AN ABSTRACT OF THE THESIS OF

Jonathan W. Kehmeier for the degree of Master of Science in Bioresource Engineering presented on September 27, 2000. Title: A Spatially Explicit Method for Determining the Effects of Watershed Scale Land Use on Stream Conditions.

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Abstract approved: ______________________________

John P. Bolte

The primary goal of this research was to identify the impacts that individual agricultural land uses have on fish communities in small streams located in the Willamette Valley of western Oregon. The diverse nature of the land use features of the valley provided a challenging but useful system for the differentiation of the impacts of various land uses.

This manuscript first presents the methods used to select the watersheds for sampling. Selecting basins that allowed for the detection of various land use impacts while capturing conditions that were representative of valley-wide land use characteristics required an innovative sampling design. Histograms representing the land use characteristics of the small watersheds in the Willamette Valley were used for this purpose.

The second manuscript in this document outlines the development and implementation of a spatially explicit method that allows for the isolation and quantification of the impacts of specific land uses. Developing a series of raster files

(grids) using a Geographical Information System (GIS) allowed for the determination of the flow path lengths of each pixel (cell) in a watershed. The inverse values of the flow path lengths were used as measures of the potential impact that each cell in a watershed had on stream conditions. Sums of these potential impacts were calculated for each land use in a watershed and used as independent variables in modeling efforts.

The selection techniques used to identify the sampled watersheds with those of the inversely weighted flow path method enabled the identification of the land use practices that have the greatest impact on stream fish assemblages. A model using the inverse values of the squared in-stream and out-of-stream flow path lengths was the most useful for describing the impacts of basin-scale land use on stream fish populations.

A Spatially Explicit Method for Determining the Effects of Watershed Scale

Land Use on Stream Conditions

by

Jonathan W. Kehmeier

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

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Jonathan W. Kehmeier, Author

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CONTRIBUTION OF AUTHORS

Drs. John Bolte and Peter Bayley were both involved in the design, development, analysis, and writing of the two papers presented in this thesis.

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CHAPTER 1. INTRODUCTION

Problem Definition

Impacts that individual land use activities have on stream conditions have been identified and isolated in small-scale studies of point and non-point source pollution (Bolstad and Swank 1997; Goldstein et al. 1999; Angermeier and Winston 1999). However, the relationships between watershed scale land use practices, aquatic organisms, and the habitat that supports those organisms has been difficult to establish. To this point, methods to identify the impacts of diverse land use patterns have fallen short in their ability to capture the spatial variability associated with these systems.

The purpose of this study was to determine the relationships between measures of native fish assemblages and watershed scale agricultural land use in the Willamette Valley of western Oregon. Several areas of interest were identified early in the research process as potential objectives of this investigation. The primary goal was to quantify the impacts that each major agricultural cropping system in the valley had on fish populations. A secondary goal was to develop a spatially explicit method to capture the variability of diverse watershed scale land use patterns and describe individual land use impacts on stream fish assemblages.

The study focused on 49 small streams draining watersheds in the Willamette Valley ecoregion of western Oregon (Figure 1.1) (Omernik and Gallant 1986). Of these 49 streams, 19 were sampled for aquatic vertebrates and habitat characteristics during the summer of 1997 for the purposes of a similar study done by the Unites States Environmental Protection Agency (USEPA) (Moser et al. 1997). An additional 23 streams were sampled for the purposes of this study during the summer of 1999. Sampling during the summer of 2000 included data collection at 7 new sites as well as 14 replicated sites that were previously sampled in 1997 or 1999.

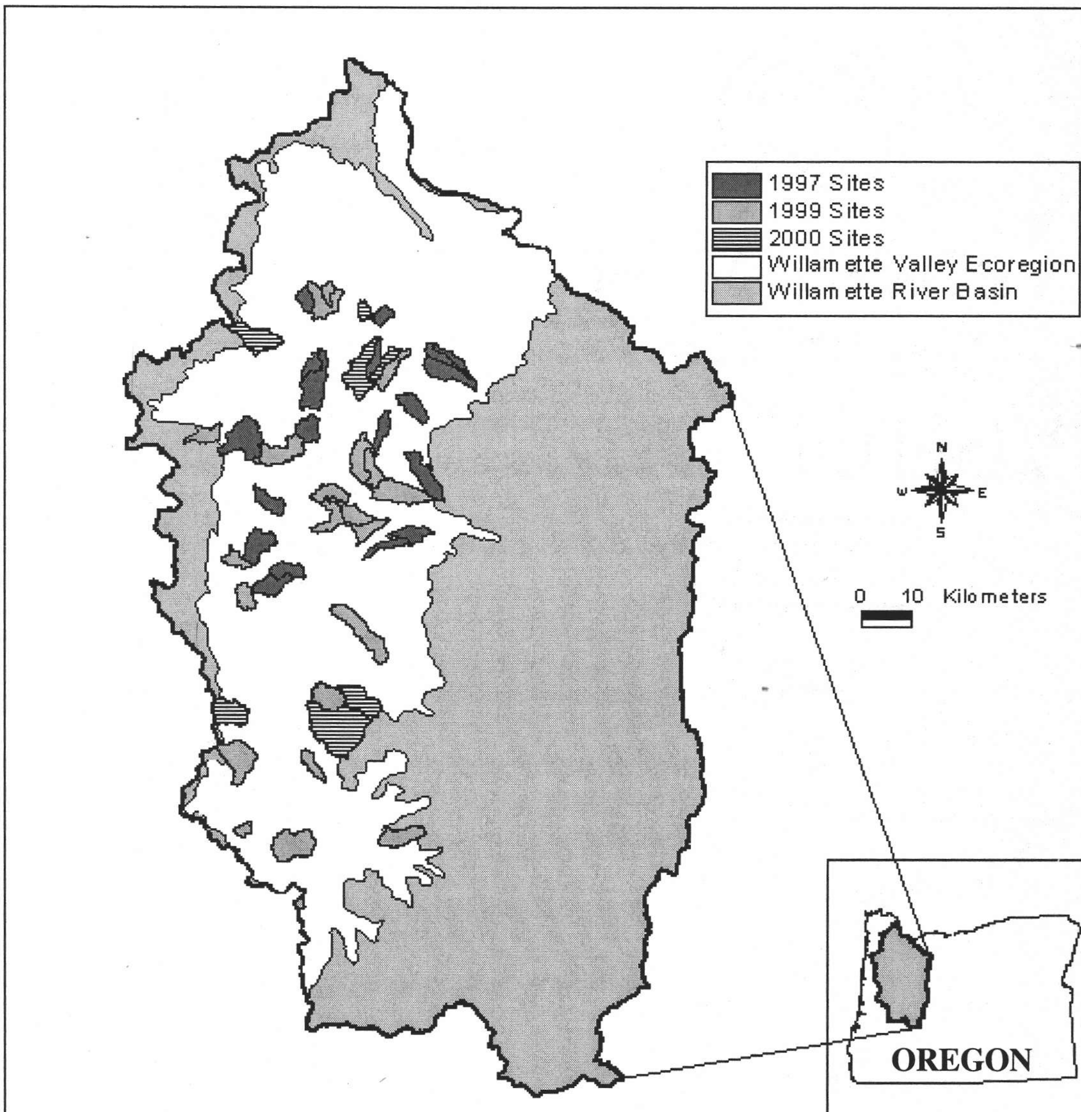

Figure 1.1. Locations of the sites selected for sampling during the summers of 1997, 1999, and 2000.

This manuscript presents the theory and methodology used to develop the techniques necessary for the quantification of watershed scale land use impacts on stream fishes. First, I set forth the methods used for the identification and selection of watersheds with the characteristics necessary for the detection of land use impacts on stream conditions. Then techniques developed for the description of each land use's impact on the response of the fish assemblage are described.

Manuscript Format

This thesis was prepared in accordance with the regulations set for the manuscript format outlined by the Graduate School of Oregon State University. The second chapter of this document has been written to comply with the configurations necessary for submission to the journal Landscape Ecology. The third chapter has been formatted in a manner consistent with the requirements of the journal Ecological Applications. In addition, the introductory and summary chapters were written to synthesize the findings of this study and conform to the style requirements of the Oregon State University Graduate School. A bibliography containing all citations in this thesis follows the concluding chapter.

Notes Regarding Chapter 2

Developing techniques for detecting the impacts of land use activities, and specifically the impacts of agricultural land use activities, on stream conditions is necessary to assess externalities in economic assessments and planning. The Willamette Valley of western Oregon is characterized by a diverse landscape of various agricultural, urban, and natural land uses. The high diversity of this landscape within a relatively uniform aquatic environment among small streams makes it a useful system for the development of techniques to detect differences among land use activities. Using quantitative and qualitative measures, a method has been developed to detect the different impacts that each land use has on stream conditions while insuring that the sites selected are representative of valley-wide conditions.

While the diversity of agricultural lands in the Willamette Valley makes the detection of the influence of different land uses on stream conditions very challenging, the inherent contrasts are essential to detect differences among land uses with various spatial distributions. Thus, sampling a set of watersheds that are representative of valley wide conditions and unique in their land use characteristics is necessary for the success of this study.

The size and geographic location of a watershed were considered to be important in the selection process. However, the most important consideration for determining whether a site was selected for sampling was the percentage of each of the agricultural land use that a basin contained. Watersheds that met the size and location requirements were ranked according to the percentages of each agricultural land use found within the basin. Sites that were identified as potential sampling locations were visually assessed to insure that their land use patterns were consistent with conditions found throughout the remainder of the Willamette Valley.

Correlations between land use and measures of stream conditions revealed that watersheds selected using the above criteria identified sites that were potentially useful for the detection of different land use impacts. However, the design of this analysis was not appropriate to determine if the spatial distributions of agricultural lands were related to stream fish populations. Thus, quantification of the effects of each land use was not attainable using this method alone.

<u>Notes Regarding Chapter 3</u>

The spatial heterogeneity of an agricultural watershed makes the detection of the impacts that a land use has on stream conditions very difficult. The methods that are normally used for this type of analysis fail to account for much of the variability that is associated with watershed scale land use. These methods either ignore the activities that occur beyond some distance from a stream or they do not account for the fact that the spatial position of a land use influences the impact that it has on stream conditions.

Topography of a watershed has been shown to be one of the most important features to consider when assessing land use impacts on stream conditions (Buckley 1997). The distance that material originating from an upland source must travel before reaching a stream is strongly influenced by the topographic properties of the landscape. The spatial location of a land use was assumed to be very important in governing the size and impact of a load of terrestrial origin on downstream aquatic conditions. Thus, concepts used in previous methods of watershed assessments, such as stream buffer approaches, were combined with the topographical properties of a watershed to form a new tool for watershed scale land use studies.

Using grids generated in the Geographic Information System (GIS) ArcInfo, a topographically sensitive method using inversely weighted flow path distances was developed to capture the spatial variability of agricultural watersheds. The inverse weighting scheme puts more emphasis on regions near the sampled reach than those far from the reach (Figure 1.2). In the inverse flow path distance method, all regions in a watershed are considered to have some impact on stream conditions and fish assemblage structure, thereby eliminating the need to identify a specific area in which land use impacts the stream.

The weighted inverse distances were used as the explanatory variables in a multiple regression developed to differentiate and quantify the impacts of land use practices on stream conditions. Analysis revealed that the inversely weighted flow path distance method was able to detect the influences that several different watershed scale land use activities had on stream fish populations. In addition, the inverse flow path method enabled the separation and quantification of the in-stream and out-of-stream processes that were important in defining the impact that each land use had on aquatic conditions.

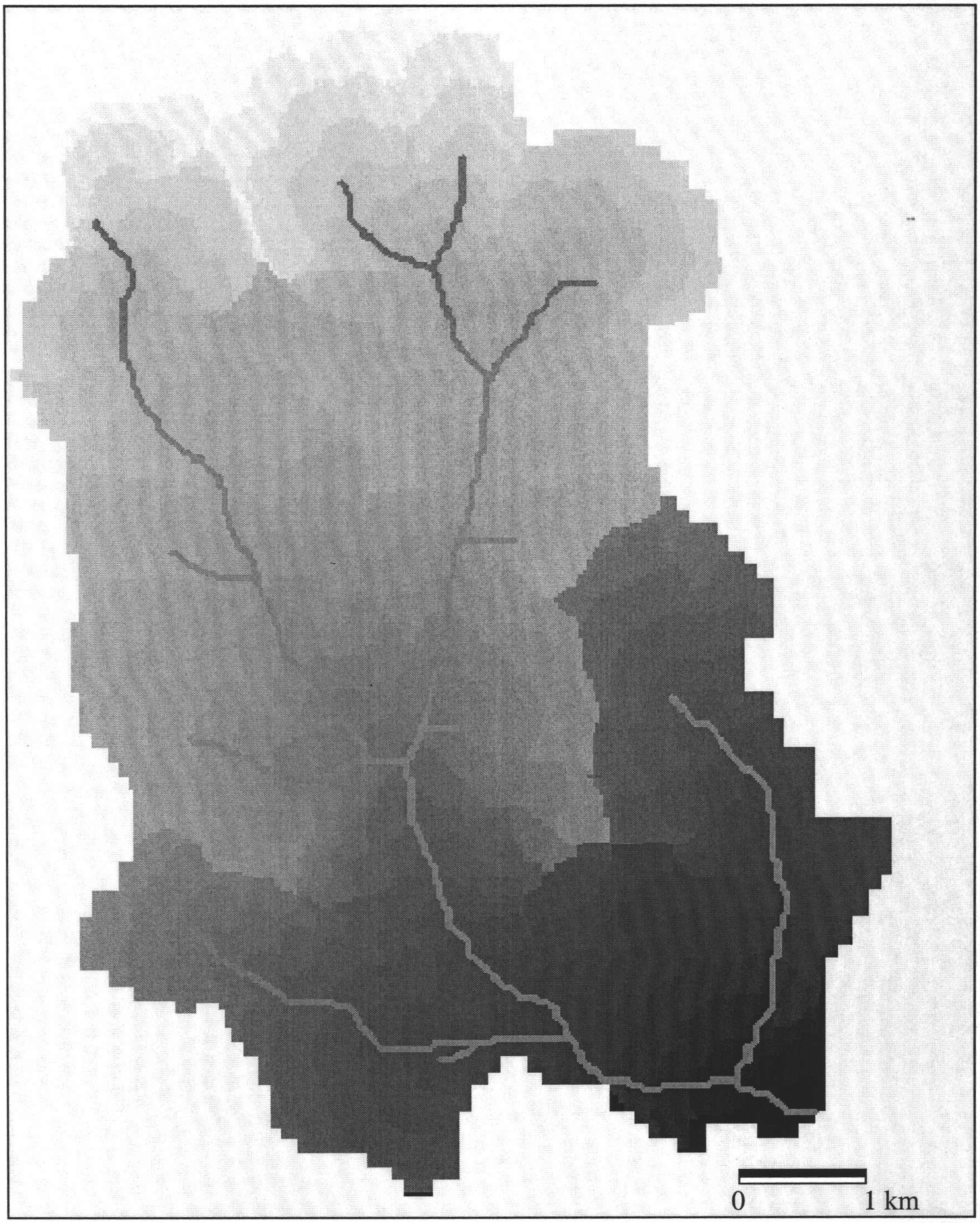

Figure 1.2. Representation of inversely weighted flow path distances in the Oak Creek watershed west of Corvallis, Oregon. Darker colors represent regions with shorter flow path distances.

CHAPTER 2.

A WATERSHED SELECTION APPROACH TO DETERMINE THE EFFECTS OF AGRICULTURAL LAND USE ON STREAM CONDITIONS

Jonathan W. Kehmeier, Peter B. Bayley, and John P. Bolte

For Submission to *Landscape Ecology*

Introduction

The effects of watershed scale processes on various definitions of stream health are well documented (Osborne and Wiley 1988; Richards and Host 1994; Roth et al. 1996; Allan et al. 1997; Buckley 1997). However, one of the greatest challenges currently facing natural resource managers is determining the effects of specific land use activities on fish community health and sustainability. This task becomes even more challenging when the spatial and environmental complexity of an agricultural catchment is considered. The patchiness of these systems, coupled with the complex interactions of air, water, and soil features, necessitates the development of consistent sampling guidelines to detect the influences of different land use practices on stream conditions.

Various studies have shown that different agricultural practices influence sedimentation (Kuhnle et al. 1996), nutrient loading (Owens et al. 1991), and water temperature (Waite and Carpenter 2000) in streams and rivers. In some cases, specific land use practices have been tied to these processes. However, in most cases, the ability to detect individual effects of specific land uses and land use patterns has been difficult (Rose 2000). Generally, in-stream impacts have been attributed to broad land use classifications such as forest, riparian, urban, and agriculture (Osborne and Wiley 1988; Richards and Host 1994; Allan et al. 1997; Wang et al. 1997). While this classification scheme may be appropriate for broadly defined land uses or certain measures of stream health, it fails to capture the associated variability that is found among agricultural watersheds and the different effects that each agricultural land use may have on fish populations. Thus, to better understand the potential impacts of specific agricultural practices on aquatic biota, a more focused approach is necessary.

Detection of land use influences is especially important in the Willamette Valley ecoregion of western Oregon, where water quality and fisheries drive many public policy issues. Therefore, determining the nature of the impacts of various land use practices on native fish is of the utmost importance. Distinguishing between adverse and advantageous land use practices may identify techniques that can be used in future restoration, mitigation, and management plans involving aquatic resources.

Past efforts in the Willamette Valley have suggested that agricultural practices affect native fishes citing pesticides, nutrients, and habitat alteration as the primary concerns (Hughes and Gammon 1987; Li et al. 1987; Wentz et al. 1998; Waite and Carpenter 2000). However, these studies did not identify which land use practices had the largest impacts. The generalization that all agricultural practices have unfavorable impacts on fish communities is unfair when just one land use or, locally, one field may be responsible for conditions observed in a stream.

To determine the importance of individual land use impacts on fish assemblages, several key factors were considered while designing our study. First, it was necessary to design the study in a manner that allowed for the detection of the individual impacts that each land use may have on stream fishes. In addition, the impacts of the different land uses had to be such that the magnitude of their influences on measured stream conditions could be quantified with reasonable certainty. Once identified, the land uses with beneficial and detrimental impacts on stream fish communities could be determined. The impacts should be interpretable to determine the benefit or detriment that each land use has on a fish assemblage. We believe that the careful and consistent selection of sampling sites will allow us to detect and quantify the impacts of specific land uses.

Methods

Study Area

The basins selected for this study lie within the Willamette Valley of western Oregon (Figure 2.1). The Willamette Valley comprises approximately one-third of the 30,000 km^2 Willamette River Basin. The valley is one of three ecoregions found in the watershed (Omernik and Gallant 1986). It is flanked to the east by the Cascade mountain range and to the west by the Coast Range Mountains. The valley is home to the majority of Oregon's population. The cities of Portland, Salem, and Eugene are the three major urban centers in the basin. Nearly 60 percent of the Willamette Valley is devoted to agriculture while most of the remaining 40 percent consists of forest and urban land uses.

The Willamette Valley is known as one of the most diverse agricultural areas in the United States (Jackson 1993). Economically and geographically, fescue and rye grass seed production are the dominant agricultural cropping systems. They dominate the southern half of the Valley while the northern half is characterized by more diverse landscapes comprised of a mixture of grass seed, row crops, orchards, berries, Christmas trees, and vineyards.

Site Selection

By necessity, this study is observational in nature. The lack of pristine conditions in the Willamette Valley does not allow for the use of control sites with which the data collected may be compared. Therefore, we need to relate observed changes in stream measures, such as fish health, with differences in land use patterns across a set of watersheds. To accomplish this in the Willamette Valley, the sites selected for sampling must be as representative of valley-wide conditions as possible.

To determine the effects of specific land uses on aquatic conditions, small agricultural catchments (15-80 km^2) were identified (Moser et al. 1997). The size limit was set to increase the probability that sampled streams were wadeable at baseflow

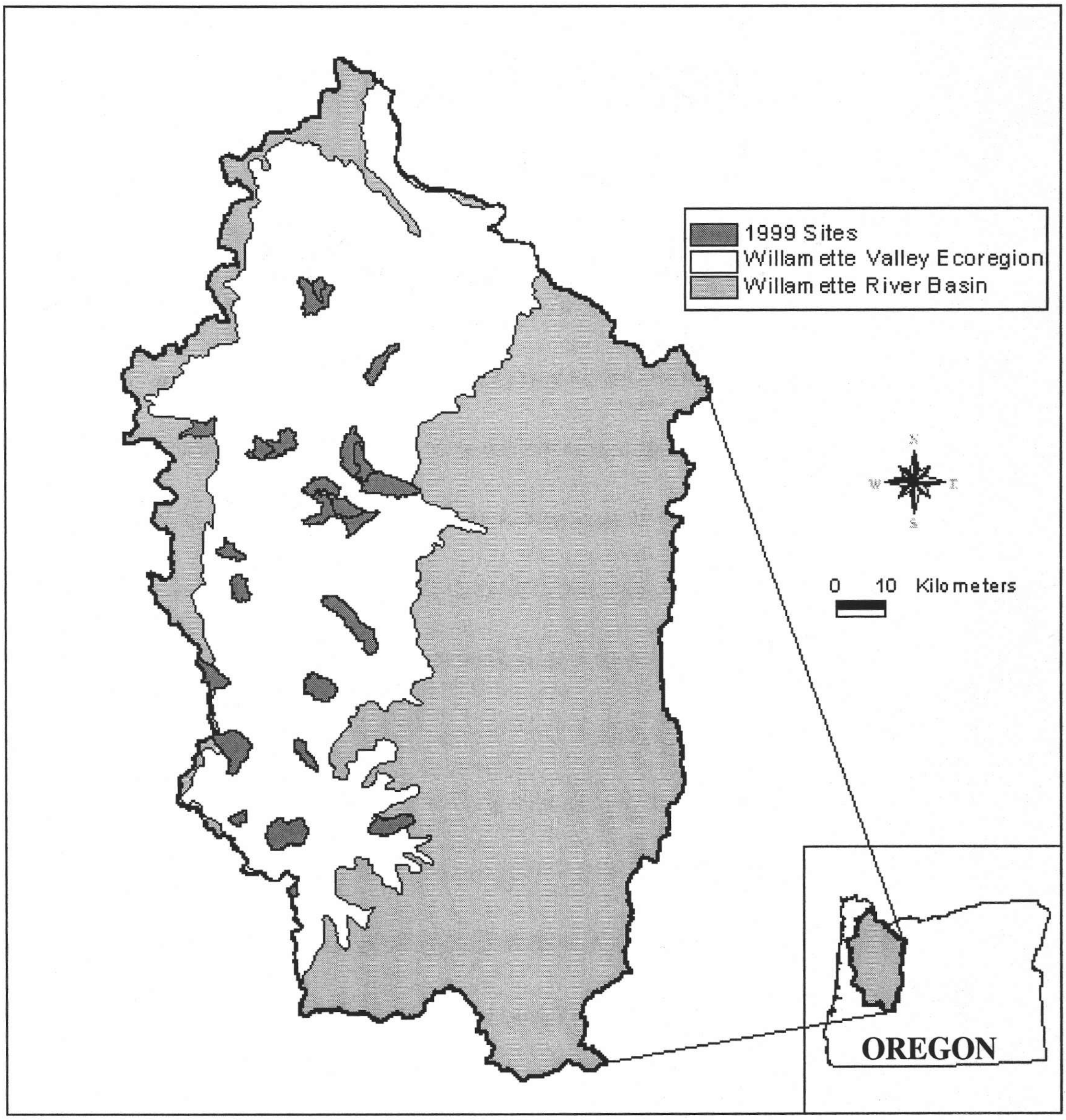

Figure 2.1. Locations of the 24 watersheds selected for sampling during the summer of 1999.

conditions for the purposes of fish sampling. Watersheds that were smaller 15 km^2 were also considered if their land use and stream characteristics were appropriate for detecting land use differences. Initially, 334 watersheds were automatically delineated using a United States Geographical Survey (USGS) 30m digital elevation model (DEM) in the Geographic Information System (GIS) ArcInfo (Environmental Systems Research Institute 1994). Of the initial set, several were removed that were erroneously included in the prescribed range because of inaccurate delineations of their watershed boundaries resulting from errors in the DEM in low gradient regions.

The land use characteristics of each of the basins was determined using a digital land use/land cover (LULC) raster file (grid) generated by the Oregon Department of Fish and Wildlife (ODFW) (Klock et al. 1998). For the purposes of this study, map was the most recent and the most accurate available. The LULC was reclassified to reduce the number of land use categories from 26 to 8 (Table 2.1). Land uses that had nearly identical management and vegetation characteristics were grouped to enhance our ability to detect the different impacts that each had on stream fish communities. The reclassified LULC consisted of 5 agricultural classes and 3 non-agricultural classes (Table 2.1). Those basins that did not contain any agricultural lands were eliminated leaving 142 basins. For each of those watersheds, the area of each land use was determined by counting the number of cells (or pixels) of each land use. That number was then multiplied by 900 m^2 (the surface area of a 30 m by 30 m cell) to obtain the surface area of each land use in the basin. Using the areas of each land use, Shannon's diversity index was calculated to determine the watersheds with the most diverse agricultural settings.

The percentage of a basin that each land use occupied was used as a preliminary screening factor in selecting watersheds from which differences among the five agricultural classifications could be detected (Table 2.1). The watersheds were ranked according to the land use percentages and the 50 highest-ranking catchments were determined for each of the five agricultural classes and plotted as histograms (Figure 2.2a).

For the purpose of clarity, the process for the selection of watersheds based on the orchard land use classification will be outlined. Keeping track of the orchard watersheds that occurred in more than one histogram, basins were selected using several criteria. Sites with conditions approaching monoculture in the orchard category were believed to be ideal. However, no agricultural monocultures were present in the Willamette Valley. Thus, watersheds consisting of a high proportion (greater than 10–15 percent) of orchard were selected for further consideration as it was believed that signals from orchards could be detected over those of other land uses in these basins (e.g. watersheds 75–55 in Figure 2.2b). The large differences between the percentages of orchard lands in these watersheds and the mean percentage of orchards among all watersheds were expected to increase the detectability of the specific impacts of the orchard land use. In addition, orchards comprised a higher percentage of the areas of the five basins (77–55 in Figure 2.2b) than did the other agricultural land uses, with the exception of perennial grass, which is a dominant feature in the majority of the watersheds in the Willamette Valley. This comparatively high percentage of orchard was assumed to be useful for detecting the specific impact that orchard and berry production had on stream fish populations.

Watersheds consisting primarily of forest with small areas of orchard near the potential sample reach were also considered because it was assumed that the impacts of orchards could be detected over the background effects produced by large areas of forest (e.g. watershed in Figure 2.2b). In addition, several candidate watersheds were selected based on their land use diversity (e.g. watersheds 135 and 147 in figure 2.2b). These sites were included to increase the likelihood that conditions representative of land use practices throughout the Willamette Valley were sampled.

ODFW Land Use Classifications	Modified Land Use Classifications
Row Crops	Row Crops*
Annual Grasses and Grains	Annual Grasses*
Perennial Grasses and Hay	Perennial Grasses*
Orchards and Berries	Orchards and Berries*
Unmanaged Pasture	Unmanaged Pastures*
Willow Cattail/Bulrush Black Hawthorne Cottonwood Riparian Reed Canary Wetland Ash/Cottonwood/Maple Gravel Bars and Sand	Riparian Vegetation and Wetlands
Doug Fir Oak/Madrone Maple/Alder/Fir Oak/Doug Fir > 50% Oak Doug Fir/Oak > 50% Doug Fir General Forest/Unclassified	General Forest
Urban Parks and Recreational Fields Doug Fir Urban Build Up (UBU) Oak/Doug Fir UBU Doug Fir/Oak UBU Ash/Cottonwood UBU Maple/Alder/Fir UBU Cottonwood Riparian UBU	Urban

* - Agricultural land use classification

Table 2.1. Reclassified land use categories as derived from the ODFW classification scheme.

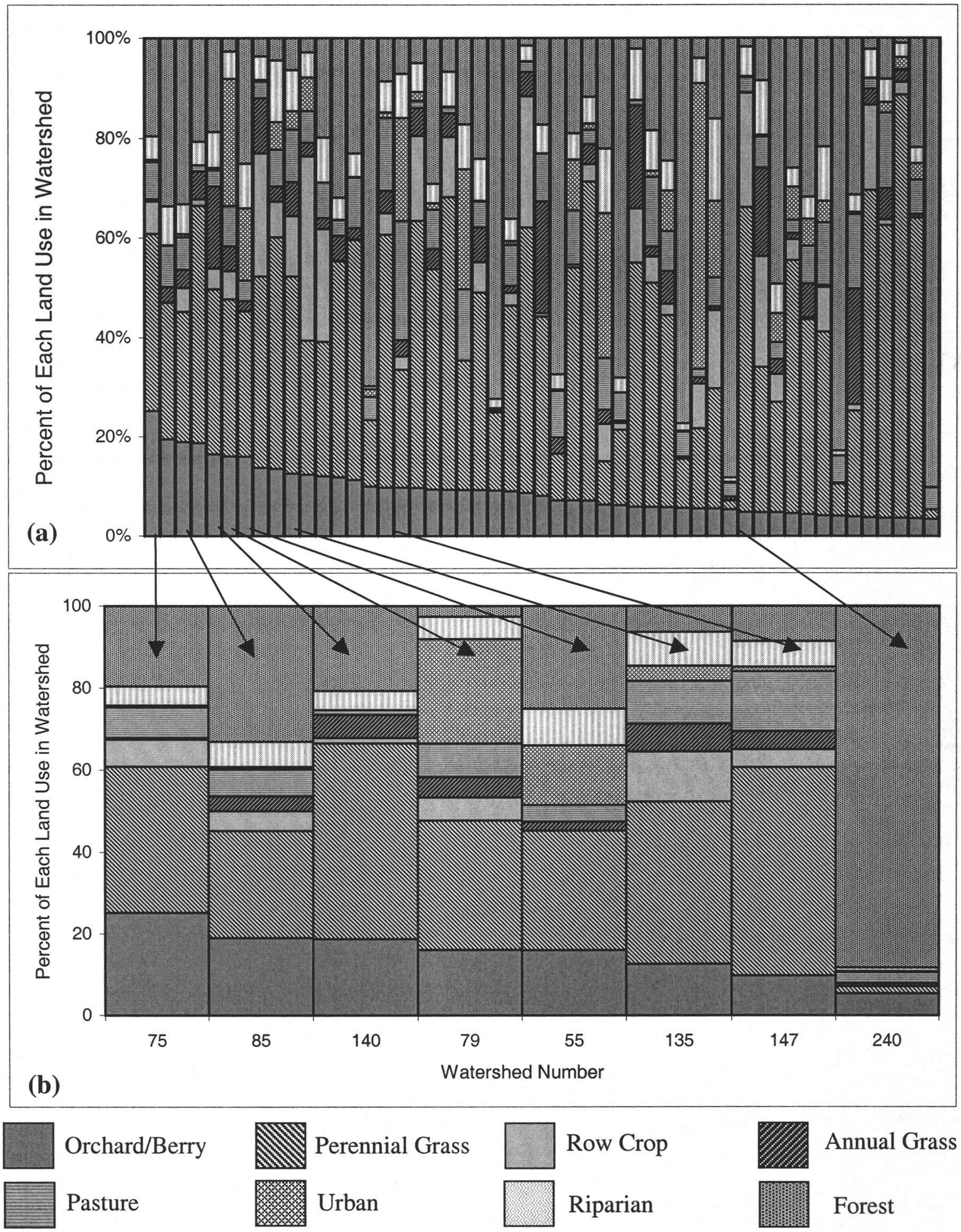

Figure 2.2: **(a)** Histogram representing the 50 highest ranking Orchard/Berry watersheds that did not contain atypical assemblages of other land uses. Arrows indicate which of the highest-ranking watersheds were selected as candidate sampling basins. **(b)** Histogram representing 8 of the 11 watersheds selected as candidates for sampling using the Orchard/Berry land use classification.

Using the above criteria on the remaining 4 agricultural land uses produced a set of 45 watersheds selected as candidates for sampling based on the percentages of the 5 agricultural land uses they contained. Due to the large proportion of perennial grass seed production in all of the watersheds (Table 2.2), only four sites were considered for sampling based on this land use alone. In addition, 8 sites were selected for row crop domination, 7 sites for annual grass seed, 11 sites for orchard/berry, and 15 sites for pasture. No sites were specifically selected for land use diversity because the 45 sites selected based on land use percentages accounted for the majority of the sites with high diversities.

	Mean land use percentages for set of 142 agricultural basins		Mean land use percentages for set of 24 selected agricultural basins		
	Mean	St. Dev.	Mean	St. Dev.	Range
Basin Area	41.4	17.7	39.5	21.7	8.5-75.4
Row Crop	3.2	6.6	2.9	6.0	0-25.2
Annual Grass	3.2	5.0	3.6	6.6	0-30.3
Perennial Grass	28.8	23.9	30.4	24.8	0-87.1
Orchard/Berry	3.7	5.0	5.1	5.9	0-17.7
Pasture	6.1	4.5	10.3	7.5	0.71-31.0
Urban	5.1	13.3	3.9	7.6	0-28.2
Riparian/Wetland	5.2	7.8	4.5	3.1	0-11.5
Forest	44.8	34.2	39.5	21.7	5.8-75.4

Table 2.2. Properties of the initial set of 142 agricultural catchments compared to the properties of the 24 basins selected for sampling in 1999.

The LULC cover maps of each of the 45 candidate watersheds were visually assessed to determine if all of the sites were acceptable for sampling. Some of the sites were eliminated due to obvious errors in their watershed boundaries that were not recognized on initial inspection. Still others were eliminated due to large impoundments directly upstream or downstream of the potential sampled reach (Moser et al. 1997). In addition, basins with large proportions (> 30%) of urban land or with urban land surrounding the drain point of the watershed were removed from consideration. Also, special care was taken to insure that sampling locations were distributed evenly across the valley. Avoiding associations between the type of agricultural land use and geographic position reduced the likelihood that geographically correlated features could confound later analyses.

Further reductions were made to the number of candidate sites based on field observations. Several sites were eliminated due to the lack of a visible channel for sampling. We recognize that this channel elimination could be a direct result of land management practices but cannot prove that stream channels ever existed at those locations. Several other sites were eliminated due to increased flows caused by irrigation diversions, the lack of wadeable sampling reaches, or the failure to gain access to streams.

The final list of sites contained 24 watersheds (Figure 2.1). Of these, 3 were selected for row crop properties, 2 for annual grass, 2 for perennial grass, 6 for orchard, and 11 for pasture. The large number of pasture sites was not of great concern as six of the pasture sites were ranked among the top twenty diversity sites indicating that the other agricultural land uses were well represented in these watersheds. Table 2.3 describes the properties of each of the selected watersheds while Table 2.2 compares the properties of the original 142 agricultural catchments to the 24 sampled basins.

		Percent of Land Use in Basin							
Basin Code	Basin Area (km^2)	Row*	Ann*	Per*	Orc*	Pas*	Urb*	Rip*	For*
55002	15.4	16.28†	0.00	72.77	3.27	2.02	0.05	4.00	1.61
55006	29.8	25.20†	3.95	32.25	0.25	15.17	1.69	6.87	14.62
55019	35.6	5.14†	2.00	44.18	6.13	14.49	1.21	7.83	19.02
55004	24.6	0.34	30.27†	51.55	3.58	3.63	2.05	4.15	4.43
55009	61.6	1.18	15.42†	51.95	11.26	2.23	1.12	4.14	12.71
55003	36.8	0.00	1.68	87.08†	0.00	4.60	0.86	1.95	3.82
55023	74.1	0.00	2.02	52.71†	0.01	6.71	3.16	5.10	30.30
55007	63.4	0.10	3.41	27.17	17.61†	7.91	0.04	7.81	35.95
55008	14.0	0.00	1.33	30.30	16.82†	5.09	0.12	8.95	37.39
55010	26.7	5.84	4.11	31.09	16.77†	8.39	25.63	5.34	2.83
55012	40.1	0.10	0.72	1.77	5.36†	2.73	0.21	0.94	88.16
55016	29.0	3.31	4.70	52.13	9.78†	15.41	1.27	5.90	7.52
55017	31.8	0.00	0.00	20.76	10.22†	15.58	28.19	8.50	16.75
55001	46.6	0.00	0.00	0.00	0.00	0.71†	0.00	0.03	99.26
55005	29.1	0.00	4.04	2.19	0.70	5.34†	0.00	0.99	86.73
55011	75.4	4.72	4.64	37.82	9.91	17.06†	12.02	6.54	7.28
55013	74.0	0.00	0.23	5.26	0.00	23.52†	0.85	4.80	65.35
55014	28.9	0.00	0.00	6.53	0.04	16.87†	5.58	1.38	69.59
55015	69.6	1.18	6.28	58.82	3.72	15.23†	2.07	4.47	8.23
55000	34.5	5.82	0.02	33.86	4.74	14.28†	5.11	11.50	24.67
55018	12.0	0.00	1.33	9.19	0.87	31.01†	2.24	4.94	50.43
55020	67.8	0.00	0.09	17.47	0.82	5.26†	0.66	1.91	73.79
55021	21.7	0.00	0.00	3.02	0.09	8.11†	0.00	0.79	87.99
55022	5.8	0.00	0.00	0.00	0.00	2.20†	0.00	0.00	97.80
MEAN	**39.5**	**2.9**	**3.6**	**30.4**	**5.1**	**10.1**	**3.9**	**4.5**	**39.4**
ST. DEV.	**21.7**	**6.01**	**6.6**	**24.8**	**5.9**	**7.7**	**7.6**	**3.1**	**34.7**

* - Row = Row Crops, Ann = Annual Grass, Per = Perennial Grass, Orc = Orchards and Berries, Pas = Pasture, Rip = Riparian Vegetation, For = General Forest.

† - Site selected based on properties of this land use

Table 2.3. Properties of the watersheds selected for sampling during the summer of 1999.

Stream Sampling and Analysis

Stream reaches at the drain point of each selected watershed were sampled during the summer of 1999 using protocols set forth in United States Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) (Lazorchak et al. 1998). Aquatic vertebrates were sampled using one pass electrofishing with a Smith-Root Model 12 backpack mounted electrofishing unit. Reach scale aquatic habitat characteristics were collected according to EMAP protocols that were consistently altered to reduce the number of redundant measurements taken. Water samples were collected from each stream for turbidity, conductivity, and pH tests in the laboratory.

For each stream sampled, the actual abundance of fish was estimated using data from backpack shocker catchabilities estimated from calibration techniques developed in agricultural areas of the Midwestern United States (Bayley and Dowling 1993). Catchability data were modeled as a function of distinctive fish taxa (suckers, other benthic/rheophilic species, and non-benthic fishes), individual fish length, maximum stream depth, and mean stream width. The estimates of fish abundance in the sampled reach were converted to density estimates as the number of fish per 1000 m^2. Biomass estimates of all fish, native fish, non-native fish, native benthic dwelling fish, and native water column dwelling fish were calculated from abundance estimates using length to weight relationships calculated using historic data collected from streams in the Willamette River Basin. Biomass estimates were expressed as a density measure (g/m^2).

Measures of aquatic habitat conditions and fish abundance/biomass were compared to the spatial distributions of catchment wide land use. Comparisons were also made between the data collected and the in-stream and out-of-stream parameters describing each land use in the watershed. Correlation analysis using Pearson's coefficients was used to identify land use activities that had possible impacts on the health of the stream systems. However, due to the multiple testing issues associated with the large dataset we used, this analysis is strictly exploratory in nature. It was used primarily as a tool to investigate the nature of each land use's impact on stream conditions.

Results

Site Characteristics

Sites that were selected for sampling adequately covered the wide range of conditions found throughout the valley (Tables 2.2 & 2.3). The range of proportions of each land use across the sampled watersheds indicates that the sampling design emphasizes the selection of watersheds with large proportions of one particular land use while maintaining an even distribution of the remaining land uses (Table 2.2). The proportions of each land use among the 24 sampled watersheds varies only slightly from the mean values observed among the entire set of 142 agricultural catchments, indicating that the basins selected for sampling adequately represent valley-wide land use conditions. However, the maximum agricultural land use percentages among the 24 selected basins deviates significantly from the mean indicating that the histogram based selection technique is able to capture representative land use characteristics while maintaining the large land use percentages thought to be necessary for the detection of the different impacts of individual land use classes.

Fish Assemblage Data

Twenty-three fish species were captured among 24 sites sampled (Table 2.4). The mean number of species captured per site was 5 (Min. 1, Max. 9). Of these 5 species, on average, 4 were native and one was non-native. The mean abundance of all individuals was estimated to be 48000 fish/1000 m^2 of stream surface area (min. 690, max. 246500). Native fish accounted for 99.3% of the estimated total abundance. The reticulate sculpin was by far the most abundant fish captured among the 24 basins making up 64% of abundance estimates (Table 2.4). This is higher than previous published results that do not account for the very low catchability of sculpins. None of the non-native species made up significant proportions of the abundance estimates, even though they comprised 4% of all fish captured.

Estimates of fish biomass were generated from the abundance estimates for each sample collected. The average mean site specific biomass was 58 g/m^2 (Min. 0.84 g/m^2, Max. 117 g/m^2). Native fish species accounted for 93.4% of the estimated total biomass. Similar to abundance estimates, the reticulate sculpin made up 63% of all fish biomass (Table 2.4).

Estimates of Shannon's diversity were calculated for all species captured as well as for native species only for each of the 24 sites. Higher values of Shannon's index indicate more diverse stream fish assemblages. Diversity values based on all species ranged from 0 to 1.40 with a mean of 0.66. The diversity values calculated for only native fish varied from 0 to 1.05 with a mean of 0.51.

Species Captured	No. Sites	Mean Abundance (N/1000 m^2)	Total Abundance (N/24 sites)	% Total	Mean Biomass (kg/1000m^2)	Total Biomass (kg/24 sites)	% Total
Native Fish							
Richardsonius balteatus (Redside Shiner)	18	7938	190502	16.6	5.8	138.4	10.0
Rhinichthys osculus (Speckled Dace)	9	857	20570	1.8	1.0	24.3	1.8
Rhinichthys cataractae (Longnose Dace)	1	10	249	0.0	0.1	1.3	0.1
Cottus perplexus (Reticulate Sculpin)	20	30586	734035	63.9	36.7	880.1	63.4
Cottus rhotheus (Torrent Sculpin)	3	2072	49730	4.3	3.4	81.8	5.9
Cottus asper (Prickly Sculpin)	1	14	330	0.0	0.1	1.6	0.1
Catostomus macrocheilus (Largescale Sucker)	11	450	10809	0.9	1.0	24.0	1.7
Gasterosteus aculeatus (Threespine Stickleback)	7	4044	97059	8.4	0.3	7.9	0.6
Ptychocheilus oregonensis (Northern Pikeminnow)	9	140	3362	0.3	1.4	33.2	2.4
Oncorhynchus clarki (Cutthroat Trout)	8	113	2707	0.2	2.4	57.2	4.1
Oncorhynchus mykiss (Rainbow Trout)	3	57	1378	0.1	0.4	10.2	0.7
Petromyzontidae sp. (Lamprey Species)	9	1230	29511	2.6	1.5	36.2	2.6
Non-native Fish							
Micropterus salmoides (Largemouth Bass)	4	21	510	0.0	0.2	5.5	0.4
Lepomis gulosus (Warmouth)	1	1	18	0.0	0.0	0.7	0.1
Lepomis macrochirus (Bluegill)	6	165	3948	0.3	0.7	15.8	1.1
Lepomis gibbosus (Pumpkinseed)	2	14	333	0.0	0.1	2.4	0.2
Pomoxis annularis (White Crappie)	1	10	260	0.0	0.0	0.2	0.0
Cyprinus carpio (Common Carp)	1	1	11	0.0	0.8	18.9	1.4
Carassius auratus (Goldfish)	2	9	215	0.0	0.6	13.7	1.0
Notemigonus crysoleucas (Golden Shiner)	2	95	2291	0.2	0.6	13.5	1.0
Ameiurus natalis (Yellow Bullhead)	3	20	479	0.0	0.9	20.4	1.5
Ameiurus melas (Black Bullhead)	1	14	326	0.0	0.0	1.0	0.1
Gambusia affinis (Mosquitofish)	2	5	112	0.0	0.0	0.0	0.0
		Total:	1148745		Total:	1388.3	

Table 2.4. Abundance and biomass estimates of the fish species captured among the 24 sites sampled during the summer of 1999.

Correlations Between Land Use and Fish

Using Pearson's correlation analysis (SAS Institute Inc. 1985), it was determined that the percent of annual grass seed production in a basin was strongly correlated with the abundance of non-native fish (Table 2.5). In addition, the percentage of areas of annual grass seed and perennial grass seed production had a significant effect on species richness (Table 2.5). However, further analysis revealed that the two types of grass seed production were themselves positively correlated ($r = 0.55$, $p = 0.0054$). Thus, the two were combined into a single value reflecting all types of grass seed production, which was correlated with species richness (Table 2.5). No significant correlations were detected between any remaining fish abundance measures and land use variables. However, urban land use was correlated with the biomass of native benthic dwelling species. Also, the diversity measure for native fish was positively correlated with the area of forest in a catchment (Table 2.5).

Correlations Between Land Use and In-stream Habitat

Measures of in-stream and riparian habitat quality were computed for each of the 24 stream reaches that were sampled according to EMAP protocols (Kaufmann et al. 1999). The amount of forest in a watershed was negatively correlated with the amount of silt and organic matter found in the streams (Table 2.5), and the area of pasture in a watershed was positively correlated with the amount of gravel in the stream. The amount of row crop production was negatively correlated with the amount of pool habitat available for fish species and positively correlated with the amount of glides present in the sampled reach.

Correlated Variables		Pearson's	Uncorrected
Variable 1	Variable 2	Coefficient (r)	p-value
Relationships between areas of land use in watershed and fish			
Annual Grass	Non-native abundance	0.85	<0.0001
	Species Richness	0.50	0.0124
Perennial Grass	Species Richness	0.56	0.0048
Annual + Perennial	Species Richness	0.58	0.0028
Urban	Nat. Benthic Biomass	0.45	0.0305
Forest	Native Fish Diversity	0.48	0.0152
Relationships between areas of land use in watershed and in-stream habitat			
Silt/Org. Matter	General Forest	-0.46	0.0239
Gravel	Pasture	0.49	0.0148
Row Crops	Pools	-0.43	0.0383
	Glides	0.49	0.0144

Table 2.5. Correlations established between the areas of a land use among the 24 watersheds and fish and in-stream habitat variables.

Discussion

The histogram based selection procedure's ability to capture the characteristics of land use in the Willamette Valley is illustrated by the relatively small standard deviations associated with the percentage of each agricultural land use among the 24 selected basins (Table 2.2). This point is further illustrated in the similar mean values observed between the percent land use measures of the full set of 142 basins and the land use measures of the set of 24 selected basins (Table 2.2). However, the strength of this selection procedure is its ability to capture representative land use conditions while retaining the high percentages of agricultural lands that were determined to be important in detecting the unique impacts that each land use has on stream conditions.

The problems associated with multiple testing in this analysis does not allow for the establishment of any conclusive statements. However, several possible trends have been identified which indicate that further analysis is needed. For instance, the large proportion of native fish in the streams sampled may indicate that water quality and habitat availability are adequate for native species to compete with exotic species that themselves are generally are more tolerant of degraded systems. However, the high percentage of native species that are tolerant of frequent disturbances (Hughes and Gammon 1987), such as the reticulate sculpin and redside shiner, might suggest that some improvement in the quality of the small streams of the Willamette Valley is necessary. Although these species are native, their domination of the fish assemblage could indicate that in-stream conditions can be improved to gain a more diverse community structure in small agricultural streams.

The positive correlations between grass seed production and species richness implies that this agricultural practice may impact the health of aquatic communities. However, the high positive correlation between annual grass seed production and the abundance of non-native fish may indicate that the increase in species richness is caused by an increase in the presence of non-native fish. The low gradient regions where grass seed production is located in the Willamette Valley may explain this pattern of increased non-native fish presence. During periods of summer baseflow these streams often become intermittent in nature forming small pools that hold large numbers of fish. These relatively harsh conditions are ideal for native and non-native species that are tolerant of warmer water temperatures, silty substrates, and increased fish densities.

The correlations between land use features and the response of the fish community have several implications. First, the positive correlation between the diversity of native fish and forest may indicate that native fish are more likely to select areas in a stream that resemble conditions under which they evolved. Conversely, the lack of infiltration in paved urban areas (the land use that least resembles historic conditions) may increase the surface flow to the stream and deter native species from colonizing these reaches as indicated by the apparent dominance of benthic fish and the resulting low diversity associated with the percentage of urban land in a stream.

The negative correlation between row crops and pool habitat could be a function of the increased flows and stream channelization characteristic of irrigation diversions in agricultural areas. As the flows increase, much of what was pool habitat may be converted to faster flowing glides. This could have several impacts on fish populations such as increased sedimentation and eutrophication caused by higher stream loading from row crop areas.

The correlations between watershed-scale land use variables, fish, and habitat data suggest that the methods used to select the sites that were sampled were adequate for establishing patterns that may indicate relationships between basin-scale land use features and stream conditions. However, this method falls short in its ability to quantify the impacts of each land use on stream conditions. Initial investigations indicate that using distance weighted metrics measuring a land use's impact on stream conditions may provide more information into the specific effects that agricultural lands have on fish.

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CHAPTER 3.

QUANTIFYING THE IMPACTS OF LAND USE ON STREAM CONDITIONS USING AN INVERSE FLOW DISTANCE METHOD

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Introduction

Many factors influence the conditions of streams and the health and structure of fish communities that depend on them. Natural factors such as geology, hydrology, and vegetation play a role in determining the features of a particular stream (Schlosser 1985; Swanson et al. 1988; Poff and Allan 1995). However, human alterations of stream features often play a much larger role in this determination. Decreases in the diversity of fish communities and increases in sediment loading have been attributed to watershed urbanization (Weaver and Garman 1994). Harvesting and road building practices associated with forestry have been linked to increased peak flows and sedimentation in many streams (Jones and Grant 1996; Lewis 1998). Similarly, agricultural land use activities have been tied to decreased habitat and channel complexity as well as increased nutrient loads (Gammon and Gammon 1993; Kuhnle et al. 1996).

Describing and quantifying the impacts of human altered landscapes on stream conditions and aquatic community integrity has been difficult (Rose 2000). This becomes even more difficult when many different land use activities must be accounted for. To address this problem, several methods have been developed to describe measures of stream health as a function of the land use characteristics of a watershed.

One of the most popular methods is the generation of varying width buffers around a stream network using a Geographic Information System (GIS) (Richards and Host 1994; Buckley 1997; Bolstad and Swank 1997; Schuft et al. 1999). The stream buffer method assumes that the area influencing stream conditions is the region adjacent to the channel that falls within a specified distance of the stream.

Point buffers have also been used to describe the impacts of land use on stream conditions (Buckley 1997). Point buffers are similar to stream buffers in that they generalize the area impacting a stream as the portion of the watershed contained within some upstream radius of the sampled stream reach.

One problem with the buffer approaches is that they fail to recognize that land use activities outside of the specified buffer have an impact on stream conditions. In addition, both of the buffer approaches use aerial distance to a stream rather than the actual flow path distance to generate the specified buffer sizes. Aerial distances fail to recognize that some points immediately adjacent to the stream have long travel distances before their loads can reach the channel. During high flow events this is of little consequence (Lowrance et al. 1984; Bolstad and Swank 1997). However, during periods of sub-bankfull flows, this factor may have a strong impact on sediment and nutrient loading (Owens et al. 1991). The simple process of using point specific flow distances rather than aerial distances to generate buffers would more realistically describe the effects of off-channel landscape features on in-stream conditions.

Using the areas of each land use in a watershed has been used to address the problems associated with ignoring land use activities outside of stream and point buffers (Omernik et al. 1981; Allan et al. 1997; Buckley 1997). The land use area approach attempts to relate the total area of each land use in a watershed with a specified stream condition. This simple approach may work when investigating general relationships between basin-scale land use and stream conditions but it falls short in describing the effects of the spatial variability associated with different land use patterns in a watershed.

To accurately capture the spatial complexity of land use patterns across a watershed, several techniques have attempted to integrate the buffer and land use area methods to describe the impacts of watershed scale land use. One such method consists of dividing a watershed into a set of classes based on elevations or slopes and using the area of each land use found within each of the classes to explain stream conditions (Buckley 1997). This method captures some of the variability associated with catchment scale land use while retaining the strengths of the buffer approaches. However, it has been used sparingly in watershed scale studies. Also, as with the previous methods described, the elevation and slope class method does not directly account for flow path distance.

Cumulative impact analyses have also been used to alleviate some of the problems inherent to the buffer and catchment scale methods (Johnston et al. 1988; Childers and Gosselink 1990; Bolstad and Swank 1997). These studies have shown that the collective contributions of land uses in a watershed are responsible for the conditions seen at some point in a stream. However, these methods generally require that a series of samples be taken across the longitudinal profile of a stream network on a somewhat regular temporal and spatial interval. Methods that are more time and cost effective should be developed to increase the efficiency of cumulative impact assessment techniques.

The basic concept that all things are related but things near one another are more related should hold true in watershed processes. If downstream influences can be ignored, the condition of a stream can be conceptualized as some function of a watershed's upstream land use activities and in-stream habitats. However, similar to the buffer approaches, the condition of a stream reach should be more heavily influenced by those land use activities that are close to the reach in question. Thus, a method that recognizes the importance of basin-scale influences while accounting for the importance of areas near the stream is needed.

Much of the weakness in the previously described methods can be assigned to the fact that they fail to capture the effect of topographical variation across a watershed. The multidimensional nature of a watershed (Stanford 1996) dictates the need for a technique that accounts for the spatial variability associated with a basin's land use patterns. We propose that using the inverse values of flow path distances will allow us to capture the importance of basin-scale land use while still weighting the activities near the sampled reach more heavily. We believe that this approach will enable us to better relate and predict the impacts that land use activities have on native stream fishes and habitat quality.

Methods

Study and Site Descriptions

The study area lies within the 30,000 km^2 Willamette River Valley of western Oregon (Figure 3.1) (Omernik and Gallant 1986). Diverse agriculture and forest lands surrounding several large urban centers and many smaller communities characterize the land use of the valley. The climate of the Willamette Valley is typified by warm, dry summers and mild, wet winters. Generally, fine textured alluvial deposits with basalt outcroppings describe the geology of the valley. The similar climatic and geologic patterns and the diverse landscape characteristics that exist across the Willamette Valley make it a good system for detecting and quantifying the effects that a diverse set of land use practices have on the conditions of small streams.

Small watersheds (15-80 km^2) in the Willamette Valley were delineated automatically using a United States Geographical Survey 30 m digital elevation model (DEM) in the GIS ArcInfo (Environmental Systems Research Institute 1994). The 15-80 km^2 range was decided upon to increase the probability that all streams sampled were capable of supporting a fish community while being wadeable at baseflow conditions for fish sampling purposes. A vector format land use/land cover (LULC) map generated by the Oregon Department of Fish and Wildlife (ODFW) was clipped to the boundaries of the watersheds before the final selection of sampling sites (Klock et al. 1998). Using similarities among disturbance regimes, water use, and chemical application rates, an independent set of 8 land uses was derived from a broader set of 26 land use types (Table 3.1).

Twenty-four watersheds were selected for sampling based on the percentage of each agricultural land use that they contained. Basins with high percentages of a particular agricultural land use were selected because it was assumed that they would provide information about that land use's impact on stream conditions. Sites that had a small percentage of a particular crop type and a high percentage of forest were also selected because the effects of the agricultural land use were assumed to be detectable over the background effects of forest. Table 3.1 summarizes the mean land use characteristics found among the 24 selected basins.

The streams draining the 24 watersheds were sampled in the summer of 1999. Fish and habitat sampling protocols followed those developed for the United States Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) (Lazorchak et al. 1998). Fish were sampled using a Smith-Root Model 12 backpack electrofishing unit. The fish captured were identified and their lengths were measured.

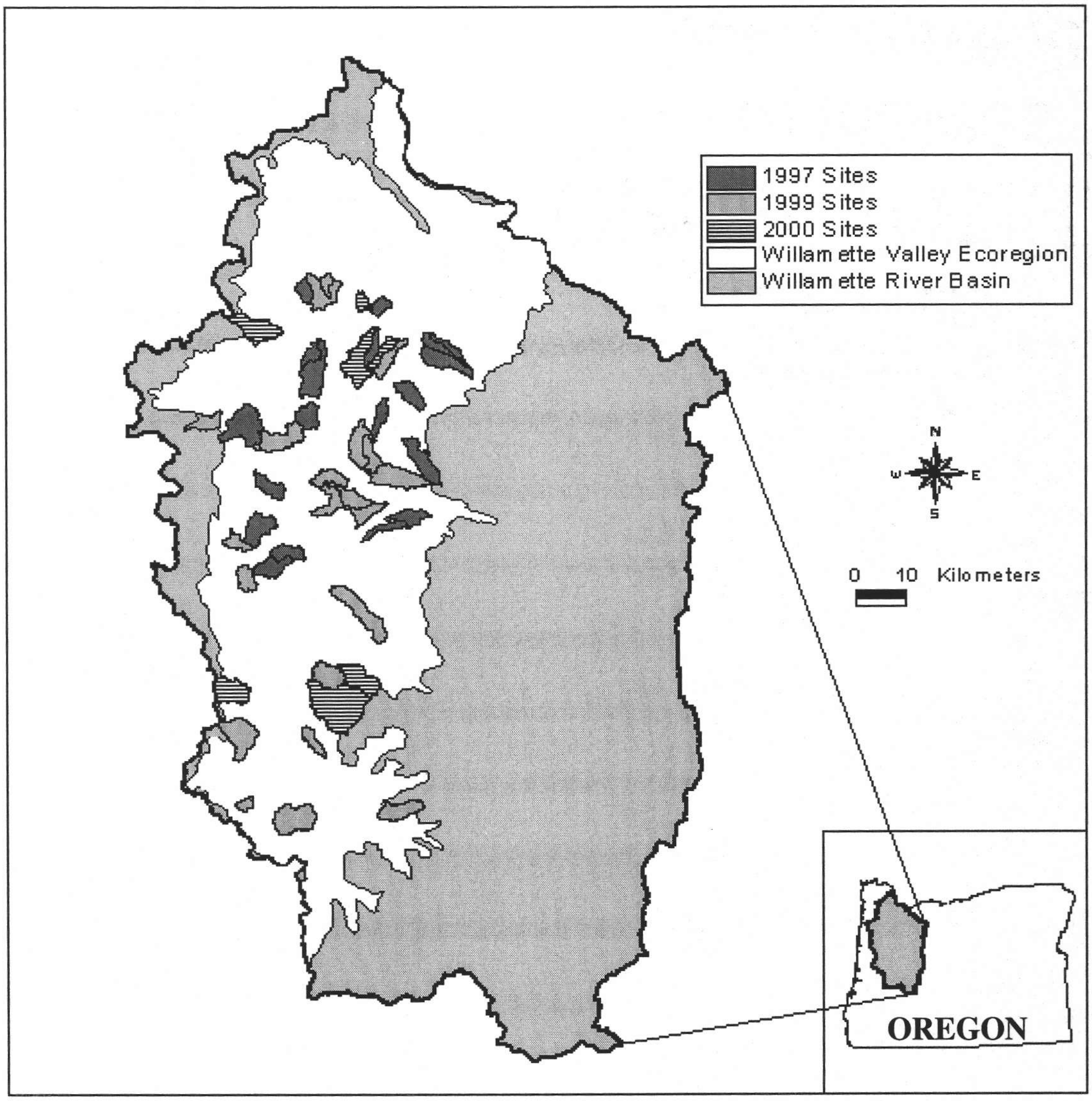

Figure 3.1. Locations of the sites selected for sampling during the summers of 1997, 1999, and 2000.

ODFW Land Use Classifications	Modified Land Use Classifications	Percent of Each Land Use Across Sampled Watersheds Mean	Range	St. Dev.
Row Crops	Row Crops*	3.6	(0-25.2)	6.5
Annual Grasses and Grains	Annual Grasses*	4.5	(0-30.3)	5.8
Perennial Grasses and Hay	Perennial Grasses*	35.6	(0-87.1)	20.1
Orchards and Berries	Orchards and Berries*	8.0	(0-34.5)	8.4
Unmanaged Pasture	Unmanaged Pastures*	8.2	(0-31.0)	6.1
Willow Cattail/Bulrush Black Hawthorne Cottonwood Riparian Reed Canary Wetland Ash/Cottonwood/Maple Gravel Bars and Sand	Riparian Vegetation	4.7	(0-11.5)	2.5
Doug Fir Oak/Madrone Maple/Alder/Fir Oak/Doug Fir > 50% Oak Doug Fir/Oak > 50% Doug Fir General Forest/Unclassified	General Forest	32.7	(0-97.8)	28.2
Urban Parks and Recreational Fields Doug Fir Urban-build-up (UBU) Oak/Doug Fir UBU Doug Fir/Oak UBU Ash/Cottonwood UBU Maple/Alder/Fir UBU Cottonwood Riparian UBU	Urban	2.7	(0-28.2)	5.8

*- Indicates agricultural land use

Table 3.1. Reclassified land use categories and their properties as derived from the ODFW classification scheme.

Data from 19 streams sampled in 1997 (Figure 3.1) (Moser et al. 1997) were included with the data collected during 1999 for analytical and validation purposes. These samples were collected using EMAP protocols for an EPA study concerning the interactions of agriculture, riparian, and stream systems. Also, during the summer of 2000, 7 new sites were selected and sampled. In addition to the 7 new sites, 14 of the 43 sites that were sampled in 1997 or 1999 were resampled to investigate the effects of year-to-year variations among the fish communities in small Willamette Valley streams.

Development of Watershed Grids

Methods to describe the impact of specific land use practices on stream conditions were developed using GIS generated raster files (grids) of 30 m resolution. Grids were used rather than other data formats such as vectors because they better describe local, small-scale land use and hydrologic features that are important in agricultural basins. In addition, grids are much simpler to use for computations and hydrologic modeling than are vector formats.

Initially, USGS DEM files were extracted for each of the sampled watersheds and used for the creation of grids describing the direction of flow for each cell in a watershed. From these grids, stream networks were created by identifying the points in a watershed that had an upstream drainage area of greater than 500 cells. The resulting stream networks closely resembled 1:100 000 scale stream line files. To insure that all data in the stream and direction grids were related properly to land use, the ODFW LULC vector coverage was resampled to a grid of 30 m resolution.

Determining Land Use Impacts

To determine a land use's impact on stream fish and habitat conditions, an algorithm was developed using the flow direction grid to determine the flow path of each cell and the distance it traveled to reach the sampling site at the outlet of the watershed. If the flow path of a cell traveled in an east, west, north, or south direction, the flow path length was incremented by 30 m (the horizontal or vertical dimension of one cell). If the path traveled northeast, northwest, southeast, or southwest, the flow length was incremented by 42.43 m (the diagonal distance across one cell).

It has been suggested that in-stream and out-of-stream processes should be separated to account for differences in the processes that act upon sediments, chemicals, and nutrients (Schlosser and Karr 1981). Thus, to enable the differentiation of these two processes, the total flow path length was separated into two components: an out-of-stream flow length (L_O = distance traveled from a cell to the stream) and an in-stream flow length (L_I = distance traveled from a cell's entry point in the stream to the sampled stream reach).

Cells closer to the sampled reach were assumed to have more influence on in-stream conditions than those far from the reach. Thus, one measure of the potential impact of an individual cell (I_{cell}) was determined by taking inverse value of its flow length components (Equation 1), while another measure of a cell's potential influence was determined by taking the inverse of the squared values of the flow lengths (Equation 2). Visual representations of the total flow path lengths (Figure 3.2), the out-of-stream flow path lengths (Figure 3.3), and the in-stream flow path lengths (Figure 3.4) were developed to investigate the general patterns of land use influence in a watershed.

$$I_{cell} = (L_O)^{-1} + (L_I)^{-1} \tag{1}$$

$$I_{cell} = (L_O)^{-2} + (L_I)^{-2} \tag{2}$$

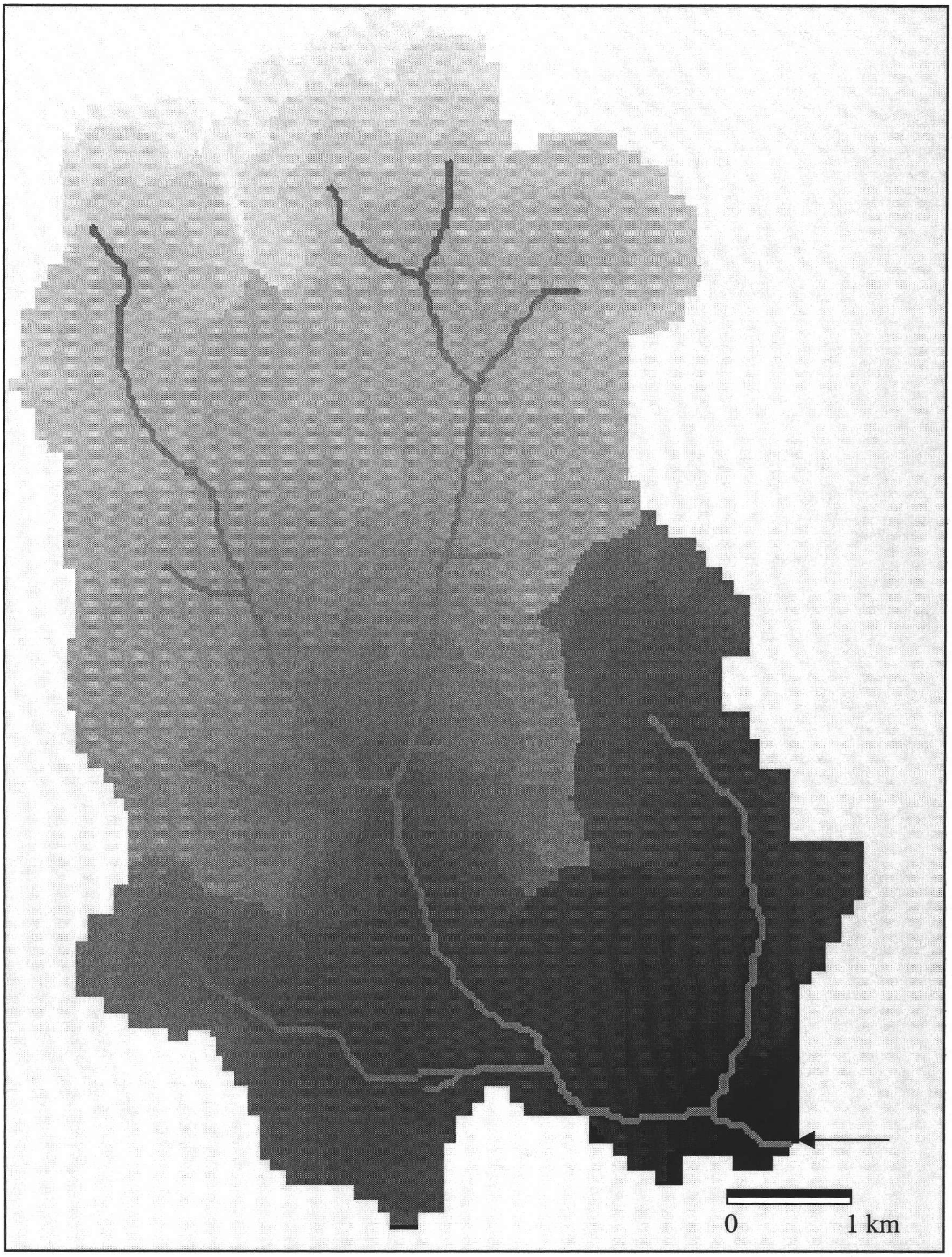

Figure 3.2. Map representing the total influence each cell in the Oak Creek watershed west of Corvallis, Oregon. Oak Creek was sampled during the summers of 1999 and 2000. Darker colors represent cells with greater influence on stream conditions. The arrow indicates the sampled stream reach

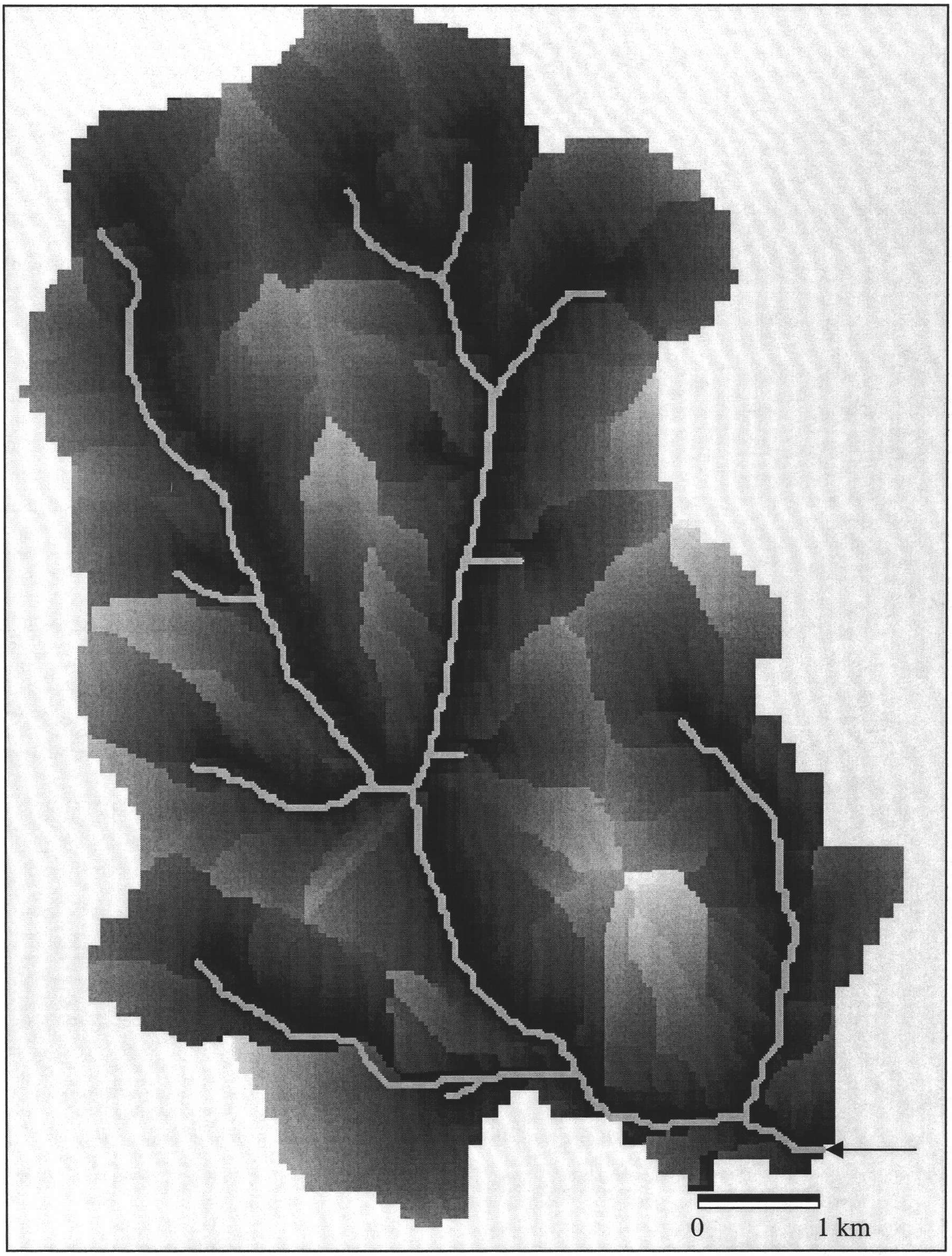

Figure 3.3. Map representing the out-of-stream influence of each cell in the Oak Creek watershed. Darker colors represent larger out-of-stream influence. The arrow indicates the sampled stream reach.

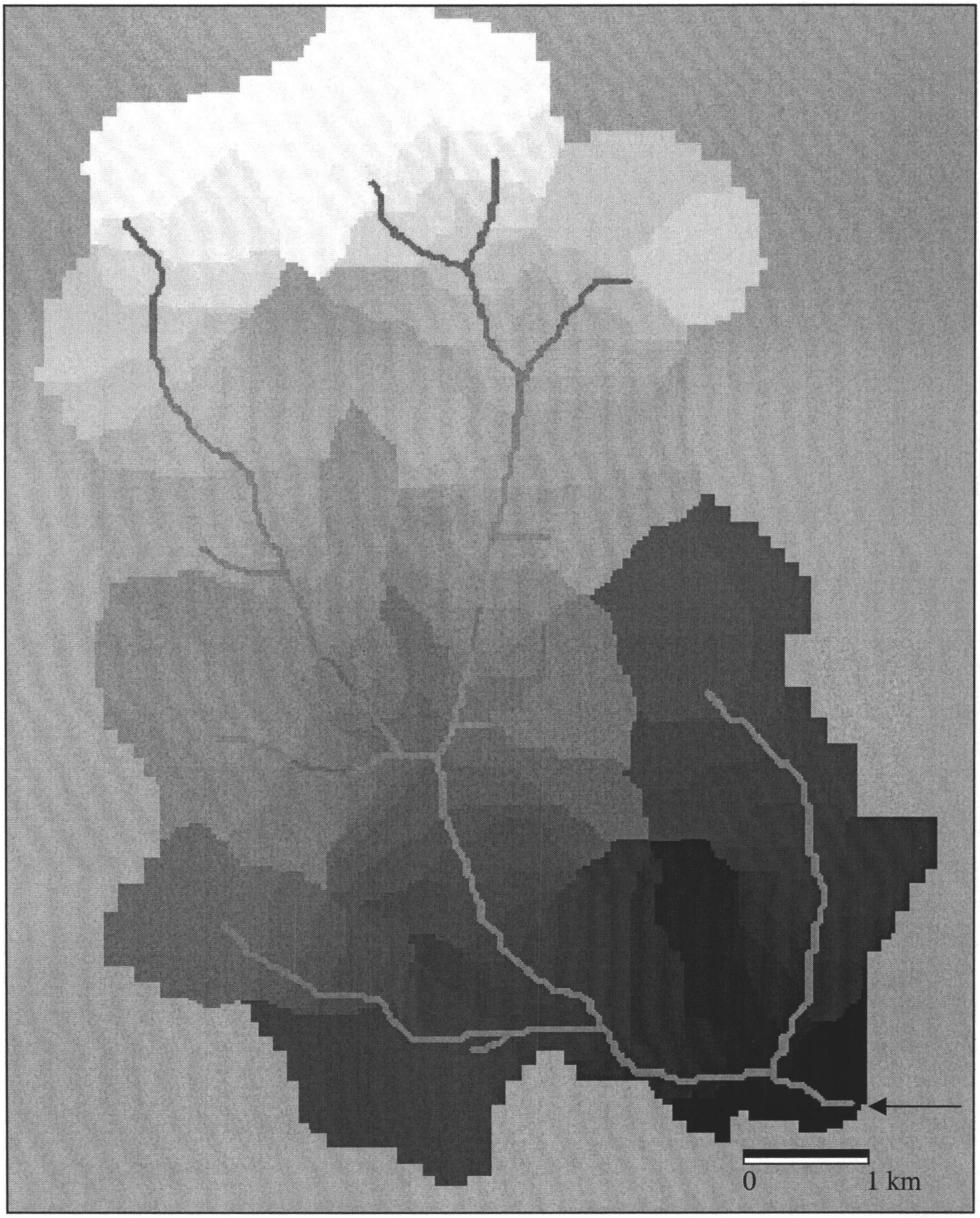

Figure 3.4. Map representing the in-stream influence of each cell in the Oak Creek watershed. Darker colors represent greater in-stream influences. The arrow indicates the sampled stream reach.

The influence of the impact that each of the 8 land uses (Table 3.1) had on stream conditions was determined by summing the flow path components for the cells of each land use type in a watershed. These sums were then used as explanatory variables in models developed to describe the influence of basin-scale land use on an appropriate measure of stream fish response (Y). The first two models that were developed assigned each land use's total impact (T_{LU}) as a function of the total flow path length. Equation 3 represents the model using the inverse of the non-squared flow path lengths (T_{LU}^{-1} model) while Equation 4 represents the model using the squared flow distance measures (T_{LU}^{-2} model). These models assumed that the differentiation of in-stream and out-of-stream impacts was not necessary to predict the response of the fish community. The formulae for these models are:

$$Y = \sum_{j=1}^{8} a_j \sum_{i=1}^{C_j} \left[\left((L_O)_{i,j} + (L_I)_{i,j} \right)^{-1} \right] \tag{3}$$

$$Y = \sum_{j=1}^{8} a_j \sum_{i=1}^{C_j} \left[\left((L_O)_{i,j} + (L_I)_{i,j} \right)^{-2} \right] \tag{4}$$

where j is the land use type (Table 3.1), i is the cell number of the land use type j, a_j is the coefficient describing the impact of each land use, and C_j is the number of cells of land use j.

Two additional models were developed to account for differences between processes occurring in and out (InOut) of the stream. The InOut^{-1} model (Equation 5) uses the inverse values of the non-squared in-stream and out-of-stream flow measures and the InOut^{-2} model (Equation 6) uses the inverse values of the squared metrics. These models are as follows:

$$Y = \sum_{j=1}^{8} a_j \sum_{i=1}^{C_j} \left[\left((L_O)_{i,j} \right)^{-1} \right] + \sum_{j=1}^{8} b_j \sum_{i=1}^{C_j} \left[\left((L_I)_{i,j} \right)^{-1} \right] \tag{5}$$

$$Y = \sum_{j=1}^{8} a_j \sum_{i=1}^{C_j} \left[\left((L_O)_{i,j} \right)^{-2} \right] + \sum_{j=1}^{8} b_j \sum_{i=1}^{C_j} \left[\left((L_I)_{i,j} \right)^{-2} \right] \tag{6}$$

where j is the land use type (Table 3.1), i is the cell number of the land use type j, a_j is the coefficient describing the out-of-stream component of each land use's impact, b_j is the coefficient describing the in-stream component of each land use's impact, and C_j is the number of cells of land use j.

Methods of Analysis

Abundance estimates utilized backpack electrofishing efficiency data from 13 calibrations conducted in the Midwestern United States (Bayley and Dowling 1993). The use of these calibrations was appropriate because habitat measures were similar between samples taken in the Midwest and those taken in the Willamette Valley. Abundance of all fish located in the sampled reach was estimated as a function of fish length, mean reach width, maximum reach depth, and species catchability (Bayley and Dowling 1993).

Estimates did not include young-of-the-year individuals, as that age class known to exhibit large variations in year-to-year abundance (Schlosser 1985; Bayley and Li 1992). Species-specific abundance estimates were then converted to the number of fish per 1000 m^2 of stream water surface area. Fish biomass as g/m^2 was estimated using the species-specific density estimates.

Biomass and abundance estimates were transformed using log(x + 1). These log transformed measures of fish response were used because we consider the lack of information on historical conditions in small Willamette Valley streams and the transient nature of many of the fish found in these systems to be indicators that the use of metrics such as the Index of Biotic Integrity (IBI) (Karr 1981) is inappropriate. In addition, biomass has been shown to be a good measure of potential productivity in stream systems (Bayley and Li 1992), although, we consider it important to separate native and non-native measures because high proportions of non-native fish may indicate poor stream conditions. Biomass of native benthic dwelling fish and native column dwelling fish were selected as the primary measures of fish response to investigate how land use activities and the resulting water quality indicators such as sedimentation, eutrophication, and habitat availability influence stream fish populations.

Investigation of the impacts of each land use on native fish was carried out using a generalized linear model (GLM) procedure (SAS Institute Inc. 1985). The impacts that basin-wide land use had on stream fish populations were investigated using each of the previously discussed models (Equation 3-6). For each of the models, calibration was carried out by randomly selecting 32 of the 49 sites sampled in 1997, 1999, and 2000.

After the model was validated, the entire set of 49 samples was combined for final model determination.

Several criteria were set to insure that only the most significant land uses were selected from each of the four models used (Equations 3-6). First, correlation analysis was done to investigate possible relationships between the explanatory variables of each model. Any independent variables that were significantly correlated at the $\alpha = 0.05$ level were removed from the analysis if it could be justified that their effects were not differentiable from the effects of the other variables in the model. Second, an identical alpha level ($\alpha = 0.05$) was set for the selection of the explanatory measures in each model to maximize the probability that the variables selected reflected the true nature of basin-scale land use impacts on stream fish responses.

A sensitivity analysis was performed to determine the magnitude of land use changes on the response of stream fish populations. For this particular investigation, the flow path distances of each of the significant land use variables in the final model were increased at the expense of another land use. To assess the impact of one land use in a basin, the total impact of another land use in that basin was decreased by 10% by converting 10% of that land use's flow path measures to those of the land use of interest. The increase in the influence of one land use at the expense of another is necessary to maintain the total flow path lengths of all land uses in the watershed. In addition, to maintain reasonable watershed land use patterns, the conversion of the influence metric of one land use to another was done in a manner where the land use whose influence was increased was a suitable replacement for the land use whose influence was decreased.

Results

Biomass of native benthic dwelling fish comprised 74% of the total biomass that was estimated for all fish among the 49 sampled watersheds. The remaining 26% of the total biomass estimate was comprised of fish that reside in the water column. One sample collected during the summer of 1999 was eliminated from the analysis as it was found to be an outlier with an extremely high concentration of native benthic fish. After sampling it was discovered that the sampled reach was located immediately downstream of an impassable irrigation diversion dam that may have played a role in concentrating fish in the sampled reach.

The data collected during the summer of 2000 for validation purposes was consistent with the trends seen in the data from previous years. A paired t-test comparing the 14 replicated samples indicated that there was no apparent difference in year-to-year variations of the estimates of native benthic biomass over the three years in which data were collected ($t = 0.5$, $p = 0.63$). This agreed with an independent study on year-to-year variations in the Willamette Valley (Waite and Carpenter 2000), and indicated that year-to-year differences appeared to be unimportant for fish older than the young-of-the-year age class; therefore, independent sites from the three different years were combined for analysis.

Model Calibration

Initially, the land use area approach that was described in the introduction was used for comparison with the inverse distance modeling approaches used (Equations 3-6).

This approach used the total area of each land use in a watershed as the explanatory variables in a multiple regression model. Neither the biomass of native benthic (Table 3.2) or water column dwelling species was related to the total area of any of the land uses investigated at an alpha level of 0.05. Detecting and quantifying the nature of the different effects of each of the eight land use activities in the study may exceed the abilities of the land use area approach.

T_{LU}^{-1} and T_{LU}^{-2} Models

Pearson's correlation analysis of the T_{LU}^{-1} model's (Equation 3) land use specific influence measures revealed that the riparian metric was positively correlated with orchard ($r = 0.47$, $p = 0.0009$) and pasture ($r = 0.48$, $p = 0.0005$) measures. In addition, the forest land use metric was negatively correlated with row crops ($r = -0.41$, $p = 0.0040$) and positively correlated with pasture ($r = 0.42$, $p = 0.0031$). Thus, to remove confounding effects from the model, riparian and forest measures were not included in the possible set of explanatory variables for the T_{LU}^{-1} model.

Analysis revealed that the best T_{LU}^{-1} model using explanatory variables related to land use contained only the row crop influence metric. However, this model only explained 19.4% of the observed variation in the biomass of native benthic fish (Table 3.2). Recognition that reach scale habitat variables may play a key role in the determination of localized fish assemblage structure led to the investigation of a T_{LU}^{-1} model containing habitat measures as possible explanatory variables. However, none of the reach scale habitat features were found to be significant.

Model	Explanatory Variables	Coefficients Value	Std. Error	p-value	r-squared	F-statistic
Land Use Area	Intercept					
	Urban	0.19	0.09	0.0812	0.079	4.00
T_{LU}^{-1}	Intercept	3.48	0.21			
	Row Crops	-1.43	0.43	0.0016	0.194	11.29
T_{LU}^{-2}-**A**	Intercept	3.45	0.18			
	Row Crops	-2159.30	459.20	0.0001	0.320	22.11
T_{LU}^{-2}-**B**	Intercept	4.13	0.38			
	Row Crops	-2007.86	451.55	0.0001	0.374	13.77
	Mean Depth	-1.82	0.91	0.0512		
InOut^{-2}-**A**	Intercept	3.44	0.20			
	IS Row Crops	-477.32	94.76	0.0001	0.433	11.46
	OS Ann Grass	-3.50	1.58	0.0315		
	OS Urban	3.67	1.68	0.0342		
InOut^{-2}-**B**	Intercept	3.08	0.24			
	IS Row Crops	-443.11	91.43	0.0001	0.497	10.86
	IS Grass	22.25	9.42	0.0227		
	OS Ann Grass	-3.96	1.52	0.0123		
	OS Urban	4.40	1.63	0.0099		
InOut^{-2}-**C**	Intercept	3.48	0.28			
	IS Row Crops	-374.44	89.95	0.0001	0.565	11.18
	IS Grass	18.79	8.96	0.0419		
	OS Ann Grass	-3.71	1.43	0.0128		
	OS Urban	5.79	1.62	0.0009		
	% Silt/Org‡	-0.01	0.01	0.0127		

Table 3.2. Table of model results from the T_{LU}, and InOut models calibrated using the 49 samples collected.

Similar analysis was done using the T_{LU}^{-2} model (Equation 4). Correlation analysis among explanatory variables indicated that the use of the inverse squared flow path measures removed the correlations that existed in the T_{LU}^{-1} model. Thus, all of the land use measures were used as potential explanatory variables. As with the T_{LU}^{-1} model, the most significant T_{LU}^{-2} model used only the row crop metric (T_{LU}^{-2}-**A** model). This model explained 32% of the variation in the biomass of native benthic fish (Table 3.2). None of the habitat measures were found to be significant at the $\alpha = 0.05$ level in the T_{LU}^{-2}-**A** model. However, adding the mean depth of the sampled stream reach to the model did account for an additional 5.4% of the variation associated with the biomass of native benthic fish (Table 3.2, T_{LU}^{-2}-**B** model).

InOut^{-1} and InOut^{-2} Models

The same criteria that were used to judge the appropriateness of the T_{LU}^{-1} and T_{LU}^{-2} models were used to assess the InOut^{-1} and InOut^{-2} models. Analysis of the InOut^{-1} model (Equation 5) revealed that the in-stream metrics for each of the eight land uses were highly correlated with their respective out-of-stream metrics (Table 3.3). In addition, the in-stream and out-of-stream metrics for forest and riparian land uses were significantly correlated with several of the other land use measures. The nature of the land use metrics generated using the InOut^{-1} method may have created these relationships. Every increase in the amount of a particular land use increased the out-of-stream and in-stream flow distances in the same direction and magnitude. Taking the inverse of the non-squared influence measures did not weight the distances strongly enough to remove the correlations. The strong relationships between the in-stream and out-of-stream measures made the meaningful separation of the two processes very difficult and analyses were discontinued.

Land Use	r-value	p-value
Row Crops	0.85	<0.0001
Annual Grass	0.73	<0.0001
Perennial Grass	0.79	<0.0001
Orchard/Berry	0.85	<0.0001
Pasture	0.71	<0.0001
Urban	0.85	<0.0001
Riparian	0.61	<0.0001
Forest	0.73	<0.0001

Table 3.3. Pearson's correlations (r-values) between the in-stream and out-of-stream components of the InOut-1 model for the 49 sampled watersheds.

The strong correlations observed between the influence measures in the InOut^{-1} model were eliminated in the InOut^{-2} model. Analysis of the InOut^{-2} model (Equation 6) revealed that the in-stream measure of row crop influence and the out-of-stream measures for urban land and annual grass were significantly related to the biomass of native benthic dwelling fish (InOut^{-2}-**A** model). The InOut^{-2}-**A** model using only those three land use variables explained 43.3% of the variation observed in the response (Table 3.2).

An additional land use variable consisting of the sum of the in-stream and out-of-stream measures of annual and perennial grass seed was developed to add to the set of potential explanatory variables (InOut^{-2}-**B** model). This influence measure was developed because the two types of grass seed production share many similar management plans throughout the Willamette Valley. The addition of the combined in-stream grass metric maintained the significance observed in the InOut^{-2}-**A** model and improved the overall fit of the model (Table 3.2).

Measures of habitat quality were also added as possible explanatory variables in the InOut^{-2} modeling approach. The addition of the percentage of silt and organic substrate to the model increased the strength of the model (InOut^{-2}**-C**). The model explained 56.5% of the variation observed in the biomass of native benthic fish. Figure 3.5 illustrates the fit of the InOut^{-2}**-C** model.

The significance of multiple variables coupled with the relatively high r-squared value indicates that the InOut^{-2}**-C** model is most sensitive in the detection of specific impacts in a watershed with diverse land use characteristics. In addition, model validation indicates that the InOut^{-2}**-C** model using only 32 data points for calibration is a good predictor of biomass of native benthic fish (Figure 3.6). Furthermore, the relatively small changes in the predicted coefficient values of the three InOut^{-2} models indicates that the variables identified as significant are appropriate indicators of the response of benthic fish biomass.

The biomass of native water-column dwelling fish was also used as a measure of the response of the fish community to basin wide land use for the land use area, T_{LU}, and InOut modeling approaches. However, none of the r-squared values for the models relating land use to column dwelling fish biomass were greater than 0.10 indicating that the land use influence metrics developed in this study were not appropriate predictors of this response.

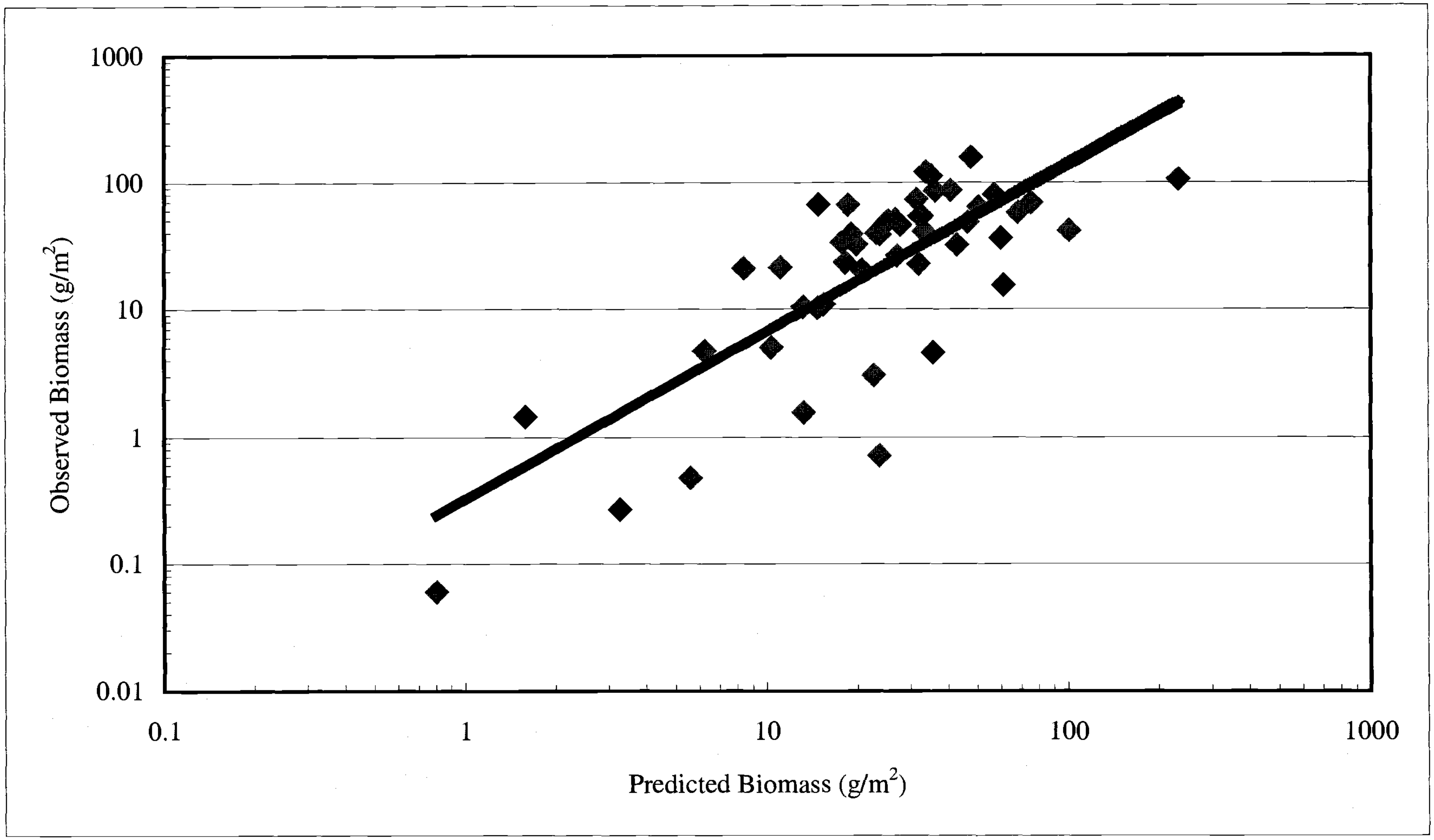

Figure 3.5. Graph of the actual estimates of native benthic fish biomass versus those predicted by the InOut^{-2}-**C** model.

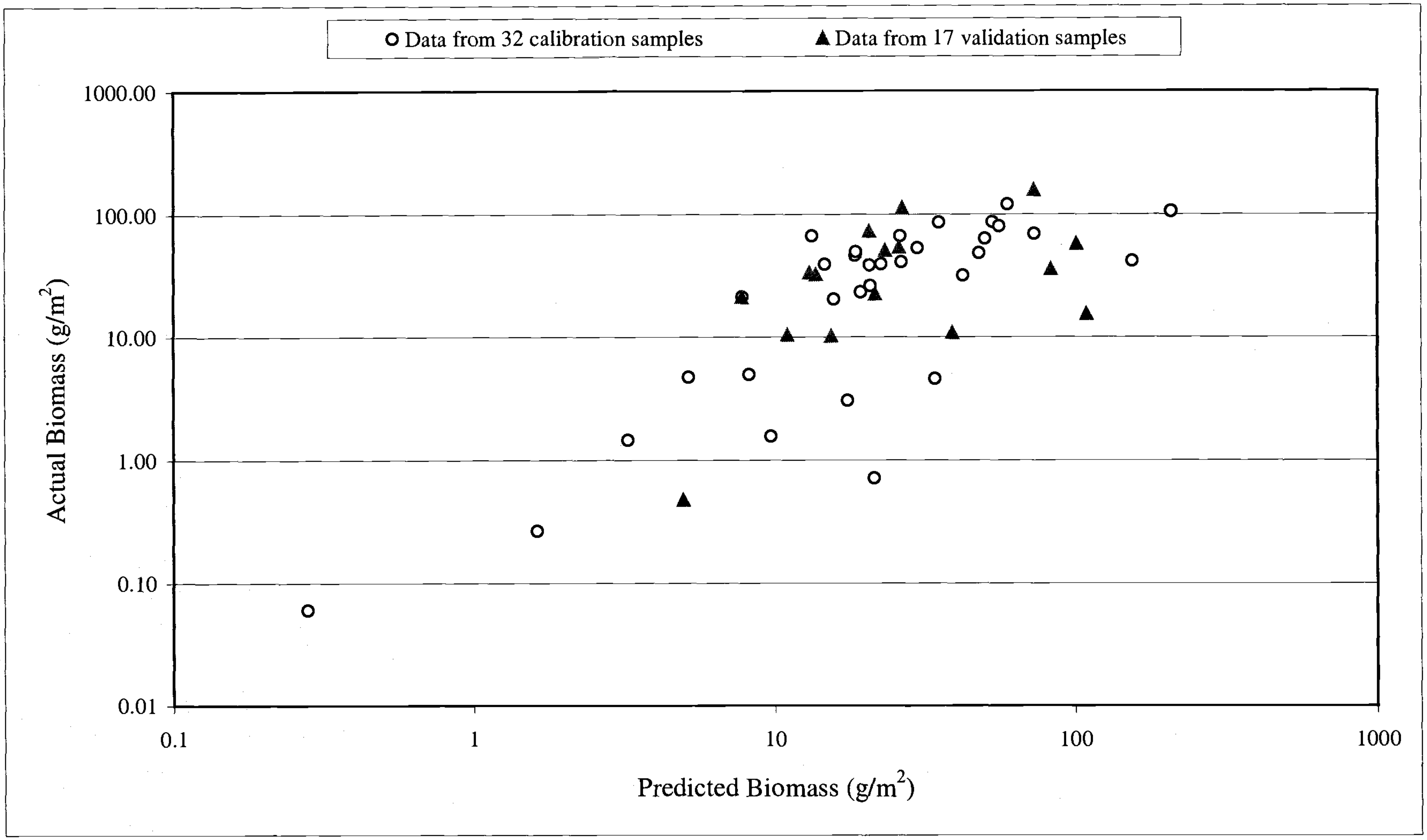

Figure 3.6. Validation of the InOut^{-2}-**C** model. This analysis consisted of initially fitting the model using data from 32 of the 49 watersheds. The values of the remaining 17 data points were calculated and plotted against the initial model for validation purposes.

Sensitivity of the InOut^{-2}-C Model

The InOut^{-2}-**C** model indicated that the biomass of native benthic fish was most sensitive to row crop production. On average, the increase in row crop flow path lengths at the expense of a 10% decrease in perennial grass decreased the biomass of native benthic fish by 33% (Table 3.4). However, as seen in Table 3.4, there is a wide range of values across the 49 sampled watersheds. This large variation is based on the fact that in watersheds where there is very little perennial grass, the values added to row crop flow lengths are very small and the biomass of native benthic fish will not decrease as dramatically.

The remaining land use conversions that were investigated did not have as great of an impact on benthic fish as row crop production. However, converting 10% of the influence of perennial grass to that of annual grass lowered the biomass of native benthic fish by 16% (Table 3.4). Altering the substrate of a stream by increasing the amount of silt and organic matter by 10% led to, on average, a 13.2% decrease in the biomass of native benthic fish.

Not all land use conversions had negative impacts on benthic fish biomass measures. Converting annual grass to urban land increased biomass estimates (Table 3.3). In addition, a 10% decrease in row crops resulting in an increase in perennial grass flow path lengths increased the biomass of benthic fish by an average of nearly 5%.

Nature of 10% Conversion	Mean change in Biomass estimate	Range of the observed change per basin	Standard Deviation
Perennial Grass to Row Crops	-33.1%	-88.75% to -0.78 %	27.42
Row Crops to Perennial Grass	+4.86%	0% to +44.08%	10.10
Perennial Grass to Annual Grass	-16.0%	-58.55% to –1.22%	12.32
Annual Grass to Urban Land	+6.00%	-1.48% to +76.84%	12.68
10% increase in Silt and Organic Substrate	-13.06	-----	-----

Table 3.4. Results of sensitivity analysis for the InOut^{-2}-**C** model after converting 10% of the flow path distances of one land use to flow path distances of another land use in the 49 sampled watersheds.

Discussion

Decreases in the biomass of native benthic dwelling fishes were most related to the effects of row crop agriculture. However, it is difficult to determine which aspects of row crop production had the largest effect on this decrease, as several mechanisms are plausible. Decreases in habitat complexity through the destruction of riffle and pool habitats could be one major area of concern for benthic and non-benthic fish (Gammon and Gammon 1993). Analysis revealed that row crops were significantly related to an increase in the mean percent of glide habitat in the sampled streams ($r = 0.5$ $p < 0.01$). Whether this increase in glides and the resulting loss of pool and riffle habitats is due to increased flow regimes from irrigation diversions or runoff remains to be seen.

Another area of concern could be sediment or nutrient loading (Newcombe and MacDonald 1991). Row crop agriculture has been shown to be associated with increases in sediment loading (Kuhnle et al. 1996). In addition, row crops often receive high amounts of nitrogen and phosphorous fertilizers. The irrigation effluents associated with row crop production could increase localized nutrient loading resulting in large increases in algae production during the summer baseflow period. The increased algal growth could in turn lower the night time levels of dissolved oxygen in the stream forcing fish to search for preferable conditions. While the nature of this investigation could not include the monitoring of nutrient or sediment loading, the potential negative impacts of these processes on native benthic fish should be monitored in the future.

Initially, the positive impact resulting from the combined in-stream annual and perennial grass seed measure and the negative nature of the out-of-stream annual grass seed measure seem to conflict. However, there may be a reasonable explanation for this. The surface roughness associated with a mature grass crop may act as a buffer and help decrease sediment and nutrient loads delivered to a stream. Also, grass crops may mimic the natural vegetation historically found in the Willamette Valley better than any other cropping strategy. On the other hand, the annual disturbance regime associated with the plowing and planting of annual grass could possibly increase sedimentation or nutrient loading in the stream which would lead to the negative coefficient associated with its out-of-stream measure. Also, the management of annual grass seed fields in the Willamette Valley leaves them relatively devoid of significant vegetation until after the first fall rain events. The initial increases in sediment and nutrient loading in streams during these early storms (Rinella and Janet 1998) may explain the negative nature of the annual grass coefficient.

The positive nature of urban lands on stream fish communities seems to disagree with previous studies (Weaver and Garman 1994). However, the use of benthic fish biomass as the response variable of interest may be the source of the positive coefficient.

The nature of stormflows from areas of urban land may select for populations of benthic fish because the flashy flows may have a larger impact on water-column dwelling species. The benthic dwellers may be able to compensate for the large changes in stream flow by remaining in or near the boundary layer just above the bed of the stream while water-column dwelling fish may be swept downstream.

The detection of significant in-stream and out-of-stream impacts of different land uses may be the result of several mechanisms. The significant in-stream components of a land use's influence could indicate that the effects of that land use, once its loads reach the stream, have a direct impact on native fish populations because the stream is unable to mitigate its impact on stream fish. Also, higher stream flows originating from certain land uses may increase sediment transport or erosion in the channel.

Significant out-of-stream metrics may indicate that the effects of loads originating from terrestrial sources are less likely to be affected by the land use activities between the load's source and the stream. In other words, the influence of land uses with strong out-of-stream measures may be so large that their impacts are not altered by other land uses closer to the stream. For example, the flashy nature of flows originating from urban lands after a storm event may be so influential that buffers of riparian forest or other land uses cannot reduce their impact on stream conditions. This may be an indication that larger areas of the more favorable land use activities such as riparian forest (Peterjohn and Correll 1984; Jordan et al. 1993; Jones et al. 1999) should be placed between the unfavorable land use and the stream to more effectively buffer a land use's impact.

It must be realized that the magnitudes of the land use impacts presented in this paper may not be an accurate reflection of the overall health of the native fish community in the Willamette Valley. The large proportion of native fish is by no means a complete indication of stream health. The majority of the native fish present in the streams studied are tolerant of a wide range of water quality and habitat conditions. Also, the lack of well established cool water fish populations is an indication that increased temperatures may be a concern in these agricultural streams.

Using the inverse square distance weighting method appears to be an effective tool for predicting impacts of land use on stream conditions. While the land use area and buffer methods have their place in establishing general relationships between forest, urban, and agricultural lands (Osborne and Wiley 1988; Allan et al. 1997; Bolstad and Swank 1997), their usefulness decreases when the diversity within land use classes increases. Cumulative impact assessments recognize that variations among land use distributions play a role in determining stream conditions. However, as with the buffer and catchment scale land use area methods, cumulative impact studies have not isolated the impacts of specific land uses (Childers and Gosselink 1990; Bolstad and Swank 1997). The inverse square flow-path distance method seems to overcome the problems associated with detecting and quantify the individual impacts of specific land uses in a diverse landscape. We suggest that this technique has distinct advantages when assessing the effects of watershed land use, planning, and management on stream biota.

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CHAPTER 4. SUMMARY

Detecting and quantifying the effects that different land use practices have on stream conditions is important in the diverse landscapes found in agricultural regions of the Willamette Valley. However, the difficulty associated with carrying out this task requires innovative techniques that are sensitive to differences found among the complex landscapes that were studied in this investigation.

Selecting sites that would allow for the detection of the impacts of different land uses on fish was one of the most difficult aspects of this investigation. Careful consideration of the features of each potential watershed was necessary for the correct identification of the best set of sampling locations. Chapter 2 illustrated the strict guidelines that were set to maximize the probability that the watersheds selected were representative of valley-wide conditions while retaining the ability to differentiate between the impacts of the different land uses studied. Using a careful ranking procedure, sites were identified according to the proportions of each of the land use classes found within a watershed. Additional considerations such as basin size and geographic location were used to confirm that the sites selected would not bias the data collected. In addition, the spatial distribution of the land uses in the candidate watersheds were visually assessed to guarantee that they were consistent with the criteria that were set for identifying sampling sites.

Chapter 2 confirms that the histogram based selection procedure identified sites that captured conditions characteristic of land use activities throughout the Willamette Valley. In addition, the reasonably large deviation from the mean of the land use practice for which a watershed was selected indicates that these methods retain the power necessary for the detection of differences among various land uses.

Coupling the physical properties of a watershed with the data collected during stream sampling allowed for the development of the methods outlined in Chapter 3. Several different methods (Osborne and Wiley 1988; Richards and Host 1994; Buckley 1997; Bolstad and Swank 1997; Wang et al. 1997) were reviewed before finally developing the inverse flow path length approach. It was determined that this approach captured the properties of agricultural catchments better than methods that have been used in the past. Also, it was assumed that integrating the underlying theories of previously successful buffer and land use area approaches would allow for the detection of the impacts of individual land uses that were spread across a watershed.

Using a series of grids to describe the physical properties of a watershed was assumed to capture small-scale effects much more efficiently than other data models such as vectors. In addition, developing complex computational procedures is much easier using the cell-based structures of grids. Not only do grids allow for the tracking of a cell's load across space, they also enable the assignment of specific values measuring the impact of a land use to each point in a watershed.

Initially, metrics using the total distance traveled to the sampling point were used to quantify the impacts of a cell on stream conditions. However, the inability of this method to capture the variability in the biomass of native fish required that in-stream and out-of-stream processes be separated. It was determined that separating the two processes allowed for the determination of the watershed features that were responsible for describing the effect of a land use on stream conditions (Schlosser and Karr 1981). If the in-stream portion of the flow path was more influential, it indicated that processes such as channel scour and sediment transport may have been important. On the other hand, if out-of-stream metrics were more influential, processes such as surface erosion and storm runoff may have been more important.

Using the inverse of the squared in-stream and out-of-stream flow distances was the best method for detecting the different impacts that specific land uses had on fish communities in the Willamette Valley. Not only did this method detect the most significant differences among land uses, it also provided the best fitting model for the data. The addition of reach scale habitat features further strengthened the model and indicated that coupling local and regional environmental controls is often the most effective method for assessing the structure of fish assemblages (Menge and Olson 1990).

Traditionally, predicting the impacts of environmental changes on fish communities has been difficult (Fausch et al. 1988). However, there have been methods that adequately describe the impacts of environmental variables on stream conditions and fish assemblage structure. The methods outlined in this thesis should be added to the list of successful methods as they have proven to effectively describe the impact of watershed scale land use on stream conditions. Furthermore, their ability to capture the spatial variability associated with diverse land use patterns adds to their effectiveness as tools for future use in watershed management.

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