different among streams. The findings support the hypothesis that the behavior of stream fishes is a function of their environment at scales ranging from microhabitat to drainage basins (Schlosser 1991).

Channel Unit Scale

Chinook salmon elected channel units differently among streams. Riffle habitat was the predominant type available to adult chinook salmon in all study streams. Despite the relative availability of riffles, adult salmon elected for pool habitats throughout the study area. The use of pools was greatest in the Middle Fork John Day River and Granite Creek, where overhead cover was comparatively less available. Conversely, pool use in the Imnaha, Wenaha, and Minam rivers nearly equaled riffle use.

Surprisingly, channel unit use by adult chinook salmon was similar between years for each stream. The use of similar channel unit types within streams and between years is intriguing because mean summer discharge was nearly double in 1993 as compared to 1994 in the Imnaha and Middle Fork John Day rivers (figure 23). The consistency of channel unit use between years may reflect a similar availability of habitats from 1993 to 1994 despite high differences in stream flow.

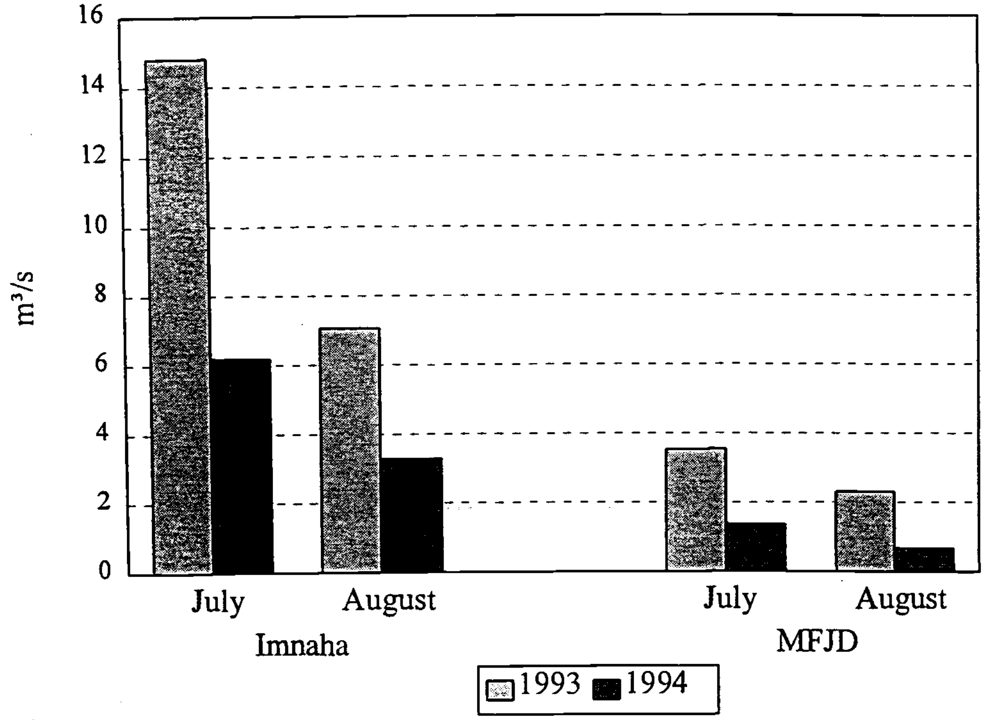


Figure 23. Mean stream discharge during July and August in 1993 and 1994 in the Imnaha and Middle Fork John Day (MFJD) rivers.

Pools were an important aspect of freshwater habitat for salmonids in other studies. Nakamoto (1994) observed disproportional pool use by adult summer steelhead in the New River, California, where greater than 99% of 427 observed steelhead occupied pools. Similarly, adult chinook salmon in the Yakima River have been observed using pools commonly (Berman and Quinn 1991). Also at the channel unit scale, Dunn (1981) and Jones (1980) reported adult steelhead densities were highly correlated to pool size in two northern California streams. My analyses support the dominant use of pools by adult salmonids within and among streams, but deep riffles also were used commonly in three study streams and should not be underestimated when assessing adult salmon habitat.

Pools have been described as a vital component of freshwater habitat to adult salmon. For example, pools have been reported as important resting habitat for adult salmonids (Bjornn and Reiser 1991), and as refugia from large-scale disturbance such as drought and fire (Sedell et al. 1990). Pools also may be selected by adult salmonids because of the relative depth they provide as protection from terrestrial predators (Bisson et al. 1982, Bjornn and Reiser 1991, and Nakamoto 1994). Riffles have been largely unknown in the literature as adult salmon habitat.

Riffle habitat was used in greater proportion than anticipated in the Minam, Wenaha, and Imnaha rivers. Three observations may help explain this result. First, most salmon observed in riffles were associated with pocket pools (shorter in length than mean wetted channel width) and thus were not assessed in my survey. Second, mean depth of riffles was ≥ 0.26m in the Imnaha, Wenaha, and Minam rivers; whereas, John Day River streams had mean depths ≤ 0.24m. Adult chinook salmon were rarely observed in depths < 0.25m. Thompson (1972) documented 0.24m as the minimum depth required of migrating and holding adult chinook salmon. The reluctance of radio tagged salmon in the Middle Fork John Day River to leave holding pools despite short intrusions into riffle habitats may also reinforce Thompson's minimum depth criteria. Lastly, salmon also may have occupied riffle habitat in the Minam, Wenaha, and Imnaha rivers in greater proportion than in the John Day system because riffles were significantly more available, and generally, offered greater cover availability in the form of depth and turbulence.

Depth was an important component to adult salmon habitat at microhabitat and channel unit scales. Adult salmon elected depths deeper than those randomly available within channel units, indicating that salmon elected depth at the microhabitat scale. Interestingly, salmon did not necessarily elect the deepest channel units within streams or reaches, except in the North fork John Day River. Depth was an important habitat variable in other studies involving adult salmonids at the channel unit scale. Nakamoto (1994) reported a greater proportion of adult steelhead used areas > 1m deep than in adjacent, shallower pools in the New River, California. Similarly, Dunn (1981) observed that most adult steelhead occupied the largest and deepest pools in Wooley Creek, California. The electivity of depth by adult salmonids may occur at multiple spatial scales, and appears to vary by stream.

Most adult chinook salmon were observed in association with cover. Combined observations in 1993 and 1994 reveal that 97% of observed salmon used cover. All adult salmon observed in the Imnaha, Wenaha (1994), Minam, and North Fork John Day rivers were associated with cover. Most fish in Granite Creek and the Middle Fork John Day River, and the Wenaha River (1993) also used cover. Cover was a primary determinant of adult chinook salmon habitat at the channel unit scale because salmon rarely elected channel units without cover. Conversely, the type of cover elected within channel units (microhabitat scale) was largely proportional to the type of cover available.

Microhabitat Scale

The microhabitat factors of importance differed among streams. The Middle Fork John Day River had less total cover available than all other study streams, perhaps making depth an attractive cover element as salmon were found at the bottom of pools almost exclusively. In Granite Creek, salmon often were observed in deep pools over small substrate. Cover elements were used as available, but deep water was used predominantly. In the North Fork John Day River, salmon often were observed under boulders in both deep and shallow water where numerous historic landslides have created boulder fields forming underwater caves and depressions. Few fish were observed in the upper Grande Ronde River. Microhabitats were located primarily under large wood placed as restoration structures, in shallow depths, and over sandy substrate. Salmon observed in the Minam River used boulders, large wood, and turbulence as cover. Salmon were not commonly observed using the deepest pools as habitat, although they were closely associated with the substrate. In the Wenaha River, salmon used the turbulence of riffles for cover most often, but also used large wood and boulders. Like the Minam River, salmon in the Wenaha River were associated with the substrate, and did not commonly use the deepest pools. Salmon in the Imnaha River used large wood as cover, reflecting its comparatively greater availability than other streams. Although salmon used deep pools in the Imnaha River, many were left vacant when adjacent riffles were occupied.

Unlike channel units, microhabitat electivity changed from year to year. The type of cover used between years was different in four streams. Generally, changes from 1993 to 1994 indicated a shift from bank-associated cover to mid-channel cover types which I have interpreted as resulting from large between-years differences in stream discharge. All other changes in microhabitat selection were minor.

Temperature Electivity

Stream temperature electivity by salmon varied across spatial scales. My *a priori* hypothesis was that salmon would elect cooler stream temperatures than available randomly or in the thalweg. Observations in the Middle Fork John Day River indicated that several salmon elected cooler stream temperatures at microhabitat scales when ambient stream temperatures were elevated, although electivity at the microhabitat scale was more uncommon than anticipated. However, observations of radio-tagged salmon throughout the 1994 summer indicate that they did not thermoregulate at microhabitat and channel unit scales. Instead, radio-tagged salmon observed in a relatively warm reach in the Middle Fork John Day River moved upstream to a relatively cool reach when stream temperatures reached their seasonal maximum. My data support Torgersen et al. (*in press*) where stream temperature electivity occurred primarily at reach scales on the Middle Fork John Day River. Because several salmon were observed using temperature refugia within channel units, I propose that temperature electivity at microhabitat scales was a secondary response.

Torgersen (1996) used thermal infrared videography to document cool patches in the Middle Fork John Day River that spanned stream width and extended beyond channel unit scales to reach scales. These cool reaches were 3-4°C cooler than adjacent reaches, and were selected by salmon over adjacent warmer reaches (Torgersen et al. *in* *press*). Berman and Quinn (1991) observed adult spring chinook salmon holding in pools up to 7.5°C cooler than adjacent channel units in the Yakima River, Washington. Neilsen et al. (1994) observed juvenile and adult summer steelhead occupying vertically stratified pools where bottom temperatures averaged 3.5°C cooler than surface temperatures. Thermal stratification could not be detected in the Middle Fork John Day River or Granite Creek.

Electivity for stream temperature was not detected in any study stream besides the Middle Fork John Day River. Several factors may have had an influence on the presence and magnitude of focal and mean random temperature differences. First, the Middle Fork John Day River was notably warmer than the other study streams, and the heterogeneity of stream temperatures may have been more pronounced thereby increasing availability of microhabitats with temperature differences. Second, sampling ceased when stream temperatures approached 24°C (1°C less than reported upper incipient lethal temperatures for chinook salmon), and the degree of difference between focal and random temperatures increased as temperature increased. In essence, sampling may have ceased before salmon received the maximum benefit from potential cool water refugia. Lastly, random temperatures were taken within a maximum distance of 8.5 m from the focal fish. Random temperatures, therefore, may have been sampled within larger cool patches or reaches of stream than anticipated.

Adequate stream temperature is an essential component to salmonid survival. Yet the upper incipient lethal temperature (UILT) for adult salmon (25°C, Brett 1952, Coutant 1970, Bell 1986, Armour 1991) was exceeded in all John Day River streams in

1994. The ULIT was exceeded in both years (1993 and 1994) in the Middle Fork John Day River, surpassing 25°C for 43 consecutive days in 1994. Most salmonids risk death when stream temperatures exceed 23 - 25°C (Bjornn and Reiser 1991). Current stream temperature regimes on the Middle Fork John Day River may represent a substantial increase from historical accounts (Torgersen 1996). Stream temperature is a vital element of habitat for adult chinook salmon in the Middle Fork John Day River and may be limiting production to upstream reaches in other streams (Torgersen 1996, Theurer et al. 1985).

Because the energy available for growth, maintenance, and reproductive capacity is the difference between energy gained through feeding and lost through activity (Ware 1982, Bryan et al. 1990), it follows that adult salmon, which do not feed for up to 14 weeks while in freshwater, should minimize energy loss by reducing activity to ensure reproductive success. Salmon caught in the lower reaches of the Middle Fork John Day River encountered reported lethal temperatures, diminished flow, little cover, and long stretches of uninhabitable shallow riffles between them and suitable habitat. I propose that movement by salmon from relatively warm lower reaches to relatively cooler upstream reaches in the Middle Fork John Day River was an obligatory response.

Although Nakamoto (1994) questioned the immediate value of the average 0.3°C lower temperature occupied by adult steelhead in the New River, California, salmonids may benefit from reduced temperatures through the course of the season. For example, Li et al. (1994) calculated that the energetic savings of thermoregulating juvenile steelhead in the John Day River ranged from 23 to 43%. Additionally, Berman and Quinn (1991) calculated that chinook salmon occupying temperatures 2.5°C less than ambient stream temperature would reserve up to 20% of daily metabolic expenditures. The energetic savings from cool water refugia also may be important in gamete production (Bartholomew 1968 and Bouck et al. 1975). Collectively, small energetic savings may be crucial to survival or reproduction in aquatic environments such as the Middle Fork John Day River, where stream temperatures exceed upper tolerance limits almost daily.

Movement Patterns

Extrapolations of radio-tagged salmon behavior to the general population require two assumptions: 1) that the behaviors of the tagged fish were not altered significantly by the initial tagging effort, or by the tags themselves throughout the summer; and 2) that the tagged salmon were "normal" representatives of the population (White and Garrott 1990). I feel that the first assumption was satisfied because tagged fish displayed similar holding and spawning distributions and utilized similar habitat as untagged fish. The second assumption, however, may be tenuous. Due to time constraints, capture methods were concentrated near the tail end of migration, not randomly throughout the run. I tagged and released the first ten fish successfully captured in the North Fork and Middle Fork John Day rivers. Nevertheless, observations of radio-tagged adult chinook salmon made throughout the summer provide useful insights into their behavior.

Assessment of movement patterns revealed two clear relationships among individuals and their responses to environmental cues at channel unit or microhabitat scales. First, they usually stayed within the confines of a single channel unit. Salmon were occasionally tracked swimming back and forth within single pools, occasionally entering riffles, but rarely holding for more than a few minutes. Second, tagged salmon usually returned to the same, precise location after wandering. High fidelity to holding locations supports the assumption made during population surveys: holding adult chinook salmon occupy the same habitat throughout the summer.

Restoration Implications

Among the primary concerns of freshwater fisheries managers trying to rebuild depressed stocks is how to restore habitat. In many sites, the severity of decline in spring chinook salmon stocks precludes sole dependence upon ecological succession to repair habitat, and heroic measures of rehabilitation may be necessary in some areas to avoid localized extinction (Anderson 1992). Although human intervention appears necessary to repair damaged stream reaches, many rehabilitation efforts in the Blue Mountain physiographic province have failed (Beschta et al. 1991), largely due to a lack of understanding of limiting factors (Reeves et al. 1991). In most circumstances, for example, managers have assumed stereotypical use of habitat by salmonids when restructuring degraded habitat. Habitat utilization by adult salmon, for example, has been widely generalized as simply "large pools" (Lindsay et al. 1986, Sedell et al. 1990, Healey 1991, Bjornn and Reiser 1991, McIntosh et al. 1994), therefore leading to proposals to increase their number (Lindsay et al. 1986, USDA 1994). To effectively restore salmon runs, an understanding of habitat used by all life history stages, and at multiple spatial and temporal scales is essential.

Fish and habitat assessment inventories are useful tools to describe stream-specific requirements of adult spring chinook salmon. The assessments made in my study suggest that the habitat elected by chinook was important at channel unit scales, and supports the work of Torgersen (1996) who determined that reach level electivity was important. Therefore, habitat restoration activities should focus at channel unit and reach scales to increase the likelihood of success.

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APPENDIX

Table A-1. Estimated habitat area available to adult chinook salmon in Granite Creek and the Imnaha, Middle Fork John Day (MFJD), Minam, North Fork John Day (NFJD), and Wenaha rivers.

Stream habitat	Pools	Glides	Riffles
Granite Cr.			
Total number	118	40	118
Total area (m^2)	52,602	11,085	77,036
Mean area (m^2)	446	277	653
Area / km	3,678	775	5,387
Imnaha R.			
Total number	147	30	160
Total area (m^2)	61,094	20,130	496,779
Mean area (m^2)	416	671	3,105
Area / km	2,023	667	16,450
MFJD R.			
Total number	220	223	330
Total area (m^2)	56,699	91,878	266,947
Mean area (m^2)	258	412	809
Area / km	1,344	2,177	6,326
Minam R.			
Total number	83	7	84
Total area (m^2)	78,381	9,278	251,541
Mean area (m^2)	944	1,325	2,995
Area / km	4,061	481	13,033
NFJD R.			
Total number	475	82	427
Total area (m^2)	212,622	82,132	743,597
Mean area (m^2)	448	1,002	1,741
Area / km	2,941	1,136	10,285
Wenaha R.			
Total number	63	6	67
Total area (m^2)	33,889	3,816	253,638
Mean area (m^2)	538	636	3,786
Area / km	1,852	209	13,860

Table A-2. Pool:Glide:Riffle ratios (by area) in the North Fork John Day (NFJD), Middle Fork John Day (MFJD), Imnaha, Wenaha, and Minam rivers, and Granite Creek.

Granite Cr.	MFJD R.	NFJD R.	Imnaha R.	Wenaha R.	Minam R.
38:8:54	14:21:65	19:8:73	10:4:86	12:2:86	23:3:74

Table A-3. (1 of 2). Corrected values for length, area, and volume by habitat type for each stream with 95% confidence intervals in parentheses. Correction factors are the quotient of the sum of measured values divided by the sum of estimated values in channel units measured in a stratified random sampling methodology (Hankin and Reeves 1988).

				Correction Factors:		
Stream Habitat	*Total Length (m)*	*Total Area (m^2)*	*Total Volume (m^3)*	*Length*	*Area*	*Volume*
Granite Cr.						
Pools	5444 (159)	52602 (1928)	21552 (1604)	0.999	0.994	0.626
Glides	1229 (59)	11085 (2856)	2498 (1474)	0.961	1.011	1.025
Riffles	7764 (197)	77036 (5040)	10984 (449)	0.996	0.992	0.920
MFJD R. (sec. 1)						
Pools	3234 (383)	34722(6249)	15835 (4575)	1.181	1.331	1.144
Glides	4079 (1125)	45575 (27555)	15711 (9951)	1.343	1.282	1.503
Riffles	14934 (3353)	195018 (47516)	47784 (17152)	1.345	1.612	1.895
MFJD R. (sec. 2)						
Pools	2303 (268)	15916 (6457)	6608 (4688)	0.910	0.758	0.613
Glides	6846 (997)	43741 (11721)	13798 (4340)	0.931	0.763	0.614
Riffles	9207 (974)	64591 (7187)	14855 (2104)	1.117	1.125	0.825
MFJD R. (sec. 3)						
Pools	1360 (1325)	6061 (8969)	2114 (4109)	1.421	1.316	1.624
Glides	790 (N/A)[a]	2562 (N/A)[a]	671 (N/A)[a]	1.227	0.868	1.172
Riffles	1691 (410)	7338 (2198)	915 (919)	0.877	0.824	0.853
NFJD R. (Sec. 1)						
Pools	9465 (436)	129814 (12592)	57437 (6626)	1.006	1.201	0.948
Glides	2804 (519)	52772 (11808)	16346 (2777)	0.940	1.143	0.962
Riffles	13232 (316)	223442 (11190)	43471 (5192)	1.021	1.206	1.046
NFJD R. (Sec. 2)						
Pools	1841 (251)	29754 (2533)	13532 (2371)	0.916	0.998	0.933
Glides	1172 (84)	22940 (251)	5234 (904)	1.002	0.995	0.679
Riffles	13536 (879)	248396 (34889)	52331 (9440)	1.060	1.004	0.884
NFJD R. (Sec. 3)						
Pools	1834 (99)	20005 (5718)	7449 (1926)	0.913	0.995	0.695
Glides	250 (N/A)[a]	3135 (N/A)[a]	540 (N/A)[a]	0.956	1.007	0.770
Riffles	10301 (178)	141674 (8452)	22477 (1410)	0.967	1.017	1.075
NFJD R. (Sec. 4)						
Pools	1383 (64)	11323 (1871)	3508 (643)	0.915	0.922	0.746
Glides	196 (N/A)[a]	1817 (N/A)[a]	399 (N/A)[a]	0.892	0.847	0.763
Riffles	8071 (515)	84191 (10167)	15355 (1869)	0.966	0.953	0.803
NFJD R. (Sec. 5)						
Pools	2815 (112)	21726 (2385)	5445 (859)	1.007	1.104	0.818
Glides	162 (N/A)[a]	1468 (N/A)[a]	298 (N/A)[a]	1.017	0.991	0.859
Riffles	4639 (150)	45894 (896)	5006 (267)	1.037	1.108	0.809

Table A-3. (2 of 2) continued. Corrected values for length, area, and volume by habitat type for each stream with 95% confidence intervals in parentheses. Correction factors are the quotient of the sum of measured values divided by the sum of estimated values in channel units measured in a stratified random sampling methodology (Hankin and Reeves 1988).

				Correction Factors:		
Stream Habitat	*Total Length (m)*	*Total Area (m²)*	*Total Volume (m³)*	*Length*	*Area*	*Volume*
Imnaha R.						
Pools	5479 (360)	61094 (8015)	26738 (3764)	1.102	1.029	0.874
Glides	1363 (103)	20130 (4621)	6197 (1704)	1.072	1.056	0.888
Riffles	26063 (1158)	496770 (37156)	144065 (25559)	1.051	1.227	1.218
Wenaha R.						
Pools	2391 (287)	33889 (10481)	18353 (4525)	1.088	1.209	0.954
Glides	228 (N/A)[a]	3816 (N/A)[a]	1906 (N/A)[a]	1.000[b]	1.000[b]	1.000[b]
Riffles	15875 (3189)	253638 (86213)	73771 (28322)	0.905	0.873	0.639
Minam R.						
Pools	4787 (924)	78381 (16210)	40693 (15315)	1.082	1.385	1.409
Glides	408 (N/A)[a]	9278 (N/A)[a]	2419 (N/A)[a]	1.140	1.632	1.855
Riffles	15327 (1059)	251541 (15054)	75821 (11757)	0.907	0.997	1.150

[a] Glides were under sampled for measurement values, confidence intervals could not be calculated.
[b] No measured values collected for this sample. Estimated values were used in all calculations.

Table A-4. Salmon abundance observed in channel units in 1993 and 1994 in Granite Creek, and the Middle Fork John Day (MFJD), North Fork John Day (NFJD), Imnaha, Wenaha, Minam, and upper Grande Ronde rivers (UGR).

Stream	1993			1994		
	Pool	Glide	Riffle	Pool	Glide	Riffle
Granite Cr.	97	1	2	51	1	3
MFJD R.	61	2	5	87	2	3
NFJD R.	a	a	a	251	3	48
Imnaha R.	15	0	10	33	4	25
Wenaha R.	8	0	15	8	0	9
Minam R.	13	1	10	b	b	b
UGR R.	27	0	5	c	c	c

[a] NFJD River was not sampled in 1993.
[B] Minam River was not sampled in 1994.
[C] Only 1 salmon was observed in the UGR River in 1994.

Table A-5. One-tailed paired t-test results of a comparison of focal to thalweg and random stream temperatures (°C) in the Middle Fork (MFJD) and North Fork (NFJD) John Day rivers, and Granite Creek.

Stream	Mean focal	Mean thalweg	p value	Mean focal	Mean random	p value
MFJD R.	17.90	17.90	0.207	17.61	17.64	0.006
NFJD R.	18.47	18.48	0.170	17.69	17.73	0.004
Granite Cr.	21.60	21.66	0.087	21.60	21.70	0.037

Table A-6. Substrate composition available (% area) in Granite Creek, and the Middle Fork John Day (MFJD), North Fork John Day (NFJD), Imnaha, Wenaha, Minam, and upper Grande Ronde rivers (UGR).

Stream	Organic	sand/ mud	sm. gravel	lg. gravel	cobble	boulder	bedrock
Granite Cr.	1	13	13	33	24	16	0
MFJD R.	3	8	6	48	26	8	1
NFJD R.	3	8	8	23	37	19	2
Imnaha R.	1	7	3	30	37	21	1
Wenaha R.	3	10	20	23	23	15	6
Minam R.	0	13	4	32	27	22	2
UGR R.	2	16	9	27	25	17	4

Table A-7. Woody debris characteristics in Granite Creek, and the Middle Fork John Day (MFJD), North Fork John Day (NFJD), Imnaha, Wenaha, Minam, and upper Grande Ronde rivers (UGR).

Stream	Wetted volume (m^3/km)[a]	Frequency of jams (#/km)[b]	% habitats with no woody debris	Frequency of single pieces (#/km)	Mean length (m)	Mean diameter (m)
Granite Cr.	2.6	2.0	59.2	11.1	9.6	0.23
MFJD R.	0.7	0.6	59.2	6.9	8.2	0.32
NFJD R.	6.8	4.9	11.8	25.6	11.1	0.25
Imnaha R.	29.4	4.5	16.1	28.8	9.0	0.38
Wenaha R.	22.8	5.5	17.4	28.8	9.7	0.41
Minam R.	13.0	4.4	21.7	21.0	11.5	0.32
UGR R.	15.5	2.4	34.2	23.0	8.5	0.34

[a] Wetted volume of single pieces observed in the wetted channel
[b] Jams include woody debris observed in aggregations of ≥5 pieces.

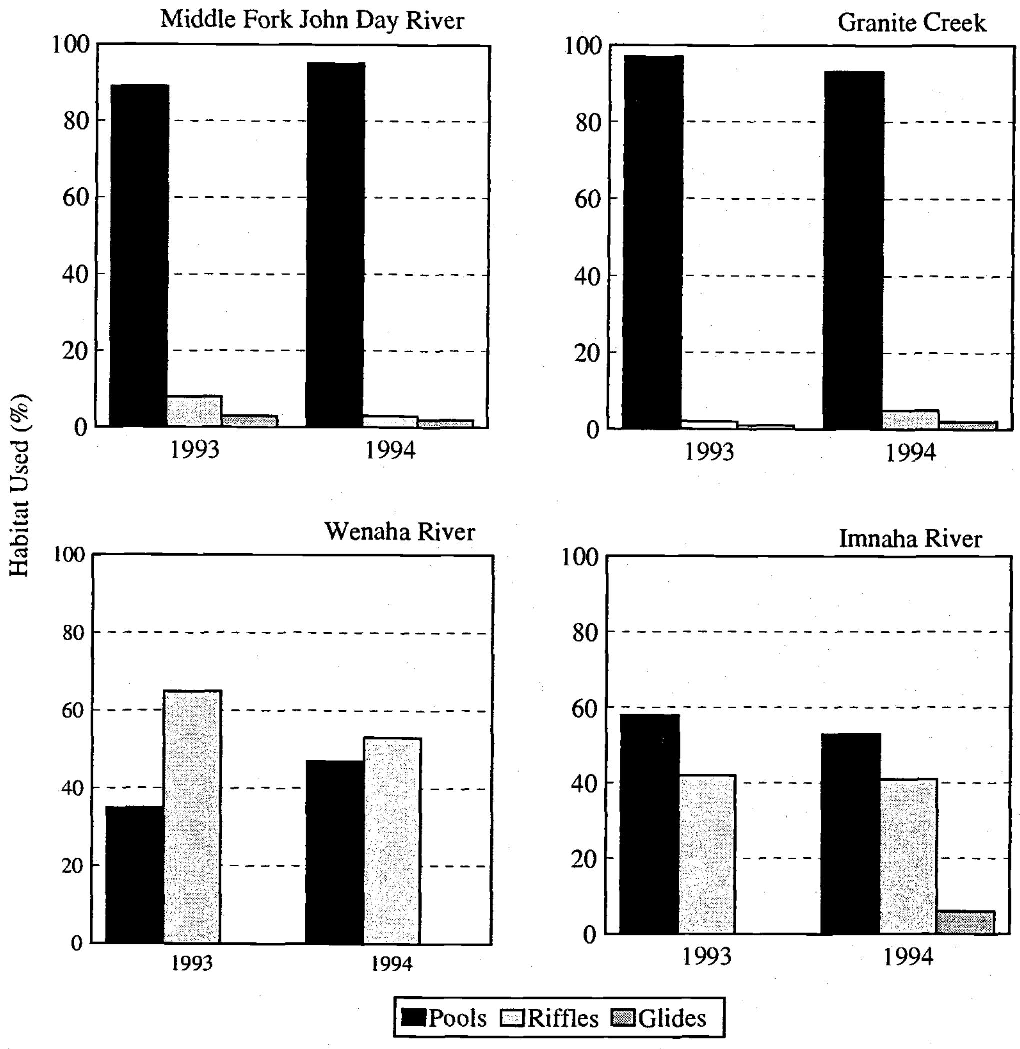

Figure A-1. Habitat use in the Middle Fork John Day, Imnaha, and Wenaha rivers and Granite Creek in 1993 and 1994.

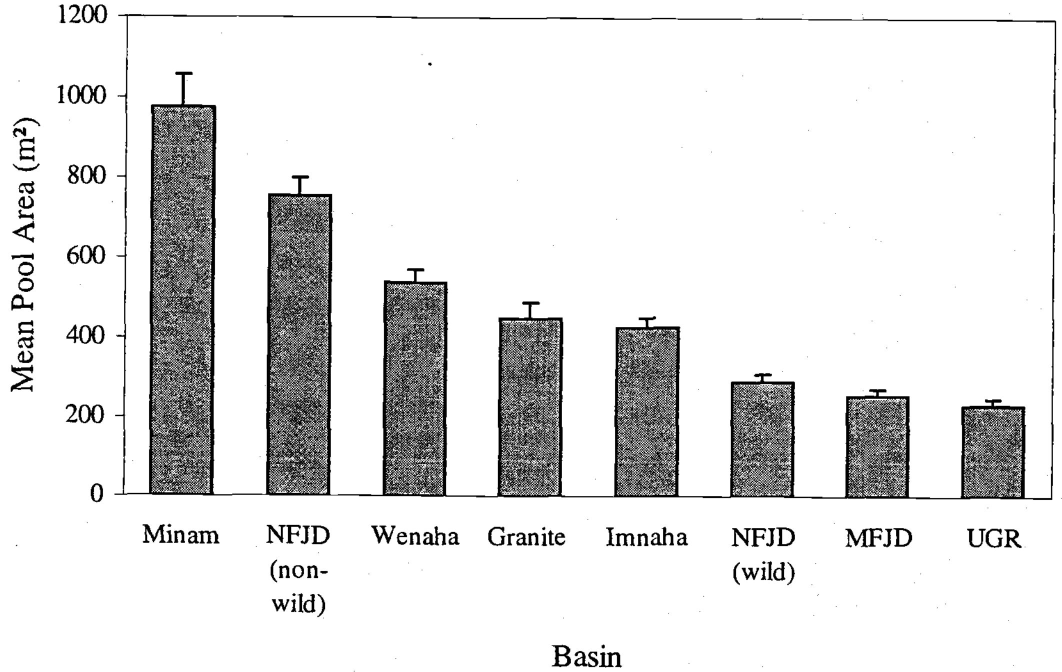

Figure A-2. Mean pool area (±SE) in the Imnaha, Wenaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek. The North Fork John Day non-wilderness reach was from Dale to Big Cr. The wilderness reach extended from Big Cr. to Baldy Cr.

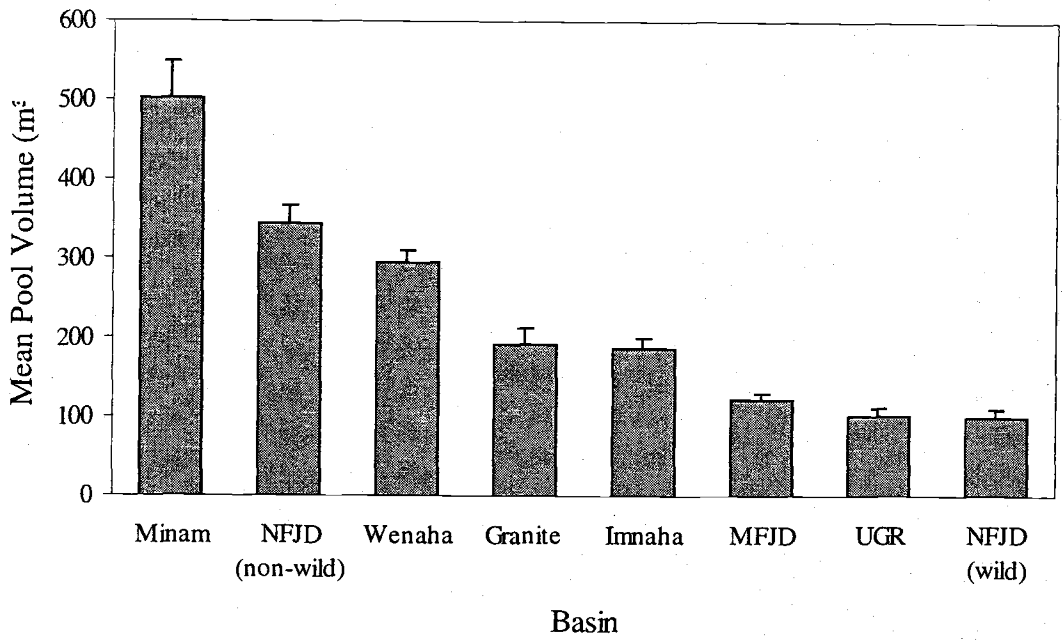

Figure A-3. Mean pool volume (±SE) in the Imnaha, Wenaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek. The North Fork John Day non-wilderness reach was from Dale to Big Cr. The wilderness reach extended from Big Cr. to Baldy Cr.

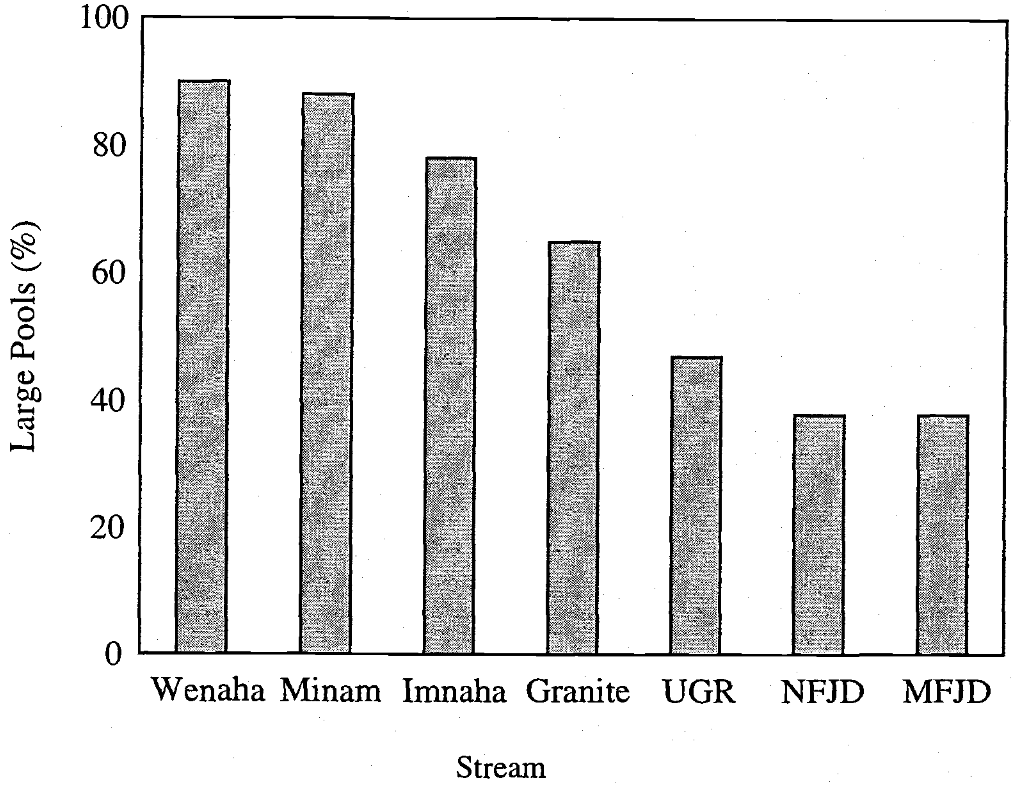

Figure A-4. The distribution of large pools* among all pools in each of the seven study streams. *Large pools are defined after McIntosh et al. 1994.

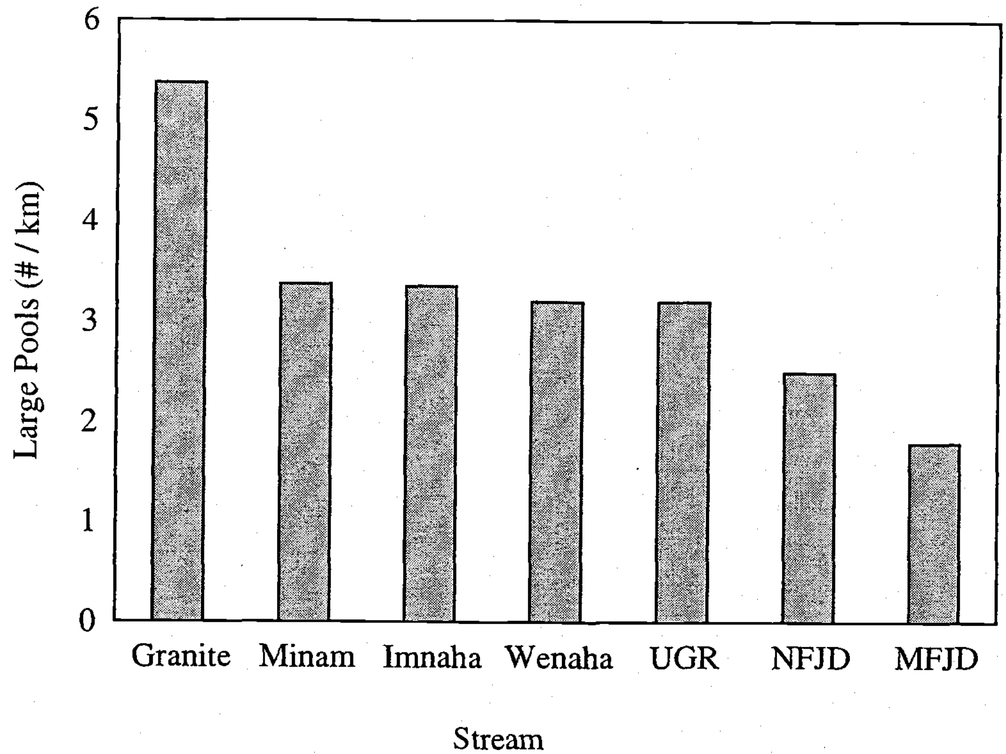

Figure A-5. The frequency of large pools* among the seven study streams. *Large pools are defined after McIntosh et al. 1994.

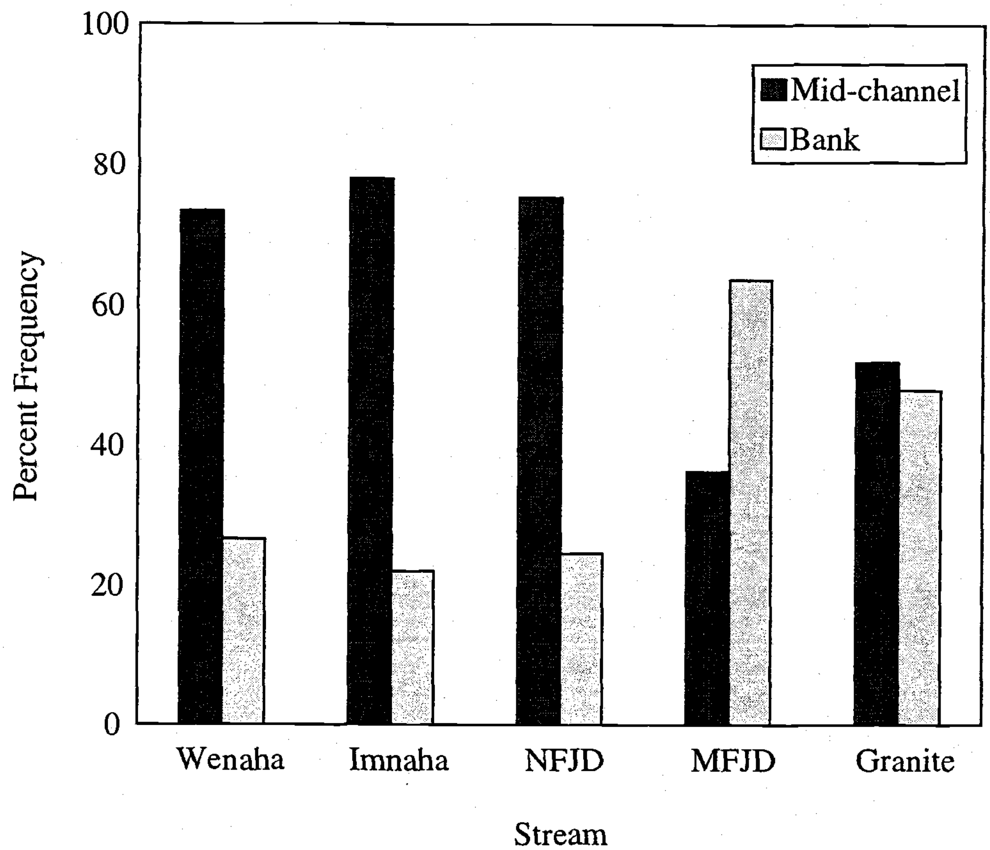

Figure A-6. Bank and mid-channel associations of adult chinook salmon in the Wenaha, Imnaha, North Fork John Day (NFJD), Middle Fork John day (MFJD) rivers, and Granite creek.

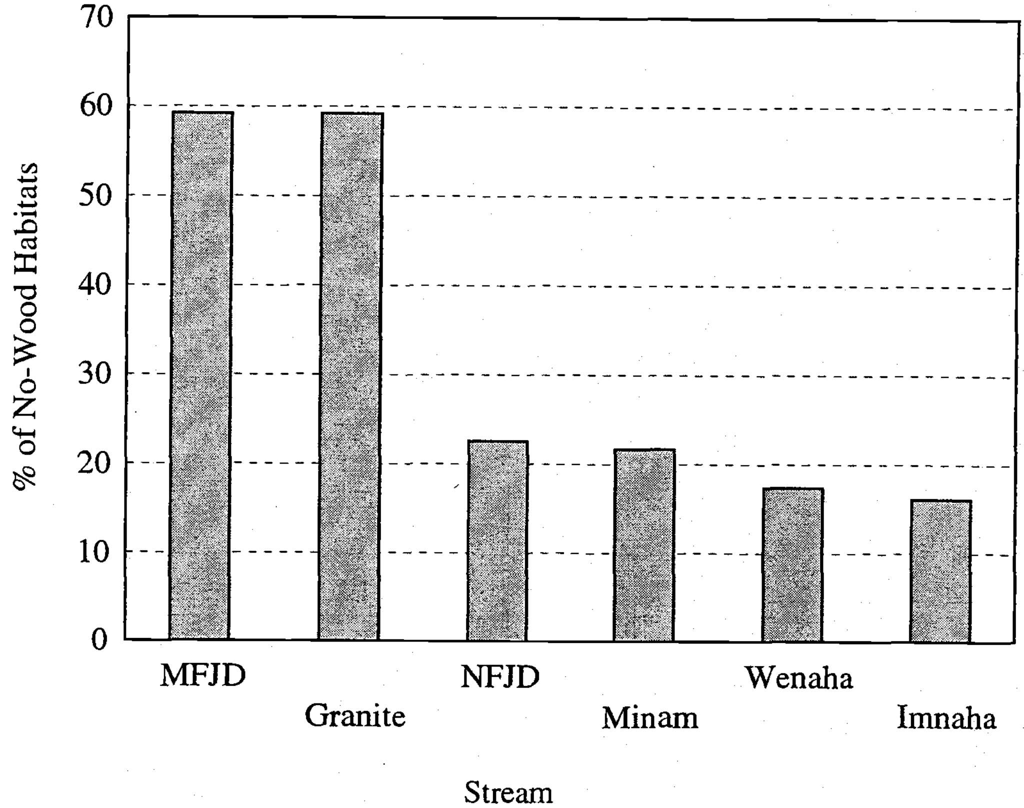

Figure A-7. Percent of channel units without large wood in the Middle Fork (MFJD), North Fork John Day (NFJD), Minam, Wenaha, and Imnaha rivers, and Granite Creek. The minimum size requirement for a wood piece was 2 m in length and 10 cm in diameter.

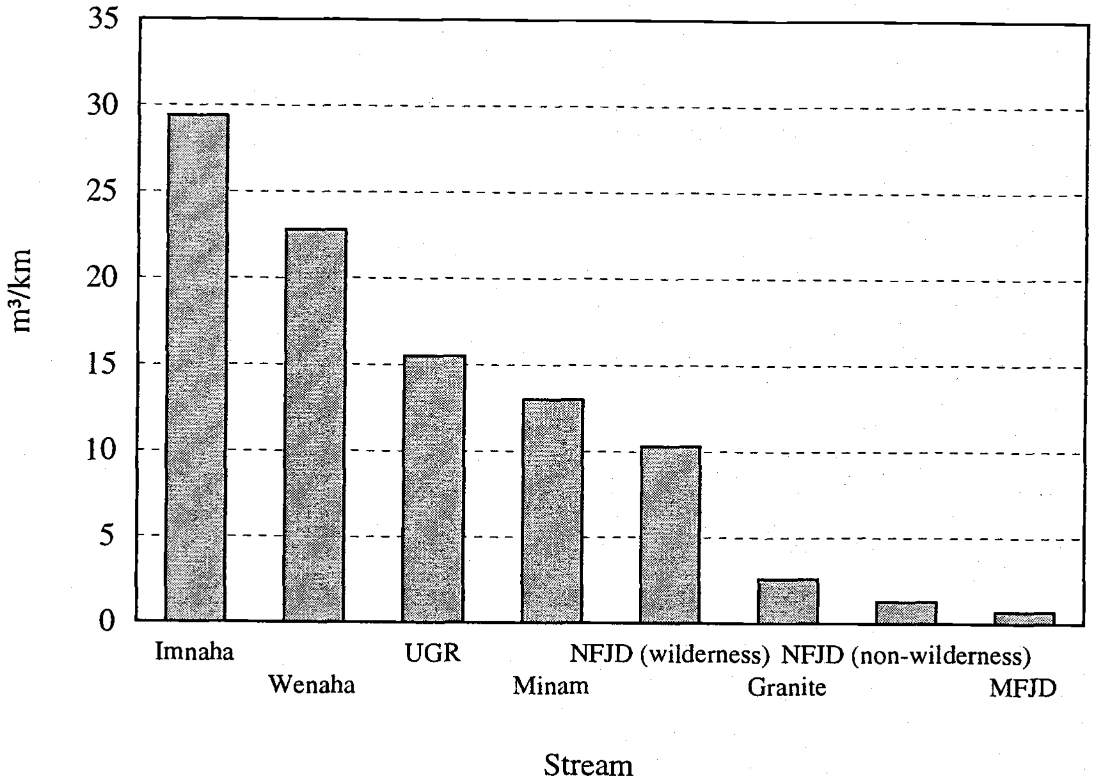

Figure A-8. Total wetted volume of woody debris occurring as single pieces in the Imnaha, Wenaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek. The North Fork John Day non-wilderness reach was from Dale to Big Cr. The wilderness reach extended from Big Cr. to Baldy Cr.

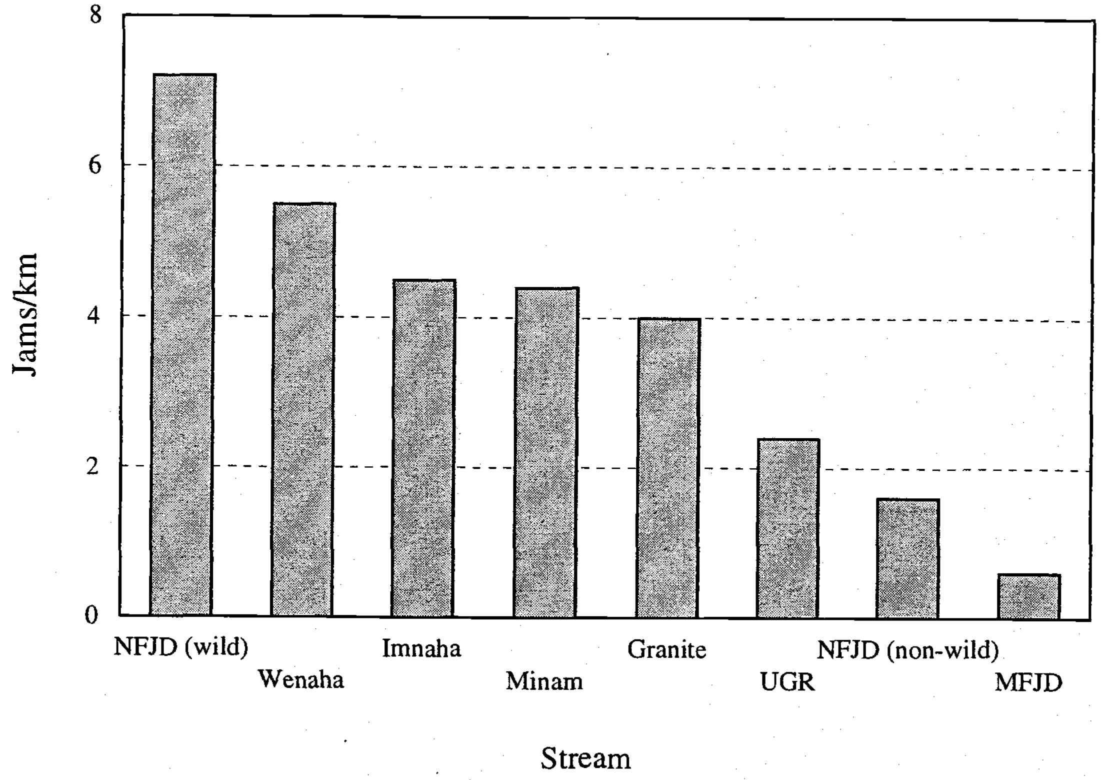

Figure A-9. Number of woody debris jams per river kilometer in the active channel in the Imnaha, Wenaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek. The North Fork John Day non-wilderness reach was from Dale to Big Cr. The wilderness reach extended from Big Cr. to Baldy Cr.

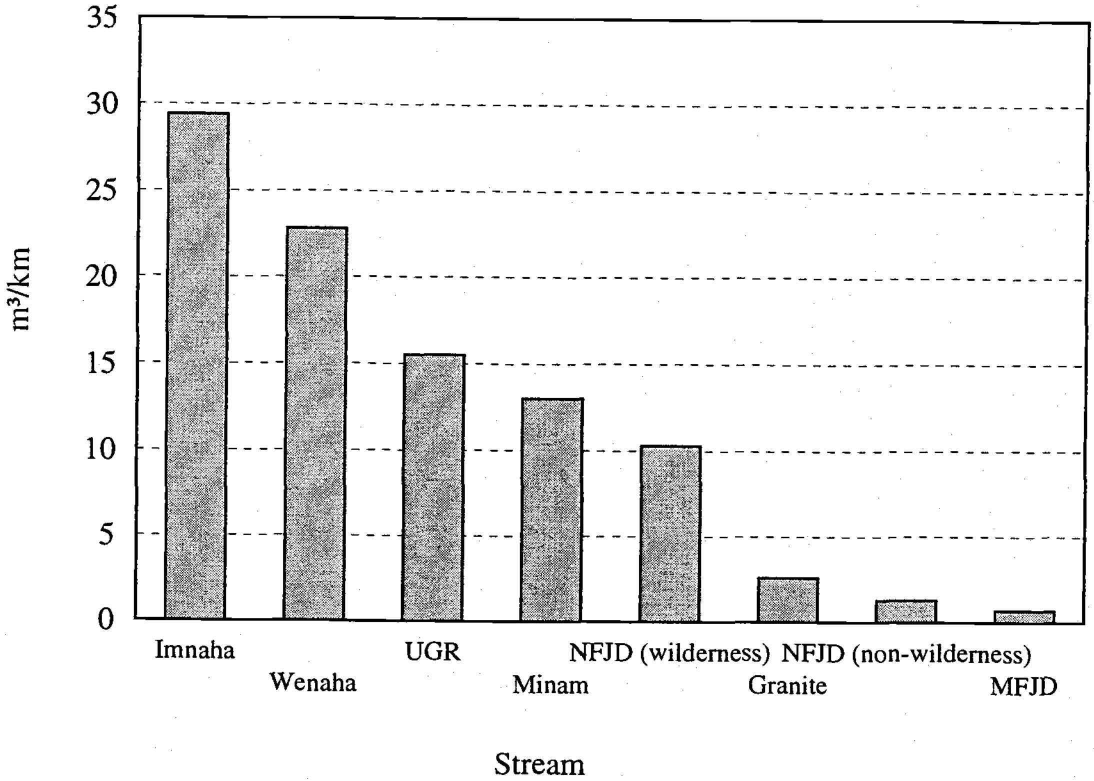

Figure A-10. Wood volume of single pieces per river kilometer in the wetted channel in the Imnaha, Wenaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek. The North Fork John Day non-wilderness reach was from Dale to Big Cr. The wilderness reach extended from Big Cr. to Baldy Cr.

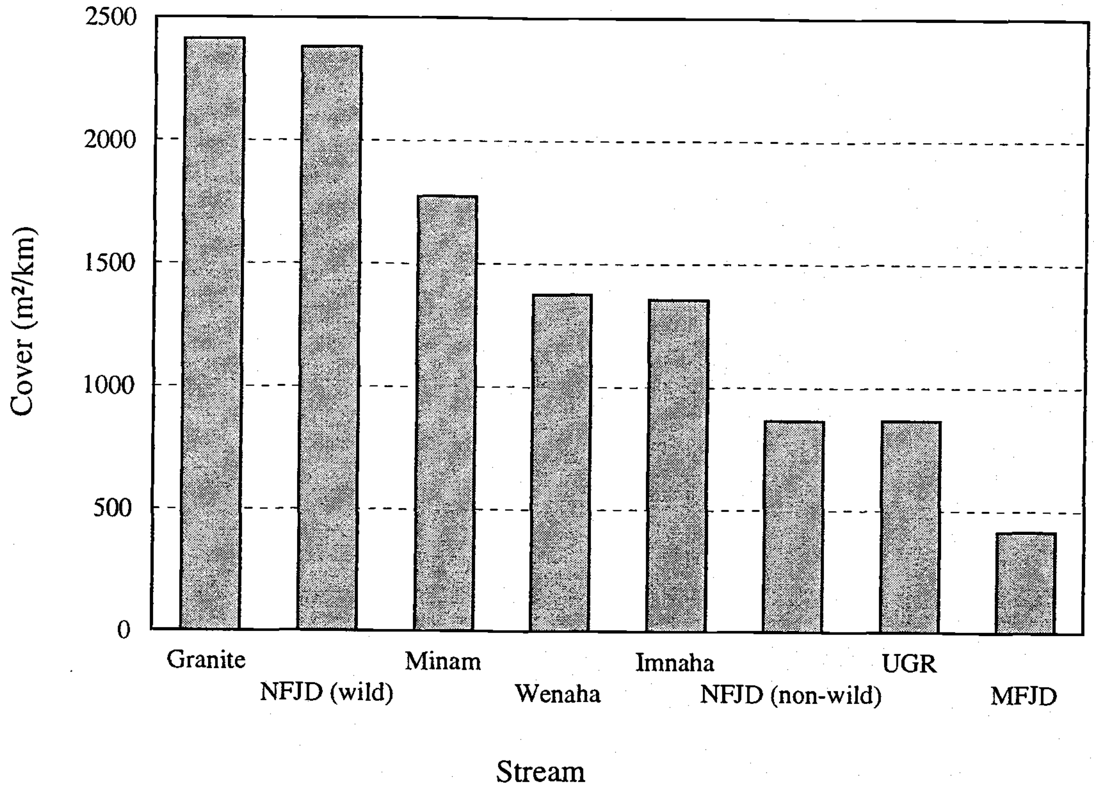

Figure A-11. Area of cover per river kilometer available to adult chinook salmon in the Imnaha, Wenaha, upper Grande Ronde (UGR), Minam, North Fork John Day (NFJD), Middle Fork John Day (MFJD) rivers, and Granite Creek. The North Fork John Day non-wilderness reach was from Dale to Big Cr. The wilderness reach extended from Big Cr. to Baldy Cr.

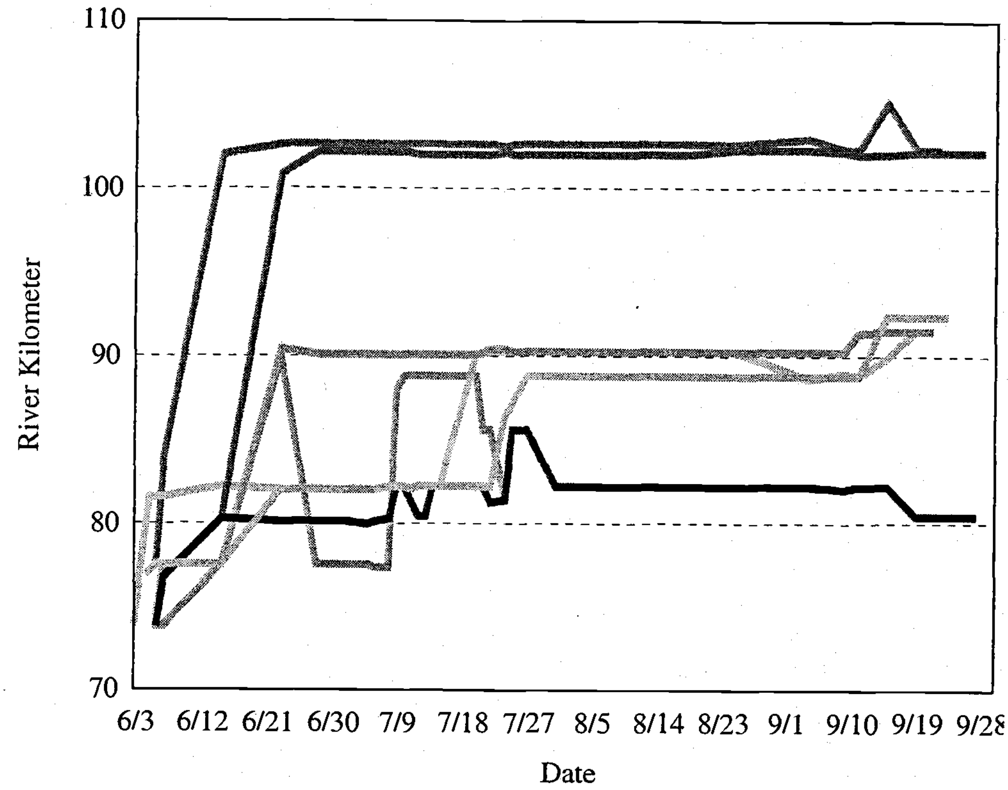

Figure A-12. Seasonal movement patterns of radio-tagged adult chinook salmon in the Middle Fork John Day River in 1994.