Distribution of Fish and Crayfish, and Measurement of Available Habitat in the Tualatin River Basin

Final Report of Research

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June 1995

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PREFACE

This document is the final report of research for a project funded in part by the Unified Sewerage Agency of Washington County and conducted by the Oregon Department of Fish and Wildlife. The Executive Summary summarizes and integrates the results, conclusions, and recommendations of the project. These results, conclusions, and recommendations pertain to the primary objectives of the project, evaluating the status of fish populations and habitat in the Tualatin River basin, and identifying stream reaches where fish populations are most likely to benefit from habitat enhancement. The report contains research papers that describe how we addressed project objectives, how we reached our conclusions, and why we made our recommendations. The papers are listed and numbered consecutively in the Table of Contents and the numbers are used to reference each paper in the Executive Summary. It is the integration of these individual papers that provides the best picture of the current status and direction for future enhancement of fish and fish habitat in the Tualatin River basin.

ACKNOWLEDGMENTS

Many thanks to all the people who helped us accomplish our objectives over the past two years. John Jackson and many other employees of the Unified Sewerage Agency were cooperative, supportive, had many helpful suggestions, and reviewed reports. Jay Massey and Pat Keeley of ODFW provided field equipment and assisted with project coordination. Steve Morrow of the Clackamas County Water District was essential in getting field work started. Several ODFW staff members volunteered to assist with field sampling. Ray Beamesderfer, Kirk Beiningen, Laurie Allen, and Rosalie Vogel of ODFW helped with administration of the project.

EXECUTIVE SUMMARY

Streams of the Tualatin River basin within the urban growth boundary near Portland, Oregon, have undergone substantial changes in water quality, fish habitat, and fish assemblages. Changes in landscape attributed to logging, agriculture, and urban development have affected the hydrology of the basin. Fish populations in the Tualatin River basin have never been quantitatively surveyed, and little has been done to study aquatic habitat; therefore, long-term effects of habitat changes on fish populations are poorly understood.

The Oregon Department of Fish and Wildlife (ODFW) and the Unified Sewerage Agency (USA) are concerned about the influence of urban development on streams in the Tualatin River basin. Little is known about the current status of fish populations and aquatic habitat in the basin, how urbanization affects these fish populations, or about the possibility of fish populations benefitting from habitat enhancement.

In 1993 ODFW and USA began a cooperative study to (1) describe the status and characteristics of fish populations in streams of the Tualatin River basin within the urban growth boundary, (2) describe the status of aquatic habitat in these streams, and (3) examine the relationship between fish assemblages and aquatic habitat to identify stream reaches that would most likely benefit from habitat enhancement. Also identified were streams where protection from habitat degradation should be of high priority, and streams where fish populations may not benefit from habitat enhancement because of water quality or other problems.

We identified 38 reaches of 15 streams to be sampled. We surveyed fish populations in spring, summer, and autumn, 1994, and in winter 1995. We surveyed aquatic habitat in 7 of the streams in late summer and early autumn 1993, and in the remaining 8 streams in late summer and early autumn 1994.

Conclusions

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

1) **Fish assemblages in streams of the Tualatin River basin are undoubtedly different from those that historically evolved in the system** (Paper 1). We collected 42,219 fish from 25 species and 10 families. Sculpins *Cottus* spp. comprised approximately 70% of the catch. Although historic information on fish assemblages is scarce, 12 species from five families were exotic to Oregon. Introduced species comprised approximately 6% of the total catch, and 7% of the catch in summer (Paper 3). Six species from three families were intolerant of habitat degradation and pollution. These fish comprised only 3% of the total catch, and 9% of the catch in summer.

2) **Fish assemblages varied widely among streams and among reaches within streams** (Paper 1). Number of species per stream ranged from 5 to 15, with number of native species ranging from 4 to 10. Number of species per reach ranged from 1 to 14, with number of native species ranging from 0 to 9. Number of native species per reach in summer ranged from 0 to 6 (Paper 3). In

general, upper reaches of streams contained the largest numbers of trout *Oncorhynchus* spp., native minnows (Cyprinidae), and sculpins, whereas lower sites contained more introduced species. All torrent sculpin *Cottus rhotheus* and approximately 81% of all trout were collected in one upper reach. Approximately 62% of introduced sunfish (Centrarchidae) and mosquitofish *Gambusia affinis* were collected at three sites near large ponds or wetlands.

3) **In general, aquatic habitat throughout the Tualatin River basin has been influenced by human development within the basin** (Paper 2). Again, historic information is scarce, but land use adjacent to reaches sampled was most commonly urban residential, followed by rural residential, agricultural, and industrial. Streams have been channelized and isolated from their natural flood plains. Glides, characterized by even flow and depth with no turbulence, were the most common habitat type. Sand, silt, and organic material were the most common substrates. The majority of stream banks were actively eroding. The amount of overhead cover, the percentage of banks that were undercut, and the amount of woody debris were all generally low.

4) **Only five of 38 reaches surveyed met most of the general habitat requirements of native species intolerant of habitat degradation and pollution** (Paper 2). These sites were upper reaches of streams that contained relatively swift water, a variety of substrates, a high amount of shade, and relatively complex habitat. Seven additional upper reaches, and all lower and middle reaches consisted mostly of glides with soil substrate and eroding banks, and had relatively little overhead cover, undercut banks, or woody debris.

5) **Biotic integrity varied throughout the basin, but was generally low** (Paper 3). We developed a modified index of biotic integrity (IBI), and only one of 34 reaches surveyed in summer 1994 had an IBI score qualitatively labeled as good. No IBI scores were considered excellent. Thirteen reaches were rated as fair, and twenty reaches had poor or very poor scores. We were unable to sample the remaining four stream reaches in summer 1994.

6) **We identified 16 stream reaches where improvements to habitat would likely result in increased biotic integrity, and an additional seven reaches that should be protected from habitat degradation, and be high priority sites for habitat enhancement** (Paper 3). Of the 16 reaches where habitat enhancement would likely increase biotic integrity, one contained especially good habitat and should be protected. We also identified 11 reaches where biotic integrity is probably limited by factors other than, or in addition to, physical habitat. Four of these reaches contained especially good habitat that should be protected (Papers 2 and 3), and water quality in these reaches should be evaluated and improved if possible.

Recommendations

Based on our findings, we have several recommendations concerning habitat protection and enhancement in streams of the Tualatin River basin within the urban growth boundary:

(1) **Stream reaches should be grouped into three major categories: (1) reaches of highest priority for habitat protection and enhancement, (2) reaches likely**

to benefit from habitat enhancement, and (3) reaches less likely to benefit from habitat enhancement unless other factors such as water quality are addressed. Within category 2 is one reach with especially good habitat that should be protected, and within category 3 are four reaches with especially good habitat where water quality should be evaluated and improved if possible. Although habitat in all streams should be protected and enhanced whenever possible, the combination of urban growth and limited funding may require that habitat enhancement be limited to streams in which fish populations are most likely to benefit. Groups of stream reaches are as follows:

Highest Priority:	Fanno Creek, middle; Chicken Creek, middle; Cedar Creek, upper; Dawson Creek, lower and upper; Beaverton Creek, lower; Bronson Creek, lower.
Likely Reaches: (exceptional habitat)	Dairy Creek, upper.
Likely Reaches: (other)	Fanno Creek, lower; Ash Creek, lower and middle; Summer Creek, lower; S. Rock Creek, middle and upper; Chicken Creek, lower; Cedar Creek, middle; Butternut Creek, middle and upper; Rock Creek, lower and middle; Bronson Creek, middle; Cedar Mill Creek, middle; Dairy Creek, middle.
Less Likely Reaches: (exceptional habitat)	Hedges Creek, upper; Fanno Creek, upper; Chicken Creek, upper; Cedar Mill Creek, upper.
Less Likely Reaches: (other)	Hedges Creek, middle; Ash Creek, upper; Summer Creek, middle and upper; Butternut Creek, lower; Beaverton Creek, middle; Johnson Creek, upper.

2) **Habitat improvements should be designed to increase the number of native intolerant species such as cutthroat trout *Oncorhynchus clarki* and torrent sculpin.** Increases in the amount of cover will likely increase the biomass of cutthroat trout and other salmonids present. Instream cover can be provided by undercut banks, rocks, woody debris, or increased water depth or turbulence. Placement of boulders and logs in streams provides direct cover, and may increase cover indirectly by causing increased depth and turbulence.

Establishment of canopy cover may also increase biomass of cutthroat trout and other salmonids by protecting streams from extreme summer water temperatures. Trees and vegetation associated with stream canopy and cover may also serve to stabilize banks and decrease erosion, thereby decreasing the amount of substrate consisting of sand, silt, and organic material. Cutthroat trout are usually associated with rocky substrates, and torrent sculpin occur only in riffles with rocky substrate. All salmonids potentially present need gravel for spawning.

3) **USA and ODFW should jointly select a number of suitable stream reaches for habitat enhancement projects.** Reaches should be selected based on management needs and likelihood of success (Recommendation 1). Because reaches vary in existing topography, hydrology, land use, existing fauna, and existing habitat, enhancement procedures should be reach-specific, and agreed to by USA and ODFW. Reaches should be studied again 3-5 years after enhancement is complete to evaluate success. Changes in biotic integrity should then be compared to changes in similar streams that were not enhanced.

4) **Other streams within the urban growth boundary likely to benefit from habitat enhancements should be identified.** Our method to identify reaches likely to benefit from habitat improvements can be an important tool for fisheries managers, especially in urban areas. Habitats in urban streams have generally been substantially modified, yet high quality habitats are considered important by many to the quality of life. Numerous urban streams are therefore potential candidates for habitat enhancements and protection.

Status and Condition of Fish Populations in Streams of the Tualatin River Basin, Oregon

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June 1995

INTRODUCTION

Like many river systems near urban areas, the Tualatin River and its tributaries within the urban growth boundary near Portland, Oregon, have undergone substantial changes in water quality, fish habitat, and fish assemblages. Agricultural practices, sewage treatment plant discharges, water allocation, and urbanization are all factors that may contribute to diminished water quality. The hydrology of the Tualatin River basin has changed significantly with the urbanization of natural floodplains and logging practices (Shively 1993). The Tualatin River basin has been the subject of intensive water quality investigations in recent years (Wolf 1992, Ervin et al. 1993, Miner et al. 1993); however, fish populations have never been quantitatively surveyed, and the long-term effects of habitat disturbances on fish may never be known.

Historic fish surveys in the basin focused primarily on salmonids, with other species usually referred to as "rough fish" or even "trash fish". A survey by the Oregon State Game Commission in 1963 addressed the need to document species other than salmonids, and included some relevant information (Hutchison and Aney 1964). The Oregon Department of Fish and Wildlife (ODFW) has continued to conduct occasional fish inventories, but information is generally limited to single day, non-replicated samples in the mainstem Tualatin River. Several consulting firms have conducted site-specific fish surveys near construction or mitigation projects (Harza Northwest 1994). Li and Gregory (1993) identified the need for a coordinated effort to survey all fish populations in the watershed.

Although historic information is scarce, native fish assemblages in the Tualatin River basin presumably included many species endemic to the Willamette and Columbia River basins. The Tualatin River now supports a significant warmwater fishery in its lower reaches, and limited opportunities for trout *Oncorhynchus* spp. and steelhead *O. mykiss* in the upper reaches and tributaries. Once extensively stocked with hatchery trout, the basin is now being managed primarily for wild trout production. Approximately 60,000 coho salmon *O. kisutch* and 10,000 steelhead are planted annually as mitigation for the construction of a dam in the upper watershed (ODFW 1993).

This paper is part of a cooperative study by ODFW and the Unified Sewerage Agency of Washington County to evaluate the effects of urbanization on fish populations of the basin. Our objective is to describe the status and characteristics of fish populations in streams of the Tualatin River basin within the urban growth boundary near Portland, Oregon. We also examine possible indicators of unhealthy fish assemblages. This information will help managers predict the effects of further urban growth and water demands on the aquatic resources of the basin, and may identify areas requiring protection because of the presence of sensitive fish species.

STUDY AREA

The Tualatin River flows easterly from its headwaters in the Coast Range of Northwestern Oregon to its confluence with the Willamette River at river kilometer 46.1 (Figure 1). Portions of all streams we studied flow through the urban growth boundary near Portland, Oregon. These streams are

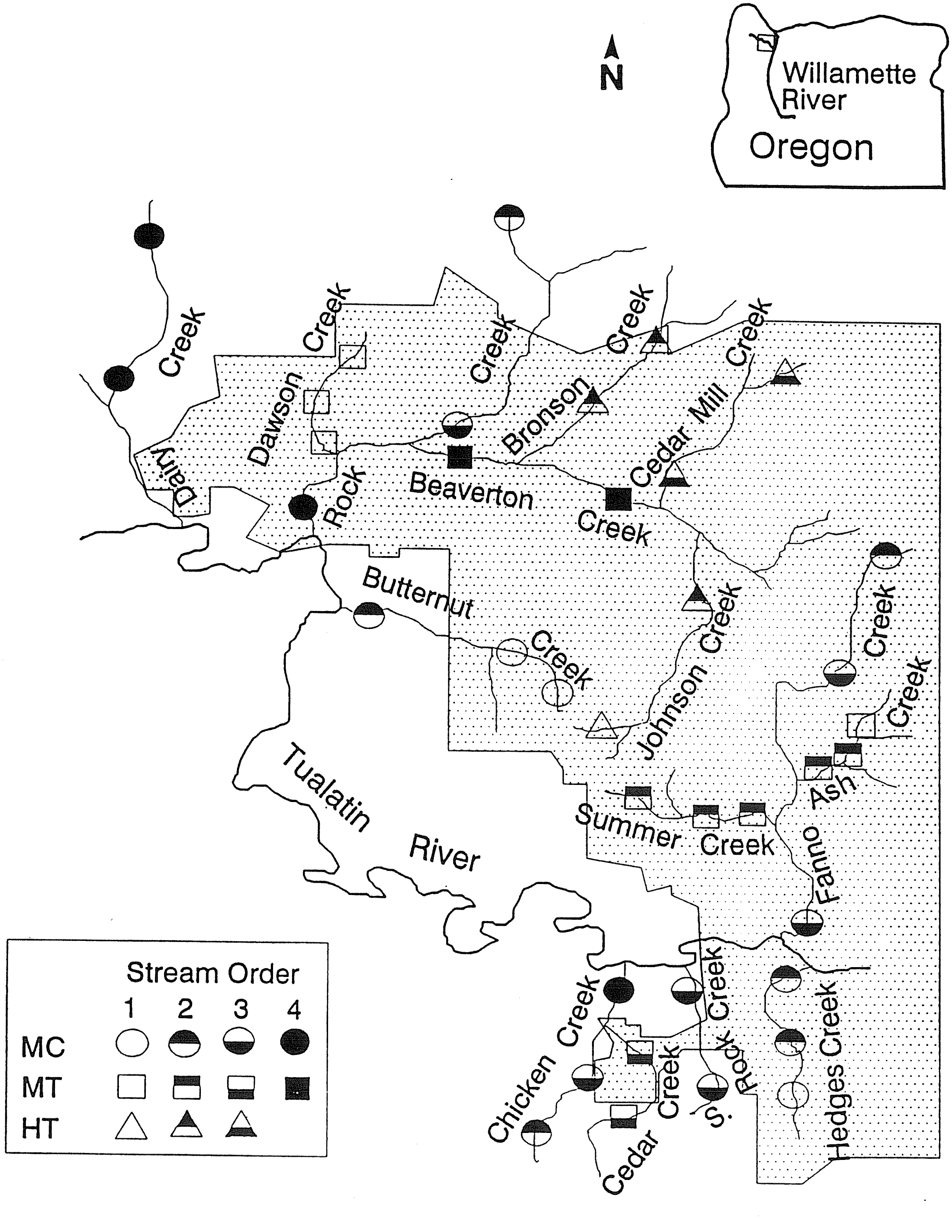

Figure 1. Streams of the Tualatin River basin sampled in 1994-95. Stream order determined by methods described by Orth (1983). MC = main-channel stream, MT = main-channel tributary, and HT = headwater tributary (Osborne et al. 1992). Shaded area approximates urban growth boundary of Washington County.

characterized by low gradient, heavy siltation, seasonal flooding, and temperature extremes, especially in the lower reaches (ODFW, unpublished data). Streams in our sampling area were of three general types (Osborne et al. 1992): main-channel streams (MC), which are tributaries of the Tualatin River, main-channel tributaries (MT), which are tributaries of MC's, and headwater tributaries (HT), which are tributaries of MT's. We sampled seven MC's, five MT's, and three HT's (Table 1).

Table 1. Streams of the Tualatin River basin surveyed in 1994-95. MC = main-channel stream, MT = main-channel tributary, and HT = headwater tributary (Osborne et al. 1992).

Creek	Stream type	Mainstem length (km)	Sites sampled by season			
			Spring	Summer	Autumn	Winter
Hedges	MC	3.8	3	2	2	2
Fanno	MC	21.7	3	3	3	2
Ash	MT	5.7	3	3	3	3
Summer	MT	5.2	3	3	2	3
S Rock	MC	8.4	2	2	2	0
Chicken	MC	9.7	3	3	3	2
Cedar	MT	10.9	2	2	2	1
Butternut	MC	8.4	3	3	3	2
Rock	MC	28.7	3	2	1	1
Dawson	MT	6.5	3	2	1	1
Beaverton	MT	15.3	2	2	1	0
Bronson	HT	10.7	2	2	2	2
Cedar Mill	HT	9.5	2	2	2	2
Johnson	HT	6.3	2	1	1	1
Dairy	MC	42.2	2	2	1	0

We identified 38 sites in the fifteen streams to be sampled (Figure 1). Sites were 100 meters long and were selected based on accessibility and proximity to concurrent habitat surveys (Neill et al. 1995). We identified one site near the mouth of each stream and one site near the headwaters. In larger streams, we identified an additional site between the upper and lower sites.

METHODS

We used electrofishing equipment to conduct three-pass removal sampling of fish populations (Armour et al. 1983, Riley and Fausch 1992) in spring (April-May) and summer (July-August). The ends of each 100-meter site were blocked with nets to ensure population enclosure. We sampled downstream to upstream using a model 12 Smith-Root backpack electrofisher. Voltage, pulse rate, and pulse width settings varied depending on water conductivity and fish recovery. Sampling in autumn (October-November) and winter (January-February) was similar, except that we were unable to utilize block nets because of high flows.

After each shocking pass, we identified specimens collected to species and inspected them for physical anomalies such as parasites or deformities. To reduce mortality, we returned all fish to the stream prior to the next pass, below the downstream end of the site.

We summarized our catch by species and family, and examined general differences in fish assemblages among streams and among sites within streams. We also examined differences in fish assemblages among stream orders. Because species richness usually increases with increasing stream order in undisturbed waters (Moyle and Cech 1988), we determined the mean number of species present for each stream order to help assess the degree of disturbance in the Tualatin River basin. Because locations of streams within a watershed may affect fish assemblages (Osborne et al. 1992), we used two-way analysis of variance (SAS Institute 1987) to compare the mean number of species present among stream orders and stream types (MC, MT, or HT), and to evaluate the interaction between stream order and stream type.

We examined seasonal trends in relative abundance of various species. We also described the general distribution of species that are intolerant to warm water, sedimentation, and organic pollution (Hughes and Gammon 1987), and assessed the relative health of fish populations by examining individuals for the occurrence of anomalies (parasites, deformities, etc.).

RESULTS

We collected 42,219 fish from 25 species and ten families in streams of the Tualatin River basin (Table 2). Reticulate sculpin were by far the most numerous species; redside shiners, threespine stickleback, speckled dace, and mosquitofish were also common. At least three trophic groups were represented: insectivores (17 species), piscivores (4 species), and omnivores (3 species). All lamprey we captured were filter-feeding juvenile pacific lamprey or non-feeding adult brook lamprey. Twelve fish species from five families were exotic to Oregon and comprised 6.3% of the total catch.

Fish assemblages varied widely among streams and among sites within streams. Number of species per stream ranged from 5 to 15, whereas number of native species ranged from 4 to 10. In general, sites in the upper sections of streams contained the largest numbers of trout, native minnows, and sculpins, whereas lower sites contained more diverse species assemblages and a larger number of introduced fish. The majority (61.5%) of sunfish species and mosquitofish were captured at three sites near large ponds or wetlands. All three sites that were free-flowing, forested, and appeared free of major urban or agricultural influences contained primarily trout and sculpin species.

Species assemblages varied considerably among stream orders (Figure 2). First-order stream sites contained a large proportion of sculpins, native minnows, and threespine stickleback. The proportion of sculpins increased with increasing stream order, whereas the proportion of minnows and threespine sticklebacks decreased. Sculpins dominated the catch in third and fourth-order stream sites, and trout were captured primarily in fourth-order stream sites. Introduced fish comprised 14.7% of the catch in second-order sites, but only 2.3% in other sites.

Table 2. Fish collected in streams of the Tualatin River basin, 1994-95. A small percentage (0.59) of the catch was not identified to species; therefore percent of catch does not total 100.0. Relative tolerance refers to physiological resistance of individual species to warm water, sedimentation, and organic pollution: IT = Intolerant, IM = Intermediate, TL = Tolerant.

Family, Species	Percent of catch	Relative tolerance	Adult trophic group
Petromyzontidae			
Western brook lamprey *Lampetra richardsoni*	0.64	IT	--[a]
Pacific lamprey *Lampetra tridentata*	0.73	IT	Piscivore
Salmonidae			
Coho salmon *Oncorhynchus kisutch*	0.02	IT	Piscivore
Cutthroat trout *Oncorhynchus clarki*	1.26	IT	Insectivore
Rainbow trout *Oncorhychus mykiss*	0.23	IT	Insectivore
Cyprinidae			
Redside shiner *Richardsonius balteatus*	7.38	IM	Insectivore
Speckled dace *Rhinichthys osculus*	4.82	IM	Insectivore
Northern squawfish *Ptycochelius oregonensis*	0.01	TL	Piscivore
Fathead minnow *Pimephales promelas*[b]	0.07	TL	Omnivore
Goldfish *Carassus auratus*[b]	0.07	TL	Omnivore
Catostomidae			
Largescale sucker *Catostomus macrocheilus*	1.41	TL	Omnivore
Ictaluridae[c]			
Yellow bullhead *Amerius natalis*	0.22	TL	Insectivore
Brown bullhead *Amerius nebulosis*	0.01	TL	Insectivore
Poecilidae[c]			
Mosquitofish *Gambusia affinis*	3.09	TL	Insectivore
Gasterosteidae			
Threespine stickleback *Gasterosteus aculeatus*	7.14	IM	Insectivore
Centrarchidae[c]			
Largemouth bass *Micropterus salmoides*	0.38	TL	Piscivore
Bluegill *Lepomis macrochirus*	0.81	TL	Insectivore
Pumpkinseed *Lepomis gibbosus*	1.40	TL	Insectivore
Warmouth *Lepomis gulosus*	0.02	TL	Insectivore
Black crappie *Pomoxis nigromaculatus*	0.01	TL	Insectivore
White crappie *Pomoxis annularis*	<0.01	TL	Insectivore
Percidae[c]			
Yellow perch *Perca flavescens*	0.03	IM	Insectivore
Cottidae			
Reticulate sculpin *Cottus perplexus*	68.40	TL	Insectivore
Prickly sculpin *Cottus asper*	1.12	IM	Insectivore
Torrent sculpin *Cottus rhotheus*	0.19	IT	Insectivore

[a] *Adults do not feed.*
[b] *Introduced species.*
[c] *Introduced family.*

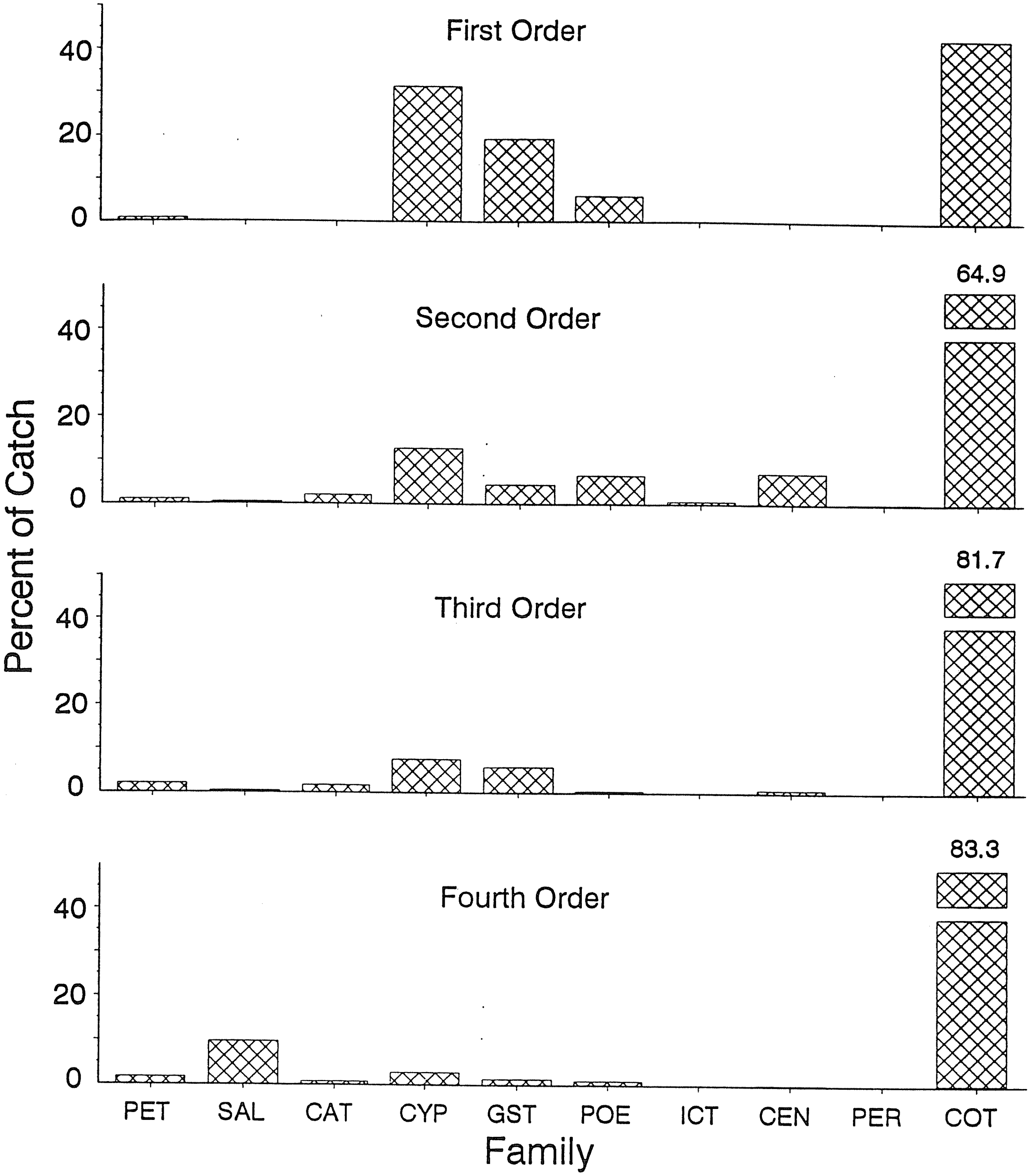

Figure 2. Percent of catch by family and stream order in the Tualatin River basin, 1994-95. Pet = Petromyzontidae (lampreys), Sal = Salmonidae (salmon and trout), Cat = Catostomidae (suckers), Cyp = Cyprinidae (minnows), Gst = Gasterosteidae (sticklebacks), Poe = Poecilidae (mosquitofish), Ict = Ictaluridae (catfish), Cen = Centrarchidae (sunfish), Per = Percidae (perch), and Cot = Cottidae (sculpins).

The average number of fish species captured per site generally increased with increasing stream order (Figure 3). For all species combined, we observed the greatest increase in species richness from first to second-order sites, largely because of the high occurrence of introduced fish in second-order sites. The mean number of native fishes increased more uniformly with stream order. Two-way analysis of variance indicated a significant ($P < 0.01$) difference in species richness among stream sites of different order, but not among sites of different stream type ($P = 0.31$). Differences among stream orders were not consistent among stream types ($P = 0.37$).

Fish assemblages also varied seasonally (Figure 4). The proportion of minnows in our catch increased considerably from spring to winter, and the proportion of sculpins captured decreased over the same period. We captured the highest proportion of trout during summer sampling; however, suckers, threespine stickleback, and mosquitofish were most common during autumn sampling.

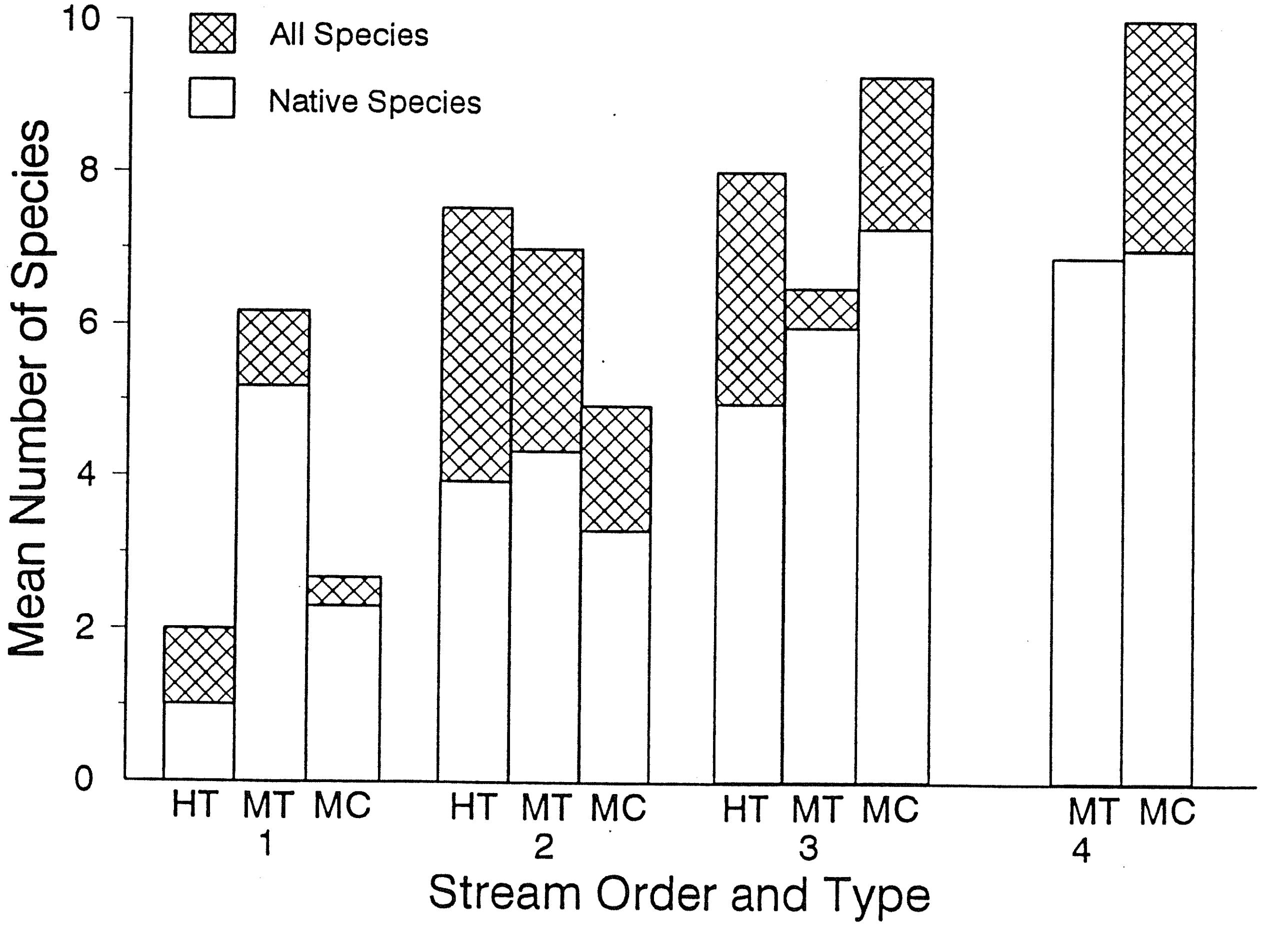

Figure 3. Mean number of species collected per site for each stream order in the Tualatin River basin, 1994-95. MC = main channel streams (tributaries of the Tualatin River), MT = main channel tributaries (tributaries of MC's), and HT = headwater tributaries (tributaries of MT's).

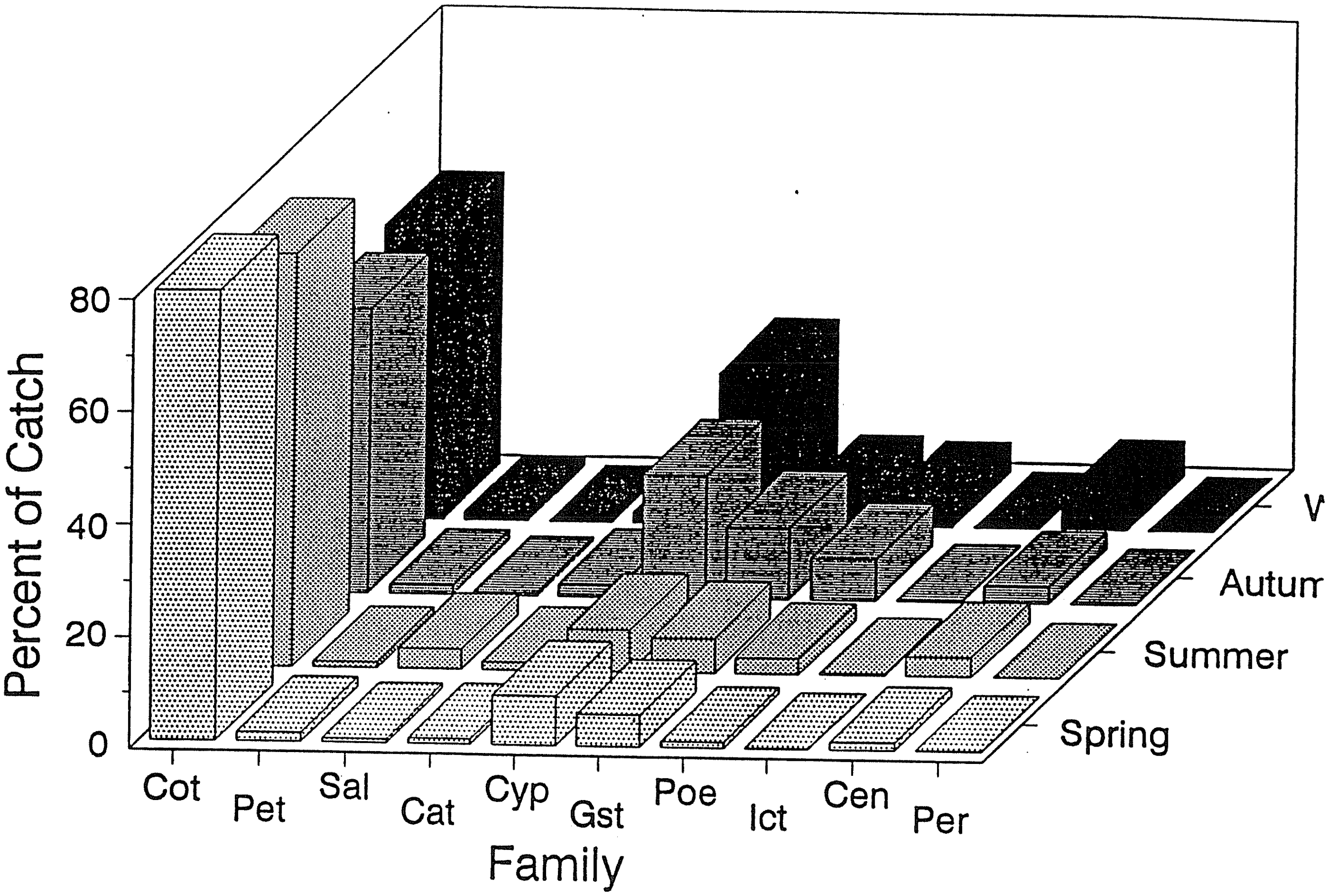

Figure 4. Percent of catch by family and season in the Tualatin River basin, 1994-95. Pet = Petromyzontidae (lampreys), Sal = Salmonidae (salmon and trout), Cat = Catostomidae (suckers), Cyp = Cyprinidae (minnows), Gst = Gasterosteidae (sticklebacks), Poe = Poecilidae (mosquitofish), Ict = Ictaluridae (catfish), Cen = Centrarchidae (sunfish), Per = Percidae (perch), and Cot = Cottidae (sculpins).

Species intolerant to warm water, sedimentation, and organic pollution comprised 3.1% of the total catch and included torrent sculpin, cutthroat trout, rainbow trout, coho salmon, pacific lamprey, and brook lamprey. Torrent sculpin were found only in upper Dairy Creek, a free-flowing, forested site free from obvious urban or agricultural influences. Cutthroat and rainbow trout were also most common at this site, representing 80.7% of all trout captured in our surveys. Juvenile coho salmon were captured in the lower portion of Fanno Creek, and three of eight of these fish were finmarked, indicating they were of hatchery origin. We also captured several recently hatched (<15 mm) cutthroat trout in Chicken and Fanno creeks during spring sampling.

We found physiological anomalies on 2.0% of all fish captured. These generally consisted of leech (Class Hirudinea) or worm (Class Nematoda) parasites, and a small proportion of fish had fungal infections or physical deformities. The percent of fish with anomalies was highest for redside shiners (8.4), largescale suckers (5.1), and cutthroat trout (3.6), and ranged from 0.0 to 15.1 among stream sites. Anomalies were present on more than 5% of the catch in five of 38 sites surveyed (Fanno Creek, middle; Ash Creek, lower and middle; Dawson Creek, lower; and Cedar Mill Creek, middle).

DISCUSSION

The results of our surveys may be broadly compared to previous surveys in the Willamette River near the Tualatin River (Hughes and Gammon 1987, Farr and Ward 1993). Farr and Ward reported 39 fish species from 17 families in the lower Willamette River (downstream from river kilometer 27). Nineteen of these species were absent from our catch in the Tualatin River basin. Hughes and Gammon surveyed the Willamette River up to river kilometer 283, including two sampling sites near the mouth of the Tualatin River. Eight species not observed in the Tualatin River basin were captured at these sites. Species common to both Willamette River surveys but not represented in our catch included mountain whitefish *Prosopium williamsoni*, mountain sucker *Catostomus platyrhynchus*, chinook salmon *Oncorhychus tshawytscha*, chiselmouth *Acrochelius alutaceus*, peamouth *Mylocheilus caurinus*, common carp *Cyprinus carpio*, and smallmouth bass *Micropterus dolomieui*. We captured three species (brook lamprey, fathead minnow, and mosquitofish) not described by Farr and Ward or Hughes and Gammon.

The smaller number of fishes occurring in the Tualatin River basin may be attributable to a variety of factors. Willamette Falls, at Rkm 43.0 of the Willamette River, presents a significant barrier to fish passage and may exclude species such as starry flounder *Platichthys stellatus* from the Tualatin River. Chinook salmon were probably never abundant in the Tualatin River basin (ODFW 1993). Mountain whitefish, peamouth, mountain sucker, and chiselmouth, common in the Willamette River, may be unable to survive in Tualatin River tributaries due to predation by introduced species, poor water quality, or marginal habitat quality. Common carp and smallmouth bass have been observed at other locations within the basin (ODFW, unpublished data).

Introduced species appear to be well established at certain sites within the basin. One such species, the fathead minnow, does not appear in historical surveys of the Tualatin or Willamette rivers (Hughes and Gammon 1987, Farr and Ward 1993), and may be a recent introduction. The large number of sunfish and mosquitofish found near wetland areas reflects the ability of these families to proliferate in warm, shallow, weedy water, and should be a consideration for future mitigation projects specifying the construction of wetlands. As these fish are generally not strong swimmers (Nikolsky 1978), they may be unable to become permanently established in smaller streams affected by high seasonal flows.

Species richness in temperate streams usually increases with increasing stream order (Moyle and Cech 1988). In systems that are affected by flooding, water removal by humans, or pollution, the number of species may decrease in larger order streams. This trend was not apparent in the Tualatin River basin, as the number of native species increased uniformly with increasing stream order. However, species richness increased only slightly in third and fourth-order streams when all species were considered, indicating that disturbances including or allowing the presence of introduced species may be greatest in smaller streams. Because the historic composition of fish assemblages in the basin is unknown, the effect of species addition or replacement on the relationship between species richness and stream order is uncertain.

The variability of species assemblages among seasons suggests that many species in the basin are transient, selecting different habitat types as stream conditions dictate. The relatively high percentage of trout captured during summer sampling supports this point, and indicates that streams in the basin are important temperature refuges for sensitive species. Likewise, the lower proportions of trout and sculpins present in winter suggests that these species may move to the mainstem Tualatin River during periods of high flow. This data must be interpreted with caution; however, as high, murky water may have contributed to reduced catchability of benthic species such as sculpins during fall and winter sampling.

Intolerant species, especially trout and torrent sculpin, were relatively uncommon and primarily occurred at sites that were forested, free-flowing, and apparently unaffected by urban or agricultural influences. The presence of recently hatched trout indicates that these fish are able to successfully spawn in at least some locations within the basin. No adult salmon or steelhead were observed, although it is likely that the rainbow trout we captured were steelhead smolts (Jay Massey, ODFW, personal communication).

Although not generally the cause of major fish kills, parasites may render fish susceptible to secondary infections or weaken their tolerance of environmental changes (Herman 1990). The relatively high incidence (>5%; Karr et al. 1986) of parasitic infestations of fish at several sites in our study area may be indicative of poor water quality or other habitat disturbances. The relatively high proportion of anomalies observed in cutthroat trout, an intolerant species, is also cause for concern.

The status of fish habitat in our study area undoubtedly impacts fish populations to some degree. Neill et al. (1995) report that many sites in this study area have habitat characteristics that do not meet those required by many native fish species. Siltation, bank erosion, lack of woody debris and insufficient overhead cover (presumably resulting in increased water temperatures) are significant factors affecting fish habitat at these sites.

The occurrence of introduced species and parasitic infestations, the low number of intolerant species, relatively low species richness in larger streams, and poor habitat quality indicate that fish populations in the Tualatin River basin within the urban growth boundary near Portland, Oregon are at least moderately unhealthy. Because at least some of these streams are able to support populations of cutthroat trout and other intolerant species, they are likely important seasonal refuges. Fish habitat in these streams should be preserved or enhanced whenever possible to ensure the continued success of these species, and of all fauna dependent on the basin. Although further changes in the basin are probably unavoidable because of continued growth, the health of urban watersheds such as the Tualatin River basin is considered by many as important to the overall quality of life. We hope that this report is used by managers as an information base to help assess the effects of past and future urbanization in the watershed, allowing management decisions that maximize public enjoyment of these urban streams.

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Status of Fish Habitat in Streams of the Tualatin River Basin, Oregon

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INTRODUCTION

The Tualatin River Basin in Washington County near Portland, Oregon, is one of the fastest growing areas in the state. With a population that has doubled in the past twenty-five years (Keisling 1993), the area is experiencing the effects of urban growth. Changes in landscape attributed to urbanization, logging, and agricultural practices have significantly affected the hydrology of the basin. With the isolation of the Tualatin River from its floodplain and the subsequent losses of biologically important wetlands and riparian areas, the basin has changed considerably in the past century (Shively 1993).

Water quality has been extensively tested throughout the basin, yet little has been done to study the aquatic habitat of Tualatin River tributaries (Ervin et al. 1993). Limited fish and habitat surveys were conducted on the mainstem and four tributaries of the Tualatin River by the Oregon Fish Commission in 1958-59 (Willis et al. 1960). The Oregon Department of Fish and Wildlife recently completed a more comprehensive survey of 15 streams in the basin (Friesen and Ward 1995). Additional studies have included aquatic habitat surveys on tributaries of the Tualatin River, focusing primarily on the restoration of water quality (Harza Northwest 1994).

Although historic information on occurrence and abundance of fish species is scarce, streams in Tualatin River basin presumably supported native salmonids, cyprinids, catostomids, gasterosteids, and cottids in their upper and lower reaches. Past timber harvests in the upper basin have reduced the amount of large woody debris in streams, removed streamside vegetation, and increased sedimentation (ODFW 1992). Although native species intolerant of habitat degradation are still found throughout the basin, they are greatly outnumbered by more tolerant introduced and native species (Friesen and Ward 1995).

This paper is part of a cooperative study by the Oregon Department of Fish and Wildlife (ODFW) and Unified Sewerage Agency of Washington county to evaluate the effects of urbanization on fish populations in the Tualatin River basin. Our objective is to describe the status of fish habitat in tributaries of the Tualatin River within the urban growth boundary near Portland, Oregon. This information will help managers predict the effects of further urban growth and water demands on the aquatic resources of the basin, and may identify areas requiring protection because of the presence of habitat required by native fish species.

METHODS

We inventoried habitat on 38 reaches of 15 streams in the Tualatin River basin, from late summer through early autumn in 1993 and 1994 (Figure 1). We surveyed three reaches of each stream, except in cases of inadequate accessibility where only two reaches were surveyed. Reaches were selected to represent lower, middle, and upper sections of streams. Reach length was limited by undergrowth density, water depth, and accessibility (Table 1). We determined stream order (Orth 1983) at each reach surveyed. Each reach was also assigned to one of three categories dependent on stream size and location within the basin (Osborne et al. 1992): main channel streams (MC), which are

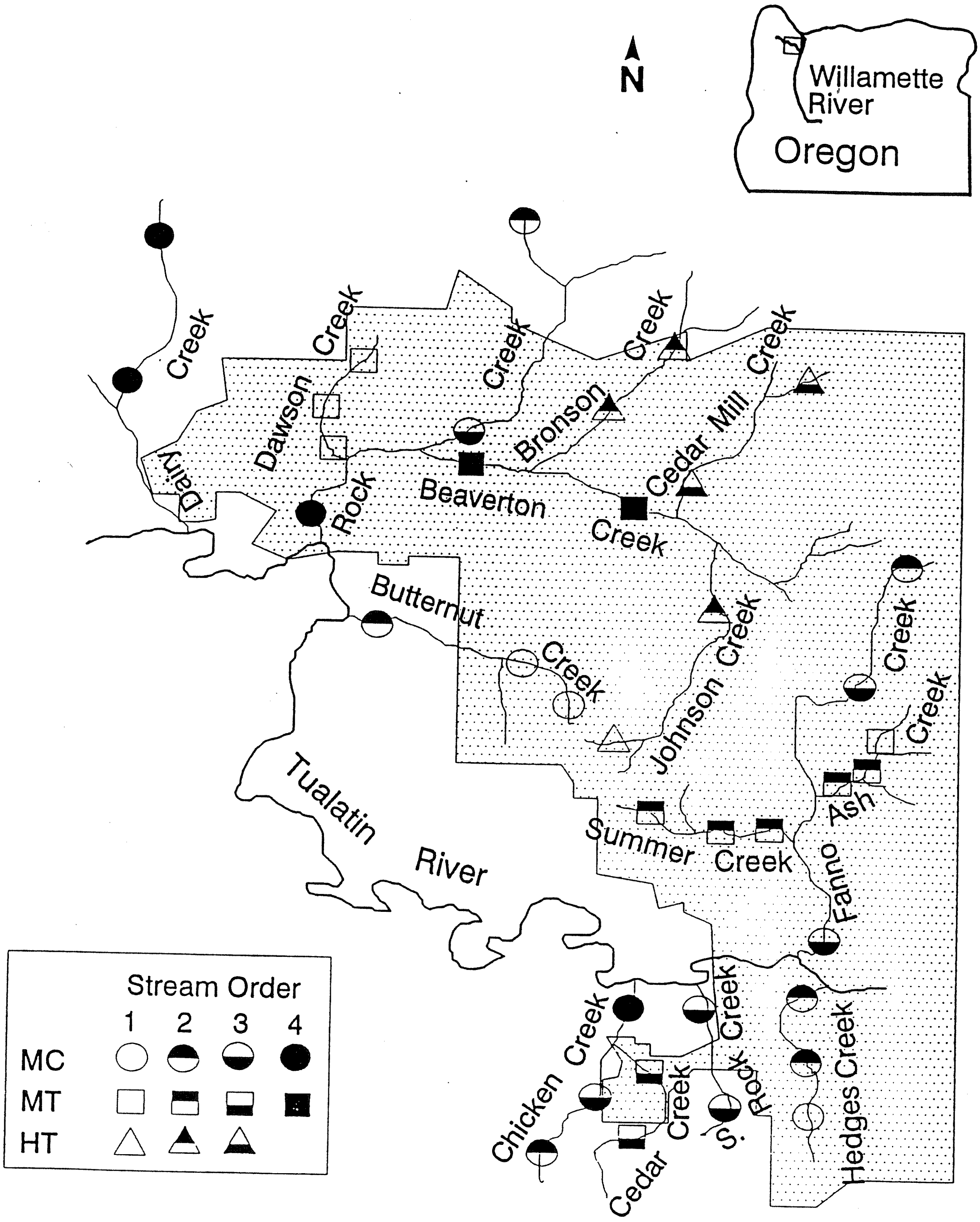


Figure 1. Streams of the Tualatin River basin sampled in 1994-95. Stream order determined by methods described by Orth (1983). MC = main-channel stream, MT = main-channel tributary, and HT = headwater tributary (Osborne et al. 1992). Shaded area approximates urban growth boundary of Washington County.

Table 1. Tributaries of the Tualatin River surveyed in 1993-94. MC = main-channel stream, MT = main-channel tributary, and HT = headwater tributary (Osborne et al. 1992).

Creek	Stream type	Mainstem length (km)	Length of reaches surveyed (m)		
			Lower	Middle	Upper
Hedges	MC	3.8	435	178	489
Fanno	MC	21.7	1898	2102	404
Ash	MT	5.7	733	584	765
Summer	MT	5.2	1046	650	250
S Rock	MC	8.4	--	300	500
Chicken	MC	9.7	585	510	285
Cedar	MT	10.9	--	599	400
Butternut	MC	8.4	351	725	500
Rock	MC	28.7	1840	1789	400
Dawson	MT	6.5	279	583	1024
Beaverton	MT	15.3	1326	1094	--
Bronson	HT	10.7	500	445	--
Cedar Mill	HT	9.5	--	800	620
Johnson	HT	6.3	--	580	400
Dairy	MC	42.2	--	1064	409

tributaries of the Tualatin River, main channel tributaries (MT), which are tributaries of MC's, and headwater tributaries (HT), which are tributaries of MT's.

We used methods developed by ODFW to describe and quantify stream habitat (Moore et al. 1993). The original concepts for this work were developed jointly by Oregon State University, forest industry, and U.S. Forest Service scientists (Bisson et al. 1982, Hankin and Reeves 1988, Gregory et al. 1991). At the downstream end of each reach we described general physical characteristics including channel form, valley form, and land form types, valley width, streamside vegetation, and stream flow. We then divided the reaches further into units of habitat such as pools, glides, riffles, and cascades. If habitat type did not change, maximum unit length was 100 meters. Within each unit we measured or estimated stream width, depth, and gradient. We also estimated canopy cover (shade), substrate composition, and percent of bank that was undercut, counted the number of boulders, and determined the dominant bank type (eroding, stable, or non-erodible). In addition, we assigned an index of wood structure as it relates to fish habitat for each unit. The index ranged from 1 to 5, with a rating of one indicating little or no wood, and a rating of five indicating a large amount of wood creating a variety of cover and refuge habitats.

We subjectively compared mean values for each habitat variable among stream orders. Because reach length varied among and within streams, we first calculated mean values for each reach so that reaches were weighted equally. Mean values reported for each stream order were therefore the mean of the mean values for each reach within that order. We then used multivariate analysis of variance (SAS Institute 1987) to test for significant differences in habitat variables among stream orders and stream types, and to test for significant interaction between stream order and stream type. We first used the arcsine transformation on habitat variables measured as percentages and the logarithmic transformation on variables counted or indexed (Sokal and Rohlf 1981). We used flexible beta ($B=-0.25$) cluster analysis (SAS Institute 1987) to group reaches according to similarities in transformed habitat data. Finally, we used correlation analysis (SAS Institute 1987) to evaluate relationships among habitat variables.

RESULTS

Land use adjacent to reaches we surveyed was most commonly urban residential (15 reaches) or rural residential (10 reaches). Many of the rural residential areas were adjacent to agricultural or forested lands. Agricultural (6 reaches) and industrial (5 reaches) uses were also common. Agricultural uses included both farming and ranching, with livestock permitted direct access to streams. Forested lands accounted for only two reaches, one of which had been partially harvested.

Glides, characterized by even flow and depth with no turbulence, were the most common habitat type throughout the basin (Figure 2). Glides were most common in reaches of third and fourth order streams, whereas occurrence of riffles and pools decreased in reaches of third and fourth order streams. Soil (sand, silt, or organic material), was the most common substrate throughout the basin. The majority of stream banks in the basin were actively eroding, with the highest proportion of eroding banks in third and fourth order reaches.

Stream gradient throughout the basin was variable but generally low (Figure 3). The amount of overhead cover in the form of shade was also variable but generally low. Several of the reaches adjacent to agricultural land use had no shade, whereas forested reaches had higher than average shade. The proportion of shade generally increased with increasing stream order. The percent of banks that were undercut and the index of wood structure were generally low. Indices of wood structure increased slightly with increasing stream order.

Although some habitat characteristics appeared to vary among stream orders (Figures 2 and 3), we found no significant ($P < 0.05$) differences among stream orders for any habitat characteristic. However, stream gradient differed ($P = 0.02$) among stream types, and we found significant interaction between stream order and stream type for the percent of habitat composed of glides ($P = 0.01$). Gradient was highest for main-channel streams within all orders (Figure 4). Glides were the most common habitat type for all stream orders and types except for second-order, main-channel streams, where glides comprised only 2.8% of the total wetted area.

Cluster analysis revealed two distinct groups of reaches at the 3.0 dissimilarity level, and four groups at the 2.0 level (Figure 5). Group D was most distinct, and consisted of five upper reaches with relatively swift water, diverse substrates, relatively little eroding bank, and a high degree of shade (Table 2). Reaches in other groups had predominantly soil substrates

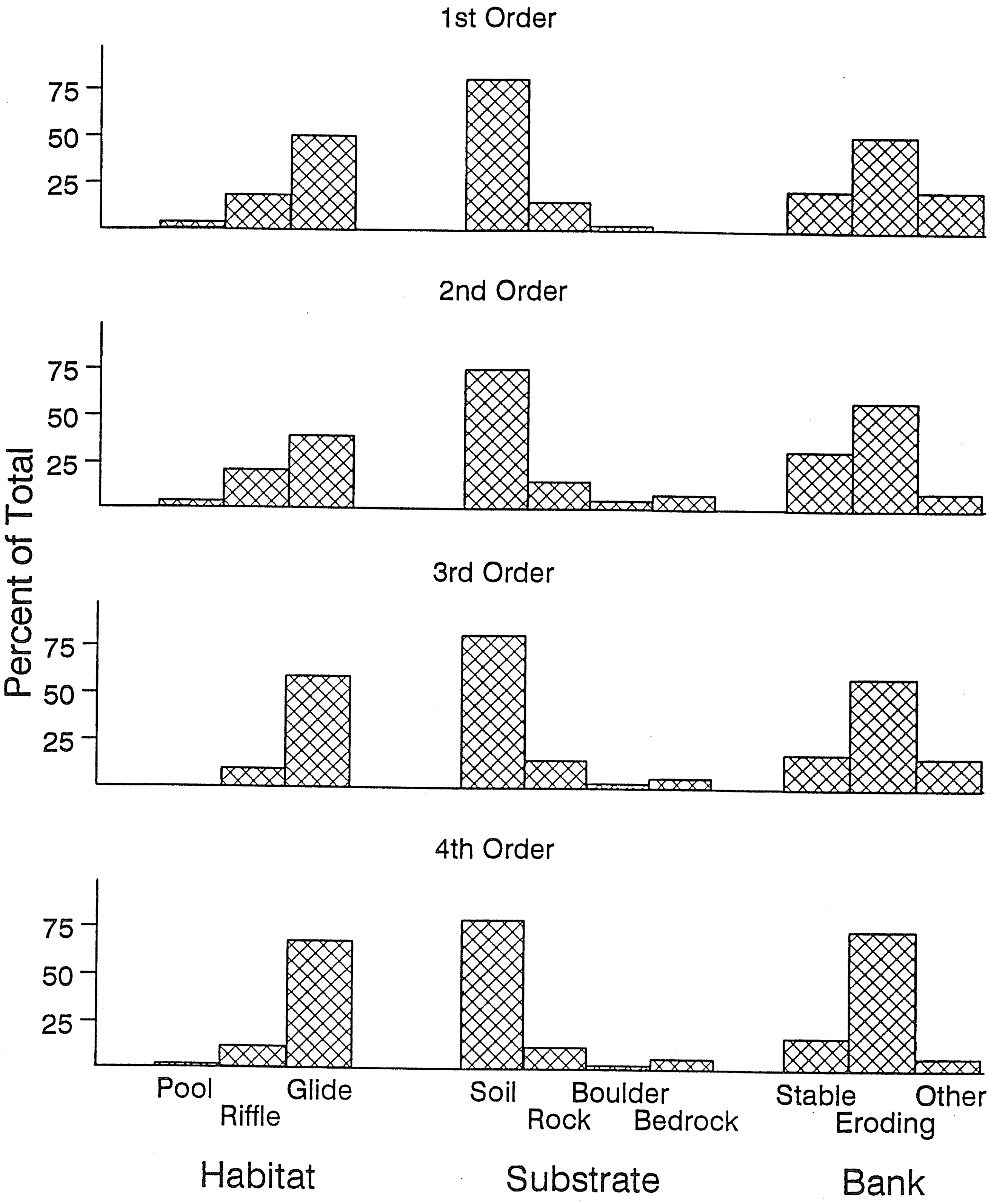


Figure 2. Percentage of total stream area (habitat and substrate) or stream length (bank) in reaches sampled consisting of various habitat characteristics.

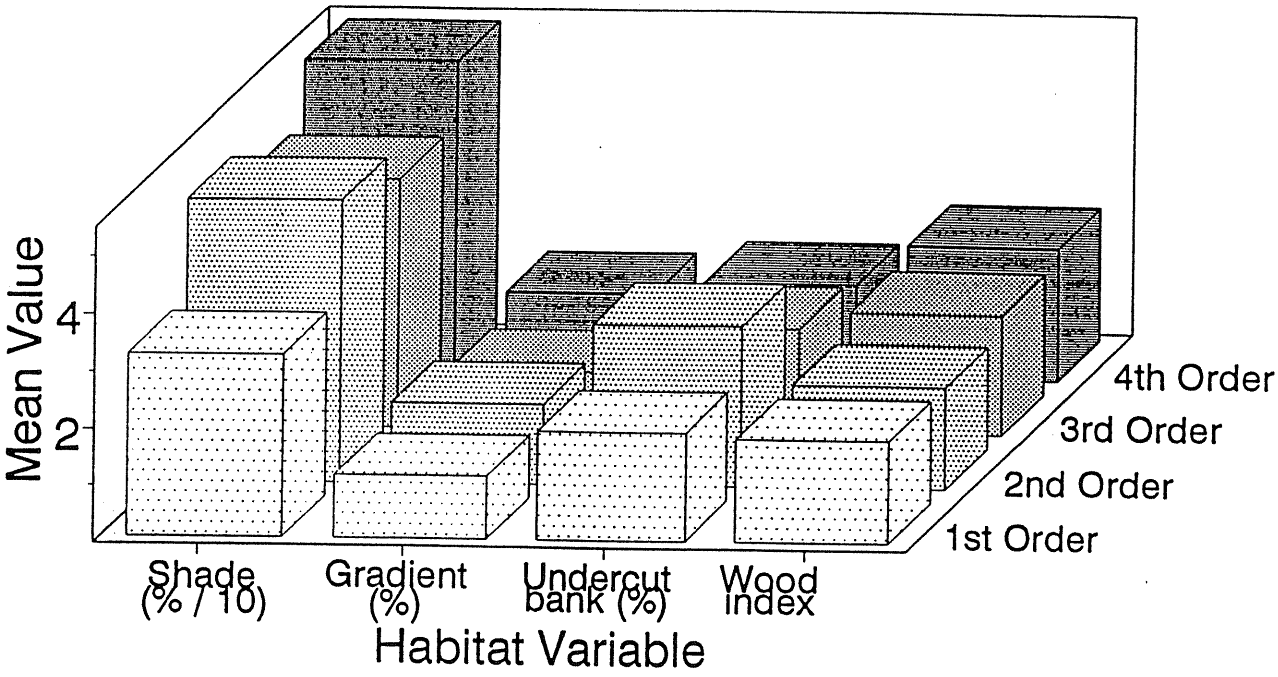


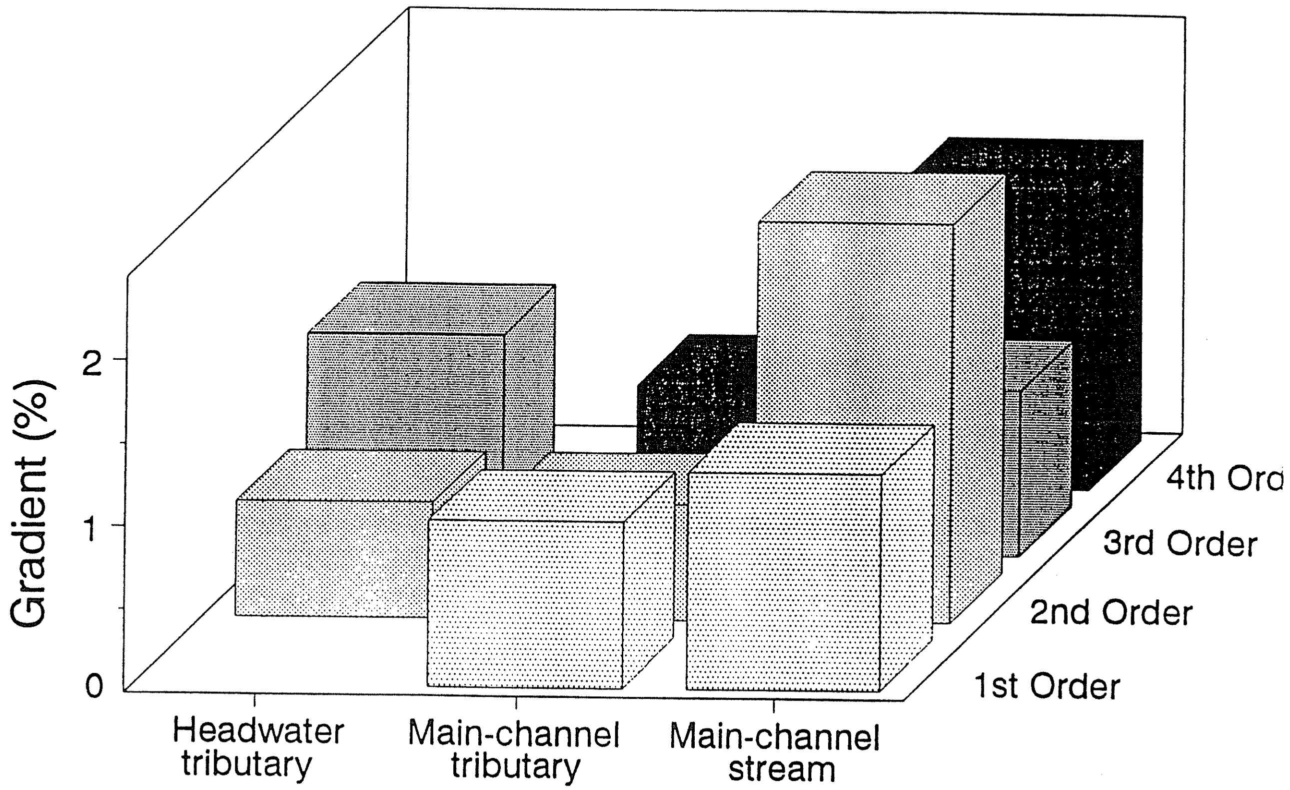
Figure 3. Mean values for habitat characteristics by stream order for reaches sampled.

and little shade. Reaches in Group A were distinct primarily because habitat type was dominated by backwaters. Reaches in Group C were distinct primarily because most banks were not eroding. The lower reach of Hedges Creek was not included in the analysis because it was completely dry when surveyed.

We found few correlations among habitat characteristics (Table 3). Stream gradient was negatively correlated with the percent of substrate composed of soil, and positively correlated with the amount of shade. Shade was also negatively correlated with the amount of soil substrate, and positively correlated with the wood structure index. The amount of habitat composed of glides was positively correlated with the amount of eroding bank.

DISCUSSION

Quantifying aquatic habitat is important to fisheries managers for predicting changes in fish populations following a habitat disturbance (Orth 1983). To properly quantify habitat, Simonson et al. (1994) recommend that length of habitat surveys be based on mean stream width. A survey length of 35 mean stream widths gave estimates that were within 5% of true values 95% of the time. Thirty seven of our 38 reaches had lengths well above the recommended 35 mean stream widths. One reach, middle Hedges creek, was an artificial wetland used for mitigation for industrial development. Access was limited in this reach and consequently length sampled was short relative to mean stream width, and did not meet the requirement of 35 mean stream widths.



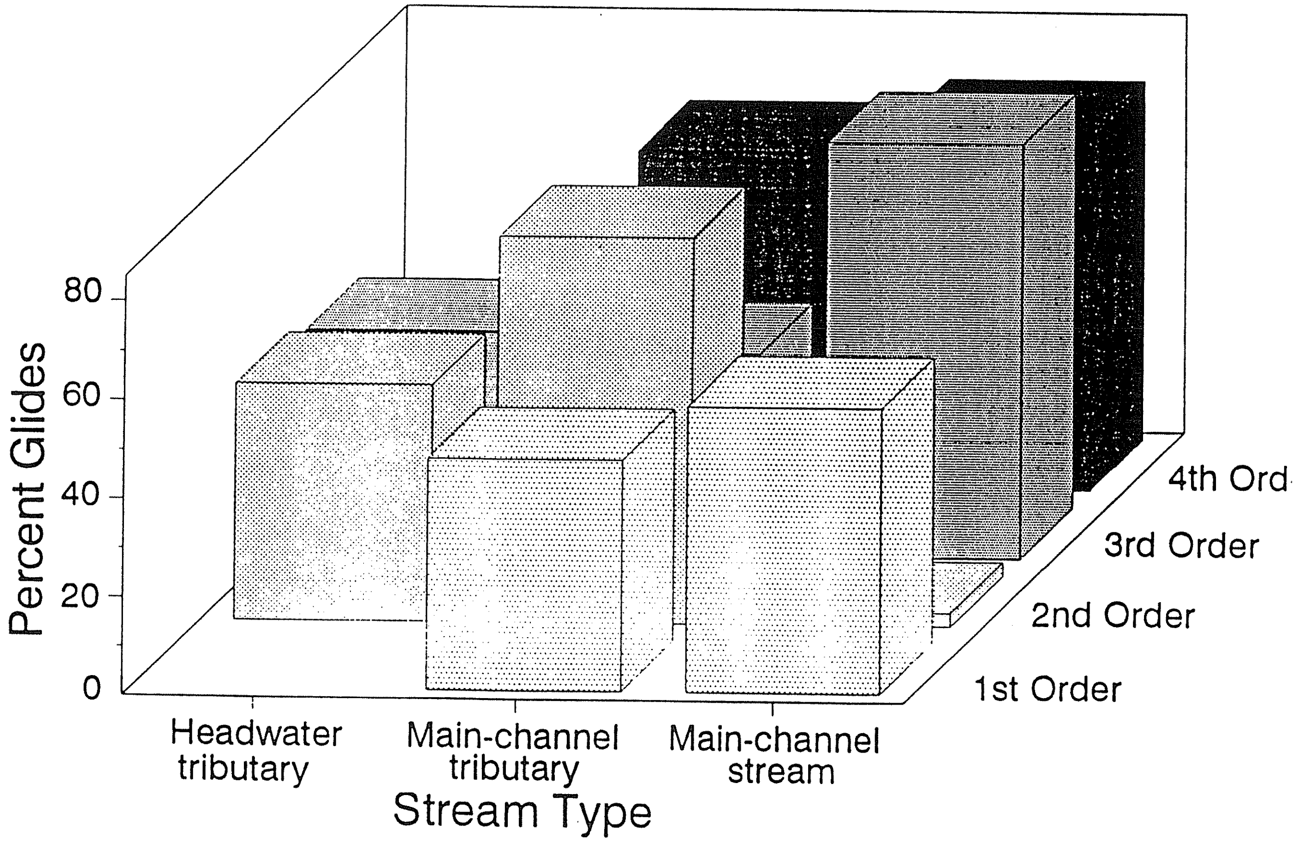


Figure 4. Comparisons of the mean gradient and percentage of stream consisting of glides among stream types and stream orders.

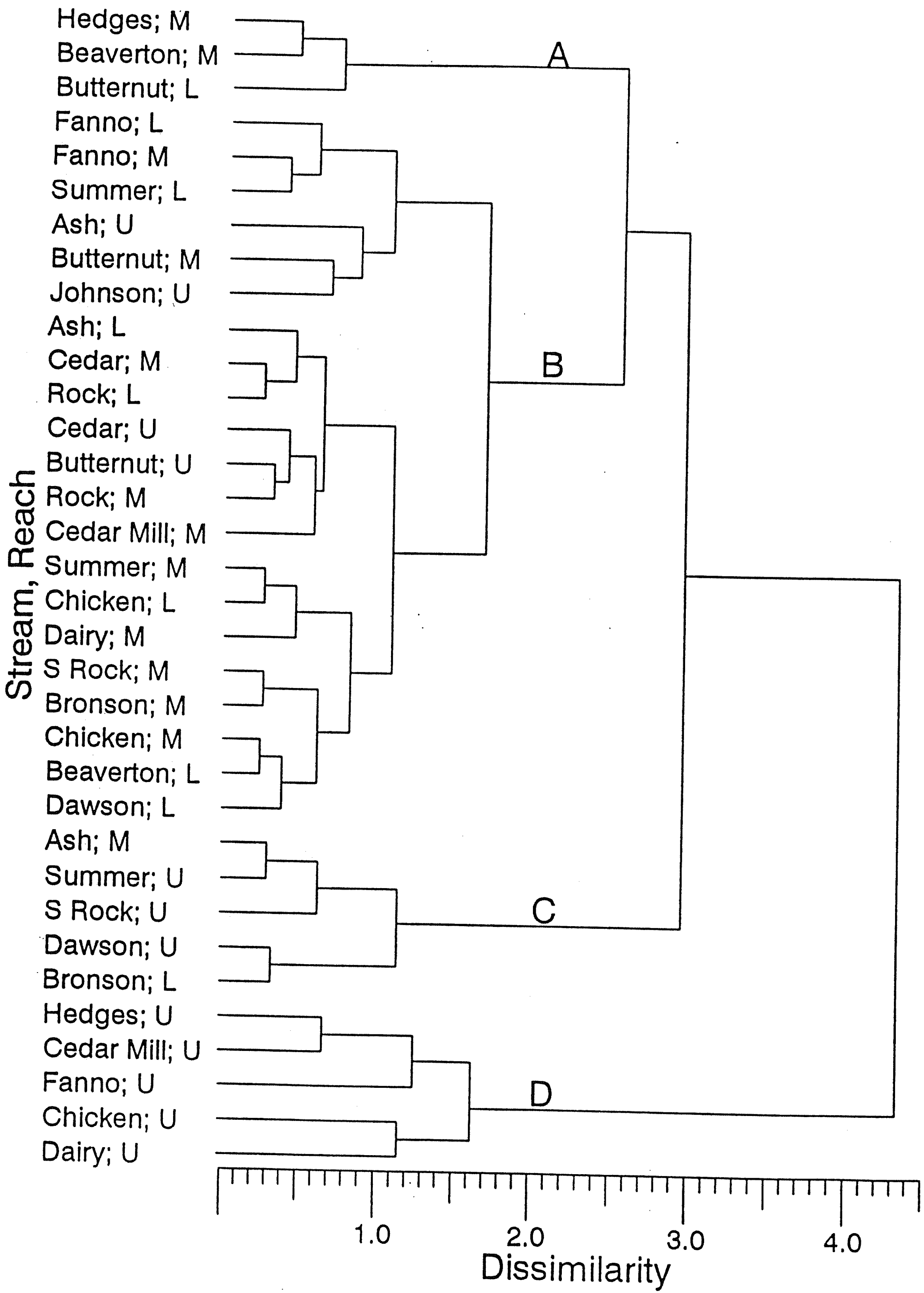


Figure 5. Stream reaches in the Tualatin River basin grouped by similarities in habitat characteristics. L =lower reach, M = middle reach, and U = upper reach.

Table 2. Mean values (and standard deviation) of selected habitat variables for reaches grouped by cluster analysis. Fast water includes riffles, rapids, and cascades. Soil substrate includes silt, sand, and organic matter. Rock substrate includes gravel and cobble.

Habitat variable	Group A	Group B	Group C	Group D
Habitat (%):				
Glides	20.6 (22.7)	90.8 (15.4)	97.5 (3.5)	7.5 (16.8)
Backwaters	68.4 (14.3)	0.7 (2.9)	0.0 (0.0)	0.1 (0.2)
Pools	0.0 (0.0)	0.4 (1.2)	0.0 (0.0)	0.6 (0.9)
Fast water	11.0 (18.7)	3.0 (8.8)	0.0 (0.0)	91.8 (17.1)
Substrate (%):				
Soil	95.5 (6.7)	85.0 (16.9)	86.7 (12.2)	36.4 (26.7)
Rock	3.3 (4.9)	12.9 (15.8)	11.7 (12.2)	36.3 (16.5)
Boulder	1.2 (1.9)	0.9 (0.9)	1.6 (1.8)	8.7 (5.1)
Bedrock	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	18.6 (17.6)
Shade (%)	28.1 (27.6)	44.9 (22.8)	15.6 (15.4)	76.9 (13.8)
Eroding bank (%)	74.6 (10.1)	87.0 (12.4)	19.1 (23.8)	31.4 (41.8)
Undercut bank (%)	1.0 (0.9)	1.9 (2.0)	2.9 (6.2)	2.3 (2.2)
Wood index	1.3 (0.3)	2.1 (0.9)	1.3 (0.6)	2.0 (0.7)

Glides, silt and organic substrate, and actively eroding banks were the most common habitat characteristics in the Tualatin River basin and are indicative of low gradient streams. Gradient was generally low for most reaches we surveyed, and frequent flooding was evident from the amount of debris in the overhead canopy. Early surveys of the Tualatin River basin describe the land as swampy, wooded, bottom lands that are subject to flooding (Shively 1993). The frequency and intensity of floods have increased because of timber harvests and because much land in the basin is now covered by pavement. Stream channelization has also contributed to increasing the intensity of floods. At least two stream reaches we surveyed had been altered to form a straight channel.

Pearsons et al. (1992) found that resistance of fish assemblages to flooding may increase with increased complexity of stream habitat. The lack of structure in most glides of the Tualatin River basin has resulted in low habitat complexity. Relatively low wood scores may be attributed to flooding that either removes wood or buries it in silt. Silt and organic material also cover gravel, cobble, and boulders, reducing complexity by filling the

Table 3. Correlations among habitat variables in the Tualatin basin. Variables other than the wood index were measured as a percent. The wood index ranged from 1 to 5 based on amount of wood structure providing fish habitat. Soil substrates are a combination of sand, silt, and organic material. An asterisk indicates $P < 0.05$.

	Gradient	Glides	Soil substrate	Shade	Eroding banks	Undercut banks
Glides	-0.39*					
Soil substrate	-0.77*	0.25				
Shade	0.62*	-0.26	-0.60*			
Eroding banks	-0.10	0.46*	0.25	-0.05		
Undercut banks	-0.01	-0.02	-0.15	-0.04	-0.06	
Wood index	0.23	-0.15	-0.02	0.40*	0.19	-0.02

interstitial spaces and forming a flat bottom. We found few undercut banks, likely due to the amount of channelization in the basin.

Cutthroat trout *Oncorhynchus clarki* and torrent sculpin *Cottus rhotheus* are two native resident fish species found in the Tualatin River basin that are intolerant of habitat characterized by sedimentation, warm water, and organic pollution (Hughes and Gammon 1987; Friesen and Ward 1995). We found that only 6 of 38 reaches surveyed met most of the general habitat requirements of these native species. These sites were upper reaches of streams that contained relatively swift water, a variety of substrates, a high amount of shade, and relatively complex habitat. The high amount of soil substrate in other reaches likely limits the amount of spawning by cutthroat trout (Thurow and King 1994), the success of cutthroat trout fry emergence (Weaver and Fraley 1993), and the distribution of torrent sculpin (Finger 1982). Absence of shade may allow summer water temperatures to limit populations of cutthroat trout (Platts and Nelson 1989). Undercut banks and wood add complexity to habitat, providing cover and protection (Bustard and Narver 1975); however, this complexity is lacking in most reaches we surveyed. The lack of turbulence associated with glides may also decrease habitat complexity.

Aquatic habitat throughout the Tualatin River basin has been significantly changed. Most streams have been channelized and isolated from their natural floodplains, increasing the frequency and severity of floods. These floods in turn reduce habitat complexity provided by wood, undercut banks, and interstitial spaces in the substrate. The resulting homogeneous streams are generally not able to support healthy populations of native fish intolerant of habitat characterized by sedimentation, warm water, or organic pollution, allowing greater abundance of exotic fish and of more tolerant native fish. Because some streams appear capable of supporting populations of native, intolerant fish species, habitat in these streams should be preserved or enhanced when possible to ensure continued success of these species.

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Biotic Integrity and Aquatic Habitat in the Tualatin River Basin, Oregon: Criteria for Protecting and Enhancing Habitat

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INTRODUCTION

Physical habitat and water quality influence both the occurrence and abundance of fishes in streams, but these relations are not well understood for many species. Most work has concentrated on examining the relationship between habitat features and a single species (Layher and Maughan 1985; Layher et al. 1987; Hubert and Rahel 1989), or between fish assemblages and a single variable such as flow (Aadland 1993). Understanding relationships between physical habitat and entire fish assemblages in streams is important if effects of development on habitat are to be evaluated, mitigated, corrected, or prevented. This is particularly true in or near urban areas, where streams may be subject to intense modification, but at the same time may be considered important to the quality of life.

Streams in the Tualatin River basin near Portland, Oregon have been altered considerably since the arrival of settlers in the mid 1800's. Early changes in the basin consisted primarily of harvesting timber and converting land use to agriculture. Changes in landscape because of agricultural practices significantly affected hydrology in the basin. More recently, dramatic increases in population have resulted in urbanization of the watershed. Parts of the Tualatin River and many tributaries now flow through or under housing developments, shopping centers, and industrial complexes. These changes in habitat have undoubtably contributed to changes in fish assemblages throughout the basin.

Historic information on fish populations and habitat in the Tualatin River basin is scarce. Limited fish and habitat surveys were conducted by the Oregon Fish Commission in 1958-59 (Willis et al. 1960). Other fish surveys were limited to single day sampling on the Tualatin River, and focused primarily on salmonids (ODFW, unpublished data). Most recent studies have focused primarily on restoration of water quality (Harza NW 1994); however, thorough fish and habitat surveys were recently conducted on 15 streams in the basin by Friesen and Ward (1995) and Neill et al. (1995).

In this study we (1) evaluated the biotic integrity of fish assemblages in 34 reaches of 15 streams in the Tualatin River basin, (2) quantified the physical habitat available at these reaches, and (3) examined the relationship between biotic integrity and physical habitat. Our goal was to use this information to identify (1) reaches where biotic integrity is high relative to available habitat and should therefore be protected, (2) reaches where biotic integrity and habitat appear related and therefore improvements to habitat may likely result in enhanced biotic integrity, and (3) reaches where biotic integrity is low relative to available habitat and is therefore likely limited by factors other than or in addition to poor habitat. This technique may be useful to fishery managers responsible for selecting from numerous candidates those streams most likely to benefit from habitat improvements.

METHODS

Field Sampling

We surveyed habitat and fish populations in 34 reaches of 15 streams in the Tualatin River basin (Figure 1). We surveyed at least two reaches in each

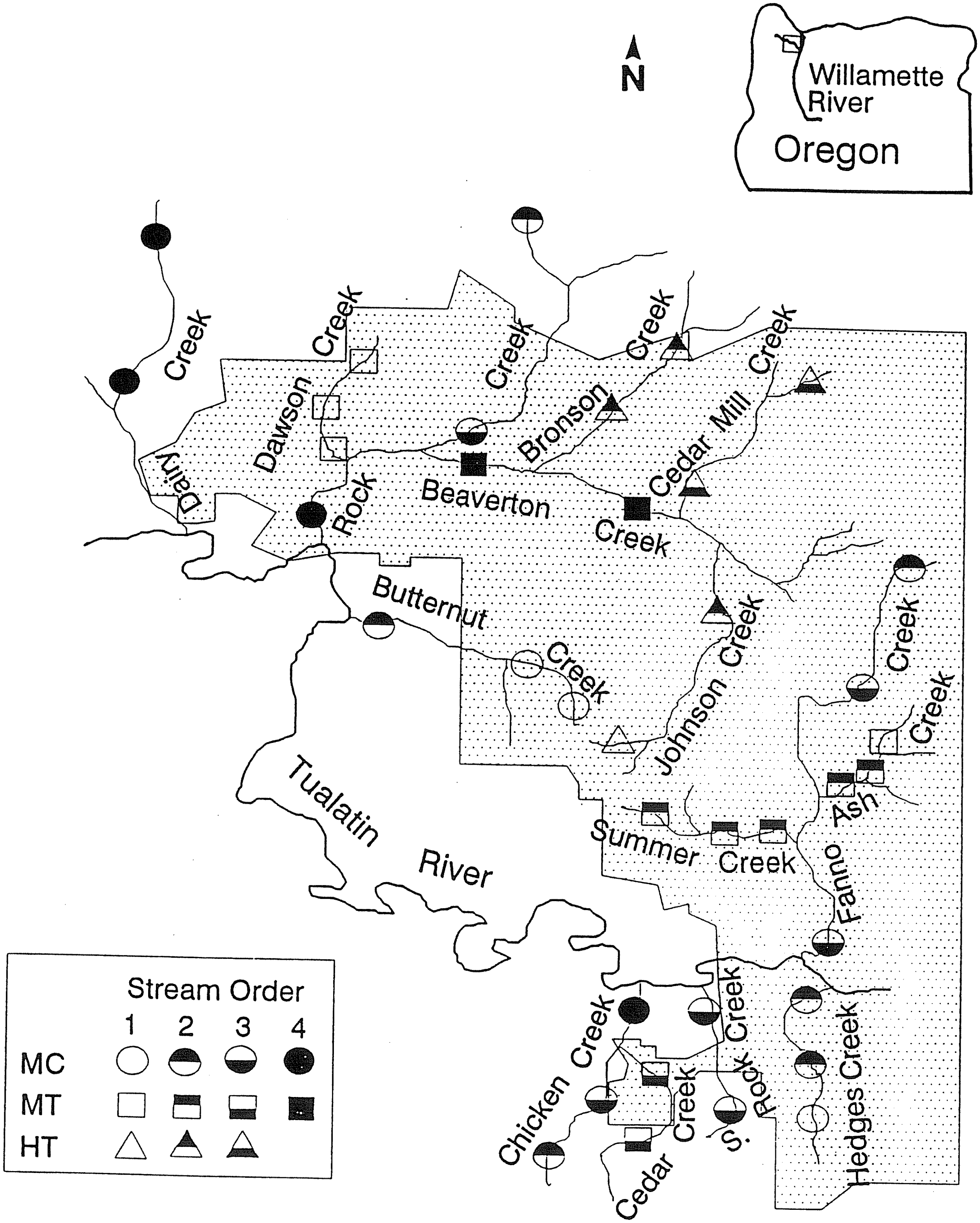

Figure 1. Streams of the Tualatin River basin sampled in 1994-95. Stream order determined by methods described by Orth (1983). MC = main-channel stream, MT = main-channel tributary, and HT = headwater tributary (Osborne et al. 1992). Shaded area approximates urban growth boundary of Washington County.

stream, one near the mouth and one near the headwaters. In larger streams we surveyed an additional reach between the lower and upper reaches. Reach length varied because of accessibility, water depth, and density of undergrowth (Neill et al. 1995). Stream size varied among reaches, ranging in order (Orth 1983) from 1 to 4. Streams were also assigned to one of three categories that reflected general location in the basin (Osborne et al. 1992): main-channel streams (MC) were tributaries of the Tualatin River, main-channel tributaries (MT) were tributaries of MC's, and headwater tributaries (HT) were tributaries of MT's.

We selected 100-m sites within each reach to sample for fish in summer 1994. Sites were selected so that habitat was representative of the reach. We blocked the ends of each site and used backpack electrofishing equipment to conduct three-pass removal sampling (Armour et al. 1983; Riley and Fausch 1992). After each downstream to upstream shocking pass, we identified specimens collected to species and inspected them for physical anomalies such as parasites or deformities.

We used methods developed by Bisson et al. (1982) and Hankin and Reeves (1988), and modified by Moore et al. (1993), to describe and quantify stream habitat in late summer and early autumn, 1993-94. We divided reaches into units of habitat such as pools, riffles, and glides. If habitat type did not change, maximum unit length was 100 m. Within each unit we measured or estimated stream width, depth, and gradient. We also estimated canopy cover (shade), substrate composition, and percent of bank that was undercut, counted the number of boulders, and determined the dominant bank type (eroding, stable, or non-erodible). In addition, we assigned an index of wood structure as it relates to fish habitat for each unit. The index ranged from 1 to 5, with a rating of one indicating little or no wood, and a rating of five indicating a large amount of wood creating a variety of cover and refuge habitats.

Biotic Integrity

We used a modified index of biotic integrity (IBI; Karr 1981) to assess fish assemblages at our sampling sites. The IBI comprises metrics that reflect structural and functional characteristics of fish communities (Karr et al. 1986), and was originally developed for use in streams of the midwestern United States. The IBI has since been modified for use in the Willamette River in Oregon (Hughes and Gammon 1987); however, no IBI has been developed for small streams in the Pacific Northwest.

We used 10 metrics to assign IBI scores for sites within the Tualatin River basin (Table 1). Five were identical to Karr's (1981) original metrics, and another was used by Hughes and Gammon (1987). The remaining four metrics were modified from Karr et al. (1986) or Hughes and Gammon (1987). First, the number of native benthic species was substituted for the number of cottid species and the number of catostomid species used by Hughes and Gammon (1987). Karr et al. (1986) recognized the importance of including benthic species (darters, subfamily Etheostomatinae), and Hughes and Gammon (1987) substituted cottids because of their specificity for benthic habitats. Both Karr et al. (1986) and Hughes and Gammon (1987) included the number of catostomids as a separate metric. Although both cottids and catostomids occur in the Tualatin

Table 1. Metrics and scoring criteria used to determine an index of biotic integrity (IBI) for streams of the Tualatin River basin. Scoring criteria differed among stream orders only when specified.

Metric, stream order	Scoring criteria		
	5	3	1
Number of native species			
1	>4	2-4	<2
2	>4	3-4	<3
3	>5	3-5	<3
4	>5	4-5	<4
Number of native benthic species			
1-3	>3	2-3	<2
4	>4	3-4	<3
Number of native pelagic species	>1	1	0
Number of intolerant species			
1-2	>1	1	0
3	>2	2	<2
4	>3	2-3	<2
Number of individuals			
1	≥400	100-399	<100
2	≥600	200-599	<200
3	≥600	300-599	<300
4	≥700	300-699	<300
Percent tolerant individuals	<40.0	40.0-74.9	≥75.0
Percent top carnivores	≥10.0	0.1-9.9	<0.1
Percent native insectivores other than cottids	≥20.0	5.0-19.9	<5.0
Percent introduced	0	0.1-9.9	≥10.0
Percent with anomalies	0	0.1-9.9	≥1.0

basin (Friesen and Ward 1995), small streams are unlikely to contain many species of either family. Benthic species included all cottids, catostomids, and speckled dace *Rhinichthys osculus*.

We substituted the number of native pelagic species for the number of centrarchid species (Karr et al. 1986) or the number of native cyprinid species (Hughes and Gammon 1987). Native cyprinids are responsive to deterioration of habitat structure; however, small streams are unlikely to contain many species. Pelagic species included redside shiners *Richardsonius balteatus*, northern squawfish *Ptychocheilus oregonensis*, and all salmonids.

We substituted percent tolerant individuals for percent green sunfish *Lepomis cyanellus* (Karr 1981) or percent common carp *Cyprinus carpio* (Hughes and Gammon 1987). We caught several tolerant species; however, no single species provided information about changing conditions.

Finally, percent native insectivores other than cottids was substituted for percent insectivores (Hughes and Gammon 1987). Most introduced fish were insectivores, and were therefore excluded. In addition, catch in most reaches was dominated by cottids. Including cottids would make this metric redundant with the number of individuals in many reaches.

Scoring criteria for some metrics varied among stream orders (Table 1; Karr et al. 1986). Because no historic information was available for fish assemblages in the Tualatin River basin, and because all streams surveyed had experienced some form of alteration, it was impossible to estimate expected IBI scores for "excellent" fish assemblages similar to those undisturbed by humans. Scoring criteria were therefore based on the range of observed scores for each stream order.

Although scoring criteria for some metrics varied among stream orders, location of a stream in a basin (MC, MT, or HT) may also bias the IBI score (Osborne et al. 1992). We therefore used two-way analysis of variance to compare IBI scores among stream orders and among stream locations, and to evaluate the interaction between stream order and stream location.

Relation Between Biotic Integrity and Habitat

We summarized data from habitat surveys to calculate the proportion of stream surface area in each reach composed of slow water (glides), fast water (riffles, cascades, and rapids), pools, and backwaters. We also calculated mean gradient, percent canopy cover (shade), substrate composition, percent of bank that was undercut, percent of bank that was actively eroding, and wood structure index for each reach.

We used analysis of variance (SAS Institute 1987) to determine which habitat variables differed significantly ($P < 0.05$) among groups of stream reaches identified by cluster analysis (Neill et al. 1995). We first used the arcsine transformation on habitat variables measured as percentages and the logarithmic transformation on variables counted or indexed (Sokal and Rohlf 1981). We included only the most common substrate (soil) and habitat type (glides) because of the high correlation among substrate types and among habitat types.

After selecting the appropriate reduced number of habitat variables based on differences among groups, we used principal components analysis to produce linear composites of the selected variables (Green 1979, SAS Institute 1987). The first principal component is the linear composite that follows the major trend of the habitat data (Green 1979); therefore the value of the first principal component for each reach can be considered a habitat score.

We plotted IBI scores against habitat scores and used discriminant analysis (SAS Institute 1987) to group reaches based on the relationship between IBI and habitat. We inspected the plot for the presence of three groups: (1) reaches where the IBI is higher than expected for the habitat score and should therefore be protected, (2) reaches where IBI and habitat appear related and therefore improvements to habitat may likely result in enhanced biotic integrity, and (3) reaches where the IBI is lower than expected for the habitat score and therefore biotic integrity is likely constrained by factors other than or in addition to poor habitat.

We used water quality information (Unified Sewerage Agency, unpublished data) to help validate separation of the reaches into groups. When possible, we compared water quality information (mean summer water temperature, turbidity, dissolved oxygen, phosphate level, and fecal coliform level) between sites that had similar habitat scores but differed in IBI. We compared the relative differences in water quality between reaches of different groups to the relative differences in water quality between reaches within groups.

RESULTS

Biotic Integrity

We collected 23 fish species from 10 families in streams of the Tualatin River basin (Table 2). Eleven species from 5 families (approximately 7% of all fish collected) were introduced. Only 6 species from 3 families (approximately 9% of all fish collected) were intolerant of pollution and habitat degradation. Most species were insectivores.

Fish assemblages and IBI scores varied widely throughout the Tualatin River basin (Table 3). The number of native species present ranged from 0 to 6, but no reach contained more than two pelagic species, and only two reaches contained more than two species intolerant to habitat degradation. The upper reach of Dairy Creek contained four intolerant species: Pacific lamprey, cutthroat trout, rainbow trout, and torrent sculpin. The only other intolerant species observed in the basin were western brook lamprey and coho salmon. Two reaches contained only introduced species, whereas 21 reaches contained only native species.

IBI scores in streams of the Tualatin River basin were generally low (Figures 2 and 3). Only one of 34 reaches sampled had a score qualitatively labeled as good. Twenty reaches had poor or very poor scores. We found no difference in mean IBI scores among stream orders ($P = 0.48$) or stream types ($P = 0.19$), and we found no evidence of interaction between stream order and type ($P = 0.51$).

Relation Between Biotic Integrity and Habitat

Habitat varied widely among reaches surveyed, and we found four habitat variables that differed significantly among groups of stream reaches identified by cluster analysis (Table 4). We therefore found four linear composites (principal components) of these variables. The first principal component, which follows the major trend of the data, accounted for 52% of the variation in the habitat data. Based on the first principal component, habitat scores were positively influenced by the amount of shade, and were negatively influenced most by the amount of soil substrate and glides. The amount of eroding bank also influenced habitat scores negatively.

Table 2. Fish collected in streams of the Tualatin River basin in summer 1994. A small percentage (1.19) of the catch was not identified to species; therefore percent of catch does not total 100.0. Relative tolerance refers to physiological resistance of individual species to warm water, sedimentation, and organic pollution: IT = Intolerant, IM = Intermediate, TL = Tolerant.

Family, Species	Percent of catch	Relative tolerance	Adult trophic group
Petromyzontidae			
Western brook lamprey *Lampetra richardsoni*	0.04	IT	--[a]
Pacific lamprey *Lampetra tridentata*	0.99	IT	Piscivore
Salmonidae			
Coho salmon *Oncorhynchus kisutch*	0.06	IT	Piscivore
Cutthroat trout *Oncorhynchus clarki*	2.94	IT	Insectivore
Rainbow trout *Oncorhychus mykiss*	0.49	IT	Insectivore
Cyprinidae			
Redside shiner *Richardsonius balteatus*	3.47	IM	Insectivore
Speckled dace *Rhinichthys osculus*	4.04	IM	Insectivore
Northern squawfish *Ptycochelius oregonensis*	0.01	TL	Piscivore
Goldfish *Carassus auratus*[b]	0.03	TL	Omnivore
Catostomidae			
Largescale sucker *Catostomus macrocheilus*	1.52	TL	Omnivore
Ictaluridae[c]			
Yellow bullhead *Amerius natalis*	0.38	TL	Insectivore
Brown bullhead *Amerius nebulosis*	0.01	TL	Insectivore
Poecilidae[c]			
Mosquitofish *Gambusia affinis*	2.77	TL	Insectivore
Gasterosteidae			
Threespine stickleback *Gasterosteus aculeatus*	6.29	IM	Insectivore
Centrarchidae[c]			
Largemouth bass *Micropterus salmoides*	0.50	TL	Piscivore
Bluegill *Lepomis macrochirus*	0.26	TL	Insectivore
Pumpkinseed *Lepomis gibbosus*	2.71	TL	Insectivore
Warmouth *Lepomis gulosus*	0.01	TL	Insectivore
White crappie *Pomoxis annularis*	0.01	TL	Insectivore
Percidae[c]			
Yellow perch *Perca flavescens*	0.01	IM	Insectivore
Cottidae			
Reticulate sculpin *Cottus perplexus*	71.32	TL	Insectivore
Prickly sculpin *Cottus asper*	0.60	IM	Insectivore
Torrent sculpin *Cottus rhotheus*	0.35	IT	Insectivore

[a] *Adults do not feed.*
[b] *Introduced species.*
[c] *Introduced family.*

Table 3. Metrics and data used to determine modified index of biotic integrity (IBI) for streams in the Tualatin River basin.

Stream, reach	No. of native species	No. of native benthic species	No. of native pelagic species	No. of intolerant species	No. of individuals	% tolerant	% top carn.	% insect.	% intro.	% with anom.	IBI
Hedges											
middle	0	0	0	0	335	100.0	0.0	0.0	100.0	0.0	16
upper	2	2	0	1	16	12.5	0.0	0.0	0.0	0.0	28
Fanno											
lower	6	3	2	2	235	67.7	4.7	5.5	0.0	6.4	32
middle	6	4	2	2	525	92.0	0.8	7.8	0.0	0.0	38
upper	4	2	2	1	352	92.0	0.8	8.0	0.6	0.3	30
Ash											
lower	5	3	1	0	863	92.7	0.0	7.3	3.0	0.6	28
middle	4	3	1	0	780	78.1	0.0	21.9	0.0	0.0	32
upper	1	1	0	0	136	100.0	0.0	0.0	0.0	0.0	20
Summer											
lower	4	3	1	1	244	96.7	0.0	2.0	7.4	0.0	26
middle	3	2	1	0	189	87.8	0.0	12.2	54.5	0.5	20
upper	0	0	0	0	301	99.7	0.0	0.0	100.0	4.3	12
South Rock											
middle	5	3	1	1	484	86.4	0.0	5.4	0.4	1.2	22
upper	1	0	0	0	106	16.0	0.0	84.0	16.0	0.0	22
Chicken											
lower	6	5	1	1	106	62.3	0.0	13.2	0.0	0.0	32
middle	6	4	2	3	332	94.3	0.6	2.1	0.0	0.3	36
upper	2	1	1	1	115	91.3	8.7	8.7	0.0	0.0	26
Cedar											
middle	4	2	1	1	321	73.8	0.0	25.9	0.0	0.6	30
upper	6	4	1	2	350	79.7	0.0	14.6	0.0	0.0	34
Butternut											
lower	2	2	0	1	282	97.9	0.0	0.0	0.0	9.9	20
middle	3	2	0	0	784	36.7	0.0	63.3	0.0	0.3	32
upper	1	1	0	0	257	0.0	0.0	100.0	0.0	0.0	28
Rock											
lower	5	3	2	1	566	97.5	0.2	2.3	0.0	0.2	28
middle	5	3	1	1	1144	96.3	0.0	3.6	1.1	0.1	24

Table 3. Continued.

Stream, reach	No. of native species	No. of native benthic species	No. of native pelagic species	No. of intolerant species	No. of individuals	% tolerant	% top carn.	% insect.	% intro.	% with anom.	IBI
Dawson											
lower	6	4	1	1	290	90.7	0.0	5.5	0.0	0.7	32
upper	4	2	1	0	412	47.6	0.0	52.4	0.0	0.7	32
Beaverton											
lower	4	3	1	2	812	99.6	0.1	0.1	0.0	0.3	30
middle	5	3	1	1	456	90.1	0.0	9.6	10.5	3.3	20
Bronson											
lower	5	4	0	1	634	70.7	0.0	28.7	0.3	0.2	34
middle	2	2	0	1	491	98.4	0.0	0.0	0.0	0.0	24
Cedar Mill											
middle	3	1	1	1	363	98.1	0.3	1.9	0.3	21.2	20
upper	2	2	0	1	377	98.1	0.0	0.0	0.0	0.0	22
Johnson											
upper	1	1	0	0	49	79.6	0.0	20.4	79.6	0.0	18
Dairy											
middle	3	2	1	2	153	96.1	0.6	0.6	0.0	0.7	22
upper	5	3	2	4	725	30.9	61.9	61.9	0.0	0.4	44

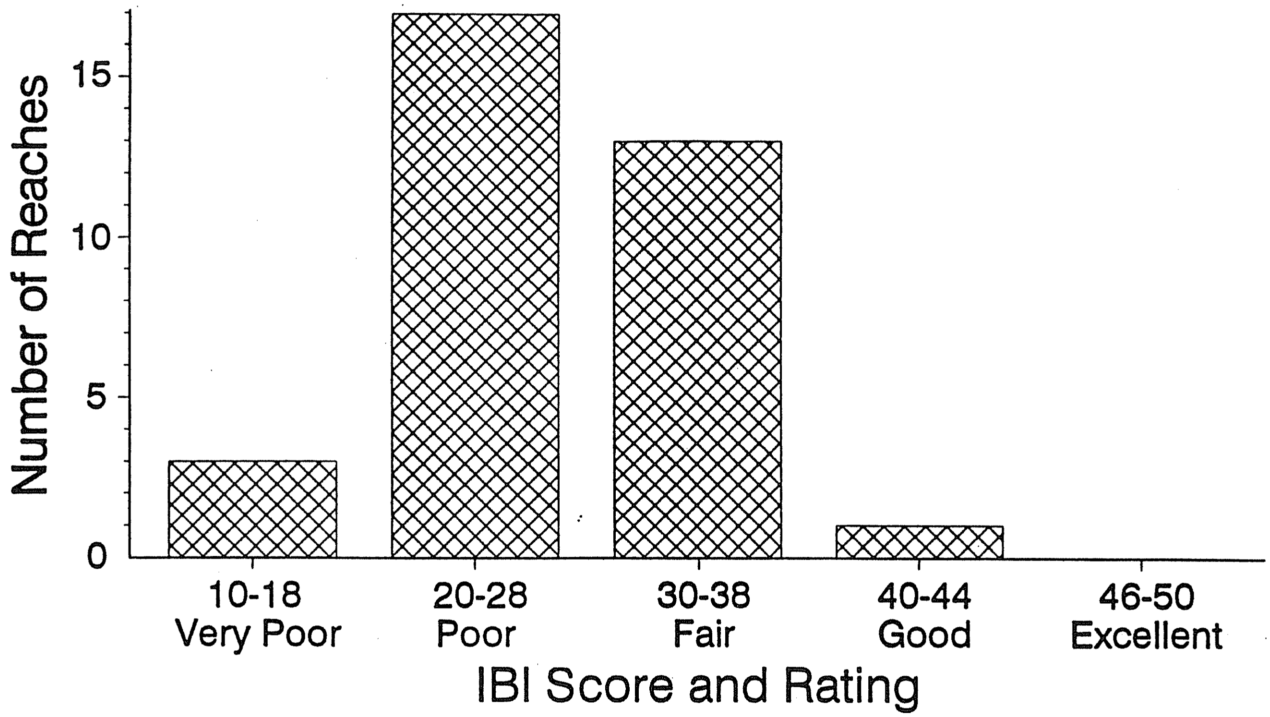

Figure 2. Number of stream reaches in each qualitatively assigned category based on index of biotic integrity (IBI) scores.

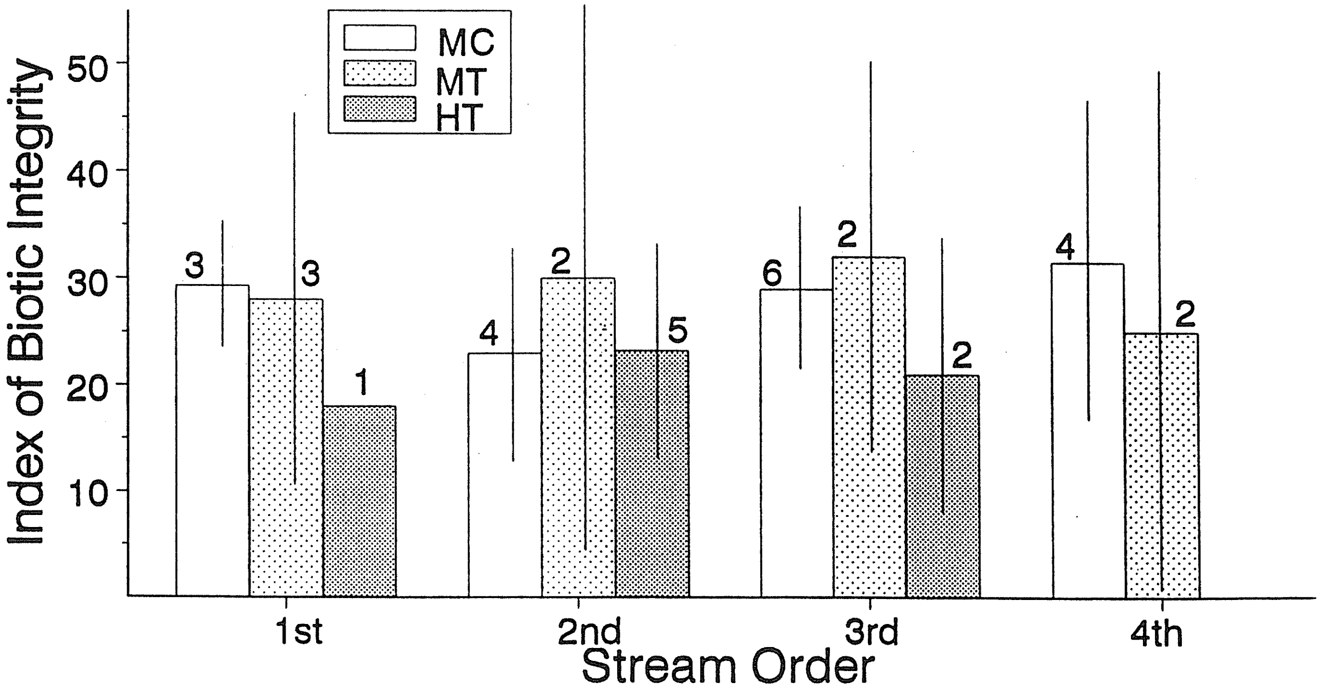

Figure 3. Mean (and 95% confidence intervals) index of biotic integrity scores for each stream order (Orth 1983) and stream type. MC = main-channel stream, MT = main-channel tributary, and HT = headwater tributary (Osborne et al. 1992). Number above each bar indicates number of reaches sampled.

Table 4. Mean values (and standard deviation) of selected habitat variables for reaches grouped by cluster analysis (Neill et al. 1995). Asterisks indicate variables that differed significantly ($P < 0.05$) among groups, and were therefore included in principal components analysis. Values (eigenvectors) for the first principal component, which accounted for 52% of the variation in habitat data, are included. Fast water includes riffles, rapids, and cascades. Soil substrate includes silt, sand, and organic matter. Rock substrate includes gravel and cobble.

Habitat variable	Group				First principal component
	A	B	C	D	
Habitat (%)*:					
Glides	20.6 (22.7)	90.8 (15.4)	97.5 (3.5)	7.5 (16.8)	-0.55
Backwaters	68.4 (14.3)	0.7 (2.9)	0.0 (0.0)	0.1 (0.2)	
Pools	0.0 (0.0)	0.4 (1.2)	0.0 (0.0)	0.6 (0.9)	
Fast water	11.0 (18.7)	3.0 (8.8)	0.0 (0.0)	91.8 (17.1)	
Substrate (%)*:					
Soil	95.5 (6.7)	85.0 (16.9)	86.7 (12.2)	36.4 (26.7)	-0.59
Rock	3.3 (4.9)	12.9 (15.8)	11.7 (12.2)	36.3 (16.5)	
Boulder	1.2 (1.9)	0.9 (0.9)	1.6 (1.8)	8.7 (5.1)	
Bedrock	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	18.6 (17.6)	
Shade (%)*	28.1 (27.6)	44.9 (22.8)	15.6 (15.4)	76.9 (13.8)	0.52
Eroding* bank (%)	74.6 (10.1)	87.0 (12.4)	19.1 (23.8)	31.4 (41.8)	-0.29
Undercut bank (%)	1.0 (0.9)	1.9 (2.0)	2.9 (6.2)	2.3 (2.2)	--
Wood index	1.3 (0.3)	2.1 (0.9)	1.3 (0.6)	2.0 (0.7)	--

A plot of IBI scores against habitat scores revealed three major groups of reaches based on the relationship between IBI and habitat (Figure 4). Seven reaches had IBI scores higher than expected for the available habitat, and should therefore be protected from further habitat degradation, and be high priority sites for habitat enhancement. Sixteen reaches had IBI scores similar to that expected, and would likely benefit from habitat enhancement. One of these reaches, upper Dairy Creek, had especially good habitat, which should be protected. Eleven reaches had IBI scores lower than expected, and are probably limited by factors other than, or in addition to, physical habitat.

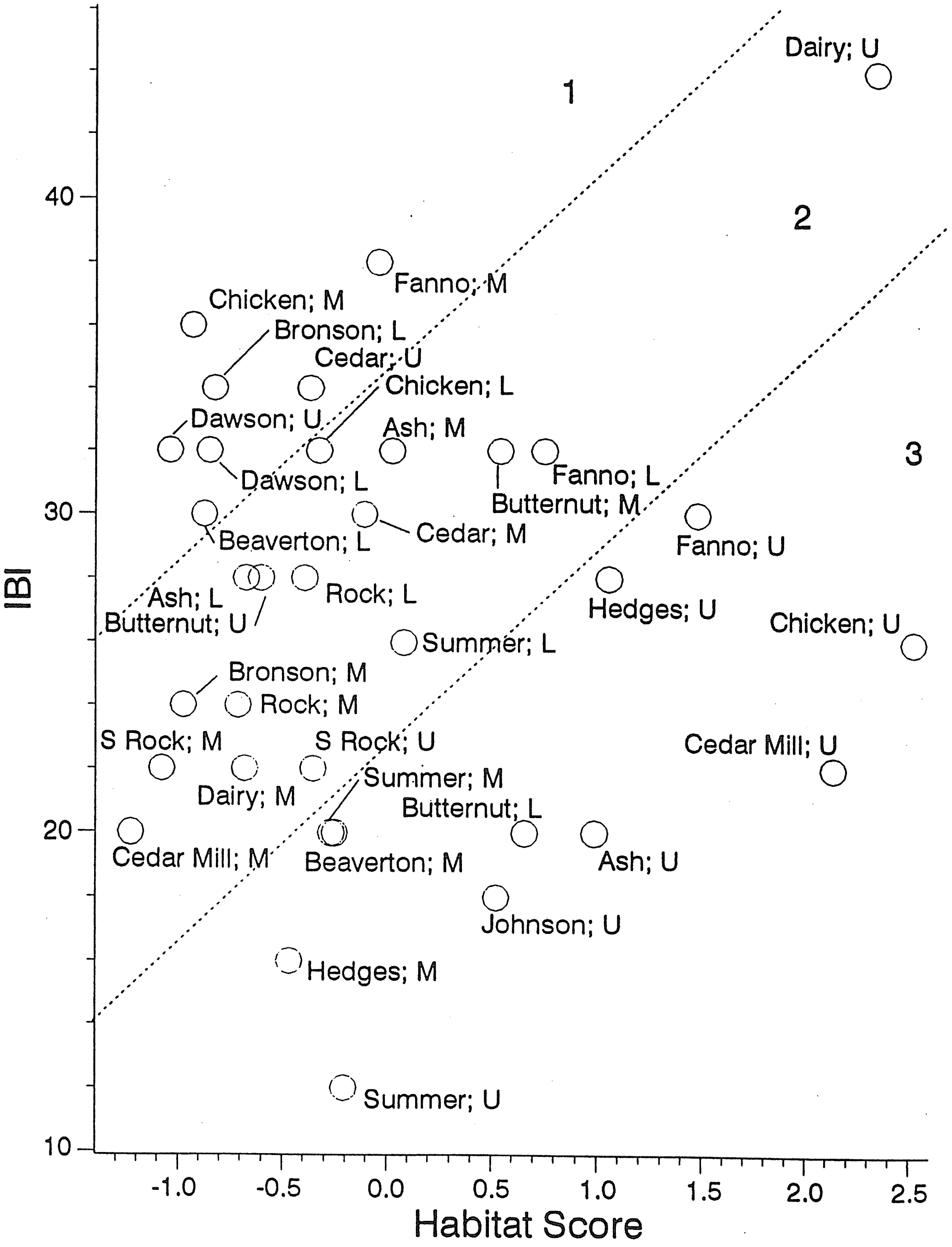

Figure 4. Relationship between index of biotic integrity (IBI) score and habitat score for stream reaches in the Tualatin River basin. Reaches in Group 1 have high IBI scores relative to habitat scores, reaches in Group 2 have moderate IBI scores relative to habitat scores, and reaches in Group 3 have low IBI scores relative to habitat scores.

DISCUSSION

We identified 16 stream reaches in the Tualatin River basin where improvements to habitat would likely result in increased biotic integrity, and an additional seven reaches that should be protected from degradation because biotic integrity is higher than expected for the available habitat. These seven reaches should be given highest priority for habitat protection and enhancement. Improvements to habitat in the remaining 11 reaches may not result in increased IBI scores because biotic integrity is likely limited by poor water quality instead of, or in addition to, poor habitat.

Although not identified as reaches with high biotic integrity for the available habitat, the five reaches with the highest habitat scores (Figure 4) also composed the most distinct group of reaches (Neill et al. 1995). These reaches (upper Chicken, Dairy, Cedar Mill, Fanno, and Hedges creeks) should be given high priority for habitat protection because they offer habitat capable of supporting native fish species intolerant of habitat degradation and pollution. Four of these reaches had biotic integrity lower than expected; water quality should therefore be evaluated and improved in upper Fanno, Chicken, Cedar Mill, and Hedges creeks if possible.

Habitat improvements designed to increase the number of native intolerant species such as cutthroat trout and torrent sculpin will likely result in the largest increases in IBI scores. An increase in cutthroat trout would affect 8 of 10 metrics positively, and an increase in torrent sculpin would affect 6 metrics positively, and one (% top carnivores) negatively. Nickelson and Reisenbichler (1977) found that biomass of cutthroat trout in streams increases with the amount of cover present, and Bryant (1983) and Elliot (1986) documented decreases in salmonid populations after removal of cover from streams. Instream cover can be provided by undercut banks, rocks, woody debris, or increased water depth and turbulence (Bustard and Narver 1975). Placement of boulders and logs in streams provides direct cover, and may also increase cover indirectly by causing increased depth and turbulence.

Restoration of canopy cover may also increase biomass of cutthroat trout in streams subject to high summer temperatures (Platts and Nelson 1989). Increases in summer water temperature in these areas are more likely to limit salmonid populations than are declines in invertebrate productivity associated with dense canopy. Summer temperatures in many streams of the Tualatin basin often exceed 18 ^{o}C (Unified Sewerage Agency, unpublished data), the upper limit of water quality standards for streams in the Tualatin River basin (Oregon Department of Environmental Quality unpublished data). Bell (1973) reported preferred temperatures of 9 to 12 ^{o}C for cutthroat trout, whereas Heath (1963) reported 15 ^{o}C as the optimal temperature for juvenile cutthroat trout.

Trees and vegetation associated with stream canopy may also serve to decrease erosion, thereby decreasing the amount of soil substrate. Neill et al. (1995) found the amount of shade and the amount of soil substrate to be negatively correlated in the Tualatin River basin. Survival of cutthroat trout embryos increases as the percentage of fine sediments decreases (Irving and Bjornn 1984). Juvenile and adult cutthroat trout are usually associated with gravel or cobble up to 30 cm (Hanson 1977), and cutthroat trout have been observed spawning in gravel of 0.2 to 5.0 cm (Hooper 1973; Hunter 1973).

Decreases in soil substrates may also benefit torrent sculpin; however, increases in numbers and distribution of torrent sculpin may be unlikely. Finger (1982) found torrent sculpin only where rock was present in the Marys River system, part of the Willamette River basin. Although intolerant of habitat degradation and pollution, where present, torrent sculpin generally displace reticulate sculpin (a tolerant species) from riffles (Bond 1963; Finger 1982). Even so, torrent sculpin are found only in upper Dairy Creek (Friesen and Ward 1995), although habitat appeared suitable in at least 6 reaches (Neill et al. 1995).

The amount of variation in habitat data explained by the first principal component (52%) was only moderate. However, this value is reasonable considering that water quality information was not included. It is probable that both water quality and physical habitat affect fish assemblages, and therefore IBI scores. Our objective was to develop a method of identifying candidate streams without expensive water quality analyses.

Our IBI meets most criteria required of valid biomonitoring programs (Herricks and Schaeffer 1985; Karr et al. 1986). Karr et al. (1986) noted that the IBI was biological in nature and interpretable at several trophic levels. We have shown that our IBI scores are not biased by stream size or location within the drainage (Osborne et al. 1992). Although easily reproducible, we have no measurement of the precision of our modified IBI. Repeated sampling to evaluate variability and the nature of the variability in our modified IBI is desirable.

Although IBI scores in the Tualatin River basin are generally low, our method may have introduced a positive bias to the scores. Karr et al. (1986) stated that scoring criteria should be based on appropriate "excellent" fish assemblages similar to those uninfluenced by humans; however, we found no comprehensive historical fish surveys for the Tualatin River system or any nearby river system. Expectations of "excellent", "fair", and "poor" fish assemblages were therefore based on the range of our observations, even though all reaches we surveyed had been influenced to some extent by humans. This likely resulted in "easier" scoring criteria than if data from undisturbed reaches had been used. However, this bias does not affect the relationship between IBI and habitat scores, which is of primary importance to our findings.

Our method to identify reaches likely to benefit from habitat improvements can be an important tool for fisheries managers, especially in urban areas. Urban streams have generally undergone substantial modification, yet quality habitats are considered important by many to the quality of life. Numerous urban streams are therefore potential candidates for habitat restoration and protection. With limited funding, managers are often in the position of choosing from numerous candidates those streams most likely to benefit from habitat enhancement. Limited funding may also preclude extensive analyses of water quality, and allow only cursory field surveys of fish assemblages and habitat in candidate streams. Any reliable method to rank streams based on limited field information may be valuable.

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APPENDIX A

Fish Surveys in the Tualatin River

We conducted fish inventories on the mainstem Tualatin River from river kilometer 12.9 to 20.9 in autumn (23 September and 17 October) 1994. Using a boat-mounted electrofisher operating at 60 volts DC and 3-5 amperes, we performed twenty-three 900-second shocking passes. We attempted to equally sample both shorelines and a variety of habitat types, collecting as many fish as possible during each pass. All fish captured were identified to species and measured (fork length to nearest millimeter).

We collected fifteen fish species from six families in the mainstem Tualatin River (Table A-1). Introduced fish were represented by six species from two families and made up 27.9% of the total catch. Largescale suckers, largemouth bass, and northern squawfish were the most common species encountered (90.3% of total catch). Approximately 2.5% of the catch consisted of species intolerant to temperature extremes, sedimentation, and organic pollution. In addition, we captured three species (chinook salmon *Oncorhynchus tshawytscha*, mountain whitefish *Prosopium williamsoni*, and common carp *Cyprinus carpio*) not observed in our surveys of smaller streams. We also captured one adult coho salmon and one adult chinook salmon.

In addition to comprising a greater proportion of the catch, largemouth bass and northern squawfish were considerably larger than those captured in smaller streams of the basin. Mean fork length of largemouth bass captured in small streams was 79.8 mm (N = 160); fork length of those captured in the mainstem averaged 121.3 mm (N = 217). Fork lengths of northern squawfish averaged 49.3 mm in small streams (N = 3) and 319.1 mm (N = 36) in the mainstem.

Differences in sampling methods and water depth in the mainstem fish surveys prevent an accurate quantitative comparison to surveys of smaller Tualatin River basin streams. However, mainstem fish assemblages seem to be similar in that a relatively small proportion of the fish are native intolerants, and a large number of introduced fish are present. One obvious difference in mainstem fish assemblages is the presence of many large, piscivorous fish. Northern squawfish are major predators of juvenile salmonids, and their consumption of fish increases with body size (Poe et al. 1991). Similarly, largemouth bass over 102 mm feed primarily on fishes, including salmonids (Stein 1970). Combined with habitat disturbances, reduced water quality, and the introduction of exotic species, the impact of predation on resident fish of the Tualatin River may be significant.

Capturing two adult salmon during our limited sampling of the Tualatin River indicates that some natural anadromous salmonid production may occur in the basin, assuming the existence of suitable spawning sites. Adult fish are apparently able to pass Willamette Falls in late summer, negotiate the Oregon Iron and Steel dam at river kilometer 6.1, and presumably enter some tributaries. Anadromous and resident salmonid production would undoubtedly be improved by habitat enhancement work.

Table A-1. Fish collected in the mainstem Tualatin River, autumn 1994.

Family, species	Percent of catch	Relative tolerance	Adult trophic group
Petromyzontidae			
Western brook lamprey	0.1	Intolerant	--[a]
Salmonidae			
Cutthroat trout	1.8	Intolerant	Insectivore
Chinook salmon	0.1	Intolerant	Piscivore
Coho salmon	0.3	Intolerant	Piscivore
Mountain whitefish	0.1	Intolerant	Insectivore
Cyprinidae			
Northern squawfish	4.4	Tolerant	Piscivore
Common carp[b]	1.0	Tolerant	Omnivore
Goldfish[b]	0.1	Tolerant	Omnivore
Catostomidae			
Largescale sucker	60.0	Tolerant	Omnivore
Centrarchidae[c]			
Largemouth bass	25.9	Tolerant	Piscivore
Pumpkinseed	0.4	Tolerant	Insectivore
Bluegill	0.2	Tolerant	Insectivore
Warmouth	0.1	Tolerant	Insectivore
Unidentified *Lepomis* spp.	0.2	--	--
Cottidae			
Reticulate sculpin	2.3	Tolerant	Insectivore
Prickly sculpin	3.2	Intermediate	Insectivore

[a] *Adults do not feed.*
[b] *Introduced species.*
[c] *Introduced family.*

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APPENDIX B

Distribution of Crayfish in the Tualatin River Basin

Little historic information exists regarding the status of crayfish *Pacifastacus leniusculus* in the Tualatin River basin. We enumerated crayfish while conducting fish inventories in stream reaches surveyed during summer 1994. Sampling gear and methods are described in Paper 1.

We collected a total of 1,211 crayfish from 34 reaches, an average of 36 crayfish per reach (Table B-1). Overall, we observed the most crayfish (217) in Summer Creek, and Cedar Creek had the highest average number of crayfish per survey (98). Number of crayfish captured averaged 69 in lower reaches, 21 in middle reaches, and 28 in upper reaches.

With the exception of several reaches we surveyed, crayfish populations in streams of the Tualatin River basin appear to be healthy. The mainstem Tualatin River has a crayfish population adequate to support a small commercial fishery (Pat Keely, ODFW, personal communication), and we observed recreational fishing for crayfish during our surveys of small streams. Point source pollutants (particularly pesticides and industrial wastes) and flow depletions are the most serious threats to these populations (ODFW 1992). We recommend increased water quality monitoring in sites that contain few or no crayfish. In addition, crayfish populations should be surveyed occasionally to monitor trends in abundance.

Table B-1. Number of crayfish captured in reaches of Tualatin River Basin streams, summer 1994.

Creek	Reach	No.
Hedges	Middle	1
	Upper	29
Fanno	Lower	25
	Middle	0
	Upper	6
Ash	Lower	12
	Middle	25
	Upper	10
Summer	Lower	187
	Middle	10
	Upper	20
South Rock	Middle	33
	Upper	0
Chicken	Lower	146
	Middle	29
	Upper	7
Cedar	Middle	20
	Upper	176
Butternut	Lower	23
	Middle	27
	Upper	5
Rock	Lower	43
	Middle	15
Dawson	Lower	26
	Upper	21
Beaverton	Lower	95
	Middle	22
Bronson	Lower	63
	Middle	32
Cedar Mill	Middle	24
	Upper	25
S. Johnson	Middle	0
Dairy	Middle	50
	Upper	4

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APPENDIX C

Fish Inventory Data

Table C-1. Number of fish collected in reaches of Tualatin River tributaries, all seasons combined, 1994-95. L = lower reach, M = middle reach, U = upper reach.

	Creek									
	Hedges			South Rock		Butternut			Dairy	
Species	L	M	U	M	U	L	M	U	M	U
Western brook lamprey	0	0	1	5	0	3	0	0	0	1
Pacific lamprey	0	0	26	33	0	6	0	0	5	4
Cutthroat trout	0	0	0	4	1	2	0	0	6	421
Rainbow trout	0	0	0	0	0	0	0	0	0	84
Coho salmon	0	0	0	0	0	0	0	0	0	0
Redside shiner	0	0	0	2	0	0	0	0	0	0
Speckled dace	0	0	0	3	0	0	596	973	0	0
Goldfish[a]	0	0	0	0	0	0	0	0	0	0
Fathead minnow[a]	0	0	0	0	0	0	0	0	0	0
Northern squawfish	0	0	0	0	0	0	0	0	0	0
Largescale sucker	0	0	0	2	0	1	0	0	0	0
Yellow bullhead[a]	0	0	0	0	0	0	0	0	0	0
Brown bullhead[a]	0	1	0	0	0	0	0	0	0	0
Mosquitofish[a]	6	210	0	2	22	1	1	0	0	0
Threespine stickleback	8	11	0	281	160	2	971	0	0	0
Black crappie[a]	0	0	0	1	0	0	0	0	0	0
White crapie[a]	0	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	50	0	0	0	1	0	0	0	0
Pumpkinseed[a]	0	340	0	0	0	0	0	0	0	0
Warmouth[a]	0	0	0	0	0	3	0	0	0	0
Largemouth bass[a]	0	56	0	0	0	0	0	0	0	0
Yellow perch[a]	0	0	0	0	0	0	0	0	0	0
Reticulate sculpin	305	68	3	1980	95	1022	709	0	328	283
Torrent sculpin	0	0	0	0	0	0	0	0	0	79
Prickly sculpin	0	0	0	329	2	0	0	0	0	0
Number of surveys	2	3	4	3	4	3	4	4	2	3

[a] *Introduced species.*

Table C-2. Fish collected in reaches of Fanno Creek and its tributaries, all seasons combined, 1994-95. L = lower reach, M = middle reach, U = upper reach.

	Creek								
	Fanno			Ash			Summer		
Species	L	M	U	L	M	U	L	M	U
Western brook lamprey	1	16	12	0	0	0	3	2	0
Pacific lamprey	1	2	3	0	0	0	25	1	0
Cutthroat trout	11	8	12	0	0	0	0	0	0
Rainbow trout	0	0	0	0	0	0	0	0	0
Coho salmon	9	0	0	0	0	0	0	0	0
Redside shiner	0	668	122	468	870	40	106	204	0
Speckled dace	1	15	39	9	8	5	2	0	0
Goldfish[a]	0	0	0	21	0	0	0	7	0
Fathead minnow[a]	0	0	0	0	0	0	0	0	8
Northern squawfish	0	0	0	0	0	0	0	0	0
Largescale sucker	5	1	0	133	17	0	50	102	0
Yellow bullhead[a]	0	0	0	0	0	0	11	75	5
Brown bullhead[a]	1	0	0	0	0	0	0	0	0
Mosquitofish[a]	3	2	4	106	0	0	5	137	236
Threespine stickleback	7	0	0	117	0	0	0	1	0
Black crappie[a]	0	0	0	0	0	0	0	0	0
White crappie[a]	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	5	0	0	10	33	204
Pumpkinseed[a]	1	0	0	42	0	0	19	56	133
Warmouth[a]	0	0	0	0	0	0	0	0	0
Largemouth bass[a]	2	0	0	5	0	0	11	55	24
Yellow perch[a]	0	0	0	0	0	0	0	13	1
Reticulate sculpin	534	1947	1002	1761	1809	852	752	837	0
Torrent sculpin	0	0	0	0	0	0	0	0	0
Prickly sculpin	115	0	0	0	0	0	0	0	0
Number of surveys	3	4	4	4	4	4	4	4	3

[a] *Introduced species.*

Table C-3. Fish collected in reaches of Chicken Creek, Rock creek, and their tributaries, all seasons combined, 1994-1995. L = lower reach, M = middle reach, U = upper reach.

	Creek										
	Chicken			Cedar		Rock			Dawson		
Species	L	M	U	M	U	L	M	U	L	M	U
Western brook lamprey	48	65	0	0	27	3	1	0	1	1	0
Pacific lamprey	20	12	4	1	76	1	0	0	15	2	0
Cutthroat trout	0	4	26	0	2	0	3	22	5	0	0
Rainbow trout	10	0	0	0	0	1	0	0	0	0	0
Coho salmon	0	0	0	0	0	0	0	0	0	0	0
Redside shiner	22	32	0	150	179	6	90	0	7	6	37
Speckled dace	2	1	0	0	0	16	0	0	30	83	220
Goldfish[a]	0	0	0	0	0	0	0	0	0	0	0
Fathead minnow[a]	0	0	0	0	0	0	0	0	0	0	0
Northern squawfish	0	0	0	0	0	1	0	0	0	0	0
Largescale sucker	8	2	0	5	140	4	96	0	8	0	0
Yellow bullhead[a]	0	0	0	0	0	0	1	0	0	0	0
Brown bullhead[a]	0	0	0	0	0	0	0	0	1	0	0
Mosquitofish[a]	0	0	0	0	0	0	16	0	12	0	0
Threespine stickleback	0	2	0	277	89	0	10	0	54	116	256
Black crappie[a]	0	0	0	0	0	0	0	0	0	0	0
White crappie[a]	0	0	0	0	0	0	0	0	0	0	0
Bluegill[a]	0	0	0	0	0	0	11	0	2	0	1
Pumpkinseed[a]	0	0	0	0	0	0	0	0	0	0	0
Warmouth[a]	0	0	0	0	0	0	3	0	0	0	0
Largemouth bass[a]	0	0	0	1	0	0	0	0	0	0	0
Yellow perch[a]	0	0	0	0	0	0	0	0	0	0	0
Reticulate sculpin	686	1231	311	834	710	937	1785	220	882	197	227
Torrent sculpin	0	0	0	0	0	0	0	0	0	0	0
Prickly sculpin	20	4	0	0	0	0	0	0	0	0	0
Number of surveys	3	4	4	3	4	2	2	3	3	1	3

[a] *Introduced species.*

Table C-4. Fish collected in reaches of Beaverton Creek and its tributaries, all seasons combined, 1994-95. L = lower reach, M = middle reach, U = upper reach.

	Creek							
	Beaverton		Bronson		Cedar Mill		Johnson	
Species	L	M	L	M	M	U	M	U
Western brook lamprey	0	3	0	65	5	8	0	0
Pacific lamprey	3	3	3	20	0	42	0	0
Cutthroat trout	2	2	0	0	1	0	0	0
Rainbow trout	0	0	0	0	0	0	0	0
Coho salmon	0	0	0	0	0	0	0	0
Redside shiner	0	100	0	0	6	0	30	0
Speckled dace	1	1	7	0	0	0	2	19
Goldfish[a]	0	0	0	0	0	0	0	0
Fathead minnow[a]	0	0	0	0	0	20	0	0
Northern squawfish	0	0	0	0	2	0	0	0
Largescale sucker	5	15	0	0	1	0	0	0
Yellow bullhead[a]	0	0	0	0	2	0	0	0
Brown bullhead[a]	0	1	0	0	0	0	0	0
Mosquitofish[a]	1	51	152	0	8	0	12	317
Threespine stickleback	1	66	318	0	56	0	212	0
Black crappie[a]	1	0	0	0	3	0	0	0
White crappie[a]	0	0	0	0	2	0	0	0
Bluegill[a]	0	0	0	0	0	25	0	0
Pumpkinseed[a]	0	0	0	0	0	0	0	0
Warmouth[a]	0	3	0	0	0	0	0	0
Largemouth bass[a]	0	3	3	0	0	0	0	0
Yellow perch[a]	0	0	0	0	0	0	0	0
Reticulate sculpin	1337	1007	784	1512	1786	1048	122	0
Torrent sculpin	0	0	0	0	0	0	0	0
Prickly sculpin	0	0	2	0	0	0	0	0
Number of surveys	2	3	4	4	4	4	1	4

[a] *Introduced species.*

APPENDIX D

Habitat Inventory Data

Table D-1. Habitat summary by reaches sampled for streams in the Tualatin River basin, 1994-95. L = lower reach, M = middle reach, U = upper reach. The wood index is a rating of wood complexity as it relates to fish habitat, ranging from 1 to 5 with 5 being the most complex.

	Creek											
	Hedges			Fanno			Summer			Ash		
Habitat characteristic	L[a]	M	U	L	M	U	L	M	U	L	M	U
Habitat type (%)												
Fast	--	0	100	10	1	98	0	0	40	0	2	0
Pool	--	0	0	0	0	2	0	0	0	1	0	0
Glides/slow	--	17	0	90	99	0	86	93	60	99	93	95
Backwater	--	83	0	0	0	0	0	0	0	0	0	0
Other	--	0	0	0	0	0	14	7	0	0	5	5
Substrate (%)												
Soil	67	100	82	49	75	30	97	74	34	79	91	89
Rock	30	0	15	49	24	44	2	21	63	20	8	10
Boulder	3	0	2	3	1	8	1	5	3	1	1	2
Bedrock	0	0	0	0	0	18	0	0	0	0	0	0
Bank type (%)												
Eroding	23	66	41	85	100	100	82	50	60	86	96	39
Stable	77	34	18	2	0	0	10	41	0	0	0	58
Other	0	0	41	13	0	0	8	9	40	14	4	3
Shade (%)	79	0	59	71	68	71	21	31	42	68	57	34
Gradient (%)	1.1	0.3	1.7	1.0	0.6	3.6	0.1	0.9	2.4	0.6	1.0	0.6
Undercut bank (%)	0.0	1.1	2.0	4.1	2.7	0.2	5.4	14.0	0.0	1.9	3.6	0.3
Wood index	1.5	1.0	2.3	2.6	2.8	2.2	1.3	1.0	1.0	1.7	2.2	0.9

[a] *Dry at time of sampling.*

Table D-2. Habitat summary by reaches sampled for streams in the Tualatin River basin, 1994-95. L = lower reach, M = middle reach, U = upper reach. The wood index is a rating of wood complexity as it relates to fish habitat, ranging from 1 to 5 with 5 being the most complex.

Habitat characteristic	Creek									
	South Rock		Chicken			Cedar		Butternut		
	M	U	L	M	U	M	U	L	M	U
Habitat type (%)										
Fast	0	0	2	0	100	0	0	33	0	0
Pool	0	0	5	0	0	0	0	0	0	0
Glides/slow	100	100	91	100	0	87	100	0	74	100
Backwater	0	0	2	0	0	13	0	67	0	0
Other	0	0	0	0	0	0	0	0	26	0
Substrate (%)										
Soil	80	74	95	95	32	92	98	88	66	91
Rock	19	24	4	5	59	8	2	9	8	9
Boulder	1	1	1	0	6	0	0	3	0	0
Bedrock	0	0	0	0	3	0	0	0	0	0
Bank type (%)										
Eroding	100	0	100	100	0	76	75	86	66	80
Stable	0	60	0	0	100	0	25	14	0	0
Other	0	40	0	0	0	24	0	0	34	20
Shade (%)	0	2	68	43	93	53	71	55	50	40
Gradient (%)	1.0	0.4	1.9	1.7	3.9	0.2	0.3	2.6	1.0	1.2
Undercut bank (%)	0.0	0.0	1.8	0.0	0.0	0.7	1.8	0.0	0.0	0.0
Wood index	1.0	1.0	2.8	3.8	2.8	2.5	2.2	1.5	1.0	1.0

Table D-3. Habitat summary by reaches sampled for streams in the Tualatin River basin, 1994-95. L = lower reach, M = middle reach, U = upper reach. The wood index is a rating of wood complexity as it relates to fish habitat, ranging from 1 to 5 with 5 being the most complex.

Habitat characteristic	Creek									
	Rock			Dawson			Beaverton		Bronson	
	L	M	U	L	M	U	L	M	L	M
Habitat type (%)										
Fast	3	0	100	4	0	0	1	0	0	1
Pool	0	0	0	3	0	0	0	0	0	0
Glides/slow	97	100	0	93	100	100	99	45	100	99
Backwater	0	0	0	0	0	0	0	55	0	0
Other	0	0	0	0	0	0	0	0	0	0
Substrate (%)										
Soil	91	96	24	92	96	100	88	99	97	91
Rock	9	2	34	8	4	0	12	1	3	7
Boulder	0	2	6	0	0	0	0	0	0	2
Bedrock	0	0	36	0	0	0	0	0	0	0
Bank type (%)										
Eroding	82	88	0	97	23	0	100	72	6	100
Stable	12	6	50	0	49	98	0	28	94	0
Other	6	6	50	3	28	2	0	0	0	0
Shade (%)	44	48	80	15	15	4	21	29	8	23
Gradient (%)	1.8	1.6	3.0	1.2	0.1	0.1	1.0	0.2	0.2	0.4
Undercut bank (%)	0.0	1.2	6.3	6.1	5.3	0.0	1.7	1.8	0.4	4.7
Wood index	2.7	2.1	4.2	2.3	2.5	2.3	3.7	1.4	1.0	1.1

Table D-4. Habitat summary by reaches sampled for streams in the Tualatin River basin, 1994-95. L = lower reach, M = middle reach, U = upper reach. The wood index is a rating of wood complexity as it relates to fish habitat, ranging from 1 to 5 with 5 being the most complex.

Habitat characteristic	Creek					
	Cedar Mill		Johnson		Dairy	
	M	U	M	U	M	U
Habitat type (%)						
Fast	0	100	0	0	0	61
Pool	0	0	0	0	0	1
Glides/slow	100	0	100	41	100	38
Backwater	0	0	0	0	0	0
Other	0	0	0	59	0	0
Substrate (%)						
Soil	98	25	99	87	99	12
Rock	2	27	1	12	1	36
Boulder	0	11	0	1	0	16
Bedrock	0	37	0	0	0	36
Bank type (%)						
Eroding	75	16	0	81	100	0
Stable	13	32	66	19	0	65
Other	12	52	34	0	0	35
Shade (%)	5	74	35	61	74	88
Gradient (%)	0.5	3.4	0.1	1.4	0.2	3.3
Undercut bank (%)	3.8	5.2	0.6	0.8	0.3	3.8
Wood index	1.0	2.0	2.1	3.4	2.0	1.0

APPENDIX E

Specific Locations of Aquatic Habitat Surveys

Table E-1. Locations of habitat surveys conducted in 1993. Fish surveys in 1994-95 were conducted in a 100 meter-long site within each reach.

Stream	Reach	Location
Hedges	L	Mouth to Boones Ferry Road
	M	Teton Road to 108th Street
	U	105th Street to 489 meters upstream
Fanno	L	Mouth to Durham Road
	M	Oregon Episcopal School to Oleson Road
	U	39th Street to 404 meters downstream
South Rock	M	Highway 99W to 300 meters upstream
	U	Tualatin-Sherwood Road to Oregon Street
Chicken	L	Mouth to 585 meters upstream
	M	Edy Road to 510 meters upstream
	U	Kruger Road to 285 meters upstream
Butternut	L	Mouth to River Road
	M	Butternut Park to 185th Street
	U	Farmington Road to Oak Street
Rock	L	Mouth to River Road
	M	Cornell Road to Evergreen Parkway
	U	Tributary crossing at Rock Creek Road to 400 meters upstream
Dairy	M	Roy Road to railroad bridge
	U	Greener Road to Little Bend Park

Table E-2. Locations of habitat surveys conducted in 1994. Fish surveys in 1994-95 were conducted in a 100 meter-long site within each reach.

Stream	Reach	Location
Cedar	M	Meineke Road to 599 meters upstream
	U	Rein Road to 400 meters downstream
Summer	L	Mouth to Fowler Junior High School
	M	121st Street to 116th Street
	U	135th Street to Old Scholls Ferry Road
Ash	L	Mouth to Highway 217
	M	Locust Street to Metzger Park
	U	Taylors Ferry Road to 765 meters upstream
Dawson	L	Mouth to Baseline Road
	M	Brookwood Road to Cornell Road
	U	Airport Road to Shute Road
Beaverton	L	Mouth to 216th Street
	M	185th Street to 170th Street
Bronson	L	Cornell Road to Bronson Road
	M	Laidlaw Road to 445 meters downstream
Cedar Mill	M	Jenkins Road to 800 meters upstream
	U	113th Street to 500 meters upstream
Johnson	M	Mouth to Division Street and 149th Street
	U	170th Street to 175th and Riegert Road