

AN ABSTRACT OF THE THESIS OF

Russell B. Langshaw for the degree of Master of Science in Fisheries Science
presented on March 14, 2003.

Title: Fish And Invertebrate Distribution At Multiple Scales In Thomas Creek,
Oregon; A Transition From Conifer Uplands To Agricultural Lowlands.

Abstract approved **Redacted for privacy**

Judith L. Li

Longitudinal patterns of fish and benthic invertebrate distribution and habitat use were similar in Thomas Creek, Oregon but clarity of these patterns differed. I studied fish and aquatic invertebrates simultaneously, at multiple scales, and used multivariate statistical techniques to compare responses to the same environmental conditions. Both types of organisms exhibited distinct longitudinal patterns along a 51 river kilometer (R km) transition from mid-elevation (ca. 365 m elevation) conifer dominated reaches to Willamette Valley agriculture dominated reaches (ca. 73 m elevation). In summer 2000, preliminary surveys of 30 R kms suggested that longitudinal changes in benthic invertebrate assemblage structure and rainbow trout diet (*Oncorhynchus mykiss*) ($n=53$), were minor and likely driven by three sites in the upper reaches. This led me to expand the survey length to 51 R kms and modify the survey design in 2001.

During 2001, I performed repeated, intensive (4 sites) and extensive (218 survey units) snorkel surveys to examine fish distribution and habitat selectivity. The intensive snorkel surveys of the upstream reaches revealed similar habitat preferences for pools with riffles directly upstream by juvenile chinook salmon (*Oncorhynchus tshawytscha*) and ages of trout (from 0 to >3 years). The extensive survey identified two distinct fish assemblages: a salmonid-dominated one in the upper 12 R kms and a second dominated by non-game fish in the

lower 20 R kms. The transition between these two zones (between 20 and 39 R kms) was populated sparsely by members of both assemblages. Fish assemblages were associated with broad-scale environmental conditions (e.g. temperature and elevation) and not with local conditions (e.g. water velocity, substrate size, depth). Differences between assemblages in riffles, glides, and pools, were only detected by blocking data according to location.

Benthic aquatic invertebrates were collected from each habitat type at 27 sites, in nine reaches, during May 2001. Invertebrate assemblages demonstrated strong longitudinal (broad-scale) and habitat type patterns. Fish assemblages changed abruptly but invertebrate assemblages changed gradually along distinct topographic and vegetation zones. My results demonstrate the importance of extensive surveys with continuous stream data and numerous sampling sites. Fish and invertebrates appeared to respond to environmental conditions at different spatial scales detected only by comparing the two groups of organisms simultaneously along an extended longitudinal gradient.

©Copyright by Russell B. Langshaw
May 7, 2003
All Rights Reserved

Fish And Invertebrate Distribution At Multiple Scales In Thomas Creek,
Oregon; A Transition from Conifer Uplands to Agricultural Lowlands

by
Russell B. Langshaw

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented March 14, 2003
Commencement June 2003

Master of Science thesis of Russell B. Langshaw presented on March 14, 2003

APPROVED:

Redacted for privacy

Major Professor, representing Fisheries Science

Redacted for privacy

Head of Department of Fisheries and Wildlife

Redacted for privacy

Dean of the Graduate School

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

Redacted for privacy

Russell B. Langshaw, Author

ACKNOWLEDGEMENTS

The Oregon Watershed Enhancement Board funded this project. On behalf of researchers and residents of Oregon, I would like to thank the board for funding small, but important, projects throughout the state. I am grateful to the South Santiam Watershed Council for approaching Judy Li and suggesting a study of Thomas Creek. Without the forethought, support, and assistance from many of the council members this project would not have been possible. Cooperation from landowners was instrumental to this project and I appreciate the many conversations, insights, and access to Thomas Creek. Helpful landowners include but are not limited to, Ron Bentz, Francine & John Cereghino, Charlie & Jerry Faessler, Bob & Sherry Gaskey, Willis Koehn, Lori McKay, Dan Meyers, Tom & Pricilla Rogers, and Willamette Industries.

I am grateful for many insightful discussions with Alan Herlihy and my committee members Hiram Li and Jim Wigington. Any expression of gratitude to my major professor is insufficient to convey my thanks to Judy. I truly believe that people we interact with shape our lives and I appreciate the opportunity to work with and learn from you.

My undergraduate mentors were critical to my early development as a researcher; Skip Smith started me down the winding path of aquatic ecology, Lixing Sun broadened my research perspectives, and Bronwynne Evans assisted me in becoming a better writer and taught me how to think like a scientist. I thank my peers and research assistants Dennis Holly, Rei Hayashi, Bill Gerth, Charles Frady, Alex Farrand, Dan Sobota, Mike Cooperman, Dave Simon, Kris Wright, Colden Baxter, Christian Torgersen, Nico Romero, Steve Hendricks, Melissa Fierke, Randy Colvin, and the stream team athletic corps for a journey I will never forget.

I owe my passion for water and streams to my family. As long as I can remember, I have been in and around water. Thank you mom, dad, Kim, Brent, grandma, and grandpa for your love and support while making water such an important part of my life. Unable to escape my habit of saving the best for last, I am forever grateful to my wife Kerensa. Without her patience, encouragement, support, assistance, and love, I never would have made it this far. I love you and look forward to our many adventures with Conley.

TABLE OF CONTENTS

	<u>Page</u>
1. Introduction.....	3
2. Management history and longitudinal patterns of aquatic invertebrates and trout diet in Thomas Creek, Oregon; preliminary surveys	
Introduction.....	7
Site description and management history	9
Methods and Analyses	12
Results.....	16
Discussion.....	21
3. Patterns of fish and invertebrates at multiple scales in Thomas Creek, Oregon	
Introduction.....	27
Study Location.....	29
Methods.....	30
Fish Sampling.....	32
Invertebrate Sampling.....	39
Statistical Analyses.....	39
Results.....	41
Invertebrate Results.....	57
Hierarchical Analyses.....	64
Discussion.....	70
Longitudinal Patterns.....	70
Habitat Use.....	76
4. Summary.....	82
Bibliography.....	87
Appendices.....	96

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2.1	A stream outline of Thomas Creek, Oregon, and a shaded Digital Elevation Model of the watershed.	8
2.2	Water quality and invertebrate sampling locations along Thomas Creek with one water quality sampling location in Neal Creek.	13
2.3	Seven-day moving average of maximum daily stream temperatures at one site in each segment.	18
2.4	NMS ordination of composite invertebrate assemblages from nine sites in May 2000.	19
2.5	Proportions of classified invertebrates in each Functional Feeding Group for the year 2000 sites.	20
2.6	Prey composition from 53 trout collected in Thomas Creek during July 2000.	22
2.7	Stream channel profile at a year 2000 Thomas Creek site.	23
3.1	Scales of study.	31
3.2	Example habitat unit for the upstream intensive snorkel survey.	37
3.3	Elevation profile of Thomas Creek within the study section.	43
3.4	Thomas Creek fish distribution based on relative densities.	46
3.5	Total densities of cold and cool-water species.	47
3.6	Densities for each fish group during the upstream intensive survey.	49
3.7	NMS ordination of fish assemblages from each site, averaged among habitat types.	56
3.8	Indicator fish species and their location along the study section (ISA, $P < 0.05$).	58

LIST OF FIGURES (Continued)

<u>Figure</u>		<u>Page</u>
3.9	Major indicator invertebrate taxa and their locations (ISA, $P < 0.05$).	59
3.10	Reach-scale proportions of classified invertebrates by tolerance value (Tv).	61
3.11	Reach-scale proportions of classified invertebrates in each Functional Feeding Group.	62
3.12	NMS ordination of invertebrate assemblages from individual samples, overlaid with segment.	65
3.13	NMS ordination of invertebrate assemblages from individual samples, overlaid with habitat type.	65
3.14	NMS ordination of invertebrate assemblages averaged by segment.	67
3.15	NMS ordination of invertebrate assemblages averaged by reach, overlaid with reach number.	67
3.16	NMS ordination of invertebrate assemblages averaged by segment, overlaid with habitat type.	69
3.17	NMS ordination of invertebrate assemblages averaged by reach, overlaid with habitat type.	69
3.18	Moving averages of relative densities of cold and cool-water species within each survey unit.	73

LIST OF TABLES

<u>Table</u>		<u>Page</u>
2.1	Nutrient and <i>E. coli</i> concentrations in Thomas and Neal Creeks during 2000 and 2001.	17
2.2	Maximum stream temperatures in each segment of Thomas Creek and dates they were recorded.	18
2.3	Minimum, maximum, and longitudinal range of water quality parameters.	19
3.1	Riparian and stream characteristics at each reach.	33
3.2	Average stream characteristics of survey units occupied and unoccupied by fish.	45
3.3	Number of survey units within each segment and the number that were unoccupied by fish.	48
3.4	Densities of fish within segments.	48
3.5	Average invertebrate and fish richness (taxa or fish group per sample) by habitat type and abundance or density within segments.	49
3.6	Unit scale habitat selection by salmonids based on upstream intensive surveys (Manly Index).	51
3.7	Subunit scale habitat selection by salmonids based on results from the upstream intensive surveys (Manly Index).	52
3.8	Differences in habitat selectivity between Riffle/pools and Glide/pools at habitat unit and subunit scales.	53
3.9	Percent change in total fish counts and pool area from July to September in Reaches 1-3.	54
3.10	Differences between habitat types for fish and invertebrate assemblages within each segment (MRBP).	55

LIST OF TABLES (Continued)

<u>Table</u>		<u>Page</u>
3.11	Differences between habitat types for fish and invertebrate assemblages within each reach (MRBP).	55
3.12	Relative abundance of invertebrate Functional Feeding Groups with values for reaches averaged by segment.	63
3.13	Differences between habitat types (e.g. pool, glide, and riffle) for fish and invertebrate assemblages at all scales (hierarchically averaged MRBP, $P < 0.05$ indicate a significant difference between habitat types).	66
3.14	Differences between locations within a scale category (e.g. Falls, Middle and Mouth segments) for fish and invertebrate assemblages at all scales (hierarchically averaged MRBP, $P < 0.05$ indicates a significant difference between locations).	66

LIST OF APPENDICES

<u>Appendix</u>		<u>Page</u>
A	Taxa list, functional feeding groups, and tolerance and indicator values for invertebrates in Thomas Creek.....	97
B	Invertebrate taxa list and abundance at sample sites in Thomas Creek.....	105
C	Fish species list and abundance at sample sites in Thomas Creek.....	113
D	Tolerance levels, thermal group, indicator type, and species list for fish in Thomas Creek.....	115
E	<i>Oncorhynchus mykiss</i> stomach contents from five sites along Thomas Creek during July 2000.....	117
F	Management recommendations and field notes.....	122

“Every now and then a man’s mind is stretched by a new idea or sensation, and never shrinks back to its former dimensions.”

- Oliver Wendell Holmes, Sr., *The Autocrat of the Breakfast Table*



FISH AND INVERTEBRATE DISTRIBUTION AT MULTIPLE SCALES IN THOMAS CREEK, OREGON; A TRANSITION FROM CONIFER UPLANDS TO AGRICULTURAL LOWLANDS

1. INTRODUCTION

Early studies of streams focused on autecology of organisms and biological patterns within streams (Minshall et al. 1993). In the 1960's and 70's, pioneering research suggested conditions within streams and rivers are controlled by characteristics of the catchments that they drain (Hynes 1975). This was one of the early attempts to link stream ecosystems to terrestrial ecosystems outside of the riparian zone. This holistic approach considered energy, organic matter (OM) including its fate after entering the stream, water sources, ionic origins, water chemical properties, and climate (Hynes 1975). Shortly afterwards, the River Continuum Concept (RCC) (Vannote et al. 1980) was proposed as a template for physical and biological processes in montane rivers.

The RCC is a conceptual framework that suggests physical gradients influence biological conditions within the river system in a predictable manner. Furthermore, communities of organisms within the stream ecosystem are structured to maximize utilization of the energy input into, as well as, energy stored within the system. Because water continuously flows downstream, the down valley communities are structured to utilize energy from upstream sources, from the terrestrial system, and from solar radiation. Organic matter used by stream animals can be derived from many sources including terrestrial vegetation (e.g. wood, leaves, pollen, flowers, fruit, etc.), aquatic plants (e.g. periphyton, phytoplankton, and macrophytes), animals, and fecal matter. Invertebrate processors of this OM, can be categorized into functional feeding groups (FFG) including shredders, collectors, predators, and grazers depending on how they collect and eat their food (Vannote et al. 1980). According to the RCC, these functional feeding groups predictably make up different proportions of

invertebrate assemblages depending on where an assemblage is located along the river gradient. In a hypothetical 'pristine' montane river system, riparian vegetation in the headwaters is dense and completely shades the stream. This results in relatively little periphyton production and large amounts of allochthonous input. Because the OM source is primarily terrestrial litter, the aquatic invertebrate assemblages are expected to be dominated by shredders and collectors. As stream order and bankfull width increase, the riparian canopy begins to open up, which allows periphyton to become a significant OM source. In these reaches, the invertebrate assemblages are expected to be dominated by grazers and collectors. As the river becomes even larger, phytoplankton becomes the primary source for OM. This results in collectors being the dominant invertebrates. Because of differences in sources for OM, the headwaters and downstream reaches are predicted to be heterotrophic, and mid-reaches are autotrophic. Though fish distributions were not the focus of the RCC, aquatic vertebrates were predicted along a gradient from cool water species to warm water species with the most diversity occurring in the warmer waters. This general conceptual model has rarely been applied to systems with extensive agricultural practices.

It is well documented that agricultural practices influence physical and biological properties of streams. Generally agricultural practices increase stream nutrients (Johnson et al. 1997, Schlosser and Karr 1981), influence riparian vegetation structure and/or production (Fail et al. 1988), and affect stream biota (DeLong and Brusven 1998, Stewart et al. 2000). For example, studies of two adjacent upstream reaches of Canagagigue Creek in southwestern Ontario demonstrated influences from several of these impacts (Dance and Hynes 1980). Surveys performed in 1843 indicate that historically, the two streams were very similar in geology, climate, size, land use, stream flows, riparian conditions, and number of barnyards near the channel. During the study the west branch had pastures directly adjacent to the stream banks and was usually dry at least six weeks each year. In contrast, the east branch had nearly five times more forested land and the riparian zone was mostly forested. The mean peak

discharge was two to four times greater in the west (maximum stream temperature of 28°C) than the east branch (20°C), and the west branch generally had higher annual mean nutrient and suspended solid levels, higher *coliform* concentrations, and lower dissolved oxygen. All of these factors affected invertebrate communities. The west branch lacked shredders, had 75% fewer Plecoptera species, 54% fewer Trichoptera species, 10% more Chironomids, and 11% fewer total taxa (Dance and Hynes 1980). This study demonstrated the magnitude of agricultural impacts; but, data were not reported in a format readily comparable to the RCC.

Lapwai Creek, Idaho, is an agricultural stream where periphyton, organic matter, riparian habitats, and aquatic invertebrate distributions have been compared to the RCC (DeLong 1991). Periphyton chlorophyll *a* concentrations were 2-10 times higher than comparable undisturbed streams in Idaho and patterns of concentrations did not match those predicted by the original RCC. Organic matter was not correlated with stream size or order and was weakly correlated with sites. Patterns of OM may be driven by local characteristics and not longitudinal position, contrary to the RCC prediction (DeLong and Brusven 1993). Invertebrate assemblages were homogenized and did not follow patterns predicted by the RCC (DeLong and Brusven 1998). In contrast to results from Lapwai Creek, studies of Wheeling Creek, West Virginia, suggested that agricultural streams could closely match predictions from the RCC. Minor anomalies were explained by conditions linked with anthropogenic disturbances, and potential modifications to adapt the RCC were discussed (Carpenter 2001). In grassland prairies, riparian vegetation may vary naturally from the RCC models; for example, streamside vegetation in the headwaters of an Illinois prairie stream had open canopies where as downstream reaches had closed canopies (Wiley et al. 1990). Thus, agricultural land use impacts to stream biota vary greatly and whether patterns match RCC predictions is unclear. I proposed a longitudinal study to examine patterns of fish and invertebrates in a stream that flows through multiple land use areas including forested and agricultural uses. During the first phase (year 2000), I sampled three sites in each of the major land

use areas along 30 river kilometers (R kms) of Thomas Creek. This stream drains approximately 374 km² of the west slope Cascade Mountains, where geology is igneous (volcanic) rock and much of the basin is covered by mid to low elevation conifer forest. Major land use areas included a stream section with conifer-dominated timberlands, a transition area with narrow agricultural valley (less than 1000 m) and mixed forest uplands, and a wide agricultural valley (greater than 1000 m). The primary objective for this phase of the project was to examine longitudinal changes of benthic invertebrate assemblage structure and trout diet composition along the 30 R km study section. Results from these surveys suggested longitudinal patterns were weak and riparian forest characteristics were not associated with trout diet or invertebrate assemblage composition. Consequently, for the second phase of the project I expanded the survey area by 20 R kms (51 R kms total), increased the number of sampling sites to 27, and modified survey techniques to better detect longitudinal and habitat use patterns. The primary objectives for the second phase of the project were to compare longitudinal patterns of fish and benthic invertebrate assemblage structures, habitat use, and distribution along the 51 R km study section.

2. MANAGEMENT HISTORY AND LONGITUDINAL PATTERNS OF AQUATIC INVERTEBRATES AND TROUT DIET IN THOMAS CREEK, OREGON; PRELIMINARY SURVEYS.

Introduction

In agricultural systems, impacts to invertebrate assemblages are inconsistent and highly variable (Carpenter 2001, Dance and Hynes 1980, Delong and Brusven 1998, Wiley et al. 1990)(see chapter 1). Indicators of stream health (e.g. taxa richness, biotic integrity scores, percent EPT, etc.) and invertebrates generally are affected negatively; sensitive species are reduced or extirpated (Dance and Hynes 1980). Additionally, riparian corridor characteristics may influence aquatic invertebrates that are sensitive to organic or sediment pollution (Stewart et al. 2000). Patterns of invertebrates may (Carpenter 2001) or may not (DeLong and Brusven 1998) match those predicted by the RCC. These variable results make predicting invertebrate patterns in agricultural landscapes difficult.

Approximately 70 percent of the Thomas Creek watershed is forested uplands with primarily agricultural lands in the lower reaches. This study will examine fish and aquatic invertebrate distribution along the longitudinal transition from conifer forested to agricultural lands. The watershed is unusual because the valley form is narrow and the stream lacks the more common dendritic form (Figure 2.1). Riparian corridors within the lower reaches that are highly variable in width and vegetation characteristics, likely influence the input of terrestrial invertebrates to streams (Cloe and Garman 1996, Edwards and Huryin 1996, Mason and MacDonald 1982) and fish diet (Wipfli 1997). Land use and elevation did not influence terrestrial inputs or salmonid diet in a Scottish river-catchment, though habitat use might have influenced diet composition (Bridcut 2000). Additionally, habitat use and production of steelhead trout (*O. mykiss*) can be impacted by stream temperature and interactions with reidside shiners (*Richardsonius balteatus*) (Reeves et al. 1987). Stream temperature and

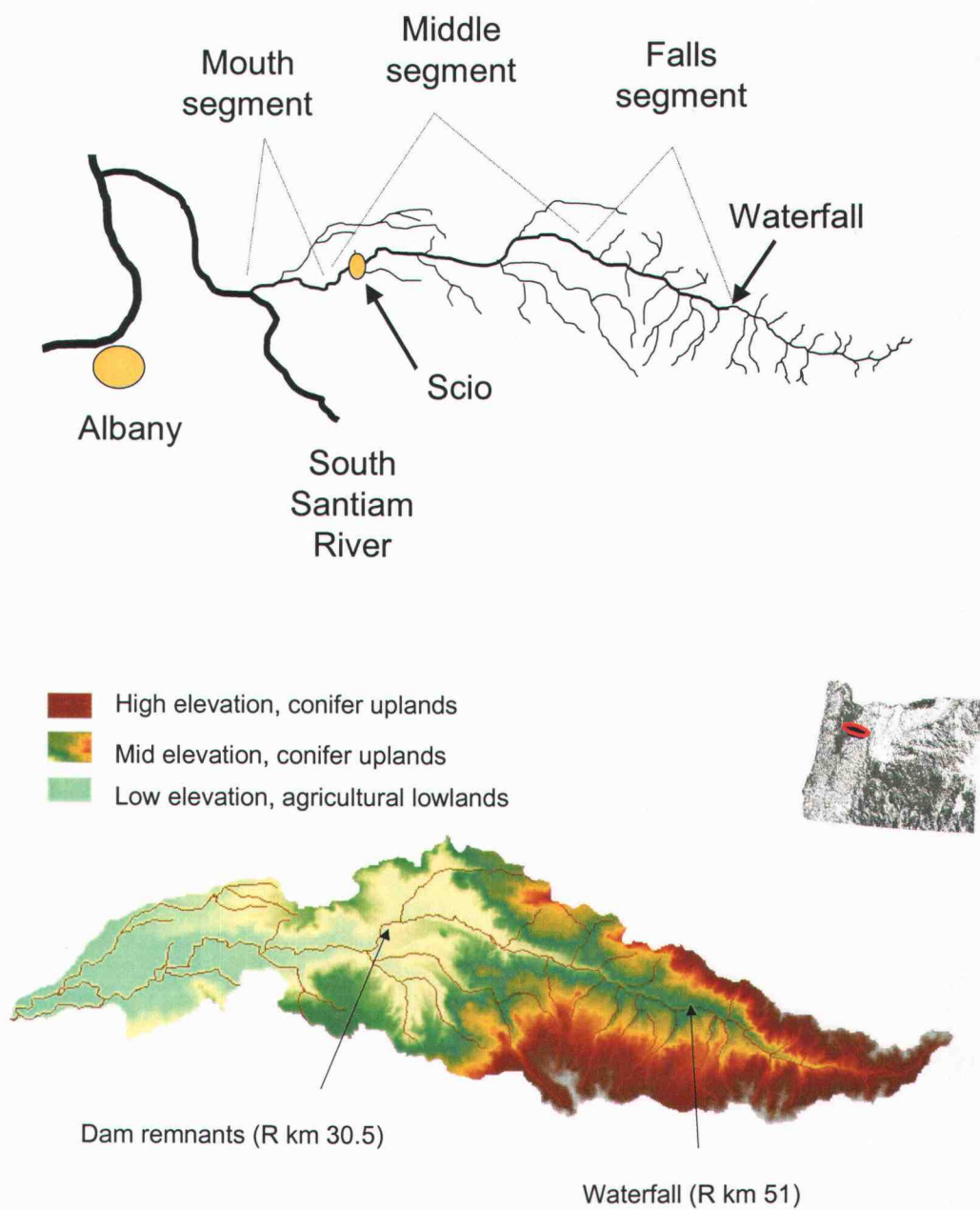


Figure 2.1. A stream outline of Thomas Creek, Oregon, and a shaded Digital Elevation Model of the watershed. Notice the relatively narrow ridge and valley form that lacks dendritic tributaries.

differences in habitat characteristics may influence competition, food availability, and ultimately diet composition.

Despite variable study results, land use conditions, and unique topographic features along Thomas Creek, I predicted that invertebrate assemblage structure and trout diet composition change longitudinally with distinct differences between upstream (without any agricultural impacts, wide riparian corridors) and downstream sites (near extensive agricultural practices, narrow riparian corridors). I hypothesized that terrestrial invertebrates would be the dominant prey for trout in the three upstream sites and be a minor component in the three downstream sites. Finally, I hypothesized that invertebrate functional feeding group composition would be similar to predictions of the RCC for mid-order streams (i.e. approximately equal proportions of collectors and scrapers with a small proportion of predators).

Site description and management history

Thomas Creek is a fifth order tributary of the South Santiam River and the watershed area is approximately 374 km². It originates in the west slope Cascade Mountains at approximately 1338 meters elevation, travels approximately 96 R kms, and enters the South Santiam River near Jefferson, OR (ca. 70 m elevation). A waterfall, about nine meters in height, prevents any anadromous fish migration above R km 51 (ca. 378 m elevation).

More than 70 percent of the Thomas Creek basin is forested land, with the remaining land area under urban, riparian, or agriculture management (Bischoff 2000). The Bureau of Land Management (BLM) manages much of the headwaters, and private timber companies own much of the mid-elevation timberland. Both areas are actively managed for timber harvest. The valley begins to open enough for agriculture at approximately R km 38, and agriculture begins to dominate the landscape at approximately R km 26 (Figure 2.1). Greater than 70 percent of agricultural land use is for grass seed farming. The riparian corridor is relatively continuous directly adjacent to the channel, and

discontinuous sections are generally in the lower reaches. These discontinuous sections are the result of roads or agriculture next to the channel. Riparian areas in the upper reaches are dominated by wide (> 30 m) mixed or conifer forests, while riparian areas in the lower reaches are commonly narrow (< 30 m) and dominated by grass, shrubs, or mixed forests (Bischoff 2000). I did not conduct vegetation species surveys along Thomas Creek, but I observed riparian vegetation commonly found in the Willamette Valley. Douglas fir (*Abies grandis*), big-leaf maple (*Acer macrophyllum*), red alders (*Alnus rubra*), snowberry (*Symphoricarpos albus*), and other woody and herbaceous plants were common throughout the upstream reaches; black cottonwood (*Populus balsamifera*), willow (*Salix spp*), big-leaf maple, Oregon ash (*Fraxinus latifolia*), Indian plum (*Oemleria cerasiformis*), white oak (*Quercus garryanna*), red alders, Himalayan blackberry (*Rubus armeniacus*), reed canary grass (*Phalaris arundinacea*), and other woody and herbaceous plants were common throughout the lower reaches. Western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) occurred occasionally throughout the study section, and Douglas fir was observed at a few locations in the downstream reaches. Vegetation upstream of the waterfall is reportedly mixed stands of Douglas fir, noble fir (*Abies procera*) and silver fir (*Abies concolor*), and western hemlock (Raible et al. 1996). Occasionally, agricultural fields were directly adjacent to the stream bankfull edge in downstream reaches.

Like many other small waterways in the Pacific Northwest, Thomas Creek has undergone active fisheries and water management for nearly a century. Water management dates back to the early 1900's for irrigation, power production, and domestic operations (Bischoff 2000). Currently, water withdrawals consume approximately 10 percent of natural flows and occur at times that are critical to both winter steelhead and spring chinook salmon (Bischoff 2000). Two low-head dams were built in the early 1900's. According to early Oregon Department of Fish and Wildlife (ODFW) reports (ODFW 1930-2001), they were so poorly designed that they were virtually impassable for anadromous fish. Both dams were breached in the mid 1950's, but concrete

remnants of the dam near the Jordan Creek confluence (R km 30.5, 152 m elevation) are still present.

Management for fisheries began in the 1930s with creel censuses (presumably for monitoring fish populations and fishing pressure) and continues today with stocking programs, a regulated fishery, and monitoring surveys. Smallmouth bass (*Micropterus dolomieu*) were introduced as a game fish in the early 1970's and lower reaches were poisoned to reduce competition from "rough" or non-game fish. During the same time period, winter steelhead trout were stocked for approximately six years, after which, a naturally reproducing run of 200-250 returning adults has maintained itself (ODFW 1930-2001). Steelhead trout are sea-run rainbow trout, which are virtually indistinguishable from resident rainbow trout as juveniles. Beginning in 1990, hatchery surplus spring chinook were stocked in an attempt to re-establish a run of these native fish. Currently, ODFW stock adults, conducts abundance and redd surveys, and plant hatchery surplus spring chinook juveniles, in Thomas Creek. Each September during 2000-2002, surplus hatchery adult carcasses (200-500 individuals) were placed in the upstream reaches. To date, numbers of returning adults have been highly sporadic, ranging from zero to 17 per year (ODFW 1930-2001).

Surveys conducted during 2001 (see chapter 3) indicate the channel was incised throughout much of the 51 R km study section and riprap was occasionally placed to reinforce stream banks. Riprap was usually found near bridges or roads that were directly adjacent to a stream bend. The exception to this was between R kms 8-10, where 30-50 car bodies (1940's and 1950's models) were half buried in the stream bank. Stream periphyton appeared to be different in this location and substrates were dark brown/black.

The only severe, direct grazing impacts to the stream that I observed were at a single pasture occupied by sheep at R km 1.5. Severe bank and riparian vegetation degradation along approximately 500 m of stream bank occurred at this site. All herbaceous and leafy vegetation within the riparian corridor was eaten; only woody stems and tree trunks remained.

Methods and Analyses

Between May and September 2000, this phase of the study compared nine sites along 30 R kms of Thomas Creek; three in conifer dominated, three in mixed forest, and three in hardwood dominated riparian forest. Each site was 100 meters in length. Riparian forest at each site was characterized by visually estimating percent cover within 50 meters of the stream channel. Percent cover was estimated for agricultural crops, grazing pasture, native understory, mature forest (trees greater than 15 m), immature forest (trees less than 15 m), and developed property (roads or homes).

Water quality measurements including instantaneous stream temperature, discharge, dissolved oxygen (DO), turbidity, conductivity, total P, total N, and total Kjeldahl nitrogen were collected at each of the study sites. Instantaneous stream temperature, conductivity, and DO were sampled with a handheld meter (YSI model # 85/10 FT) at each site immediately after water samples were collected. Stream water (250 ml) was collected in Nalgene® bottles, immediately placed in an ice bath and transported to the Central Analytical Laboratory (CAL) at Oregon State University for chemical analysis. Nutrient concentrations were determined using CAL's standard protocols and equipment. Generally, water samples were collected monthly at four sites, quarterly at 10 sites, and once or twice per year at the four main sites to capture nutrient levels during high flow events (Figure 2.2). During 2000 (May-September) and 2001 (May-October), thermal temperature loggers (Onset StowAway XT108) were placed in the stream at various locations, not limited to the study sites, between river kilometers 1 and 51. The loggers were placed in shaded areas of the thalweg to prevent direct sunlight influencing temperature readings. Stream temperature was recorded every 30 minutes and downloaded after recovery in September 2000 and October 2001. Seven-day moving averages of the daily maximum temperatures were calculated.

Benthic invertebrates were collected from the nine study sites during May 2000, using a surber sampler modified for deep water with 0.135 m² enclosed

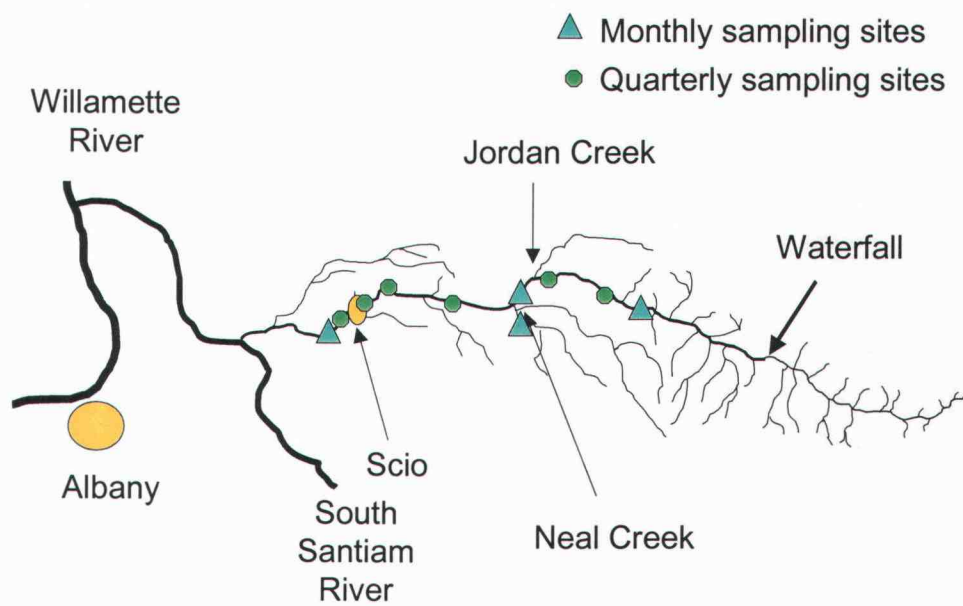


Figure 2.2. Water quality and invertebrate sampling locations along Thomas Creek with one water quality sampling location in Neal Creek.

sample area (500 micron net). The surber was placed randomly (longitudinally and laterally) on the stream bottom and the substrates within the surber area were disturbed to approximately 10 cm depth for one minute. At the point of each surber sample, depth was measured, and dominant and sub-dominant substrates were recorded. Substrates were categorized as bedrock, large boulder, small boulder, large cobble, small cobble, coarse gravel, fine gravel, sand, and silt, based on a modified Wentworth scale (Wentworth 1922). Categorical stream flow was estimated and each sample point and was considered: very slow (no visible water movement), slow (slight visible water movement), moderate (currents visible on the water surface but surface not broken), fast (broken water surface), and very fast (broken water surface with bubbles visible underwater). At each site, six invertebrate samples were collected, transferred to 95 percent ethanol, and transported back to the laboratory for sorting and microscope identification. Invertebrates were identified to the lowest reasonable taxonomic resolution: genus in most cases, occasionally family or species, and tribe for the family Chironomidae (Merritt and Cummins 1996). Invertebrate taxa were classified by functional feeding group (FFG), if feeding characteristics were known (Merritt and Cummins 1996). Analyses were performed with composite samples of the six individual samples from within each site.

Non-metric Multidimensional Scaling (NMS; Kruskal 1964, Mather 1976, PC-ORD version 4.20) was used to compare invertebrate assemblages between habitat types and stream locations at all scales. NMS is robust to non-normal distributions and relieves zero-truncation problems commonly found in heterogeneous community data (McCune et al. 2002). Additionally, it can be consistently applied to data sets that vary in the number of attributes across sample units (i.e. 205 invertebrate taxa versus 10 fish groups) (Faith and Norris 1989).

Data were analyzed using the "slow and thorough" autopilot settings of PC-ORD (version 4.20) and Sørensen's distance measure. Sørensen's distance measure is robust to long environmental gradients (Beals 1984). Final

configurations were limited to three dimensions. Stress of ordination solutions is an inverse measure of how well the data fits the solution, and it was used to determine dimensionality of the solution. A significant decrease in the amount of stress when solution dimensions are increased indicates a significant increase in variation explained by the solution (Faith and Norris 1989). In order to compare ordinations, each was rotated so that longitudinal position was along axis 1. Individual r^2 was calculated for each axis to determine the amount of variation in the data explained by that particular axis. Pearson's correlation coefficients were calculated for quantitative environmental variables and abundance of individual taxa on each axis.

Resident rainbow and steelhead trout were captured at five sites between river kilometers 18 and 40 using electroshocking and hook-and-line techniques. Electroshocking proved inefficient for capturing trout in initial surveys because the water was too deep and conductivity was insufficient. Therefore, hook-and-line techniques were the primary method of capturing fish. Fishermen with extensive fishing experience used artificial lures and flies with single barbless hooks. Fish were caught and held in buckets for less than 30 minutes before being processed. After each fish was anesthetized using MS 222 (buffered for pH with sodium bicarbonate), its stomach contents were gently flushed out using a water bottle with a straw (ca. 1 mm diameter) attached to the nozzle. The stomachs were flushed continuously until matter no longer came out of the fish's mouth (usually 30-45 seconds). Each fish was then placed in a recovery bucket containing freshwater and monitored. After normal swimming functions returned (ca. ten minutes) the fish were released in the stream. Stomach contents were collected onto a paper coffee filter, preserved with 95 percent ethanol, and returned to the lab for microscope identification to the lowest reasonable taxonomic level (usually family). Prey items were classified as terrestrial invertebrates, winged aquatic invertebrates, and others. Terrestrial invertebrates included obvious terrestrial organisms such as spiders, ants, and bees. The origin of Dipteran adults can be difficult to determine so all Dipteran were classified as Diptera or Chironomidae. Winged aquatic invertebrates were

aquatic invertebrates that had or were emerging when eaten. Invertebrates classified as "others" were usually benthic invertebrate larvae or exuviae with an occasional adult elmids beetle or *Juga* snail.

Results

Water chemistries did not consistently distinguish between sites. Nitrogen and phosphorus levels appeared to be fairly uniform between upstream and downstream sites (between R kms 11 and 41) (longitudinal range in Table 2.1). Additionally, water nutrient levels at these sites were below concentrations of concern and in some cases were undetectable during summer flows (Table 2.1). Nutrient peaks during the first flushing rains of fall reached 440 g/l for nitrate nitrogen and 100 µg/l for total phosphorus (Table 2.1).

Seven-day moving averages for daily maximum stream temperatures ranged between 9 and 30°C (Figure 2.3 & Table 2.2). The maximum longitudinal range between the upstream and downstream sites was 10.4°C during August 2001 (Figure 2.3). Maximum daily stream temperatures at the survey sites during water collection ranged between 5.2 and 24.9°C (Table 2.3). Dissolved oxygen levels ranged between 8.7 and 16 mg/l and were higher than 12 mg/l except during June and July 2000. Stream conductivity ranged between 31 and 62 µS (Table 2.3).

An NMS ordination of invertebrate assemblages from nine sites within the 2000 study section demonstrated a slight longitudinal pattern and no pattern based on riparian vegetation composition, stream gradient, or discharge (Figure 2.4). Axis 1 explained 55% of the variation and was correlated with river kilometer, total count, and total richness. Axis 2 explained 30% of the variation in invertebrate assemblages and was correlated with total count and total richness. The longitudinal pattern appeared to be driven by sites 1, 2, and 4; no longitudinal pattern existed for assemblages between R km's 27 and 10 (Figure 2.4).

Table 2.1. Nutrient and *E. coli* concentrations in Thomas and Neal Creeks during 2000 and 2001. Values are the minimum and maximum (when detected) from any sample point throughout the sample period. Longitudinal range is the maximum difference between the most upstream and downstream sites during a single sampling period. Nitrate, ammonium, and phosphorus often were undetectable between June and October.

	Nitrate Nitrogen ($\mu\text{g N/l}$)	Ammonium Nitrogen ($\mu\text{g N/l}$)	Total Kjeldahl Nitrogen ($\mu\text{g/l}$)	Total Phosphorus ($\mu\text{g/l}$)	<i>E. coli</i> (MPN/100 ml)
Minimum	2	2	52	5	0
Maximum	440	20	800	100	14
Longitudinal Range	340	11	450	75	n/a
Neal Creek Maximum *	540	65	740	40	n/a

* Samples were not collected from Neal Creek on the day that Thomas Creek values peaked.

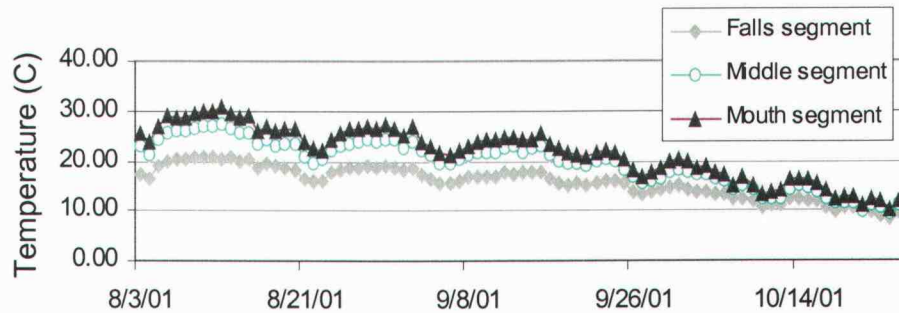


Figure 2.3. Seven-day moving average of maximum daily stream temperatures at one site in each segment. Temperatures were recorded between August 3 and October 25, 2001. These dates captured the annual maximum temperature and temperature profiles from other loggers in the stream during the same time period followed similar patterns

Table 2.2. Maximum stream temperatures in each segment of Thomas Creek and dates they were recorded.

	Temperature (°C)	Date
Falls	22	8/12/01
Middle	27	8/13/01
Mouth	30.5	8/13/01

Table 2.3. Minimum, maximum, and longitudinal range of water quality parameters during sample collection. Longitudinal range is the difference between the upper and lower most sites on the same sampling day. Neal Creek is the largest tributary to Thomas Creek.

	Dissolved Oxygen	Specific Conductivity (μS)	Stream Temperature ($^{\circ}\text{C}$)
Minimum	8.7	31	5.2
Maximum	16.0	62	24.9
Longitudinal Range	1.3	10	10.4
Neal Creek Maximum	16.0	37	13.5

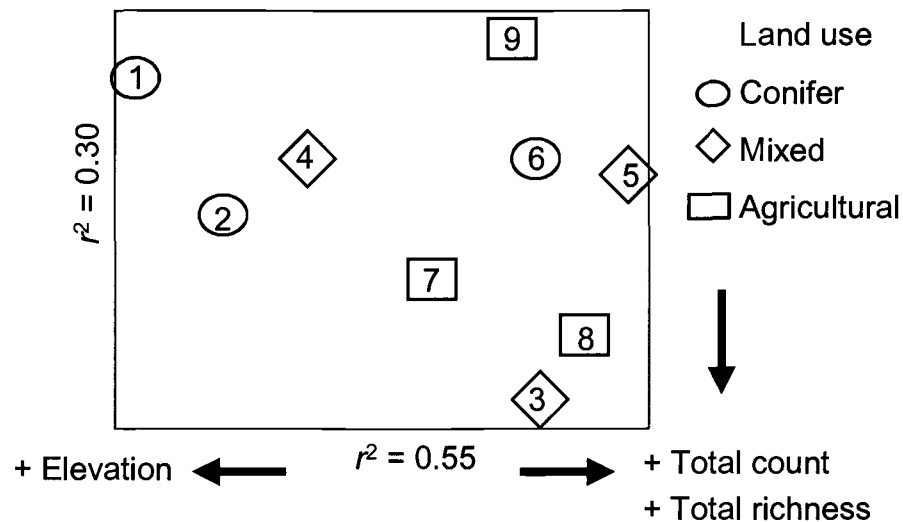


Figure 2.4. NMS ordination of composite invertebrate assemblages from nine sites in May 2000. Samples are overlaid with year 2000 site numbers that correspond with longitudinal position. Site 1 is furthest upstream and site 9 is furthest downstream.

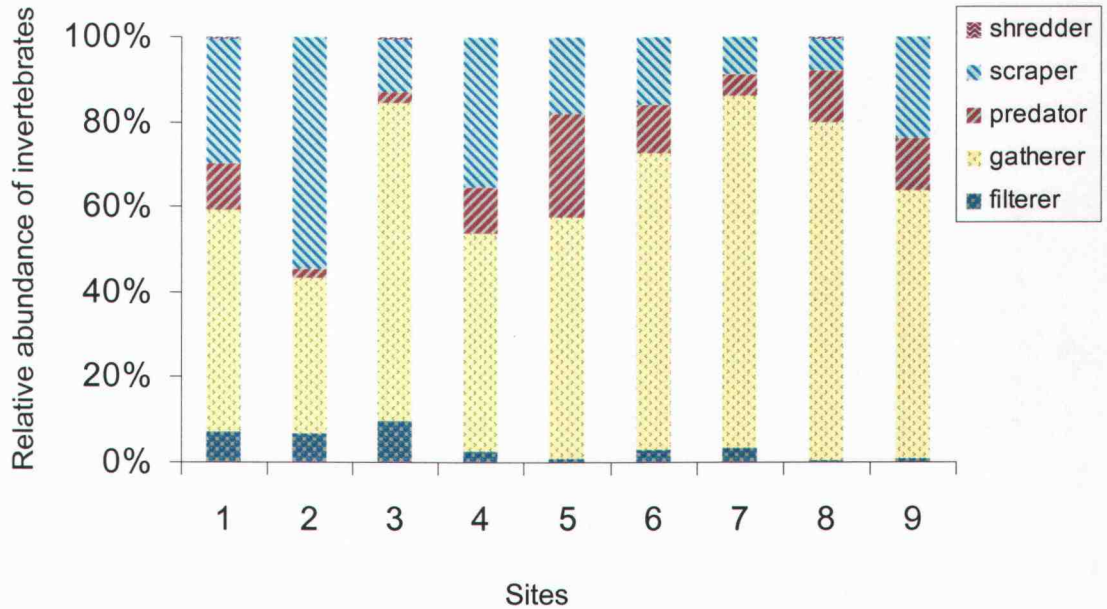


Figure 2.5. Proportions of classified invertebrates in each Functional Feeding Group for the year 2000 sites. Approximately 83% of all collected invertebrates were classified into FFG's. Site 1 is upstream and Site 9 is downstream.

Of the benthic invertebrates classified by Functional Feeding Group, collectors were most abundant at all sites, except site 2 where scrapers were the most abundant (Figure 2.5). Relative abundance of gatherers at each site ranged from 36 to 82 percent and averaged 63 percent of the total abundance. Scrapers were the second most abundant group and ranged from 8 to 55 percent and averaged 23 percent of the total. With the exception of sites 2 and 3, FFG proportions were uniform throughout the entire 30 R kms (Figure 2.5).

Fish diet composition from year 2000 surveys exhibited weak longitudinal gradients. Trout caught using hook-and-line techniques, increased from virtually zero below R km 18, to 2.5 per hour at R km 41. Generally trout in at the upstream sites ate more prey and more diverse prey types (Figure 2.6). Trout diet from Thomas Creek was composed primarily of winged adult aquatic insects with a small proportion of terrestrial derived organisms (Figure 2.6). Forty percent of all prey items were adult Ephemeroptera and terrestrial derived prey comprised only six to 24 percent of total diet. Percent others was negatively correlated with river kilometer and ranged from 12 to 50 with the greatest proportions of other prey items in the downstream sites (Pearson's $r = -0.82$). Percent chironomids was correlated with river kilometer and decreased from 20 at the furthest upstream site to zero at the furthest downstream site (Pearson's $r = 0.93$). See Appendix E for a complete list of prey items found in each fish.

Discussion

Given dramatic changes in land use (conifer forests to agricultural lands) and longitudinal changes in riparian vegetation (wide conifer to narrow deciduous), I expected strong longitudinal changes of stream biota in Thomas Creek. However, stream characteristics (e.g. discharge, wetted width, thalweg depth, etc.) throughout much of the 2000 study section appeared homogeneous and neither stream conditions nor riparian vegetation composition seemed to influence stream biota. This may reflect low summer and fall flows (as much as a ten-fold decrease from winter flows) and disconnection from riparian vegetation.

Trout (<i>n</i>)	18	7	11	10	7
Prey items	20	32	39	16	9

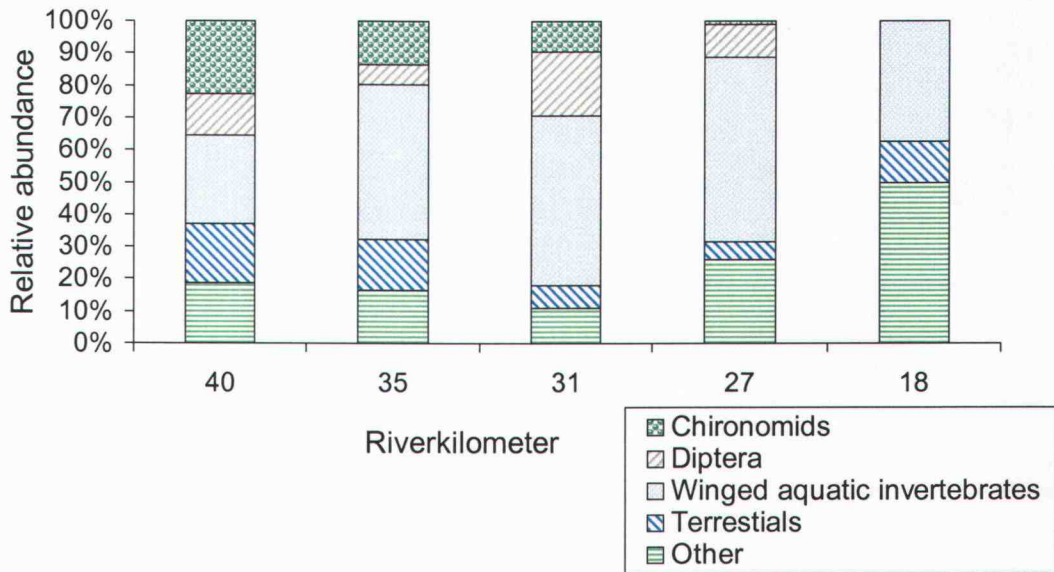


Figure 2.6. Prey composition from 53 trout collected in Thomas Creek during July 2000. Samples were collected at seven sites between Rkms 40 and 18. Values are an average of all fish at each site.

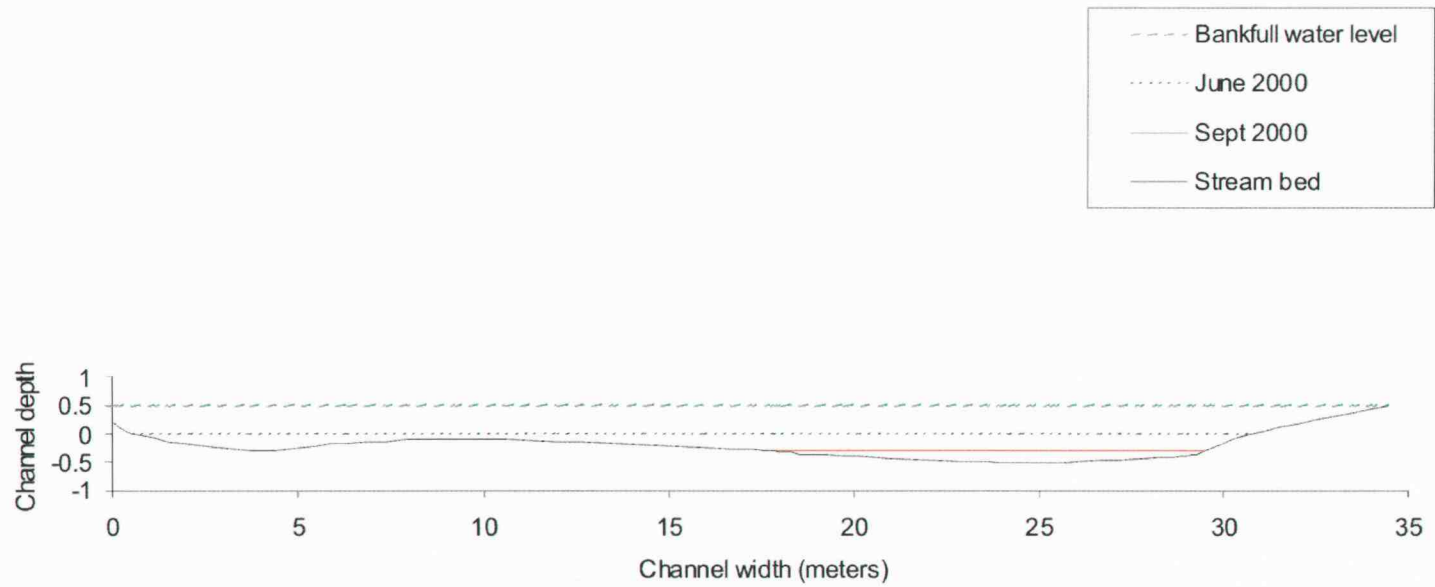


Figure 2.7. Stream channel profile at a year 2000 Thomas Creek site. Bankfull water level is at 0.5m, June 2000 water level is at 0.0 m, and the September 2000 water level is at -0.3 m (red line). Bankfull width is 34.5 m at this transect, while June wetted width is 30.3 m and September is 11.8 m.

In some places during September 2000, the wetted channel occupied only approximately 10 percent of the bankfull channel bed (Figure 2.7). This may limit organic matter, in the form of leafy vegetation (invertebrate food) or terrestrial invertebrates (fish food), entering the channel and likely contributes to high stream temperatures.

As I predicted, trout diet at upstream sites differed from downstream sites. Contrary to my prediction, there was not a longitudinal pattern of terrestrial invertebrates in the diet. In studies of smaller streams, terrestrial invertebrates were the primary prey or comprised a large proportion of salmonid diet during some parts of the year (Nakano et al. 1999, Wipfli 1997, Wright 2000). However, stream size and canopy cover may influence these results (Wright 2000). Similar to studies of larger streams, a low proportion of terrestrial invertebrates in Thomas Creek likely resulted from stream size, the disconnection between riparian vegetation and the stream channel, or reduced canopy cover (Cloe and Garman 1996, Wright 2000). Nevertheless, the high proportion of winged adult aquatic invertebrates suggests trout in Thomas Creek may be oriented to prey associated with the stream surface (e.g. emerging or laying eggs). Previous studies of fish diet have not suggested terrestrial invertebrates are associated with the stream surface, but it is not an unrealistic assumption.

I observed unique upstream and downstream invertebrate assemblages based on assemblage composition, however, sites do not group according to their longitudinal or major land use location (Figure 2.4). Year 2001 surveys suggested sites 5 through 9 were in the same reach type based on similar geomorphic and stream, riparian, and upland characteristics (see chapter 3). This may explain why I did not observe a longitudinal pattern of invertebrate assemblage composition from these sites. With the exception of sites 2 and 3, FFG composition was fairly uniform and dominated by gatherers (Figure 2.5). Site 2 had unusually large areas of bedrock, which may explain high scraper abundances. Site 3 samples inexplicably contained much higher total abundances than other sites, and assemblage composition was more similar to downstream sites (Figure 2.4). Total invertebrate densities ranged between 304

to 1556 invertebrates per square meter, which is comparable to other western Oregon streams (Li et al. 2001). My observations were similar to a study of an agriculturally dominated stream basin in Idaho, where collectors dominated FFG composition and the authors suggested that agricultural practices homogenized invertebrate assemblage composition (DeLong and Brusven 1998).

Longitudinal trends of nutrient levels were not as strong as I expected. Possibly the total area of agricultural land use is low enough (less than 30%) to keep impacts to nutrient levels low and minimize longitudinal patterns. The temporal pattern of nutrient levels I observed in Thomas Creek is common for Willamette Valley streams. They usually have low nutrient concentrations during spring and summer months followed by a strong peak in nutrient levels during the first flushing rains of fall/winter (personal communication, Herlihy 2003) which gradually decrease throughout the winter. In contrast to nutrient levels, stream temperatures in Thomas Creek are a concern.

Stream temperatures peaked at 30.5°C in the downstream reaches during August 2001. Furthermore, stream temperatures exceeded Oregon Department of Environmental Quality (DEQ) temperature standards (17.8°C) upstream to the waterfall including areas with the highest steelhead and chinook densities. Potentially, these high water temperatures resulted from stream aspect, low summer flows, and wide, shallow channels. The stream flows east to west over much of its length, and receives direct solar radiation throughout much of the day. Low summer flows in conjunction with wide, bankfull wetted widths (Figure 2.7) and stream aspect, result in wide, shallow glides and riffles that receive little shade throughout the day (see Table 3.1 in chapter 3). These conditions are conducive for high water temperatures; currently Thomas Creek is listed as an Oregon DEQ 303d stream of concern in Oregon.

Considering the dramatic changes in land use along Thomas Creek, homogeneity of physical conditions and biological responses in my study section was surprising. Potentially, stream size, terrestrial conditions, and perception of scale influenced my expectations and observations. Conditions in headwater streams can change radically within a few kilometers, while it may take several

hundred kilometers for large rivers; mid-order streams are likely somewhere in-between. Vegetation composition and valley width were the main features that drove my perceptions of different sites. Changes of these dramatic terrestrial features were distinct and obvious, while changes in stream conditions particularly gradient, width, and depth, were gradual and obscure. It appears that some studies to examine and clarify changes in stream conditions and biological responses may require greater distance than 30 R kms.

3. PATTERNS OF FISH AND INVERTEBRATES AT MULTIPLE SCALES IN THOMAS CREEK, OREGON

Introduction

In the two decades since the River Continuum Concept (RCC) was proposed (Vannote et al. 1980), a number of studies have attempted to support or refute the suggestion that biotic assemblages change in a predictable longitudinal pattern (Perry and Schaeffer 1987, Statzner and Higler 1985, Townsend 1989, Ward and Stanford 1995). Most studies examine patterns of particular stream organisms separately. Separate studies have examined longitudinal zonation patterns of fish and invertebrate assemblages, and observed similar, broad-scale, upstream/downstream assemblage patterns (reviewed in Hawkes 1975).

Though fish assemblages are briefly mentioned in the original RCC (Vannote et al. 1980), studies of longitudinal changes in fish assemblages related to the RCC are rare. Instead, fish studies tend to focus on large-scale regional patterns (Angermeier and Winston 1998, Baxter 2002, Magalhaes et al. 2002), fine-scale habitat use (Baltz et al. 1991, Fausch 1985, Riehle and Griffith 1993), or occasionally both (Torgersen 2002). Longitudinal studies of fish assemblages center on changes in habitat use (Inoue and Nunokawa 2002) or distribution and zonation patterns (Li et al. 1987, Matthews 1998, Rahel and Hubert 1991, Vila-Gispert et al. 2002).

Longitudinal studies of stream invertebrates testing biotic assemblage changes produced variable results. For example, four distinct groups of invertebrate assemblages were identified along 80 river kilometers (R kms) of a Colorado stream, without significant shifts in functional feeding groups (Perry and Schaeffer 1987). In a different Colorado stream, significant changes in assemblage composition were observed along 39 R km (Allan 1975). In contrast to these, there was no longitudinal shift of invertebrate assemblage composition along 48 river kilometers of an Idaho stream (Delong and Brusven 1998). Other

studies suggest that habitat differences or local conditions were more important to invertebrates than longitudinal position (Brown and Brussock 1991, Doisy and ^{Paolini} Charles 2001).

The lack of studies examining longitudinal changes in both fish and invertebrate assemblages simultaneously, may be a result of fish and invertebrate research groups that focus almost exclusively on their respective taxa, or simply that differences of the organisms themselves make them difficult to study concurrently. These organisms clearly differ in size and other characteristics (e.g. food resources, mobility, range, etc.), which suggests they may respond to conditions functioning at different spatial scales.

It has been well documented that organisms respond to their surroundings at different scales. For example, an invertebrate scraper may be responding to conditions at the cobble-scale (e.g. food availability or velocity) (Wellnitz et al. 2001), while a fish in that same riffle may be responding to large-scale temperature patterns (Roper et al. 1994). Organisms may have different requirements that are met with resources occurring at different scales (Wiens 1989), they might have similar requirements but use the landscape differently (Menge and Olson 1990, Wellnitz et al. 2001), or they may perceive the same resource at different scales (Kolasa and Rollo 1991). In the case of stream fish and invertebrates, some resource requirements are similar (e.g. specificity to riffle habitats) and others are different (e.g. prey for insectivorous or piscivorous fish versus periphyton for invertebrate scrapers). The objective of my study was to determine at what scales habitat characteristics were relevant to fish and invertebrates within the same stream. I hypothesized that fish and invertebrate assemblages would respond equally to fine-scale conditions; and expected differences in both fish and invertebrate assemblages between habitat types (i.e. riffle versus pool habitats). In addition, I hypothesized that fish and invertebrate assemblages would respond equally to large-scale conditions; both fish and invertebrate assemblages would differ between stream segments (i.e. upstream versus downstream segments) and between stream reaches. To test these

hypotheses, I examined habitat use and distribution of fish and invertebrate assemblages at multiple scales in Thomas Creek.

Study Location

Thomas Creek is a fifth order tributary of the South Santiam River in the Willamette Valley, Oregon (Figure 2.1). The creek originates on the west-slope of the Cascade Mountains at approximately 1340 meters (m) elevation and flows 96 river kilometers to its mouth (ca. 70 m elevation). The headwaters are managed for timber harvest; downstream land use starts to change to agriculture (primarily grass seed production) at R km 38 and is dominated by agriculture practices downstream of R km 26. Historical land use practices (e.g. clear-cut logging, splash dams, two low-head concrete dams, etc) have resulted in a relatively simple channel structure with little large wood retained in the channel (Raible et al. 1996). At R km 51, a 9-meter high waterfall prevents upstream anadromous migration of fish. My study was performed downstream of the falls to reduce issues associated with dispersal upstream of the falls. The 51 R km extent of the study stream begins as 3rd order and increases to 5th order. As observed in other mid-order streams, Thomas Creek widens (from 15 to 35 m), discharge increases, and riparian vegetation has less influence on the channel (e.g. shade, allochthonous input) along the 51 R km study section. (Table 3.1)

Thomas Creek was selected for study because it was judged to have high restoration potential and it is representative of many Cascade Mountain/Willamette valley streams (Bischoff 2000). Many low elevation forests in this region have similar geological characteristics (e.g. headwaters are basalt, andesite, and pyroclastic deposits and lowlands are terrace and alluvial deposits), forest types, and historical and current land use practices (England et al. 2001, Graves et al. 2002, Raible et al. 1996). It is listed as a 303d temperature-limited water body in Oregon. Because no previous studies of invertebrates and fish have been made at this extent, my work will provide baseline data for future restoration projects in Thomas Creek.

Methods

Throughout this chapter, I will refer to the sampled area as "survey units". Survey units for fish and invertebrate surveys were classified as one of three habitat types, that were defined as riffles (broken water surface less than one meter deep), glides (non-broken water less than one meter deep), or pools (any water deeper than one meter). Survey units were delineated at the point where conditions clearly changed (e.g. water surface became broken, the bubble curtain ended, or depth reached 1 m). Forty-four survey units that contained no fish were removed from the analyses; no survey units sampled for invertebrates were empty. Although an argument could be made that units without fish provide valuable information, statistical methods I used for analyses were not compatible with empty units. Because no fish group occurred in less than five percent of the units, I included all fish groups in the analysis.

In addition to differentiating between habitat types, I subdivided portions of the stream based on a hierarchical structure (segments, reaches, sites, and habitat units) (Frissell et al. 1986). I selected stream segments to coincide with the end of conifer dominated upland and riparian forests (ca. R km 38) and after the stream flows through the town of Scio, Oregon (ca. R km 7.5) (Figure 2.2). I will refer to these as the Falls segment (waterfall through the region of conifer riparian dominance, ca. 13 R kms), Middle segment (from the region of conifer riparian dominance to Scio, ca. 30 R kms), and the Mouth segment (from Scio to the stream mouth, ca. 7.5 R kms) (Figure 3.1).

During six days in May 2001, two people in an inflatable kayak floated the entire 51 R kms. During the float, we noted general stream, riparian, and upslope characteristics, and surveyed riparian transects at every river kilometer using more precise techniques. I delineated reach types by using 28 stream and riparian variables collected at 52 riparian transects. Transects were 15 m x 50 m plots on the right and left stream banks at each river kilometer. Stream and riparian variables measured in the transects included percent cover of seven

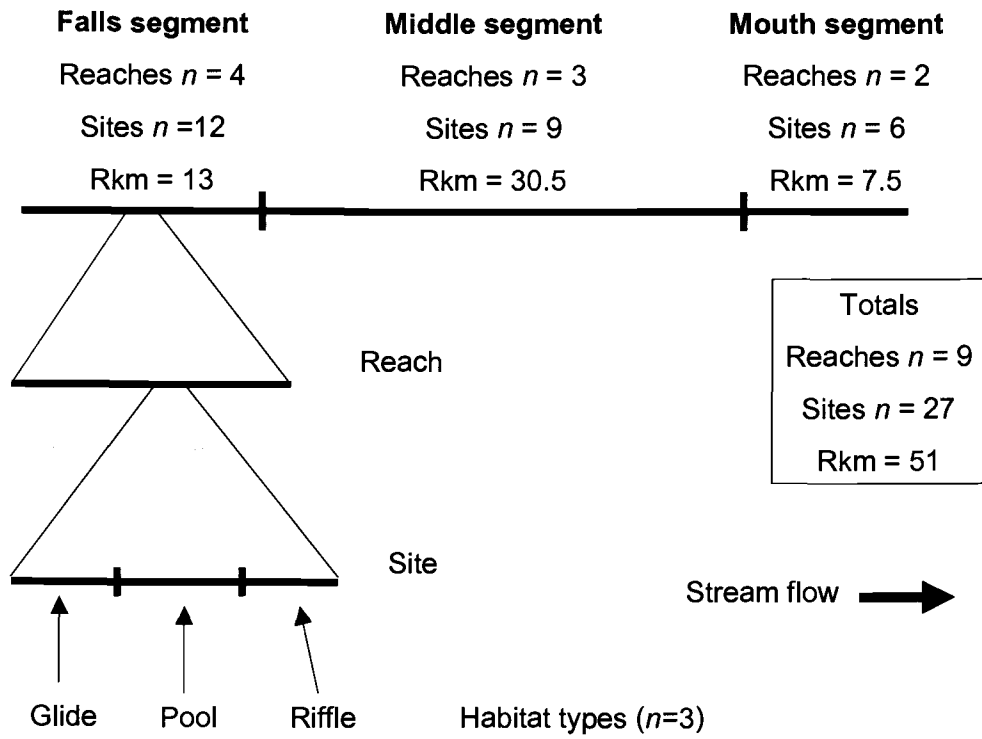


Figure 3.1. Scales of study. The number of Reaches, Sites, and Rkm's within each segment are listed.

vegetation types, dominant vegetation height, valley width, bank slope and height, terrace slope and height, and presence of roads in the riparian zone. Cluster analyses (by group average and Ward's method) of riparian transects in Thomas Creek failed to produce a logical pattern of reaches. Therefore, I separated the stream into nine reach types using general characteristics and distinct changes in stream, riparian, and upslope conditions (Table 3.1). Elevation, valley width, valley slope, stream order, and sinuosity were calculated using 7.5-minute USGS topographic maps. Sinuosity was calculated for each R km, reach, and segment by measuring the channel length between the two end points and dividing it by the straight-line distance between the same two points (Muller 1968).

Sites within reaches were not at identical locations for fish and invertebrates, but the same general criteria were required. Survey sites consisted of at least three adjacent survey units and included one riffle, glide, and pool. Because sites were not selected prior to the initial longitudinal fish survey, 27 fish sites were randomly selected from the original 218 survey units, empty units were excluded whenever possible. For the invertebrate survey, 27 sites (three per reach) were randomly selected from a pool of approximately 50 sites (limited by physical access and permission). Sites were generally between 100 and 300 meters in length.

Fish sampling

During summer 2000, electroshocking and seining for fish proved inefficient because of deep water and low conductivity in Thomas Creek. Therefore, I used snorkel surveys to count fish in 2001. Data were recorded with a waterproof handheld computer. Because juvenile cutthroat (*Oncorhynchus clarki*), juvenile steelhead, and resident rainbow trout are difficult to correctly identify during snorkel surveys, these species were combined into one group called trout. Based on frequency analysis of 300 trout captured for diet studies on Thomas Creek in the year 2000, trout age classes were defined as age 0 (<75

Table 3.1. Riparian and stream characteristics at each reach in Thomas Creek. Channel characteristics are averages from the extensive snorkel survey in May 2001.

		Dominant Substrate	Rkm	Sinuosity	Valley Width	Riparian Vegetation	Upslope Vegetation
Falls Segment	Reach 1	Boulder / Large Cobble	51-46.5	0.90	< 250m	Conifer	Conifer logged ~ 1985
	Reach 2	Bedrock / Cobble	46.5 - 45	0.90	< 100m	Conifer	Conifer
	Reach 3	Cobble	45 - 42.5	0.87	< 250m	Old-growth conifer / some deciduous	Conifer logged ~ 1985
	Reach 4	Cobble / Gravel some Bedrock	42.5 - 38.5	0.90	250-1000m	Even mix Conifer and deciduous	Agriculture corn / grass seed
Middle Segment	Reach 5	Cobble / Gravel	38.5 - 30	0.87	500-1000m	Deciduous/ agriculture	Agriculture/ grass seed
	Reach 6	Cobble / Gravel	30 - 27	0.80	< 500m	Even mix Conifer and deciduous	Deciduous/ conifer
	Reach 7	Cobble / Gravel	27 - 7.5	0.80	> 1500m	Deciduous/ agriculture	Agriculture/ grass seed
Mouth Segment	Reach 8	Gravel	7.5 - 4.5	0.74	> 1500m	Deciduous/ occasional conifer	Agriculture/ grass seed corn
	Reach 9	Gravel	4.5 - 0	0.78	> 1500m	Deciduous/ agriculture	Agriculture/ grass seed, corn, grazing

Table 3.1. (Continued)

		Unit length (m)	Unit width (m)	Minimum depth (m)	Maximum depth (m)	Average depth (m)	Number of units with greater than 5 pieces of large wood (#/R km)
Falls Segment	Reach 1	37.8	8.5	0.1	2.5	0.6	0
	Reach 2	37.3	8.9	0.1	3.5	0.9	0
	Reach 3	54.2	10.3	0.1	3.8	0.8	0
	Reach 4	64.4	13.7	0.1	3.0	0.7	0.75
Middle Segment	Reach 5	51.8	12.7	0.1	5.0	0.6	0.71
	Reach 6	61.2	16.4	0.1	3.1	0.7	0
	Reach 7	58.5	13.9	0.1	4.0	0.6	0.41
Mouth Segment	Reach 8	75.2	15.0	0.1	4.0	0.9	3.7
	Reach 9	55.2	13.3	0.1	2.0	0.4	0.4

mm fork length), age 1-2 (100-125 mm fork length), age 3 and greater trout (>145 mm fork length).

I used an extensive downstream survey to enumerate fish at whole-stream, segment-, reach-, and site-scales. During 12 sampling days between June 19 and July 10, 2001, I systematically surveyed 218 channel units in the study section of Thomas Creek. Depending on channel unit lengths and frequencies within a reach, survey units were systematically selected for every third, fourth, or fifth unit within habitat types. For example, I sampled every fifth riffle in reaches with short, frequently occurring riffles or every third riffle in reaches with long, infrequently occurring riffles. This approach maximized the number of units surveyed, minimized survey time, and kept the habitat type area surveyed generally equal across different reach types.

Within each survey unit, a team of two snorkelers swam downstream (side-by-side) and recorded abundances (specific counts whenever possible, and estimates of small numerous fish) of all non-benthic fish species or size classes observed. Fish groups included age 0 trout, age 1-2 trout, age 3 and greater trout, juvenile chinook salmon, mountain whitefish (*Prosopium williamsoni*), adult largescale suckers (*Catostomus macrocheilus*), juvenile largescale suckers, northern pikeminnow (*Ptychocheilus oregonensis*), smallmouth bass, and redbside shiners. Channel unit characteristics were described concurrently and included unit length, width, and estimated minimum, maximum, and mean thalweg, and large wood volume. Concentrations of each fish group within their distribution range were determined by plotting within group relative densities.

To examine the influence of water temperature on fish distribution, counts for all fish species were combined into thermal tolerance groups. All salmonid species were considered cold-water species, and all other fish species were considered cool-water species (Zaroban et al. 1999). To clarify fish density trends, moving averages were calculated by averaging density values from the fifteen adjacent survey units. Moving averages were calculated from relative densities within each survey unit, for cold and cool-water species. High redbside shiner densities from three survey units in the Mouth segment were especially

influential to density trends and were removed from statistical analyses and figures.

To assess salmonid habitat use at fine-scales (e.g. habitat unit and subunit), intensive upstream snorkel surveys were performed in the four farthest upstream reaches during July and September 2001. Within each reach, I selected one location containing at least three survey units of each habitat type, resulting in at least nine survey units per reach. The length of surveyed area depended on the number and length of habitat types and ranged between 350-700m. Each unit was separated into habitat subunits, which were defined as a unit head (upstream 25% of the unit), unit body (middle 50%), and unit tail (downstream 25% of the unit). Prior to snorkel surveys, boundaries were marked on the stream bottom using colored flagging to maintain consistency during repeated trials. During each survey, two snorkelers (side-by-side) moved slowly upstream recording abundances for each fish group in each habitat subunit. Care was taken to avoid double counting fish. Each site was snorkeled on three consecutive days. During July, each site was snorkeled once in the morning (at approximately 9 am) and once in the afternoon (at approximately 3 pm). After repeated measures ANOVA suggested no significant difference between morning and afternoon surveys, counts for the final analyses were averaged from all passes. Twice-a-day surveys were continued during September, until it was determined that there was no significant difference between morning and afternoon surveys, after which only morning surveys were performed.

Channel characteristics measured in each habitat subunit included unit length, wetted width, mean depth, and substrate sizes. Unit lengths and widths were measured at a line perpendicular to the stream channel; the line was estimated as an average if the end of the unit was not perpendicular to the channel. Characteristics were measured at seven transects (two in the head and tail and three in the body) perpendicular to the stream channel (Figure 3.2). Each transect consisted of seven points where depth was measured and substrate was classified. Substrates were estimated as bedrock, large boulder, small boulder, large cobble, small cobble, coarse gravel, fine gravel, sand, and

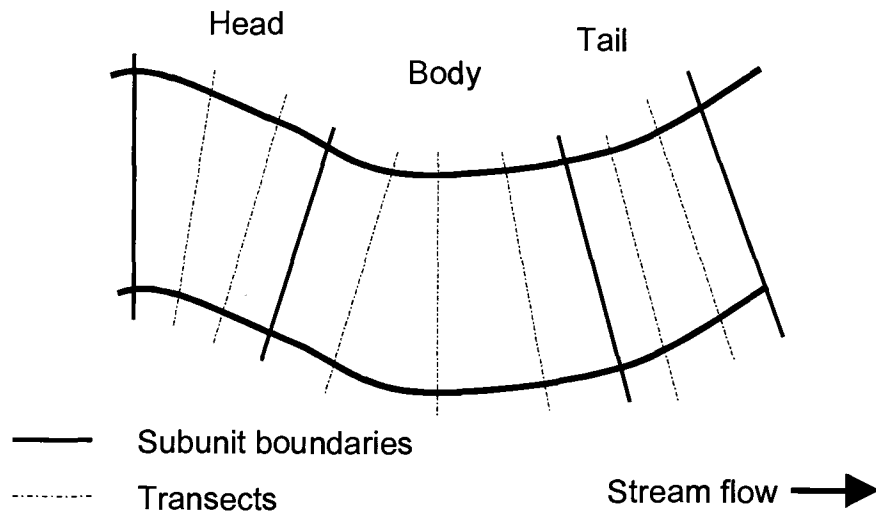


Figure 3.2. Example habitat unit for the upstream intensive snorkel survey. Channel characteristics are measured at each transect.

silt, based on a modified Wentworth scale (Wentworth 1922). The measurement points were approximately equidistant from each other including one in the thalweg. Volume was estimated for large wood (>10 cm in diameter and > 1 m in length) with categories defined as: none (no large pieces), low (1-3 large pieces), med (4-5 large pieces), and high (> 5 pieces).

Manly's Index (MI) (Chesson 1978, Manly et al. 1972) was used to assess fish habitat electivity. Manly values range from zero to one, with zero indicating no use and one indicating exclusive use of that particular habitat. Within each reach, this index indicates the proportion of fish (0-100%) found in a particular habitat type in relation to its availability. A Manly value was calculated for each fish group in each habitat ($m=4$) and sub-habitat ($m=9$) type in each reach.

Manly's Formula:

$$\alpha_i = \frac{r_i/n_i}{\sum_{j=1}^m r_j/n_j} \quad i = 1, 2, \dots, m$$

α_i = preference for an i -th subunit type

r_i = proportion of the i -th subunit type in cells used by fish

n_i = proportion of the i -th subunit type in cells available

m = total number of different habitats available

Within habitat types, habitats can be further divided by stream velocity (Inoue and Nunokawa 2002). Because I did not measure current velocity, I attempted to differentiate pools by the habitat type directly upstream. Pools that were directly downstream of riffles or glides were defined as Riffle/pools and Glide/pools respectively. Mann-Whitney U tests were used to test for electivity differences between Riffle/pools and Glide/pools, as well as between habitat subunits within habitats (e.g. head, body, and tail within Riffle/pools). Density data were log transformed to improve homogeneity of variances.

Invertebrate sampling

Invertebrate samples were collected from 27 sites during May 2001, with a surber sampler modified for deep water with 0.135 m² enclosed sample area (500 micron net). The surber was placed randomly (longitudinally and laterally within each survey unit) on the stream bottom and the substrates within the surber area were disturbed to approximately 10 cm depth for one minute. At each site, two samples were collected within each habitat type (e.g. riffle), transferred to 95 percent ethanol, and transported back to the laboratory for sorting and microscope identification. Invertebrates were identified to the lowest reasonable taxonomic resolution: genus in most cases, occasionally family or species, and tribe for the family Chironomidae (Merritt and Cummins 1996). Invertebrate taxa were classified by functional feeding group (FFG), if feeding characteristics were known (Merritt and Cummins 1996). Taxa tolerance values were assigned to each family or genera (Mandaville 2002); values of 0 indicate the least tolerance for organic pollution and values of 10 indicate the most tolerance. Because tolerance can vary for species within a genus, I assigned the most conservative value listed for each genus or family. After identification, the two samples from the same habitat within a site were combined to make one sample per habitat type per site.

At the point of each surber sample, depth was measured, and dominant and sub-dominant substrates were recorded. Substrate size and velocity classifications techniques were the same as for the fish survey.

Statistical Analyses

Outlier analysis was performed by examining a frequency distribution of average Sørensen distances between assemblages from each survey unit and all other survey units in fish or invertebrate species space (McCune et al. 2002). At each scale, survey units with greater than three standard deviations from the mean distance, frequency distribution were removed from subsequent analyses. Three, two, and eight survey units were outliers for fish assemblages in the Falls, Middle, and Mouth segments, respectively. Standard deviations of removed

units ranged from 3.0 to 5.8 from the mean distance frequency distribution. Invertebrate outliers were not greater than 2.7 standard deviations from the grand mean and were not removed.

Data were analyzed as hierarchically averaged composite samples, which were samples averaged within habitat types at each scale. For example, a reach-scale riffle composite sample was an average of all individual riffle samples within that reach. This was done to reduce variability of notoriously patchy invertebrate data (Li et al. 2001) and clarify ordination patterns.

Non-metric Multi-response Randomized Block Permutation Procedures (MRBP, PC-ORD version 4.20), were used to examine differences in assemblage structure between habitat types. MRBP is similar to Non-metric Multi-response Permutation Procedures (MRPP; Mielke 1984, Zimmerman et al. 1985), except MRBP is modified for blocked sampling designs to reduce location effects. In non-metric MRBP the distance matrix is converted to ranks before the test statistic is calculated. Assemblages consisted of abundance (for invertebrates) or density (for fish) values for each taxon in each sample (individual or hierarchically averaged). Tests for differences between habitat types were conducted at the stream segment-scale (7.5-30.5 R km), stream reach-scale (1.5-7 R km), and stream site-scale (100-300 m). MRBP was also used to test for differences in assemblage structure between stream segments and reaches. *P*-values less than 0.05 suggest a significant difference between groups or treatments. *A*-values express within-group agreement and values of 1.0 indicate all samples within a group (e.g. riffles from the Falls, Middle, and Mouth segments) were identical. Values greater than zero indicate groups were more similar than expected from random chance, and values less than zero indicate groups were less similar than would be expected by random chance. *A*-values less than 0.1 are common; values greater than 0.3 are rare in ecological research and are considered to be exceptionally similar (McCune et al. 2002). However, low numbers of taxa types can inflate *A*-values, which may have occurred in my fish analyses. At the site-scale, there is only one sample per habitat type so MRBP cannot test for differences between sites. However, the *A*-

values for tests between habitat types indicate similarity between site samples within habitat types.

Non-metric Multidimensional Scaling (NMS; Kruskal 1964, Mather 1976; PC-ORD version 4.20) was used to describe assemblage differences between habitat types and survey locations at all scales. NMS is robust to non-normal distributions and relieves zero-truncation problems commonly found in heterogeneous community data (McCune et al. 2002). It can be consistently applied to data sets that vary in the number of attributes across sample units (i.e. 205 invertebrate taxa versus 10 fish groups) (Faith and Norris 1989).

Data were analyzed using the "slow and thorough" autopilot settings of PC-ORD (version 4.20) and Sørensen's distance measure. Sørensen's distance measure was used because it is one of the most effective techniques available for measuring similarity between samples (McCune et al. 2002) and is robust to long environmental gradients (Beals 1984). Final configurations were limited to three dimensions. Stress of ordination solutions is an inverse measure of how well the data fits the solution, and it was used to determine dimensionality of the solution. A significant decrease in the amount of stress when solution dimensions are increased indicates a significant increase in variation explained by the solution (Faith and Norris 1989). In order to compare ordinations, each was rotated so that longitudinal position was along axis 1. Individual r^2 for each axis determined the variation explained by each particular axis. Pearson's correlation coefficients were calculated (bi-plots in NMS) for quantitative environmental variables and individual taxon with each axis. Significant relationships and categorical environmental variables were used to characterize patterns of biological assemblages in each ordination.

Data were analyzed as individual sites and as hierarchical averages. Analyses at each scale were performed with one sample from each habitat type at each location for a total of 81 site, 27 reach, and 9 segment samples. For example, site 1 consisted of one pool sample, one glide sample and one riffle sample. Within Reach 1, sites 1, 2, and 3 were hierarchically averaged so that Reach 1 assemblages consisted of one pool sample, one glide sample and one

riffle sample. A total of 205 identified invertebrate taxa and 10 fish groups were used in the analyses. NMS analyses of hierarchically averaged fish assemblages produced 1-dimensional and 2-dimensional distorted ordinations at the segment- and reach-scales. Because 1-dimensional or distorted solutions are uninformative and/or unreliable in NMS (McCune et al. 2002), these ordinations will not be included. However an ordination of fish densities averaged across habitat types within each site was informative and will be included in the results.

Indicator Species Analysis (ISA; Dufrene and Legendre 1997; PC-ORD version 4.20) was used to describe compositional differences between stream segments, reaches, and habitat types for both fish and invertebrates. Indicator values are calculated by combining species abundance in a particular group with the faithfulness of that species to occur in that group. For each species, the indicator value is tested for statistical significance with a Monte Carlo randomization technique. I used density data with 1000 Monte Carlo randomizations in each trial to find indicator species for fish and invertebrates at each scale and for habitat types.

Results

The elevation profile of Thomas Creek is gradual with an average elevation increase of 12.9 m, 4.2 m, and 1.5 m per river kilometer in the Falls, Middle, and Mouth Segments respectively (Figure 3.3). The extensive survey of riparian transects failed to reveal a logical pattern of reaches. Adjacent transects did not cluster together to form distinct reaches, groups were generally small and included transects from throughout the stream. For example, transect 3 clustered with transects 13, 14, 19, and 42. Therefore, I separated reaches based on general stream, riparian, and land use characteristics. Substrates decreased in size from boulders and cobble upstream to gravels and sand downstream (Table 3.1). Land use transitioned from conifer timberlands to grass

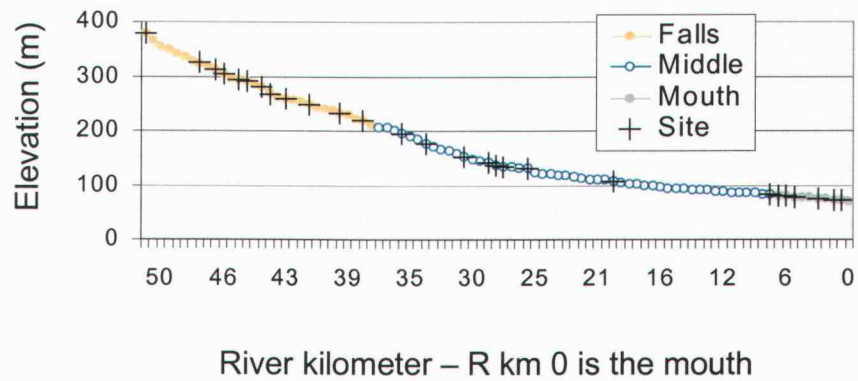


Figure 3.3. Elevation profile of Thomas Creek within the study section. Segments are denoted by color and site locations are indicated by the addition symbol (+).

seed agricultural lands, while riparian vegetation transitioned from conifers to deciduous and agricultural crops (Figure 2.1 & Table 3.1).

Seven day moving averages of maximum water temperatures peaked in early August at 15.5°C near the falls and 30.5°C near the mouth. During September surveys, water temperatures ranged between 12 and 16°C, with the coolest temperatures in the upstream reaches (Figure 2.3).

Large wood (>10cm in diameter and > 1m in length) accumulations of more than 5 pieces were rare in the Falls (0.25/ R km) and Middle (0.45 /R km) segments but common in the Mouth segment (1.7 /R km) (Table 3.1). Channel characteristics in the Middle segment appeared to be intermediate to Falls and Mouth segments. Pool lengths were shortest and riffles were longest in the Falls segment, while pools were longest and riffles were shortest in the Mouth segment (Table 3.2). Comparisons of survey units with and without fish revealed significant differences ($p < 0.05$) between unit lengths and widths (Table 3.2). In the Middle segment, empty riffles were shorter and empty glides were wider than their counterparts with fish in the Falls and Mouth segments.

The longitudinal fish survey revealed patterns of an upstream salmonid assemblage and downstream non-game fish dominated assemblage (Figure 3.4). During the study period, 74 percent of the salmonid population in the study section was observed in the Falls segment (R kms 51-35). When fish were grouped according to thermal tolerances (Zaroban et al. 1999), total assemblage densities occurred in a strong upstream/downstream pattern with a depauperate zone in-between (Figure 3.5). In association with the breached dam at R km 30.5, fish density increased (relative to surrounding survey units). The Middle segment, described as depauperate, had the greatest number of empty units (Table 3.3) and the lowest fish densities and richness (Tables 3.4 & 3.5).

During upstream intensive surveys of the four Falls segment reaches, age 0 trout were the only fish group to exhibit a longitudinal pattern. The downstream decrease in density in this group correlated with R km (Pearson's $r = 0.79$) and elevation ($r = 0.87$) (Figure 3.6). During July and September, Manly Index values indicated that within reaches, all fish groups strongly selected for the same

Table 3.2. Average stream characteristics of survey units occupied and unoccupied by fish. Characteristics with significant differences ($P < 0.05$, Mann-Whitney U) between occupied and unoccupied survey units within segments are in bold. Significant differences between segments are marked by letters; identical letters are significantly different from each other. Distances and depths are in meters.

Pools

Segment	Occupied			Unoccupied		
	Thalweg	Length	Width	Thalweg	Length	Width
Falls	1.6	45a	10	-	-	-
Middle	1.4	60	12	1.7	70	11
Mouth	1.4	105a	13	-	-	-

Glides

Segment	Occupied			Unoccupied		
	Thalweg	Length	Width	Thalweg	Length	Width
Falls	0.4	38bc	11	0.3	27	17
Middle	0.4	70c	16	0.4	52	15
Mouth	0.4	66b	16	0.3	43	24

Riffles

Segment	Occupied			Unoccupied		
	Thalweg	Length	Width	Thalweg	Length	Width
Falls	0.3	76d	11	-	-	-
Middle	0.3	53e	13	0.2	32	12
Mouth	0.2	19de	11	-	-	-

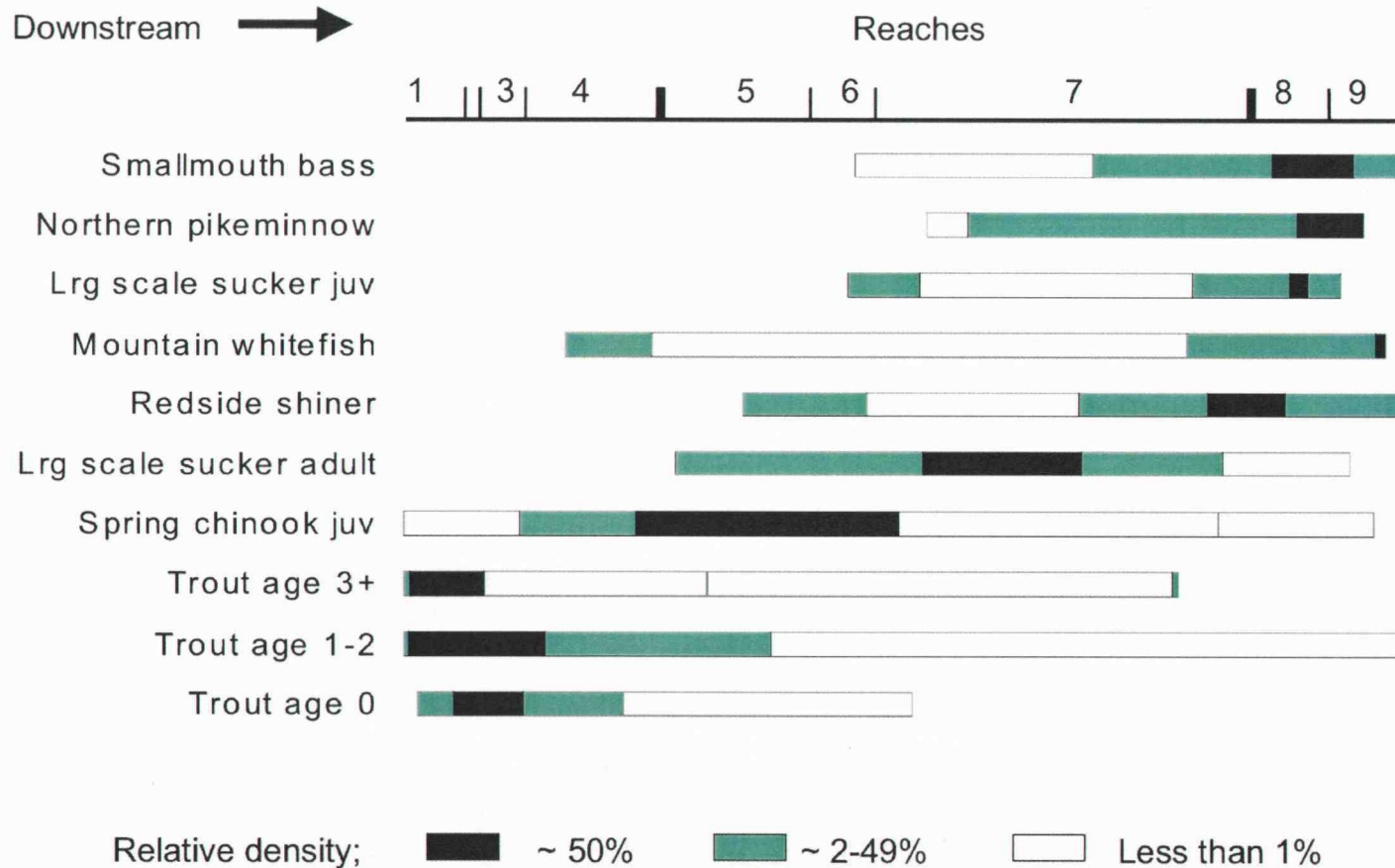


Figure 3.4. Thomas Creek fish distribution based on relative densities. The entire study section is 51 Rkms and reach numbers are listed on top of the figure. Breaks between segments are indicated by wider lines between reach numbers.

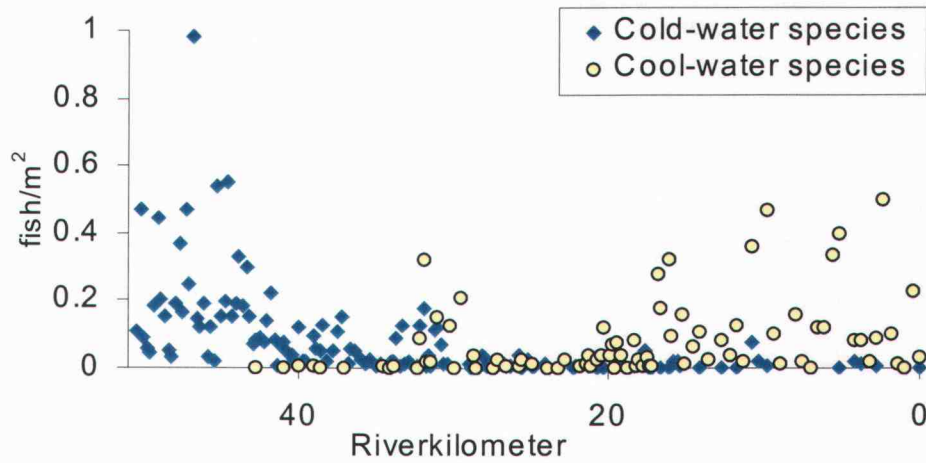


Figure 3.5. Total densities of cold and cool-water species. The dam remnants are at Rkm 31. Total density outliers for the cool-water group were 1.48, 2.03, and 3.0 fish/m² at Rkms 15.7, 15.6, and 10.3, respectively.

Table 3.3. Number of survey units within each segment and the number that were unoccupied by fish.

	Number of pools	Number of glides	Number of riffles	Total
Falls	22	26	26	74
Middle	28	44	41	113
Mouth	12	12	7	31

	Number of empty pools	Number of empty glides	Number of empty riffles	Total
Falls	0	5	0	5
Middle	6	21	9	36
Mouth	0	3	0	3

Table 3.4. Densities of fish within segments. Densities are total numbers of fish counted per total area surveyed.

Segment	Pool Density	Glide Density	Riffle Density	Total Density
Falls	0.073	0.084	0.049	0.062
Middle	0.064	0.036	0.020	0.037
Mouth	0.104	0.041	0.187	0.081

Table 3.5. Average invertebrate and fish richness (taxa or fish group per sample) by habitat type and abundance or density within segments.

Invertebrates				
Richness				
Segment	Pool	Glide	Riffle	Abundance
Falls	22.2	32.6	24.9	219.2
Middle	25.4	31.2	40.2	245.8
Mouth	28.6	34.1	37.1	269.7

Fish				
Richness				
Segment	Pool	Glide	Riffle	Density
Falls	2.8	2.3	2.5	0.062
Middle	2.7	2.1	2.3	0.037
Mouth	3.5	2.3	2.7	0.081

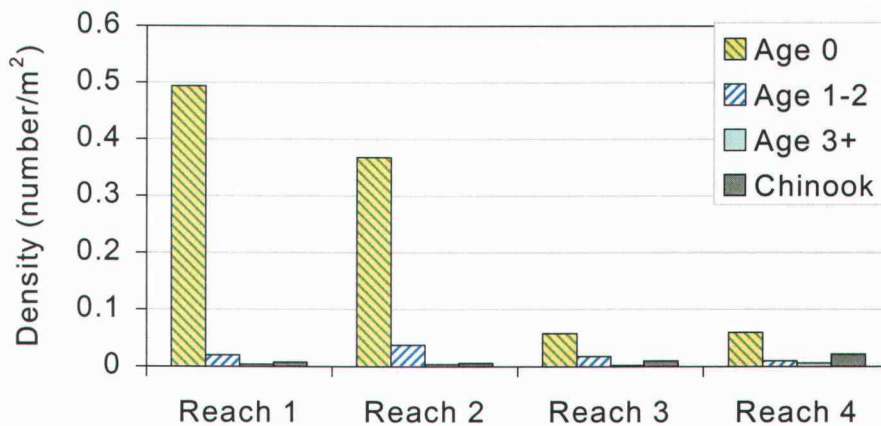


Figure 3.6. Densities for each fish group during the upstream intensive survey. Densities are an average of July and September surveys at each reach. Reach 1 is upstream and Reach 4 is downstream.

habitat types during both seasons. Therefore, I present average values among fish groups within reaches by habitat type and subunit type. The Manly Index values, at the habitat unit-scale, indicate all salmonid groups selected for pool habitats with riffles directly upstream (Riffle/pools) in Reaches 1-3; they selected for riffles and pools with glides directly upstream (Glide/pools) in Reach 4 (Table 3.6). At the subunit-scale, all salmonid groups most strongly selected for pool heads in Reaches 1-3 and 4, and secondly for Riffle/pool bodies in Reaches 1-3 and riffle tails in Reach 4 (Table 3.7). Age 1-2 trout, age 3 and greater trout, and juvenile chinook selected for Riffle/pool heads. Age 0 trout, age 1-2 trout, and juvenile chinook selected for Riffle/pool bodies significantly more than Glide/pool heads and bodies ($P < 0.05$) (Table 3.8). There was no significant difference in selectivity between Riffle/pool and Glide/pool tails (Table 3.8). Although Reach 4 habitat selectivity differed from Reaches 1-3, as a whole Riffle/pools were selected for significantly more than Glide/pools for all fish groups (Mann-Whitney U, $P < 0.05$) (Table 3.8).

Between July and September, the greatest increase in numbers of age 1-2 trout, age 3 and greater trout, and chinook were in Reach 2 (a 1.5 R km gorge) (Table 3.9). Age 0 trout decreased in all reaches, but the least decrease was in Reach 1. During this interval, total and pool survey area decreased for all reaches with the greatest changes occurring in Reaches 2 and 3 (Table 3.9).

When blocked by site to reduce location effects, fish assemblages were significantly different between habitat types within the Falls segment (Table 3.10) and within all reaches (Table 3.11) (MRBP, $p < 0.05$). *A*-values averaged 0.06 for segments (Table 3.10) and 0.956 for reaches (Table 3.11).

Densities of fish averaged among survey units within each site produced a two-dimensional ordination that explained 76 percent of the variation in fish assemblages (Figure 3.7). Longitudinal position and channel unit width were associated with axis 1 and total site density was associated with axis 2. Generally, this ordination delineates an upstream, high-density salmonid group, a low-density group (Middle segment), and a high-density non-game fish downstream group.

Table 3.6. Unit scale habitat selection by salmonids based on upstream intensive surveys (Manly Index). The two highest values in each reach (bolded) indicate strongest selection. Values are averages for all salmonid groups during both seasons. Reach 4 is calculated for September only.

Habitat type	Reach 1	Reach 2	Reach 3	Reach 4
Riffle	0.15	0.19	0.13	0.47
Glide	0.14	0.08	0.07	0.09
Riffle/pool	0.63	0.56	0.63	0.03
Glide/pool	0.08	0.05	0.11	0.39

Table 3.7. Subunit scale habitat selection by salmonids based on results from the upstream intensive surveys (Manly Index). Two highest values in each reach (bolded) indicate strongest selection in that reach. Values are averages for all salmonid groups during both seasons; Reach 4 calculated for September only.

Habitat type	Reach 1	Reach 2	Reach 3	Reach 4
Riffle Head	0.03	0.07	0.05	0.11
Riffle Body	0.03	0.05	0.04	0.10
Riffle Tail	0.10	0.07	0.03	0.25
Glide Head	0.05	0.04	0.02	0.06
Glide Body	0.05	0.01	0.02	0.01
Glide Tail	0.04	0.04	0.03	0.02
Riffle/pool Head	0.28	0.44	0.57	0.02
Riffle/pool Body	0.21	0.10	0.08	0.01
Riffle/pool Tail	0.06	0.07	0.02	0
Glide/pool Head	0.04	0.05	0.08	0.36
Glide/pool Body	0.03	0	0.03	0.05
Glide/pool Tail	0.05	0	0	0

Table 3.8. Differences in habitat selectivity between Riffle/pools and Glide/pools at habitat unit and subunit scales. *P*-values < 0.05 indicate greater selection for Riffle/pool habitats (Mann-Whitney U).

Unit	Age 0	Age 1-2	Age 3+	Chinook
Riffle/pool greater than Glide/pool	$p < 0.05$	$p < 0.025$	$p < 0.025$	$p < 0.025$
Subunit	Age 0	Age 1-2	Age 3+	Chinook
Head		$p < 0.01$	$p < 0.01$	$p < 0.05$
Body	$p < 0.025$	$p < 0.025$		$p < 0.025$
Tail				

Table 3.9. Percent change in total fish counts and pool area from July to September in Reaches 1-3. The greatest increase (or smallest decrease) in fish counts and the greatest decrease in area are bolded. Reach 2 is the gorge reach. Counts are averages of three to six passes during three consecutive days.

	Reach 1 (R km 48)			Reach 2 (R km 45)			Reach 3 (R km 43)		
	July Count	Sept Count	Change (%)	July Count	Sept Count	Change (%)	July Count	Sept Count	Change (%)
Age 0 trout	249.8	240.0	-3.9	327.5	257	-21.5	35.2	4.0	-88.6
Age 1-2 trout	17.2	20.3	17.7	18.2	65.7	261.5	32.8	7.7	-76.6
Age 3 and greater trout	3.8	3.3	-14.5	2.3	8.7	271.4	3	2.3	-22.2
Juvenile chinook	3.8	14.0	268.4	5.7	24.7	335.3	17.8	38.0	113.1
Pool area (M ²)	387	358	-7.4	987	565	-42.7	1033	579	-43.9
Total survey area (M ²)	3262	3083	-5.5	3683	2900	-21.3	8207	6261	-23.7

Table 3.10. Differences between habitat types for fish and invertebrate assemblages within each segment (MRBP). Samples are blocked by site; *P*-values indicate differences between habitat types (e.g. pool, glide, and riffle) and *A*-values indicate similarity between sites within each segment.

Segment	Invertebrates		Fish	
	<i>A</i> -value	<i>P</i> -value	<i>A</i> -value	<i>P</i> -value
Falls	0.157	0.000	0.092	0.002
Middle	0.160	0.000	0.013	0.286
Mouth	0.155	0.001	0.065	0.163

Table 3.11. Differences between habitat types for fish and invertebrate assemblages within each reach (MRBP). Samples are blocked by site; *P*-values indicate differences between habitat types (e.g. pool, glide, and riffle) and *A*-values indicate similarity between sites within each reach.

Reaches	Invertebrates		Fish	
	<i>A</i> -value	<i>P</i> -value	<i>A</i> -value	<i>P</i> -value
Reach 1	0.258	0.008	0.946	0.010
Reach 2	0.146	0.042	0.920	0.010
Reach 3	0.252	0.008	0.963	0.010
Reach 4	0.263	0.009	0.983	0.010
Reach 5	0.199	0.008	0.939	0.010
Reach 6	0.215	0.009	0.993	0.010
Reach 7	0.236	0.013	0.974	0.010
Reach 8	0.250	0.009	0.946	0.010
Reach 9	0.237	0.007	0.943	0.010

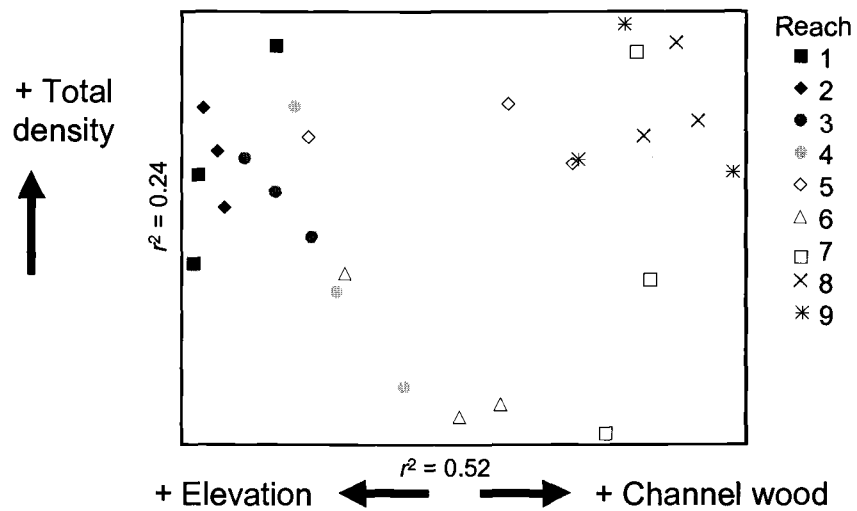


Figure 3.7. NMS ordination of fish assemblages from each site, averaged among habitat types. Reach numbers and segment types are overlaid. Solid symbols indicate the Falls, open symbols indicate the Middle, and line symbols indicate the Mouth segment.

Indicator species analysis identified fish species as distinctive segment, reach, and habitat type indicators. All trout groups were indicators for the Falls segment, adult largecale suckers for the Middle segment, and smallmouth bass, mountain whitefish, redbreast shiners, and northern pikeminnow were indicators for the Mouth segment. Only two reaches had indicator species: age 0 and age 1-2 trout for Reach 2, and juvenile largescale suckers, smallmouth bass, and redbreast shiners for Reach 8. The only indicators for habitat types were age 3 and greater trout and adult largescale suckers, which were indicators for pools (Figure 3.8).

Invertebrate Results

When blocked by site to reduce location effects, invertebrate assemblages were significantly different (MRBP, $p < 0.05$) between habitat types within all segments and all reaches. *A*-values averaged 0.15 for segments and 0.228 for reaches (Tables 3.10 & 3.11).

Of the 205 identified invertebrate taxa, 64 were indicator species at the segment-scale, 54 at the reach-scale, 24 at the site-scale, and 35 species were indicators for habitat type (26 were indicators for riffles) (Figure 3.9). For segments, true flies had the most indicator species (15) followed by caddisflies (13), mayflies (11), and stoneflies (8). Reach 9 had the most indicator species (15), followed by Reach 8 (10) and Reach 7 (7). Craneflies (Tipulidae) were indicators for the upstream segments and genera included: *Dicranota*, *Limnophila*, and *Hesperoconopa* in the Falls segment and *Antocha* in the Middle segment. There were Ephemerellidae mayfly and Brachycentridae caddisfly indicator taxa in each segment (*E. Ephemerella*, *B. Amiocentrus*, *E. Timpanoga*, *B. Micrasema*, *E. Attenella*, and *B. Brachycentrus*). See Appendix A for a complete species list including indicator taxa. Site indicators are likely rare species, and it is logical that the number of indicators increased with increased area. As longitudinal distance increases, the likelihood of individual taxa being contained within that sample area increases. Yet I observed 30 indicator species for the Mouth segment (only 7.5 R kms) including eight non-insects, seven caddisfly, and six mayfly indicator species. The high number of indicator species

Habitat types: Pool indicators are Age 3 and greater trout and Adult largescale suckers

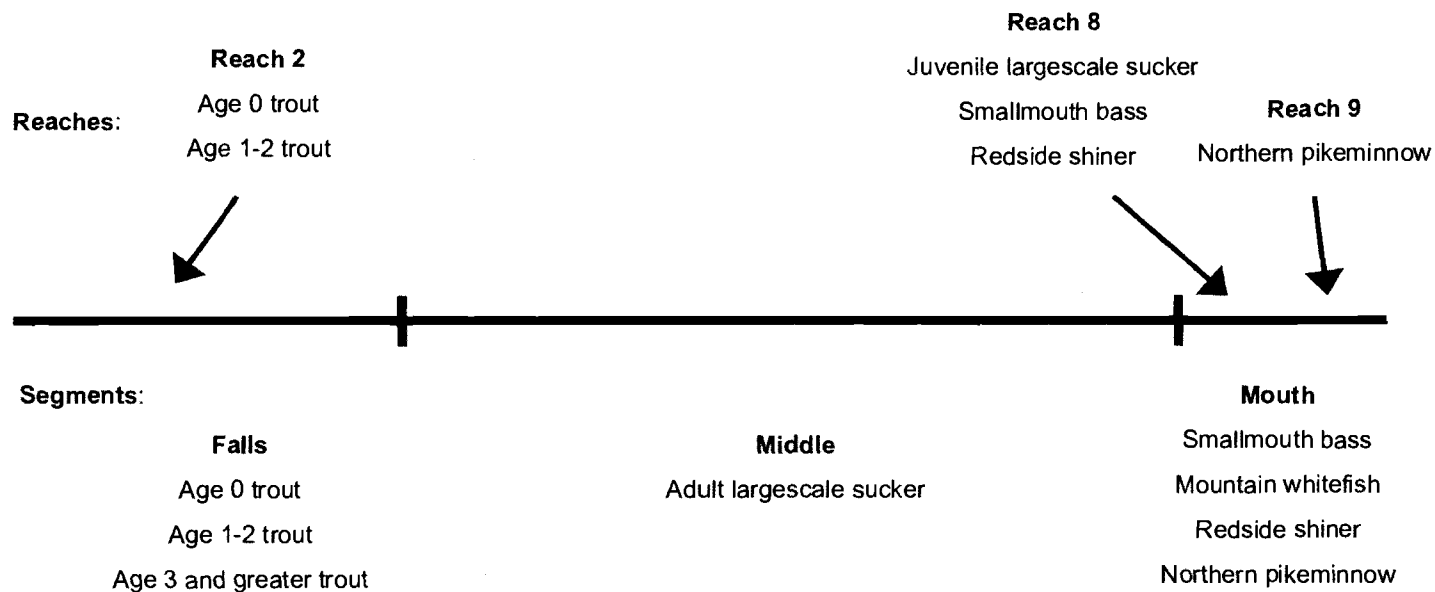


Figure 3.8. Indicator fish species and their location along the study section (ISA, $P < 0.05$). Species or trout groups above the line are indicators for reaches and those below the line are indicators for segments. Segment delimiters are approximately equivalent to spatial distance along the 51R kms of Thomas Creek.

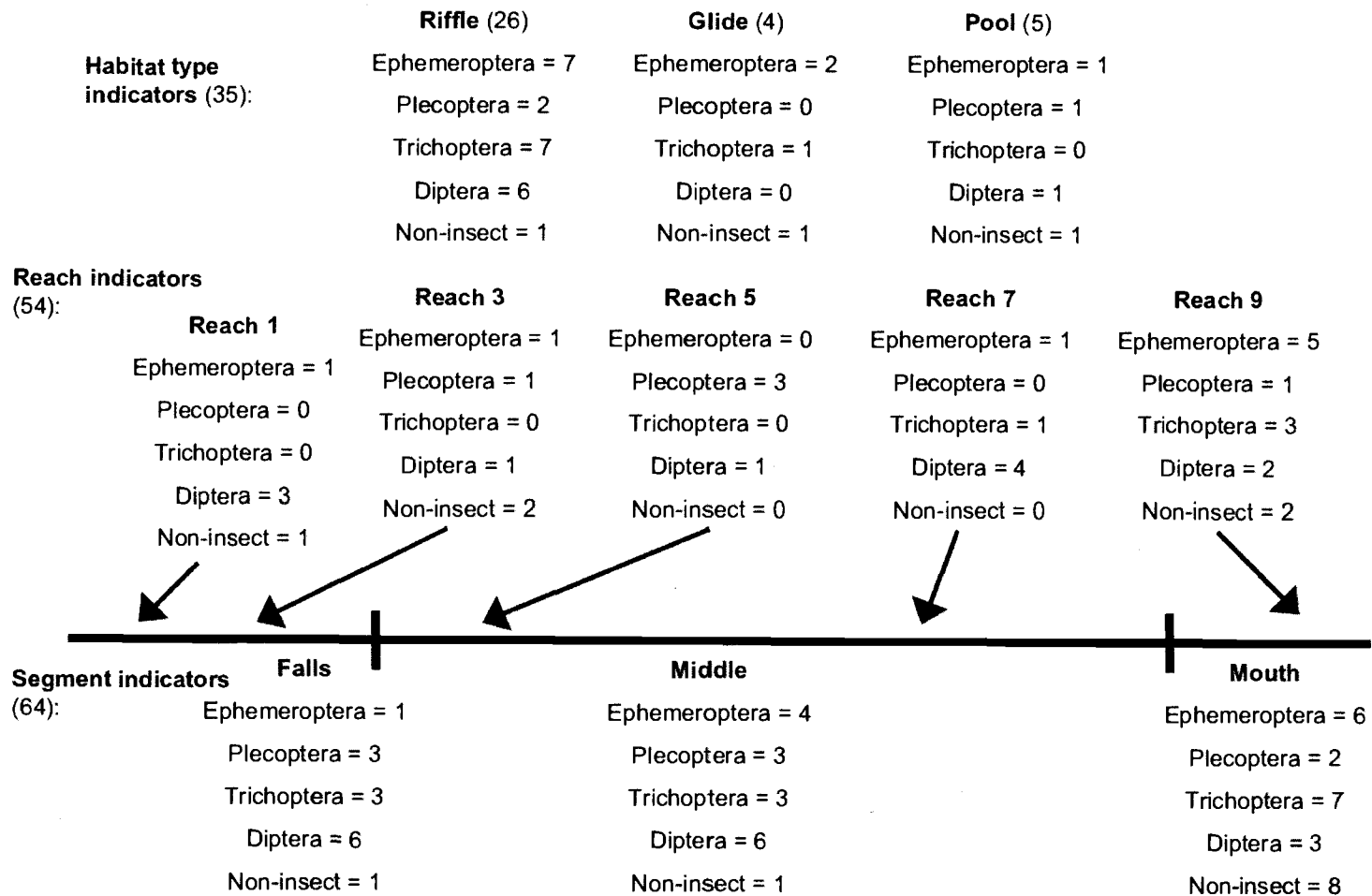


Figure 3.9. Major indicator invertebrate taxa and their locations (ISA, $P < 0.05$). Numbers represent the number of taxa indicators within each order. Taxa above the line are indicators for reaches and those below the line are indicators for segments. The numbers in parentheses are the total number of indicator taxa within categories. Breaks between segments are scaled to the 51 R km study section. See complete list of invertebrate indicators, including those for even numbered reaches, in Appendix A.

per R km (4.1) and the number of non-insects (80% of non-insect indicators were in the Mouth segment), suggests this segment was especially unique in Thomas Creek. Its proximity to the South Santiam River might explain this phenomenon.

Tolerance values were assigned to each taxon and values of 0 indicate the least tolerance for organic pollution and values of ten indicate the greatest tolerance (Mandaville 2002). Tolerance values (Tv) for indicator taxa within segments and reaches varied. For example, a stonefly (Chloroperlidae) and a biting midge (Ceratopogonidae) were both indicator taxa for the Falls segment with tolerance values of 0 and 6, respectively. A stonefly Pteronarcyidae (Tv = 0) and a true fly Psychodidae (Tv = 10) were two of the indicator taxa for the Middle segment and a caddisfly Glossosomatidae (Tv = 0) and a leech Hirudinoidea (Tv = 8) were two of the Mouth segment indicators. There were no taxa with a Tv of 9 and taxa with a Tv of 10 were very rare. Relative abundance of taxa with Tv values 0-4 were fairly consistent throughout the study section at approximately 35% (Figure 3.10). Proportions were also relatively consistent for Tv 6-10 in reaches 1-4 (ca. 10%) and 5-9 (ca. 40%)(Figure 3.10). See Appendix A for a complete taxa list including tolerance values.

Relative abundances of invertebrate functional feeding groups were similar throughout the study section of Thomas Creek (Figure 3.11). Of the 38564 benthic invertebrates collected during May 2001, ninety-seven percent were assigned to functional feeding groups. A majority of the unclassified invertebrates were individuals in poor condition that could not be identified at a resolution to confidently classify FFG. Proportionally by reach, gatherers were most abundant (average 53%); filterers, predators, and scrapers comprised from 14-17%. Seventy-eight percent of shredders were collected in the Falls segment and collectors were approximately twice as abundant in reaches within the Mouth segment as other reaches (Table 3.12). Invertebrate densities at each site ranged from 554 to 2988 and averaged 1773 individuals per square meter.

An NMS ordination of individual invertebrate samples produced a three-dimensional solution that explained 86% of variation in invertebrate

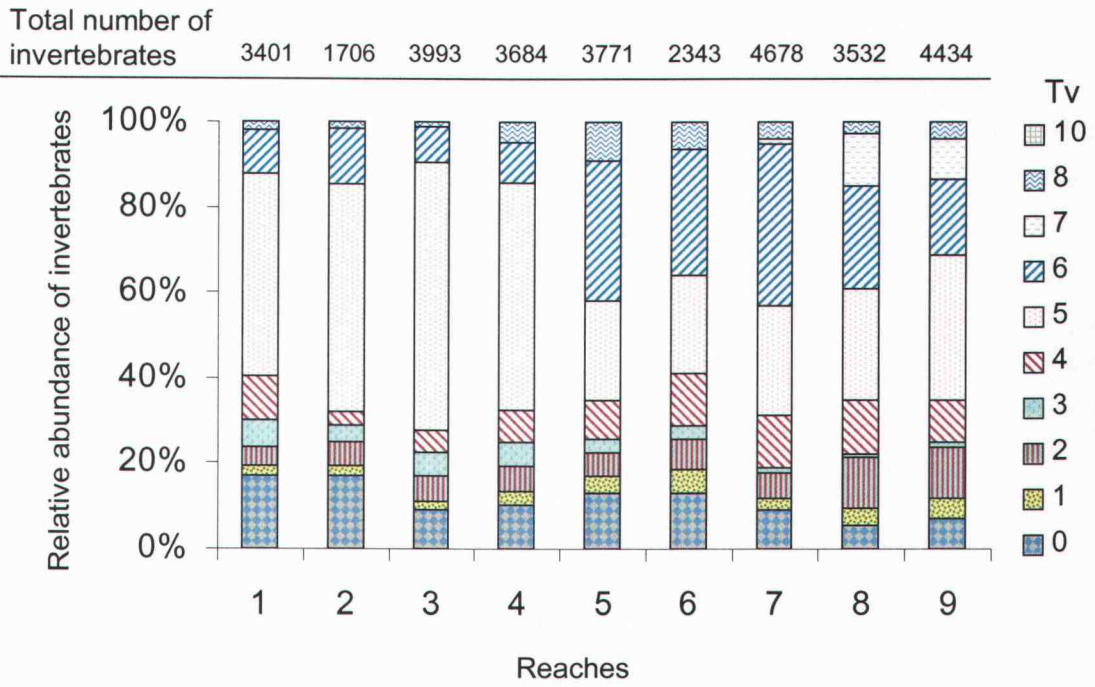


Figure 3.10. Reach-scale proportions of classified invertebrates by tolerance value (Tv). Approximately 82% of all collected invertebrates were classified by Tv. Reach 1 is upstream and Reach 9 is downstream; Tv of 0 is least tolerant and 10 is most tolerant.

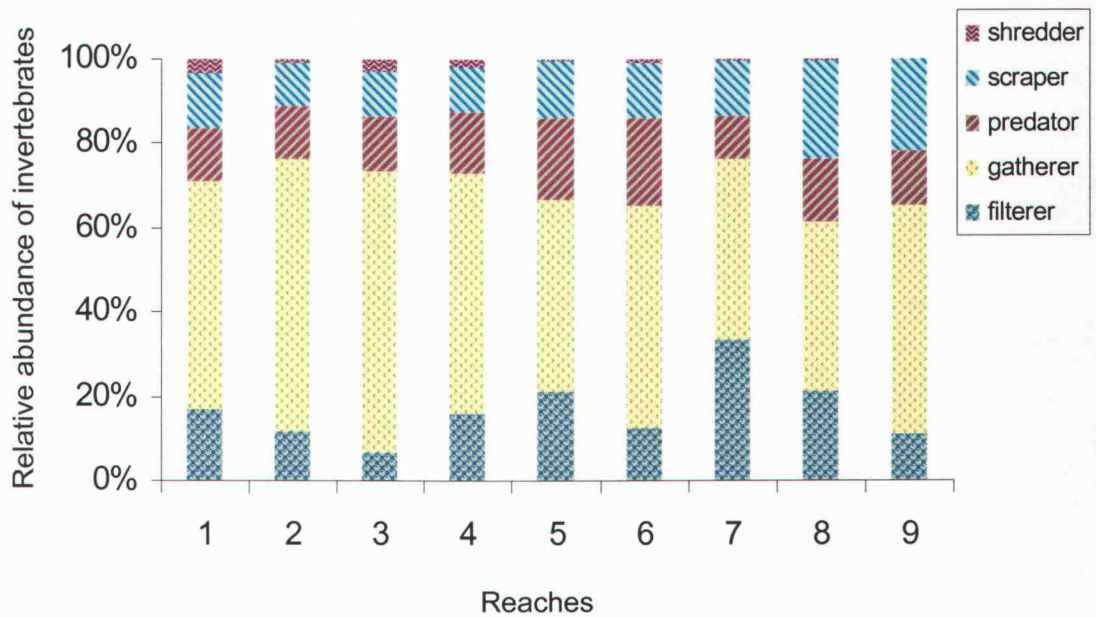


Figure 3.11. Reach-scale proportions of classified invertebrates in each Functional Feeding Group. Approximately 97% of all collected invertebrates were classified into FFG's. Reach 1 is upstream and Reach 9 is downstream.

Table 3.12. Relative abundance of invertebrate Functional Feeding Groups with values for reaches averaged by segment

Functional Feeding Group	Segment		
	Falls	Middle	Mouth
Shredder	0.20	0.06	0.02
Scraper	0.08	0.10	0.19
Predator	0.10	0.13	0.12
Gatherer	0.12	0.10	0.11
Filterer	0.08	0.16	0.11

assemblages. Axis 1 explained 25% of the total variation and was correlated with elevation. Axis 2 explained 28% of the total variation, suggesting a gradient in the data, but it was not correlated with any of the variables that I measured. Axis 3 explained 33% of the total variation and was associated with substrate size. There was a clear pattern of segments along axis 1 and a less clear pattern of unit types along axis 3 (Figures 3.12 & 3.13). Though there was considerable overlap of pool, glide, and riffle samples, pool samples generally were in the upper half and riffles were in the lower half of the ordination.

Hierarchical Analyses

To test for differences between habitat types, hierarchically averaged samples were grouped by habitat type and blocked by scale category (e.g. stream segment). There was a significant difference (MRBP, $p < 0.01$) between habitat types (e.g. pool vs. riffle vs. glide) for assemblages of invertebrates at all scales and for fish assemblages at site and reach-scales (Table 3.13). To test for differences between locations, hierarchically averaged samples were grouped by scale category and blocked by habitat type. There were significant differences ($p < 0.01$) between locations (e.g. Falls, Middle, and Mouth segments) at all scales for invertebrate and fish assemblages (Table 3.14).

In tests for differences between habitat types, within scale categories, invertebrate *A*-values were greater than fish *A*-values (Table 3.13). In contrast, tests for differences between locations, within scale categories, fish *A*-values were greater than invertebrate *A*-values (Table 3.14). Larger *A*-values suggest more similarity between blocks, therefore, invertebrate assemblages appear to be more similar across locations and fish assemblages appear to be more similar across habitat types.

Ordinations (NMS) of hierarchically averaged invertebrate assemblages produced surprisingly clear patterns. At segment (Figure 3.14) and reach-scales (Figure 3.15), NMS produced two-dimensional ordinations that explained 97% and 91% of the variation in invertebrate assemblages, respectively. At both scales, longitudinal position explains axis 1 and habitat type explains the second

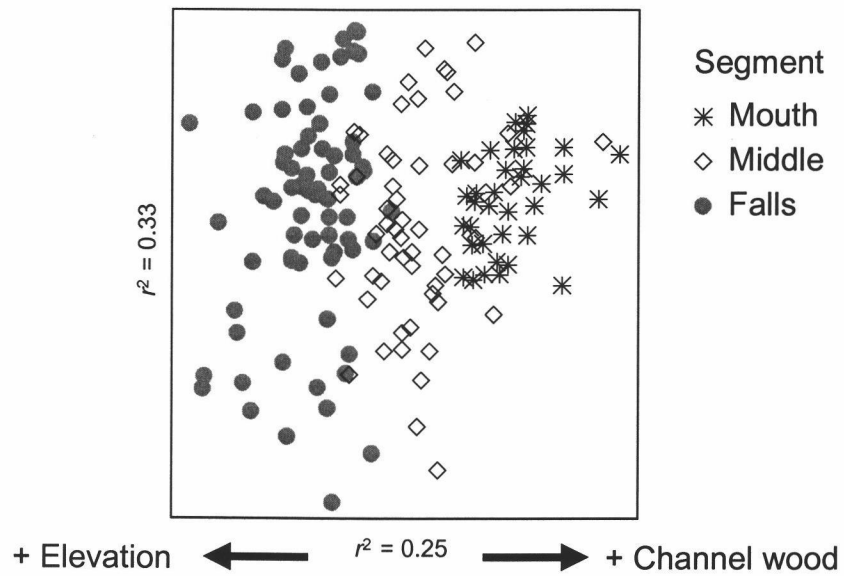


Figure 3.12. NMS ordination of invertebrate assemblages from individual samples, overlaid with segment. Each point is an individual sample.

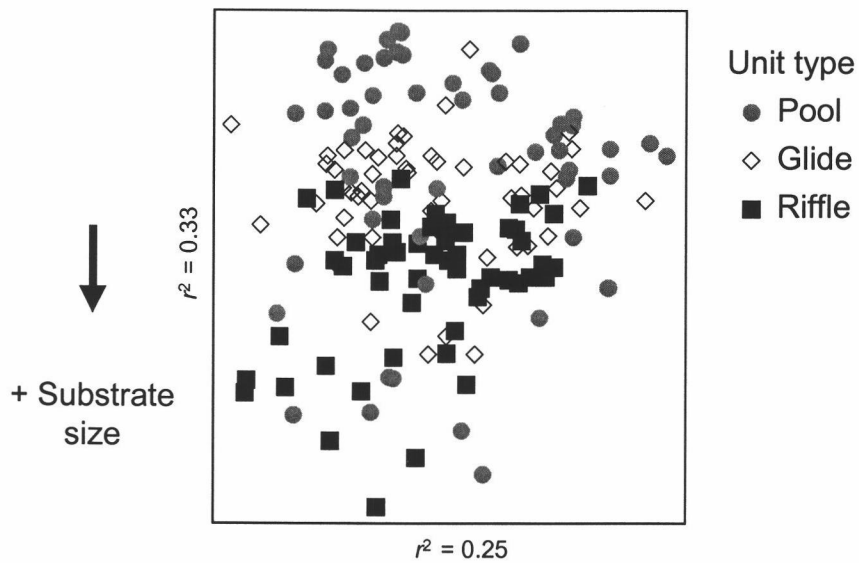


Figure 3.13. NMS ordination of invertebrate assemblages from individual samples, overlaid with habitat type. Each point is an individual sample.

Table 3.13. Differences between habitat types (e.g. pool, glide, and riffle) for fish and invertebrate assemblages at all scales (hierarchically averaged MRBP, $P < 0.05$ indicate a significant difference between habitat types). Samples were blocked by location; A-values indicate similarity among locations within a scale category (e.g. similarity among Falls, Middle and Mouth segment assemblages).

Scale category	Invertebrates		Fish	
	A-value	P-value	A-value	P-value
Segment	0.232	0.014	0.063	0.214
Reach	0.202	0.001	0.096	0.001
Site	0.110	0.000	0.025	0.015

Table 3.14. Differences between locations within a scale category (e.g. Falls, Middle and Mouth segments) for fish and invertebrate assemblages at all scales (hierarchically averaged MRBP, $P < 0.05$ indicates a significant difference between locations). Samples were blocked by habitat type; A-values indicate similarity of samples across habitat types.

Scale category	Invertebrates		Fish	
	A-value	P-value	A-value	P-value
Segment	0.322	0.009	0.451	0.012
Reach	0.270	0.000	0.432	0.000
Site	0.163	0.000	0.285	0.000

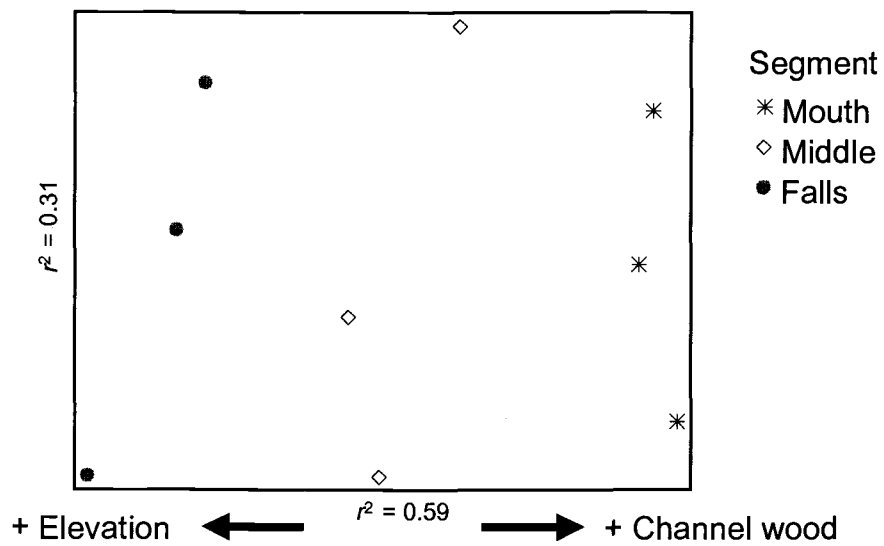


Figure 3.14. NMS ordination of invertebrate assemblages averaged by segment. Each point is an average of 18 samples per segment. Habitat types are averaged separately.

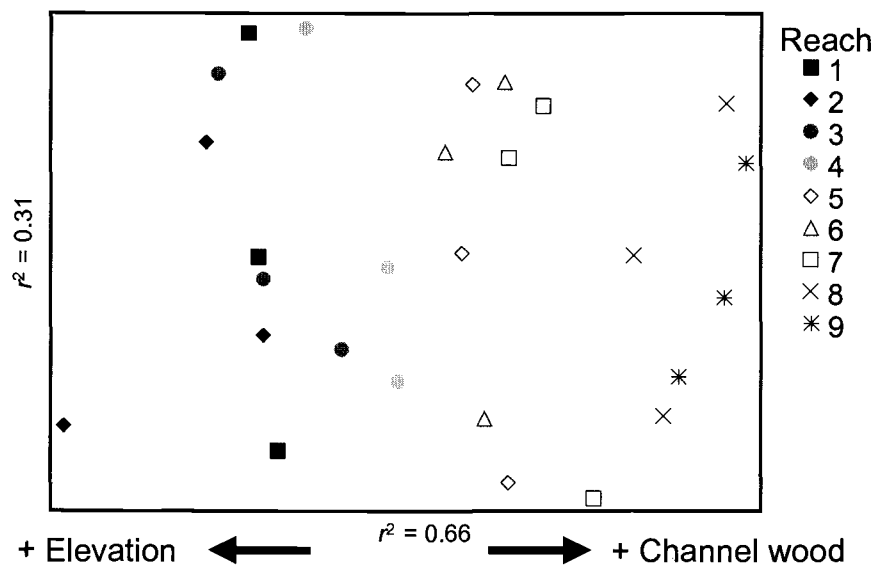


Figure 3.15. NMS ordination of invertebrate assemblages averaged by reach, overlaid with reach number. Each point is an average of six samples within each reach. Habitat types are averaged separately.

axis with glide habitats intermediate to pool and riffle habitats (Figures 3.16 & 3.17). Hierarchically averaged ordinations resulted in more variation explained by longitudinal position than habitat type; elevation and R km were both highly correlated with axis 1, which explained 66% (segment-scale) and 59% (reach-scale) of variation in invertebrate samples (Figures 3.14 & 3.15). Longitudinal changes in assemblage structure (axis 1) appeared consistent across habitat types (axis 2): within each habitat type the order of composite samples corresponded well with the longitudinal order of reaches. The second axis, which explains 31% (at both scales) of variation in invertebrate samples, was associated with velocity and substrate size increasing towards riffle habitats, and depth increasing towards pool habitats (Figures 3.16 & 3.17).

Correlations with axis 1 indicate that the midges *Orthoclaadiinae* and *Dasyhelea*, a riffle beetle larva *Zaitzevia*, a flatworm *Turbellaria spp.*, the snail *Lymnaeidae/Ancylidae spp.*, and many other invertebrates increased in abundance downstream, while only the stonefly *Calineuria* and small *Oligochaeta spp.* had strong upstream associations. Generally, invertebrate taxa associated with axis 2 (habitat type) were moderately abundant in glides and most abundant in riffles (e.g. the caddisflies *Hydropsyche/Ceratopsychae*, the stonefly *Hesperoperlia*, and the mayflies *Epeorus* and *Pseudocloeon*, etc). Only the midges *Tanypodinae* and the mayfly *Ameletus* became more abundant in pools.

Generally, invertebrate taxa correlated with each axis were also indicator species (Appendix A). In some instances, Indicator Species Analysis was more informative than correlations with ordination axes. Of the eighteen Middle segment indicator species, only the mayfly *Acentrella* was associated with the longitudinal axis. Among others, the caddisfly *Tricorythodes*, crane fly *Antocha*, mayfly *Cinygmula*, and stonefly *Cultus* were indicators for the Middle segment and were not associated with the longitudinal axis.

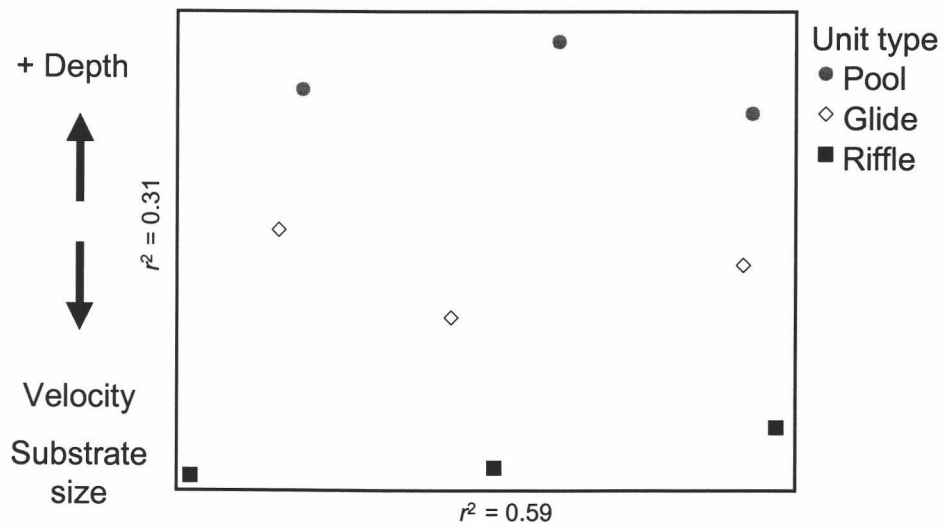


Figure 3.16. NMS ordination of invertebrate assemblages averaged by segment, overlaid with habitat type. Each point is an average of 18 samples within a segment.

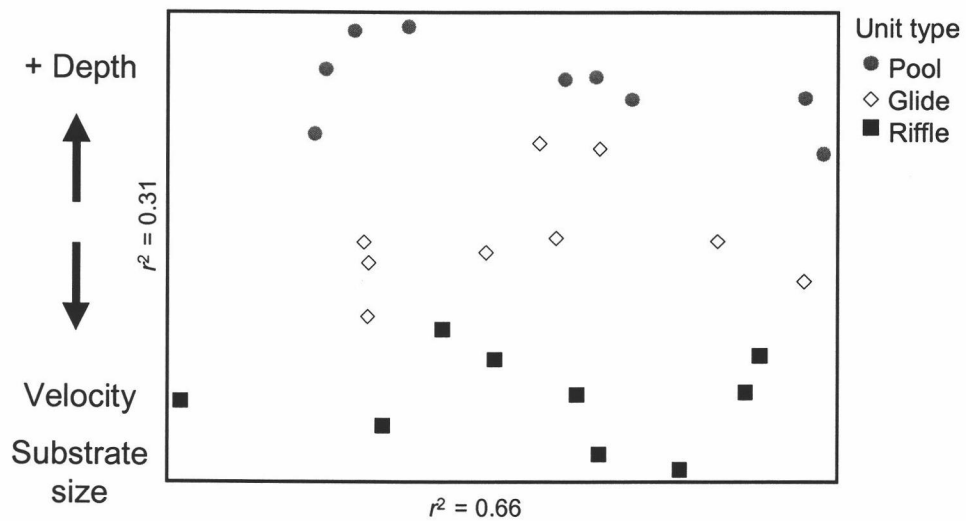


Figure 3.17. NMS ordination of invertebrate assemblages averaged by reach, overlaid with habitat type. Each point is an average of six samples within a reach.

Discussion

Longitudinal Patterns

Fish have been described by longitudinal patterns with gradual, continuous changes (Evans and Noble 1979, Paller 1994), or distinct zones with rapid transitions (Matthews 1998, Propst 1982 cited in Rahel and Hubert 1991). See Hawkes (1975) for a review of early zonation studies. In Thomas Creek I observed a pattern strikingly different from any of these previous studies. A sparsely populated Middle segment (Figures 3.4 & 3.5) separated an almost exclusively salmonid populated Falls segment and a Mouth segment dominated non-game fish. In the Middle segment, one third of the surveyed units contained no fish (half of all glides); fish densities were approximately one third to one half of the other segments (Tables 3.3 & 3.4). The only fish indicator species for the Middle segment was adult largescale sucker that was rare throughout the creek. Outside of a study that attributed several downstream sites lacking fish to organic pollution and low dissolved oxygen (Vila-Gispert et al. 2002), this is the first report of a fish-depauperate zone between upstream and downstream fish assemblages. Although largescale suckers are considered tolerant species (Zaroban et al. 1999), I was unable to determine if habitat complexity or water quality conditions were influencing fish assemblages in this segment. There were no obvious sources of pollution and water quality parameters including dissolved oxygen were well within state water quality standards (see chapter 2).

Structures within the channel such as boulders (Streubel and Griffith 1993), and large (Abbe and Montgomery 1996, Bilby and Ward 1991) and fine wood (Culp et al. 1996) increase habitat complexity and provide cover for fish. Channel characteristics that I measured were not easily converted to habitat complexity indices. However, the Falls and Mouth segments appeared to have more complex habitats than the Middle segment. The Falls segment was estimated to average 9 boulders per 100 meters during a 1992 survey (ODFW 1930-2001), and 11% of survey units contained at least one piece of large wood during my survey in 2001. Accumulations of greater than five pieces of large

wood were, by far, most common in the Mouth segment (Table 3.1), and 74% of surveyed units contained at least one piece of large wood. Only 26% of survey units in the Middle segment contained more than one piece of large wood. Compared to boulders and large wood in the Falls segment and large wood in the Mouth segment, the Middle segment appeared to have fewer channel structures. Stream power and channel complexity have a direct impacts on retention of large wood (Abbe and Montgomery 1996). Therefore, large wood may have been rare in the upper reaches because of high stream power and relatively simple channel structure. In Reach 8, where accumulations averaged 3.7 /R km, the channel gradient was low and the channel was complex with high sinuosity and numerous braided channels. These factors, in conjunction with reduced stream power, likely result in wood being retained after passing through the upper and middle reaches without snagging. Non-salmonid fish assemblages were better correlated with large wood accumulations than salmonids because salmonids were rare in the downstream reaches.

In other studies, rapid transitions of fish assemblages were attributed to sharp environmental changes caused by land use (Hawkes 1975) or rapid geomorphic changes (e.g. elevation, waterfall) (Edds, 1989, Balon and Stewart 83). With the exception of a gorge in Reach 2, stream characteristics in Thomas Creek gradually change downstream without sharp changes in geomorphic or environmental conditions. The valley widens and agriculture land use increases gradually (Figure 2.1). Although Middle and Mouth segment riparian forests were somewhat narrow and discontinuous in some locations (Bischoff 2000), riparian vegetation composition changed gradually and remained fairly intact in most locations. Elevation changes gradually (Figure 3.3); pool lengths increased and riffle lengths decreased in a downstream direction, while wetted-width remained relatively constant (Table 3.2). Therefore, I expected a gradual shift in fish assemblage structure as the creek transitioned into the valley. Surprisingly, fish assemblages in the Middle segment were quite unique and significantly different from the Falls and Mouth segments (Table 3.14). Additionally, small MRBP A-values within segments suggest transitions between assemblages were rapid.

Differences in survey approaches may account for dissimilar outcomes in longitudinal studies. Site-based studies generally result in strong differences between zones and an inability to determine how rapidly transitions occur. At two sites along a Wyoming stream continuum there was a strong change from a trout dominated zone to a sucker-minnow zone (Rahel and Hubert 1991). The change in elevation between those two sites was 420 m, which was greater than the change in elevation over my entire study section. Because the investigators used a site-based approach, they could not determine how rapidly or precisely where the change occurred. Furthermore, authors used proportional data to describe sites, which could potentially indicate two very different samples are similar, mask longitudinal density patterns, and/or reduce the significance of rare species.

Generally, Thomas Creek fish were native, cold or cool water species that are sensitive or intolerant of anthropogenic disturbance. The upstream fish assemblage could be characterized as a cold-water, disturbance sensitive guild, while the Middle and Mouth segment assemblages were a cool-water, intolerant guild (Zaroban et al. 1999) (Figure 3.5). The only warm-water fish were single individuals of non-native brown bullhead (*Ameiurus nebulosus*) and sunfish (*Lepomis spp.*) during 2000. Absolute densities describe a patchy distribution where adjacent units were often quite dissimilar, and the longitudinal transition from cold to cool-water fish assemblages appeared long and depauperate (Figure 3.5). However, a moving average of relative abundances, within each survey unit, produced a gradual transition between cold and cool-water species (Figure 3.18). The long depauperate zone suggests that in addition to temperature, some unmeasured conditions were driving fish assemblage patterns. Perhaps, the frequency of habitat units with undesirable physical conditions (e.g. increased glide widths or decreased habitat complexity) increased in this segment. Some habitats with similar physical dimensions (e.g. length or depth) can have very different hydraulic characteristics (e.g. sheer stress) (Statzner et al. 1988), which may explain non-significant differences of some dimensions between empty and occupied survey units. Survey timing may

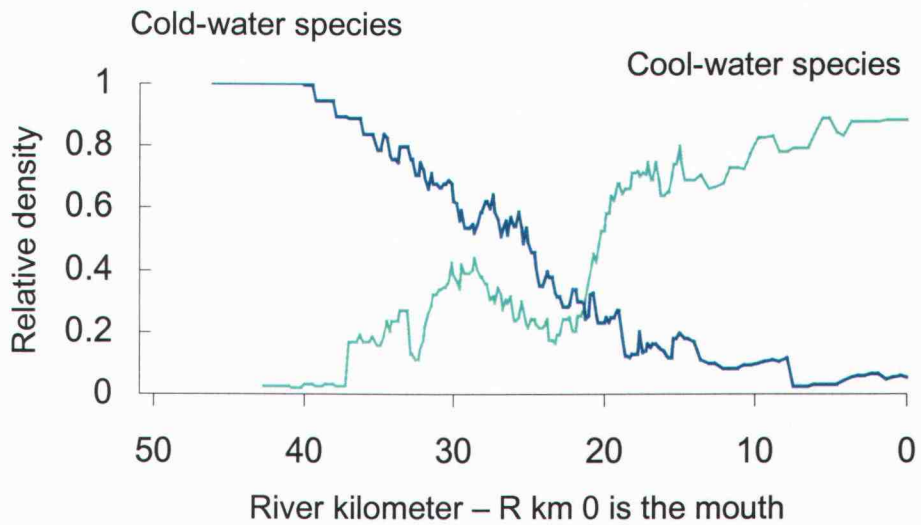


Figure 3.18. Moving averages of relative densities of cold and cool-water species within each survey unit. The lines are moving averages of 20 survey units. The dam remnants are at Rkm 30.

account for some of the patchiness and disconnection between thermal/disturbance tolerance guilds.

Seasonal changes in assemblage structure can be high in some instances (Baxter 2002) and lack of additional surveys limit my ability to discuss temporal variability and how it may have influenced patterns that I observed. However, the intensive snorkel surveys conducted in July and September indicate fish are apparently moving between seasons in Thomas Creek. Abundance changes that ranged between negative 89% and positive 335% (Table 3.9) imply seasonal movement, apparently associated with neither pool availability nor temperature. The greatest increases in abundance were in a gorge reach where pool area decreased over 40 percent during a period with lower water temperatures. Larger bodied salmonids were apparently preferentially selecting the gorge reach, but reasons for this behavior are unknown. In addition to temperature, ontogenetic differences in distribution or habitat use (Moyle and Vondracek 1985, Streubel and Griffith 1993) may have influenced distribution patterns (e.g. largescale sucker, Figure 3.4). Two months after my extensive survey, maximum stream temperatures reached approximately 30°C at locations with the highest densities of juvenile suckers. Presumably these cool water species moved, but without downstream surveys late in the year I cannot tell how the cool water species responded to high temperatures.

For invertebrates, differences between segments were distinct, yet assemblage changes appeared to be gradual (Figure 3.15) and occurred over greater longitudinal distances than for fish. Similarities of sites within segments were quite high ($A = 0.155-0.160$), which suggests that invertebrate assemblages were similar at greater longitudinal distances than segment lengths. There were both segment-specific and generalist invertebrate taxa. Similarly, within a 1000 m change in elevation, many species were observed to replace other species, and others were generalists throughout 39 R km of a Colorado stream (Allan 1975). In contrast to fish patterns, the Middle segment was intermediate to Falls and Mouth segments for the number of invertebrate indicator species, richness, and abundance.

One might expect proportions of FFG in assemblages to change in a stream that travels 51 R kms through diverse land use types. Similar to 80 R kms of a Colorado stream (Perry and Schaeffer 1987), land use changes dramatically within the Thomas Creek study section. Both of these streams differ from 48 R kms of an Idaho stream where land use is similar throughout (DeLong and Brusven 1998). Irrespective of land uses, no corresponding changes in FFG were observed in any of the three streams. The RCC predicts mid-order streams to be dominated by collectors and scrapers in approximately equal proportions (Vannote et al. 1980). My observations of assemblages dominated by collectors (ca. 69%), may result from the size and characteristics of Thomas Creek.

Although land use changes dramatically along the study section, stream physical conditions (e.g. channel width, average depths, etc.) were similar throughout the 51 R kms (Tables 3.1 & 3.2). Additionally, the study section is categorized 3-5th order, but it is larger than many streams of similar order. For example, Thomas Creek has approximately 25 percent less land area than nearby similar watersheds (similar elevations, geology, vegetation, land use, etc), yet mean annual peak discharge is within $100 \text{ ft}^3\text{s}^{-1}$ of these larger watersheds ($1100\text{-}1200 \text{ ft}^3\text{s}^{-1}$ peak) (England et al. 2001, Graves et al. 2002). Even the third order section is not safely wadeable during at least six months of the year. Matthews (1998) suggested that stream order for ridge-and-valley streams, such as Thomas Creek (Figure 2.1), would need to be increased by one or two for conditions to match dendritic streams. This would suggest Thomas creek is more similar to a six or seventh order stream, which supports my observations of assemblages with large proportions of collectors. If I had included the headwaters with narrower channels and closed riparian canopies (likely stream orders 1 or 2 in this case), a more obvious longitudinal change in FFG proportions would be expected.

Although assemblages based on FFG proportions were relatively constant throughout my study section, I observed a longitudinal change in assemblages based on taxa composition (Figures 3.14 & 3.15). This supports a study that documented four distinct assemblage types along 80 R kms (Perry and Schaeffer

1987) but contrasts with a study that did not observe a change in assemblage taxa composition along 48 R kms (DeLong and Brusven 1998). The changes in assemblage composition along Thomas Creek appear to be gradual and include species addition more than replacement. Most invertebrates associated with the longitudinal axis, had increased abundances downstream (e.g. the caddisflies *Brachycentrus*, *Cheumatopsyche*, and *Oecetis*, and the mayflies *Heptagenia* and *Acentrella*). Oligochaetes of different sizes appear to be longitudinally replaced, with small ones (<5mm) found upstream and large ones (>1.5 cm) found downstream. In a similar gradual gradient of species additions and replacements, changes in Cement Creek, Colorado, occurred over a much greater change in elevation (1000 m versus 308 m) and presumably stream characteristics (Allan 1975). Different distribution patterns for genera within a family indicate genus level identification often is required to detect a longitudinal gradient.

Correlation of abundances with each of the ordination axes indicates some genera were associated with particular habitats, longitudinal position, or both. For example, mayflies *Attenella* and *Serratella* increased in a down-stream direction, while *Drunella* abundance increased in riffles. All three of these ephemereids are considered gatherers, but they were apparently responding to stream conditions differently. The water pennies *Psephenus* and the caddisfly *Glossosoma* were correlated with both axes indicating increased abundances in downstream riffles.

Habitat Use

I observed significant differences between habitat associations for assemblages of fish and invertebrates and this study supports previous ones documenting fish selectivity of specific habitats. In other studies of *O. mykiss* habitat use, habitat selectivity (Bisson et al. 1988, Fausch 1985, Roper et al. 1994, Streubel and Griffith 1993), seasonal shifts in habitat use (Baltz et al. 1991) (Heifetz and M. L. Murphy 1986, Hillman et al. 1987, Simpkins et al. 2000, Smith and Griffith 1994), ontogenetic differences in habitat use (Baltz et al. 1991,

Cunjak and Green 1983, Werner and Gilliam 1984), and competition for habitat use (Fausch 1984, Fausch 1988, Reeves et al. 1987) were documented. Habitats used for feeding (Fausch 1984) and habitats used for concealment or refuge (Everest and Chapman 1972, Riehle and Griffith 1993, Smith and Griffith 1994) have also been examined. Interestingly, all of these studies focused on one or two species and did not consider assemblage differences in habitat use. During the intensive upstream survey, I observed strong fish preferences for specific habitat and sub-habitat types (Tables 3.6 & 3.7) by individual fish groups. However, individual behaviors or patterns may not translate into large-scale patterns (Peckarsky et al. 1997).

In this study, NMS ordinations of data collected at the habitat unit-scale failed to detect a strong enough pattern to create a reliable ordination. Potential explanations include: inconsistent differences between fish assemblages at different locations, too few taxa groups, or taxa that are mobile enough to reduce the importance of heterogeneity at the habitat unit-scale (Wellnitz et al. 2001). When I averaged all habitat types within a site, NMS produced a reliable ordination (Figure 3.7). Fish can readily move between habitat units, and averaging samples at this scale reveals a pattern previously undetected. Unfortunately, by combining survey units much of the specific information is lost as a result of averaging. Though biological mechanisms driving patterns may be revealed with fine-scale studies (e.g. habitat preference), broader patterns (e.g. longitudinal distribution) may require collapsing information (Wiens 1989).

Habitat use by fish in Thomas Creek changes longitudinally. In particular, salmonid habitat preferences changed from Riffle/pools in Reaches 1-3 to riffles and Glide/pools in Reach 4 (Table 3.6). The only other longitudinal study of juvenile rainbow trout habitat use, found they prefer pools upstream and riffles downstream (Roper et al. 1994). In Thomas Creek these changes may result from competitive interactions with downstream fish species, particularly redbreasted shiners. At warmer water temperatures, redbreasted shiners can out-compete juvenile rainbow trout for food resources in pool but not riffle habitats (Reeves et al. 1987).

Habitat indicator species were limited to larger bodied fish in pools. Riffle indicators and patterns may have clarified, if I had used other techniques to quantify benthic species. For example, electroshocking during year 2000 surveys captured longnose dace (*Rhinichthys cataractae*) almost exclusively in riffle habitats with adequate interstitial space. Including dace and sculpin would potentially strengthen structure within the data.

There were strong differences in fish assemblages between habitat types at reach- and site-scales, but not at the segment-scale (Table 3.13). The shift of salmonid habitat preferences within the Falls segment (between Reaches 3 and 4) may account for non-significant differences between habitat types at the segment-scale. Data were blocked, thus removed location effects, reduced variation, and clarified patterns of habitat use at other scales. Even blocking would not reduce variation caused by changes in habitat use.

In contrast to fish ordinations, NMS analysis of invertebrate assemblages produced reliable ordinations with clear patterns (Figure 3.14 & 3.15). The difference between fish and invertebrates may result from more strict physical and/or physiological requirements of invertebrates. Smaller sizes and more restricted mobility of invertebrates, suggest that they rely on finer-scale local stream conditions. For example, many filter feeders are adapted to specific hydrologic conditions, while some scrapers are morphologically restricted to particular algal growth patterns (Merritt and Cummins 1996). Distinct invertebrate assemblages between habitat types were consistent throughout the entire study section, and longitudinal changes within habitat types appeared consistent for all habitat types (Figure 3.16 & 3.17).

In contrast to fish, invertebrate indicators were most numerous in riffles (74% of the total, Figure 3.9). Only one mayfly scraper (*Cinygmula*) was an indicator for non-riffle habitats. It is likely that conditions for adequate periphyton production do not occur in pools (particularly deposition during low flows), and periphyton accumulations may not be structured to maximize efficiency of scrapers' specialized mouthparts. Potentially, these conditions would limit scrapers occupancy of pool habitats. Surprisingly, only 28% of riffle indicator

taxa were classified as scrapers. Collectors (52% of riffle indicator taxa, such as the mayflies *Acentrella* and *Serratella*) may find suitable habitat and feeding conditions in the interstitial spaces of riffles.

There were not strong differences between invertebrate assemblages from reaches within segments but there were significant differences between habitat types. This may be a result of invertebrates responding to environmental conditions at scales broader than segments and finer than habitat units. Finer taxonomic resolution may improve distinctions between assemblages at broader-scales. For example, two species within the same genus may clearly replace each other longitudinally, but genus level identification would reveal an even distribution.

More complex definitions of habitat types may help clarify patterns of fish and invertebrate assemblages. Potentially, more complex definitions would increase the number of habitat types and decrease the number of replicate samples that could be collected. Additionally, for 11 different habitat types defined in a Missouri stream, local conditions explained more variation than longitudinal position but did not clarify habitat type patterns (Doisy and Charles 2001). Therefore, research objectives must be carefully considered before decisions can be made about the number and types of habitats studied.

Because I observed strong changes of invertebrate assemblage composition but not FFG proportions, observed changes of assemblages may result from changes in habitats or biotic interactions rather than resource availability. To determine what invertebrates are responding to, beyond basic channel characteristics (e.g. depths, substrate sizes, or water velocities) will require further investigation. For example, closer examination of sediment deposition may prove insightful for invertebrate patterns (Miyake and Nakano 2002, Shaw and Richardson 2001). Additionally, species level identification might reveal other responses to longitudinal position or habitat use.

Although longitudinal patterns I observed for fish and invertebrate assemblages were somewhat different, all scales I used appear to be appropriate for studying both fish and invertebrates. Notably, different sampling designs and

statistical methods were required to detect patterns at some scales. Sacrificing resolution of invertebrate surveys allowed more samples to be collected and helped to clarify patterns. Sacrificing precision of fish surveys (through single pass snorkel surveys), increased survey area and allowed more continuous data collection (Torgersen et al. 1999). But in some instances patterns were only revealed by blocking observations according to location. To measure habitat electivity, finer-scale intensive surveys were required. However, local conditions that influence invertebrates and scales of study to examine these factors (e.g. cobble-scale), are not likely appropriate for fish. Rapid movement by organisms within a scale makes heterogeneity at that scale less important (Wellnitz et al. 2001). Fish can easily move cobble-scale distances, thus making habitat heterogeneity at that scale less important and likely irrelevant for fish. However, boulder-scale habitat heterogeneity might be important for fish.

Potentially, the strong longitudinal pattern I observed results from hierarchically averaging samples. Longitudinal invertebrate studies that use ordination techniques for analysis of individual samples, generally observe that local factors are more important than longitudinal factors for structuring stream invertebrate assemblages (Brown and Brussock 1991, Doisy and Charles 2001). Similarly, ordinations of my invertebrate data from individual samples, resulted in more variation explained by local conditions than longitudinal position (Figure 3.12). Combining samples by habitat types within reaches, reduced variation of assemblages within habitat types and emphasized the longitudinal pattern.

As scale decreased (e.g. from segment- to reach-scale), similarity among sites increased for fish (Tables 3.10 & 3.11). Similarities between fish assemblages within segments were small (Table 3.10), but they were highly similar within reaches (Table 3.11). These results suggest that fish were responding to environmental conditions between reach- and segment-scales in Thomas Creek. For example, seven-day moving-averages of high temperatures within the Falls segment ranged from 16 to 21°C; resulting in temperatures above the 303d maximum temperature (17.8°C) for much of the 13 R km Falls segment. However individual reaches did not exhibit the same broad temperature ranges.

The shortest reach in this segment was 1.5 R kms, where water temperature only increased approximately 1°C over this distance. This minor temperature change was likely insufficient to cause salmonids to alter behaviors, potentially resulting in similar assemblages throughout this reach.

The clear and consistent habitat type pattern that I observed for invertebrate assemblages at multiple scales (Figures 3.16 & 3.17), suggest that three simple habitat definitions were adequate for studying invertebrates at all but the finest scales (e.g. cobble) in Thomas Creek. Invertebrates responding to local and broad-scale conditions support previous findings that invertebrates respond to conditions at cobble and finer scales (Wellnitz et al. 2001) as well as large longitudinal changes (Allan 1975). It appears that fish were responding to conditions at shorter longitudinal distances (e.g. shorter than segments) and broader local conditions (e.g. broader than habitat type) than invertebrates. However, differences in taxa numbers and richness may influence results. Fish had far few abundances and richness numbers per sample (Table 3.5), which can be influential in multivariate analysis (McCune et al. 2002).

This study revealed longitudinal patterns differ between fish and invertebrates in Thomas Creek. Generally fish had patchy distributions and upstream assemblages were disconnected from downstream assemblages by a depauperate Middle segment. In contrast, invertebrate assemblages gradually changed from upstream to downstream. Surprisingly, physical longitudinal distance did not correspond with ordination longitudinal distance. Differences between reaches within the Falls, Middle, and Mouth segments appeared to be relatively equal for invertebrate assemblages (Figures 3.14 & 3.15), but elevation changes and longitudinal distances within and between reaches along Thomas Creek were quite different (Table 3.1). This suggests that invertebrates were responding to conditions more complex than longitudinal distances or changes in elevation. Biological responses of diverse taxa along a longitudinal gradient required different sampling and analytical techniques to detect changes at multiple scales.

4. Summary

My perception of scale, longitudinal structure of streams, and the importance of site selection changed during this study. Viewing the entire study section on several occasions was beneficial and insightful. By floating down the entire 51 R km section twice, snorkeling it once, and walking a majority of the falls segment numerous times, I saw variation in the stream at multiple scales. Initial observations and perceptions led me to select a 30 R km study section in the year 2000. Preliminary results from my 2000 study and observations during my first full stream float, caused me to realize river distance does not always equal biologically relevant distance. Although 30 R kms is much longer than many studies that find significant biological differences, differences in Thomas Creek were minimal. It was not until I added 21 R kms to the survey area in 2001 that patterns became clear. By including the upstream and downstream ends of the 51 R kms, I found strong longitudinal patterns. Additionally, I realized the limitations of site-based sampling.

Parametric statistical theory requires that site selection is random; however, basin-wide studies in privately-owned landscapes are usually selected based on access and perceived representation of specific locations. When a site is unusual (e.g. near Jordan dam in this instance) or an outlier, it can have dramatic influences on results. For example, during my 2000 invertebrate survey abundances collected near the dam (site 3) were approximately double the average of the eight other year 2000 sites. Although this site was physically located near the upstream sites (1 and 2), in the ordination it grouped with downstream sites having higher abundances. Furthermore, abundances in 2001 from this location were in the middle range when compared with invertebrate abundances from the other 26 sites. Sacrificing some resolution to increase the number of sites reduced the influence of what appeared to be an outlier in 2000.

Snorkeling also changed how I perceived streams. During the first few hours underwater in my study area, my understanding of the stream and study organisms changed. On one occasion during hook-and-line sampling in 2000,

my assistant was underwater while I was fishing. I would feel bites on virtually every cast and catch a fish approximately every third or fourth cast. While underwater, my assistant observed five to ten strikes at the lure for every one that I felt. Sometimes the same fish continued to strike until it was caught and other times several different fish would strike the lure. This may influence the results of studies using hook-and-line capture techniques. Relying on fish to strike and be caught may introduce biases based on the aggressiveness and experience of the target fish. Fish that pursued the lure may have been either dominant, the most aggressive, or naive to fishing lures. Consequently, the captured fish may not be a representative sample of fish occurring at that particular site.

Surprisingly, perceptions of invertebrate distribution can change after snorkeling. Patchy and highly variable, invertebrate distributions were very distinct when viewed underwater. Simuliid larvae often occur in large patches on solid substrates in flowing water. I commonly observed patch shape to be highly variable and expected distribution to be based on currents and velocity. In contrast, I observed several large, dense patches of larvae experiencing obvious differences in currents and velocity (based on larvae moving with the current), yet density was consistent throughout the patches. Surber placement on these patches would influence simuliid density in samples. Without measuring conditions (e.g. hydraulic parameters) that are influencing these densities and shapes, patterns and characteristics of habitat use may go undetected. As a result of these observations, my perceptions of scale and pattern changed throughout the study and I would recommend that anyone studying streams view them, at least once, from underwater.

Frequently interacting with a variety of landowners provided me insight into how people perceive streams in their backyards. To initiate contact and gain permission to visit sites, I knocked on doors of homes with reasonable access to Thomas Creek. I described my intention to study fish and insects in the creek and how they responded to riparian and water quality conditions. By far, the most common reply was, "Study fish in Thomas Creek? There aren't any fish in

that creek." The second most common reply was "You're going to swim in that creek? I wouldn't swim in there." Both opinions were enormous misconceptions. Fish were abundant (greater than 95% were native species) and bacteria counts were well within state standards. With the exception of two landowners that denied access to the creek, everyone I contacted was excited to have research occurring in their backyard. My hope is that my relationship with these landowners will have direct impacts on their perception of science and research, which could influence future research and restoration projects in Thomas Creek.

In preliminary surveys, longitudinal patterns appeared relatively weak. NMS ordinations of benthic invertebrates from nine sites along 30 R kms, suggested that longitudinal changes in assemblage structure were minor and likely driven by three sites in the upper reaches (Figure 2.4). Invertebrate assemblage composition was not associated with riparian vegetation composition, stream gradient, or discharge. Steelhead and rainbow trout diet ($n=53$) in the middle and upstream reaches did not reveal longitudinal patterns of prey number or composition; adults of aquatic insects were the primary prey consumed. However, riparian and channel surveys revealed most of the sample sites in 2000 were in a single reach type.

By extending the length of stream surveyed in 2001 to 51 R kms, patterns for fish and invertebrates became clearer. Both groups were associated with broad-scale environmental conditions particularly elevation, river kilometer, stream temperature. Extensive downstream snorkel surveys revealed two distinct fish assemblages: salmonid dominated (cold species) and non-game fish dominated (cool species). The transition between these two zones (between R kms 20 and 39) was populated sparsely by members of both assemblages. Fish were not associated with local conditions (e.g. water velocity, substrate size, depth) and differences between habitat types were only detected by reducing location effects (blocked design). Intensive snorkel surveys of upstream reaches, revealed habitat preferences (pools with riffles directly upstream) for individual fish groups.

Benthic invertebrate assemblages demonstrated strong longitudinal (broad-scale) and habitat type (local conditions) patterns. Densities of some genera were correlated with the longitudinal and/or habitat axes of NMS ordinations. This suggests that similar to fish, individual invertebrates had habitat preferences. But in contrast to fish, invertebrates did not demonstrate a depauperate zone and assemblages exhibited strong patterns based on habitat types. Additionally, fish assemblages changed rapidly and invertebrate assemblages changed gradually along distinct topographic and vegetation zones.

Multivariate statistical techniques revealed broad-scale patterns of fish and invertebrates in Thomas Creek were similar along a 51 R km transition from mid-elevation (ca. 365 m) conifer dominated reaches to Willamette Valley agriculture dominated reaches (ca. 73 m). However, assemblage transitions and fine-scale patterns differed. My results demonstrate the importance of extensive surveys with continuous data or numerous sites. Resource managers should consider fish and invertebrates simultaneously, because they appear to respond differently to the same environmental conditions. The fact that much of an organism's energetic requirements, potential for resource exploitation, and susceptibility to natural enemies depends on its size (Werner and Gilliam 1984), explains some of the differences in fish and invertebrate patterns.

Additionally, this study demonstrates that methods chosen for processing and analyzing invertebrate samples can have profound effects on research results. Composite samples emphasized strong longitudinal patterns while individual samples emphasized the effects of local conditions. Because identification and analysis of invertebrate samples can be time consuming, sample design is critical for studies and monitoring. If the objective is to monitor streams or detect large-scale patterns, combining samples within habitat types is likely adequate. Combining samples within habitat types compromises between maximizing (analyzing individual samples) and minimizing (combining all samples) information about local conditions. Given the patterns I observed were consistent within habitat types, sampling from one habitat type might be an

adequate, cost effective method for future monitoring or detection of broad-scale patterns in Thomas Creek. However, this technique would greatly reduce information gathered about local conditions, so it must be considered carefully. If fine-scale information is desired, combining samples will likely be inadequate as patterns of local variation would be lost. For example, combining riffle and pool samples would lose variation caused by different depths, substrates, and velocities.

Because shifts in land use and stream conditions occur relatively slowly along Thomas Creek, I expected the biotic assemblages to change slowly as well. I observed a gradual transition of invertebrate assemblages, but not for fish. This brings up the question of whether fish may be more sensitive to land use than invertebrates. Responses by fish appear to be more dramatic and are revealed by greatly reduced densities, shifts in assemblage composition, and empty habitat units. From my study, what fish were responding to beyond elevation and temperature was unclear. Characteristics influencing fish may or may not be influencing invertebrate assemblages. The next logical step would be to examine fish and invertebrates at the same sites to determine if conditions that were associated with occupancy and no occupancy by fish were associated with changes of invertebrate assemblages.

Bibliography

- Abbe, T. E., and Montgomery, D. R. 1996. Large woody debris jams, channel hydraulics, and habitat formation in large rivers. *Regulated Rivers* **12**: 201-221.
- Allan, J. D. 1975. The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. *Ecology* **56**: 1040-1053.
- Angermeier, P. L., and Winston, M. R. 1998. Local vs. regional influences on local diversity in stream fish communities of Virginia. *Ecology* **79**: 911-927.
- Araujo, R., and Ramos, M. A. Action Plan for *Margaritifera margaritifera*. *Convention on the Conservation of European Wildlife and Natural Habitats*, Bern, 29-66.
- Baltz, D. M., Vondracek, B., Brown, L. R., and Moyle, P. B. 1991. Seasonal changes in microhabitat selection by rainbow trout in a small stream. *Transactions of the American Fisheries Society* **120**: 166-176.
- Bauer, G. 1987. Reproductive strategy of the freshwater pearl mussel *Margaritifera margaritifera*. *Journal of Animal Ecology* **56(2)**: 691-704.
- Baxter, C. V. 2002. Fish movement and assemblage dynamics in a Pacific Northwest riverscape. PhD dissertation, Oregon State University, Corvallis, Oregon.
- Beals, E. W. 1984. Bray-Curtis ordination: an effective strategy for analysis of multivariate ecological data. *Advances in Ecological Research* **14**: 1-55.
- Bilby, R. E., and Ward, J. W. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. *Canadian Journal of Fisheries and Aquatic Sciences* **48**: 2499-2508.
- Bischoff, J. M. 2000. South Santiam Watershed Assessment , E&S Environmental Chemistry, Inc. South Santiam Watershed Council, Corvallis.
- Bisson, P. A., Sullivan, K., and Nielson, J. L. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. *Transactions of the American Fisheries Society* **117**: 262-273.

- Bridcut, E. E. 2000. A study of terrestrial and aerial macroinvertebrates on river banks and their contribution to drifting fauna and salmonid diets in a Scottish catchment. *Hydrobiologia* **427**: 83-100.
- Brown, A. V., and Brussock, P. P. 1991. Comparisons of benthic invertebrates between riffles and pools. *Hydrobiologia* **220**: 99-108.
- Carpenter, D. A. 2001. Testing the river continuum concept: exploring ecological processes in the Wheeling Creek watershed. MA thesis, West Virginia University, Morgantown, West Virginia.
- Chesson, J. 1978. Measuring preference in selective predation. *Ecology* **59(2)**: 211-215.
- Cloe, W. W. I., and Garman, G. C. 1996. The energetic importance of terrestrial arthropod inputs to three warm-water streams. *Freshwater Biology* **36**: 105-114.
- Culp, J. M., Scrimgeour, G. J., and Townsend, G. D. 1996. Simulated fine woody debris accumulations in a stream increase rainbow trout fry abundance. *Transactions of the American Fisheries Society* **125**: 472-479.
- Cunjak, R. A., and Green, J. M. 1983. Habitat utilization by brook char (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdneri*) in Newfoundland streams. *Canadian Journal of Zoology* **61**: 1214-1249.
- Dance, K. W., and Hynes, H. B. N. 1980. Some effects of agricultural land use on stream insect communities. *Environmental Pollution (Series A)* **22**: 19-28.
- DeLong, M. D. 1991. Ecosystem processes and community structure in an agriculturally impacted stream. PhD dissertation, University of Idaho, Moscow.
- DeLong, M. D., and Brusven, M. A. 1993. Storage and decomposition of particulate organic matter along the longitudinal gradient of an agriculturally -impacted stream. *Hydrobiologia* **262**: 77-88.
- DeLong, M. D., and Brusven, M. A. 1998. Macroinvertebrate community structure along the longitudinal gradient of an agriculturally impacted stream. *Environmental Management* **22(3)**: 445-457.
- Doisy, K. E., and Charles, ^{C.F. Babeni} F. R. 2001. Flow conditions, benthic food resources, and invertebrate community composition in a low-gradient stream in Missouri. *Journal of North American Benthological Society* **20(1)**: 17-32.

- Dufrene, M., and Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**: 345-366.
- Edwards, E. D., and Huryn, A. D. 1996. Effect of riparian land use on contributions of terrestrial invertebrates to streams. *Hydrobiologia* **337**: 151-159.
- England, J., Graves, L., Hibler, C., Rosling, D., Barney, W., Caliva, S., Barber, J., Roberts, D., Philipek, F., Freeman, F., Brayton, S., and Raible, B. 2001. Crabtree Watershed Analysis , Bureau of Land Management, Salem.
- Evans, J. W., and Noble, R. L. 1979. The longitudinal distribution of fishes in an east Texas stream. *The American Midland Naturalist* **101(2)**: 333-343.
- Everest, F. H., and Chapman, D. W. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. *Journal of the Fisheries Research Board of Canada* **29**: 91-100.
- Fail, J. L., Jr., Haines, B. L., and Todd, R. L. 1988. Riparian forest communities and their role in nutrient conservation in an agricultural watershed. *American Journal of Alternative Agriculture* **2**: 114-121.
- Faith, D. P., and Norris, R. H. 1989. Correlation of environmental variables with patterns of distribution and abundance of common and rare freshwater macroinvertebrates. *Biological Conservation* **50**: 77-98.
- Fausch, K. D. 1984. Profitable stream positions: relating specific growth rate to net energy gain. *Canadian Journal of Zoology* **62**: 441-451.
- Fausch, K. D. 1985. Experimental analysis of microhabitat selection by juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in a British Columbia stream. *Canadian Journal of Fisheries and Aquatic Sciences* **50(6)**: 1198-1207.
- Fausch, K. D. 1988. Tests of competition between native and introduced salmonids in streams: what have we learned? *Canadian Journal of Fisheries and Aquatic Science* **45**: 2238-2246.
- Frissell, C. A., Liss, W. J., Warren, C. E., and Hurley, M. D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management* **10(2)**: 199-214.
- Graves, L., England, J., Hibler, C., Rosling, D., Caruso, J., Roberts, D., Raible, B., Philipek, F., Freeman, F., Barney, W., Brayton, S., Shank, D., Smith, A., Halemeier, D., Loree, K., McGinely, B., Buchholz, T., Easterbrook, K.,

- Hubbard, M., Ginn, R., and Devlin, D. 2002. Quartzville Watershed Analysis, Bureau of Land Management/ US Forest Service, Salem / Sweet Home.
- Hawkes, H. A. 1975. River Zonation and Classification. Los Angeles, Blackwell Scientific Publications.
- Heifetz, J., and M. L. Murphy, a. K. V. K. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaska streams. *North American Journal of Fisheries Management* **6**: 52-58.
- Herlihy, A. 2003. Water Quality of Thomas Creek. US EPA, Corvallis, Oregon.
- Hillman, T. W., Griffith, J. S., and Platts, W. S. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. *Transactions of the American Fisheries Society* **116**: 185-195.
- Hoag, J. C., Young, G. L., and Gibbs, J. L. 1992. Planting techniques for vegetating riparian areas from the Aberdeen Plant Materials Center. USDA-NRCS Aberdeen Plant Materials Center, Aberdeen, ID. Jan. 1992. 8p.
- Hynes, H. B. N. 1975. Edgardo Baldi memorial lecture: the stream and its valley. *Verhandlungen der Internationale Vereinigung fur Theoretische und Angewandte Limnologie* **19**: 1-15.
- Inoue, M., and Nunokawa, M. 2002. Effects of longitudinal variations in stream habitat structure on fish abundance: an analysis based on subunit-scale habitat classification. *Freshwater Biology* **47**: 1594-1607.
- Johnson, L. B., Richards, C., Host, G. E., and Arthur, J. W. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology* **37**: 193-208.
- Johnson, P. D., and Brown, K. M. 2000. The importance of microhabitat factors and habitat stability to the threatened Louisiana pearl shell, *Margaritifera hembeli* (Conrad). *Canadian Journal of Zoology* **78(2)**: 271-277.
- Kostow, K. 2002. Oregon Lampreys: Natural history, status, and analysis of management issues. , Oregon Department of Fish and Wildlife.
- Kruse, A. 1988. Relationships between fish species distribution and habitat in the Willamette River drainage in Western Oregon. Masters Thesis, Oregon State University, Corvallis.

- Kruskal, J. B. 1964. Nonmetric multidimensional scaling: a numerical method. *Psychometrika* **29**: 115-129.
- Li, H. W., Schreck, C. B., Bond, C. E., and Rexstad, E. 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. Community and evolutionary ecology North American stream fishes, W. J. Matthews and D. C. Heins, eds., University of Oklahoma, Norman, OK, 193-202.
- Li, J., Herlihy, A., Gerth, W., Kaufmann, P., Gregory, S., Urquhart, S., and Larsen, D. P. 2001. Variability in stream macroinvertebrates at multiple spatial scales. *Freshwater Biology* **46**: 87-97.
- Magalhaes, M. F., Batalha, D. C., and Collares-Pereira, M. J. 2002. Gradients in stream fish assemblages across a Mediterranean landscape: contributions of environmental factors and spatial structure. *Freshwater Biology* **47**: 1015-1031.
- Manci, K. M. 1989. Riparian ecosystem creation and restoration: A literature summary *89(20)*, U.S. Fish and Wildlife Service, Jamestown, ND.
- Mandaville, S. M. 2002. Benthic macroinvertebrates in freshwaters- taxa tolerance values, metrics, and protocols *H-1*, Soil & Water Conservation Society of Metro Halifax.
- Manly, B. F. J., Miller, P., and Cook, L. M. 1972. Analysis of a selective predation experiment. *American Naturalist* **106**: 719-736.
- Mason, C. F., and MacDonald, S. M. 1982. The input of terrestrial invertebrates from tree canopies to a stream. *Freshwater Biology* **12**: 305-311.
- Mather, P. M. 1976. Computational methods of multivariate analysis in physical geography. London, J. Wiley & Sons.
- Matthews, W. J. 1998. Patterns in Freshwater Fish Ecology. New York, Chapman & Hall.
- McCune, B., Grace, J. B., and Urban, D. L. 2002. Analysis of Ecological Communities. Gleneden Beach, Oregon, MjM Software Design.
- Menge, B. A., and Olson, A. M. 1990. Role of scale and environmental factors in regulation of community structure. *Trends in Ecology and Evolution* **5**: 52-57.
- Merritt, R. W., and Cummins, K. W. 1996. An Introduction to the Aquatic Insects of North America. Dubuque, IA, USA, Kendal/Hunt Publishing Co.

- Mielke, P. W. J. 1984. Meteorological applications of permutation techniques based on distance functions. *Handbook of Statistics*, P. R. Krishnaiah and P. K. Sen, eds., Elsevier Science Publishers, 813-830.
- Minshall, G. W., Cummins, K. W., Petersen, R. C., Cushing, C. E., Bruns, D. A., Sedell, J. R., and Vannote, R. L. 1993. Developments in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* **42**: 1045-1055.
- Miyake, Y., and Nakano, S. 2002. Effects of substratum stability on diversity of stream invertebrates during baseflow at two spatial scales. *Freshwater Biology* **47**: 219-230.
- Moorkens, E. A. 1999. Conservation management of the freshwater pearl mussel *Margaritifera margaritifera*. Part 1: Biology of the species and its present situation in Ireland No. 8. *Dúchas*, The Heritage Service, Dublin, Ireland.
- Moyle, P. B., and Vondracek, B. 1985. Persistence and structure of the fish assemblage in a small California stream. *Ecology* **66(1)**: 1-13.
- Muller, J. E. 1968. Introduction to hydraulic and topographic sinuosity indexes. *Annals of the Association of American Geographers* **58**: 371-385.
- Nakano, S., Miyasaka, H., and Kuhara, N. 1999. Terrestrial-aquatic linkages: riparian arthropod inputs alter trophic cascades in a stream food web. *Ecology* **80(7)**: 2435-2441.
- ODFW, V. a. 1930-2001. Various reports and field notes for Thomas Creek, OR , Oregon Department of Fish and Wildlife, Salem, OR.
- Paller, M. H. 1994. Relationships between fish assemblage structure and stream order in South Carolina coastal plain streams. *Transactions of the American Fisheries Society* **123**: 150-161.
- Peckarsky, B. L., Cooper, S. D., and McIntosh, A. R. 1997. Extrapolating from individual behavior to populations and communities in stream. *Journal of the North American Benthological Society* **16(2)**: 375-390.
- Perry, J. A., and Schaeffer, D. J. 1987. The longitudinal distribution of riverine benthos: a river dis-continuum? *Hydrobiologia* **148**: 257-268.
- Powers, P. D., and Orsborn, J. F. 1985. Analysis of barriers to upstream fish migration An investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls *BPA Report DOE/BP-36523-1*, Albrook Hydraulic Laboratory, Washington State University, Portland, Oregon.

- Propst, D. L. 1982. Warmwater fishes of the Platte River basin, Colorado; distribution, ecology, and community structure. PhD dissertation, Colorado State University, Fort Collins.
- Rahel, F. J., and Hubert, W. A. 1991. Fish assemblages and habitat gradients in a Rocky Mountain - Great Plains stream: biotic zonation and additive patterns of community change. *Transactions of the American Fisheries Society* **120**: 319-332.
- Raible, B., Hibler, C., England, J., Depuy, J., Herrin, R., Freeman, F., Ruediger, B., Caliva, S., Graves, L., Barney, W., Robin, R., Ahrendt, B., Koski, M., and Davis, J. 1996. Thomas Creek Watershed Analysis , Bureau of Land Management, Salem, Oregon.
- Reeves, G. H., Everest, F. H., and Hall, J. D. 1987. Interactions between the reidside shiner (*Richardsonianus balteatus*) and the steelhead trout (*Salmo gairderi*) in western Oregon: the influence of water temperature. *Canadian Journal of Fisheries and Aquatic Sciences* **44**: 1603-1613.
- Riehle, M. D., and Griffith, J. S. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (*Oncorhynchus mykiss*) in fall and the onset of winter in Silver Creek, Idaho. *Canadian Journal of Fisheries and Aquatic Sciences* **50**: 2119-2128.
- Robinson, E. G., Mirati, A., and Allen, M. 1999. Oregon road/stream crossing restoration guide: spring 1999 , Oregon Department of Fish and Wildlife.
- Roper, B. B., Scarnecchia, D. L., and Marr, T. J. L. 1994. Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. *Transactions of the American Fisheries Society* **123**: 298-308.
- Rosgen, D. L. Geomorphological Approach to Restoration of Incised Rivers. *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*.
- Schlosser, I. J., and Karr, J. R. 1981. Water quality in agricultural watersheds: impact of riparian vegetation during base flow. *Water Resources Bulletin* **17**: 233-240.
- Shaw, E. A., and Richardson, J. S. 2001. Direct and indirect effects of sediment pulse duration on stream invertebrate assemblages and rainbow trout (*Oncorhynchus mykiss*) growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* **58**: 2213-2221.

- Simpkins, D. G., Hubert, W. A., and Wesche, T. A. 2000. Effects of fall-to-winter changes in habitat and frazil ice on the movements and habitat use of juvenile rainbow trout in a Wyoming tailwater. *Transactions of the American Fisheries Society* **129**: 101-118.
- Smith, R. W., and Griffith, J. S. 1994. Survival of Rainbow trout during their first winter in the Henrys fork of the Snake River, Idaho. *Transactions of the American Fisheries Society* **123**: 747-756.
- Statzner, B., Gore, J. A., and Resh, V. H. 1988. Hydraulic stream ecology: observed patterns and potential applications. *Journal of the North American Benthological Society* **7(4)**: 307-360.
- Statzner, B., and Higler, B. 1985. Questions and comments on the River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* **42**: 1038-1044.
- Stewart, J. S., Downes, D. M., Wang, L., Wierl, J. A., and Bannerman, R. Influences of riparian corridors on aquatic biota in agricultural watersheds. *International conference on riparian ecology and management in multi-land use watersheds*, 209-214.
- Streubel, D. N., and Griffith, J. S. 1993. Use of boulder pocket habitat by rainbow trout (*Oncorhynchus mykiss*) in Fall River, Idaho. *Great Basin Naturalist* **53(2)**: 194-198.
- Thompson, P. D., and Rahel, F. J. 1998. Evaluation of artificial barriers in small Rocky Mountain streams for preventing the upstream movement of brook trout. *North American Journal of Fisheries Management* **18**: 206-210.
- Torgersen, C. 2002. A geographical framework for assessing longitudinal patterns in stream habitat and fish distribution. PhD dissertation, Oregon State University, Corvallis, Oregon.
- Torgersen, C. E., Price, D. M., Li, H. W., and McIntosh, B. A. 1999. Multiscale thermal refugia and stream habitat associations of chinook salmon in Northeastern Oregon. *Ecological Applications* **9(1)**: 301-319.
- Townsend, C. R. 1989. The patch dynamics concept of stream community ecology. *Journal of the North American Benthological Society* **8(1)**: 36-50.
- Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* **37**: 130-137.

- Vila-Gispert, A., E. G.-B., and R. M.-A. 2002. Fish zonation in a Mediterranean stream: Effects of human disturbances. *Aquatic Sciences* **64(2)**: 163-170.
- Ward, J. V., and Stanford, J. A. 1995. The serial discontinuity concept; extending the model to floodplain rivers. *Regulated Rivers; Research & Management* **10**: 159-168.
- Wellnitz, T. A., Poff, N. L., Cosyleon, G., and Steury, B. 2001. Current velocity and spatial scale as determinants of the distribution and abundance of two rheophilic herbivorous insects. *Landscape Ecology* **16**: 111-120.
- Wentworth, C. K. 1922. A scale of grade and class terms for classic sediments. *Journal of Geology* **30**: 377-392.
- Werner, E. E., and Gilliam, J. F. 1984. The ontogenetic niche and species interactions in size-structure populations. *Annual Review of Ecology and Systematics* **15**: 393-425.
- Wetzel, R. G. 2001. Limnology: lake and river ecosystems. San Diego, Academic Press.
- Wiens, J. A. 1989. Spatial scaling in ecology. *Functional Ecology* **3**: 385-397.
- Wiley, M. J., Osborne, L. L., and Larimore, R. W. 1990. Longitudinal structure of an agricultural prairie river system and its relationship to current stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* **47**: 373-384.
- Wipfli, M. S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth riparian forests in southeastern Alaska, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* **54**: 1259-1269.
- Wright, K. K. 2000. From continua to patches: Longitudinal patterns in the Middle Fork of the John Day River, Oregon. PhD dissertation, Oregon State University, Corvallis, Oregon.
- Zaroban, D. W., Mulvey, M. P., Maret, T. R., Hughes, R. M., and Merritt, G. D. 1999. Classification of species attributes for Pacific Northwest freshwater fishes. *Northwest Science* **73(2)**: 81-93.
- Zimmerman, G. M., Goetz, H., and Paul W. Mielke, J. 1985. Use of an improved statistical method for group comparisons to study effects of prairie fire. *Ecology* **66(2)**: 606-611.

Appendices

Appendix A. Taxa list, functional feeding groups, and tolerance and indicator values for invertebrates in Thomas Creek.

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level
Non-insect							
Amphipoda	Amphipoda	Amphipoda sp.	unknown				6
Aquatic unknown	Aquatic unknown	unknown blob	unknown				
Cladocera	Cladocera	Cladocera sp.	unknown				8
Copepoda	Copepoda	Copepoda sp.	unknown				8
	Copepoda	Harpacticoida	unknown				8
Corbiculacea	Corbiculidae	Corbicula fluminea	filterer				6
	Sphaeriidae	Sphaeriidae sp.	filterer				8
Fish	Fish larvae	Fish larvae sp.	unknown				
Hirudinoidea	Hirudinoidea	Hirudinoidea sp. Leech	leech	Mouth			8
Hydroida	Hydroida	Hydroida sp.	filterer	Mouth			5
Isopoda	Isopoda	Isopoda sp.	unknown				8
Nematoda	Nematoda	Nematoda sp.	unknown			Riffle	
Oligochaeta	Oligochaeta	Oligochaeta sp. >10mm	gatherer	Mouth	8		5
	Oligochaeta	Oligochaeta sp. 5-10mm	gatherer		3		5
	Oligochaeta	Oligochaeta sp. <5mm	gatherer	Falls	3	Glide	5
Ostracoda	Ostracoda	Ostracoda sp.	unknown				8
Prosobranchia	Hydrobiidae	Hydrobiidae sp. Large	scraper	Mouth	8		7
	Hydrobiidae	Hydrobiidae sp. Small	scraper	Mouth	9		7
	Pleuroceridae	<i>Juga</i> Large	scraper	Middle	6		6
	Pleuroceridae	<i>Juga</i> Small	scraper				6
	Lymnaeidae/						
Pulmonata	Ancylidae	Lymnaeidae/Ancylidae sp.	scraper	Mouth	8		6
	Physidae	Physidae sp.	scraper				
	Planorbidae	Planorbidae sp.	scraper				
Tardigrada	Tardigrada	Tardigrada sp.	unknown				
Turbellaria	Turbellaria	Turbellaria sp.	unknown	Mouth	9		4
Unionacea	Unionidae	Unionidae sp.	filterer				8
Coleoptera	Coleoptera	Coleoptera Species	sp				6

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level
Coleoptera	Coleoptera	Coleoptera Species one	sp				6
	Dytiscidae	Hydrovatus adult	predator	Falls		Pool	5
	Elmidae	<i>Ampumixus</i>	gatherer				5
	Elmidae	<i>Dubraphia</i> adult	gatherer				6
	Elmidae	Elmidae sp.	sp				6
	Elmidae	<i>Narpus</i> adult	gatherer				5
	Elmidae	<i>Narpus</i> larvae	gatherer		8		5
	Elmidae	<i>Optioservus</i> adult	scraper			Riffle	4
	Elmidae	<i>Optioservus</i> larvae	scraper	Mouth			4
	Elmidae	<i>Ordobrevia</i> adult	gatherer				5
	Elmidae	<i>Ordobrevia</i> larvae	gatherer				5
	Elmidae	<i>Zaitzevia</i> adult	gatherer			Riffle	5
	Elmidae	<i>Zaitzevia</i> larvae	gatherer	Mouth	9		5
	Psephenidae	<i>Psephenus</i>	scraper	Mouth	8	Riffle	4
	Diptera	Athericidae	<i>Atherix</i>	predator	Falls		
Blephariceridae		<i>Blepharicera</i>	scraper		7	Riffle	0
Blephariceridae		Blephariceridae pupae	scraper		2		0
Ceratopogonidae		<i>Bezzia/Palpomyia</i>	predator	Falls	4		6
Ceratopogonidae		Ceratopogonidae sp. or adult	sp				
Ceratopogonidae		<i>Dasyhelea</i>	gatherer	Mouth	8		6
Ceratopogonidae		<i>Probezzia</i>	predator				6
Ceratopogonidae		<i>Stilobezzia</i>	predator				6
Chironomidae		Chironomidae adult	adult		7		
Chironomidae		Chironomidae pupae or sp.	sp	Mouth	9		8
Chironomidae		Chironomini	gatherer	Middle	4		8
Chironomidae		Diamesinae	gatherer				2
Chironomidae		Krenosmitta	unknown				1
Chironomidae		Orthocladiinae	gatherer	Mouth	9	Riffle	5
Chironomidae		Tanypodinae	predator	Middle			8

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level	
Diptera	Chironomidae	Tanytarsini	filterer			Pool		
	Deuterophlebiidae	<i>Deuterophlebia</i>	scraper			Riffle		
	Diptera	Diptera Adult	adult					
	Diptera	Diptera sp.	sp					
	Diptera	Diptera Species one	sp					
	Diptera	Diptera Species two	sp					
	Empididae	<i>Chelifera/Metachela</i>	predator				6	
	Empididae	Empididae Adult	adult					
	Empididae	Empididae sp. or pupae	predator			7	6	
	Empididae	<i>Hemerodromia</i>	predator	Middle			6	
	Empididae	<i>Neoplasta</i>	predator				6	
	Empididae	<i>Tricho/Clinocera</i>	predator	Falls		3	6	
	Nymphomiidae	Nymphomiidae sp or adult	scraper					
	Pelecorhynchidae	<i>Glutops</i>	predator					
	Psychodidae	<i>Maruina</i>	scraper	Middle			10	
	Simuliidae	Simuliidae pupae	filterer	Middle		7	Riffle	6
	Simuliidae	Simuliidae sp	filterer			8	Riffle	6
	Tabanidae	<i>Tabanus/Whitneyomia/ Atylotus</i>	predator					6
	Tanyderidae	<i>Protanyderus</i>	unknown					
	Tanyderidae	Tanyderidae sp.	unknown					
	Tipulidae	<i>Antocha</i>	gatherer	Middle			Riffle	3
	Tipulidae	<i>Antocha</i> pupae	gatherer					3
	Tipulidae	<i>Dicranota</i>	predator	Falls		1		3
Tipulidae	<i>Erioptera</i>	gatherer					4	
Tipulidae	<i>Hesperoconopa</i>	unknown	Falls		1		4	
Tipulidae	<i>Hexatoma</i>	predator			1		2	
Tipulidae	<i>Limnophila</i>	predator	Falls		4		3	
Tipulidae	<i>Rhabdomastix</i>	unknown					4	

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level
Diptera	Tipulidae	Tipulidae adult	adult				
	Tipulidae	Tipulidae pupae	sp				4
	Tipulidae	Tipulidae sp.	sp				4
	Tipulidae	Tipulidae Species one	sp		5		4
	Tipulidae	Tipulidae Species two	sp				4
Ephemeroptera	Ameletidae	<i>Ameletus</i>	scraper				0
	Baetidae	<i>Acentrella</i>	gatherer	Middle		Riffle	6
	Baetidae	Baetidae Adult	adult				
	Baetidae	<i>Baetidae sp.</i>	gatherer				4
	Baetidae	<i>Diphedor</i>	gatherer			Riffle	6
	Baetidae	<i>Procloeon</i>	gatherer				6
	Baetidae	<i>Pseudocloeon</i>	gatherer			Riffle	6
	Caenidae	<i>Caenis</i>	gatherer				7
	Ephemerellidae	<i>Attenella</i>	gatherer	Mouth	9		1
	Ephemerellidae	<i>Attenella delantala</i>	gatherer				1
	Ephemerellidae	<i>Drunella doddsi</i>	predator				0
	Ephemerellidae	<i>Drunella flavinea/other</i>	gatherer			Riffle	0
	Ephemerellidae	<i>Drunella pelosa</i>	scraper				0
	Ephemerellidae	<i>Drunella spinifera</i>	predator				0
	Ephemerellidae	<i>Ephemerella</i>	gatherer	Falls	3	Glide	1
	Ephemerellidae	Ephemerellidae sp.	sp				1
	Ephemerellidae	Ephemerellidae Species One	sp				1
	Ephemerellidae	Ephemerellidae Species Two	sp				1
	Ephemerellidae	<i>Serratella</i>	gatherer	Mouth	9	Riffle	2
	Ephemerellidae	<i>Timpanoga</i>	gatherer	Middle			2
	Ephemeroptera	Ephemeroptera sp.	sp				1
	Heptageniidae	<i>Cinygmula</i>	scraper	Middle		Glide	2
	Heptageniidae	<i>Epeorus</i>	gatherer			Riffle	0
	Heptageniidae	<i>Heptagenia</i>	scraper	Mouth	9		4

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level
Ephemeroptera	Heptageniidae	Heptageniidae sp.	sp				3
	Heptageniidae	<i>Leucrocuta</i>	scraper	Mouth	9		1
	Heptageniidae	<i>Nixe</i>	scraper				2
	Heptageniidae	<i>Rhithrogena</i>	gatherer			Riffle	0
	Heptageniidae	<i>Stenonema</i>	scraper	Mouth			3
	Leptophlebiidae	Leptophlebiidae sp.	gatherer				1
	Leptophlebiidae	<i>Paraleptophlebia</i>	gatherer	Mouth	9		1
	Siphonuridae	<i>Parameletus</i>	gatherer				7
	Tricorythidae	<i>Tricorythodes</i>	gatherer	Middle	7	Pool	4
Hemiptera	Corixidae	Corixidae sp.	sp				5
	Lepidoptera	Cossidae	Cossidae	borer			5
	Cossidae pupae	Cossidae pupae	borer				5
	Noctuidae/ Cossidae	Noctuidae/Cossidae	borer				5
	Pyalidae	<i>Petrophila</i>	scraper	Mouth	9		5
Megaloptera	Corydalidae	<i>Orohermes</i>	predator				4
	Sialidae	<i>Sialis</i>	predator				4
Odonata	Coenagrionidae	<i>Argia</i>	predator	Mouth			6
	Gomphidae	<i>Ophiogomphus</i>	predator	Middle			1
Plecoptera	Chloroperlidae	Chloroperlidae sp.	sp				1
	Chloroperlidae	<i>Haploperla</i>	predator		5		1
	Chloroperlidae	<i>Katheroperla/Paraperla</i>	gatherer				1
	Chloroperlidae	<i>Neaviperla</i>	unknown				1
	Chloroperlidae	<i>Plumiperla</i>	predator	Falls	5		0
	Chloroperlidae	<i>Suwallia</i>	predator		5		0
	Chloroperlidae	<i>Sweltsa</i>	predator	Middle			0
	Chloroperlidae	<i>Triznaka</i>	predator				0
	Leuctridae	<i>Moselia</i>	shredder				0

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level	
Plecoptera	Leuctridae/ Capniidae	Leuctridae/Capniidae sp.	shredder	Falls		Pool	3	
	Nemouridae	<i>Malenka</i>	shredder		8		2	
	Nemouridae	Nemouridae sp.	shredder				2	
	Perlidae	<i>Calineuria</i>	predator	Falls	3	Riffle	3	
	Perlidae	<i>Hesperoperla</i>	predator				3	
	Perlidae	Perlidae sp.	predator				3	
	Perlidae/ Perlodidae	Perlidae/Perlodidae sp.	predator				3	
	Perlodidae	<i>Cultus</i>	predator	Middle			2	
	Perlodidae	<i>Frisonia</i>	predator				2	
	Perlodidae	<i>Isoperla</i>	predator	Mouth	9		2	
	Perlodidae	<i>Kogotus/Rickera</i>	predator				2	
	Perlodidae	<i>Megarcys</i>	predator				2	
	Perlodidae	<i>Osobenus yakimae</i>	predator				2	
	Perlodidae	Perlodidae sp.	predator	Mouth				
	Perlodidae	<i>Skwala</i>	predator				2	
	Plecoptera	Plecoptera sp.	sp					
	Trichoptera	Pteronarcyidae	<i>Pteronarcys</i>	shredder	Middle		Riffle	0
		Brachycentridae	<i>Amiocentrus</i>	gatherer	Falls		Riffle	2
Brachycentridae		Brachycentridae sp.	sp				2	
Brachycentridae		<i>Brachycentrus</i>	filterer	Mouth	9	Riffle	1	
Brachycentridae		<i>Micrasema</i>	shredder	Middle			2	
Glossosomatidae		<i>Agapetus</i>	scraper				0	
Glossosomatidae		<i>Glossosoma</i>	scraper	Mouth	9	Riffle	0	
Glossosomatidae		Glossosomatidae Adult	scraper				1	
Glossosomatidae		Glossosomatidae pupae or sp.	scraper	Mouth		Riffle	1	
Glossosomatidae		<i>Protoptila</i>	scraper	Middle	7		1	

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level
Trichoptera	Goeridae	<i>Goera</i>	scraper				3
	Goeridae	<i>Goera pupae</i>	scraper				3
	Hydropsychidae	<i>Cheumatopsyche</i>	filterer	Mouth			5
	Hydropsychidae	<i>Hydropsyche/Ceratopsychae</i>	filterer			Riffle	5
	Hydropsychidae	<i>Hydropsychidae Pupa</i>	filterer				5
	Hydropsychidae	<i>Hydropsychidae sp.</i>	filterer				5
	Hydroptilidae	<i>Ochrotrichia</i>	gatherer				6
	Lepidostomatidae	<i>Lepidostoma</i>	shredder				1
	Lepidostomatidae	<i>Lepidostoma three</i>	shredder				1
	Lepidostomatidae	<i>Lepidostoma unicolor</i>	shredder				1
	Lepidostomatidae	Lepidostomatidae pupae or sp.	shredder	Middle	6		1
	Leptoceridae	Leptoceridae sp.	sp				4
	Leptoceridae	<i>Mystacides</i>	gatherer				4
	Leptoceridae	<i>Oecetis</i>	predator	Mouth	9		5
	Limnephilidae	<i>Dicosmoecus</i>	scraper		4		4
	Limnephilidae	Limnephilidae sp.	sp				4
	Limnephilidae	Limnephilidae Species one	sp				4
	Limnephilidae	<i>Limnephilus</i>	shredder				3
	Limnephilidae	<i>Oncosmecus</i>	shredder				4
	Philopotamidae	<i>Wormaldia</i>	filterer	Mouth	8	Riffle	2
	Phryganeidae	Phryganeidae Adult	adult				
	Polycentropodidae	<i>Polycentropus</i>	predator				6
	Rhyacophilidae	<i>Rhyacophila</i>	predator			Riffle	1
	Rhyacophilidae	<i>Rhyacophila Brunnea & Vemna</i>					
	Rhyacophilidae	<i>grps</i>	predator				1
	Rhyacophilidae	<i>Rhyacophila Coloradensis grp</i>	predator				1
	Rhyacophilidae	Rhyacophilidae pupae	predator	Falls		Glide	1

Appendix A. (Continued)

Order	Family	Taxa	Functional Feeding Group	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level
Trichoptera	Sericostomatidae	<i>Gumaga</i>	shredder				3
	Trichoptera	Trichoptera adult	adult				
	Trichoptera	Trichoptera sp.	sp	Mouth Falls			
	Uenoidae	<i>Neophylax</i>	scraper		4		3
Terrestrial	Terrestrial	Anthomyiidae	terrestrial				
	Terrestrial	Aphihidae	terrestrial				
	Terrestrial	Aracnidae	terrestrial				
	Terrestrial	Collembola	terrestrial				
Terrestrial	Terrestrial	Diplopoda	terrestrial				
	Terrestrial	Diptera terr.	terrestrial		7		
	Terrestrial	Hemiptera	terrestrial				
	Terrestrial	Homoptera	terrestrial				
	Terrestrial	Hymenoptera ant	terrestrial				
	Terrestrial	Hymenoptera wasp	terrestrial				
	Terrestrial	Psocoptera	terrestrial				
	Terrestrial	Terrestrial sp.	terrestrial				
	Terrestrial	Thysanoptera	terrestrial				
	Terrestrial	Tingidae	terrestrial				
	Terrestrial	Tortricid	terrestrial				

Appendix B. Invertebrate taxa list and abundance at sample sites in Thomas Creek.

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
Amphipoda sp.	0	0	0	0	0	0	0	0	1	1
unknown blob	0	0	0	0	0	0	2	0	0	2
Cladocera sp.	0	0	0	0	0	0	0	0	1	1
Copepoda sp.	0	1	0	0	0	0	0	0	0	1
Harpacticoida	0	0	0	2	0	1	0	0	0	3
Corbicula fluminea	0	0	0	0	1	1	1	0	4	7
Sphaeriidae sp.	0	0	0	0	1	0	0	0	0	1
Fish larvae sp.	0	0	0	0	1	0	1	3	0	5
Hirudinoidea sp. Leech	0	0	0	0	0	0	0	1	1	2
Hydroida sp.	0	0	0	0	0	0	0	4	1	5
Isopoda sp.	1	1	0	0	0	0	0	0	0	2
Nematoda sp.	20	12	32	37	40	33	54	34	18	280
Oligochaeta sp. >10mm	3	5	20	28	4	22	98	74	77	331
Oligochaeta sp. 5-10mm	45	78	174	115	8	48	142	58	30	698
Oligochaeta sp. <5mm	1156	654	1851	997	106	75	323	155	153	5470
Ostracoda sp.	1	0	2	4	1	0	0	3	3	14
Hydrobiidae sp. Large	0	0	0	0	2	0	15	18	13	48
Hydrobiidae sp. Small	0	0	0	0	1	0	38	411	403	853
<i>Juga</i> Large	0	3	7	8	6	22	52	4	16	118
<i>Juga</i> Small	39	39	22	29	37	21	22	4	12	225
Lymnaeidae/Ancylidae sp.	0	0	0	0	0	0	14	66	68	148
Physidae sp.	0	0	0	0	1	0	0	0	0	1
Planorbidae sp.	0	0	0	0	0	1	0	0	1	2
Tardigrada sp.	0	0	0	0	0	0	0	0	1	1
Turbellaria sp.	0	0	0	0	1	0	7	29	47	84
Unionidae sp.	0	0	0	1	0	0	0	0	0	1
Coleoptera Species	0	0	0	1	0	0	0	0	0	1

Appendix B. (Continued)

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
Coleoptera Species one	0	0	0	1	0	0	1	0	0	2
Hydrovatus adult	7	1	3	1	0	0	0	0	0	12
<i>Ampumixus</i>	1	0	0	0	0	0	0	0	0	1
<i>Dubraphia</i> adult	0	0	0	0	0	0	0	1	0	1
Elmidae sp.	0	0	0	0	1	1	0	2	0	4
<i>Narpus</i> adult	1	0	0	0	0	0	0	0	0	1
<i>Narpus</i> larvae	5	1	2	8	9	21	5	22	4	77
<i>Optioservus</i> adult	40	6	71	15	110	17	17	38	19	333
<i>Optioservus</i> larvae	205	28	105	207	140	111	241	257	242	1536
<i>Ordobrevia</i> adult	0	0	0	0	0	0	0	1	0	1
<i>Ordobrevia</i> larvae	0	0	0	0	0	0	0	3	0	3
<i>Zaitzevia</i> adult	5	3	9	4	3	2	6	6	5	43
<i>Zaitzevia</i> larvae	20	11	15	17	10	14	72	30	94	283
<i>Psephenus</i>	0	0	0	0	4	22	18	25	7	76
<i>Atherix</i>	2	5	2	1	0	0	0	0	0	10
<i>Blepharicera</i>	2	14	0	1	0	0	46	0	0	63
Blephariceridae pupae	0	3	0	0	0	0	0	0	0	3
<i>Bezzia/Palpomyia</i>	43	3	90	29	14	18	14	0	5	216
Ceratopogonidae sp. or adult	0	0	0	0	3	0	0	0	0	3
<i>Dasyhelea</i>	1	0	1	2	95	78	90	112	115	494
<i>Probezzia</i>	0	0	0	0	0	0	0	0	2	2
<i>Stilobezzia</i>	0	0	0	2	1	3	0	1	1	8
Chironomidae adult	1	0	1	3	4	7	15	8	3	42
Chironomidae pupae or sp.	10	11	27	50	177	42	94	63	126	600
Chironomini	22	4	4	71	107	72	34	9	31	354
Diamesinae	0	0	0	0	0	0	0	0	0	0
Krenosmitta	1	0	0	0	0	0	0	0	0	1
Orthoclaadiinae	366	129	406	757	658	306	511	523	1052	4708
Tanypodinae	36	8	20	52	56	31	64	25	12	304

Appendix B. (Continued)

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
Tanytarsini	686	179	265	695	260	309	706	520	469	4089
<i>Deuterophlebia</i>	3	1	0	0	1	0	4	0	0	9
Diptera Adult	0	0	0	0	0	0	2	0	0	2
Diptera sp.	0	0	0	0	0	0	0	0	0	0
Diptera Species one	1	0	0	0	0	0	0	0	0	1
Diptera Species two	1	0	0	0	0	0	0	0	0	1
<i>Chelifera/Metachela</i>	3	2	7	12	3	12	8	2	1	50
Empididae Adult	0	0	0	0	0	0	0	0	1	1
Empididae sp. or pupae	0	0	0	5	13	2	15	16	7	58
<i>Hemerodromia</i>	0	0	2	7	4	8	7	1	2	31
<i>Neoplasta</i>	0	2	1	0	2	0	1	0	0	6
<i>Tricho/Clinocera</i>	30	6	36	26	24	9	9	0	0	140
Nymphomiidae sp or adult	0	0	0	0	0	0	0	0	1	1
<i>Glutops</i>	0	0	0	0	1	0	0	0	0	1
<i>Maruina</i>	1	0	0	0	3	3	1	0	0	8
Simuliidae pupae	0	0	0	0	16	7	50	1	0	74
Simuliidae sp	17	27	7	8	558	39	1035	274	20	1985
<i>Tabanus/Whitneyomia/</i>										
<i>Atylotus</i>	0	0	0	1	0	0	0	0	0	1
<i>Protanyderus</i>	1	0	0	0	0	0	0	0	0	1
Tanyderidae sp.	0	0	0	0	0	0	0	0	0	0
<i>Antocha</i>	15	6	9	27	32	35	41	14	13	192
<i>Antocha</i> pupae	0	0	0	7	1	7	3	5	3	26
<i>Dicranota</i>	17	6	8	1	1	0	0	0	0	33
<i>Erioptera</i>	3	0	5	1	0	0	0	0	0	9
<i>Hesperoconopa</i>	81	11	20	13	1	1	0	0	0	127
<i>Hexatoma</i>	10	1	2	1	10	0	0	0	0	24
<i>Limnophila</i>	6	0	5	8	1	0	0	0	0	20
<i>Rhabdomastix</i>	1	0	0	1	0	0	0	0	0	2

Appendix B. (Continued)

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
Tipulidae adult	1	0	0	0	0	0	0	0	0	1
Tipulidae pupae	0	0	0	0	1	1	1	0	1	4
Tipulidae sp.	0	0	0	0	2	0	0	0	0	2
Tipulidae Species one	6	0	0	4	8	0	0	0	0	18
Tipulidae Species two	4	0	0	0	1	0	0	0	0	5
<i>Ameletus</i>	109	32	44	32	17	21	41	12	6	314
<i>Acentrella</i>	2	6	7	50	167	262	177	139	365	1175
Baetidae Adult	0	0	1	0	1	0	0	1	0	3
<i>Baetidae sp.</i>	0	0	0	0	0	0	0	0	0	0
<i>Dipheter</i>	6	7	8	21	20	8	19	26	9	124
<i>Proclleon</i>	0	0	0	0	0	0	0	0	1	1
<i>Pseudocloeon</i>	200	129	138	141	268	197	245	201	167	1686
<i>Caenis</i>	0	0	0	0	0	0	3	1	0	4
<i>Attenella</i>	2	0	1	1	3	0	1	13	65	86
<i>Attenella delantala</i>	0	0	0	2	0	0	0	0	0	2
<i>Drunella doddsi</i>	0	0	2	2	0	0	0	0	0	4
<i>Drunella flavinea/other</i>	43	20	62	79	50	26	46	21	11	358
<i>Drunella pelosa</i>	5	0	0	0	0	0	0	0	0	5
<i>Drunella spinifera</i>	1	0	0	0	0	0	2	0	0	3
<i>Ephemerella</i>	27	9	30	29	24	16	9	4	4	152
Ephemerellidae sp.	0	0	0	0	1	0	0	1	0	2
Ephemerellidae Species One	17	8	5	4	1	2	1	20	3	61
Ephemerellidae Species Two	0	0	0	0	0	1	0	0	0	1
<i>Serratella</i>	3	6	24	36	48	27	66	128	326	664
<i>Timpanoga</i>	0	0	0	0	3	5	7	0	2	17
Ephemeroptera sp.	0	0	0	0	0	0	0	0	0	0
<i>Cinygmula</i>	110	69	192	119	108	103	85	17	5	808
<i>Epeorus</i>	323	195	149	205	189	186	158	70	44	1519
<i>Heptagenia</i>	0	2	2	3	38	12	5	50	94	206

Appendix B. (Continued)

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
Heptageniidae sp.	0	0	2	5	2	0	0	7	19	35
<i>Leucrocuta</i>	0	0	0	0	0	0	0	5	51	56
<i>Nixe</i>	0	0	0	1	0	0	0	2	0	3
<i>Rhithrogena</i>	21	8	23	4	46	20	36	27	115	300
<i>Stenonema</i>	0	0	0	0	0	0	0	0	2	2
Leptophlebiidae sp.	0	0	0	0	0	0	0	0	0	0
<i>Paraleptophlebia</i>	2	4	2	4	2	1	3	9	18	45
<i>Parameletus</i>	1	0	0	0	0	0	0	0	0	1
<i>Tricorythodes</i>	0	1	0	3	32	119	263	46	25	489
Corixidae sp.	0	0	0	0	0	0	0	0	0	0
Cossidae	0	1	0	0	0	0	0	0	0	1
Cossidae pupae	0	1	0	0	0	0	0	0	0	1
Noctuidae/Cossidae	0	0	0	0	0	0	0	1	0	1
<i>Petrophila</i>	1	0	0	0	0	0	0	3	8	12
<i>Orohermes</i>	0	0	0	1	0	0	0	0	0	1
<i>Sialis</i>	0	0	0	0	0	0	1	0	0	1
<i>Argia</i>	0	0	0	0	0	0	2	1	4	7
<i>Ophiogomphus</i>	0	0	1	1	15	6	2	0	0	25
Chloroperlidae sp.	1	2	4	5	10	1	0	1	0	24
<i>Haploperla</i>	1	0	0	1	5	1	0	0	0	8
<i>Katheroperla/Paraperla</i>	1	0	0	0	0	0	0	0	0	1
<i>Neaviperla</i>	0	0	0	1	0	1	0	0	1	3
<i>Plumiperla</i>	42	11	58	34	111	16	21	3	6	302
<i>Suwallia</i>	0	0	3	1	11	0	0	0	1	16
<i>Sweltsa</i>	0	0	2	1	8	5	11	0	0	27
<i>Triznaka</i>	0	0	1	0	2	1	0	0	0	4
<i>Moselia</i>	3	0	0	0	0	0	0	0	0	3

Appendix B. (Continued)

Taxa	Reach1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
Leuctridae/Capniidae sp.	125	11	108	81	2	1	2	0	0	330
<i>Malenka</i>	0	3	3	14	1	3	3	18	0	45
Nemouridae sp.	0	2	2	0	5	0	0	0	1	10
<i>Calineuria</i>	39	34	67	42	69	24	9	2	7	293
<i>Hesperoperla</i>	0	2	1	1	2	2	1	1	0	10
Perlidae sp.	0	0	0	0	0	0	0	0	0	0
Perlidae/Perlodidae sp.	0	3	2	7	7	2	0	3	1	25
<i>Cultus</i>	0	0	1	1	2	5	6	0	2	17
<i>Frisonia</i>	0	0	0	0	0	0	1	0	4	5
<i>Isoperla</i>	0	0	0	1	11	6	67	183	178	446
<i>Kogotus/Rickera</i>	13	2	13	18	5	10	13	2	0	76
<i>Megarcys</i>	0	0	0	0	0	0	0	0	0	0
<i>Osobenus yakimae</i>	0	0	0	0	7	3	3	5	1	19
Perlodidae sp.	1	0	4	0	2	0	0	1	5	13
<i>Skwala</i>	1	0	0	0	0	0	0	0	0	1
Plecoptera sp.	0	0	0	1	0	0	1	0	0	2
<i>Pteronarcys</i>	0	0	0	0	2	1	5	0	1	9
<i>Amiocentrus</i>	15	10	12	39	7	4	1	1	2	91
Brachycentridae sp.	0	0	0	0	1	0	0	1	0	2
<i>Brachycentrus</i>	0	1	2	2	8	1	9	17	27	67
<i>Micrasema</i>	2	0	2	0	5	2	3	0	0	14
<i>Agapetus</i>	0	0	0	0	0	0	2	0	0	2
<i>Glossosoma</i>	30	4	13	14	54	31	62	59	126	393
Glossosomatidae Adult	0	0	0	0	0	0	0	0	1	1
Glossosomatidae pupae or sp.	0	0	2	17	28	9	24	20	22	122
<i>Protoptila</i>	0	0	0	1	5	12	12	1	1	32

Appendix B. (Continued)

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
<i>Goera</i>	0	0	0	1	0	2	3	0	0	6
<i>Goera pupae</i>	0	0	0	0	0	0	1	0	0	1
<i>Cheumatopsyche</i>	0	0	0	4	1	6	7	7	10	35
<i>Hydropsyche/Ceratopsychae</i>	8	25	18	33	54	12	32	14	21	217
<i>Hydropsychidae Pupae</i>	0	2	1	3	1	0	1	2	1	11
<i>Hydropsychidae sp.</i>	0	0	0	0	0	0	0	0	0	0
<i>Ochrotrichia</i>	0	0	0	0	0	1	0	0	0	1
<i>Lepidostoma</i>	3	0	1	2	10	3	2	0	0	21
<i>Lepidostoma three</i>	0	0	1	1	0	0	0	0	0	2
<i>Lepidostoma unicolor</i>	1	0	1	0	1	0	0	0	0	3
<i>Lepidostomatidae pupae or sp.</i>	1	0	0	1	3	16	2	0	0	23
<i>Leptoceridae sp.</i>	0	0	0	0	0	0	0	0	0	0
<i>Mystacides</i>	5	0	0	0	0	0	0	0	0	5
<i>Oecetis</i>	0	0	0	1	23	30	8	13	46	121
<i>Dicosmoecus</i>	0	0	4	19	4	3	15	1	0	46
<i>Limnephilidae sp.</i>	0	0	0	0	0	0	0	0	0	0
<i>Limnephilidae Species one</i>	0	0	3	0	1	0	0	0	0	4
<i>Limnephilus</i>	0	0	0	0	0	1	0	0	0	1
<i>Oncosmecus</i>	0	1	0	0	0	3	1	0	1	6
<i>Wormaldia</i>	0	0	0	0	0	0	10	51	8	69
<i>Phryganeidae Adult</i>	0	0	0	0	0	1	0	0	0	1
<i>Polycentropus</i>	0	0	1	0	2	0	0	2	0	5
<i>Rhyacophila</i>	21	14	21	32	28	53	63	55	20	307
<i>Rhyacophila Brunnea & Vernna grps</i>	0	0	1	3	0	0	1	0	0	5
<i>Rhyacophila Coloradensis grp</i>	0	0	0	1	0	0	0	0	0	1
<i>Rhyacophilidae pupae</i>	2	7	6	9	3	1	2	0	0	30

Appendix B. (Continued)

Taxa	Reach 1 Total Count	Reach 2 Total Count	Reach 3 Total Count	Reach 4 Total Count	Reach 5 Total Count	Reach 6 Total Count	Reach 7 Total Count	Reach 8 Total Count	Reach 9 Total Count	Total
<i>Gumaga</i>	0	0	0	0	0	1	0	0	0	1
Trichoptera adult	0	0	0	1	0	0	0	0	0	1
Trichoptera sp.	0	0	0	0	2	0	1	3	2	8
<i>Neophylax</i>	7	3	12	21	1	1	0	0	0	45
Amthomyiidae	0	0	1	0	0	0	0	0	0	1
Aphihidae	1	5	10	8	2	4	5	3	0	38
Aracnidae	1	5	2	1	1	1	1	0	1	13
Collembola	3	3	2	0	0	2	8	0	0	18
Diplopoda	0	1	0	0	0	0	0	0	0	1
Diptera terr.	0	1	0	1	2	1	6	1	1	13
Hemiptera	1	1	0	0	0	0	2	0	2	6
Homoptera	0	0	0	0	4	0	1	6	0	11
Hymenoptera ant	1	0	1	0	1	0	1	0	0	4
Hymenoptera wasp	0	0	1	3	2	0	1	2	0	9
Psocoptera	0	1	0	3	1	1	0	1	0	7
Terrestrial sp.	0	0	0	4	0	0	1	0	0	5
Thysanoptera	0	0	1	1	2	1	2	3	3	13
Tingidae	0	0	0	1	1	0	0	0	0	2
Tortricid	0	0	0	0	1	0	0	0	0	1

Appendix C. Fish species list and abundance at sample sites in Thomas Creek.

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9
Total survey length (m)	453	410	1246	1803	1659	1040	3741	1504	607
Total survey width (m)	102	98	237	384	406	278	889	300	146
Total age 0 trout	363	425	753	76	30	13	0	0	0
Total age 1-2 trout	117	170	569	429	197	80	54	11	3
Total age 3 and greater trout	13	10	27	22	18	12	7	0	0
Total juvenile chinook	1	0	51	48	187	23	11	13	3
Total redbside shiners	0	0	0	0	807	8	2081	2050	235
Total largescale suckers adult	0	0	0	14	17	32	46	15	0
Total largescale suckers juvenile	0	0	0	0	1	1	13	73	0
Total northern pikeminnow	0	0	0	0	0	52	222	275	1
Total smallmouth bass	0	0	0	0	1	0	18	83	16
Total mountain whitefish	0	0	3	5	0	1	5	7	18

Appendix C. (Continued)

Fish per meter (m)	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9
Age 0 trout m ⁻¹	0.80	1.04	0.60	0.04	0.02	0.01	0.00	0.00	0.00
Age 1-2 trout m ⁻¹	0.26	0.41	0.46	0.24	0.12	0.08	0.01	0.01	0.00
Age 3 and greater trout m ⁻¹	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
Juvenile chinook m ⁻¹	0.00	0.00	0.04	0.03	0.11	0.02	0.00	0.01	0.00
Redside shiners m ⁻¹	0.00	0.00	0.00	0.00	0.49	0.01	0.56	1.36	0.39
Largescale suckers adult m ⁻¹	0.00	0.00	0.00	0.01	0.01	0.03	0.01	0.01	0.00
Largescale suckers juvenile m ⁻¹	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Northern pikeminnow m ⁻¹	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.18	0.00
Smallmouth bass m ⁻¹	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03
Mountain whitefish m ⁻¹	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03

Appendix D. Tolerance levels, thermal group, indicator type, and species list for fish in Thomas Creek.

	Segment Indicator	Reach Indicator	Habitat Indicator	Tolerance Level	Thermal Group
Age 0 trout	Falls	2		Sensitive	Cold
Age 1-2 trout	Falls	2		Sensitive	Cold
Age 3 and greater trout	Falls		Pool	Sensitive	Cold
Juvenile chinook	Falls			Sensitive	Cold
Redside shiners	Mouth	8		Intermediate	Cool
Largescale suckers adult	Middle		Pool	Tolerant	Cool
Largescale suckers juvenile		8		Tolerant	Cool
Northern pikeminnow	Mouth	9		Tolerant	Cool
Smallmouth bass	Mouth	8		Intermediate	Cool
Mountain whitefish	Mouth			Intermediate	Cool

Appendix D. (Continued)

Captured in 2000				Tolerance Level	Thermal Group
Sunfish (<i>Lepomis spp</i>)				Tolerant	Warm/cool
Mottled sculpin (<i>Cottus bairdi</i>)				Intermediate	Cool
Reticulate sculpin (<i>Cottus perplexus</i>)				Intermediate	Cool
Torrent sculpin (<i>Cottus rhotheus</i>)				Intermediate	Cool
Longnose dace (<i>Rhinichthys cataractae</i>)				Intermediate	Cool
Speckled dace (<i>Rhinichthys osculus</i>)				Intermediate	Cool
Brown bullhead (<i>Ameirus nebulosus</i>)				Tolerant	Warm
Sand roller (<i>Percopsis transmontana</i>)				Intermediate	Cool
Pacific lamprey (<i>Lampetra tridentata</i>)				Intermediate	Cool

Appendix E. *Oncorhynchus mykiss* stomach contents from five sites along Thomas Creek during July 2000.

River kilometer	40	40	40	40	40	40	40	40	40	40	40
Trout number	s1t97	s1t98	s1t99	s1t100	s1t101	s1t102	s1t113	s1t104	s1t105	s1t106	s1t107
Pleuroceridae											
<i>Juga</i>	0	0	0	0	0	0	0	0	0	0	0
Diptera adult	0	1	0	5	0	0	3	2	4	5	2
Trichoptera adult	1	0	0	1	1	2	0	2	0	1	2
Limnephilidae											
<i>Dicosmoecus</i>	0	0	0	0	0	0	0	0	0	0	0
Plecoptera adult	3	0	2	2	0	0	3	3	4	3	0
Ephemeroptera adult	0	1	0	3	7	0	0	15	3	7	0
Ephemeroptera nymph	0	0	0	0	0	0	0	0	0	0	0
Other	4	3	2	1	5	1	0	0	3	0	2
Terrestials	3	2	0	3	8	2	4	3	4	7	7
Chironomidae adult	2	4	1	8	4	0	14	5	4	1	4
Exuviae	5	0	0	0	0	0	0	0	10	0	0
Total	18	11	5	23	25	5	24	30	32	24	17

Appendix E. (Continued)

River kilometer	40	40	40	40	40	40	40	Site Total	35	35	35
Trout number	s1t108	s1t109	s1t110	s1t111	s1t112	s1t113	s1t114	n=18	s2t98	s2t99	s2t100
Pleuroceridae <i>Juga</i>	0	0	0	0	0	0	0	0	0	0	0
Diptera adult	6	8	5	0	1	0	3	45	2	2	0
Trichoptera adult	0	0	0	1	1	1	0	13	0	0	0
Limnephilidae <i>Dicosmoecus</i>	0	0	0	0	0	0	0	0	0	0	0
Plecoptera adult	5	2	8	0	1	1	0	37	0	0	0
Ephemeroptera adult	3	3	2	2	1	0	1	48	3	3	5
Ephemeroptera nymph	0	0	0	0	0	0	0	0	0	0	0
Other	3	4	3	0	1	0	0	32	0	0	1
Terrestials	4	2	3	1	3	7	2	65	0	6	0
Chironomidae adult	6	7	11	2	1	3	4	81	0	2	0
Exuviae	5	10	0	0	5	0	0	35	0	5	0
Total	32	36	32	6	14	12	10	356	5	18	6

Appendix E. (Continued)

River kilometer	35	35	35	35	Site Total	31	31	31	31	31	31
Trout number	s2 t 104	s2 t106	s2 t108	s2 t112	n=7	s3 t1	s3t2	s3t3	s3t4	s3t5	s3t6
Pleuroceridae											
<i>Juga</i>	0	0	0	0	0	0	0	0	0	0	0
Diptera adult	7	0	1	2	14	30	13	4	3	10	10
Trichoptera adult	0	2	0	4	6	0	0	0	1	0	0
Limnephilidae											
<i>Dicosmoecus</i>	0	0	0	0	0	0	0	0	0	0	0
Plecoptera adult	0	0	1	0	1	4	0	0	0	0	5
Ephemeroptera adult	2	6	81	1	101	16	38	6	33	6	48
Ephemeroptera nymph	17	0	5	0	22	0	8	0	5	0	5
Other	4	2	0	3	10	3	5	1	0	3	0
Terrestials	15	8	5	2	36	0	7	0	11	6	5
Chironomidae adult	19	2	1	7	31	4	2	0	29	0	0
Exuviae	0	0	0	0	5	0	0	0	0	0	3
Total	64	20	94	19	226	57	73	11	82	25	76

Appendix E. (Continued)

River kilometer	31	31	31	31	31	Site Total	27	27	27	27	27	27	27
Trout number	s3t97	s3t98	s3t99	s3t100	s3t118	n=11	s4t1	s4t 97	s4t98	s4t99	s4t100	s4t101	s4t102
Pleuroceridae <i>Juga</i>	0	0	0	0	0	0	0	0	0	0	0	3	1
Diptera adult	6	0	5	3	0	84	1	0	4	1	0	1	0
Trichoptera adult	1	2	0	1	1	6	0	0	1	0	0	7	0
Limnephilidae <i>Dicosmoecus</i>	0	0	0	0	0	0	0	0	0	0	0	2	0
Plecoptera adult	0	0	1	1	0	11	0	0	2	1	1	0	1
Ephemeroptera adult	2	16	23	17	1	206	21	3	3	0	5	2	26
Ephemeroptera nymph	2	0	0	0	0	20	0	0	3	0	0	0	0
Other	6	0	2	3	0	23	0	0	2	0	1	1	1
Terrestrials	1	0	0	1	0	31	0	0	0	0	0	2	1
Chironomidae adult	0	1	4	1	0	41	0	0	0	0	1	0	0
Exuviae	0	0	0	0	0	3	0	5	0	5	0	0	5
Total	18	19	35	27	2	425	22	8	15	7	8	18	35

Appendix E. (Continued)

River kilometer	27	27	27	Site total	18	18	18	18	18	18	18	Site total
Trout number	s4t103	s4t104	s4t105	n=10	s6t96	s6t97	s6t98	s6t99	s6t107	s6t120	s6t121	n=7
Pleuroceridae <i>Juga</i>	1	0	1	6	0	0	0	1	0	0	2	3
Diptera adult	1	5	3	16	0	0	0	0	0	0	0	0
Trichoptera adult	0	0	1	9	0	0	3	0	1	1	1	6
Limnephilidae <i>Dicosmoecus</i>	0	0	1	3	1	0	1	0	0	0	0	2
Plecoptera adult	0	1	2	8	1	0	1	1	1	1	0	5
Ephemeroptera adult	5	6	2	73	0	1	4	2	2	3	1	13
Ephemeroptera nymph	0	3	0	6	0	0	0	0	0	0	0	0
Other	0	3	1	9	1	2	0	3	0	0	0	6
Terrestials	1	2	3	9	0	0	1	0	0	0	7	8
Chironomidae adult	1	0	0	2	0	0	0	0	0	0	0	0
Exuviae	5	0	0	20	0	3	5	0	10	5	0	23
Total	14	20	14	161	3	6	15	7	14	10	11	66

Appendix F. Management recommendations and field notes.

Disconnection between the stream and its floodplain is likely the greatest concern for proper stream function in Thomas Creek. Connecting the creek with its floodplain may be difficult because of severe channel incision throughout the creek and narrow riparian buffers in the downstream reaches. Expanding riparian corridors may be difficult and would require cooperation from agricultural landowners. The current riparian corridor in the downstream reaches is primarily composed of mature trees and the exotic plants Himalayan blackberry (*Rubus discolor*) and/or reed canary grass (*Phalaris arundinacea*). I did not survey age structures of riparian forests; however, they appeared uniformly composed of mature trees (breast height diameters greater than 50 cm); recruitment of younger trees is minimal. In many locations the corridor is one mature tree wide with an understory of exotic grass and shrubs. When the channel migrates beyond the current riparian zone, agricultural vegetation will provide little support or structure for stream banks.

Furthermore, channel incision may make establishing new generations of trees difficult. Common riparian trees such as willow and cottonwood can be difficult to establish when planting sites are disconnected from the water table because plantings must be deep enough to reach midsummer water tables and tall enough to reduce shading by surrounding vegetation (Hoag et al. 1992). Severe channel incision (average of 2.5 meters in the riparian survey sites) would require significant stream bank modifications to establish successful vegetation plantings (Manci 1989, Rosgen 1997). Active restoration appears to be the only option at many locations because stream and riparian conditions are not conducive for either natural recruitment or establishing a wider, more structurally diverse riparian corridor.

Flooding is a major concern for local landowners (personal communication with numerous landowners and South Santiam Watershed Council members). Convincing landowners that connecting the stream to its floodplain is beneficial may be difficult because of perceived and actual property

loss and/or damage. Widening the riparian zone would require taking agricultural lands out of production in many locations and assisting the stream to overflow its banks has potential for property damage to nearby structures. Future restoration work will require communication, education, and cooperation with landowners. Because riparian forest regulations are lax for lower elevation streams (no harvest within 5 m of the channel), an aggressive proactive approach is required to maintain current riparian conditions or improve future conditions.

Remnants of the dam near river kilometer (R km) 30 may result in a barrier for small or juvenile fish in Thomas Creek (e.g. dace (*Rhinichthys spp*), sculpins (*Cottus spp*), redbase shiners, chinook, and trout during some seasons. It has been demonstrated that jumping ability of fish is determined by fish size and swimming speed, launching pool depth, and landing pool resting stations (Thompson and Rahel 1998). The structure results in drops greater than 30 cm (personal observations), which may be too high for smaller fish. However, studies of barrier heights have focused on adult salmonids (Powers and Orsborn 1985) and jumping abilities of juveniles and non-salmonids are relatively unstudied (Robinson et al. 1999).

The impact of car bodies in the stream on biota and channel characteristics is unknown. The different color substrates in this area suggest some type of biotic impact and deserves further investigation. I do not know if they were strategically placed or were uncovered by the migrating stream channel. Action plans would likely differ if they were strategically placed or uncovered from a landfill or junkyard.

Field Notes

I spent over 2000 hours in and around Thomas Creek during my study. Although fish surveys in downstream reaches were limited to five electroshocking sites during July and September 2000, and my extensive snorkel survey in May 2001, I spent numerous days recreational fishing. During this time, I observed only three exotic fish species. In 2000, I collected a single

brown bullhead (*Ameiurus nebulosus*, at R km 13) while electroshocking and I observed a single sunfish (*Lepomis spp*, at R km 27) while recreational fishing. Smallmouth bass were the most abundant exotic species, and they were relatively rare. The furthest upstream that I observed smallmouth bass was R km 23; they were caught while recreational fishing in August 2000. If more numerous and/or intensive surveys are performed during other seasons, greater abundances or more species of exotic fish may be observed.

Generally, my observations of native species distribution matched the fish surveys performed in 1982-1983 (Kruse 1988). I observed trout throughout the entire length of study stream; northern pikeminnow (up to R km 32), largescale sucker (up to R km 43), speckled dace (*Rhinichthys osculus*, up to R km 37), and redbreast shiner (up to R km 34) were found in the middle and lower reaches. Juvenile chinook salmon were not reported in 1988 and my observations are a result of reintroduction efforts of ODFW (ODFW 1930-2001). During the May 2001 longitudinal survey I observed 26 adult chinook salmon. However, the sightings were on different days, at different locations, so I may not have seen some individuals or counted some individuals more than once.

On several occasions, I observed Pacific lamprey (*Lampetra tridentata*) ammocoetes, redds, or active spawning throughout the middle and upper reaches of the creek (Appendix C); the farthest upstream that I observed an adult Pacific lamprey was R km 48. However, I did not attempt to quantify lamprey because of sampling efficiency and my inconsistent ability to capture them. Because of rapidly declining spawning adult returns, Pacific lamprey was listed as an Oregon State sensitive species in 1993 and was given extra legal protection in 1996. These are relatively unstudied anadromous fish and little is known about their distribution and population levels in the Willamette Valley. As in this instance, most information on lampreys in Oregon was collected incidentally while surveying for other fish species (Kostow 2002). Pacific lampreys were not reported from the 1982-1983 Thomas Creek surveys.

Native western pearl shell mussels (*Margaritifera falcata*) were present throughout the lower reaches. Mussels were generally sparse with the

exception of a large bed with approximately 300, 10-12 cm individuals (location, N 44.41.293 W 122.53.167) and a smaller bed with approximately 100 individuals (location, N 44.42.801 W 122.45.013). Coarse and fine gravels dominated substrates near the mussel beds. *Margaritifera* are especially sensitive to pollution (e.g. silting, temperature, pesticides, nutrients, etc.) and may be indicators of stream stability and disturbance as they are sedentary and require relatively stable substrates (Johnson and Brown 2000, Moorkens 1999 cited in Araujo and Ramos 2001). Because their life history includes a parasitic larval stage, these mussels rely on fish (likely salmonids in the Pacific Northwest) to disperse (Bauer 1987). Low abundances of salmonids were observed in the proximity of the largest mussel beds, so present salmonid distributions may be limiting mussel dispersal and distribution.

Freshwater sponges (*Spongillidae spp*) were also observed in reaches seven and eight. Freshwater sponges are generally sensitive to nutrient enrichment, pollution, and overall water quality conditions. However, some species are tolerant and positive identification is required to infer water quality conditions (Wetzel 2001).

During stream surveys in Thomas Creek, I frequently observed wildlife including beaver (*Castor spp*), Roosevelt elk (*Cervus canadensis roosevelti*), and harlequin duck (*Histrionicus histrionicus*). I observed only three beavers during stream surveys, however, signs of beaver were occasionally seen so I am confident they are more numerous than I documented. Elk were common between R kms 40 and 50 but occasionally they were as far downstream as R km 35. I observed an adult female elk that, according to wounds and carcass location and condition, apparently was killed by a cougar at R km 48. I observed three female harlequin ducks in May 2000 at approximately R km 45. On one occasion, I was snorkeling and witnessed a garter snake (*Thamnophis spp*) dive underwater approximately 70cm and capture an adult sculpin.