

8-2002

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**RELATIONSHIPS BETWEEN STREAM GEOMORPHOLOGY AND FISH
COMMUNITY STRUCTURE AND DIVERSITY IN MAINE**

By

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B.A. Colgate University, 1997

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Ecology and Environmental Sciences)

The Graduate School

The University of Maine

August, 2002

Advisory Committee:

John R. Moring, Professor of Zoology, Advisor

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By Emily Gaenzle

Thesis Advisor: Dr. John R. Moring

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
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Predicting patterns in species distribution and abundance for resource management and conservation is a major focus of applied ecology. The primary objective of this study was to determine if there is a predictable relationship between stream geomorphology and fish community structure, native species richness, and native salmonid abundance in Maine. Specifically, I examined relationships between fish assemblages and geomorphic stream types, as delineated by the Rosgen classification system (Rosgen 1996). Fifty-three stream reaches in Maine were classified, and fish communities within the reaches were characterized using backpack electrofishing. Species richness was lowest in A-type streams (i.e., steep, entrenched, confined), which supported brook trout (*Salvelinus fontinalis*) and slimy sculpins (*Cottus cognatus*). Richness was highest in C-type streams (i.e., low gradient, meandering with broad, well defined flood plains). Salmonids were in greatest abundance in B- (i.e., moderately entrenched, moderate gradient) and C-type streams.

A secondary objective was to identify environmental correlates of fish community structure using a geographic information system (GIS). Specifically, I examined relationships between fish community attributes (e.g., species richness, species distribution) and watershed landcover, proximity to dams, biophysical region, and elevation. Fish species richness was negatively correlated with elevation and was significantly different among different biophysical regions in the state. Atlantic salmon (*Salmo salar*) distribution was significantly correlated to watershed landcover.

The ability to predict species distribution and abundance based on physical stream characteristics and biophysical region has important implications for watershed and fisheries management. Collecting data on geomorphic variables is more efficient and is less invasive than sampling fish communities through the use of electrofishers and gill nets. GIS is an important tool that can be used to predict species richness and distribution. Data on broad-scale environmental variables, such as landcover and elevation, are easily obtained using GIS coverages, thus reducing the need for extensive field work. Ultimately, the ability to identify which stream reaches may contain diverse fish assemblages and/or abundant salmonid populations will contribute to decision-making for watershed conservation and channel restoration efforts.

DEDICATION

In loving memory of John Moring, advisor and friend.

ACKNOWLEDGMENTS

I would like to thank the biologists at the Maine Department of Inland Fisheries and Wildlife for their logistic support, for assisting me in the field, and for supplying me with data. In particular, thank you to Joan Trial, Forrest Bonney, Frank Frost, and Paul Johnson who helped me tremendously. Also, thank you to the Maine Atlantic Salmon Commission for supplying me with Atlantic salmon abundance data. Thank you to Peter Parizzi, my summer field assistant, for all of your hard work and long hours, and thanks to all of the other students who assisted me in the field. Thank you to Cyndy Loftin for filling in on my committee at the last minute. I would also like to thank Sue Anderson for her attention to detail and for her moral support through the whole Masters process. Thank you to my committee members Alex Huryn and Joan Trial for your guidance. Finally, I would like to thank my advisor John Moring for your encouragement, advice, and for keeping a smile on my face.

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GENERAL INTRODUCTION

Identifying the mechanisms and processes that determine community structure and species distribution is a major focus of community ecology. Many studies have examined the influence of environmental variables on aquatic communities. Early studies demonstrated longitudinal gradients in aquatic community structure. The River Continuum Concept (RCC) was introduced in a seminal paper by Vannote et al. (1980). The RCC links the changes in physical factors that occur from headwater streams to large rivers to changes in lotic community structure. Fluvial geomorphology sets the template for a downstream gradient in food resources, which regulates the structure and function of the lotic invertebrate community. Schlosser (1982) later applied the RCC to patterns in fish community structure. He demonstrated that, concordant with the RCC, consistent shifts in fish community organization are associated with spatial and temporal changes in channel morphology and resource availability. Specifically, he found that generalized insectivores are predominant in temporally variable areas (upstream and riffles) and insectivore-piscivores are more common in stable habitats (downstream and pools). These changes in fish trophic structure were attributed to changes in resource availability (measured as invertebrate abundance and young-of-the-year fish) and habitat diversity.

Many studies conducted at varying spatial scales have demonstrated relationships between environmental variables and stream fish communities. Environmental correlates to fish community structure have been determined at local (Jackson & Harvey 1989, Wiley et al. 1997, Angermeier & Winston 1998), regional

(Jackson & Harvey 1989, Wiley et al. 1997, Angermeier & Winston 1998), and global scales (Oberdorff et al. 1995). Several studies have examined a suite of variables to document environmental correlates to fish community structure and diversity at the watershed level (Hawkes et al. 1986, Hughes et al. 1987, Whittier et al. 1988, Rahel & Hubert 1991, Lyons 1996, Maret et al. 1997, Angermeier & Winston 1999, Waite & Carpenter 2000). The findings of these studies vary with the region in which they were conducted. For example, a study conducted in the Snake River Basin, Idaho, determined that the major environmental correlates to fish distributions were stream gradient, watershed size, conductivity, and percentage of watershed covered by forest (Maret et al. 1997). A study examining fish assemblage patterns in Kansas, however, found that mean annual runoff, length of growing season, and discharge were the most important variables (Hawkes et al. 1986). While results differ, these studies all demonstrate that landscape features may provide a basis for assessing fish community diversity and assemblage structure.

My research focused on examining the influence of stream geomorphology on fish communities in the state of Maine. My primary objective was to determine if there is a predictable relationship between the geomorphological characteristics of streams in Maine and fish community structure and diversity. Specifically, I examined the relationship between the stream types, as delineated by the Rosgen classification system (Rosgen 1996), and various characteristics of fish community structure and diversity. The Rosgen (1996) stream classification system integrates many geomorphological variables into a hierarchical delineation of stream type.

A secondary objective focused on assessing the value of variables not included in the Rosgen classification system. Because this system includes only geomorphological variables, other factors suspected to influence fish communities in Maine, such as elevation (Beecher et al. 1988, Rahel & Hubert 1991), beaver dam location (Snodgrass & Meffe 1998), water quality (Matthews et al. 1992, Keleher & Rahel 1996), the location of upwelling ground water (Wiley et al. 1997), and land use (Waite & Carpenter 2000), are not taken into account. Specifically, the effects of elevation, biophysical region, proximity to dams, and watershed landcover were studied through the use of GIS.

The major objectives of this study were to determine:

- 1) if there is a predictive relationship between geomorphological stream type and fish community structure, fish species diversity, and/or salmonid abundance
- 2) if other environmental variables, such as elevation or watershed landcover, are useful in identifying fish communities in Maine

This study integrates local- and landscape-scale analyses. Considering multiple spatial scales can increase understanding and predictive ability, because attributes of fish communities can be influenced by environmental variables correlated with different spatial scales (Poff 1997). The variables that were examined outside of the Rosgen classification were landscape characteristics that can be analyzed through the use of GIS. The benefit of analyzing such broad-scale variables is that data are easily obtained using pre-existing GIS coverages, thus reducing the need for extensive field work and allowing field assessments of fish communities to

be more focused and economical. However, an important consideration when using broad-scale variables as predictors of community attributes is that this type of analysis introduces error due to interpolation of data and generalization of detail. Therefore, results should be interpreted with caution and should be ground-truthed.

Studies examining relationships between stream geomorphology and fish communities have shown that, because a general association exists between the different scales of geomorphic characteristics of streams (Hubert and Kozel 1993), habitat-geomorphology relationships seen at the reach-scale can be extrapolated to larger spatial scales (Fukushima 2001). The collection of data for Rosgen classification involved detailed field measurements at the stream reach-scale. Because site specific information from reference reaches can be extrapolated to similar reaches, the implications of a predictive relationship between stream type and fish community structure, diversity, or salmonid abundance are important. If stream type is proven to be a powerful predictor of fish community characteristics, such as community structure or species diversity, a great deal of time and money could be saved by focusing field work.

Collecting data on geomorphic variables and broad-scale environmental variables is more efficient and less invasive than sampling fish communities. Ultimately, the ability to identify which stream reaches may contain diverse fish assemblages and/or abundant salmonid populations can aid in deciding where to focus fisheries and watershed conservation as well as channel restoration efforts.

The results of this study are presented in two chapters, each in the form of a scientific paper. The first chapter presents the geomorphological component of my

research, relating fish community attributes to stream geomorphology using the Rosgen classification system (Rosgen 1996). The second chapter, which deals with the GIS component of my research, discusses broad-scale environmental correlates to fish community structure and diversity that are not considered in the Rosgen classification system.

Chapter 1

GEOMORPHOLOGICAL RELATIONSHIPS TO FISH COMMUNITY STRUCTURE AND DIVERSITY IN MAINE

Introduction

Habitat quality for stream fishes is dictated in part by the functioning and interactions of hydrology and channel morphology (Heede and Rinne 1990). Previous studies have examined relations of geomorphology to stream habitat and trout standing stock (Lanka et al. 1987) and distribution (Nelson et al. 1992). Nelson et al. (1992) demonstrated that trout distribution in Nevada is related to geomorphic history, indicating that stream reach location within a particular geomorphic land class is a valid starting point for habitat capability analysis. Lanka et al. (1987) found that drainage basin morphology could accurately predict trout standing stock, indicating a functional link between stream habitat quality and basin morphology.

Recently, there has been increased interest in investigating the relationships between fluvial morphology and fish communities. One reason for the increased interest in fisheries-geomorphology relationships is that many rivers and streams in North America have been altered by human activities. Hydrological alterations, such as dam construction, stream channelization, and groundwater exploitation all affect the channel form of streams (Rosenburg et al. 2000). In addition, alterations of riparian areas through livestock grazing, development, and deforestation have great impacts on instream habitat conditions (Schlosser 1991). Ultimately, these changes to the natural functioning of streams and rivers have dramatic effects on stream biota

(Schlosser 1991). For example, Elser (1968) examined the effects of stream channel alterations on trout populations in Little Prickly Pear Creek, Montana and estimated that trout numbers decreased by 12% and weight decreased by 19% due to a loss of 1.4 miles of natural channel. To preserve and restore streams, there is a need to understand the intricate interaction between their physical state and the aquatic communities that inhabit them (Heede and Rinne 1990).

A potential means of assessing stream geomorphology is through the use of a geomorphic classification system. The Rosgen stream classification system integrates many geomorphological variables into a hierarchical delineation of stream type (Rosgen 1996). The general objectives for this system are to: 1) predict a river's behavior from its appearance, 2) develop hydraulic and sediment relationships for a given stream type, 3) provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics, and 4) provide a consistent framework of reference for communicating stream morphology and condition among a variety of disciplines.

The first level of the classification system (level I) is a broad geomorphic description that integrates basin characteristics, landforms, and valley types with stream system morphology and sorts streams into major stream types at a landscape level (Table 1). The different geomorphic characteristics incorporated into this level include channel entrenchment, channel patterns, channel slope, and channel shape. Level I is assessed on the basis of valley landforms and channel dimensions observable on aerial photographs or topographic maps.

Table 1. Description of all level I stream types (Rosgen 1996; copied with permission from Dave Rosgen, Wildland Hydrology).

Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/ Soils/Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams.	<1.4	<12	1.0 to 1.1	≥10	Very high relief. Erosional, bedrock or depositional features; debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools; waterfalls.
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.	<1.4	<12	1.0 to 1.2	.04 to .10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step/pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.	1.4 to 2.2	>12	>1.2	.02 to .039	Moderate relief, colluvial deposition, and/or structural. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate w/scour pools.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains.	>2.2	>12	>1.4	<.02	Broad valleys w/terraces, in association with floodplains, alluvial soils. Slightly entrenched with well-defined meandering channels. Riffle/pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<.04	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment, w/abundance of sediment supply. Convergence/divergence bed features, aggradational processes, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive, well vegetated floodplains and associated wetlands. Very gentle relief with highly variable sinuities and width/depth ratios. Very stable streambanks.	>2.2	Highly variable	Highly variable	<.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomosing (multiple channel) geologic control creating fine deposition w/well-vegetated bars that are laterally stable with broad wetland floodplains. Very low bedload, high wash load sediment.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<.02	Broad valley/meadows. Alluvial materials with floodplains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width/depth ratios.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.	<1.4	>12	>1.4	<.02	Entrenched in highly weathered material. Gentle gradients, with a high width/depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/pool morphology.
G	Entrenched "gully" step/pool and low width/depth ratio on moderate gradients.	<1.4	<12	>1.2	.02 to .039	Gullies, step/pool morphology w/moderate slopes and low width/depth ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials, i.e., fans or deltas. Unstable, with grade control problems and high bank erosion rates.

The second level of the classification scheme (level II) is a detailed morphological description involving higher-resolution quantitative assessment. This level assesses sediment supply, fish habitat potential, and stream sensitivity to disturbance and potential for natural recovery. The level II classification is based upon field measurements from specific channel “reference” reaches and fluvial features within the river's valley. The level I classification is verified and calibrated with reference reach data collected during the level II assessment. Specifically, four criteria are used to verify the level I classification: 1) entrenchment ratio, 2) width-depth ratio, 3) sinuosity, and 4) slope. Assessment of dominant channel material is a fifth parameter measured during level II classification, and this is used to break stream types into six subtypes based on the median particle diameter of channel materials (Figure 1).

A key aspect of the Rosgen stream classification system is that the information gathered from reference reaches (level II) can be extrapolated to other areas with similar valley and lithological types through use of maps and photos (level I). This reduces the need to take field measurements for every stream reach of interest.

The primary objective of this research was to determine if there is a predictable relationship between the geomorphological characteristics of streams in Maine and fish community structure and diversity. Specifically, I examined relationships between the stream types, as delineated by the Rosgen classification system (Rosgen 1996), and 1) fish species richness and 2) salmonid abundance.

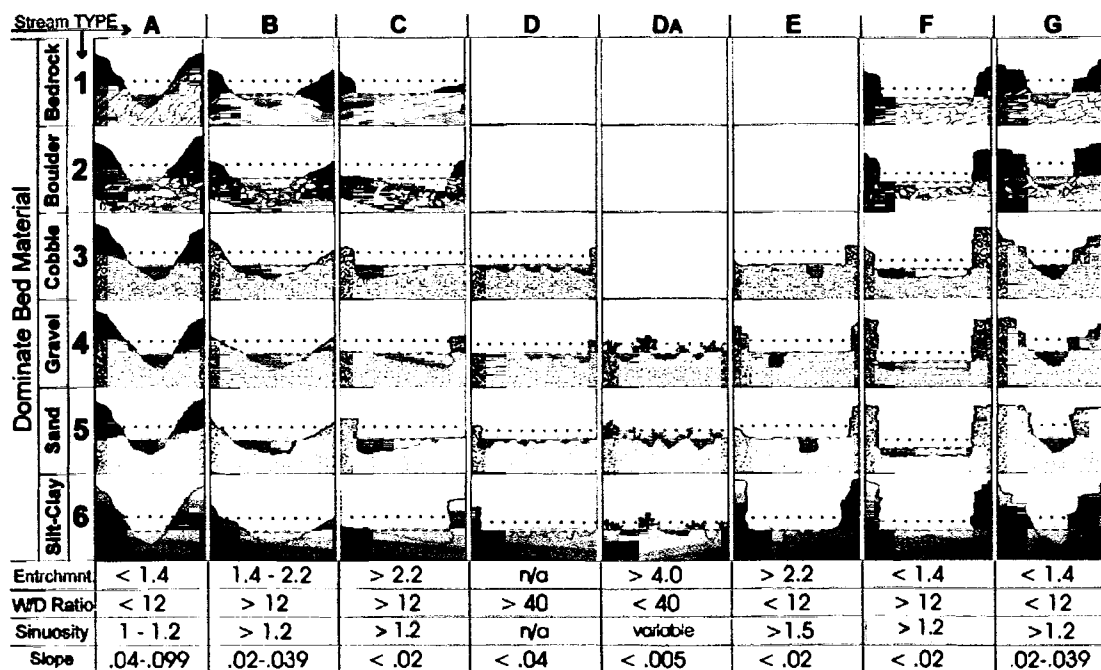


Figure 1. Cross sectional view of the Rosgen stream types (Rosgen 1996; copied with permission from Dave Rosgen, Wildland Hydrology).

Methods

Data Collection - Maine Department of Inland Fisheries and Wildlife

Much of the fish community data used in this study was collected by the Maine Department of Inland Fisheries and Wildlife (IFW) as part of its long-term salmonid stream monitoring project. Biologists with IFW collected brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) population data, including abundance estimates, biomass, and size-class ratios for approximately 60 streams throughout the state. Using backpack electrofishing units, fish were collected and salmonid abundance was estimated using Zippin's three-run removal method (Armour et al. 1983). Electrofishing was conducted in an upstream direction with blocking nets positioned at both ends of the sample reach. Fishing effort (wand time) was approximately equal for each run. Captured fish were held in a cage outside the section during successive runs. The area of the section electrofished ranged from 418-669 square meters (4500-7200 square feet). Counts of salmonids were recorded for all three runs, and fish lengths and weights were recorded. Population estimates for brook trout and Atlantic salmon were calculated using the Zippin method (Armour et al. 1983). Fish species occurrence was also documented, providing a list of species present in each stream reach and an estimate of species richness.

The original focus of the IFW monitoring project was to document salmonid populations throughout the state to assess effects of a regulation change (from a daily bag limit of ten to one of five in all but two counties where five was the current regulation). More recently, however, IFW biologists have included habitat assessments of study streams using the Rosgen classification system. As of 2001,

IFW classified 37 salmonid streams to the second level of the Rosgen system (see below for detailed methods of Rosgen classification).

Data Collection - Summer 2001

Most streams classified by IFW were B-type streams (i.e., moderately entrenched, moderate gradient) and C-type streams (i.e., low gradient, meandering, with broad, well defined flood plain). Therefore, additional surveys were conducted during summer 2001 on additional streams to include the range of Rosgen stream types. Regional biologists around the state were consulted for locations of other types of streams, and topographic maps were examined to define possible study sites. A key criterion was that potential study streams be relatively undisturbed, because a goal of the research was to determine fish-geomorphology relationships in natural stream channels. It should be noted, however, that different stream types are subject to varying levels of disturbance based on their landscape position and their channel form. For example, steep gradient streams with bedrock substrate (e.g., A1-type) will likely be less disturbed than low gradient streams in limestone plains (e.g., C4-type), which would be subject to the effects of agriculture. The additional streams selected for study in summer 2001 were located in the western mountains as well as in Aroostook County and in Downeast Maine (Figure 2).

The level I stream types of potential sites were assessed using topographic maps. The level I classification was then verified using field measurements from the level II classification. For the level II classification a surveyor's rod and transit were used to survey a cross section and to obtain a longitudinal profile for each sample

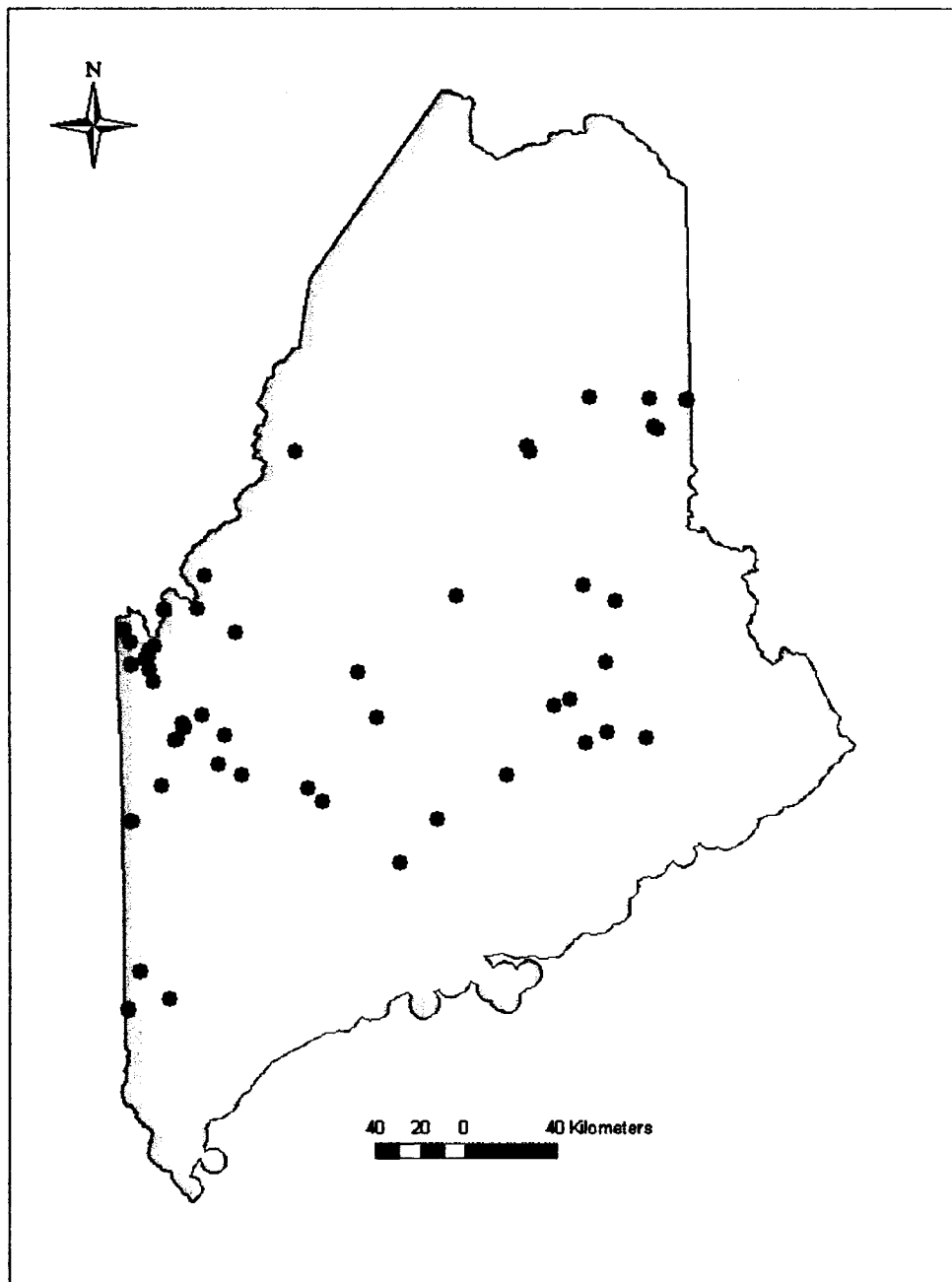


Figure 2. Location of study stream reaches.

reach. Three of the four parameters (entrenchment, width-depth ratio, and slope) necessary to verify the level I stream type were calculated by using measurements obtained in the cross section and longitudinal profile. The fourth parameter (sinuosity) was calculated using Terrain Navigator 2001, a digital mapping software program from Maptech, Inc. (10 Industrial Way, Amesbury, MA 01913; Telephone: 978-792-1000).

The cross section was generally located in the middle of a 100m stream reach on a straight section between two meander curves and in a location that was visually estimated to be representative of the entire reach. In riffle-pool sequences the cross section was taken in a riffle. A surveyor's transit was leveled on a tripod on the stream bank. The transit was placed high enough so that the observer could survey an entire cross section of the flood prone area. A metric tape was anchored in the flood prone area and was stretched across the stream to be anchored in the flood prone area on the opposite bank. Rod readings were taken at intervals across the entire length of the tape (approximately 20 readings). A reading also was taken wherever there was a significant change in the stream bed. Rod readings were always taken at bankfull stage on each side of the stream.

Bankfull stage is the height water reaches when the flow fills the channel to the top of its banks. Bankfull stage is the most important parameter used in the level II classification (Rosgen 1996). It is required to estimate entrenchment ratio and width-depth ratio, two of the five level II criteria. Field determination of bankfull stage can be difficult. The best indicator of bankfull stage is the elevation where flooding begins for flows that extend above the bankfull stage. For streams with

poorly developed floodplains, indicators include stains on rocks, exposed root hairs below intact soil, a change in the particle size distribution, the top of the highest depositional feature, or a break in bank slope.

The longitudinal profile for sample stream reaches began upstream of the cross section and extended downstream for approximately 100m. The transit was either left where it was located for the cross section or, if visibility was obstructed, it was relocated to have a clear view from the top to the bottom of the longitudinal profile. A metric tape was extended along the entire length of the profile. Rod readings were taken at regular intervals (approximately every 3m) and whenever there was a noticeable drop in elevation. At each station along the transect, rod readings were taken at bankfull stage, on the water surface, and at maximum depth.

Finally, a pebble count determined the dominant bed material. For the pebble count, ten transects were placed across the channel, spaced equally along the length of the reach. Ten rocks were measured within each transect. Observers randomly chose rocks from the stream bed by taking a step and picking up the first rock to touch their boot. The width of each rock was measured with a ruler by orienting the rock as if it were passing through a sieve and measuring the widest point.

Topographic maps in Terrain Navigator 2001 were used to measure sinuosity. Global positioning system (GPS) coordinates of sample stream reaches were entered into Terrain Navigator 2001 to locate the exact position of each sample stream reach. For each sample stream, the reach length was determined by drawing a line following the contours of the reach. Valley length was measured by drawing a straight line

connecting the start and end points used for the reach length measurement. Sinuosity was calculated by dividing the reach length by the valley length.

The field data for the level II classification were entered into a series of Microsoft Excel worksheets developed by D.E. Mecklenburg (1999). These worksheets are designed to calculate the parameters necessary to determine the stream type. One worksheet diagrams the cross section and calculates the width-depth ratio and entrenchment. A second worksheet diagrams the longitudinal profile, and calculates water surface slope and sinuosity. Finally, a third worksheet graphs the percentage of each substrate size and calculates the dominant bed material.

In sample reaches where fish community data were not available from IFW, species composition and diversity were assessed using a backpack electrofisher. The methodology was similar to that of IFW. However, population size was not estimated, so only one pass was made at each site. For sample reaches that were too deep to electrofish, a seine was used to collect fish. Specimens of unknown species were kept for later identification. Digital photographs were taken of each sample reach to include in the database. And, the location of the cross section in each sample reach was recorded using a handheld Magellan GPS unit.

Data Analysis

Analysis of variance (ANOVA) was used to determine if there were significant differences in native species richness among the different level I stream types and among different level II stream types (determined by dominant bed material). Following significant ANOVA results ($\alpha = 0.05$), significant differences

between pairs of means were detected using the Fisher's protected Least Significant Difference test (LSD). Ideally, a nested ANOVA would have been used to detect an interaction between the level I and level II stream types. However, there was insufficient data to conduct this type of analysis.

A more precise analysis of the relationships between native species richness and the individual variables measured to determine level I stream type (i.e., entrenchment ratio, width-depth ratio, slope, and sinuosity) was conducted using principal components analysis (PCA). PCA is a technique that identifies the principal components (PC) as orthogonal, linear combinations of the original variables, thus reducing the dimensionality of complex datasets. The first PC accounts for the greatest amount of variability in the dataset, and each successive PC accounts for a smaller portion of the remaining variance. PCA calculates component loadings for each variable to indicate their contribution to each PC. The loadings indicate which variables explain the highest portion of the variance for each PC and also which variables explain similar portions of the variance. Because the PCs are linear combinations of the original variables, they can be used as independent variables in regression analyses.

Poisson loglinear regression was conducted to examine relationships among level I Rosgen variables and native species richness. The Poisson loglinear model is a generalized linear model that assumes a Poisson distribution for the dependent variable and uses the log link (Agresti 1996). The Poisson distribution is a distribution for discrete variables that occurs when the number of organisms (or species) in a region is counted. A key feature of the Poisson distribution is that its

variance increases with the mean (Agresti 1996). The Poisson loglinear model takes the form: $\log \mu = \alpha + \beta x$, where the mean is $\mu = \exp(\alpha + \beta x)$. Poisson loglinear regression was used to examine relationships between species richness and the principal components, with the aim of drawing out patterns in native species richness in relation to stream geomorphology.

The species composition data were somewhat limited because only presence/absence data were available. However, detailed analyses of native salmonid (i.e., Atlantic salmon and brook trout) distribution and abundance were possible using the population estimates generated by IFW. Three measures of native salmonid abundance were used to analyze relationships with stream geomorphology: number of fish per 100 square meters (FISH100), kilograms per hectare (KGHA), and number of fish per mile (FISHMILE; original data were calculated by IFW based on English units). A nested ANOVA was used to examine the relationship of salmonid abundance to level I and level II classifications of sample stream reaches which supported salmonids, and to see if there was an interactive effect of level I and level II stream types on salmonid abundance. Fischer's protected LSD was used to detect pairwise means differences. The analysis was restricted to those stream types which supported salmonids and for which there was sufficient abundance data to conduct the analysis.

Several years of salmonid abundance data were available for many of the study streams. Rather than averaging abundance over the different years, the highest recorded value for each of the three abundance measures for each sample reach was used. This approach was chosen to facilitate interpretation for management purposes;

the highest recorded abundance represents a potentially meaningful measure of habitat capacity. In streams where both Atlantic salmon and brook trout occurred, the abundance estimates were combined to give an overall estimate of total native salmonid abundance.

Results

Fifty-six stream reaches were classified (Figure 3). Although attempts were made to locate stream reaches that would represent each of the different level I Rosgen stream types, no E-type (i.e., low gradient, stable, meandering, with low width-depth ratio) or G-type streams (i.e., gully) were located, and only one D-type (i.e., braided channel) stream was sampled (Table 2). Several streams did not fall neatly into one of Rosgen's level I categories, therefore these streams were labeled as intermediate types. For example, several reaches had slope values that were consistent with A-type streams, but their width-depth ratio and/or entrenchment indicated a B-type. In this case, the stream was classified as a BA-type stream. There also were streams with slope and sinuosity values consistent with B-type streams, but width-depth ratio and entrenchment values typical of C-type streams. These were labeled as BC-types.

There were significant differences in native species richness among the different level I stream types (ANOVA, $p < 0.01$). Mean species richness was highest in C-type and lowest in AA+-type streams (Figure 4, Table 3). None of the three AA+ streams sampled contained fish. There were also significant differences in native species richness among the different level II stream types (ANOVA, $p < 0.01$). Mean

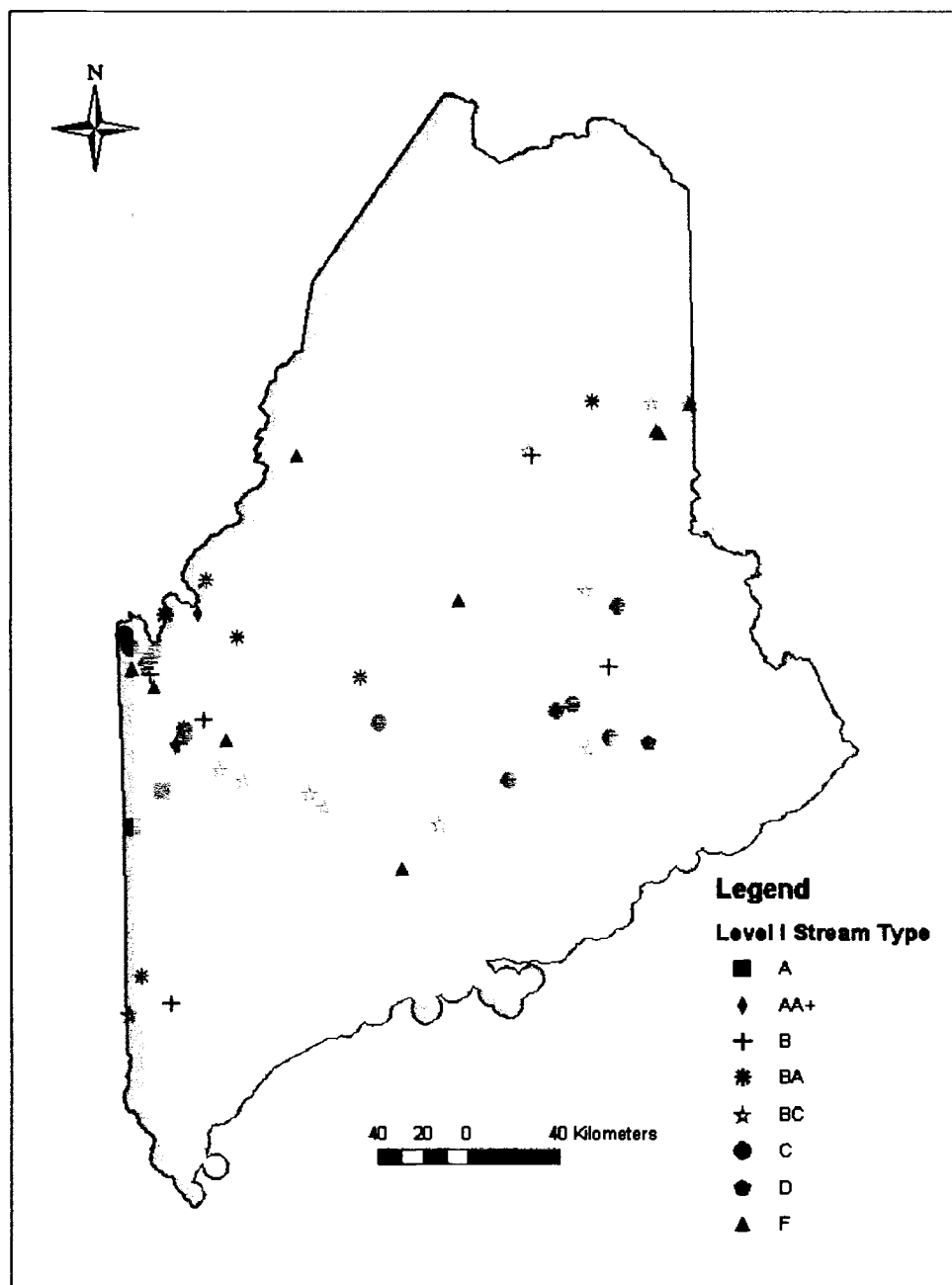


Figure 3. Location of classified stream reaches labeled with level I stream type.

Table 2. Number of streams of each Rosgen type that were classified.

Stream Type	AA+	A	BA	B	BC	C	D	F
1	1	-	-	-	-	-	-	-
2	-	1	2	4	1	-	-	-
3	1	1	4	2	1	3	1	8
4	1	1	3	2	8	3	-	-
5	-	-	-	-	1	-	-	1
6	-	-	-	-	1	3	-	-

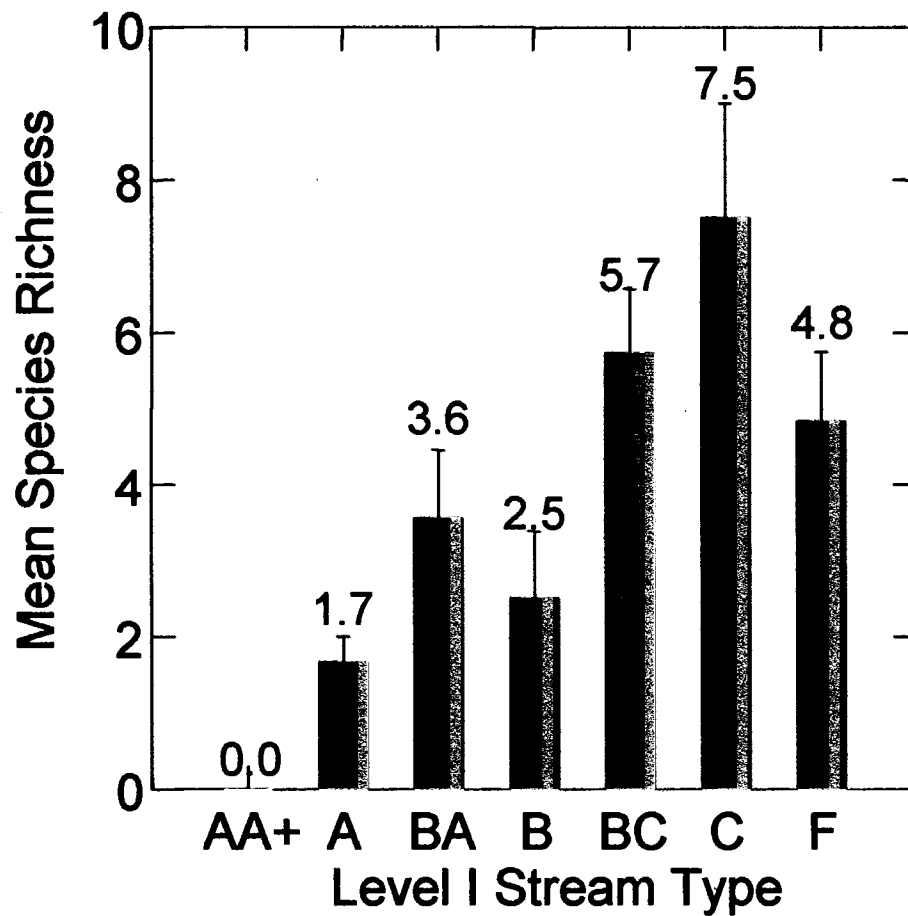


Figure 4. Mean native fish species richness by level I Rosgen stream type (mean richness is indicated above each bar; error bars indicate standard error of the mean).

Table 3. Matrix of pairwise mean differences comparing mean native richness in different level I stream types; * indicates significant difference detected by Fischer's protected LSD ($p < 0.05$).

Level I Stream Type	AA+	A	BA	B	BC	C	F
AA+	0.000						
A	1.333	0.000					
BA	3.222	1.889	0.000				
B	2.167	0.833	-1.056	0.000			
BC	5.394*	4.061*	2.172	3.227*	0.000		
C	7.167*	5.833*	3.944*	5.000*	1.773	0.000	
F	4.500*	3.167	1.278	2.333	-0.894	-2.667	0.000

species richness was significantly higher in type 6 streams (i.e., those with silt-clay as their dominant bed material) than the other stream types (Figure 5, Table 4).

Two principal components accounted for substantial amounts of variation in the geomorphic dataset. Slope and sinuosity were heavily loaded on the first PC, which explained 37% of the variance among the study stream reaches (Table 5). Entrenchment ratio and width-depth ratio were heavily loaded on the second PC, explaining 29% of the variance in the dataset. Slope and sinuosity were inversely related as were entrenchment and width-depth ratio (Figure 6). A-type streams have low values for PC1, meaning that they are steep and not very sinuous, whereas C- and F-type streams are at the opposite end of PC1 with low slope and high sinuosity (Figure 7). Except for a few streams, there was little separation of different stream types along PC2, meaning that there was not a high degree of variation in entrenchment and width-depth ratio.

A Poisson loglinear regression of native species richness against PC 1 was significant. The maximized likelihood fit of the Poisson loglinear model with PC 1 as the explanatory variable was: $\log \mu = \alpha + \beta x = 1.351 + 0.737x$ (Figure 8). The effect $\beta = 0.737$ of PC 1 has an asymptotic standard error of 0.09. This model shows that PC 1 has a positive estimated effect on species richness. The likelihood ratio statistic comparing the complex model with PC 1 as an explanatory variable ($\log \mu = \alpha + \beta x$) to the simpler model containing only one constant ($\log \mu = \alpha$) is: $-2(L_0 - L_1) = -2(104.432 - 170.709) = 132.554$. This tests the null hypothesis that $\beta = 0$. With $df = 1$ the G^2 statistic shows that β does not equal zero, and therefore species richness is

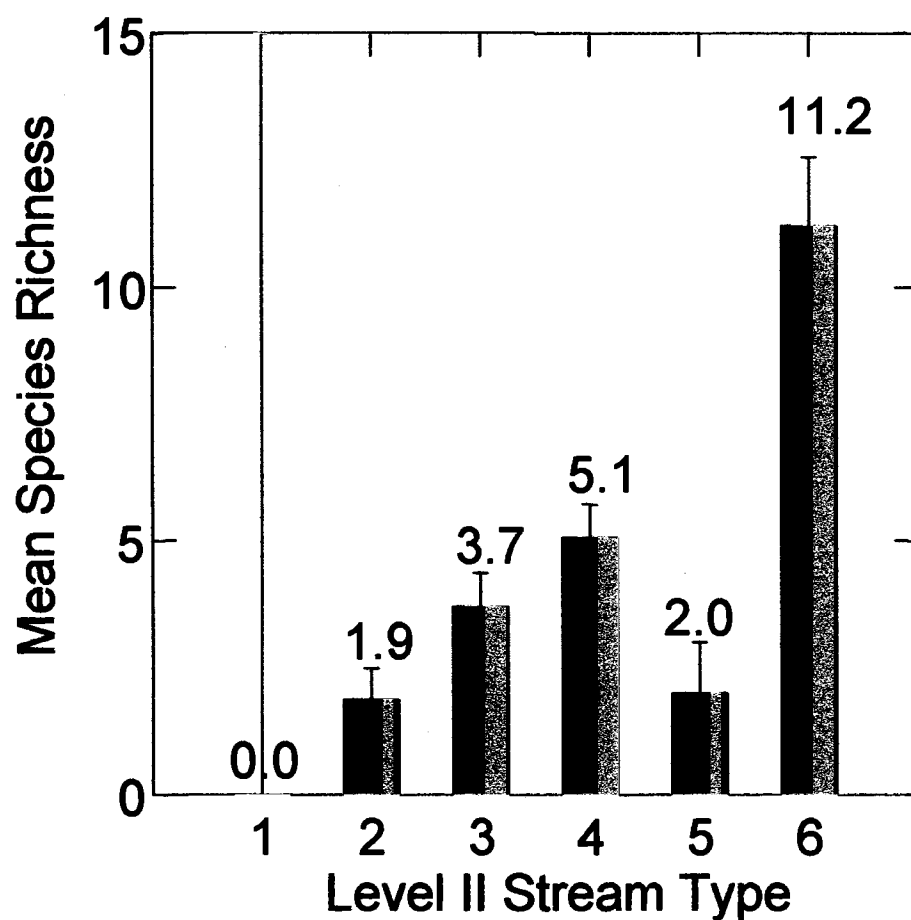


Figure 5. Mean native fish species richness by level II Rosgen stream type. Numbers indicate dominant channel material: 1= bedrock, 2 = boulder, 3 = cobble, 4 = gravel, 5 = sand, 6 = silt-clay (mean richness is indicated above each bar; error bars indicate standard error of the mean).

Table 4. Matrix of pairwise mean differences comparing mean native richness in different level II stream types; * indicates significant difference detected by Fischer's protected LSD ($p < 0.05$).

Level II	1	2	3	4	5	6
1	0.000					
2	1.875	0.000				
3	3.688	1.812	0.000			
4	5.056	3.181*	1.368	0.000		
5	2.000	0.125	-1.688	-3.056	0.000	
6	11.200*	9.325*	7.513*	6.144*	9.200*	0.000

Table 5. Component loadings for Rosgen variables in the PCA.

	PC 1	PC 2
Slope	-0.838	0.209
Sinuosity	0.841	0.182
Width-depth ratio	0.149	-0.752
Entrenchment	0.184	0.731

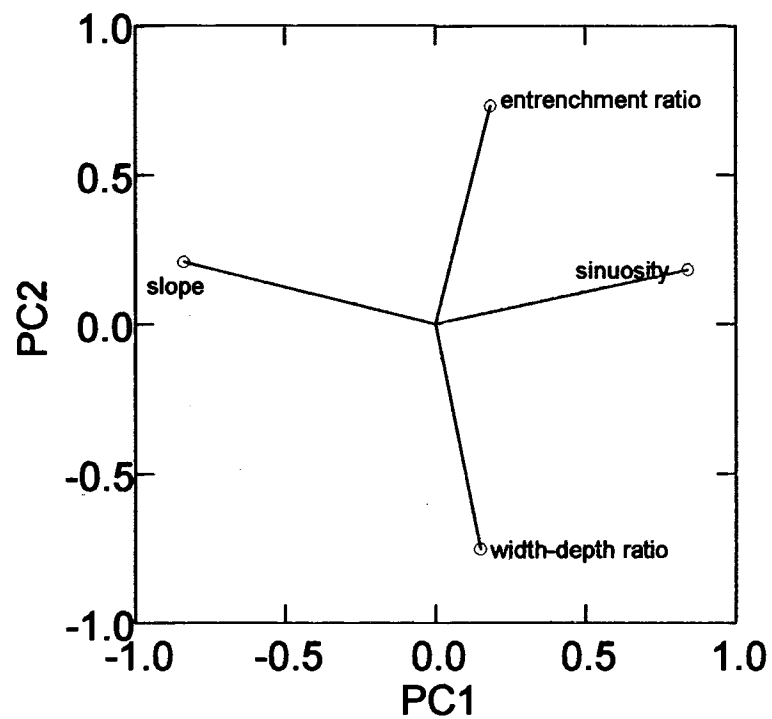


Figure 6. Factor loadings determined by principle components analysis for each of the level I Rosgen variables.

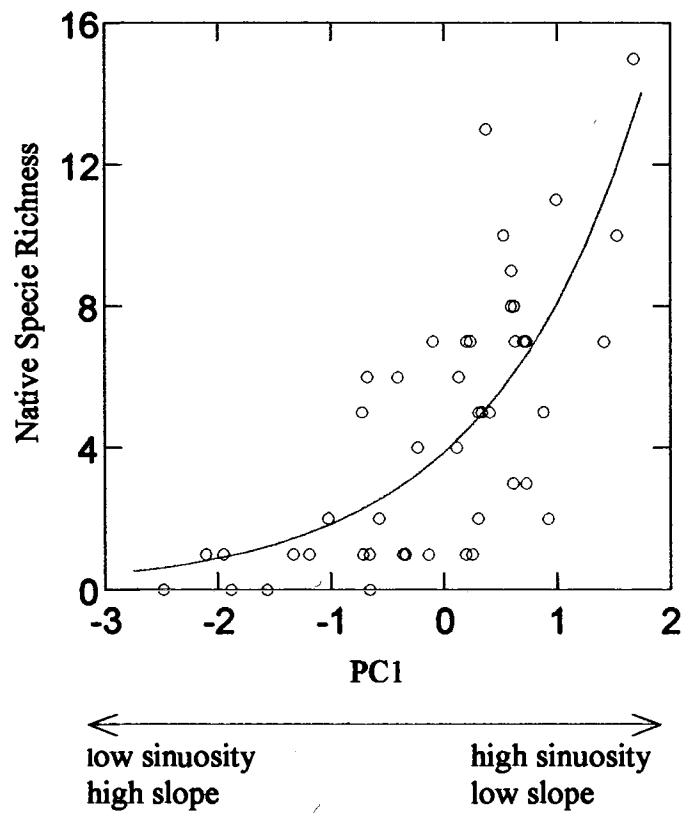


Figure 8. Poisson loglinear model $\log(\mu) = 1.351 + 0.737x$. Study streams with high sinuosity and low slope have higher species richness than those with low sinuosity and high slope.

dependent on PC 1 ($p < 0.001$). Using Poisson loglinear regression, no relationship was found between PC 2 and native species richness ($p < 0.05$). Thus, native species richness is inversely correlated with slope and positively correlated with sinuosity, whereas richness does not seem to be correlated with width-depth ratio and entrenchment.

Estimates of salmonid abundance were available for 27 of the 46 classified stream reaches that support salmonids. However, not all stream types were represented. Abundance estimates were available only on BA-, B-, BC-, and C-type streams. Atlantic salmon were found in only seven of the study streams. Brook trout occurred in all but seven of the study reaches and were present in each of the different stream types except AA+. No study streams that had bedrock as the dominant substrate material supported salmonids; all other level II stream types did support salmonids.

For the nested ANOVA, abundance estimates of FISH100, FISHMILE, and KGHA were log transformed to meet normality requirements. Each of the abundance measures had similar trends, so only the results for FISH100 are shown. There were no significant differences in salmonid abundance among the level I stream types for which abundance data were available (Figure 9), nor were there significant differences in salmonid abundance among the level II stream types (Figure 10). And, there was no interactive effect of I and level II stream type on salmonid abundance (Figure 11).

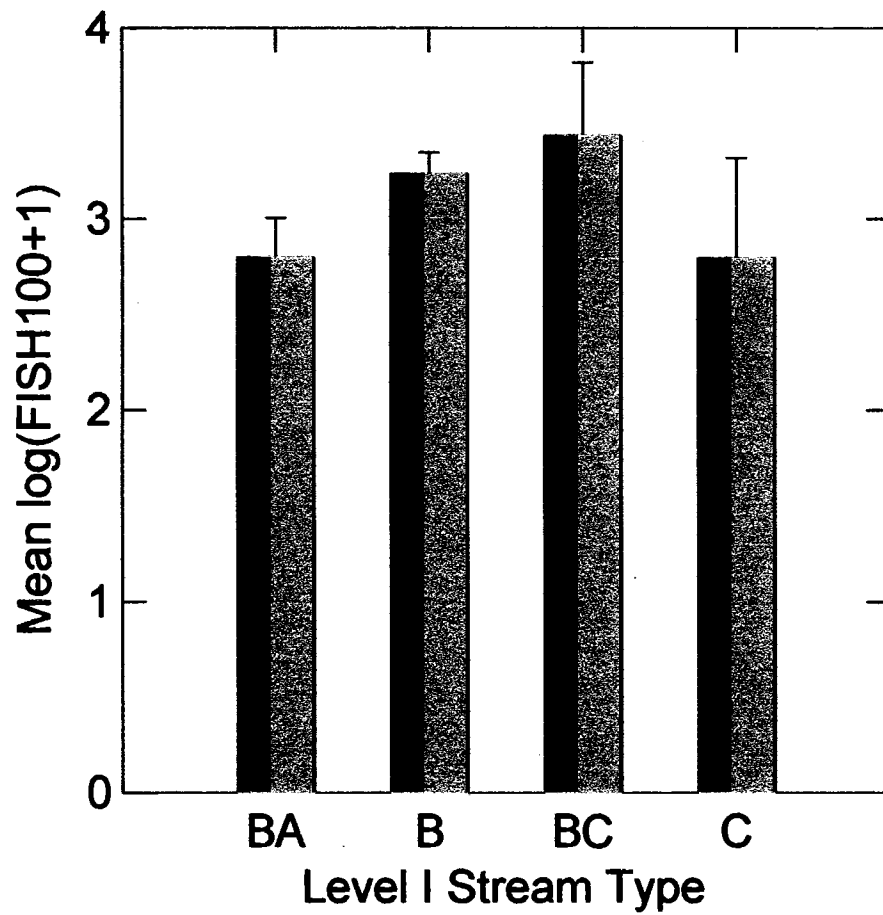


Figure 9. Mean salmonid abundance, measured as $\log(\text{fish per } 100\text{m}^2+1)$, by level I stream type (error bars represent standard error of the mean).

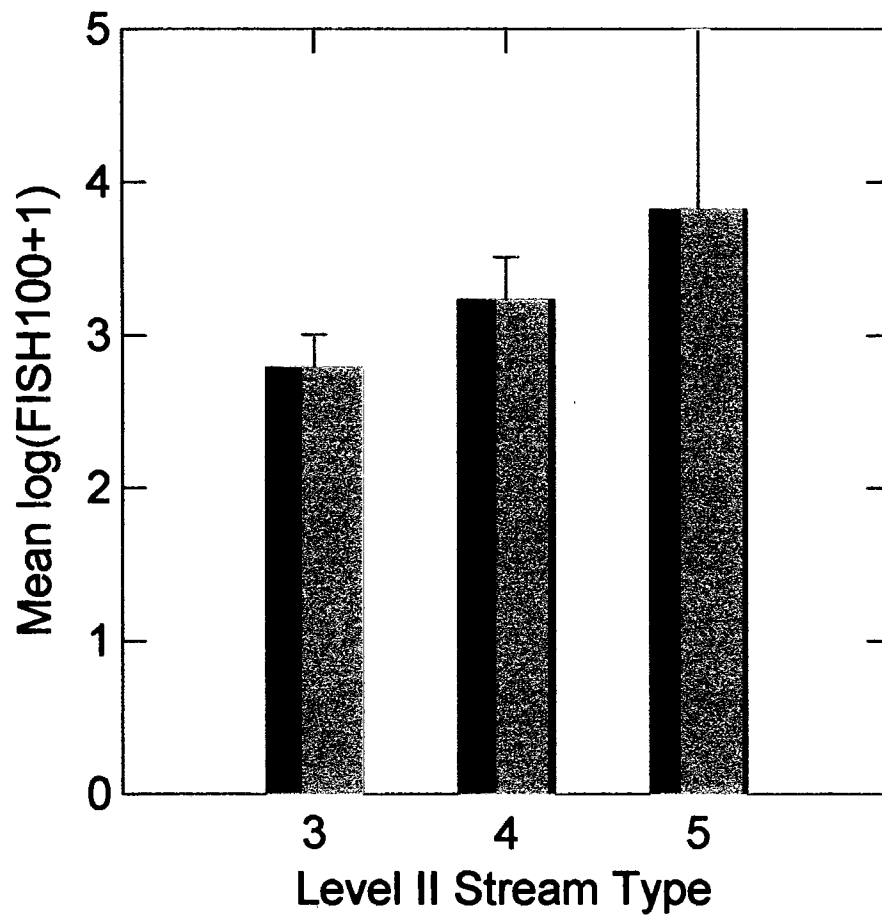
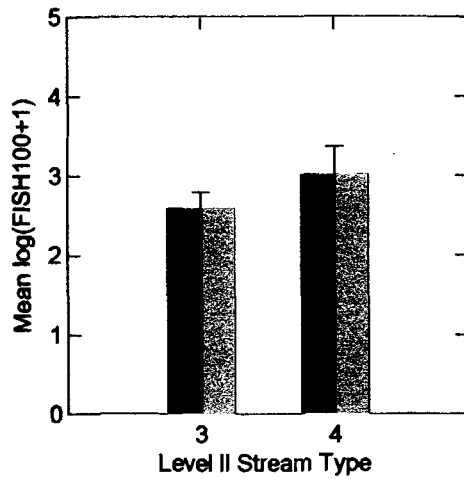
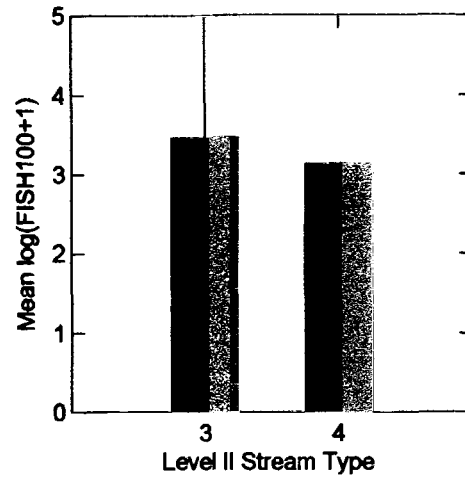


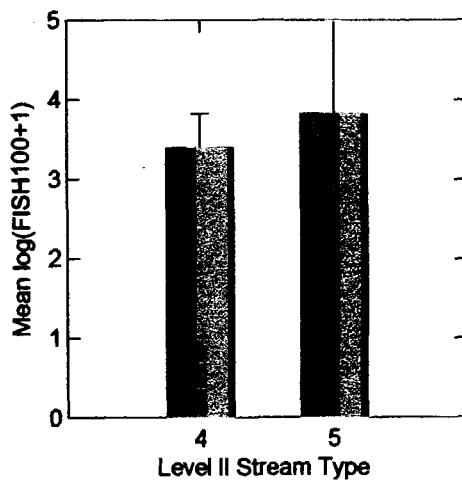
Figure 10. Salmonid abundance, measured as $\log(\text{fish per } 100\text{m}^2 + 1)$, by level II stream type. Numbers indicate dominant channel material: 3 = cobble, 4 = gravel, 5 = sand (error bars represent standard error of the mean).



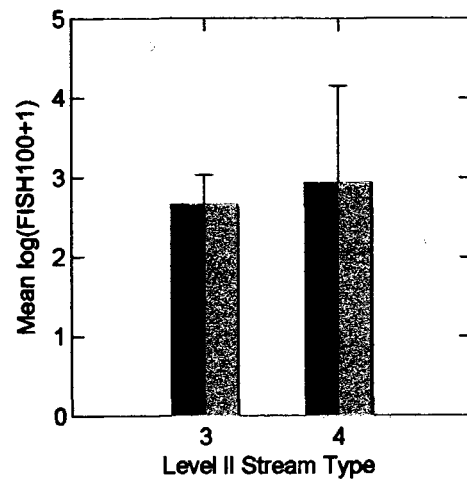
BA



B



BC



C

Figure 11. Mean salmonid abundance, measured as $\log(\text{fish per } 100\text{m}^2 + 1)$, by level I and level II stream type. Level I stream type is indicated beneath each graph. Numbers on the x-axis indicate dominant channel material (level II stream type): 3 = cobble, 4 = gravel, 5 = sand (error bars represent standard error of the mean).

Discussion

Geomorphological variables measured as part of the Rosgen stream classification system have the potential to predict fish species richness in Maine's streams. Principal components analysis showed that the study streams are better distinguished by slope and sinuosity than width-depth ratio and entrenchment (Figure 7). Native species richness was correlated with slope and sinuosity. The level I stream types with high slope and low sinuosity (i.e., AA+, A, BA, B) showed lower species richness, whereas stream types with low slope and high sinuosity (i.e., BC, C, and F) were highest in species richness. All AA+ streams (those with a slope greater than 10%) were fishless. A Poisson loglinear model indicated that slope is negatively correlated and sinuosity is positively correlated to species richness (Figure 8).

Other studies examining the relationship between stream slope and species richness have yielded similar results (Beecher et al. 1988). A likely cause for the inverse relationship between channel slope and native species richness is that stream gradient can cause barriers to fish movement. Waterfalls, which are an important component of steep gradient streams, prevent fish movement upstream and thus can limit species richness. Also, streams examined in this study with steeper slopes (i.e., AA+, A, and BA streams) tended to be located at higher elevations than other stream types, where water temperatures are lower, which can also affect fish community structure and diversity (Rahel & Hubert 1991). Conversely, several of the species-rich C-type streams in this study were found at lower elevations and closer to the coast, where there are typically warmer water temperatures and fish are less likely to encounter barriers due to gradient.

It is not surprising that sinuosity and slope show opposing relationships with species diversity, because the two variables are inversely correlated. Low-gradient, sinuous streams (i.e., C- and F-type) provide more habitat types than steep-gradient, confined streams (i.e., AA+-, A-, and BA-type). Streams with higher sinuosity demonstrate riffle-pool bed morphology (Rosgen 1996, Fukushima 2001), thus creating habitat that can support species with different requirements. Also, low-gradient, sinuous streams have well-defined floodplains that provide refugia during flooded conditions. Thus, the positive correlation between sinuosity and species richness is best explained by increased habitat diversity in sinuous streams.

The lack of a predictable relationship between species richness and entrenchment and width-depth ratio may be related to small range in these parameters among the study streams. It is also possible that observer error played a role. As previously mentioned, bankfull stage is a key parameter for determining both width-depth ratio and entrenchment. It is also a difficult parameter to measure because it is subject to the observer's identification of bankfull indicators. Because the study stream classifications were conducted by several different observers, it is possible that there were discrepancies in the definition of bankfull stage.

Streams with silt-clay as the dominant bed material (type 6) had significantly higher richness than the other types. All of the silt-clay streams were either BC- or C-type streams. When combining the level I and level II classifications, C6 streams may be expected to have the highest richness of all stream types.

Relationships between stream geomorphology and salmonid abundance were less clear than relationships between geomorphology and species richness. There

were no significant differences in abundance among the level I stream types that supported salmonids. The only stream type which did not support salmonids was AA+. Again, AA+-type streams are those with the highest gradient. Other studies have shown that trout biomass is negatively correlated with channel gradient (Kozel and Hubert 1989). Differences in habitat features and structural elements in streams of differing gradients can lead to such differences in biomass.

No relationship was found between the level II stream type and salmonid abundance. This is surprising considering that Atlantic salmon and brook trout have specific substrate requirements for breeding. Also, there was no interactive effect of level I and level II stream types on salmonid abundance.

Perhaps few patterns in salmonid abundance and stream type emerged due to limited data. Salmonid abundance estimates were available for only 27 of the 46 classified stream reaches that supported brook trout. If more abundance data were added to the database of Rosgen streams, relationships between salmonid abundance and geomorphic stream type might be more apparent. Also, the analysis may have been more meaningful if abundance had been divided into age class categories, because different age classes may not be distributed evenly among different stream types. My analysis would not show such differences because I analyzed total abundance. Another possibility is that measures of population health other than abundance may have been correlated to stream geomorphology. For example, Fukushima (2001) showed a positive correlation between Sakahlin taimen (*Hucho perry*) redd placement and stream reach sinuosity. The underlying mechanism behind

this relationship is the formation of pool-riffle sequences that create the hydraulic and substrate conditions suitable for salmonid egg deposition.

In conclusion, the Rosgen classification system may provide a means to predict fish community attributes (e.g. species richness, salmonid abundance) in Maine. The results from this study contribute to our understanding of the natural associations between fish assemblages and physical stream features, which can help us evaluate the effects of human alterations of streams on fish communities. Conservation and management of fish assemblages over broad scales requires an understanding of the major environmental variables that explain patterns of fish assemblage composition and distribution (Lyons 1996).

Chapter 2

THE USE OF A GEOGRAPHIC INFORMATION SYSTEM (GIS) TO ASSESS ENVIRONMENTAL CORRELATES TO FISH COMMUNITY STRUCTURE AND DIVERSITY IN MAINE

Introduction

Traditionally, stream ecologists conducted site-based studies that emphasized the importance of local stream features in determining aquatic community structure. Such studies are conducted at small spatial scales of microhabitats ($\approx 1\text{m}$), pool-riffle sequences ($\approx 10\text{m}$), and/or stream reaches ($\approx 100\text{m}$; Frissell et al. 1986). These studies focus on the importance of local physical (e.g., habitat structure) and biotic interactions (e.g., competition, predation) on structuring aquatic communities (Angermeier & Winston 1998). Increasingly, however, researchers are becoming more aware of the importance of regional factors, such as landscape features and land use, in shaping aquatic communities (Isaak & Hubert 1997). As a result, a new body of ecological research has emerged that is based on a landscape perspective. Many researchers are now asking broad-scale questions focusing on entire drainages, watersheds, or river basins as opposed to smaller stream habitat units. This type of research lends itself easily to GIS-based analyses.

GIS is an effective tool for analyzing spatial relationships at broad geographic scale. GIS enables researchers to: 1) store, retrieve, update, and display map data, 2) analyze spatial relationships, 3) communicate analytical results through thematic maps, and 4) address management issues across scales (i.e., local to landscape).

Recently there has been a trend in fisheries science to use GIS to analyze large-scale ecological processes and to facilitate watershed-scale management (Isaak & Hubert 1997). Angermeier and Bailey (1992), for example, developed a GIS for Clinch River Basin, Virginia, to approach the conservation of riverine biodiversity at the basin-scale. Hawkes et al. (2000) used a similar approach to facilitate making management decisions regarding river basin health for the Meramec River Basin, Missouri. GIS has also been used to predict effects of global warming on coldwater fishes (Keleher & Rahel 1996, Rahel et al. 1996) and to determine environmental correlates to fish distribution (Nelson et al. 1992) and assemblage structure (Waite & Carpenter 2000, Maret et al. 1997).

In this study, GIS is used to analyze spatial patterns in stream fish species composition and native species richness with respect to selected environmental variables for streams in Maine. The main objective of the study was to identify environmental correlates with stream fish species richness and species distribution, emphasizing salmonid streams located throughout the state. The variables that were examined included landcover, biophysical region, proximity to dams, and elevation.

Methods

Fish Data Collection

Much of the fish community data used in this study were collected by the Maine Department of Inland Fisheries and Wildlife (IFW) as part of its long term salmonid stream monitoring project. Biologists with IFW collected brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) population data, including

abundance estimates, biomass, and size-class ratios for approximately 60 streams throughout the state. Using backpack electrofishing units, fish were collected and salmonid abundance was estimated using Zippin's three-run removal method (Armour et al. 1983). Electrofishing was conducted in an upstream direction with blocking nets positioned at both ends of the sample reach. Fishing effort (wand time) was approximately equal for each run. Captured fish were held in a cage outside the section during successive runs. The area of the section electrofished ranged from 418-669 square meters (4500-7200 square feet). Counts of salmonids were recorded for all three runs, and fish lengths and weights were also recorded. Population estimates for brook trout and Atlantic salmon were calculated using the Zippin method (Armour et al. 1983). Fish species occurrence was also documented, providing a list of species present and an estimate of species richness.

Additional field work was conducted during the summer of 2001 to increase the scope of the study to include a broader geographic range of study sites (Figure 12). During the 2001 sampling period, species composition and diversity were assessed using a methodology similar to that of IFW. However, population size was not estimated, so only one pass was made at each site. For sample reaches that were too deep to electrofish, a seine was used to collect fish. Specimens of unknown species were kept for later identification. Digital photographs were taken of each sample reach to include in the database. And, the location of the middle of each sample reach was recorded using a handheld Magellan GPS unit.

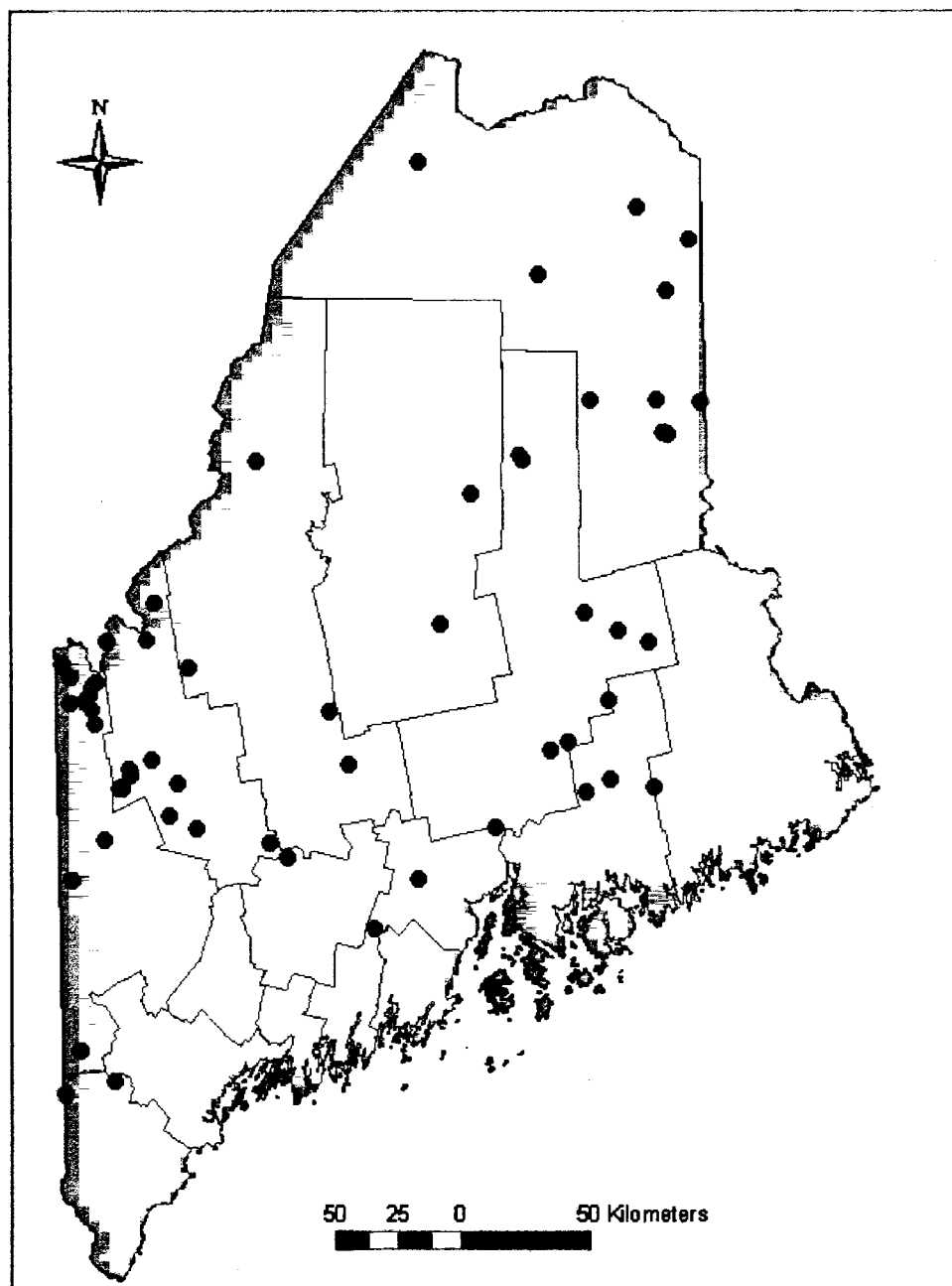


Figure 12. Location of all study stream reaches in Maine.

Creating the GIS Database

Spatial data were compiled from various sources. Several data layers were obtained from the Maine GAP project (Krohn et al. 1998), including the landcover grid and the biophysical region polygon coverage. The watersheds polygon coverage and the digital elevation model (DEM) were obtained from the Maine Office of GIS. A point coverage of licensed dam locations in the state was obtained from the Maine Department of Environmental Protection. All fish data were plotted in an ArcGIS point coverage from a dbase file, using the *Table to Point Coverage* tool in ArcToolbox. All layers were set to the UTM NAD 27, zone 19 coordinate system.

The next step in creating the database was to determine the percentage of each landcover type by watershed. In ArcToolbox, the watershed polygon coverage was converted to a grid. The grid was then converted to an image file that was opened in Erdas Imagine. The landcover map was opened into the same viewer and the *Image Interpreter/GIS analysis* tool was used to open a summary matrix. This summary matrix, showing the number of pixels in each landcover class, was exported to a dbase file and then opened in Excel. To simplify the analyses, the number of landcover classes was reduced from 38 in the original map to six general classes (agriculture, forest, clearcut, developed, water, and other). The percentage of each landcover type in each watershed was then calculated and imported to an ArcGIS INFO table. The INFO table was joined back to the original watersheds polygon coverage to combine the new attribute information with the polygons. This coverage was then joined to the fish points and biophysical regions coverages to combine attribute information into the fish point coverage.

The next step in data preparation was to determine which sample sites were within close proximity to licensed dams. This was done using the ArcToolbox *proximity/near* command with the fish points coverage as the *input* file and the dams point coverage as the *near* file. After testing several buffer distances (100m to 5000m), the buffer radius was set at 3000m. The output of this was saved as a separate point coverage called "fish_dams." The original dams point coverage was then joined to "fish_dams" in order combine attribute information. This coverage was then joined to the fish point coverage. The resulting coverage contained only six fish sample sites, meaning that only six sites were within 3000 meters of a dam. It was important to determine whether these sites were up or downstream from the dams. So, a flow direction grid was created in ArcGRID using the DEM and the *flowdirection* command. By visually interpreting the flow direction grid, it was observed that none of the fish sample sites were located within 3000 meters upstream of dams. No further analyses were conducted using the dams coverage, because the intent was to determine whether dams limit the number of species occurring upstream.

The final step in data preparation was to determine the elevation of all of the fish sample sites. Elevation data had already been collected for most sites by entering UTM coordinates into Terrain Navigator 2001, a digital topographic mapping program from Maptech, Inc. (10 Industrial Way, Amesbury, MA 01913; Telephone: 978-792-1000). However, a few sites were missing elevation data. The elevation of these sites was determined by overlaying the fish point coverage and the DEM and then using the *identify* tool on the DEM to determine the elevation of the sample locations.

Data Analysis

The attribute table from the fish points coverage, containing all of the attributes of the stacked data layers (landcover, watersheds, biophysical regions, dams), was exported as a dbase file. The data were analyzed with Systat. Analysis of variance (ANOVA) was used to compare native species richness in different biophysical regions. Following significant ANOVA results ($\alpha = 0.05$), significant differences between pairs of means were detected using the Fisher's protected Least Significant Difference (LSD) test. Linear regression was used to examine the relationship of landcover type with species richness, and Poisson loglinear regression was used to examine the effects of elevation on species richness. Logistic regression was used to examine relationships between the various environmental variables and species presence/absence for selected species. Specifically, I looked at the distribution of brook trout, slimy sculpin (*Cottus cognatus*), and Atlantic salmon. These species were chosen for analysis because of the study's emphasis on salmonid streams. For regression analyses, significance tests of the hypothesis $H_0: \beta=0$ were conducted using the log likelihood-ratio test statistic ($\chi^2 = -2\ln[\text{likelihood ratio}]$) to test the improvement of the fitted model ($\alpha+\beta x$) over the simplest model containing only one constant (α).

Results

Landcover

There was no significant relationship between species richness and percent landcover type. Atlantic salmon was the only species whose distribution was significantly correlated with the percent landcover type (Figure 13). The presence of

Atlantic salmon, either landlocked or anadromous, was positively correlated with the percentage of developed lands (logit (Π) = $-1.685 + 0.586x$; $p < 0.01$) and percentage of agriculture lands (logit (Π) = $-1.417 + 0.045x$; $p < 0.05$), and negatively correlated with percentage of forested lands (logit (Π) = $1.705 - 0.037x$; $p < 0.05$).

Biophysical Regions

Species richness varied among different sample sites in each biophysical region (Figure 14). There were significant differences in richness among the biophysical regions (ANOVA, $p < 0.05$; Figure 15). Based on the Fischer's protected LSD, mean richness in region 3 was significantly lower than each of the other four regions (Table 6). Mean richness in regions 1, 2, 4, and 5 were not significantly different from one another.

Elevation

Species richness tended to be lower in the western mountainous region of the state and higher in the lowland coastal areas (Figure 16). Species richness was negatively correlated with elevation; the maximized likelihood fit of the Poisson loglinear model with elevation as the explanatory variable for native species richness is: $\log \mu = \alpha + \beta x = 2.165 + -0.002x$. The effect $\beta = -0.002$ of elevation has an asymptotic standard error of 0.000. Since $\beta < 0$, elevation had a negative estimated effect on species richness (Figure 17). A one meter increase in elevation yielded an estimated 0.2% decrease in species richness [$\exp(\beta) = \exp(-0.002) = 0.998$]. So, to compare the expected stream fish species richness near the coast of Maine with the western

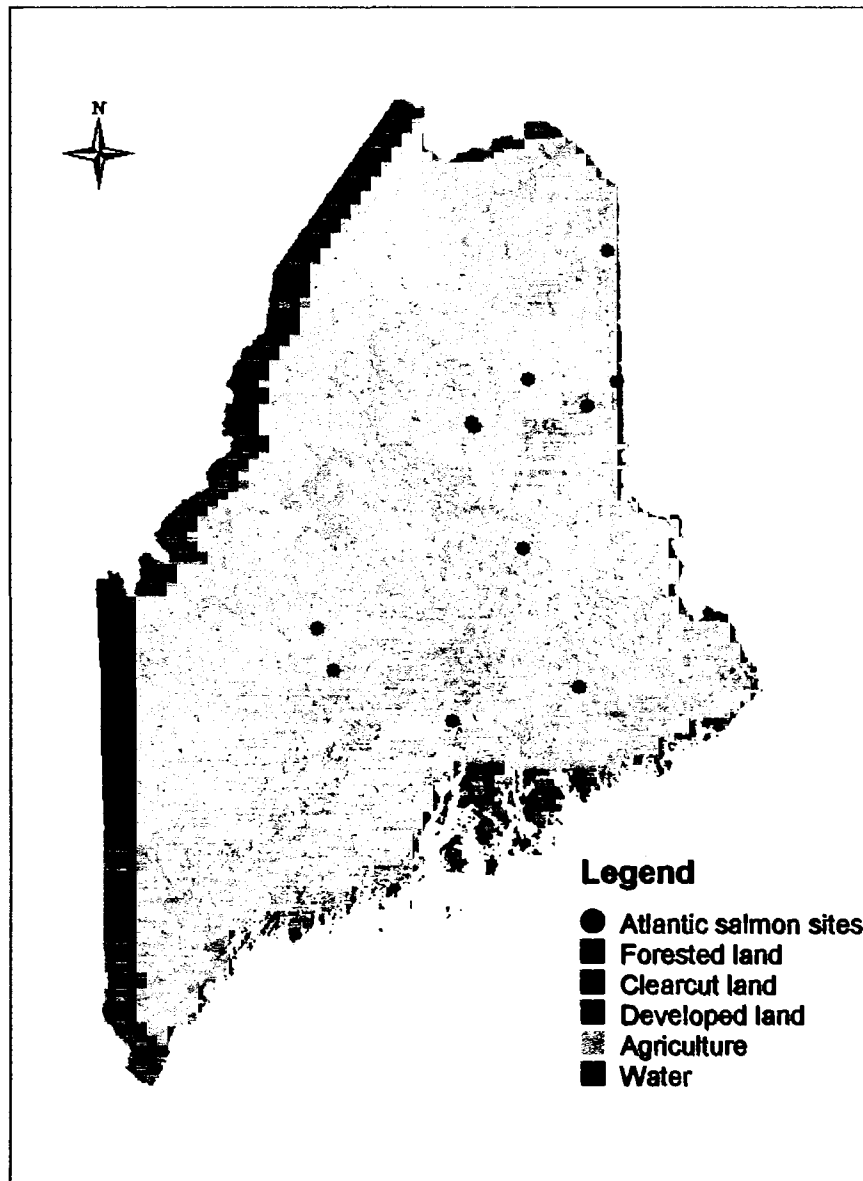


Figure 13. Landlocked and sea-run Atlantic salmon distribution and land cover type in Maine.

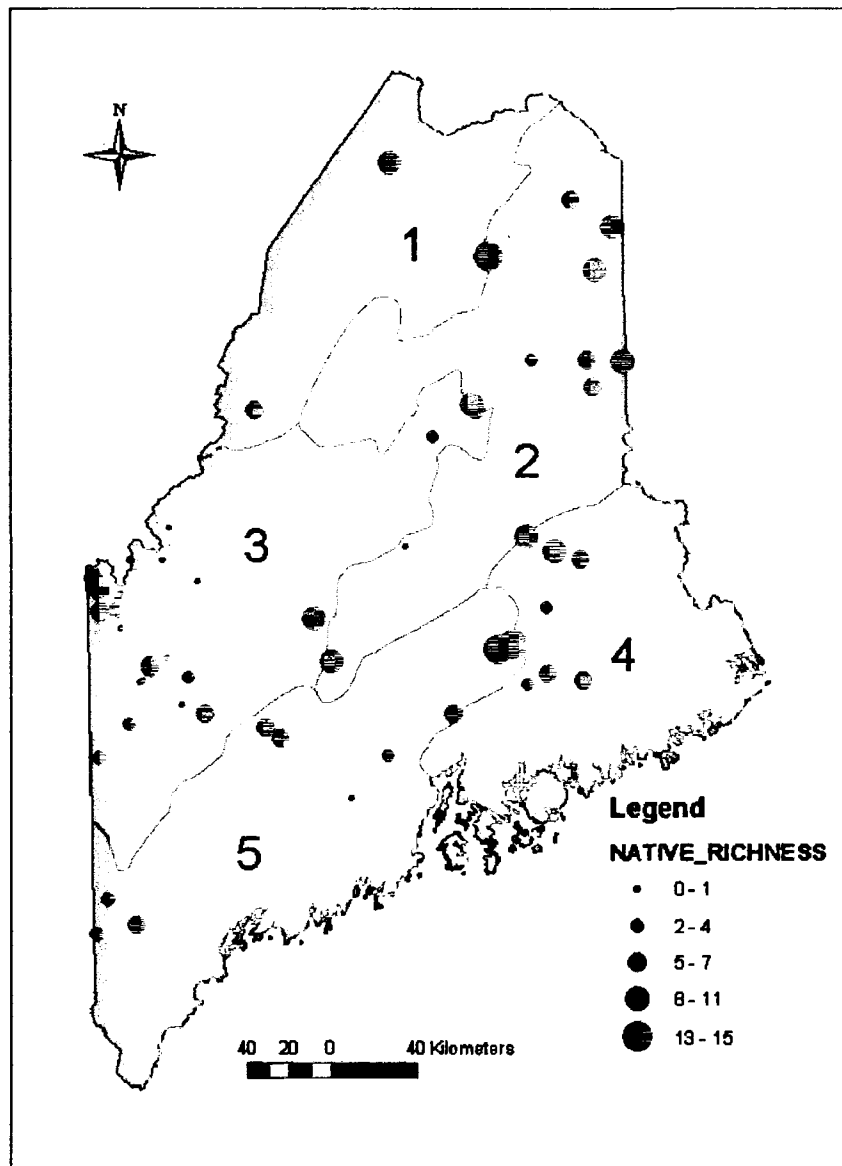


Figure 14. Native species richness at each sample site in the five biophysical regions of Maine (1 = St. John Uplands; 2 = St. John Valley and Interior Foothills; 3 = Western and Interior Mountains; 4 = Eastern Lowlands and Foothills; 5 = Coastal Plains and Foothills).

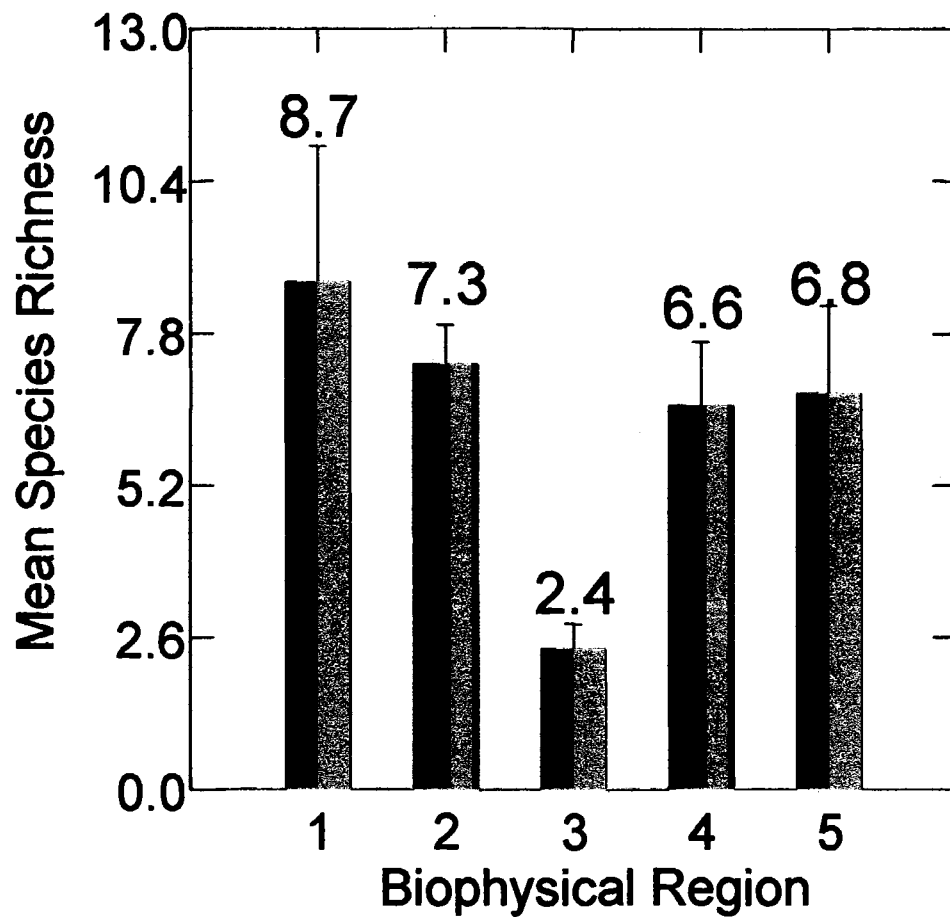


Figure 15. Mean native fish species richness by biophysical region (mean richness is indicated above each bar; error bars indicate standard error of the mean).

Table 6. Matrix of pairwise mean differences of native species richness by biophysical region; * indicates significant difference detected by Fischer's protected LSD ($p < 0.05$).

Biophysical Region	1	2	3	4	5
1	0.000				
2	-1.394	0.000			
3	-5.274*	-4.880*	0.000		
4	-2.095	-0.701	4.179*	0.000	
5	-1.889	-0.495	4.385*	0.206	0.000

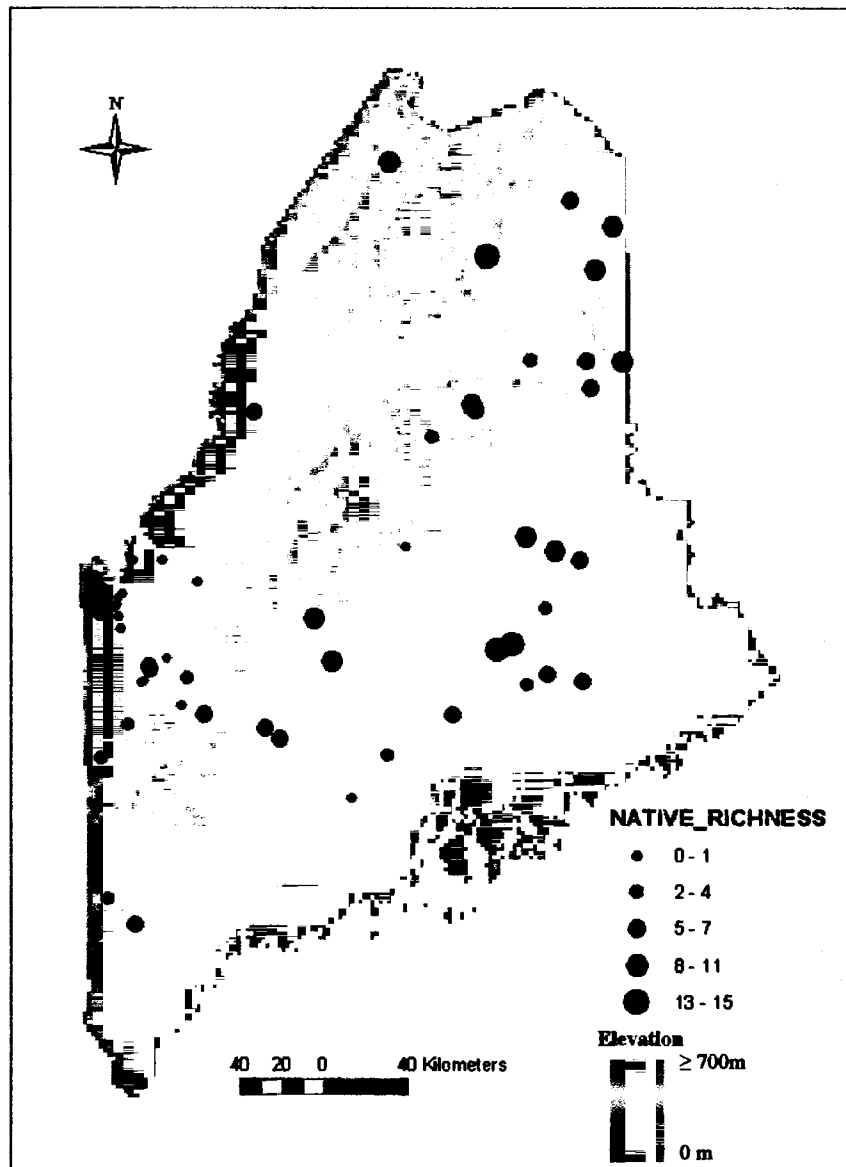


Figure 16. Native fish species richness by elevation.

mountains, one might compare the fitted value for species richness at 0m: $\mu = \exp(2.165) = 8.715$ to the fitted value for 700m in elevation: $\mu = \exp[2.165 - 0.002(700)] = 2.149$. The likelihood ratio statistic comparing the complex model with elevation as an explanatory variable ($\log \mu = \alpha + \beta x$) to the simpler model containing only one constant ($\log \mu = \alpha$) is: $-2(L_0 - L_1) = -2(134.299 - 173.989) = 79.380$. This tests the null hypothesis that $\beta = 0$. With $df = 1$, the G^2 statistic means that β does not equal zero, and therefore species richness was dependent on elevation ($p < 0.001$).

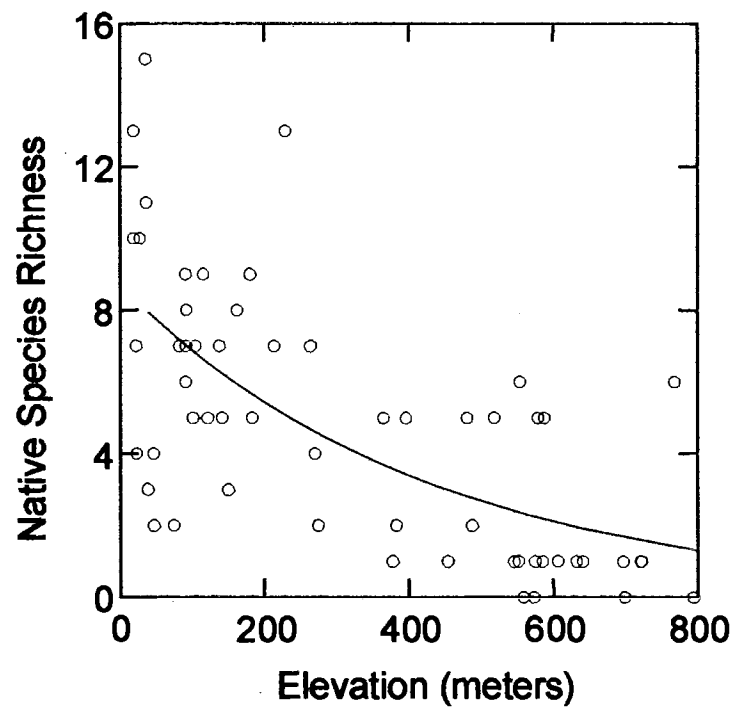


Figure 17. The model $\log \mu = \alpha + \beta x = 2.165 + 0.002x$. Native fish species richness decreased by an estimated 2% with a one meter increase in elevation.

Discussion

GIS was a useful tool for determining landscape patterns in fish species richness and distribution. Several environmental variables were represented as data layers in a GIS. Three patterns emerged from this analysis. First, species richness was negatively correlated with elevation. Other studies have demonstrated similar relationships between fish species richness and elevation (Beecher et al. 1988, Rahel & Hubert 1991). Second, species richness was correlated with biophysical region. It is not surprising, however, that both elevation and biophysical region show similar relationships with species richness, since elevation was part of the delineation criteria for the biophysical regions (Krohn et al. 1999). Third, the distribution of Atlantic salmon was positively correlated with variables that are normally considered to be detrimental to ecosystem health (i.e., agriculture and development), and was negatively correlated with the percentage of forest, a variable that is usually thought to indicate good stream conditions.

Atlantic salmon is an anadromous species, therefore they are more likely to be found in streams and rivers that are closer to the coast. Also, due to dam construction on many rivers and streams throughout the state, upstream migrations of anadromous fishes are limited, thus restricting their range to coastal areas. The coastal areas of Maine, where many sample sites with Atlantic salmon are located, were the first areas of the state to be settled by humans and therefore have a long history of agriculture and development (Figure 13). There are also native populations of landlocked Atlantic salmon in the state, however the landlocked salmon sites in this study contained populations introduced outside of their native range. There are only four

river basins in the state that support native populations of landlocked salmon, including the Union, the Penobscot, the Presumpscot, and the St. Croix (Figure 18). Starting in the late 1800's landlocked salmon were introduced into other watersheds in order to support a sport fishery (Warner & Havey 1985). Therefore, it is not surprising that there is a positive correlation between salmon distribution and variables normally considered to be detrimental to ecosystem health – both sea-run and introduced landlocked salmon tend to be found in disturbed watersheds. Maine represents the southern fringe of Atlantic salmon's declining range. Historically, this species was much more widespread throughout Maine and southern New England (Figure 19). There is a need to protect the remaining rivers and watersheds that support wild Atlantic salmon populations, a species that is now listed under the Endangered Species Act in eight rivers of Downeast and central coastal Maine.

The lack of a significant relationship between total fish species richness and landcover could be due to the simplification of landcover types from the original 38 to 5 (i.e., forest, wetland, agriculture, developed, other). Perhaps the categories analyzed were too general and were not ecologically meaningful to fish communities. For example, it may have been more informative to examine the differences in species richness in streams dominated by coniferous versus deciduous forest. Another possibility is that perhaps the scale of landcover by watershed was too coarse to identify specific correlations. Rather, following the methods of Richards et al. (1996), an analysis of landcover types within stream buffers may have been more meaningful. This alternative analysis would emphasize landcover types within the riparian corridor upstream and downstream of sampling sites rather than landcover in the

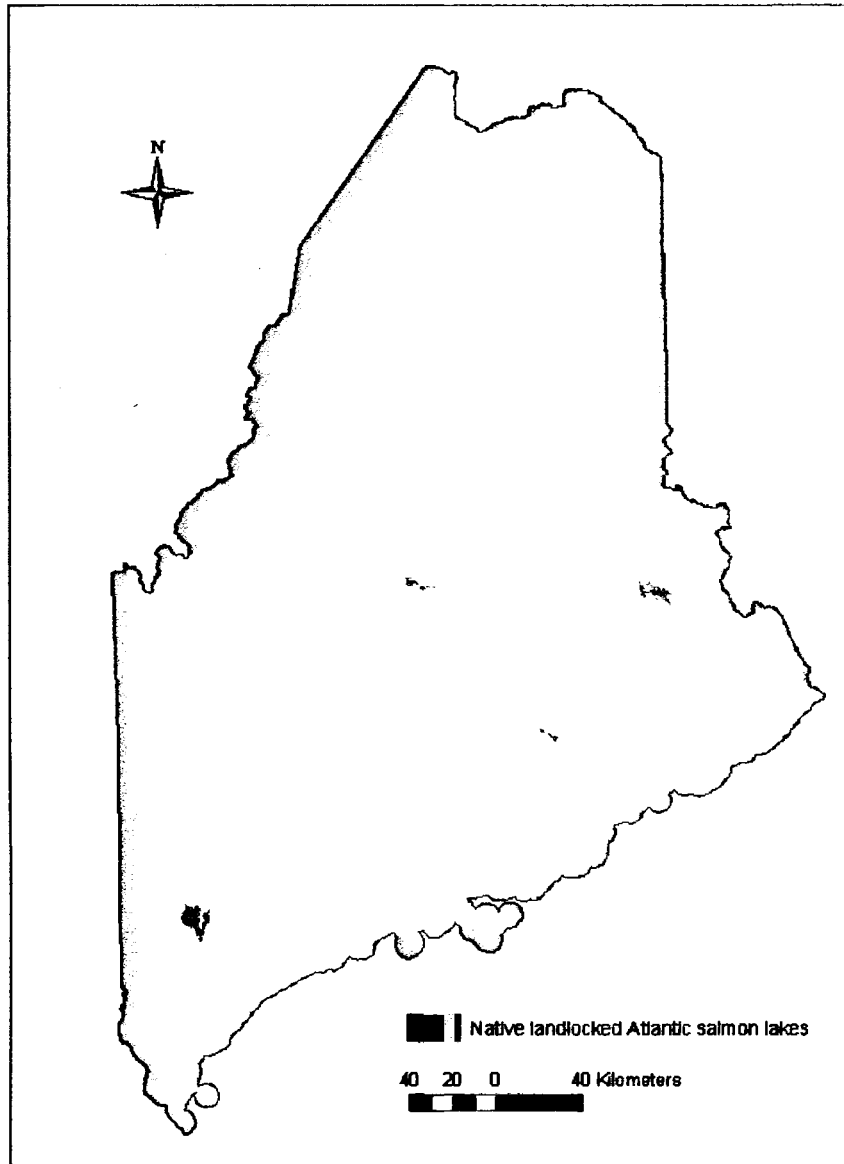


Figure 18. Lakes containing native populations of landlocked Atlantic salmon in Maine.

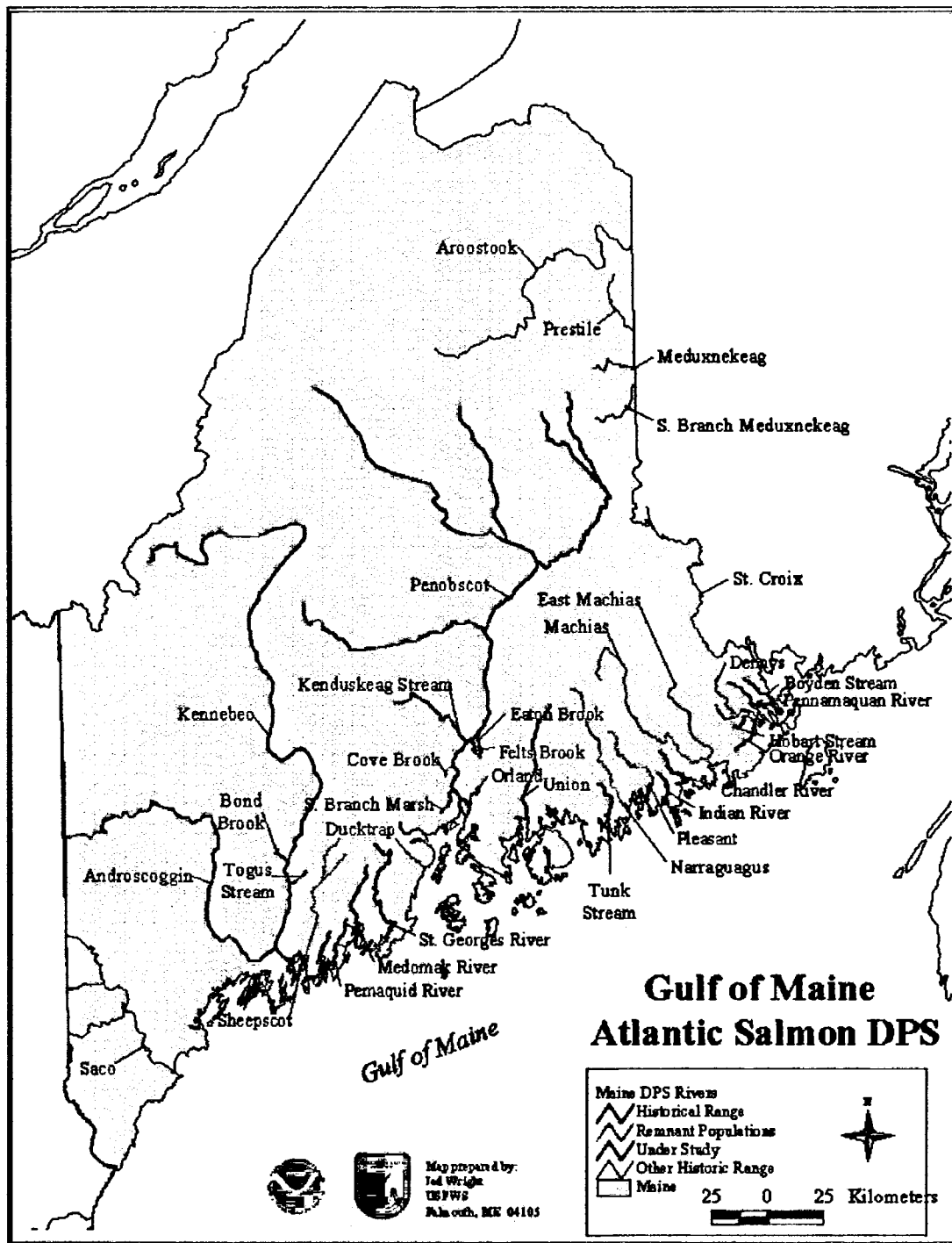


Figure 19. Map of the current and historic distribution of wild sea-run Atlantic salmon populations in Maine (copied with permission from Jed Wright, U.S. Fish and Wildlife Service).

entire watershed. Other studies have demonstrated significant relationships between landscape land use (a surrogate measure of landcover) and fish community structure. Roth et al. (1996) used GIS to examine the effects of land use on stream biotic integrity, as determined by the Index of Biotic Integrity (IBI), at several spatial scales. The IBI is a biological assessment tool based on species richness and composition of stream fish assemblages (Karr et al. 1986, Karr 1991). They determined that land uses measured at larger spatial scales (i.e., catchment upstream of a site and riparian corridor upstream of a site) were the most effective predictors of IBI scores. They concluded that catchment land use and riparian vegetation play a strong role in structuring stream habitat features, which ultimately influence fish community structure. In a similar study, Allan et al. (1997) also found that land use was a strong predictor of biological and habitat integrity and that catchment-wide land use was a better predictor than local land use. Both studies suggest that effective management practices should take into account broad-scale effects of land use on fish communities rather than focusing solely on local effects.

Future work should examine relationships between fish species richness and other abiotic variables that were taken into account in delineating the biophysical regions, such as precipitation, slope, and heat accumulation. Each of these variables also may influence species richness. For example, elevation and slope probably work together to create barriers that prevent fish passage, thus limiting fish species richness at higher elevations. Other studies have shown that species richness is higher in low gradient, low elevation streams (Beecher et al. 1988). It would be illuminating for future analyses to use digital elevation models to investigate the effect of valley slope,

channel gradient, and number of upstream reaches on salmonid biomass. Differences in habitat features and structural elements in streams of differing gradients can lead to differences in trout biomass. Studies have shown that trout biomass is negatively correlated with channel gradient (Kozel and Hubert 1989). In addition, water temperature, which is related to heat accumulation, changes along elevational gradients, and has also been shown to affect fish community structure and diversity (Rahel & Hubert 1991). My results demonstrate that, at higher elevations, brook trout and slimy sculpin (both of which are coldwater adapted fish) tend to be the only species present. It is likely that fish species adapted to warmer water temperatures can not survive in the cool streams in western Maine.

The global pattern in fish species richness in rivers is strongly correlated with drainage basin area (Oberdorff et al. 1995). Osborne and Wiley (1992) demonstrated a similar relationship between drainage area and species richness on a smaller scale in the state of Illinois. They also showed that the spatial position of tributaries within the larger stream network had a large influence on fish species richness. Neither of these studies used GIS; however, it would be an appropriate tool for these types of analyses. In the future, GIS could be used to examine relationships between fish species richness in Maine and drainage basin area and tributary spatial position.

In conclusion, due to recent trends in stream ecology, many researchers now rely on the capabilities of GIS to analyze the importance of large-scale processes in determining the biological and physical conditions of streams. GIS technologies are opening the door to spatially extensive analyses and are giving ecologists a new perspective for understanding aquatic ecosystems. The ability to use environmental

variables as predictors of fish species richness across broad spatial scales has important implications for fisheries management. First, collecting data on environmental variables over broad spatial scales is more efficient than collecting fish assemblage data. Physical stream features, such as elevation, can be determined from maps or through the use of a geographic information system, whereas gathering data on individual fish communities requires intensive field work. Also, taking measurements of the physical environment is less invasive to aquatic communities than sampling fish through the use of electrofishers and gill nets. The use of environmental variables as predictors of species richness also has important implications for watershed management. The ability to identify areas of high species diversity efficiently and non-invasively can aid in prioritizing which areas to focus conservation efforts within and across watersheds.

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