DISTRIBUTION OF FISH AND CRAYFISH, AND MEASUREMENT OF AVAILABLE HABITAT IN URBAN STREAMS OF NORTH CLACKAMAS COUNTY

Final Report, 1997-1999

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EXECUTIVE SUMMARY

The Oregon Department of Fish and Wildlife (ODFW) and Water Environment Services, a Department of Clackamas County (WES) are concerned about the influence of continuing urbanization on streams of the North Clackamas County (NCC) area. Little is known about the status of fish and crayfish *Pacifasticus* spp. in these streams, what factors limit their distribution and abundance, or which areas are likely to benefit from habitat enhancement and conservation.

In 1997, ODFW and WES began a cooperative study to (1) describe the status and characteristics of fish and crayfish populations in NCC streams, (2) describe the quality and quantity of available aquatic habitat, and (3) examine the relationship between fish assemblages and aquatic habitat to identify limiting factors and propose means by which fish populations could be enhanced.

We surveyed seven NCC streams (Kellogg, Mt. Scott, Phillips, Dean, Cow, Sieben, and Rock creeks) from 1997 to 1999. Instream and riparian habitats were surveyed during summer months (21 stream reaches), and fish and water quality sampling were conducted quarterly in summer, autumn, winter, and spring (20 stream reaches). Cursory fish surveys were performed in nine secondary tributaries.

Conclusions

We believe there are several important findings of our study. These include:

1) **Streams of NCC generally lacked complexity and other habitat components that provide good fish habitat.** While adequate or good habitat exists in some stream reaches, cover for fish in most reaches was limited to infrequent undercut banks and small numbers of riffles, pools, and boulders. Secondary channels and other off-channel habitats were rare, and woody debris quality and quantity was low in all reaches. Homogenous habitat types, such as glides and culverts, dominated many reaches. Stream shading was often less than 50%. In addition, high proportions of silt, sand, and fine organic matter in many areas may adversely affect the spawning success of salmonids *Oncorhynchus* spp. and lampreys *Lampetra* spp.

2) **Fish species present in NCC streams were typical of other Willamette Valley locations, but varied considerably among streams and reaches.** We collected 7,484 fish from 9 families and 16 genera during the first electrofishing pass in all primary streams, reaches, and seasons combined. Reticulate sculpin *Cottus perplexus*, speckled dace *Rhinichthys osculus*, redside shiner *Richardsonius balteatus*, and western mosquitofish *Gambusia affinis* were the most common species observed. The number of species ranged from eight in Dean and Sieben creeks to 20 in Cow Creek. Among reaches, the number of species ranged from zero (reach 3 of Cow Creek and reach 3 of Sieben Creek) to 20 in reach 1 of Cow Creek. Threespine stickleback *Gasterosteus aculeatus* were notably absent. Introduced fish composed 5.7% of the total catch, and the majority of these were western mosquitofish.

Crayfish *Pacifasticus leniscululus* were present in 17 of 20 reaches, but were abundant only during summer.

3) **Anadromous or resident salmonids occurred in all streams we surveyed, including three species listed as threatened or endangered under endangered species acts (ESAs).** Native salmonids were present in every primary stream, 13 of 20 primary stream reaches, and 4 of 9 secondary streams. Rainbow trout or steelhead *O. mykiss* composed 63.9% of the salmonid catch (resident rainbow trout are indistinguishable from juvenile steelhead). The estimated number of native salmonids per 100-m sampling site ranged from zero (seven reaches) to 185 (Rock Creek reach 2). The majority (61%) of native salmonids were collected from the lower two reaches of Rock Creek. Nearly all salmon and trout captured were juveniles; mean fork length for all salmonids was 90.4 mm. Observations of recently hatched fry, juvenile salmonids of various ages, and live adult steelhead strongly indicated that natural propagation occurred in most NCC streams. We collected three species (rainbow trout or steelhead, chinook salmon *O. tshawytscha*, and coho salmon *O. kisutch*) that are currently protected under federal or state ESAs.

4) **Biotic integrity of fish communities in NCC streams is severely degraded with respect to historic conditions.** The index of biotic integrity (IBI) utilizes fish community composition to assess the biological health of streams. The IBI consists of a numerical score generated by applying field data to a set of criteria based on historic conditions, species ranges, fish habitat requirements, and reference sites. Scores range from zero (no biotic integrity) to 100 (ideal conditions), and are qualitatively labeled as acceptable (≥75), moderately impaired (51-74), or severely impaired (≤50). The mean IBI score for all seasonal fish surveys was 42.9. Of the 79 seasonal scores, five were acceptable, 24 were moderately impaired, and 50 were severely impaired. Among the 20 reaches sampled (all seasons combined), 8 were moderately impaired and 12 were severely impaired.

5) **Several habitat and water quality components were significantly correlated with biotic integrity.** We examined correlations between IBI scores and 35 habitat and water quality variables. Water velocity, proportion of surface area as fast water (riffle, rapid, and cascade) habitat units, and woody debris rating were positively correlated ($P<0.05$) with mean seasonal IBI. The number of potential downstream barriers, the proportion of downstream surface area as culverted units, and the proportion of surface area as glides were negatively correlated ($P<0.05$) with mean seasonal IBI.

Recommendations

Based on our findings, we have several recommendations concerning the monitoring and management of NCC streams:

1) **All culverts and other potential barriers to fish passage within the NCC area should be inspected, and repaired or removed if they are found to impair fish movement.** Culverts are numerous in NCC streams, sometimes constitute a high proportion of the total stream surface area, and are negatively correlated with biotic integrity. At least two culverts (in Mt.

Scott Creek reach 3 and Dean Creek reach 2) clearly prevent upstream fish passage. Fish passage improvements could enhance biotic integrity and the production of anadromous fish by opening additional spawning, rearing, and refuge areas.

2) **Habitat restoration efforts should focus on vegetative planting and the placement of large woody debris (LWD) or other instream structures.** Many observed habitat deficiencies, including homogeneity, bank erosion, low shading, and poor woody debris quality could be improved with the addition of LWD and live trees. Tree planting would improve habitat in the long term, while LWD and other instream structures would provide immediate benefits to fish. Working together, ODFW and WES should select sites and determine specific strategies for habitat enhancement.

3) **Biotic integrity should be used as a guide to prioritize habitat conservation and enhancement among stream sites.** Stream reaches with relatively high IBI scores would undoubtedly benefit from restoration and enhancement activities; however, such areas already contain generally healthy fish communities and adequate habitat. These reaches (especially the lower two reaches of Rock Creek) should be conserved and protected. Reaches with relatively low biotic integrity should be protected from additional degradation, but are also poor candidates for habitat enhancement. Fish have been completely extirpated from several of these reaches; considerable culvert removal and habitat enhancement would be required for the re-establishment of any species. Instead, enhancement efforts should focus on reaches with moderate IBI scores. Small numbers of sensitive species generally persist in these areas, and should respond to modest habitat improvements in the absence of other limiting factors.

4) **Continued monitoring and additional surveys would provide a variety of benefits.** Spawning surveys should be conducted on the larger streams to better ascertain their utilization by spawning anadromous salmonids. Though our data and observations strongly indicated natural production in some areas, our sampling was not designed to quantify adult salmon, steelhead, and sea-run cutthroat trout *O. clarki* escapement. This would be particularly useful information in light of recent ESA listings. All streams within the jurisdiction of WES, including secondary tributaries, should be surveyed to determine the presence or absence of ESA-listed species. It is likely that future land development will further degrade these streams. Surveys should be conducted and protective measures implemented before areas of critical habitat are lost. Additional water quality components that are monitored by WES, such as chlorides and nitrogen, should be related to IBI scores in NCC streams to identify additional factors limiting fish communities. Biotic integrity should be monitored periodically, especially in areas where habitat work has been done, to determine if these activities have improved the health of fish communities. Relating land-use variables (e.g. road and housing density, frequency of impervious surfaces) to IBI within individual watersheds may identify relationships between urban development and the quality of aquatic ecosystems.

INTRODUCTION

The North Clackamas County (NCC) area is becoming increasingly urbanized as a result of residential and commercial growth. From 1994 to 2020, both the number of residences and the human population of this area are expected to increase approximately 47% (Meyer 1998). Major changes in residential, commercial, industrial, and agricultural land uses will occur in some parts of the county (Metro 1997). The Oregon Department of Fish and Wildlife (ODFW) and Water Environment Services, a Department of Clackamas County (WES), are concerned about the impacts of continued rapid growth and development on aquatic ecosystems of this region. In 1997, ODFW and WES developed a project to address these concerns; this report presents the final results of the study.

Historic information regarding fish habitat and fish communities in urban streams of NCC is scarce. Some streams have been surveyed intermittently for spawning salmon *Oncorhynchus* spp. since the early 1950s, but the frequency of surveys has diminished with declining salmon abundance (ODFW unpublished data). Some cursory observations of fish and fish habitat in this area were recorded by the Oregon Fish Commission (Willis et al. 1960). Environmental consulting firms, ODFW, and other agencies have periodically surveyed specific sites in recent years (e. g. Johnson and Means 1996; ODFW unpublished data), but a more comprehensive effort was needed to better document the status of aquatic resources.

The primary objectives of this project were to (1) determine the relative and seasonal abundance of fish and crayfish *Pacifasticus* spp. present in NCC streams; (2) identify local patterns of fish and crayfish abundance; (3) determine the quality and quantity of aquatic habitat; (4) measure basic water quality parameters; (5) apply an index of biotic integrity (IBI; Karr et al. 1986) to characterize the health of stream reaches; and (6) compare IBI scores with habitat and water quality variables to determine factors affecting biotic integrity.

Several races of salmonid species were listed as threatened or endangered during the course of the study. Federal Endangered Species Act listings included lower Columbia River steelhead *O. mykiss* (threatened; NOAA 1998) and lower Columbia River chinook salmon *O. tshawytscha* (threatened; NOAA 1999). Lower Columbia River coho salmon *O. kisutch* were listed as an endangered species under Oregon's Endangered Species Act (ODFW 1999). Because of these actions, we placed a special emphasis on relating our original objectives to salmonids.

Study Area

Seven primary streams within NCC were selected by WES for detailed habitat and fish surveys: Kellogg, Mt. Scott, Phillips, Dean, Cow, Sieben, and Rock creeks (Figure 1). Mt. Scott Creek is the major tributary of Kellogg Creek, which flows into the Willamette River near the city of Milwaukie. Phillips and Dean creeks are tributaries of Mt. Scott Creek. Cow, Sieben, and Rock creeks are tributaries of the Clackamas River, which enters the Willamette River at Oregon City.

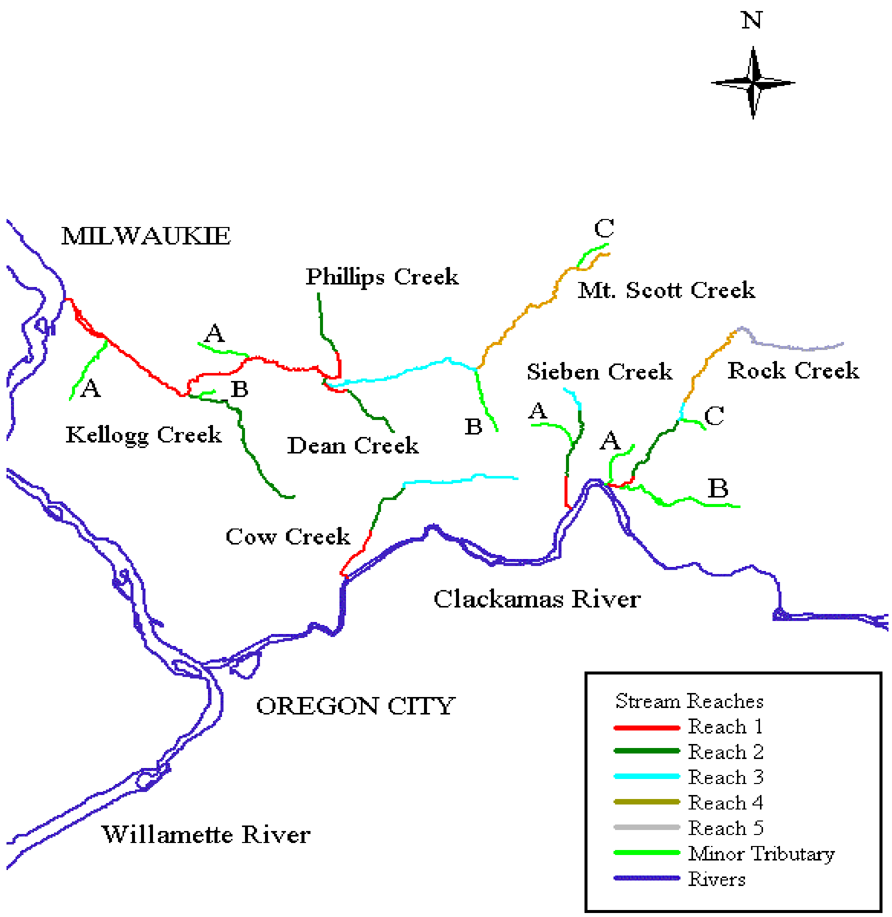

Figure 1. Streams of the North Clackamas County area. Aquatic habitat was surveyed throughout each reach during 1997-98. Fish, crayfish, and water quality data were collected within a 100-m section of each reach during 1997-1999. Upper-case letters (A, B, C) denote minor tributaries. Figure courtesy of Water Environment Services, a Department of Clackamas County.

In addition, nine secondary streams, all tributaries of Kellogg, Mt. Scott, Rock, and Sieben creeks, were identified by WES and the Oregon Division of State Lands (DSL) for cursory (presence/absence) fish surveys. Because these streams were generally unnamed, we assigned each a letter designation corresponding to its relative position within the primary drainage (Figure 1). Surveys were conducted in all streams between May 1997 and June 1999.

METHODS

Field Surveys

Habitat and Water Quality

We conducted fish habitat surveys using standardized ODFW sampling protocol (Hankin and Reeves 1988; Moore et al. 1997). Stream order, a measure of relative stream size within a watershed, was determined from 1:24,000 scale topographic maps as described by Strahler (1957). Habitat surveys were conducted during summer 1997 (Kellogg, Mt. Scott, and Rock creeks) and summer 1998 (Cow, Sieben, Phillips, and Dean creeks). Surveys began at the mouth of each stream and continued upstream until sampling became ineffective due to reduced water volume or dense undergrowth in each stream's headwaters.

We divided each primary stream into a series of reaches (Figure 1), designating a new reach when we encountered a significant landscape change, major tributary, or natural barrier to fish passage, such as a waterfall. Stream reaches are referred to by stream name and reach number throughout the text (e.g. Kellogg 1, Rock 4), and locations of individual stream reaches are described in Appendix A. Within each reach, geomorphic habitat units, such as pools, glides, and riffles, were identified.

For each geomorphic habitat unit, we measured or estimated length, width, and depth. Estimates were made by pacing distances (length) or using a 1.5-m wading staff (width and depth). Unit length and width were measured, rather than estimated, in every tenth unit using a metric measuring tape. Unit length was limited to a maximum of 100 m in particularly long sections of homogenous habitat. Substrate composition was visually estimated as the proportion of silt and organic matter, sand, gravel (2-64 mm diameter), cobble (65-256 mm), boulders (>256 mm), and bedrock in the streambed. We categorized streambanks as actively eroding, vegetated-stabilized, boulder-cobble, or non-erodible. The proportion of undercut bank was visually estimated and the number of boulders in each unit were counted. Stream shading was estimated for each habitat unit by using a clinometer. We measured the angle, in degrees, from the middle of the stream channel to the apex of the riparian canopy or landform on each side of the stream. A woody debris rating was assigned to each unit, ranging from 1 (little or no wood contributing to fish habitat) to 5 (large amount of wood creating a variety of cover and refuge habitats). Detailed methodology is described in Moore et al. (1997). We also noted potential fish passage barriers.

We selected shaded sites with water velocity and depth characteristics representative of the entire reach to measure basic water quality parameters. Variables measured included average water velocity (over a one-minute interval; m/s), turbidity (nephelometric turbidity units; NTU), percent oxygen saturation, dissolved oxygen (mg/L), temperature (^{o}C), conductivity (microSiemens; μS/cm), salinity (ppt), and total dissolved solids (mg/L).

Fish Surveys

Fish surveys were conducted on Kellogg, Mt. Scott, and Rock creeks during 1997-1998, and on Phillips, Dean, Cow, and Sieben creeks during 1998-1999. When possible, we performed one survey every season (summer, autumn, winter, and spring) within each stream reach. Fish surveys were conducted at the same sites from which we collected water quality data. Site lengths varied slightly due to undergrowth and other barriers, but were generally 100 m. Sampling was conducted with a backpack electrofisher operating at 200-400 volts DC and 3-5 amperes. During summer sampling, low flows allowed us to block the ends of many sites with nets to prevent fish movement into and out of the sampling area. We began at the downstream end of the site and moved upstream, collecting as many stunned fish as possible. If salmonids were observed during the first electrofishing pass, we conducted additional passes until no salmonids were captured (maximum of three passes; Armour et al. 1983). Nonsalmonid fish were generally collected only during the first pass; however, if additional passes were conducted, we collected all species that did not appear in the catch from the initial pass. We counted all crayfish observed during the first pass.

All fish collected during the first pass and all salmonids collected in subsequent passes were identified to species and counted. We measured a maximum of 50 individuals of each species (fork length; mm), and examined these individuals for parasites and other anomalies. Fish were released well downstream of the sampling site, prior to the next pass.

Cursory fish surveys were conducted in the nine secondary tributaries during spring 1998, except Mt. Scott tributary A and Sieben Creek tributary A, which were surveyed during winter and spring 1999, respectively. These surveys were intended only to determine species presence or absence; no attempt was made to standardize sampling effort or site length. We performed one electrofishing pass in each tributary through a 30- to 60-m section. All fish collected were identified and counted, and all salmonids were measured.

Data Analysis

Habitat and Water Quality

We estimated length, surface area, and percent of surface area contained in the primary stream channel for each stream and reach. Geomorphic habitat units were separated into four classifications and reported as the percent of total surface area in each reach. Unit classifications included “fast” (riffles, rapids, and cascades), “glide” (glides and meadow trenches), pools (all pool types, e.g. plunge pool, dammed pool), and “other” (e.g. culverts, dry units, backwaters). Substrate composition was reported as the percent of total surface area for gravel, cobble, boulder, and bedrock. Silt, sand, and fine organic matter were pooled as “fines”. Bank erosion was determined as the proportion of habitat units in each reach containing actively eroding stream banks. We also calculated mean shading (combined value for right and left sides; 0-180 degrees), percent undercut bank, number of boulders per meter, woody debris rating, and percent of woody debris ratings greater than class 2 in each reach. Water quality parameters and results are tabulated in Appendix C.

Fish Surveys

Except for salmonid population estimates, all analyses of fish surveys were based on catch from the first electrofishing pass. We determined overall percent of catch for each species, number of species in each stream and reach, and percent catch of each species for individual reaches. Fish catch in secondary streams and crayfish catch in primary streams is reported as the total number of individuals observed. The number and species of fish captured in each seasonal survey (first electrofishing pass) are tabulated in Appendix B.

To provide an index of salmonid abundance, we used the model of Armour et al. (1983), which calculates an estimate of population size for an area based on the reduction in catch among successive electrofishing passes. The model generates unrealistic estimates if catch increases from one pass to the next; when this occurred, we used the total number of salmonids captured (all passes combined) as a substitute population estimate. We estimated the number of native salmonids for each season and sampling site, and examined the proportional abundance of each species. We compared native salmonid fork length frequencies (20 mm size intervals) among seasons to evaluate the seasonal abundance of various life stages.

Juvenile salmonids are often difficult to identify. Because resident and anadromous forms of both juvenile *O. mykiss* and juvenile *O. clarki* are indistinguishable (Wydoski and Whitney 1979), we use the terms "rainbow trout" and "cutthroat trout", respectively, to indicate either form. "Steelhead" is used in the text only when large size (> 508 mm fork length; 20 inches) indicated the anadromous form of *O. mykiss*. Steelhead were considered rainbow trout in all data summaries and analyses. In addition, cutthroat trout and rainbow trout less than 100 mm fork length are very similar (Pollard et al. 1997). Though we were able to identify most individuals, some very small fish (<40 mm fork length) were classified as "unidentified fry".

Index of Biotic Integrity

The index of biotic integrity (Karr et al. 1986) is a widely used tool for determining and monitoring the biological integrity of streams. The IBI consists of a numerical score generated by applying field survey data to a set of scoring criteria, which are based on fish assemblage characteristics (metrics). We adopted the IBI developed and tested by Hughes et al. (1998) for wadeable Willamette Valley streams. Scoring criteria for this IBI were based on interpretations of pre-settlement stream conditions, species ranges, fish habitat requirements, and reference sites. Continuous scoring of 0.0-10.0 for metrics and 0-100 for the IBI score was employed.

We modified the IBI slightly in applying it to NCC streams. Hughes et al. (1998) included a "native top carnivore" metric as one of three trophic guild measurements. Species listed as native top carnivores by Hughes et al. (1998) and found in NCC streams included northern pikeminnow *Ptychocheilus oregonensis*, cutthroat trout, coho salmon, rainbow trout and steelhead, chinook salmon, and torrent sculpin *Cottus rhotheus*. These species are typically carnivorous only at larger sizes (and only in saltwater, in the case of anadromous salmonids), and are more accurately described as insectivores or invertivores (Zaroban et al. 1999) at smaller sizes. Northern pikeminnow, for example, prey primarily on other fish species only after reaching 250 mm fork length (Vigg et al. 1991). Because we captured very few large, native top carnivores, we dropped this metric from the original IBI, reducing the total number of metrics to twelve (Table 1). Other metrics and their scoring criteria remained unchanged.

An IBI score was calculated for each seasonal fish survey completed, and mean values were determined for seasons, streams, and reaches. Biotic integrity was judged as acceptable (score of ≥75), marginally impaired (51-74), or severely impaired (≤50; Hughes et al 1998). We assigned an IBI score of 0.0 to those reaches that contained no fish.

Statistical Tests

We used one-way analysis of variance (ANOVA; Zar 1984) on ranks to determine if IBI scores were significantly different among seasons. All other statistical comparisons were performed using the Pearson correlation (Zar 1984). We used a decision level of $P \leq 0.05$ to determine statistical significance. Proportional data was arcsine transformed (Sokal and Rohlf 1981) prior to analysis.

We evaluated the correlation between habitat data and seasonal and mean IBI scores for each reach. Two different sets of habitat data were used for correlations with IBI: data summarized for the entire reach (reach data), and data summarized for the area contained within the fish sampling site (site data). Fourteen reach data variables were used in correlations with IBI: (1) the proportion of habitat units containing actively eroding stream banks; (2) mean pool depth; (3) mean shading; (4) mean number of boulders per habitat unit; (5) undercut bank (mean percent undercut per habitat unit); (6) number of culverts contained within the reach; (7) proportion of stream surface area as culverted units; (8) mean woody debris rating; (9) proportion of units containing woody debris ratings of greater than 2; (10) proportion of substrate as fines; (11) proportion of substrate as gravel or cobble; (12) proportion of stream surface area as fast water; (13) proportion of stream surface area as glides; and, (14) proportion of stream surface area as pools. Site data comparisons were similar, except variable (2) was replaced by mean habitat unit depth, variable (6) was replaced by the number of potential barriers below the fish sampling site, and variable (7) was replaced by the proportion of culverted stream area below the fish sampling site.

Unlike habitat data, water quality sampling was collected over all four seasons. We therefore correlated seasonal and mean water quality values with seasonal and mean IBI scores (e.g. summer turbidity vs. summer IBI). Variables included in this analysis included turbidity, percent oxygen saturation, dissolved oxygen level, water temperature, water velocity, conductivity, and total dissolved solids.

Table 1. Scoring criteria for IBI metrics used for North Clackamas County streams. Raw data values at the low (and lower) end of the ranges are scored as zero; those at the high (and higher) end are scored as 10; scores for intermediate values are calculated by dividing the raw value by the score range. Modified from Hughes et al. (1998).

	Raw values	
Metric	Stream order 1	Stream orders 2 and 3
Taxonomic richness		
Number of native families	0-4	0-7
Number of native species	0-5	0-11
Habitat guilds		
Number of native benthic species	0-3	0-7
Number of native water column species	0-2	0-4
Number of hider species	0-4	0-4
Number of sensitive species	0-2	0-5
Number of native nonguarding lithophil nester species[a]	0-3	0-3
Percent tolerant individuals	10-0	10-0
Trophic guilds		
Percent filter-feeding individuals	0-10	0-10
Percent omnivores	10-0	10-0
Individual health and abundance		
Percent of target species that include lunkers[b]	0-100	0-100
Percent individuals with anomalies	2-0	2-0

[a]Species that create nests in gravel or cobble substrate.

[b]Lunkers are relatively old, large individuals of the following species and sizes (fork length): prickly sculpin (100 mm), torrent sculpin (100 mm), rainbow trout (300 mm), cutthroat trout (250 mm), chiselmouth (300 mm), northern pikeminnow (300 mm), and largescale sucker (300 mm).

RESULTS

Habitat and Water Quality

We surveyed a total distance of 66,504 m (66.5 km) in primary NCC streams (Table 2). Mt. Scott Creek was the longest stream surveyed and contained the greatest total surface area; Dean Creek was the shortest stream and had the smallest total surface area. Reach length ranged from 137 m (Mt. Scott 2) to 3,858 m (Mt. Scott 1). Three creeks (Kellogg, Mt. Scott, and Rock) were third-order streams in their lowest reaches, one (Sieben) was a second-order stream, and the remainder were first-order streams. Multiple channels were generally uncommon, and surface area of the primary channel constituted 94-100% of the total surface area among streams. Only Rock 1 contained a considerable (16%) amount of habitat in secondary channels.

Glides constituted greater than 10% of the stream surface area in all reaches, and were the predominant habitat type in 15 of 21 reaches (Figure 2). Fast water habitat types were common (>20% of total surface area) in Kellogg 1, Mt. Scott 3 and 4, Phillips 1, Sieben 1 and 2, and all reaches of Rock Creek. Pools were scarce in Kellogg, Mt. Scott, Phillips, and Dean creeks, but were present in proportions of greater than 10% in most reaches of Cow, Sieben, and Rock creeks. Other habitat types, primarily culverts, were rare in most stream reaches but made up more than 20% of the total surface area in Phillips Creek, Dean 1, and Cow 3.

Fines were the greatest proportional substrate component in 9 of 21 reaches, including all reaches of Cow Creek and Dean Creek (Figure 3). Within streams, the proportion of fines was generally greatest in upstream reaches and lowest in downstream reaches. Gravel and cobble combined composed greater than 25% of the total substrate surface area in all reaches, except those that were heavily dominated by fines (Dean 1 and 2, Cow 1 and 3). Bedrock was present in proportions of greater than 10% only in Rock 2-5 and Mt. Scott 3.

The proportion of habitat units containing actively eroding stream banks varied widely among stream reaches (Figure 4). Greater than 25% of habitat units were actively eroding in all reaches of Phillips and Sieben creeks and the upper two reaches of Rock Creek. Six reaches exhibited little or no bank erosion. Stream banks that were not eroding were stabilized by vegetation, boulder and cobble, or non-erodible material such as concrete. Culverted units were also classified as non-erodible.

Like other habitat characteristics, shading varied considerably among streams and reaches (Figure 5). Only 7 of 21 reaches were more than 50% (90^{o}) shaded, including Cow 1 and all reaches of Phillips and Sieben Creeks. In general, first- and second-order streams were more heavily shaded than third-order streams. Shading was often provided by terraces, hillslopes, shrubs, and grasses, rather than forest canopies.

Both undercut banks and boulders made modest contributions to habitat complexity (Table 3). Mean percent bank undercut (per habitat unit) was greater than zero in all reaches and averaged 6.7%. Boulder density was considerably higher (mean 0.4 boulders per m) in Kellogg 1, Mt. Scott 3 and 4, and the upper four reaches of Rock Creek than in other reaches (mean 0.04 per m). Three reaches contained no boulders.

Table 2. Stream order, total length, surface area, and percent of surface area contained in the primary channel for North Clackamas County stream reaches, 1997-1998.

Stream	Reach	Stream order	Length (m)	Surface area (m^2)	Surface area in primary channel (%)
Kellogg Creek	1	3	1,943	15,529	98.6
	2	1	3,160	9,247	97.2
	Total	--	5,103	24,776	98.0
Mt. Scott Creek	1	3	3,858	20,761	98.8
	2	3	137	548	100.0
	3	3	3,193	10,271	99.7
	4	2	2,902	10,279	98.8
	Total	--	10,090	41,859	99.0
Phillips Creek	1	1	381	885	100.0
	2	1	1,763	4924	94.5
	Total	--	2,144	5,809	95.4
Dean Creek	1	1	650	1,723	100.0
	2	1	497	1,507	93.8
	Total	--	1,147	3,230	97.1
Cow Creek	1	1	976	2,473	93.9
	2	1	1,075	2,654	100.0
	3	1	2,543	4,761	100.0
	Total	--	4,594	9,888	98.5
Sieben Creek	1	2	885	2,499	98.4
	2	1	1,270	3,361	94.7
	3	1	770	713	100.0
	Total	--	2,925	6,573	96.7
Rock Creek	1	3	455	2,496	83.9
	2	3	1,587	7,724	96.8
	3	3	727	3,637	97.1
	4	3	2,251	12,001	98.8
	5	2	2,229	5,705	100.0
	Total	--	7,249	31,563	97.2

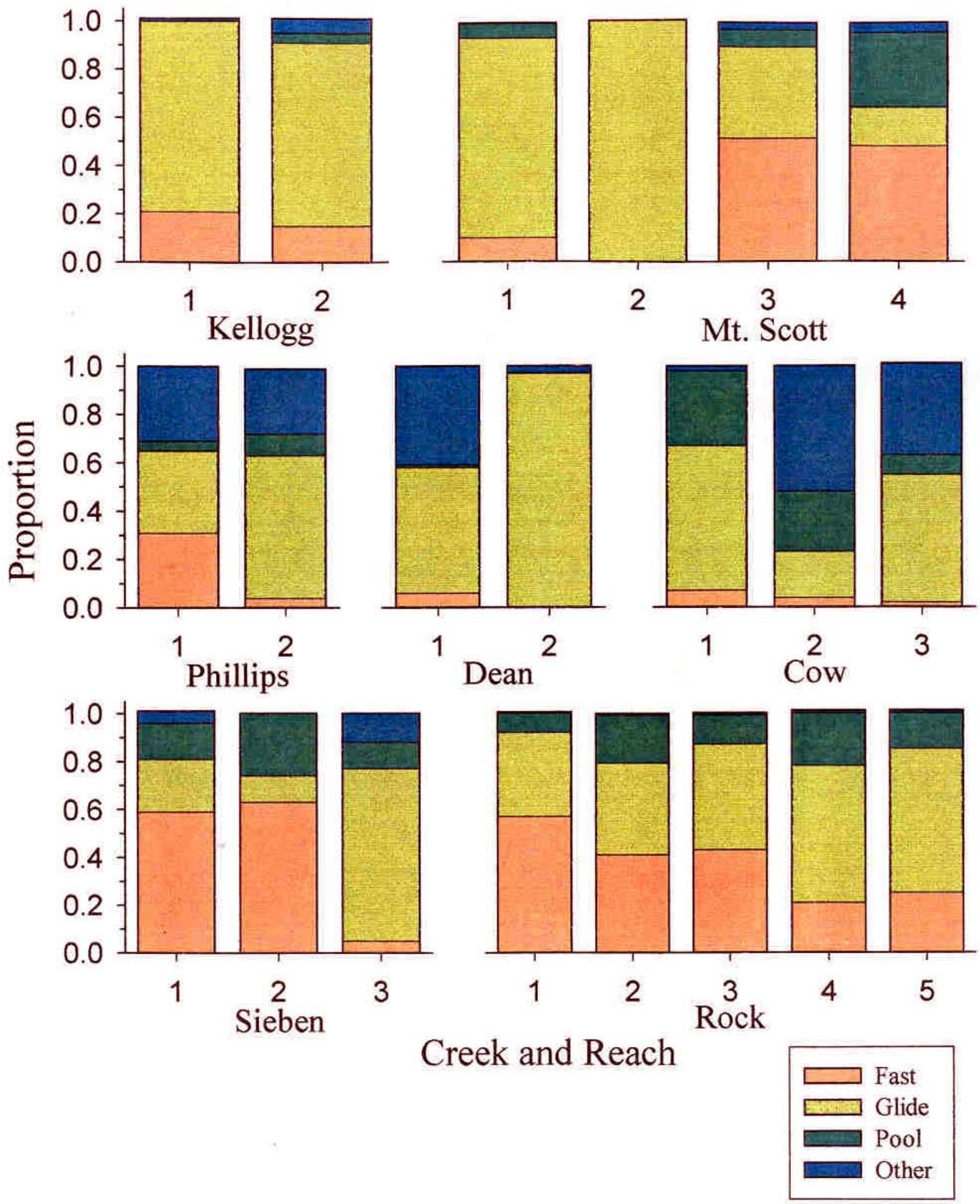

Figure 2. Proportional surface area of habitat unit categories for North Clackamas County stream reaches, 1997-1998. Fast = riffles, rapids, and cascades; glide = glides and meadow trenches; pool = all pool types (e.g. plunge pool, dammed pool); other = all other types (e.g. culverts, dry units).

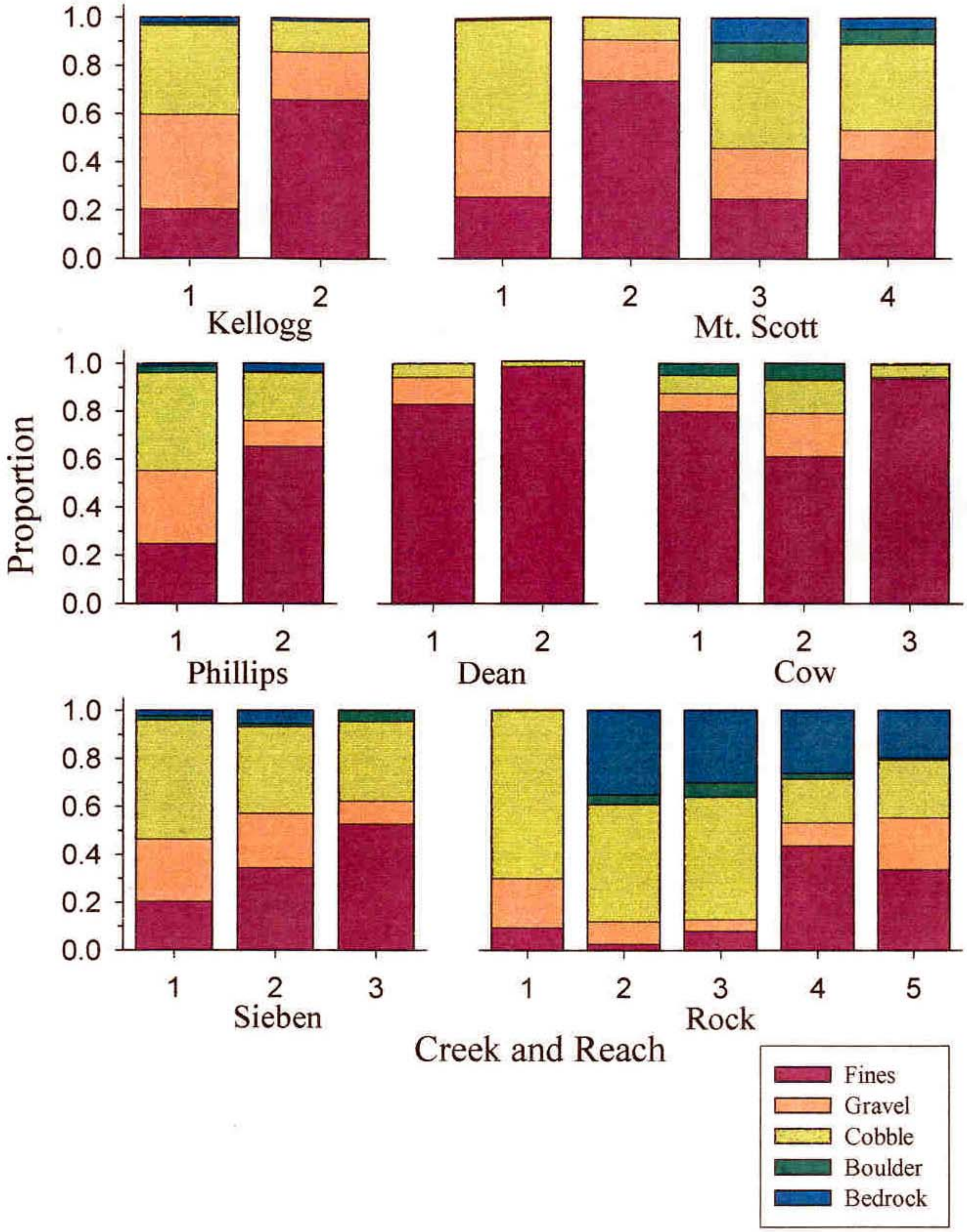

Figure 3. Proportional surface area of substrate types for North Clackamas County stream reaches, 1997-1998. Substrate types and diameters are: fines (silt, sand, and organic matter), gravel (2-64 mm), cobble (65-256 mm), and bedrock (Moore et al. 1997).

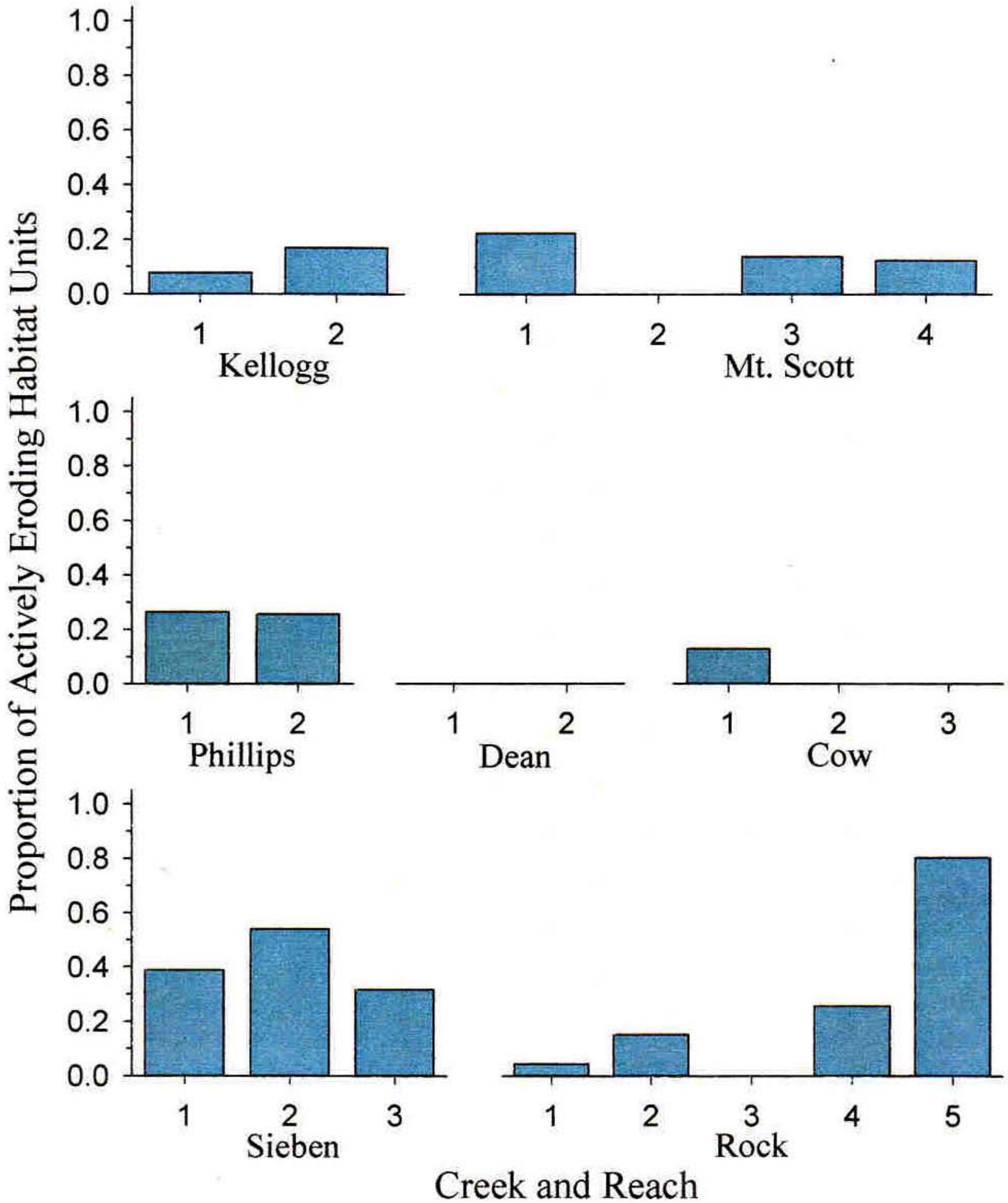

Figure 4. Proportion of habitat units containing actively eroding banks in North Clackamas County stream reaches, 1997-1998.

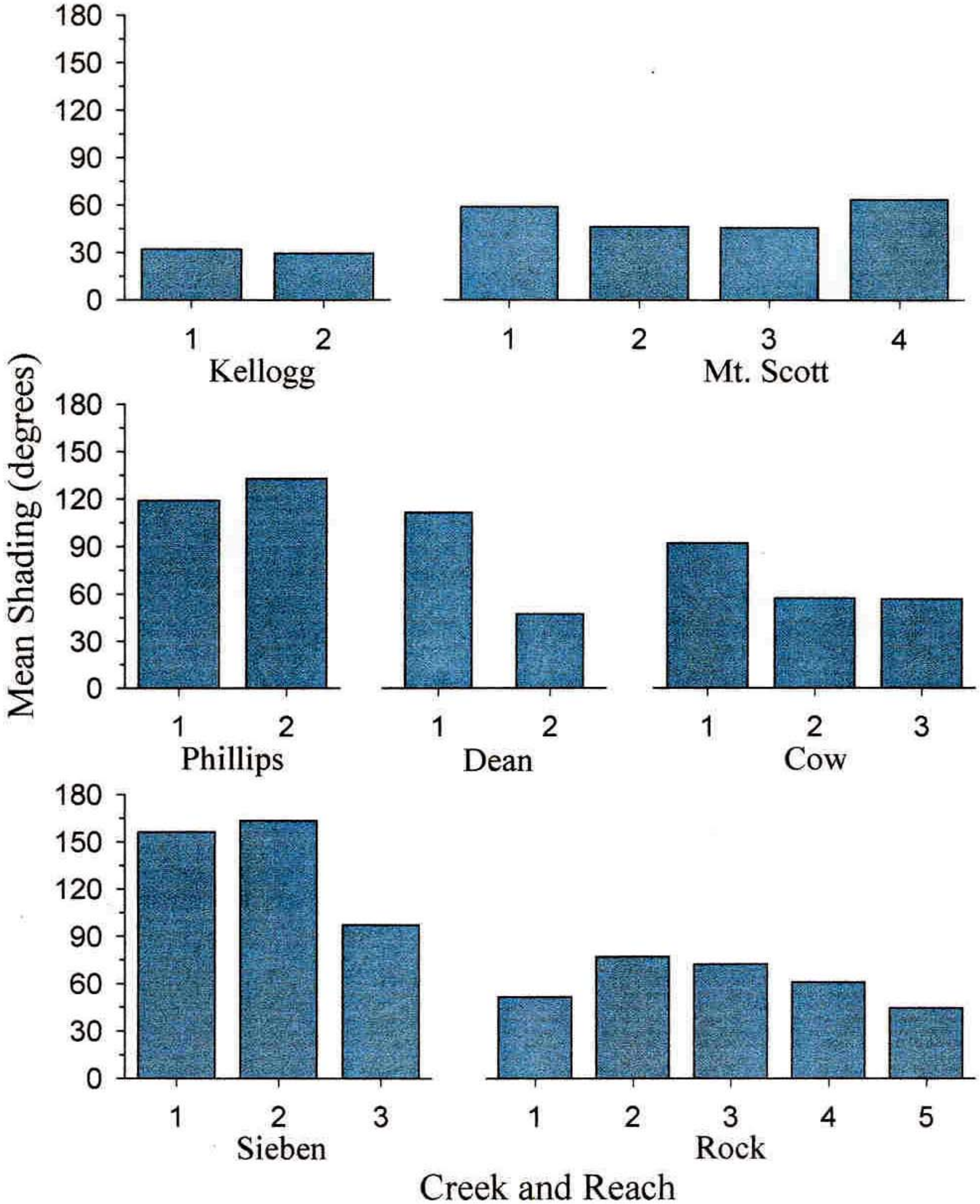

Figure 5. Mean stream shading in reaches of North Clackamas County streams, 1997-1998.

Table 3. Mean percent undercut bank per habitat unit, mean number of boulders per meter, mean woody debris rating, and percent of habitat units containing class 3, 4, or 5 woody debris for North Clackamas County stream reaches, 1997-1998. A woody debris rating of 1 indicates little or no wood contributing to fish habitat; a rating of 5 indicates a large amount of wood, creating a variety of cover and refuge habitats (Moore et al. 1997).

Stream	Reach	Undercut bank (%)	Boulders (number/m)	Mean woody debris rating	Woody debris > class 2 (%)
Kellogg	1	5.0	0.32	1.11	1.54
	2	9.9	0.05	1.35	4.95
Mt. Scott	1	9.5	0.06	1.18	3.20
	2	10.0	0.01	1.00	0.00
	3	2.4	0.52	1.11	0.76
	4	2.1	0.63	1.11	2.70
Phillips	1	3.4	0.07	1.11	5.26
	2	1.7	0.01	1.00	0.00
Dean	1	15.8	0.00	1.68	10.53
	2	8.6	0.00	1.00	0.00
Cow	1	10.7	0.09	1.83	17.02
	2	14.1	0.11	1.56	18.52
	3	5.9	0.04	1.27	9.76
Sieben	1	6.1	0.04	1.16	4.08
	2	9.6	0.01	1.22	4.00
	3	2.1	0.00	1.05	0.00
Rock	1	5.7	0.03	1.43	13.10
	2	4.6	0.37	1.13	2.50
	3	1.4	0.54	1.02	0.00
	4	2.8	0.35	1.23	1.28
	5	8.9	0.17	1.22	4.49

Woody debris generally provided little fish cover or habitat complexity (Table 3). Among stream reaches, woody debris ratings were low and exhibited little variation, ranging from 1.00 (three reaches) to 1.83 (Cow 1). The percent of habitat units that received wood ratings of 3, 4, or 5 was less than 10% in all but four reaches. Woody debris ratings were greatest in Kellogg 2, Cow 1 and 2, and Rock 1.

Culverts and other potential barriers to fish passage were common in primary streams (Table 4). Every stream contained at least four potential barriers in their primary channel, and Cow Creek contained 20. The number of culverts in each reach ranged from zero (6 reaches) to 11 (Cow 3), and only three reaches (Mt. Scott 1, Rock 1 and 2) had no potential barriers. The percent of total stream surface area contained within culverts was estimated to be greater than 10% in six reaches, and exceeded 40% in Dean 1. Other potential barriers included one fish ladder, two dams, six falls, and seasonally dry channels. We did not make a detailed inspection of each barrier; however, two culverts (Mt. Scott Creek crossing at I-205 and Dean Creek near I-205), all of the falls, at least one dam (Sieben 2), and all dry channels were clearly impassable to fish.

Fish surveys

We conducted 79 electrofishing surveys of primary streams during 1997-1999. Each stream was successfully surveyed once in summer, autumn, winter, and spring, except Kellogg 1 was not surveyed during winter due to high flows and turbid water. Mt. Scott 2 was not surveyed in any season because of its short length and similarity to reach 1.

A total of 7,484 fish from 9 families and 16 genera were collected during the first electrofishing pass in all primary streams, reaches, and seasons combined (Table 5). Reticulate sculpin constituted the greatest proportion of the catch, followed by speckled dace, redside shiner, and western mosquitofish. Fishes introduced to Oregon consisted of ten species and made up a small proportion (5.7%) of the total catch.

The seven primary streams contained an average of 13.3 species of fish, ranging from 8 in Dean and Sieben creeks to 20 in Cow Creek (Table 6). Among individual reaches, the number of species ranged from zero (Cow 3 and Sieben 3) to 20 (Cow 1). The mean number of species per reach was 6.6. Several species were found only in certain streams or reaches. Torrent sculpin were present only in the lower two reaches of Rock Creek; oriental weatherfish, chislemouth, and peamouth were captured only in Cow 1. Despite dominating the catch in many reaches, reticulate sculpin were absent from all reaches of Sieben Creek, Cow 2 and 3, and Dean 2. Introduced species composed a small proportion of the catch in most reaches, except Cow 2 and Dean 2 were dominated by introduced western mosquitofish.

Native salmonids, including chinook salmon, coho salmon, rainbow trout, and cutthroat trout, were present in every primary stream, and in 13 of the 20 reaches surveyed (Tables 6 and 7). We captured several non-native brook trout in Kellogg 2. Rainbow trout were the most common salmonid species observed, comprising 2.5% of the total catch and 63.9% of the salmonid catch. Salmonids typically composed less than 10% of the total catch in a reach, except in Rock 2 (25%) and Sieben 2 (24%). The total estimated number of native salmonids

Table 4. Number of culverts, total estimated culvert surface area, percent culverted area, and other potential fish passage barriers in North Clackamas County stream reaches, 1997-1998. Reaches not listed contained no barriers.

Stream	Reach	Number of culverts	Culverted surface area (m^2)	% of total area	Other barriers
Kellogg	1	0	0	0.0	fish ladder
	2	3	200	2.2	--
Mt. Scott	3	3	324	3.2	--
	4	8	261	2.6	dam and pond
Phillips	1	4	272	30.7	--
	2	9	1,265	27.2	3-m falls
Dean	1	4	681	40.5	--
	2	1	48	3.4	--
Cow	1	4	36	1.5	--
	2	4	467	17.6	--
	3	11	1,593	33.4	dry channels in summer
Sieben	1	1	40	1.6	three 2- to 3-m falls
	2	0	0	0.0	dam and pond
	3	3	83	11.6	3-m falls
Rock	3	0	0	0.0	7-m falls
	4	1	40	0.3	--
	5	3	19	0.3	--

Table 5. Fish collected from streams of North Clackamas County, 1997-1999. Number of fish and percent of catch are based on one electrofishing pass per stream reach for all seasons (spring, summer, autumn, and winter) combined.

Family, species	Common name	Number	Percent of catch
Petromyzontidae			
Lampetra richardsoni	western brook lamprey	9	0.12
Lampetra tridentata	Pacific lamprey	26	0.35
Unidentified *Lampetra* spp.	--	2	0.03
Cyprinidae			
Acrocheilus alutaceus	chiselmouth	80	1.07
Carassius auratus[a]	goldfish	1	0.01
Mylocheilus caurinus	peamouth	2	0.03
Ptychocheilus oregonensis	northern pikeminnow	198	2.64
Rhinichthys cataractae	longnose dace	41	0.55
Rhinichthys osculus	speckled dace	1,699	22.71
Richardsonius balteatus	redside shiner	1,483	19.81
Cobitidae[b]			
Misgurnus anguillicaudatus	oriental weatherfish	25	0.33
Catostomidae			
Catostomus macrocheilus	largescale sucker	91	1.22
Ictaluridae[b]			
Ameiurus natalis	yellow bullhead	1	0.01
Ameiurus nebulosis	brown bullhead	2	0.03
Salmonidae			
Oncorhynchus clarki	cutthroat trout	37	0.50
Oncorhynchus kisutch	coho salmon	18	0.24
Oncorhynchus mykiss	rainbow trout, steelhead	186	2.48
Oncorhynchus tshawytscha	chinook salmon	11	0.15
Salvelinus fontinalis[a]	brook trout	1	0.01
Unidentified Salmonidae	--	32	0.43
Poeciliidae[b]			
Gambusia affinis	western mosquitofish	379	5.07

Table 5. (Continued)

Family, species	Common name	Number	Percent of catch
Cottidae			
Cottus asper	prickly sculpin	53	0.71
Cottus perplexus	reticulate sculpin	3,003	40.12
Cottus rhotheus	torrent sculpin	56	0.75
Unidentified Cottidae	--	33	0.44
Centrarchidae[b]			
Lepomis gibbosus	pumpkinseed	4	0.05
Lepomis macrochirus	bluegill	2	0.03
Unidentifed *Lepomis* spp.	--	2	0.03
Micropterus dolomieu	smallmouth bass	1	0.01
Micropterus salmoides	largemouth bass	6	0.08

[a]Introduced species
[b]Introduced family

Table 6. Percent catch of each fish species collected in reaches of Kellogg, Mt. Scott, Rock, Cow, Sieben, Phillips, and Dean creeks, 1997-1999 (one electrofishing pass, all seasons combined). Individuals not identified to species are omitted and percentages are rounded; catch within a reach may not total 100%.

	Creek, reach									
	Kellogg		Mt. Scott			Rock				
Species	1	2	1	3	4	1	2	3	4	5
Western brook lamprey	0	0	0	0	0	0	<1	0	0	3
Pacific lamprey	0	2	0	1	3	<1	<1	<1	1	2
Chiselmouth	0	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0	0
Peamouth	0	0	0	0	0	0	0	0	0	0
Northern pikeminnow	0	0	0	0	0	2	1	0	0	0
Longnose dace	0	0	0	0	0	4	1	0	0	0
Speckled dace	6	<1	3	0	0	21	14	0	0	0
Redside shiner	29	<1	7	0	0	49	7	0	0	0
Oriental weatherfish[a]	0	0	0	0	0	0	0	0	0	0
Largescale sucker	1	0	<1	0	0	1	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	<1	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0	0
Chinook salmon	0	<1	0	0	0	<1	0	0	0	0
Coho salmon	<1	2	0	0	1	0	1	0	0	0
Rainbow trout	<1	1	0	0	1	5	24	0	0	0
Cutthroat trout	<1	0	0	5	6	<1	0	0	0	3
Brook trout[a]	0	<1	0	0	0	0	0	0	0	0
Mosquitofish[a]	2	0	4	0	0	0	0	0	0	0
Prickly sculpin	9	0	<1	0	0	0	0	0	0	0
Reticulate sculpin	53	94	85	95	78	6	51	95	98	91
Torrent sculpin	0	0	0	0	0	8	1	0	0	0
Pumpkinseed[a]	<1	0	0	0	0	<1	0	0	0	0
Bluegill[a]	0	<1	0	0	0	0	0	0	1	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	<1	0	<1	0	0	<1	0	0	0	0

Table 6 . (Continued)

	Creek, reach									
	Cow			Sieben			Phillips		Dean	
Species	1	2	3	1	2	3	1	2	1	2
Western brook lamprey	<1	0	0	0	0	0	<1	0	1	0
Pacific lamprey	1	0	0	0	0	0	<1	0	<1	0
Chiselmouth	6	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	<1	0	0
Peamouth	<1	0	0	0	0	0	0	0	0	0
Northern pikeminnow	11	0	0	8	0	0	0	0	0	0
Longnose dace	<1	0	0	1	0	0	0	0	0	0
Speckled dace	45	0	0	82	77	0	17	36	1	12
Redside shiner	23	0	0	3	0	0	44	48	50	13
Oriental weatherfish[a]	2	0	0	0	0	0	0	0	0	0
Largescale sucker	6	0	0	1	0	0	0	0	<1	0
Brown bullhead[a]	0	0	0	0	0	0	0	<1	0	0
Yellow bullhead[a]	<1	0	0	0	0	0	0	0	0	0
Chinook salmon	<1	0	0	1	0	0	0	0	0	0
Coho salmon	<1	0	0	1	0	0	0	<1	0	0
Rainbow trout	<1	0	0	1	23	0	1	1	0	0
Cutthroat trout	<1	0	0	0	0	0	2	1	<1	0
Brook trout[a]	0	0	0	0	0	0	0	0	0	0
Mosquitofish[a]	<1	100	0	0	0	0	0	2	1	75
Prickly sculpin	<1	0	0	0	0	0	0	0	0	0
Reticulate sculpin	5	0	0	0	0	0	36	13	46	0
Torrent sculpin	0	0	0	0	0	0	0	0	0	0
Pumpkinseed[a]	<1	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	<1	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	0	0	0	0	0	0	<1	0	0

[a]Introduced species

Table 7. Estimated number of native salmonids per 100-m sampling site for North Clackamas County stream reaches, 1997-1999. Sampling consisted of multiple-pass electrofishing, and estimates were calculated using the model of Armour et al. (1983). NS = no survey.

		Estimated number of salmonids				
Stream	Reach	Summer	Autumn	Winter	Spring	Total
Kellogg	1	3	1	NS	0	4
	2	0	0	2	2	4
	Total	3	1	2	2	8
Mt. Scott	1	0	0	0	0	0
	3	8	0	1	0	9
	4	2	4	10	2	18
	Total	10	4	11	2	27
Phillips	1	1	3	0	11	15
	2	2	2	2	5	11
	Total	3	5	2	16	26
Dean	1	0	0	2	4	6
	2	0	0	0	0	0
	Total	0	0	2	4	6
Cow	1	4	2	10	3	19
	2	0	0	0	0	0
	3	0	0	0	0	0
	Total	4	2	10	3	19
Sieben	1	7	6	0	48	61
	2	34	5	2	1	42
	3	0	0	0	0	0
	Total	41	11	2	49	103
Rock	1	31	27	14	52	124
	2	24	40	17	104	185
	3	0	0	0	0	0
	4	0	0	0	0	0
	5	3	0	0	1	4
	Total	58	67	31	157	313

(all seasons combined) ranged from zero (7 reaches) to 185 in Rock 2 (Table 7). Over 61% of all native salmonids were collected from the lower two reaches of Rock Creek . The estimated number of salmonids per reach was greater in spring (11.7) than in summer (6.0), autumn (4.5), or winter (3.2). Based on physical appearance, large size, and anecdotal information, all rainbow trout in Sieben Creek were likely stocked, non-migratory fish that had escaped from a pond in reach 2.

All four native salmonid species observed in this study were captured in Kellogg, Cow and Rock creeks. Mt. Scott, Phillips, and Sieben creeks contained three species; Dean Creek contained only cutthroat trout and unidentified fry. Rainbow trout constituted the major proportion of the salmonid catch in Kellogg, Sieben, and Rock creeks, while cutthroat trout were more numerous in Mt. Scott, Dean, and Phillips creeks (Figure 6). Unidentified fry were present in all streams except Kellogg, Mt. Scott, and Phillips creeks, and were a substantial component of the catch in Dean, Cow, and Sieben creeks. Chinook and coho salmon were relatively rare; however, all streams except Dean Creek contained at least one salmon species, and four streams contained both. Salmon species individually composed less than 20% of the salmonid catch in all streams except Cow Creek.

Salmonids collected were generally small, averaging 90.4 mm fork length for all individuals measured (Figure 7). Mean fork length ranged from 62.5 mm during spring surveys to 121.3 mm during winter surveys. The mean fork length and proportional distribution of 20-mm size intervals was similar during summer and autumn, except the modal length interval increased from 60-79 mm in summer to 80-99 mm in autumn. The variance of mean fork length was less in winter than in other seasons, and nearly all salmonids captured during spring were less than 79 mm in fork length. Most salmonids exhibited parr marks, indicative of immature or juvenile fish. Very few large, adult salmonids were captured. We observed (1) several large (>240 mm fork length) cutthroat trout in Kellogg Creek and its tributaries, including a recently-spawned male at the mouth of Phillips Creek, (2) a 580-mm adult hatchery steelhead captured during winter in Rock 1, (3) an unidentified adult salmon or steelhead carcass in Rock 1, (4) a live adult steelhead observed by ODFW and WES staff at a flood control facility in Mt. Scott 1, and (5) stocked rainbow trout that escaped from a pond in Sieben Creek. No salmonids, with the exception of the live adult steelhead in Rock 1, were finmarked.

All secondary tributaries were first-order streams (except Mt. Scott B) and appeared as seasonal or intermittent streams on topographic maps. We collected fish from seven families and eight genera in these tributaries (Table 8). The number of species ranged from one in Mt. Scott C and Rock C to six in Kellogg B; we observed no fish in Mt. Scott A or Sieben A. Introduced species were uncommon, except Kellogg B was dominated by introduced centrarchids, primarily pumpkinseed. Salmonids were present in four of the eight tributaries, and all of these fish were less than 135 mm in fork length.

We observed a total of 501 crayfish during the first electrofishing pass of fish surveys (Table 9). Three reaches contained no crayfish in any season (Cow 3, Sieben 2 and 3), and only one crayfish was collected from Sieben 1. Crayfish were considerably more abundant in Mt. Scott 1, Phillips 1 and 2, Dean 1, and the upper three reaches of Rock Creek than in other

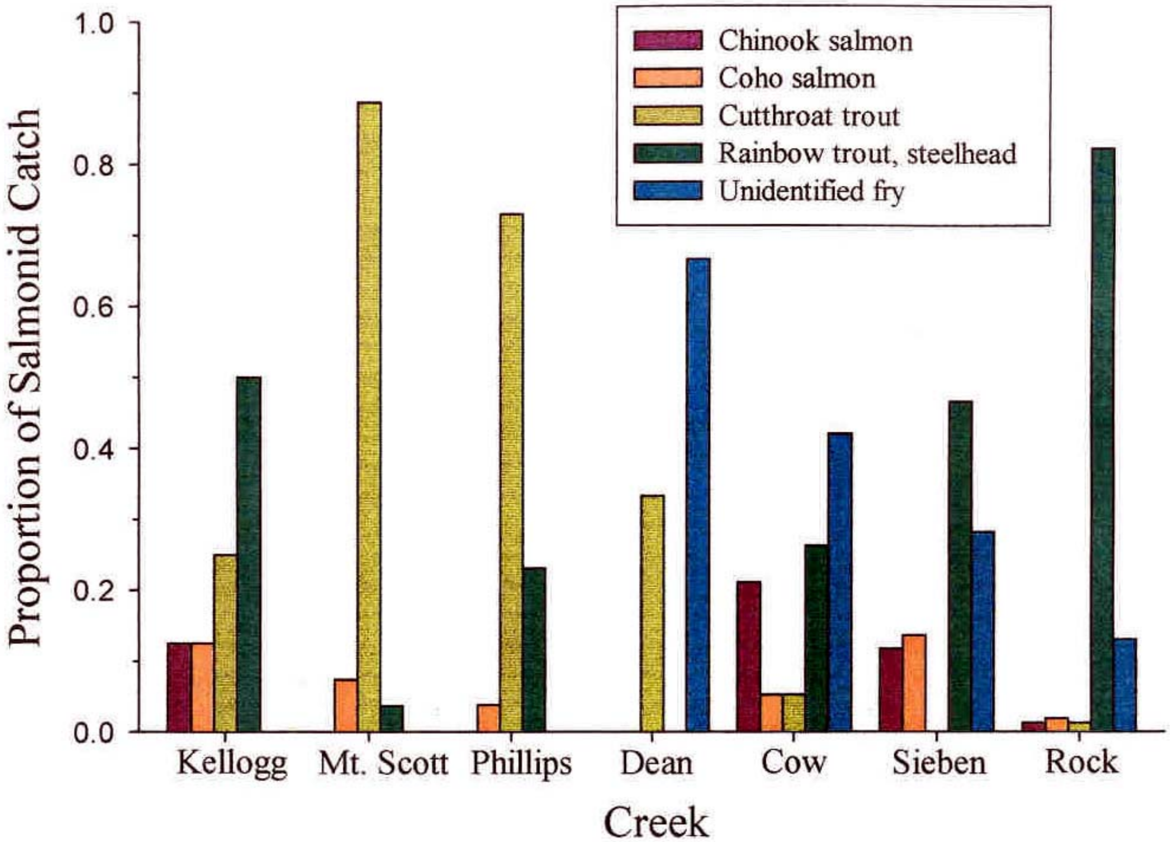

Figure 6. Proportional abundance of native salmonid species in reaches of North Clackamas County streams, 1997-1999.

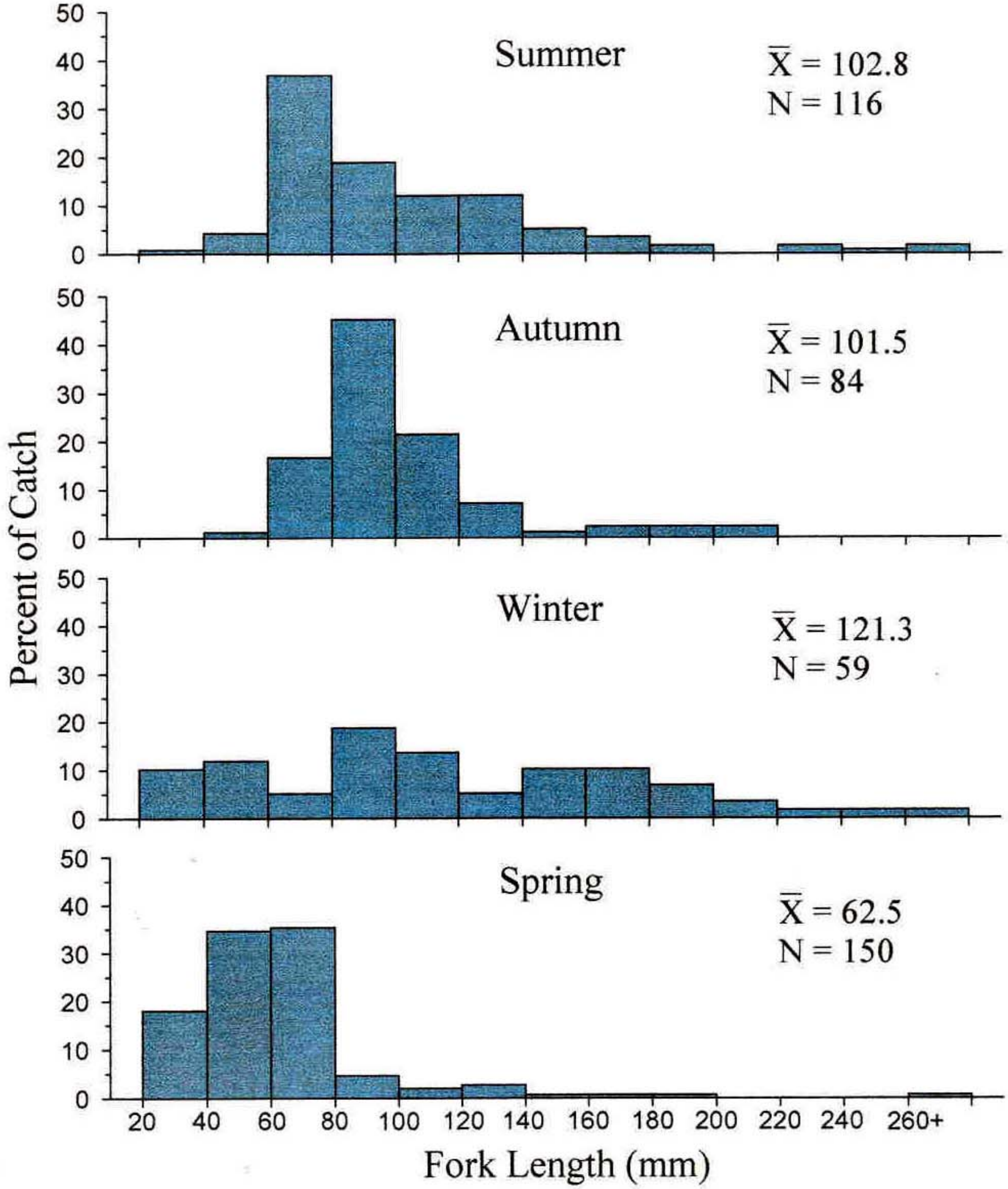

Figure 7. Seasonal length-frequencies for native salmonids captured in North Clackamas County streams, 1997-1998.

Table 8. Fish collected by electrofishing in secondary tributaries of Kellogg, Mt. Scott, Rock, and Sieben creeks, 1998-1999. The number of fish collected is not comparable among tributaries; sampling was conducted only to determine presence or absence.

	Creek, tributary								
	Kellogg		Mt. Scott			Rock			Sieben
Species	A	B	A	B	C	A	B	C	A
Unidentified *Lampetra* spp.	0	1	0	0	0	0	0	0	0
Speckled dace	0	0	0	0	0	0	3	0	0
Longnose dace	0	0	0	0	0	0	3	0	0
Largescale sucker	0	1	0	0	0	0	0	0	0
Rainbow trout	0	0	0	0	0	7	7	0	0
Cutthroat trout	0	0	0	5	0	0	0	0	0
Unidentified Salmonidae	8	0	0	0	0	0	0	0	0
Mosquitofish[a]	0	1	0	0	0	0	0	0	0
Reticulate sculpin	6	5	0	0	7	6	4	67	0
Prickly sculpin	7	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	4	0	0	0	0	0	0	0
Pumpkinseed[a]	0	11	0	0	0	0	0	0	0

[a] Introduced species

Table 9. Number of crayfish observed in stream reaches of North Clackamas County, 1997-1999. Crayfish were counted during the first electrofishing pass of fish assemblage surveys. NS = no survey.

Stream	Reach	Summer	Autumn	Winter	Spring	Total
Kellogg	1	15	0	NS	3	18
	2	0	0	0	1	1
	Total	15	0	0	4	19
Mt. Scott	1	67	13	1	16	97
	3	5	0	0	1	6
	4	11	4	0	4	19
	Total	83	17	1	21	122
Phillips	1	22	15	1	0	38
	2	58	5	0	4	67
	Total	80	20	1	4	105
Dean	1	48	4	0	11	63
	2	0	2	0	0	2
	Total	48	6	0	11	65
Cow	1	0	0	1	2	3
	2	2	0	0	0	2
	3	0	0	0	0	0
	Total	2	0	1	2	5
Sieben	1	0	0	0	1	1
	2	0	0	0	0	0
	3	0	0	0	0	0
	Total	0	0	0	1	1
Rock	1	9	0	0	0	9
	2	7	0	0	5	12
	3	40	1	0	1	42
	4	53	0	0	4	57
	5	57	1	0	6	64
	Total	166	2	0	16	184

reaches. Abundance was greater during summer (19.2 crayfish per reach) than in autumn (2.3), winter (0.2), or spring (3.0). Examined individuals appeared healthy and free of parasites.

Data Analysis

Index of biotic integrity scores are summarized in Table 10. The overall mean IBI score for reaches was 42.9, and varied from 38.8 during winter to 46.9 during spring. Scores were not significantly different among seasons (P=0.73), but the power of the ANOVA test (β=0.05) was lower than the desired power of β=0.80. Cow Creek had the lowest (26.5) mean biotic integrity; Phillips Creek had the highest (63.8). Scores were highly variable for some reaches and seasons, and consistent for others. Phillips 1, for example, ranged from 42.3 during winter to 81.0 during autumn, whereas Cow 2 and Sieben 2 received the same score in each season. Cow 3 and Sieben 3 contained no fish in any season and received scores of 0.0. Of the 79 individual scores, 5 (6.3%) were acceptable, 24 (30.4%) were moderately impaired, and 50 (63.3%) were severely impaired. Mean scores for each reach (all seasons combined) included 8 (40.0%) moderately impaired sites and 12 (60.0%) severely impaired sites. Mean scores for each stream (all reaches and seasons combined) were in the range of severe impairment for all streams except Kellogg and Phillips creeks, which were moderately impaired.

Biotic integrity scores were not highly correlated with most water quality variables (Table 11). Summer IBI scores were negatively correlated with summer total dissolved solids (P=0.01), but this relationship was not apparent in other seasons. Similarly, turbidity had a weak negative correlation (P=0.04) with IBI during winter only. However, water velocity was positively correlated with seasonal IBI scores during both winter (P=0.03) and spring (P=0.04). These relationships were relatively weak, but statistically significant. The strongest association was a positive correlation between mean water velocity and mean IBI (P<0.01). We did not attempt to correlate salinity with IBI because salinity values were extremely low and exhibited very low variability (all values were either 0.0 or 0.1 ppt).

Statistically significant correlations were also uncommon for habitat data that were summarized for an entire reach (Table 12). For 70 separate correlations of habitat variables and seasonal IBI scores, only five significant relationships were apparent, and their strength of association was relatively weak. The proportion of substrate composed of gravel and cobble was positively correlated with autumn (P=0.03) and winter (P=0.04) IBI. The proportion of stream surface area consisting of “fast” unit types was positively correlated with autumn, winter, and seasonal mean IBI (P=0.03, P=0.02, and P=0.05, respectively).

Significant relationships between habitat variables and IBI scores were much more frequent when site data, rather than reach data, was used. Statistically significant associations were found for 21 of 70 comparisons (Table 13). Three habitat variables (total culverted area below the fish sampling site, percent of surface area as fast water unit types, and percent of surface area as glides) were correlated with IBI during all seasons, and with the mean IBI score. Two other variables (number of barriers below the fish sampling site and mean wood rating) were correlated with IBI in two seasons, as well as with mean IBI. The percent substrate composed of gravel and cobble was correlated with IBI in autumn only. Number of barriers,

Table 10. Index of biotic integrity (IBI) scores for North Clackamas County stream reaches, 1997-1999. Scores were considered acceptable, marginally impaired, or severely impaired if they were ≥75, 51-74, or ≤50, respectively (Hughes et al. 1998). NS = no survey.

		IBI score					
Stream	Reach	Summer	Autumn	Winter	Spring	Mean	Stream mean
Kellogg	1	56.7	53.2	NS	38.0	49.3	
	2	58.4	33.6	49.3	83.4	56.2	53.2
Mt. Scott	1	28.1	33.5	41.1	34.3	34.2	
	3	40.8	30.2	55.4	30.2	39.1	
	4	55.5	38.7	32.4	48.1	43.7	39.0
Phillips	1	65.0	81.0	42.3	76.3	66.2	
	2	63.9	57.6	50.5	73.7	61.4	63.8
Dean	1	65.8	48.2	50.5	82.7	61.8	
	2	24.8	24.8	0.0	39.4	22.3	42.0
Cow	1	69.3	64.7	77.3	64.7	69.0	
	2	10.4	10.4	10.4	10.4	10.4	
	3	0.0	0.0	0.0	0.0	0.0	26.5
Sieben	1	63.3	63.2	45.3	61.2	58.2	
	2	50.5	50.5	50.5	50.5	50.5	
	3	0.0	0.0	0.0	0.0	0.0	36.2
Rock	1	63.9	71.5	69.1	57.9	65.6	
	2	50.0	72.5	59.5	59.2	60.3	
	3	30.2	30.2	42.9	30.2	33.4	
	4	40.8	30.2	30.2	39.9	35.3	
	5	53.5	30.2	30.2	58.8	43.2	47.5

Table 11. Pearson correlation coefficients for comparisons of index of biotic integrity (IBI) scores with water quality variables in North Clackamas County stream reaches, 1997-1999. The "mean" column compares mean IBI score and mean water quality variable for all seasons combined. Strongly correlated variables (*P*<0.05) are denoted with an asterisk (*).

	IBI				
	Summer	Autumn	Winter	Spring	Mean
Turbidity (NTU)[a]	-0.02	0.19	-0.47*	-0.04	-0.27
Percent oxygen saturation	-0.31	0.33	-0.04	0.08	-0.01
Dissolved oxygen (mg/L)	-0.33	0.35	-0.15	0.17	0.13
Temperature (^{o}C)	-0.44	-0.05	0.19	-0.27	-0.31
Water velocity (m/s)	0.41	0.43	0.51*	0.47*	0.65*
Conductivity (μS/cm)[b]	-0.32	0.11	0.03	-0.10	-0.12
Total dissolved solids (mg/L)	-0.56*	0.04	0.04	-0.10	-0.30

[a] nephelometric turbidity unit
[b] microSiemens/cm

Table 12. Pearson correlation coefficients for comparisons of index of biotic integrity (IBI) scores with habitat data summarized for entire stream reaches, 1997-1998. Statistically significant relationships (*P*<0.05) are denoted with an asterisk (*).

	IBI				
Habitat variable	Summer	Autumn	Winter	Spring	Mean
% of units with eroding banks	0.31	0.22	0.19	0.17	0.26
Mean pool depth (m)	0.01	0.29	0.39	0.21	0.19
Mean shading (degrees)	0.29	0.40	0.23	0.31	0.32
Number of boulders	0.03	-0.08	0.02	-0.18	-0.06
Mean % undercut bank	0.07	-0.02	0.04	0.18	0.08
Number of culverts	-0.13	-0.27	-0.28	-0.10	-0.21
% Culverted area (m^2)	-0.16	-0.20	-0.37	-0.01	-0.19
Mean wood rating	0.23	0.11	0.35	0.24	0.24
% of units with wood rating >2	0.19	0.18	0.26	0.16	0.20
% Silt or sand substrate	-0.27	-0.44	-0.46	-0.08	-0.34
% Gravel or cobble substrate	0.34	0.49*	0.47*	0.16	0.39
% Surface area as fast water units (m^2)	0.44	0.49*	0.54*	0.26	0.45*
% Surface area as glides (m^2)	-0.21	-0.27	-0.27	-0.08	-0.21
% Surface area as pools (m^2)	0.02	0.02	0.22	-0.11	0.02

Table 13. Pearson correlation coefficients for comparisons of index of biotic integrity (IBI) scores with habitat data from fish sampling sites, 1997-1998. Statistically significant relationships (*P*<0.05) are denoted with an asterisk (*).

	IBI				
Habitat variable	Summer	Autumn	Winter	Spring	Mean
% of units with eroding banks	0.26	0.32	0.29	0.29	0.32
Mean unit depth (m)	0.23	0.18	0.23	0.10	0.20
Mean shading (degrees)	0.31	0.36	0.11	0.34	0.30
Number of boulders	0.09	0.06	0.23	-0.11	0.08
Mean % undercut bank	-0.14	-0.10	-0.05	-0.01	-0.08
Number of barriers below site	-0.40	-0.47*	-0.50*	-0.35	-0.47*
Total culverted area below site (m^2)	-0.60*	-0.64*	-0.69*	-0.57*	-0.67*
Mean wood rating	0.52*	0.37	0.53*	0.39	0.49*
% of units with wood rating >2	0.39	0.28	0.34	0.21	0.34
% Silt or sand substrate	-0.36	-0.42	-0.45	-0.21	-0.36
% Gravel or cobble substrate	0.38	0.45*	0.45	0.25	0.40
% Surface area as fast water units (m^2)	0.52*	0.45*	0.49*	0.48*	0.50*
% Surface area as glides (m^2)	-0.58*	-0.47*	-0.59*	-0.56*	-0.57*
% Surface area as pools (m^2)	0.24	0.04	0.28	0.27	0.22

total culverted area, and percent glide area were negatively correlated with IBI, whereas all other correlations were positive. The habitat variables with the strongest IBI correlation and lowest (<0.01) *P* value were total culverted area (R = -0.57 to -0.67) and percent glide area (R = -0.47 to –0.59).

DISCUSSION

Habitat complexity is one of the most important factors influencing the diversity and health of stream communities (Angermeier and Karr 1984; Reeves et al. 1993). Woody debris, boulders, secondary channels, undercut banks, and backwaters all contribute to habitat complexity, and are important components of salmonid habitat (Nickelson et al. 1992; Crispin et al. 1993; Moore et al. 1997; Reeves et al. 1997). Streams of the NCC area generally exhibited a low degree of habitat complexity. They lacked secondary channels and woody debris in amounts that provide good fish habitat, and cover for fish was limited to infrequent undercut banks and small numbers of riffles, pools, and boulders. Homogenous habitat types (primarily glides and culverts) dominated many stream reaches. Shading was often less than 50%, especially in third-order streams.

Substrate composition and quality affect a stream's ability to support lithophil nester species such as salmon, trout, and lampreys. These fish use gravel or cobble substrates to create nests for spawning, and the fertilized eggs and fry of salmonids may spend up to four months in the substrate (Scott and Crossman 1973). While most NCC streams contained at least moderate amounts of gravel and cobble substrate, high proportions of silt, sand, and fine organic matter may adversely affect the success of lithophil nesters. Wydoski and Whitney (1979), for example, reported that the principal cause of mortality in developing steelhead eggs was suffocation due to siltation. Actively eroding banks, observed in 15 of 21 NCC stream reaches, contribute to siltation and substrate embeddedness (ODFW 1994).

Fish species found in primary NCC streams were generally similar to other locations in the Willamette River basin (Hughes and Gammon 1987; Farr and Ward 1993; ODFW unpublished data). Friesen and Ward (1996) conducted similar surveys of Tualatin River tributaries (which are similar in size and geomorphology to streams in our study area) in 1994-1995, and also found reticulate sculpin and native cyprinids to be the most abundant species. Threespine stickleback *Gasterosteus aculeatus*, which composed 7.1% of the catch in Tualatin river tributaries, were notably absent from our surveys. This species is not especially intolerant of environmental disturbances (Hughes et al. 1998), and their absence is not easily explained. The absence of the ubiquitous reticulate sculpin from six of 20 reaches in our study area is also cause for concern. Although five of these reaches have culverts or other potential barriers below the fish sampling site, other native species have persisted (e.g. Dean 2 and Sieben 2), and one reach, Sieben 1, contains no barriers below the sampling site. We collected six species (chinook salmon, longnose dace, peamouth, chiselmouth, oriental weatherfish, and smallmouth bass) in NCC streams that were not observed by Friesen and Ward (1996) in Tualatin River tributaries. Conversely, Tualatin River streams contained five species (fathead minnow *Pimephales promelas*, warmouth *Lepomis gibbosus*, black crappie *Pomoxis nigromaculatus*, white crappie

Pomoxis annularis, and yellow perch *Perca flavescens*), all introduced, that were not present in NCC surveys.

All streams we surveyed supported small numbers of native salmonids, both resident and anadromous, and Rock Creek contained many rainbow trout in its lower two reaches. Actual salmonid abundance was probably somewhat higher than our calculations indicated, as we were unable to use the model of Armour et al. (1983) when salmonid catch increased from one electrofishing pass to the next. Despite major (probably impassable) barriers, small numbers of cutthroat trout persist in the upper two reaches of Mt. Scott Creek and Rock 5. These populations likely have a high risk of extirpation due to their small numbers and geographic isolation. All juvenile coho salmon, chinook salmon, and rainbow trout appeared to be naturally propagated (none were finmarked), and as such, are protected under federal and state ESAs (NOAA 1998, 1999; ODFW 1999).

Though adult salmonids were rarely seen, we observed strong evidence that native cutthroat and rainbow trout naturally reproduce in Mt. Scott, Phillips, Dean, Cow, Sieben, and Rock creeks. We observed many small fry (often not identifiable to species) at locations in these streams that were either above potential barriers or a long distance from a larger stream. It is highly unlikely that these small fish negotiated existing barriers and distances to reach the areas from which they were captured. The presence of adult steelhead, a recently spawned adult cutthroat trout, and an anadromous salmonid carcass also strongly suggests spawning activity. We recommend that spawning surveys (ODFW 1992) be conducted during known spawning times and periods of low flow to better ascertain the use of these streams by anadromous salmonids.

Seasonal length frequencies indicate several ages and life stages of native salmonids are present throughout the year in NCC streams. Juvenile rainbow trout, which composed the greatest proportion of the NCC salmonid catch, are typically 100 mm fork length at age 1, 160 mm fork length at age 2, and 220 mm fork length at age 3 (Carlander 1969). All three of these size and age classes were represented in the catch from NCC streams, and salmonids greater than 160 mm fork length were an important component of the catch in summer, autumn, and winter. The presence of many small (<40 mm) juvenile salmonids in spring indicates successful spawning by anadromous or resident fish during winter. Coho salmon, cutthroat trout, and steelhead are all known to spawn during winter months (Scott and Crossman 1973; Wydoski and Whitney 1979). The time period from fertilization to emergence from the nest varies with species and water conditions, but generally occurs within six weeks for cutthroat trout and steelhead and 10 weeks for coho salmon (Wydoski and Whitney 1979). Small salmonids we observed had adequate time to hatch, emerge, and grow to 20-40 mm between our winter and spring sampling (approximately 12 weeks).

Despite their small size, secondary streams support fish communities, including juvenile salmonids. These tributaries may provide additional spawning areas for smaller salmonids, such as cutthroat trout, as well as rearing and refuge areas for juvenile fish. Because the primary streams contained few secondary channels or other off-channel habitat, additional habitat provided by secondary streams may be particularly valuable. Mt. Scott A and Sieben A, which contained no fish and no obvious barriers near the sampling site, are probably limited by water quality or degraded habitat. Because habitat and water quality surveys were not performed, and our electrofishing surveys were cursory, additional information regarding secondary tributaries is desirable.

Crayfish are ecologically important in all ecosystems that they occupy (Hogger 1988; Lewis 1997). They convert organic debris into particulate matter that is consumed by other organisms, and are a major food source for mammals and fish (Mitchell and Smock 1991; Zimmerman 1999). Crayfish in NCC streams were abundant in some reaches, but usually only during summer months. The mechanism driving seasonal fluctuations in abundance is unclear. Crayfish tolerate temperatures between 4 and 25^{o}C (Shimizu and Goldman 1981), but may become inactive during cold periods (Oregon State University Extension Service 1978), thereby reducing capture efficiency during winter months. The presence of barriers below the sampling site may partially explain the lack of crayfish in Cow 3, Sieben 2, and Sieben 3; however, other reaches with significant barriers (e.g. Rock 3, 4, and 5) contained relatively high numbers of crayfish. Sieben 1, with no barriers between the sampling site and the Clackamas River, contained only one crayfish.

Substrate size is one factor that may limit crayfish abundance in our study area. Crayfish are generally associated with large substrate (Flint 1975; Shimizu and Goldman 1981; Davies 1989; Mitchell and Smock 1991), and reaches of primary streams that contained few crayfish also contained relatively small proportions of large substrate. Mean percent substrate consisting of cobble, boulder, and bedrock was 24.2% for the eight reaches in which we observed less than six crayfish each; the remaining 12 reaches averaged 62.0%.

A biological community exhibits integrity if its composition and function are comparable to those in undisturbed (i.e. minimal human impact) habitats (Hughes et al. 1998). The mean IBI score of 42.9, for all seasons and reaches, indicates that biotic integrity of NCC streams is, in general, severely impaired with respect to historic conditions. No stream or stream reach received a mean IBI score in the “acceptable” range, though several reaches did during individual seasons. This may reflect changes in seasonal abundance of certain species (e.g. salmonids seeking thermal refugia during summer), variability in sampling and capture efficiency, or fluctuations in water quality and quantity. Biotic integrity was highest in the lowermost reaches of all streams (except Kellogg and Mt. Scott creeks), perhaps due to the cumulative effects of barriers and a gradual reduction in available habitat (especially water volume) in upstream reaches. The proximity of downstream reaches to larger streams also contributes to this pattern. Fish sampling in Cow 1, for example, was conducted near the stream’s confluence with the Clackamas River, and yielded 20 species and a mean IBI of 69.0. Less than 1,200 m upstream (Cow 2), only one species was collected and mean IBI decreased to 10.4.

Although the IBI is usually based on summer sampling (Hughes et al. 1998), we believe that calculating seasonal and mean IBI scores is useful, especially in small urban streams that are susceptible to rapid seasonal changes in flow and turbidity. In Kellogg 2, for example, calculating only a summer IBI would result in a score of 58.4 (moderately impaired), while calculating scores for all seasons reveals that biotic integrity in this reach can range from severely impaired (33.6; autumn) to acceptable (83.4; spring). Scores are probably not significantly different (the power of this test was low) among seasons, but calculating IBI values for all seasons appears to more accurately describe individual reaches.

Correlations provided considerable insight into habitat and water quality factors driving biotic integrity. Because sample sizes were relatively small (19 or 20 surveys for each season), and many variables were estimated (e.g. most unit lengths and widths), correlations should not be considered absolute proof of significant relationships, or lack thereof. Nevertheless, some comparisons were highly correlated, statistically significant, and intuitively sound. Statistically significant relationships were always oriented (positive or negative) as expected, and many were consistently significant over all four seasons. Site-specific, rather than reach-specific, habitat data yielded a greater number of significant relationships. Site-specific habitat data is considerably more variable than data summarized for a larger area. Consequently, correlations for site data are more sensitive to significant relationships among variables than reach data.

Of the variables we tested, total culverted area below the fish sampling site had the strongest relationship with IBI. Biotic integrity scores decreased as the amount of culverted area increased. The number of potential barriers (primarily culverts) below the fish sampling site was also negatively correlated with IBI, but the association was not as strong. This may indicate that the proportion of stream surface area contained within culverts has a greater influence on biotic integrity than the number of culverts. Relationships between culverts and fish abundance are well documented. Eaglin and Hubert (1993), for example, found that the standing stock of trout in a watershed was negatively correlated with culvert density. Because many factors (e.g. gradient, water velocity, distance above the active channel, and roughness coefficient) affect the ability of culverts to pass fish (Belford and Gould 1989; ODFW 1996), we suggest that all culverts in our study area be inspected by qualified fisheries professionals. Removing or replacing culverts that do not pass fish effectively will likely have a positive effect on IBI, and may serve to open additional spawning, rearing, and refuge areas to native salmonids and other fish.

Some habitat types were also correlated with IBI. The proportion of stream surface area as glides was strongly and negatively correlated with IBI, while the proportion of stream surface area as fast water units (riffles, cascades, etc.) had a somewhat weaker, positive association with IBI. These results probably reflect the value of habitat complexity. Glides are characterized as homogenous habitat units having low gradient, uniform depth and flow, and low habitat complexity. Fast water unit types are associated with increased structure, higher gradient, greater water velocity, and rockier substrate than glides (Moore et al. 1997). In stream reaches containing long sections of homogenous habitat, biotic integrity and stream function could be improved by adding structure, such as large woody debris (LWD). Instream LWD acts to improve habitat complexity, promote pool and riffle formation, increase cover for fish, and improve nutrient flow (Bilby and Likens 1980; Bisson et al. 1987; Beechie and Sibley 1997). The creation of backwaters and secondary channels, which are lacking in most reaches, could also be achieved by using LWD. Though all reaches could potentially benefit from the addition of LWD, several reaches containing large areas of homogenous habitat (Kellogg 1, Mt. Scott 1 and 2) may be significantly improved.

Despite very low variability in woody debris ratings (92% of habitat units received a score of 1 or 2), mean woody debris rating was positively correlated with summer, winter, and mean IBI scores. As mentioned previously, LWD is valuable for stream structure and function; it also has been associated with the abundance of specific species. McMahon and Holtby (1992), for example, showed that the abundance of coho salmon smolts was positively related to debris volume in a small coastal stream. Similarly, the density of rainbow trout fry increased significantly in a mountain stream that was enhanced with the addition of wood structures and fine woody debris (Culp et al. 1996). Pools created by LWD are also preferred habitats for various age classes of juvenile coho salmon, cutthroat trout, and rainbow trout (Bisson et al. 1988). Because most NCC streams are in deforested, highly urbanized areas, the natural recruitment of LWD is low, as reflected in the woody debris ratings. Tree planting in these watersheds would improve LWD recruitment over the long term, and provide other benefits, such as increased shading, decreased water temperatures, and bank stabilization (ODFW 1994). Fish habitat in virtually every stream would benefit from plantings or LWD placement, and increases in biotic integrity would likely be observed over time.

Water quality parameters were not generally correlated with IBI scores. The lack of a significant relationship for conductivity with IBI suggests sampling conditions did not bias our electrofishing catch. Low water conductivity reduces sampling efficiency, which may cause some species to be misrepresented in the catch or missed entirely (Tillma 1996). Total dissolved solids were negatively correlated with IBI during summer, but the mechanism driving this relationship is unclear. Total dissolved solids may be related to a variety of factors, including organic pollution, salinity, mineral deposits, and soil leaching. Levels of total dissolved solids preference and avoidance have also been demonstrated for some fish species (Pimentel and Bulkley 1983). We did not expect percent oxygen saturation, dissolved oxygen, or temperature to correlate with IBI, because these values were generally within the tolerance range of most species. For example, preferred and lethal temperatures for rainbow trout have been reported as less than 21^{o}C and greater than 27^{o}C, respectively (Carlander 1969; Wydoski and Whitney 1979) Temperatures in NCC stream reaches exceeded 21^{o}C only once, during summer in Cow 3. Similarly, lethal dissolved oxygen level for rainbow trout is generally reported as less than 5.0 mg/L (Doudoroff and Shumway 1970; Sowden and Powder 1985). Observed dissolved oxygen levels in NCC streams were well above 5.0 mg/L in 76 of 79 surveys. Differences in fish assemblages due to oxygen and temperature levels, therefore, were not apparent and did not affect IBI scores. Turbidity had a weak negative relationship with IBI in winter, suggesting that winter fish sampling was somewhat influenced by increased turbidity during periods of high flow. This may be reflected in the somewhat lower (but not significantly different) mean IBI during winter. Testing for other water quality components, especially pollutants such as chlorides and nitrogen, may help identify additional mechanisms affecting biotic integrity (Hughes et al. 1998).

Water velocity was the one water quality variable that showed a significant relationship with IBI over several seasons. A positive association was observed with winter, spring, and mean IBI scores. Summer and autumn correlation coefficients, though not statistically significant, were both positive and greater than 0.40. These results are complimentary to the positive relationship between the percent of habitat as fast water units and IBI score, as fast water units have higher velocities. Greater diversity of pool and fast water habitat types may be associated with more diverse salmonid communities (Lonzarich 1994) and could be achieved through the addition of LWD or other instream structures.

We suggest prioritizing enhancement activities among reaches according to biotic integrity scores. This is similar to methods used to prioritize habitat restoration in the Tualatin River basin (Ward and Friesen 1995). Habitat in reaches with relatively high IBI scores (Phillips 1 and 2, Dean 1, Cow 1, Rock 1 and 2) should be protected and conserved whenever possible. These reaches contain relatively healthy fish populations, and generally have high quality habitat. The lower two reaches of Rock Creek, in particular, should be protected due to the large number of native salmonids present, its potential value as an anadromous salmonid spawning area, and its exceptional habitat. Reaches with moderate IBI scores (e.g. Kellogg 1 and 2, Sieben 1 and 2) are the best candidates for habitat enhancement and restoration. Sensitive species generally persist in these streams, though not in large numbers, and habitat quality is not severely degraded. Stream reaches with very low IBI scores (Dean 2, Cow 2 and 3, Sieben 3, possibly others) are not as likely to respond to small or moderate-scale restoration efforts. Fish have been completely extirpated from two of these reaches, and considerable culvert removal and habitat enhancement would be required for the re-establishment of any species. Water and habitat quality in these reaches, however, should not be allowed to degrade further because of potential effects to downstream areas.

Continued monitoring and investigation of NCC streams would provide a variety of benefits. Because the status of fish and aquatic habitat in many streams managed by WES is unknown, these streams should be surveyed to ensure the protection of salmonid populations from continuing urban development. At a minimum, the presence or absence of ESA-listed species should be determined. Biotic integrity should be monitored in all streams when possible, including those already surveyed. The use of the IBI as a monitoring tool is relatively simple, and continued monitoring would reveal trends in stream health, determine the effectiveness of habitat restoration activities, and improve our knowledge of stream community dynamics. In addition, we recommend that land-use variables (e.g. housing and road density, frequency of impervious surfaces) be measured and correlated with IBI to determine factors limiting individual watersheds. Such analyses may define direct relationships between urban development and the quality of aquatic ecosystems.

Habitat deficiencies, low biotic integrity, and localized extirpation of fish species indicate that streams in the urbanized NCC area have been greatly impacted by human activities. Though additional watershed impacts are probably unavoidable due to continued residential and commercial growth, the presence of ESA-listed species requires that fish habitat and water quality receive protection or enhancement (NOAA 1998, 1999; ODFW 1999). Many indirect benefits could result from protection and enhancement activities, including increased production for downstream fisheries, increased biodiversity, enhanced wildlife communities, and improved aesthetic stream qualities. We hope this report is used to make management decisions that will enhance the aquatic fauna of the region, thereby maximizing public enjoyment of these streams.

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APPENDIX A

Stream Reach Locations

Appendix Table A. Approximate location of stream reaches designated during aquatic habitat inventories of North Clackamas County streams, 1997-1998. A new reach was designated when a significant landform change or major tributary was encountered. Fish and water quality surveys were conducted within a 100-m section of each reach.

Stream	Reach	Location
Kellogg	1	Upstream end of Kellogg Lake to Mt. Scott Creek confluence
	2	Mt. Scott Creek confluence to Webster Road
Mt. Scott	1	Mouth to Phillips Creek confluence
	2	Phillips Creek confluence to Dean Creek confluence
	3	Dean Creek confluence to small tributary 200 m downstream of Sunnyside Road
	4	Small tributary 200 m downstream of Sunnyside Road to 700 m upstream of 129th Street
Phillips	1	Mouth to Sunnybrook Road
	2	Sunnybrook Road to enclosed box culvert (below-ground flow)
Dean	1	Mouth to Interstate 205
	2	Interstate 205 to upstream side of culverts crossing Lawnfield Road
Cow	1	Mouth to 224 m downstream of concrete bridge near Evelyn Street
	2	224 m downstream of concrete bridge near Evelyn Street to Highway 212
	3	Highway 212 to Stone Ridge apartments
Sieben	1	Mouth to Highway 212
	2	Highway 212 to 2.5-m falls near SE Red Maple Lane
	3	2.5-m falls near SE Red Maple Lane to dammed pool upstream of Sunnyside Road
Rock	1	Mouth to beginning of narrow canyon below Highway 212
	2	Beginning of narrow canyon below Highway 212 to 7-m vertical falls
	3	7-m vertical falls to 465 m downstream of Sunnyside Road
	4	465 m downstream of Sunnyside Road to large tributary entering from the north, upstream of Troge Road
	5	Large tributary entering from the north, upstream of Troge Road, to tree farm near the end of Heuke Road

APPENDIX B

Fish Inventory Data

Appendix Table B-1. Number of fish collected (first electrofishing pass) during summer in Kellogg, Mt. Scott, Phillips, and Sieben creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
Species	1	2	1	3	4	1	2	1	2
Western brook lamprey	0	0	0	0	0	0	0	2	0
Pacific lamprey	0	1	0	0	5	0	0	0	0
Chiselmouth	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0
Peamouth	0	0	0	0	0	0	0	0	0
Northern pikeminnow	0	0	0	0	0	0	0	0	0
Longnose dace	0	0	0	0	0	0	0	0	0
Speckled dace	18	1	22	0	0	20	56	1	7
Redside shiner	52	0	45	0	0	50	114	34	15
Oriental weatherfish[a]	0	0	0	0	0	0	0	0	0
Largescale sucker	1	0	0	0	0	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	1	0	0
Cutthroat trout	1	0	0	6	1	0	2	0	0
Coho salmon	*	0	0	0	0	0	0	0	0
Rainbow trout	0	0	0	0	0	1	0	0	0
Chinook salmon	0	0	0	0	0	0	0	0	0
Brook trout[a]	0	0	0	0	0	0	0	0	0
Western mosquitofish[a]	8	0	29	0	0	0	2	0	31
Prickly sculpin	16	0	1	0	0	0	0	0	0
Reticulate sculpin	187	117	249	76	62	29	7	36	0
Torrent sculpin	0	0	0	0	0	0	0	0	0
Pumpkinseed[a]	*	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	1	0	*	0	0	0	1	0	0

[a]Introduced species

Appendix Table B-2. Number of fish collected (first electrofishing pass) during summer in Cow, Sieben, and Rock creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach										
	Cow			Sieben			Rock				
Species	1	2	3	1	2	3	1	2	3	4	5
Western brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Pacific lamprey	3	0	0	0	0	0	0	0	0	1	3
Chiselmouth	1	0	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0	0	0
Peamouth	0	0	0	0	0	0	0	0	0	0	0
Northern pikeminnow	13	0	0	0	0	0	0	0	0	0	0
Longnose dace	*	0	0	0	0	0	*	3	0	0	0
Speckled dace	69	0	0	16	41	0	12	4	0	0	0
Redside shiner	6	0	0	0	0	0	1	0	0	0	0
Oriental weatherfish[a]	11	0	0	0	0	0	0	0	0	0	0
Largescale sucker	2	0	0	0	0	0	*	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	0	0	0	0	0
Cutthroat trout	0	0	0	0	0	0	1	0	0	0	3
Coho salmon	0	0	0	3	0	0	0	0	0	0	0
Rainbow trout	3	0	0	1	34	0	18	15	0	0	0
Chinook salmon	*	0	0	0	0	0	0	0	0	0	0
Brook trout[a]	0	0	0	0	0	0	0	0	0	0	0
Western mosquitofish[a]	0	39	0	0	0	0	0	0	0	0	0
Prickly sculpin	0	0	0	0	0	0	0	0	0	0	0
Reticulate sculpin	7	0	0	0	0	0	0	0	141	99	76
Torrent sculpin	0	0	0	0	0	0	41	0	0	0	0
Pumpkinseed[a]	0	0	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	0	0	0	0	0	0	0	0	0	0

[a]Introduced species

Appendix Table B-3. Number of fish collected (first electrofishing pass) during autumn in Kellogg, Mt. Scott, Phillips, and Sieben creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
Species	1	2	1	3	4	1	2	1	2
Western brook lamprey	0	0	0	0	0	*	0	0	0
Pacific lamprey	0	0	0	0	0	1	0	0	0
Chiselmouth	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	*	0	0
Peamouth	0	0	0	0	0	0	0	0	0
Northern pikeminnow	0	0	0	0	0	0	0	0	0
Longnose dace	0	0	0	0	0	0	0	0	0
Speckled dace	13	0	5	0	0	23	80	1	13
Redside shiner	97	0	17	0	0	89	89	53	9
Oriental weatherfish[a]	0	0	0	0	0	0	0	0	0
Largescale sucker	5	0	0	0	0	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	0	0	0
Cutthroat trout	0	0	0	0	2	0	0	0	0
Coho salmon	0	0	0	0	0	0	0	0	0
Rainbow trout	1	0	0	0	0	2	1	0	0
Chinook salmon	0	0	0	0	0	0	0	0	0
Brook trout[a]	0	0	0	0	0	0	0	0	0
Western mosquitofish[a]	1	0	18	0	0	0	6	1	115
Prickly sculpin	19	0	1	0	0	0	0	0	0
Reticulate sculpin	58	46	299	21	36	79	14	32	0
Torrent sculpin	0	0	0	0	0	0	0	0	0
Pumpkinseed[a]	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	1	0	0	0	0	0	0	0	0

[a]Introduced species

Appendix Table B-4. Number of fish collected (first electrofishing pass) during autumn in Cow, Sieben, and Rock creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach										
	Cow			Sieben			Rock				
Species	1	2	3	1	2	3	1	2	3	4	5
Western brook lamprey	1	0	0	0	0	0	0	0	0	0	0
Pacific lamprey	0	0	0	0	0	0	*	*	0	0	0
Chiselmouth	11	0	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0	0	0
Peamouth	0	0	0	0	0	0	0	0	0	0	0
Northern pikeminnow	19	0	0	35	0	0	7	2	0	0	0
Longnose dace	3	0	0	0	0	0	2	1	0	0	0
Speckled dace	147	0	0	323	56	0	26	19	0	0	0
Redside shiner	38	0	0	1	0	0	280	22	0	0	0
Oriental weatherfish[a]	8	0	0	0	0	0	0	0	0	0	0
Largescale sucker	5	0	0	4	0	0	6	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	*	0	0	0	0
Cutthroat trout	0	0	0	0	0	0	0	0	0	0	0
Coho salmon	0	0	0	0	0	0	0	2	0	0	0
Rainbow trout	2	0	0	4	4	0	7	20	0	0	0
Chinook salmon	0	0	0	1	0	0	2	0	0	0	0
Brook trout[a]	0	0	0	0	0	0	0	0	0	0	0
Western mosquitofish[a]	2	72	0	0	0	0	0	0	0	0	0
Prickly sculpin	0	0	0	0	0	0	0	0	0	0	0
Reticulate sculpin	25	0	0	0	0	0	14	48	107	31	13
Torrent sculpin	0	0	0	0	0	0	6	*	0	0	0
Pumpkinseed[a]	1	0	0	0	0	0	*	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	0	0	0	0	0	2	0	0	0	0

[a]Introduced species

Appendix Table B-5. Number of fish collected (first electrofishing pass) during winter in Kellogg, Mt. Scott, Phillips, and Sieben creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
Species	1[a]	2	1	3	4	1	2	1	2
Western brook lamprey	--	0	0	0	0	0	0	0	0
Pacific lamprey	--	0	0	1	0	0	0	0	0
Chiselmouth	--	0	0	0	0	0	0	0	0
Goldfish[b]	--	0	0	0	0	0	0	0	0
Peamouth	--	0	0	0	0	0	0	0	0
Northern pikeminnow	--	0	0	0	0	0	0	0	0
Longnose dace	--	0	0	0	0	0	0	0	0
Speckled dace	--	0	5	0	0	3	0	0	0
Redside shiner	--	0	13	0	0	0	0	0	0
Oriental weatherfish[b]	--	0	0	0	0	0	0	0	0
Largescale sucker	--	0	1	0	0	0	0	0	0
Yellow bullhead[b]	--	0	0	0	0	0	0	0	0
Brown bullhead[b]	--	0	0	0	0	0	0	0	0
Cutthroat trout	--	0	0	1	6	0	1	1	0
Coho salmon	--	0	0	0	0	0	0	0	0
Rainbow trout	--	2	0	0	0	0	0	0	0
Chinook salmon	--	0	0	0	0	0	0	0	0
Brook trout[b]	--	0	0	0	0	0	0	0	0
Western mosquitofish[b]	--	0	0	0	0	0	0	0	0
Prickly sculpin	--	0	0	0	0	0	0	0	0
Reticulate sculpin	--	62	239	15	5	9	*	1	0
Torrent sculpin	--	0	0	0	0	0	0	0	0
Pumpkinseed[b]	--	0	0	0	0	0	0	0	0
Bluegill[b]	--	1	0	0	0	0	0	0	0
Smallmouth bass[b]	--	0	0	0	0	0	0	0	0
Largemouth bass[b]	--	0	0	0	0	0	0	0	0

[a]Not sampled because of high flow and turbidity

[b]Introduced species

Appendix Table B-6. Number of fish collected (first electrofishing pass) during winter in Cow, Sieben, and Rock creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach										
	Cow			Sieben			Rock				
Species	1	2	3	1	2	3	1	2	3	4	5
Western brook lamprey	0	0	0	0	0	0	0	1	0	0	0
Pacific lamprey	4	0	0	0	0	0	0	0	1	0	0
Chiselmouth	2	0	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0	0	0
Peamouth	2	0	0	0	0	0	0	0	0	0	0
Northern pikeminnow	2	0	0	6	0	0	8	0	0	0	0
Longnose dace	0	0	0	0	0	0	8	0	0	0	0
Speckled dace	48	0	0	24	3	0	48	12	0	0	0
Redside shiner	88	0	0	18	0	0	37	3	0	0	0
Oriental weatherfish[a]	1	0	0	0	0	0	0	0	0	0	0
Largescale sucker	*	0	0	0	0	0	1	0	0	0	0
Yellow bullhead[a]	*	0	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	0	0	0	0	0
Cutthroat trout	1	0	0	0	0	0	0	0	0	0	0
Coho salmon	0	0	0	0	0	0	0	*	0	0	0
Rainbow trout	0	0	0	0	2	0	5	11	0	0	0
Chinook salmon	2	0	0	0	0	0	1	0	0	0	0
Brook trout[a]	0	0	0	0	0	0	0	0	0	0	0
Western mosquitofish[a]	0	13	0	0	0	0	0	0	0	0	0
Prickly sculpin	0	0	0	0	0	0	0	0	0	0	0
Reticulate sculpin	8	0	0	0	0	0	17	15	27	11	8
Torrent sculpin	0	0	0	0	0	0	4	0	0	0	0
Pumpkinseed[a]	0	0	0	0	0	0	1	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	0	0	0	0	0	0	0	0	0	0

[a]Introduced species

Appendix Table B-7. Number of fish collected (first electrofishing pass) during spring in Kellogg, Mt. Scott, Phillips, and Sieben creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
Species	1	2	1	3	4	1	2	1	2
Western brook lamprey	0	0	0	0	0	*	0	*	0
Pacific lamprey	0	4	0	0	0	1	0	1	0
Chiselmouth	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0
Peamouth	0	0	0	0	0	0	0	0	0
Northern pikeminnow	0	0	0	0	0	0	0	0	0
Longnose dace	0	0	0	0	0	0	0	0	0
Speckled dace	0	0	0	0	0	29	24	2	3
Redside shiner	3	1	3	0	0	50	10	53	1
Oriental weatherfish[a]	0	0	0	0	0	0	0	0	0
Largescale sucker	0	0	0	0	0	0	0	*	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	0	0	0
Cutthroat trout	0	0	0	0	0	8	3	0	0
Coho salmon	0	0	0	0	1	0	*	0	0
Rainbow trout	0	1	0	0	1	0	0	0	0
Chinook salmon	0	*	0	0	0	0	0	0	0
Brook trout[a]	0	1	0	0	0	0	0	0	0
Western mosquitofish[a]	0	0	0	0	0	0	0	1	0
Prickly sculpin	11	0	0	0	0	0	0	0	0
Reticulate sculpin	34	71	120	30	11	40	35	60	0
Torrent sculpin	0	0	0	0	0	0	0	0	0
Pumpkinseed[a]	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0
Smallmouth bass[a]	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	0	0	0	0	0	0	0	0

[a]Introduced species

Appendix Table B-8. Number of fish collected (first electrofishing pass) during spring in Cow, Sieben, and Rock creeks. Unidentified species are not included. Species captured during a subsequent electrofishing pass are denoted with an asterisk (*).

	Creek, reach										
	Cow			Sieben			Rock				
Species	1	2	3	1	2	3	1	2	3	4	5
Western brook lamprey	0	0	0	0	0	0	0	0	0	0	4
Pacific lamprey	1	0	0	0	0	0	0	0	0	0	0
Chiselmouth	66	0	0	0	0	0	0	0	0	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0	0	0
Peamouth	0	0	0	0	0	0	0	0	0	0	0
Northern pikeminnow	100	0	0	5	0	0	*	0	0	0	0
Longnose dace	0	0	0	3	0	0	21	0	0	0	0
Speckled dace	298	0	0	111	37	0	63	14	0	0	0
Redside shiner	151	0	0	0	0	0	37	0	0	0	0
Oriental weatherfish[a]	5	0	0	0	0	0	0	0	0	0	0
Largescale sucker	62	0	0	0	0	0	3	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	0	0	0	0	0
Cutthroat trout	0	0	0	0	0	0	0	0	0	0	0
Coho salmon	1	0	0	3	0	0	0	2	0	0	0
Rainbow trout	0	0	0	0	1	0	7	41	0	0	1
Chinook salmon	1	0	0	3	0	0	0	0	0	0	0
Brook trout[a]	0	0	0	0	0	0	0	0	0	0	0
Western mosquitofish[a]	0	41	0	0	0	0	0	0	0	0	0
Prickly sculpin	5	0	0	0	0	0	0	0	0	0	0
Reticulate sculpin	19	0	0	0	0	0	15	71	53	47	14
Torrent sculpin	0	0	0	0	0	0	3	2	0	0	0
Pumpkinseed[a]	1	0	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	0	0	0	1	0
Smallmouth bass[a]	1	0	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	0	0	0	0	0	0	*	0	0	0	0

[a]Introduced species

APPENDIX C

Water Quality Data

Appendix Table C-1. Summer water quality measurements for Kellogg, Mt. Scott, Phillips, and Dean creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
	1	2	1	3	4	1	2	1	2
Turbidity (NTU)	22	9	4	11	25	3	3	4	9
Oxygen saturation (%)	73	83	99	78	71	93	91	71	67
Dissolved oxygen (mg/L)	7	9	10	8	7	8	8	6	5
Temperature (^oC)	17	15	16	16	17	19	17	20	18
Mean water velocity (m/s)	0.2	0.6	0.2	0.3	0.3	2.2	3.0	1.1	0.0
Conductivity (µS/cm)	184	161	232	--[a]	153	230	211	167	276
Salinity (ppt)	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Total dissolved solids (mg/L)	86	75	110	--[a]	74	110	100	79	130

[a]Equipment failure

Appendix Table C-2. Summer water quality measurements for Cow, Sieben, and Rock creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach										
	Cow			Sieben			Rock				
	1	2	3	1	2	3	1	2	3	4	5
Turbidity (NTU)	4	6	14	1	3	1	3	2	4	5	7
Oxygen saturation (%)	65	88	149	127	95	91	83	73	90	88	88
Dissolved oxygen (mg/L)	6	8	11	10	8	8	8	7	10	8	9
Temperature (^{o}C)	19	20	31	20	17	18	16	15	17	18	16
Mean water velocity (m/s)	0.7	0.1	0.0	0.6	1.0	1.0	0.5	0.3	0.1	0.0	0.1
Conductivity (µS/cm)	194	184	144	200	201	384	--[a]	161	136	129	130
Salinity (ppt)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Total dissolved solids (mg/L)	93	88	267	95	95	152	--[a]	75	65	61	59

Appendix Table C-3. Autumn water quality measurements for Kellogg, Mt. Scott, Phillips, and Dean creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
	1	2	1	3	4	1	2	1	2
Turbidity (NTU)	18	--[a]	4	17	10	2	2	5	3
Oxygen saturation (%)	87	--[a]	82	93	71	78	86	66	47
Dissolved oxygen (mg/L)	9	--[a]	9	11	8	8	9	7	5
Temperature (^{o}C)	11	8	9	8	10	13	14	14	14
Mean water velocity (m/s)	0.5	0.2	0.5	0.4	0.1	0.1	0.2	0.3	0.0
Conductivity (µS/cm)	130	184	23	129	137	142	209	105	262
Salinity (ppt)	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Total dissolved solids (mg/L)	61	86	108	60	65	68	99	50	124

[a]Equipment failure

Appendix Table C-4. Autumn water quality measurements for Cow, Sieben, and Rock creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach										
	Cow			Sieben			Rock				
	1	2	3	1	2	3	1	2	3	4	5
Turbidity (NTU)	5	6	4	1	4	3	20	18	11	14	8
Oxygen saturation (%)	90	48	73	89	87	83	92	77	97	84	79
Dissolved oxygen (mg/L)	10	5	7	10	10	9	10	8	11	9	8
Temperature (^{o}C)	11	15	11	12	12	13	10	11	10	12	12
Mean water velocity (m/s)	0.1	0.0	0.0	0.2	0.1	0.0	0.9	0.6	0.4	0.3	0.5
Conductivity (µS/cm)	199	88	189	183	170	147	118	109	102	--[a]	--[a]
Salinity (ppt)	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Total dissolved solids (mg/L)	93	42	89	86	80	69	48	51	47	--[a]	--[a]

[a]Equipment failure

Appendix Table C-5. Winter water quality measurements for Kellogg, Mt. Scott, Phillips, and Dean creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
	1[a]	2	1	3	4	1	2	1	2
Turbidity (NTU)	--	12	16	18	21	15	12	21	16
Oxygen saturation (%)	--	72	91	78	94	105	98	98	80
Dissolved oxygen (mg/L)	--	8	10	9	12	12	11	11	9
Temperature (^{o}C)	--	9	10	9	7	11	11	10	11
Mean water velocity (m/s)	--	0.5	0.3	0.4	0.5	1.3	0.8	0.3	0.4
Conductivity (µS/cm)	--	153	163	93	80	136	129	129	127
Salinity (ppt)	--	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Total dissolved solids (mg/L)	--	71	76	43	38	64	61	60	60

[a]Not sampled because of high flow and turbidity

Appendix Table C-6. Winter water quality measurements for Cow, Sieben, and Rock creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach										
	Cow			Sieben			Rock				
	1	2	3	1	2	3	1	2	3	4	5
Turbidity (NTU)	6	25	6	10	15	35	12	8	11	13	15
Oxygen saturation (%)	91	81	103	107	93	98	82	81	76	78	89
Dissolved oxygen (mg/L)	9	9	11	13	11	12	10	10	9	9	10
Temperature (^{o}C)	15	9	10	7	8	8	8	8	8	8	8
Mean water velocity (m/s)	0.8	0.3	0.0	0.8	1.1	0.5	1.0	0.4	0.7	0.5	0.5
Conductivity (µS/cm)	161	133	157	94	88	72	88	91	76	75	67
Salinity (ppt)	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dissolved solids (mg/L)	76	62	73	43	41	33	42	42	36	35	31

Appendix Table C-7. Spring water quality measurements for Kellogg, Mt. Scott, Phillips, and Dean creeks. NTU=nephelometric turbidity unit; µS=microSiemens.

	Creek, reach								
	Kellogg		Mt. Scott			Phillips		Dean	
	1	2	1	3	4	1	2	1	2
Turbidity (NTU)	4	5	6	5	10	7	4	4	25
Oxygen saturation (%)	99	93	88	97	95	88	97	73	42
Dissolved oxygen (mg/L)	10	10	9	9	9	9	10	7	4
Temperature (^{o}C)	15	10	14	14	15	12	14	16	17
Mean water velocity (m/s)	0.3	0.2	0.2	0.2	0.2	0.4	0.3	0.3	0.4
Conductivity (µS/cm)	222	--[a]	206	135	125	153	175	151	185
Salinity (ppt)	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Total dissolved solids (mg/L)	107	--[a]	92	64	58	72	84	72	88

[a]Equipment failure

Appendix Table C-8. Spring water quality measurements for Cow, Sieben, and Rock creeks. NTU=nephelometric turbidity unit; μS=microSiemens.

	Creek, reach										
	Cow			Sieben			Rock				
	1	2	3	1	2	3	1	2	3	4	5
Turbidity (NTU)	5	7	3	2	10	6	15	4	6	8	16
Oxygen saturation (%)	67	73	78	99	86	84	89	81	98	98	94
Dissolved oxygen (mg/L)	7	7	8	10	9	9	9	8	10	9	11
Temperature (^{o}C)	15	20	15	16	12	13	14	15	12	15	10
Mean water velocity (m/s)	0.1	0.1	0.0	0.0	0.1	0.1	0.3	0.1	0.3	0.3	0.1
Conductivity (μS/cm)	166	175	165	164	114	92	103	118	--[a]	79	69
Salinity (ppt)	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0
Total dissolved solids (mg/L)	79	84	79	78	54	43	50	56	--[a]	39	34

[a]Equipment failure