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Development of a watershed and stream-reach spawning habitat model for river herring Alosa pseudoharengus and Alosa aestivalis

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Development of a Watershed and Stream-Reach Spawning Habitat Model for River Herring (*Alosa pseudoharengus* and *A. aestivalis*)

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Abstract

This research develops a model to identify indicators of potential suitable spawning habitat for river herring, *Alosa pseudoharengus* and *A. aestivalis*, using watershed and stream-reach metrics. The results of icthyoplankton samples collected from thirty-four streams feeding into the Rappahannock River below the Embree Dam at Fredericksburg indicate where river herring spawning occurred. Watershed and stream-reach metrics were either measured in the field or derived from digital data in a GIS. Benthic macroinvertebrate analysis was used to compare habitat quality among sites. Streams were classified as either absence or presence of herring eggs or larvae based on the results of the ichthyoplankton samples. Depending on the distributions of the metrics, T-tests or Mann-Whitney U tests determined which metrics were significantly different between the absence and presence groups. Variables from Principal Component Analyses were used in discriminant analyses to examine the relative importance of watershed and stream-reach metrics in predicting suitable spawning habitat. The results of the analyses show that river herring tend to spawn in larger, elongated watersheds with greater mean elevations and habitat complexity. River herring prefer watersheds with greater percentages of deciduous forest and less grassland areas and stream reaches with less organic matter and less fine sediment in the substrate, and more canopy cover and snags. The discriminant analysis using watershed metrics has a better predication ability, 88.2%, than other discriminant models using stream-reach metrics. Except for two metrics, the ratios of %*Chironomous* to %Chironomidae and %*Chironomous* to %Chironomini, most of the benthic macroinvertebrate metrics indicate that the presence group has a more degraded environment. This model could be used to target restoration efforts not only in the Rappahannock River but elsewhere in the Chesapeake Bay. Furthermore, the multi-scale model design could be used to target management efforts for other aquatic species.

Development of a Watershed and Stream-Reach Spawning Habitat Model for River Herring (*Alosa pseudoharengus* and *A. aestivalis*)

Chapter 1
Introduction

Small tributaries in the Chesapeake Bay and elsewhere along the eastern coast of North America provide spawning habitats for two closely-related anadromous fishes, alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*). These fishes are collectively called river herring. Reported landings often combine these two species and refer to both as alewives (Loesch 1987). All life stages (egg, larvae, juvenile and adult) of river herring are important food sources for many freshwater and marine fishes, amphibians, reptiles, birds and mammals and thus play an important ecological role. Additionally, post-spawning mortality of migratory *Alosa* fishes is an important episodic source of energy and nutrients to freshwater systems (Dubin *et al.* 1979, Garman 1992).

In the early 1970s commercial landings of river herring declined sharply (Richkus and DiNardo 1984) and currently are extremely low (NOAA 1994, Hightower *et al.* 1996). Numerous factors could have contributed to the decline. The populations were subject to heavy exploitation in the 1960s and early 1970s by both inshore national fisheries and offshore foreign fisheries (ASMFC 1985, 1990) and historic impediments to migration have reduced available spawning areas (Loesch and Atran 1994). Remaining spawning habitats may have been degraded (Klauda *et al.* 1991) by changes in hydrology regime (Meador *et al.* 1984, Cooke and Eversole 1994), increased chlorine levels (Loesch 1981) and lowered pH (Byrne 1988), or a combination of these and other factors.

Figure 1.1 shows the commercial river herring landings for the Atlantic Coast and Virginia from 1950 to 2000 and clearly illustrates the sharp decline in landings starting in the early 1970s. Landings in the 1990s were very low. Commercial fish catch landings are sometimes used to assess fish populations, although historical data such as shown in Figure 1.1 may lack precision, accuracy and temporal continuity (Richkus *et al.* 1992). Fishery-dependent data are often used to assess fish populations, particularly when fishery-independent data are limited or unavailable.

Juvenile indices are used by fishery scientists and managers to help estimate adult population size for fish that are particularly sensitive to changes in the young-of-year. A historical record of juvenile indices can then be used to estimate the age composition of adult fish. If a good relationship can be established between the juvenile indices and population estimates, then the indices can be used to predict future year-class strength and used in the development of management strategies. Work at the Virginia Institute of Marine Sciences was undertaken to determine if the historical records of juvenile indices of river herring are applicable to fisheries management. Figure 1.2 shows the indices of alewife and blueback herring derived from the Virginia Institute of Marine Science beach seine survey.

The graph of the commercial landings (Figure 1.1) and the graph of the juvenile indices (Figures 1.2.) both indicate low populations and show the need, thus, to take actions to enhance these populations. Unfortunately, the historical juvenile indices do not include the period before 1980 and thus cannot confirm the sharp decline in the 1970s seen in the graph of the commercial landings. The indices for early 1990's were extremely low.

The decline of river herring populations, particularly in recent decades, is not unique. Other anadromous fishes, such as wild Atlantic and Pacific salmon, are also showing declines. Many different strategies have been used to try to protect and enhance estuarine and marine fish populations. Harvest quotas and catch and release programs have been used to lessen the exploitation of fish populations, dams have been removed or access ways (i.e., fish ladders and locks) installed to allow fish to reach spawning habitats, and habitats such as sea grass beds and wetlands have been created or restored. In the Chesapeake Bay, these and other management strategies have had varying levels of success.

Anadromous fish require management efforts in freshwater, brackish and marine environments since these fish span these three environments at different stages of their lives. Historically, fishery management of freshwater streams has largely focused on cold-water sport fishes and on small streams and their riparian zones (White 1996). As with marine and estuarine fisheries, the complex interactions of economic, ecological, social and political factors have caused over-harvesting and destruction of freshwater stream habitat (White 1996).

Figure 1.1. Commercial landings of river herring between 1950 and 2000. A sharp decline can be seen during the early 1970s both in the Chesapeake Bay and the Atlantic Coast overall. The Chesapeake Bay landings are the combined landings of Virginia and Maryland.
Source: National Marine Fisheries Service, National Oceanic and Atmospheric Administration
http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html

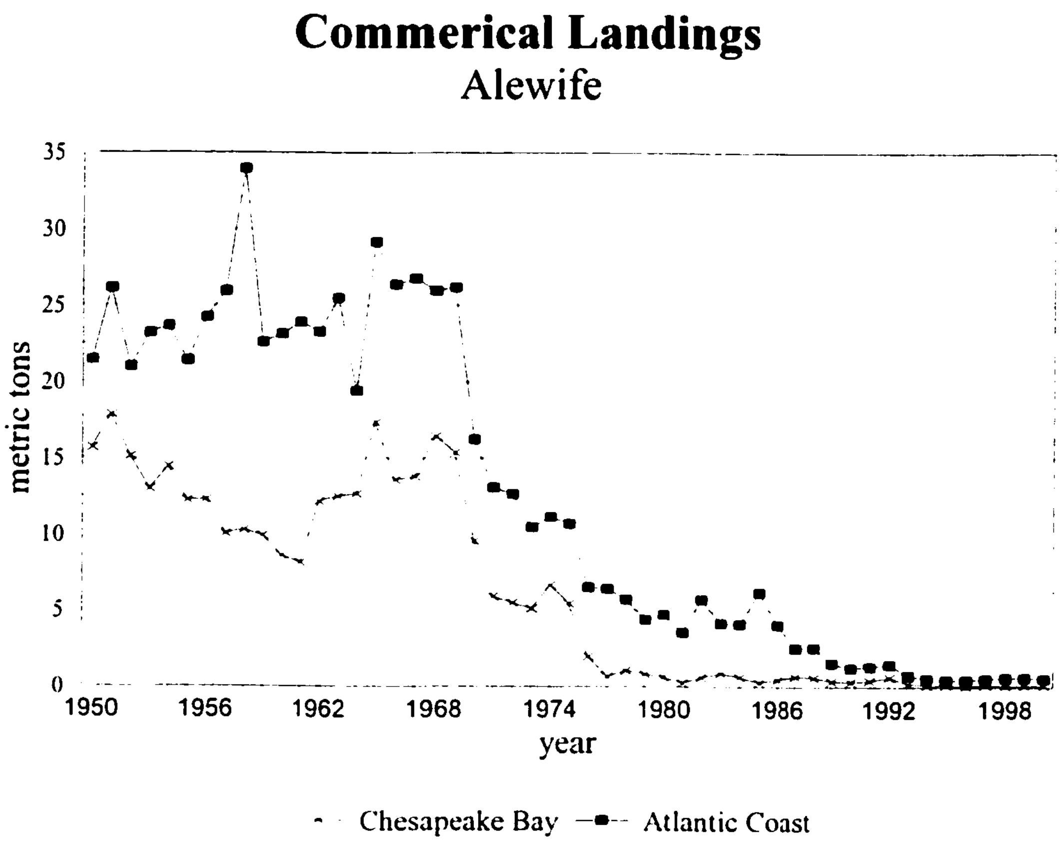
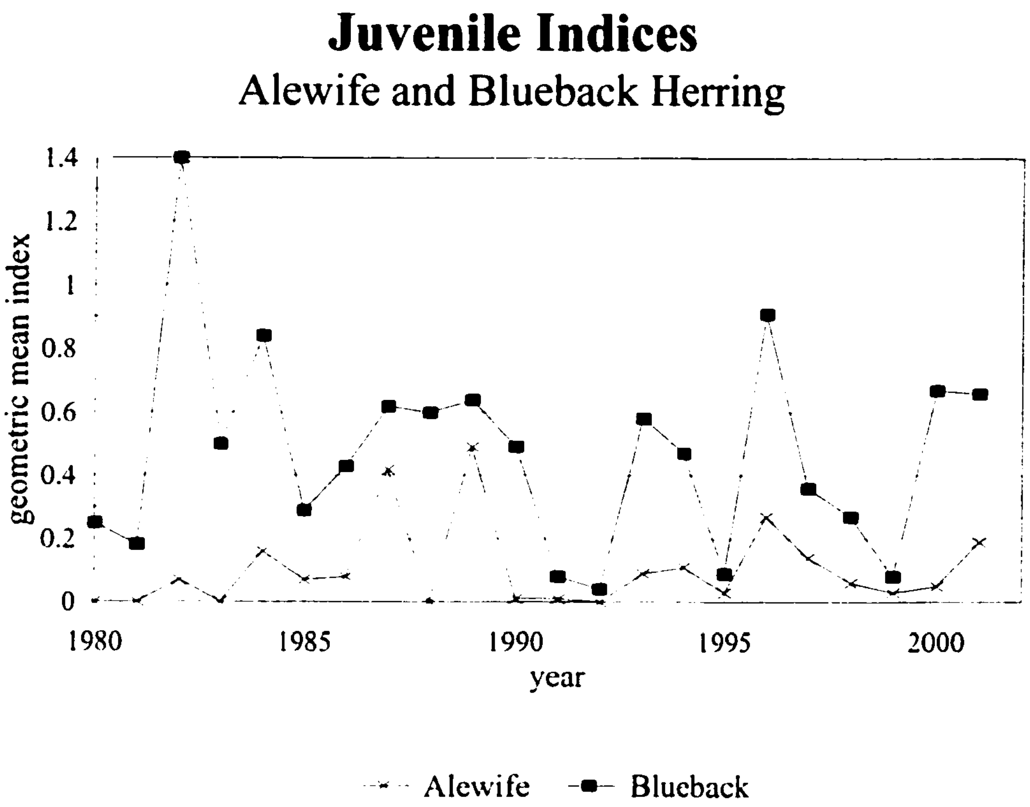

Commerical Landings
Alewife
35
30
25
20
15
10
5
0
metric tons
1950
1956
1962
1968
1974
1980
1986
1992
1998
year
Chesapeake Bay
Atlantic Coast

Figure 1.2. Juvenile indices for alewife and blueback herring.
Source: Virginia Institute of Marine Science Beach Seine Survey
http://www.fisheries.vims.edu/trawlseine/seinegraphs/seineindicesframe.htm


Juvenile Indices
Alewife and Blueback Herring
1.4
1.2
1
0.8
0.6
0.4
0.2
0
geometric mean index
1980
1985
1990
1995
2000
year
Alewife
Blueback

In the past two decades, freshwater management efforts have started to target wild fish (not just for recreational anglers) and have increasingly employed habitat-based approaches to manage species instead of population-level rates and processes (Bain *et al.*, 1999). Habitat-based approaches assume that if habitats are healthy, then fish populations are likely to be as well unless most or all the fish get caught. For the management of marine fishes, since the re-authorization of the Magnuson-Stevens Fishery Conservation Management Act of 1996 and the 1996 Sustainable Fisheries Act's amendments to this legislation, more efforts have been undertaken to consider marine fish habitat in fishery management plans. These bills called for the identification of essential fish habitat (EFH) and steer marine fishery management toward a more wholistic approach (Langton and Auster 1999).

It is essential to have some understanding of the behavior and biology of target species for fishery management plans to be effective and understanding habitat requirements is increasingly important. Successful species management requires an understanding of the factors influencing presence and abundance of species and the spatial and temporal scales in which these factors operate (Bartholomew 1986, Lewis *et al.* 1996, Rabeni and Sowa 1996, Mather *et al.* 1998).

Much freshwater fish habitat research focuses on quantifying characteristics of stream sites. The spawning habitats of wild Atlantic salmon, for instance, are well documented. Studies have identified "preferred" habitat stream velocity, sediment grain size, and pH, for example. Other life stages of the Atlantic salmon have been equally well studied. Despite the fairly robust body of research, wild Atlantic salmon populations remain low. In 1997, a workshop entitled "Integrating across scales: predicting patterns of change in Atlantic salmon" was held to address, in part, how to enhance wild Atlantic salmon populations. Outcomes of the symposium emphasized the need to approach Atlantic salmon research and management at multiple temporal and spatial scales (Folt *et al.* 1998, Parrish *et al.* 1998, Wilzbach *et al.* 1998).

The recommendations to research and manage wild Atlantic salmon at various temporal and spatial scales follows the more general trend to use hierarchical multi-scale approaches for understanding aquatic species habitat. Frissel *et al.* (1986), proposed a hierarchical framework for stream habitat classification. Drawing on this work and others (e.g., Petts 1994), other research has taken a multi-scale approach (e.g., Marshall 1996, to Roth *et al.* 1996, Watson and Hillman 1997) to determine which factors at which spatial scale are effective predictors of stream integrity or suitable habitat for targeted species.

When viewed within a scaled hierarchical framework, a system develops within the constraints set by a larger-scale system, with smaller-scale systems providing the mechanics for that middle-scale system to exist (O'Neill *et al.* 1989). To give an example for stream morphology, channel shape and sinuosity in a stream reach are influenced partly by the parent geology and the amount of rainfall. These are limits set by a larger scale. The movement of sediment by water depends on the interaction between the sediment and water along the bed and sides of the stream, a process occurring at a smaller scale than the observed character of the stream reach.

Central to studies exploring relationships of processes occurring at different scales is the premise that cause-response relationships exist between phenomena occurring at different scales. Adopting a hierarchical approach may lead to the conclusion that it would be better to target aquatic management efforts at a larger scale (Armstrong *et al.* 1998) - a watershed versus a stream reach for instance. This may be true but it is more difficult to establish cause-effect relationships to fish populations at larger scales because of greater ecosystem complexities (Imhof *et al.* 1996). It may be that stream-reach scale indicators are better predictors, for instance, of where river herring spawn. By applying multiple scales in habitat research, one may be better able to identify the optimum foci for targeting management action (Armstrong *et al.* 1998).

Viewing the world as processes occurring at different spatial and temporal scales and better understanding of how these processes are connected between and among scales are some of the basic principals for the field of landscape ecology (e.g., Allen and Hoekstra 1992, Forman 1995, Peterson and Parker 1998). Wiens (1989) talks about the surrounding areas organisms perceive, in particular, his paper discusses the landscape perceived by a beetle. The world of a beetle is much smaller than that of ours. What we perceive as a simple field of grass is full of complexity to the beetle and this complexity can affect its movement and survival. The beetle responds to tiny holes and mounds in the ground, different soil textures, small patch works of plant densities and types. Likewise, a fish perceives and interacts with the surrounding water. It is affected by the qualities of the water such as pH, DO content, temperature, and metals. The growth and survival of the fish depends on its surrounding environment, in addition to food availability and predators.

But what creates the pH, DO content, temperature and other aspects of the environment the fish perceives? Even if we understand the ranges in which a fish species such as alewife or blueback herring can grow and reproduce, will this allow us to effectively manage the species? Undoubtedly, knowledge of specific habit requirements will help, but we also need to better understand the relationships that affect water quality. In freshwater and estuarine environments, specific cause and effect relationships between and among terrestrial and aquatic variables are difficult to quantify. Exact prediction of stressors and ecosystem responses may not be possible in complex systems with natural variability and random variation (May 1986). Variables interact and relationships are often nonlinear. Nonetheless, we know at least qualitatively, that land-based activities affect water quality and aquatic habitats. We can identify important factors and identify general trends which can then influence management efforts.

The spawning habitat requirements of river herring have not been studied to the extent of Atlantic salmon nor will they likely become the objects of intensive study since river herring are not as important commercially as Atlantic salmon. Chapter 2 provides an overview of what is known about habitat requirements of river herring in freshwater environments.

Based on a review of the habitat requirements, this study develops a model to identify indicators of potential suitable spawning habitat for river herring. The research uses a two-scale approach; watershed and stream reach. A variety of metrics at both scales were examined to test their usefulness as potential spawning habitat indicators. Metrics were chosen that are known to affect the habitat the fish perceive. This approach differs from one that uses all possible metrics and looks for correlations and relationships. The term, metric, is used because it is a general term describing measured and derived variables. The study uses both directly measured variables and variables derived from direct measurements such as the ratio of stream width to length. Chapter 3 describes the metrics and their derivations.

Imhof *et al.* (1996) proposes using three scales to study fish habitats: watershed, stream reach and site. This may work well for nonmigratory species or migratory species that have been studied extensively such as the Atlantic salmon. The locations of spawning sites of Atlantic salmon are well documented in many streams. Similar information, however, is lacking for distribution of river herring spawning within Chesapeake Bay watersheds. Documentation of river herring usage in small tributaries is typically either very general (Hildebrand and Schroeder 1928), anecdotal information or geographically-isolated research (Mudre *et al.* 1984, Odom *et al.* 1986, Odom *et al.* 1988a, Odom *et al.* 1988b, O'Connell and Angermeier 1997). Uzee and Angermeier (1993) assessed the present and possible extent of anadromous fishes in the Rappahannock River. Results were based on consultations with knowledgeable personnel concerned with the resource and inspections of sites in Rappahannock River tributaries. Tributaries were classified as either probable, confirmed or uncertain with regard to their use by river herring.

Data derived from the collection of river herring eggs and larvae are used in this research, but these data only allow identification of approximate spawning locations. Because of this, a two-scale (watershed and stream-reach) approach was necessary.

The streams entering the Rappahannock River below the Embree Dam at Fredericksburg, Virginia were sampled. After identifying streams where evidence of spawning was found, comparisons of the watershed and stream reach between the absence and presence of spawning groups.

To summarize, there are three main components to the study:

1. Identification of stream reaches used by river herring for spawning within the Rappahannock River watershed.

2. Identification and testing of various stream-reach metrics to develop stream-reach spawning habitat indices.

3. Identification and testing of various watershed metrics to develop watershed spawning habitat indices.

Materials and methods are discussed in Chapter 4. The results discussed in Chapters 5 and 6 can then be used to target habitat restoration efforts for river herring. The results may also inform restoration efforts focused on management of land use. At present the area around the Rapphannock River is predominately rural; however, the metropolis of Washington, DC is expanding and coastal areas in the United States in general are places of increasing human populations. Restoration of river herring populations will require scientifically-based actions aimed at controlling habitat degradation as a consequence of changing land uses.

Anadromous fishes such as river herring, pose difficult challenges for protection and restoration. Throughout their lives, these fish migrate large distances through widely varying environments of coastal oceans, estuaries and freshwater streams and lakes. Without question, more research is always wanted and helpful to improve management plans. However in the real world of limited funding and manpower, scientists and resource managers may never fully understand the development, detailed habitat requirements, and year-to-year recruitment variability. Management decisions are made with missing information and with uncertain outcomes (Howell, 1993). The model presented here can be applied to other regions or to other species. It presents a way to help manage species using existing information and provides the tools to help target areas for restoration or protection against further population decline.

Chapter 2

Life Histories of River Herring in Freshwater Environments

The alewife *Alosa pseudoharengus* and blueback herring *A. aestivalis* are two closely related anadromous fish species of the family Clupeidae. These species are found along the East Coast of North America from Newfoundland, Canada, to Florida, United States. These fish migrate from marine and estuarine areas to spawn in coastal streams and lakes. River herring, a name commonly used for these two species, can first spawn from ages 3 to 6, but age-class 4 is when they most commonly start spawning. Spawning populations are generally composed of age-classes 3-8 with males dominating age-classes 3-5 and females tending to dominate the older age-classes. River herring can spawn more than once during their adult lives (Loesch 1987).

Blueback herring have a more southern distribution of spawning areas than alewife. Blueback herring spawn from Florida to New Brunswick whereas alewife herring spawn from South Carolina north to Newfoundland. The onset of migration and egg fertilization is temperature dependent and thus varies with latitude (Loesch 1987). In the Chesapeake Bay, alewife spawning migrations extend from early March to the end of April when water temperatures range between 10 and 18°C. Blueback herring appear about 3 to 4 weeks after alewives, beginning in early April in the lower part of the

Chesapeake Bay tributaries and late April in the upper Bay tributaries. The spawning period generally ends in late May (Klauda *et al.* 1991). Water temperatures generally range between 14 and 25°C (Jones *et al.* 1978).

In addition to temperature, upstream movements of alewives are influenced by light intensity and water flow. Richkus (1974) reports more movement during daylight hours as well as during higher flows. Tyus (1974), on the other hand, observed a weak diurnal movement with peaks between dawn to noon and from dusk to midnight. Spawning events may occur during the day or night (Loesch and Lund 1977, Johnston and Cheverie 1988), but may be greater at night (Klauda *et al.* 1991). In Connecticut, groups of adult alewives arrive at spawning sites and release their eggs during a period of two to three days (Kissil 1974). A single group or 'wave' of blueback herring releases eggs during a period of five days or less (Loesch and Lund 1977). Groups of adult alewife and blueback herring generally consist of a single female and several males. Eggs and sperm are extruded simultaneously. Spent adults migrate downstream.

Although alewives spawn in a variety of habitats from coarse gravel to organic detritus (Jones *et al.* 1978), Loesch (1987) suggests they favor slow-moving reaches of streams, coastal ponds and lakes. Jones *et al.* (1978) report that blueback herring spawn in freshwater and slightly brackish waters; however, most accounts of spawning habitats are in freshwater environments above the head of the tide. When blueback and alewife herring use the same streams to spawn, studies in New England indicate that blueback herring prefer to spawn where water flows swiftly over clean gravel and sand substrates. Most river systems in New England show a dominance of alewives (90% or more) over blueback herring. This dominance may be attributed to the local prevalence of headwater ponds in coastal streams. In New Brunswick and Nova Scotia rivers with few ponds or lakes, blueback herring exceed alewives (Loesch 1987) even though this area is near the northern limit of blueback herring.

In southern states where alewives are relatively few, blueback herring tend to spawn over shallow areas covered with vegetation (i.e., seasonally flooded rice fields and swampy areas, Osteen and Christie 1989, Eversole *et al.* 1994). Both species exhibit flexibility in selection of spawning environments. Blueback herring may show a greater adaptive ability to accommodate geomorphological changes that occur from the Canadian maritime provinces to the broad coastal plains of the southern United States (Loesch 1987). Loesch (1987) suggests that this flexibility allows a spatial separation of spawning habitats when the species coexist which reduces competition. O'Connell and Angermeier (1997) found a strong temporal separation when both species spawned in a tributary creek of the Rappahannock River.

Evidence indicates that alewife and blueback herring may return to natal streams for spawning (Christie 1985, Klauda *et al.* 1991). This conclusion is based on morphometric and meristic differences among fish from different systems (Messieh 1977), the establishment or re-establishment of spawning runs after gravid fish are placed in ancestral or new systems (Belding 1920, Bigelow and Welsh 1925, Havey 1961), and olfaction experiments (Thunberg 1971). Spawning, at least for blueback herring , may extend into adjacent streams (Messieh 1977). Alewife and blueback herrings may travel considerable distances upstream to spawn. For instance, blueback herrings swim 150-200 kilometers upstream in the Carolinas (Davis and Cheek 1967, Adams and Street 1969, Adams, 1970).

Alewives may have a higher tolerance than blueback herring to low pH. In New Jersey the median pH value of lakes and creeks where both blueback herrings and alewives run was 6.1. The median pH value of sites where only alewives run was 5.0 (Byrne 1988). The early life history stages of blueback herring are adversely affected by pH values between 6.0 and 6.5 pH (Klauda and Palmer 1987, Klauda *et al.* 1987, Hall *et al.* 1994).

River herring are classified as particulate and filter-feeders (Stone and Daborn 1987). Alewives can select individual prey or filter water through their gill rakers (Janssen 1976). Migrating adults eat while in freshwater (Creed 1985). What and how herring eat depends on their size, visibility, and prey availability and density (Janssen 1976, 1978a, 1978b). Stomach contents can contain a diversity of zooplankters, benthos, terrestrial insects and/or fish eggs (Klauda *et al.* 1991) in estuarine (Stone and Daborn 1987) and freshwater environments (Gannon 1976, Janssen 1978a, Gregory *et al.* 1982, Creed 1985). Near-bottom feeding of benthic organisms can be difficult because herring normally take their prey from beneath (Janssen 1978a). As with a differentiation of spawning habitats, alewives and blueback herring may differ in what they eat when sympatric (Stone and Daborn 1987).

Table 1.1, adapted from Klauda *et al.* (1991), summarizes the physical requirements of spawning habitats of alewife and blueback herring. The quantities shown are either directly taken or estimated from the literature. For some of the variables, quantities were unavailable.

The fertilized eggs of alewives are described as demersal to pelagic, indicating that the eggs may be found throughout the water column and in the sediments. The eggs range between 0.80 to 1.27 mm in diameter and are slightly adhesive until they become water-hardened. Incubation periods for alewives generally range between 2 and 6 days, depending on temperature. Blueback eggs are slightly more buoyant and described as pelagic and demersal in still water, and as with the fertilized eggs of alewives, slightly adhesive until water hardened (Jones *et al.* 1978). The lack of oil globules in fertilized eggs of alewives may account for differences in buoyancy (Wang and Kernehan 1979). Fertilized eggs of blueback herring range between 0.87 and 1.11 mm in diameter. Incubation durations for blueback herring generally range between 2 and 4 days (Klauda *et al.* 1991).

Yolk-sac larvae of alewives range between 2-5 mm total length (TL) at hatching and begin to feed exogenously after three to five days. Yolk-sac larvae of blueback herring are 3-5 mm at hatching and begin to feed exogenously after about four days (Klauda *et al.* 1991). The yolk sacs are large and larvae have limited ability to swim (Chambers *et al.* 1976). The eggs and larvae of alewives and blueback herring are difficult, if not impossible, to distinguish visually. Chambers *et al.* (1976) found differences in morphologic and meristic characters. However, Cianci (1969) did not. Sismour (1994a, 1994b) found no difference in pigments of yolk-sac larvae and preflexion larvae, but did find diagnostic pigment distributions in postflexion larvae.

Metamorphosis to the juvenile stage occurs when larvae are about 20 mm for both species (Lippson and Moran 1974, Jones *et al.* 1978).

Post yolk-sac larval blueback herring exhibit vertical migration. Density of larvae at the surface increases from day through dusk and night. Maximum densities were found at dawn (Meador *et al.* 1984). This diel vertical migration is similar to the pattern observed with juvenile herrings (Loesch *et al.* 1982).

Table 2.1. Summary of the habitat requirements of spawning adult alewife and blueback herring in freshwater environments. NA = Not Available.

	BLUEBACK		**ALEWIFE**	
	optimal	suitable	optimal	suitable
temp (°C)	21 to 25.5	13 to 27	11 to 19	8 to 22
salinity (ppt)	0	0 to 5	0	0
DO (ppm)	NA	>5	NA	>5
pH	6.5 to 8	6 to 8	NA	5 to 8
suspended solids (ppm)	NA	25	NA	25
current velocity	NA	fast-flowing	NA	slow-flowing
substrate	gravel/sand	variable	sand/silt/clay	variable

Chapter 3

Watershed and Stream-Reach Habitat Metrics

3.1. Introduction

Coastal areas along eastern North America are under increasing development pressure. Currently, the coastal area of the United States contains 53% of the nation's population, increasing by 3,600 people per day. It is estimated that between 1998 and 2015, the coastal population will increase by 27 million people (NOAA 1998).Tthe increasing human population pressure, and resultant changes in land use, cause degradation and/or elimination of river herring, necessitating careful management.

Because river herring cover a large spatial extent of diverse aquatic environments (freshwater, estuarine and marine), effective management requires coordination of activities operating at different spatial scales. Examples of such activities include riparian property owner land disturbance, county land use planning, and state/regional fishery regulation. Individually and cumulatively, these and other activities, affect the spawning success and recruitment of the species.

In recognition of the varying scales of potentially important factors, Frissel *et al.* (1986) proposed a hierarchical framework for stream habitat classification. As a point of clarification, 'small scale' means either covering a relatively small spatial extent or short time period. 'Large scale' means the opposite, covering a relatively large spatial extent or long time period. These uses differ from the cartographic definitions of small and large scales. Drawing on Frissel *et al.* (1986) and other works, (e.g., Petts 1994), researchers have increasingly taken a multi-scale approach (e.g., Marshall 1996, to Roth *et al.* 1996, Watson and Hillman 1997) to detect effective predictors of stream integrity or habitat suitability.

Viewed in a framework of hierarchical scales, every system is composed of smaller scale processes and constrained by larger-scale conditions (DeAngelis and White 1994, O'Neill *et al.* 1989). As an example, stream-reach morphology is influenced by local geology and regional rainfall (larger-scale conditions), as well as erosion and deposition of channel sediments (smaller-scale processes). Understanding parameter/process linkages within and among scales is one of the challenges for ecosystem management (Lewis *et al.* 1996).

Table 3.1, adapted from Folt *et al.* (1998), identifies conditions at reach, watershed and region scales affecting spawning habitat suitability of river herring. The table is general and provides a theoretical framework for using a multi-scale approach. The subsequent sections list watershed and stream-reach metrics and rationales for their use in this study.

Table 3.1. Conditions at stream-reach, watershed and region scales affecting certain metrics of spawning habitat suitability.

	TEMPERATURE	DO	PH	CURRENT VELOCITY	SUBSTRATE
stream reach	Overhead cover, impoundment, ground water sources	Local current speeds, shading effects on primary production, temperature affects on solubility	Point source inputs	Channel slope and sinuosity, macrohabitat transitions such as riffle to pool	Channel slope and sinuosity, macrohabitat transitions such as riffle to pool, land use/cover
watershed	Basin-wide influences on runoff and temperature	Land use/cover; basin-wide influences on runoff and temperature	Land use/cover, parent geology, atmospheric inputs	Basin size, parent geology, land use/cover	Parent geology, land use/cover
region	Regional climate	Regional climate, parent geology	Parent geology	Regional precipitation and runoff	Parent geology

3.2. Watershed Metrics

Rationales for the selection of watershed metrics are based on the potential to influence stream-reach water quality (pH, dissolved oxygen, temperature, turbidity and velocity) and stream-reach morphology (substrate type, channel shape, pools and riffles). It should be noted that these metrics do not act independently and that the unique characteristics of any stream is an interplay of two or more variables (Richards *et al.* 1996).

Percentages Land Use/Cover

The effects of land use/cover on water quality, stream morphology and flow regimes are numerous. Land use/cover may be the most important factor determining quantity and quality of aquatic habitats. Studies have shown that land use/cover influences: dissolved oxygen (Limburg and Schmidt 1990, Welch *et al.* 1998); sediments and turbidity (Basnyat *et al.* 1999, Comeleo *et al.* 1996); water temperature (Hartman *et al.* 1996, Mitchell 1999); pH (Osborne and Wiley 1988, Schofield 1992) and nutrients (Basnyat *et al.* 1999, Osborne and Wiley 1988; Peterjohn and Correll 1984); and flow regime (Johnston *et al.* 1990, Webster *et al.* 1992).

Land use/cover was analyzed using a variety of riparian buffer sizes including 15-meter, 30-meter, 90-meter, and 200-meter widths. Entire watershed areas were also included. Recommended buffer width for protecting stream-reach functions and habitat vary and depend on a variety of factors: soil types, riparian vegetation, extent of groundwater input and geomorphology. Studies of buffer zones recommend widths between 30 and 200 meters (Large and Petts 1994). Comparisons among buffer widths were conducted to see what differences, if any could be detected, and to determine if a particular buffer or entire watershed is best as a landscape indicator.

Size of watershed

The size of the watershed is a basic descriptor that influences the number and size of streams (Gordon *et al.* 1992). Catchment areas affect discharge, hydrograph (the graph of water discharge or depth with time) and flashiness of rain or snow melt events (Black 1996). Although river herring spawn in small streams, there may be a minimum size threshold. Larger watersheds may have the opportunity to provide more suitable spawning areas and greater habitat complexity.

Area above 5-foot contour

The five-foot contour on topographic maps was used as an approximate indicator of the limit of tidal influence. Although the literature indicates that river herring may spawn in brackish or tidal waters (Jones *et al.* 1978), preferred areas may be above tidal influence. As with the overall size of the watershed, there may be a minimum size threshold for the non-tidal portion.

Road density

The density of roads can be used as an indicator of the intensity of development (Jones *et al.* 1997). This may indicate non-point source pollution inputs or hydrograph alterations.

Shape of the watershed

A preliminary examination of the shapes of all the watersheds used in the study suggested that watersheds situated largely within the flood plain of the Rappahannock River tend to be wider and shorter than the other watersheds examined. Shape may thus serve as an indicator of potential hydrograph. Wide, flat watersheds may have comparatively low gradients and more moderate flow regimes. The type of flow regime will affect the delivery of sediments, nutrients and chemicals into the creek, particularly in the spring when precipitation, run-off, and water levels tend to be higher. The shape metric in conjunction with elevation may help to differentiate between potentially suitable and unsuitable spawning habitats. A metric was chosen that compares the perimeter of the watershed with a circle of the same area. If a watershed is a circle, then it is given a value of 1.

Drainage Density

Drainage density is a ratio of stream channel length to catchment area. The density can reflect effects of climate patterns, geology, soils, and vegetation cover in the watershed (Gordon *et al.* 1992). The index may be useful for comparisons between ecoregions, but its usefulness for comparisons of small watersheds within the same region may be limited. In general, increased density allows a more efficient drainage of the watershed. Greater values may be associated with flashier runoff behavior and greater total surface runoff (Black 1996). Flashy responses during the spawning season may reduce the suitability of spawning habitat.

Drainage density is affected by the scale of analysis. In more detailed (larger scales) maps, smaller features such as small creeks are captured that are not represented in smaller-scale maps. Here, the cartographic definition of small and large scales is used - small scale applies to maps covering large areas with less detail than what is represented in large-scale maps. To compare the drainage densities among different watersheds, it is important to consistently use the same scale of maps. In this study, all the watersheds were analyzed at the same scale of 1:100,000.

Elevation: mean and standard deviation

Digital Elevation Models (DEMs) were used to derive mean elevation values for watersheds. In a DEM, each pixel (30 x 30-meter area) has one elevation value associated with it based on an estimate of the average value for the pixel area. The DEM values may indicate relative proportion of tidally-influenced stream reaches. Although Jones *et al.* (1978) state that river herring can spawn in tidal freshwater and brackish water, the majority of river herring spawning research has been conducted in non-tidal freshwater environments (e.g., Christie 1985, Kissil 1974, Jessop 1994). Higher mean elevations would suggest greater proportions of non-tidal stream reaches, and potentially greater habitat suitability.

The standard deviation of elevation can be used to measure topographic complexity (Richards *et al.* 1996) and may thus indicate heterogeneity of habitat types. Previous studies show that river herring have been found spawning in both lentic (slow-flowing) and lotic (fast-flowing) environments. When coexisting, there is evidence of a separation of spawning preferences with alewives selecting lentic sites and blueback herring selecting lotic sites (Loesch 1987). It may be expected that both lentic and lotic habitats may be used for spawning, perhaps with a preference toward faster-flowing areas to accommodate larger populations of blueback herring in the Chesapeake Bay. Assuming that both lentic and lotic environments are used by river herring, habitat complexity is desirable. Watersheds with greater standard deviations would indicate greater habitat complexity.

Slope of stream network: mean, median, maximum, standard deviation

Slope affects stream velocity. Increased slope can cause increased velocity. This in turn can affect substrate type, bank erosion, and water quality (e.g. dissolved oxygen and turbidity). It is likely that with increased slope, dissolved oxygen values will increase because of increased mechanical mixing through turbulence. The affect of velocity on turbidity may vary and depends largely on bank stability and sediment type.

Some studies have associated fish habitat types with slope, but these studies are generally in mountainous areas (e.g., Lunetta *et al.* 1997, Watson and Hillman 1997). Montgomery *et al.* (1999) grouped gradient ranges with stream morphology types (i.e, pool and riffle and plane-bed); however, they found considerable errors when comparing predictions of channel types based on maps with field surveys.

Slope values were derived from the DEMs. The derivation of a slope value for each pixel mathematically includes all surrounding cells. This is different than a calculation of slope from a topographic map. An examination of the slope values for each watershed revealed extremely positively skewed distributions with many values at or near 0 degrees and a considerable tail of comparatively large values. Transformations (log and square root) did not create normal distributions. For this reason, means were not deemed to be particularly descriptive and/or useful in characterizing watersheds. Instead median values were used. Standard deviations were used to indicate relative diversity of slope values in each watershed.

In a rasterized stream network, the slope values may not realistically represent slopes in the direction of stream flow in these small creeks. Because of potential inaccuracies of using raster slope values, a minimum slope value for each creek was calculated from maximum and minimum elevation values and total stream length.

Creek mouth dimensions

It is possible that herring can sense the morphology of tributary entrances, and/or it may be that the entrance morphology somehow integrates various hydrologic and geomorphic characteristics of the tributary. For these reasons, creek mouth dimensions (depth, width, and the depth/width ratio) were used as potential dependent metrics in the habitat suitability models.

3.3. Stream-Reach Metrics

This section describes the metrics chosen to quantify the stream-reach habitat including stream-reach morphology and water quality. Benthic macroinvertebrate analysis was used to assess the water quality in addition to the measurements taken with the plankton collections. The rationales for the stream-morphology metrics are based on the potential to influence water quality or possible stream-morphology conditions necessary or preferred for spawning. As with the watershed metrics, it is difficult to predict the exact response of water quality to alterations in the land use/cover, geomorphology and hydrograph since water quality is a response to complex interactions of these processes of a watershed (Basnyat *et al.* 1999, Peterjohn and Correll 1984).

3.3.1. Stream-Reach Morphology

% Canopy Cover

The percentage of canopy cover at a stream reach depends on the width of the stream and the type of vegetation in the riparian zone. Canopy cover moderates water temperature and prevents excessive heating in the warm summer months (Barton *et al.* 1985). Temperature influences metabolic rates and growth, migration patterns and overall biological communities (Hetrick *et al.* 1998, Mitchell 1999). As well, canopy cover may provide protection from predation such as birds. In the beginning of the spawning season, there are few leaves on the deciduous trees and shrubs in the study area. However, as the season progresses the percentage of cover from overhanging branches may greatly affect water temperature.

Transect Measurements: Bankfull Width and Depth

In addition to influencing the percentage of canopy cover, the width of stream reaches may influence spawning habitat selection more directly. River herring may prefer narrow stream reaches where encounters among males and females are greater. Narrow stream reaches may also increase the percentage of fertilized eggs.

There may be a minimum depth required for spawning based, in part, on the size of the fish. Depth also influences the temperature throughout the water column (Stoneman and Jones 1996), which can then affect the amount of dissolved oxygen the water can hold.

Substrate Sediment Texture

Loesch (1987) states that when alewife and blueback herring coexist, there may be a spatial separation of spawning habitats with blueback herring spawning in the faster-flowing sandy or gravel environments than alewife. The juvenile indices shown in Figure 1.2 have slightly greater values for blueback herring. Perhaps there are more spawning areas with substrates preferred by blueback herring in the study area.

Percentages of Pools and Riffles

Riffles are faster-flowing shallower sections of the stream reach that have less mud and higher dissolved oxygen contents. Pools are deeper areas with generally finer sediments, although streams in wetland areas may show little difference in sediment types between pools and riffles (Jurmu and Andrle 1997). Pool and riffle sequences can be desirable in small streams because they can allow deeper areas for herring to spawn while still being in reaches with high dissolved oxygen content.

Percentages of Erosion Along the Stream-Reach Banks

Erosion is a natural process that affects the water quality by providing sediments, nutrients and chemicals to the aquatic environment. However, the amount of erosion is greatly affected by human activities, particularly when riparian vegetation is removed (Osborne and Kovacic 1993). Sediment inputs can change the stream-reach morphology (Beschta and Platts 1986, Leopold 1994), for example, by increasing the width and decreasing depth. The amount of fine sediments may affect the quality of fish spawning habitat, particularly if the species prefer larger sediment substrates (Rinne 1990). Although the literature reveals an ability for river herring to spawn in a variety of habitats, sand and gravel may be preferred.

Number of Snags

The type of riparian vegetation and the extent of human impact influence how many snags are in stream reaches. Generally in less disturbed areas within forested areas, there will be a considerable number of snags. Downed trees affect channel morphology by creating areas of scour or deposition and may help to increase the residence time of coarser sediments while facilitating the removal of finer sediments (Beschta and Platts 1986). Snags increase habitat complexity (Schlosser 1991) and it is likely that river herring prefer increased habitat complexity since there may be a spatial separation of spawning when alewife and blueblack herring are spawning simultaneously.

3.3.2. Benthic Macroinvertebrates

Benthic macroinvertebrate analysis was used to assess stream-reach water quality, since physical and chemical measurements (dissolved oxygen, temperature and pH) taken during plankton sampling have limited utility as indicators of general conditions (healthy or degraded). The use of benthic macroinvertebrates to assess water quality is an active area of research. This section gives some background on the use of benthic biological monitoring. For a more detailed review of benthic macroinvertebrate monitoring in the Chesapeake Bay area, refer to Draheim (1998).

In recent years there has been considerable research in the use of benthic macroinvertebrates to assess water quality, largely in an attempt to overcome limitations of chemical and physical monitoring (Metcalfe-Smith 1994). Biological monitoring is based on the premise that resident (sessile or limited mobility) aquatic organisms function as natural monitors of water quality. Many benthic macroinvertebrates live more than one year. Anthropogenic stresses to aquatic habitats will cause the loss of non-tolerant organisms by either migration or death (Hilsenoff 1977). Generally, displaced organisms will be replaced by species of similar, but more tolerant taxa (Cairns and Pratt 1993). Consequently, an analyses of benthic macroinvertebrate assemblages may reveal effects of cumulative stresses to the aquatic environment.

Benthic macroinvertebrate assemblages are generally analyzed by either multivariate analyses (e.g., cluster) or metrics. In benthic macroinvertebrate analyses, the term "metrics" is defined as easily observable characteristics of the biological assemblage that respond to stress in some predictable way. This relationship makes the metrics useful indicators of pollution and/or cumulative impacts (Karr and Chu 1999). Considerable research has been and is being undertaken to determine metrics that are useful indicators of habitat degradation.

The use of the "metrics" for the benthic macroinvertebrate analysis differs from how the term is used for the other parts of the study. For the watershed and other stream-reach metrics, "metric" is used as a general term to describe an entity. A metric can be a measurable variable or a derived characteristic. Furthermore, the watershed and other stream-reach metrics do not have to respond in a predictable way.

The sites explored in this study cover a range of benthic habitats including: tidal oligohaline (< 5.0 ppt); tidal fresh; non-tidal with substrates of clay, silt and sand; and non-tidal riffle sites with pebbles and cobbles. Benthic sampling in cobble riffles has received considerable attention and benthic indexes have been developed and tested in a variety of regions in the United States and elsewhere (Barbour *et al.* 1999, Karr *et al.* 1986, Karr 1995). Many state agencies charged with assessing waterways to meet section 305(b) of the Clean Water Act, are using macroinvertebrate sampling in riffles to assess and identify degraded reaches (Karr and Chu 1999). Non-tidal stream environments of clay, silt and sand in the coastal plain have received less attention and the benthic metrics are not as well established. Lenat (1993) and U.S. EPA (1997) have explored the use of benthic macroinvertebrate analyses to assess the health of coastal streams in North Carolina and elsewhere along the Mid-Atlantic region.

The use of benthic macroinvertebrate metrics for estuarine environments is less established than for lacustrine and riverine benthos. Research on tidal fresh and oligohaline environments in the Chesapeake Bay has been undertaken in an attempt to develop a benthic index (Draheim 1998, Weisberg *et al.* 1997). These two studies did not generate strong evidence for using benthic macroinvertebrate metrics in tidal freshwater and low salinity environments. Unlike the sample locations for those studies, the sites for the present study were located within small, predominantly non-tidal creeks. It was assumed this condition would allow the benthic community to more easily reflect the character of the local watershed.

Selection of metrics for this study was generally inclusive rather than selective. After examining the literature, all metrics that seemed applicable to study site environments were subjected to statistical analyses. Metrics are grouped into three types: richness measures, composition and tolerance measures, and feeding strategies. The metrics are discussed below. Table 3.2 at the end of this chapter lists the metrics and their expected responses to stress.

Richness measures

The overall richness measure (total number of taxa) reflects the variety of the benthic community (Resh and Jackson 1993). In general the richness value increases with better biological health when comparing similar habitats. However, overall richness can show increased values with increased organic inputs (considered environmental degradation) from anthropogenic activity (Johnson *et al.* 1993). Depending on the benthic assemblage, richness measures of groups of related taxa may better indicate the extent of stress. In lakes, slow-flowing streams and estuarine environments, oligochaete and chironomids often contribute greatly to the assemblage and may require the identifications of genera or species to identify stressed habitats. Only with genera or species identifications may a reduction in taxa richness be observed. Chironomidae and Oligochaeta taxa are often not used in pollution studies because of the tedious work required for processing and identification (Johnson *et al.* 1993, Ristich *et al.* 1977). The number of Polychaeta taxa was included following Draheim (1998). Weisberg *et al.* (1997) suggest that polychaete taxa show a range of pollution tolerance. As an assemblage, they are considered more pollution sensitive than oligochaetes (Draheim 1998).

In fast-flowing streams, richness values for chironomids and oligochaetes are used infrequently. Emphasis is placed more on the richness of Ephemeroptera, Plecoptera, and Tricoptera (EPT). These insects do not require clearing and mounting individuals to identify the genera or species. As well, the life histories of many EPT are well understood. Although, there is great variety in the pollution tolerance of unique EPT genera or species, generally lower richness values indicate increased pollution (Wallace *et al.* 1996).

Many of the samples in this study contained Crustacea (isopods, amphipods, cumaceans, and decapods) and Mollusca (gastropods and bivalves) taxa. Barbour *et al.* (1996) used metrics with Mollusca and Crustacea taxa as measures of benthic health, in particular benthos associated with macrophyte beds. A reduction of calcium-dependent taxa may reflect a stressed habitat.

Composition and Tolerance Measures

It is generally accepted that values of diversity indexes decrease with decreasing water quality (Norris and George 1993). However, depending on the type and degree of stress, community response may vary and even result in increased diversity (Barbour *et al.* 1996). Numerous diversity indexes have been developed. The Shannon-Weiner Index is a widely used diversity index in environmental monitoring and research. It combines evenness and richness and reaches its maximum value when all species are evenly distributed. Although widely used, it tends to lessen diversity values with decreasing sample size.

$$DI = -\sum_{i=1}^{k} x_i \log_2 x_i$$

where:
k = number of categories, and
x_i = the proportion of observations found in category i (Zar 1996).

Biotic indexes have been developed as a means to assess pollution impact. The biotic index used here is based on Hilsenhoff (1977). The Hilsenhoff index requires counts of unique taxa and an understanding of their pollution tolerances. Pollution tolerance values used in this study are based on those used by (Bode *et al.* 1996). Bode *et al.* (1996) lists values for species, genera and/or families. The tolerance list provided by Bode *et al.*

(1996) was chosen over the list developed by Lenat (1993) since Bode *et. al.* (1996) provided a more complete list of the taxa found. Species within a genus or family often show a wide range of pollution tolerances. For those taxa that were not identified to the species, the lowest value (least tolerant species) was selected for the calculation of the biotic index.

$$BI = \frac{\sum x_i * t_i}{n}$$

where:
x_i = number of individuals within a taxon
t_i = tolerance value of a taxon
n = total number of organisms in the sample.

The relative abundances of various taxa are used to indicate the level of stress and is thought to be a better indicator of biological health than absolute abundance values (Barbour *et al.* 1996). Population sizes may vary greatly even under natural conditions (Karr and Chu 1999). Chironomids are generally considered good indicators of organic pollution (Cairns and Pratt 1993, Wilson and McGill 1977); however, comparisons of unique taxa show a variety of pollution tolerances (Bode *et al.* 1996, Lenat 1993). The use of subfamily measures may be more sensitive to more subtle changes in stress, particularly since tidal-freshwater and oligohaline habitats contain robust organisms. Within the Chironomidae family, the red-blooded midges (Chironomini) may be pollution tolerant (Bode *et al.* 1996). In particular, a *Chironomus* species was found to be dominant in highly polluted areas in England (Johnson *et al.* 1993). Brinkhurst (1969), though, found an absence of *Chironomus* in eutrophic conditions. Likewise, species of Orthocladinae indicate a spectrum of responses. Bode *et al.* (1996) considers them pollution sensitive whereas Barbour *et al.* (1996) found Orthocladinae pollution tolerant, especially to metals. Tanytarsini may be more pollution sensitive (Barbour *et al.* 1996).

A community dominated by a few species frequently indicates a stressed environment (Plafkin *et al.* 1989), although it should be noted that some unstressed environments show dominance by a few taxa (Resh and Jackson 1993). Dominance by a single taxon is thought to be a good measure of community imbalance perhaps resulting from human activity (Bode 1988, U.S. EPA 1997). It may be that the dominant taxon is pollution-tolerant or one that has been introduced.

The metrics for number of pollution indicative and pollution tolerant taxa are taken from Weisberg *et al.* (1997) and are limited to tidal fresh and oligohaline sites.

Feeding Strategies

The functional feeding groups are based on those used by Bode *et al.* (1996), who rely largely on Merritt and Cummins (1996) and Pennak (1989). Shredders include those macroinvertebrates that feed on living or decomposing vascular hydrophyte plant tissue and wood; collectors and gatherers feed on decomposing fine particular organic matter (FPOM); scrapers feed on periphyton-attached algae and associated material; and predators feed on living animal tissue (Merritt and Cummins 1996; p. 76). The composition of the feeding strategies in a community reflect trophic interactions, production and availability of food source (Karr *et al.* 1986), and so an analysis of the feeding composition may reveal impacts. Specialized feeders such as predators are more selective and should respond earlier to stresses (Barbour *et al.* 1996). Shredders are sensitive to chemical toxins and structural modification of the riparian zone (Plafkin *et al.* 1989). Scrappers, too, generally indicate a healthy environment, although certain species are pollution tolerant (Resh and Jackson 1993). Generalists such as collectors and gatherers have a broader range of acceptable food sources and are generally more tolerant (Barbour *et al.* 1996). Organic enrichment may produce dominance by collector-filterers (Resh and Jackson 1993), although filter feeders may be sensitive in low-gradient streams (Wallace *et al.* 1977).

Table 3.2. Explanation of candidate benthic metrics, expected responses to increasing anthropogenic stresses and metric sources.

CATEGORY	METRIC	DEFINITION AND COMMENTS	EXPECTED RESPONSE	METRIC SOURCE
Richness Measures	Total No. taxa	Measures the overall variety of assemblage	Decrease	Barbour *et al.* 1996, Karr and Chu 1999
	No. Diptera taxa	Number of "true" fly taxa, including midges	Decrease	Barbour *et al.* 1996
	No. Chironomidae taxa	Number of midges	Decrease	Barbour *et al.* 1996, Fore *et al.* 1996
	No. Crustacea + Mollusca taxa	Sum of calcium-dependent taxa	Decrease	Barbour *et al.* 1996
	No. Oligochaeta taxa	Number of oligochaete taxa	Decrease	Brinkhurst 1969
	No. Polychaeta taxa	Number of polychaete taxa	Decrease	Draheim 1998
	No. Coleoptera taxa	Number of Coleoptera taxa	Decrease	Barbour *et al.* 1996
	No. of Ephemeroptera + Plecoptera + Trichoptera taxa (EPT)	The majority of these three orders are pollution sensitive.	Decrease	U.S. EPA 1997
Composition Measures	Shannon-Weiner Diversity Index	Incorporates both richness and evenness in a measure of general diversity and composition	Decrease	Weisberg *et al.* 1997
	Biotic Index	Relative measure of pollution	Decrease	Hilsenoff 1977, Bode et al. 1996
	% Diptera	Percent "true" fly taxa, including midges	Increase	Barbour *et al.* 1996

Table 3.2 (continued). Explanation of candidate benthic metrics, expected responses to increasing anthropogenic stresses and metric sources.

CATEGORY	METRIC	DEFINITION AND COMMENTS	EXPECTED RESPONSE RESPONSE	METRIC SOURCE
Composition Measures	% Chironomidae	Percent midges	Increase	Barbour *et al* 1996; Karr and Chu 1999
	% Crustacea + Mollusca	Percent calcium-dependent taxa	Decrease	Barbour *et al.* 1996
	% Oligochaeta	Percent oligochaete taxa	Increase	Brinkhurst 1969; Karr and Chu 1999
	% Polychaeta	Percent polychaete taxa	Decrease	Draheim 1998
	% EPT	Percent of Ephemeroptera, Plecoptera and Tricoptera	Decrease	U.S. EPA 1997
	% Planaria Amphipods	Percent Planaria and Amphipods	Decrease	Bode *et al.* 1996
	% Isopoda	Percent isopod taxa	Increase	Barbour *et al.* 1996
	No. pollution indicative taxa	Number of taxa indicative of pollution (for estuarine environments)	Increase	Weisberg *et al.* 1997
	% Oligochaeta to % Chironomidae	Relative abundance ratio of dominant taxa	Increase	Kolkwitz and Marson 1908
	% *Chironomus* to % Chironomidae	Ratio of pollution tolerant midge genus to all midges	Increase	Bode *et al* 1996

Table 3.2 (concluded). Explanation of candidate benthic metrics, expected responses to increasing anthropogenic stresses and metric sources.

CATEGORY	METRIC	DEFINITION AND COMMENTS	EXPECTED RESPONSE	METRIC SOURCE
Composition Measures	% Tanytarsini to % Chironomidae	Ratio of pollution sensitive midge genus to all midges	Decrease	Barbour *et al.* 1996
	No. pollution sensitive taxa	Number of taxa sensitive to pollution (for estuarine environments)	Decrease	Weisberg *et al.* 1997
	% *Chironomus* to % Chironomini	Ratio of pollution tolerant midge genus to all red-blooded midges	Increase	Johnson *et al.* 1993
	% Orthocladinae to % Chironomidae	Ratio Orthocladinae sub family to all midges	Variable	Barbour *et al.* 1996, Bode et al 1996
	% Dominant taxon	Relative abundance of single dominant taxon.	Increase	U.S. EPA 1997
Feeding Strategies	% Collector-filterers	Percent collector-filterer functional feeding group	Decrease	Barbour *et al.* 1996
	% Collector-gatherers	Percent collector-gatherer functional feeding group	Variable	Barbour *et al.* 1996
	% Predators	Percent predator functional feeding group (variable for Barbour et al. 1996)	Decrease	Barbour *et al.* 1996 Fore *et al.* 1996
	% Scrappers	Percent scrappers functional feeding group	Decrease	Plafkin *et al.* 1989
	% Shredders	Percent shredders functional feeding group	Variable	Karr and Chu 1999

Chapter 4

Materials and Methods

4.1. Site Selection

Thirty-four creeks feeding into the Rappahannock River were chosen for this study (Figure 4.1). These creeks enter the Rappahannock River between the Embree Dam at Fredericksburg and slightly south of the town of Tappahannock. Approximately 60 creeks enter this section of the Rappahannock River. Two of the study creeks, Millbank Creek and Peedee Creek, had two sites. All other study creeks had one site.

Site selection was based on accessibility, stream size, and location of impediments to migration. All study creeks had minimum channel dimensions of 20 cm wide and 20 cm deep. Sampling sites were always located downstream of anthropogenic blockages such as dams.

Many creeks in the study area are not accessible by motor boat from the Rappahannock River due to narrow channel widths, shallow depths (particularly at low tides), and natural blockages (i.e., beaver and debris dams). As a result, sites were selected that could be accessed by roads. Preference was given to sites located upstream of bidirectional tidal flow but as close to the mouth of the creek as possible. Often this required gaining access to creeks through privately-owned properties. Creeks were selected where permission was granted to cross private property.

The net used to collect the plankton samples had a 20 cm diameter. This dimension established the minimum stream-channel dimension requirement. Since dams may interfere with the migratory movements of river herring, sites were chosen below dams. Many dams once used for powering sawmills and grain mills are present throughout the landscape. The dam on Massaponax Creek was used for electric generation. The locations of beaver dams did not influence site selection except for Millbank Creek. A beaver dam at Millbank Creek is located at the edge of tidal influence. Since both sides of the dam were accessible, a net was placed downstream of the dam and another upstream, where water flowed through the beaver dam.

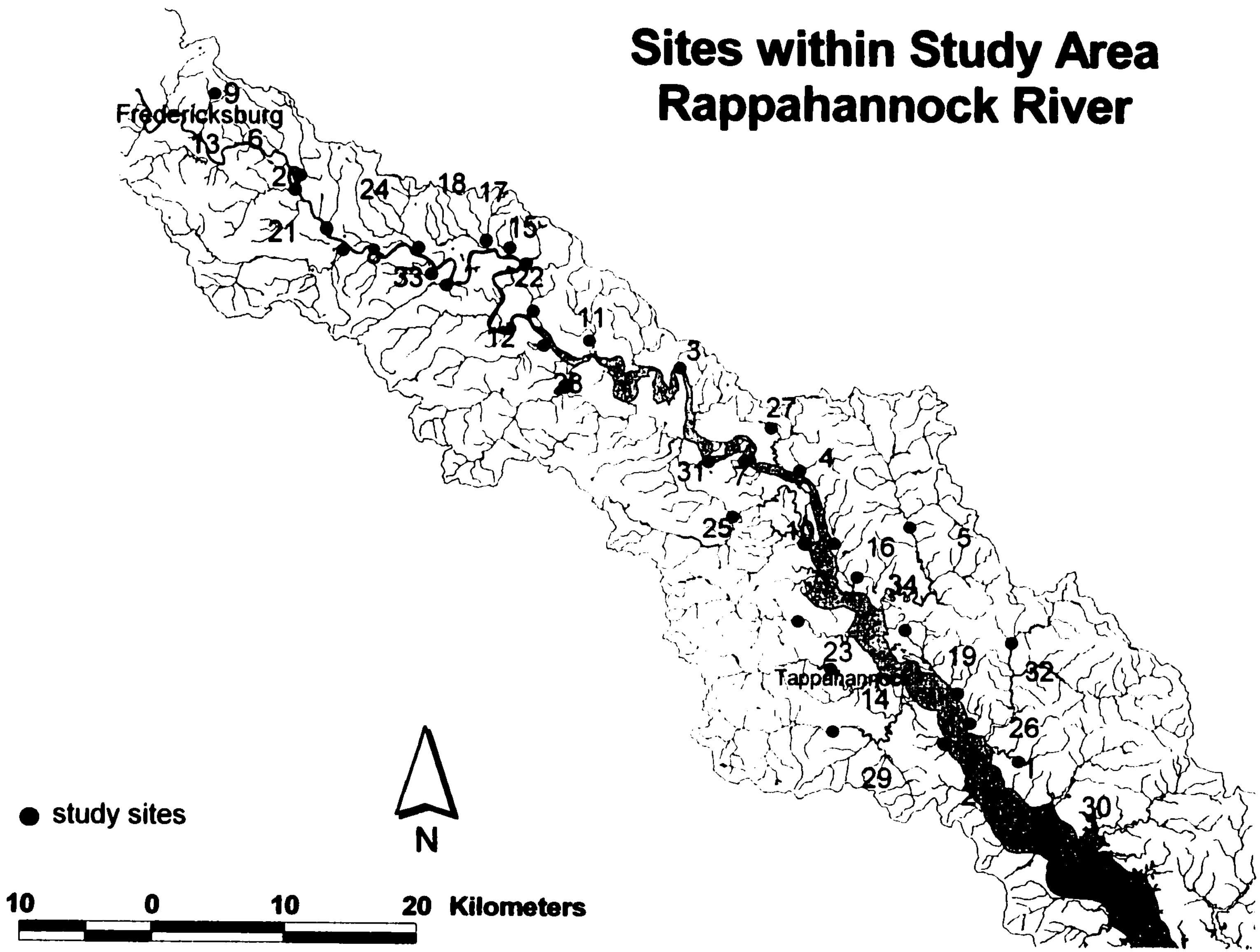
Geographic positions were determined by GPS units. The GPS positions were differentially corrected.

4.2. Plankton Collection

Sampling with a fixed-position plankton nets was the method used to collect herring eggs and larvae in this study. Because the sample sites were typically small streams and widely distributed, use of towed plankton nets was impractical or impossible. Plankton sampling provided the necessary evidence of herring spawning activity (Bovee 1986), and was much more efficient than capturing adults with electro-shocking, nets, or traps.

Figure 4.1. Creeks sampled in study area.

1. Balls
2. Bellview
3. Bristle Mine Run
4. Brockenbrough
5. Cat Point
6. Claiborne Run
7. Colemans
8. Dicks
9. Falls Run
10. Farmers Hall
11. Gingoteague
12. Goldenvale
13. Hazel Run
14. Hoskins
15. Hugh
16. Jones
17. Keys Run
18. Lambs
19. Little Carter
20. Little Falls Run
21. Massaponax
22. Millbank
23. Mount Landing
24. Muddy
25. Occupacia
26. Pecks
27. Peedee
28. Peumansend
29. Piscataway
30. Richardson
31. Saunders
32. Totuskey
33. Ware
34. Waterview


Sites within Study Area
Rappahannock River
Fredericksburg
Tappahannock
9
13
6
20
21
24
18
17
15
33
22
12
11
28
3
27
31
7
4
25
10
16
5
34
23
19
32
14
26
1
29
2
30
study sites
N
10
0
10
20
Kilometers

4.2.1. 1996 Collection

Preliminary sampling was conducted between March and May 1996. The main objective was to determine which streams were used for spawning. At each site, a net was manually held in the channel either from the stream bank or suspended from a bridge. The net was placed in the water for 10 to 30 minutes depending on a visual estimate of the velocity of the stream current to filter approximately the same amount of water. Thirty-six sites were sampled in 27 streams. There were 18 sites located in tidal stream reaches and 18 in non-tidal stream reaches. Samples collected in tidal stream reaches were collected during ebb tide. Samples were taken once a week with a 0.202 mm-mesh net.

Each collection was sieved and fixed in a 5% buffered formalin solution. Formalin was chosen over ethanol because it causes less destruction of the larvae (Sismour 1994a, Theilacker 1990).

4.2.2 1997 Collection

In order to increase the volumes of water sampled and to standardize the timing of sampling, the 1997 collection used nets suspended in the water column for 24 hours. Samples were collected once a week between March 20 and May 20. Photo 1 illustrates the net design. The mouth of each net was attached to a 20-cm pvc pipe with a detachable metal ring. The pvc pipe was attached to two metal poles that were inserted in the channel sediments. The cod end was a separate bag made of the same material as the net and attached to the net by a small pvc pipe and metal ring. The pvc pipe at the cod end was attached to a third metal pole. This design eliminated the possibility that the net would become tangled or touch the bottom sediments. The poles did not interfere with the water flowing through the net.

The mouths of all staked nets faced into the downstream flow of water. In unidirectional reaches, nets captured plankton for a continuous 24 hours. In bidirectional reaches, the bag at the cod end turned upstream and closed the mouth of the bag, limiting the loss of material.

Three streams, Massaponax Creek, Occupacia Creek and Peumansend Creek, are known as spawning areas for river herring and recreational fishermen go to these sites each year. It was not possible to place a stationary net at these locations. Instead plankton samples were collected one time in each of the streams for 20 minutes during spawning runs to confirm the presence of eggs and larvae.

The mesh width was increased from the 0.202 mm used in 1996 to 0.33 mm in 1997 to lessen the amount of detritus captured. The diameters of fertilized and unfertilized eggs of blueback herring range between 0.87 and 1.11 mm and alewife between 0.80 and 1.25 mm.

For each sampling location, nets were placed for twenty-four hours. Samples were retrieved and fixed in a 5% buffered formalin solution. The 24-hour period increased sample volumes and eliminated possible biases resulting from samples taken at different times of the day during different tidal cycles (factors that may influence migratory movements of adults). In addition, the extended sampling may have reduced the probability of missing a spawning event.

Photo 1. Net in Hoskins Creek. See text for explanation of net design.

4.2.3. Icthyoplankton Identification

Since eggs and larvae of alewives and blueback herring are difficult to differentiate (Jones *et al.* 1978, Lippson and Moran 1974, Sismour 1994a, Sismour 1994b), the two closely related species were grouped together. River herring embryos and larvae have some unique features and are fairly easy to distinguish from most other species found in these environments. The eggs have tiny oil globules or none, and the yolks are granular. The larvae are long and slender with a vent near the posterior end. Blueback herring have 46-49 myomeres and alewifes have 45-50 myomeres (Lippson and Moran 1974). Evidence of spawning by river herring was based on the presence of herring yolk-sac larvae and eggs.

To ensure correct identification, herring identification was limited to embryos and yolk-sac larvae, particularly since many samples contained gizzard shad (*Dorosoma cepedianum*) larvae. The post yolk-sac larvae of gizzard shad and river herring look very similar (i.e., number of myomers and total length). The vent of the gizzard shad is closer to the caudal fin than of herring (Lippson and Moran 1974); however, this characteristic alone does not allow identification. Unlike river herring larvae, the yolk-sac larvae and embryos of the gizzard shad have large posterior oil globules making identification at the early stages relatively simple.

4.2.5. Water Sampling

At the times of net placement and retrieval, surface water temperature, dissolved oxygen, and pH were measured. A YSI oxygen meter measured temperature and dissolved oxygen. An Orion SA 250 pH meter measured pH with a resolution of 0.01.

Clod cards were used to obtain relative, integrated measures of flow over the 24-hour period (Bingham 1992, Doty 1971, Farnsworth and Ellison 1996). Clod cards are made of slowly-dissolving solid, of which dissolution is proportional to water flow velocity. The clod cards were attached to the net frames.

4.3. Watershed Characterization

4.3.1. Data Sources

The data sets used to characterize the watersheds were:

- USGS 7.5 minute Digital Elevation Models (DEM) with a 30 meter resolution.
- Environmental Protection Agency's MRLC (Multi-Resolution Land Characteristics), version 2 with a 30 meter resolution (1996). This data set is based on Landsat Thematic Mapper (TM) data acquired in 1991, 1992 and 1993.
- Topologically Integrated Geographic Encoding and Referencing (TIGER/Line (TM)) data (1995); stream and road networks; 1:100,000 scale. Spatial features in the TIGER/Line (TM) are categorized into Census Feature Class Codes (CFCC). The road coverage used in the study included all primary, secondary, tertiary roads and railroads (all feature class A and B). The hydrology coverage included all streams, lakes, ponds, reservoirs and other types of water bodies included in feature class H. Some of the feature classes listed in the TIGER/Line (TM) data are regional and may not be applicable in the study site.
- A point coverage of the site locations based on GPS measurements taken at the sites.

4.3.2. Geographic Information System (GIS) Analysis

Geographic Information Systems (GIS) are computer based systems designed for the input, storage, analysis and display of spatial information. GIS technology permits the manipulation and integration of diverse data sets. The systems store geographical data within layers, for instance, one layer may contain soil information, another land use/cover and a third, ponds and lakes. In addition, GIS can store non-spatial attribute data associated with the map features. A city, for instance, can have all sorts of information associated with it - population, age distributions, ethnic diversity, the number and types of crimes, historical information, and so on. In one sense, a GIS can be viewed as a huge filing system.

Spatial data in GIS are stored in one of two ways, either in arrays of cells (pixels, a shortened version of "picture cells") or as vectors (points, lines and polygons). The array of cells is often called a raster format. The DEM and land use/cover data are represented in pixels with a 30-meter resolution. This means that for every 30-meter by 30-meter square area, only one value is associated with each pixel. The other data used in the analysis are in a vector format.

In the GIS software, ARCINFO®, raster data and vector data can be analyzed together. As well, raster data can be converted to vector data and vice versa. The types of functions GIS can perform are many and vary in complexity. Fairly simple functions include overlaying maps to show exclusions, gaps or similarities; compute areas of similar features; compute buffer zones from features such as a stream or lakeshore and calculate lengths of lines such as streams and perimeters of polygons. More complicated functions include modeling or computing an expression within a cell or polygon; and linking with simulation models to anticipate natural changes or those associated with development (Costanza *et al.* 1990, Costanza *et al.* 1993, Giles and Nielsen 1992, Maquire and Dangermond 1991, Remillard and Welch 1993).

Geometric Rectification

A central problem in cartography is how to best represent spatial data on spherical Earth on a two-dimensional map. Map projections are mathematical models used to convert locations on Earth's three-dimensional surface to a flat two-dimensional surface. A datum is a set of control points and parameters used to describe the shape of Earth. Datums are used in map projections to create the two-dimensional map.

In order to process the data layers (coverages) in a GIS, they must be in a common map projection and datum. This then allows the layers containing different spatial features (e.g. rivers, streets, land use/cover) to be stacked one on top of another, much like a stack of pancakes. Because the layers are spatially referenced the same way, relationships between and among layers can be examined, and mathematical functions can be performed involving two or more layers.

Projection changes may cause a loss in accuracy, in particular, changing projections in DEMs may result in elevation errors greater than changing the projections of other layers (Lunetta *et al.* 1997). Because DEMs were used to define the watershed boundaries and thus play an important role in the analysis, DEM data were kept in their original Universal Transverse Mercator (UTM) projection. The TIGER/Line data and

MRLC data were transformed to UTM projections in ARC/INFO®. The point coverage of site locations was also in a UTM projection. All coverages had a North American Datum (NAD) 27 datum.

EPA MRLC Data

Definitions for the level 1 and level 2 land use/cover classes are given in Table 4.1. The land use/cover for the entire Rappahannock River watershed is shown in Figure 4.2. Since only a small portion of the entire watershed is covered by the five level 2 classes for barren, only the level 1 class for barren was used in the analyses. Overall, forests and agricultural areas dominant the watershed.

DEM Processing and Watershed Delineation

Two paper maps covering adjacent areas often do not line up perfecting at the edges of the maps. This is because of distortions resulting from a 3-D surface being represented on a 2-D map surface. The same problem occurs with digital spatial data. To cover the entire study area individual 7.5 minute DEMs grids had to be connected together to create one layer. In a GIS different algorithms can be used to merge the edges of two maps. To create the large DEM for this study, average values along the edges were used to merge the individual DEMs. The edges were then visually examined to identify incongruities.

Figure 4.2. Land use/cover map of the Rappahannock River watershed.
Source: EPA MRLC 1996.

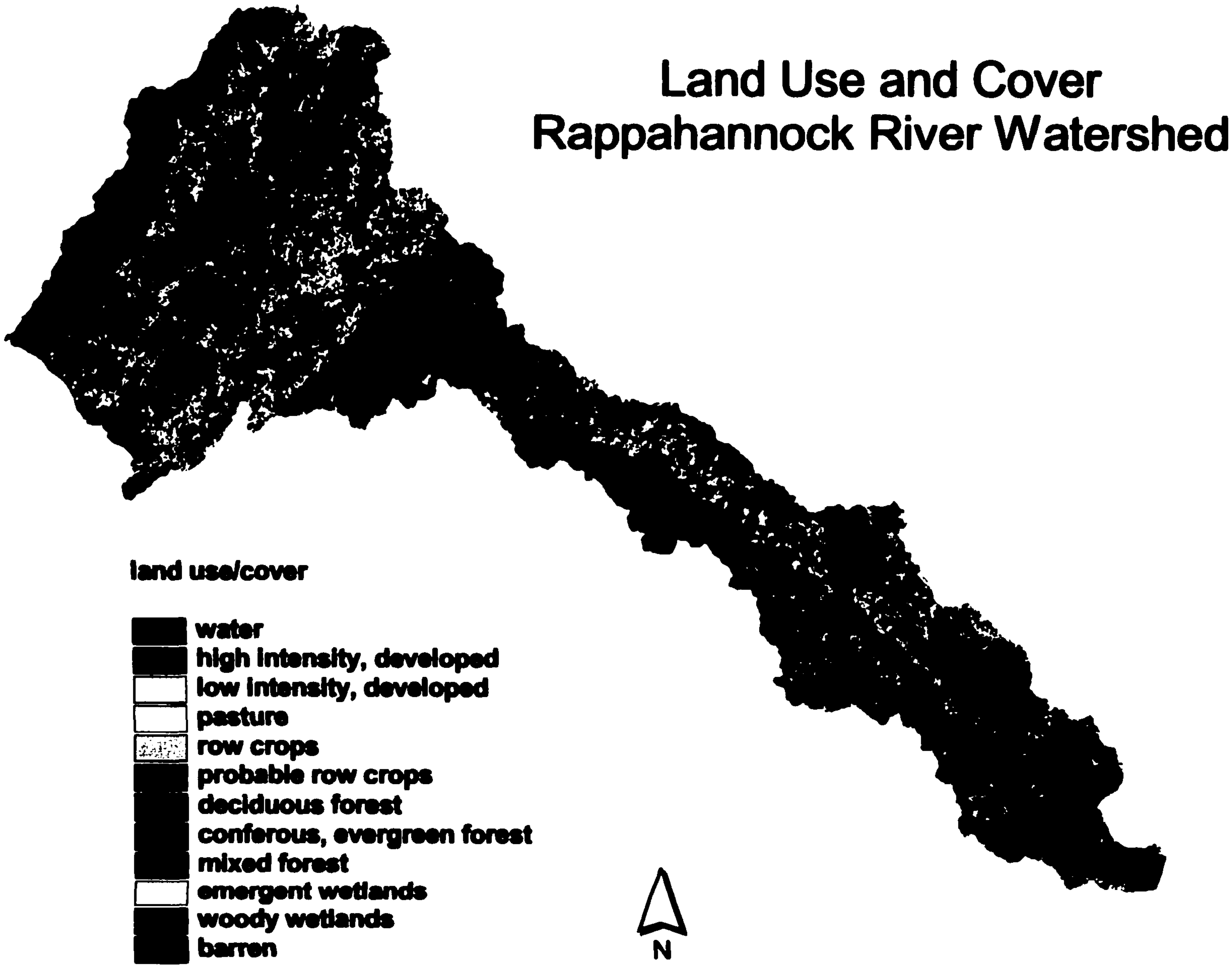

Land Use and Cover
Rappahannock River Watershed
land use/cover
water
high intensity, developed
low intensity, developed
pasture
row crops
probable row crops
deciduous forest
conferous, evergreen forest
mixed forest
emergent wetlands
woody wetlands
barren
N

Table 4.1. Multi-Resolution Land Characteristics (MRLC) Land Cover/Land Use Classifications, version 2 (EPA 1996). The level 1 and level 2 class definitions are both shown.

CLASS LEVEL 1	CLASS LEVEL 2	DEFINITION AND COMMENTS
water		all areas of open water, generally with less than 30% cover of vegetation/land cover
developed		areas characterized by high percentage (approximately 50% or greater) of construction materials (e.g. asphalt, concrete, buildings, etc.)
	low intensity developed	approximately 50-80% constructed material; approximately 20-50% vegetation cover; high percentage of residential development typifies this class
	high intensity developed	20% or less vegetation, high percentage (80-100%) building materials, typically low percentage of residential development in this class
cultivated		areas that are typically planted, tilled, or harvested
	grasslands	areas characterized by high percentages of grasses and other herbaceous vegetation that are regularly mowed for hay and/or grazed by livestock; predominantly hay fields and pastures, but also currently includes golf courses and city parks
	row crops	areas regularly tilled and planted, often on an annual or biennial basis; examples include corn cotton, sorghum, vegetable crops
	probable row crops	sometimes can be confused with other areas, such as grasslands that were not green during times of spring data acquisitions
upland forests		trees covering 40% or greater area
	conifers/ evergreens forest	of trees present, 70% or greater conifers
	mixed forest	both conifers and deciduous tree species present, with neither particularly dominant
	deciduous forest	of trees present, 70% or greater deciduous tree species

Table 4.1 (concluded). MRLC Land Cover/Land Use Classifications

CLASS LEVEL 1	CLASS LEVEL 2	DEFINITION AND COMMENTS
wetlands		characterized by hydrophytic plants, hydric soils, and continuous or periodic flooding
	woody wetlands	wetlands with substantial amount of woody vegetation present, either trees or shrubs
	emergent wetlands	wetlands without a substantial amount of woody vegetation present, usually with substantial amounts of herbaceous vegetation
barren		composed of bare rock, sand, gravel, or other earthen material with little (in the order of 20% or less) living vegetation present
	quarries	includes are quarry areas (including sand/gravel operations)
	dark coal areas	dark coal piles and strip mines, mostly in northern Pennsylvania, outside of study area
	beaches	no definition given
	transitional	includes areas likely to change to other land cover categories, such as clear cuts

The resulting DEM grid was then processed to remove sinks following the ARC/INFO® hydrology modeling tools (ESRI 1992). Sinks are cells surrounded by cells with higher elevation which cause depressions or pits to be formed. Some sinks may be natural in karst or glacial areas. Most sinks are errors that can interfere with the calculation of flow direction. This was the likely case in the Rappahannock River watershed since it is not in a karst or glacial area.

The watersheds were created from DEMs following the ARC/INFO® hydrology modeling tools. The processed and compiled DEM was then used to generate a flow accumulation coverage. The next step required identifying pour points. Pour points are the cells with the lowest elevations in watersheds. For any watershed, surface flow exits the watershed at the pour point. Pour points were located by overlaying the flow accumulation coverage with the elevation (DEM) coverage. This allowed identification of a pixel for each watershed that had the lowest elevation and highest flow accumulation value without being in the Rappahannock River itself. The resulting watershed grids were converted to vector coverages.

Portions of the study area show little change in elevation. This is particularly true in the flood plain of the Rappahannock River. Subtle changes in topography can be lost with a 30-meter resolution. After the watersheds were generated, each watershed polygon was placed over the TIGER/Line hydrology data of the study area to see if the watershed boundary captured tributaries (or sections of tributaries) belonging to neighboring watersheds or if parts of tributaries were inappropriately excluded. In addition, the watershed boundaries with the stream networks were visually compared to USGS topographic maps (1:24,000) to check for correctness. The watersheds were classified into three quality groups; good, modified, poor. Modifications were made in watershed boundaries to correct for obvious errors. Of the watersheds generated, 21 were well delineated and required little or no modifications to the watershed boundaries generated from the ARC/INFO® hydrology modeling tools. Nine of the watersheds each had area associated with a major tributary either removed or added from a tributary belonging to an adjacent watershed. These were classified as 'modified' and required the area to be corrected by manual digitization. Four of the watersheds were poorly formed and the entire watershed boundaries had to be manually digitized. The topographic maps were used for the digitizing. Table 4.2 shows the watershed quality classifications.

Preprocessing of TIGER/Line Stream and Road Data

TIGER/Line (TM) files are organized by counties. After extracting the required road and hydrology feature classes by county, the resulting hydrology coverages for each county were stitched together in ARC/INFO®. The procedure was repeated to create a compiled road coverage. Duplicate arcs were removed from the resulting stream and road coverages. Arc intersections were checked to make sure that 1) arcs intersected where they should, and that 2) no dangling arcs appeared at these intersections.

4.3.3. Watershed Metrics

Table 4.3 lists the metrics used in the watershed analysis and how the metrics were derived using GIS techniques.

4.4. Stream-Reach Characterization

4.4.1. Stream-Reach Metrics

Measurements of the stream reaches were taken within a 50-m length. The stream reaches are fairly homogeneous within this length of the creeks. Creek profiles were taken with a stadia rod and flexible measure tape. Where possible three transects were made. At some sites, the sediments were either too soft and deep and/or the depths too large to allow a person to walk across the creek. Depths are based on bankfull conditions estimated from the vegetation limits, scour lines and changes in slope (Gordon *et al.* 1992). The percentages of canopy cover, stream bank erosion, pools and riffles were based on visual estimates. Only the snags visible above the surface of the water were counted. Table 4.4 lists the metrics and their derivations.

4.4.2. Benthic Collection

Field

Benthic macrofauna samples were taken between March 24 and 31, 2000. The sites differ in their sediment composition (cobbles, sand and fine materials). For the sites with mainly sand, silt and clay, a single grab sample was taken at each site using a Ekman Grab. Grabs were collected within the channels. All samples were sieved through a 0.5 mm mesh screen and preserved in a buffered 10% formalin solution containing rose bengal, a biological staining agent.

Approximately 100 ml of sediment was taken at the top of the grab for organic content and sediment particle size distribution. The samples were placed on ice in the field and taken back to the lab for analysis.

For the cobble-dominated sites, Claiborne Run, Falls Run, Dicks Creek and Massaponnax Creek, sediment could not be collected with an Ekman Grab. Instead, a D-frame dip net was used to collect the samples. The dimensions of the frame were 0.3 meters wide and 0.3 meters height. The net was placed in a characteristic riffle in a 50-meter stream reach. Within 1 meter upstream of the net, all large cobbles were rubbed by hand in the stream, after which any remaining sediment in the 0.3m x 1m area was stirred by foot for 1 minute. The net collected loose macrofauna and debris floating downstream. Macrofauna and debris were picked from the net and preserved in a buffered 10% formalin solution containing rose bengal.

The different data collection method used for the pebble and cobble-dominated sites limits comparability of results.

Lab

Samples were sorted and specimens were transferred to a 70% ethanol solution. The macrofauna of all samples were identified to the genus or species if possible. The Chironomidae and Oligochaeta were mounted on slides, but not cleared. This limited the identification of some specimens. Voucher specimens were examined by experts for verification of classification.

Macroinvertebrate Aquatic Habitat Assessment

During the macroinvertebrate sampling in March 2000, visual-based habitat assessments were made using a method for low and high gradient streams developed by EPA (Barbour *et al.*, 1999). In this method, each metric is given a score. The total and individual scores for each metric were compared among sites to indicate relative stream quality. Sediment size and organic content were measured in the sediments.

4.5. Statistical Analyses

4.5.1. Watershed and Stream Reach

After grouping the creeks into presence or absence of icthyoplankton based on the results of the plankton sorting, the Kolmogrov-Smirnov and Shapiro Wilk techniques were used to determine which watershed and stream-reach metrics for absence and presence groups had normal distributions. If both groups for the metrics shown in Table 4.3 had normal distributions, T-tests were used to determine if the means were significantly different. Nonparametric Mann-Whitney U tests tested medians of metrics that did not have normal distributions.

Benthic Macroinvertebrate Metrics

Four macroinvertebrate habitat types were sampled: tidal brackish, tidal freshwater, non-tidal sand/silt/clay and pebble/cobble riffles. The expected responses of

Table 4.2. Quality of watersheds generated by ARC/INFO® hydrology modeling functions. good = little or no modification; modified = one or more major tributary added or removed; poor = entire watershed manually digitized.

STREAM	WATERSHED QUALITY
Balls Creek	good
Bellview Creek	modified
Bristle Mine Run	good
Brockenbrough Creek	modified
Cat Point Creek	good
Claiborne Run	good
Colemans Creek	good
Dicks Creek	poor
Falls Run	good
Farmers Hall Creek	modified
Gingoteague Creek	good
Goldenvale Creek	good
Hazel Run	good
Hoskins Creek	good
Hugh Creek	modified
Jones Creek	modified
Keys Run	good
Lambs Creek	good
Little Carter Creek	modified
Little Falls Run	good
Massaponax Creek	good
Millbank Creek	good
Mount Landing Creek	good
Muddy Creek	good

Table 4.2 (concluded). Quality of watersheds generated by ARC/INFO® hydrology modeling functions. good = little or no modification; modified = one or more major tributary added or removed; poor = entire watershed manually digitized.

STREAM	WATERSHED QUALITY
Occupacia Creek	good
Pecks Creek	poor
Peedee Creek	modified
Peumansend Creek	good
Piscataway Creek	good
Richardson Creek	modified
Saunders Creek	poor
Totuskey Creek	modified
Ware Creek	good
Waterview Creek	poor

Table 4.3. Metrics and derivations used in watershed analysis.

METRIC	DERIVATION
percentages land use/cover	The watershed polygons were used to clip out the MRLC data. For each watershed a table containing the number of pixels for each land cover/use class was downloaded as a text file and then imported into a spreadsheet where percentages were calculated. The hydrology network was buffered to create 15-meter, 30-meter, 90-meter, and 200-meter buffers around the stream networks. The resulting polygons were then used to clip out the land cover/use data, which were then downloaded into a spreadsheet.
size (km^2)	After creating the watersheds from the DEMs, watershed (polygon) area was extracted.
area above 5 ft contour (km^2)	Where the 5-ft contour crosses the stream was used as the pour point for each watershed.
shape	The equation used to determine shape is $K = 0.28P/A^{0.5}$; where K = compactness coefficient; P = watershed perimeter; and A = area. This dimensionless index compares the perimeter of the watershed with a circle of the same area. If the watershed is a circle, then K = 1 (Black 1996).
drainage density	Total kilometers of streams/area of watershed.
road density	Kilometers roads/area of watershed.
mean elevation (m)	Elevation data from the processed USGS Digital Elevation Models (DEMs) were downloaded. Weighted averages were calculated.
elevation standard deviation.	Standard deviations were calculated from the downloaded elevation data.
overall slope (degree)	The difference of the maximum and minimum elevations divided by the stream lengths.
maximum slope (degree)	Slope coverages for the entire watershed were derived from the DEMs using ARC/INFO. The vector stream coverage was buffered by 15-m distance to create a 30-m width to correspond to slope coverage pixel size. This was then used to clip out the slope grid coverage. The data were downloaded and maximum slopes were determined.

Table 4.3 (concluded). Metrics and derivations used in watershed analysis

METRIC	DERIVATION
median slope (degree)	The median slope values were determined from the downloaded slope data.
mean slope (degree)	Mean slope values were calculated from the downloaded slope data. Weighted averages were calculated.
slope standard deviation	Standard deviations were calculated from the downloaded slope data.
depth at mouth (m)	Transects were taken at the creek mouths. The maximum depth soundings were corrected for tidal affects. Values shown are mean low water.
width at mouth (m)	Widths at creek mouths were measured.
width/depth at mouth	Widths divided by depths at creek mouths.

Table 4.4. Stream-reach characterization metrics.

Metric	Derivation
% canopy cover	A visual estimate of the percentage of wetted area shaded by shrub or tree canopy was made at each site. The estimates were grouped into 4 categories: 0-25%, 26-50%, 51-75%, and 76-100%.
bankfull width	One to three profiles were taken at each site using a tape measure and stadia rod. Bankfull elevation was determined by one or a combination of: vegetation limits, changes between bed and bank materials, changes in slope and scour lines (Gordon *et al.* 1992). In a few instances, one side of the stream a steep (and eroding) cliff. Bankfull was based on the opposite side.
bankfull maximum depth	Maximum depth was determined from the representative reach profiles and walking longitudinally within the stream channel.
bankfull mean depth	Mean depth was estimated by calculating the average of 4 depths along each representative profile.
% fine sediments (silt and clays; < 0.0625 mm)	Particle size distribution was obtained using a pipette analysis. No samples were taken in the gravel and cobble-dominated streams.
% pebbles/ cobbles	In streams where pebbles and cobbles dominated, estimates using a modified Wentworth scale were made in the field. Percentages for the other sites were calculated in the lab.
% sand/pebbles and cobbles	Particle size distribution was obtained using a pipette analysis. In streams where pebbles and cobbles dominated, estimates using a modified Wentworth scale were made in the field.
% volatile solids in sediment	Samples were taken in the upper 5 cm to estimate the % organic content in sediments.
% bank eroded (left and right banks)	A visual estimate.
bank stability (left and right banks)	Based on EPA's Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers (Barbour *et al.* 1999), this metric indicates whether the stream banks are eroded or have the potential for erosion. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil.
% pools	A visual estimate.
% riffles	A visual estimate.
number of snags	The number of exposed logs were counted.

the metrics listed in Table 3.2 are equivalent. Two approaches were taken to examine the metrics. The first approach involved dividing all sites into two groups, absence and presence of herring larvae, and comparing the means or medians of the metrics, similar to that done for the stream-reach and watershed analyses. For the second approach, the means or medians of the metrics for absence and presence groups within each macroinvertebrate habitat type were compared. Unfortunately, this second method is limited since the tidal brackish and pebble/cobble riffle types both only have four sites. Furthermore, no river herring larvae were found in the tidal brackish sites. Consequently, for this approach, only the tidal freshwater and non-tidal sand/silt/clay habitat types were compared.

4.5.3. Multivariate Analyses

Principal component analysis (PCA) was used to explore patterns in the stream-reach and watershed variables. This technique is based on the assumption that a simple underlying structure can be found within a data set containing numerous variables (Davis 1986). PCA reduces a large number of variables (or metrics, the term used in this study) down to a few components and the resulting components are interpreted from the variables (or metrics) that are grouped together for each component. The variables grouped together for a particular component are more highly correlated for that component than with variables in other components.

In PCA, linear combinations of the variables are made to account for the variation in multi-dimensional space. The first linear combination (component) generally accounts for the largest amount of variation in the data; the second component, the next largest amount and so on until all the variation is accounted for. The components are the eigenvectors of a variance-covariance or a correlation matrix and can be thought of as axes in multi-dimensional space. The eigenvalue for each eigenvector represents the length of the eigenvector and describes the shape of the distribution of values around the axis.

In PCA, each original value is converted to a another value, called a score, by projecting it onto the component axes. Principal component loadings refer to the coefficients of the linear equation of the variables which the eigenvector defines. The stronger the loading (in other words, the larger the coefficient) the more important that variable plays in the linear equation of each component. Scores computed for the components can be used as input for other types of statistical analyses such as discriminant analysis used in this study.

Discriminant analysis creates a linear combination of the variables that produces the maximum difference between previously defined groups. The linear combination of variables is called the discriminant function and can be used to predict the classification of new cases. The purpose for this study is to see how well the components from the PCA maximize the difference between the absence and presence groups. If the results are good, the disciminant function could then be used to predict the group membership of a stream not used in the analysis within the Rappahannock River watershed or a stream feeding into another watershed such as the York River or James River.

Discrimant analysis was also used to explore the relative importance of stream-reach and watershed metrics in predicting group membership. To do this, five groups of metrics were selected:

Watershed 1 - watershed land use/cover and watershed morphology metrics,

Watershed 2 - watershed morphology and land use/cover within a 200-m buffer metrics,

Watershed-Reach with Land Use/Cover within Watershed - watershed morphology, land cover/use within the watershed metrics, reach substrate, water quality and morphology metrics,

Watershed-Reach with Land Use/Cover within a 200 m Buffer - watershed morphology, land use/cover within the 200-meter buffer metrics, reach substrate, water quality and morphology metrics,

Reach - land use/cover within the 200-meter buffer and reach substrate, water quality and morphology metrics.

The first two groups use watershed morphology metrics but differ in the land use/cover metrics. The first group uses land use/cover within the watershed and the other uses land use/cover within a 200-m buffer. The reach group uses reach metrics and land use/cover within a 200-m buffer. The two watershed-reach groups use a combination of watershed morphology metrics and differ in the land cover/ use; one uses land use/cover within the 200-m buffer or watershed and the other uses land use/cover within the watershed. The results from these analyses should indicate whether watershed morphology or reach metrics are better at predicting the presence or absence of herring spawning as well as indicating whether the land use/cover within the 200-m buffer or the watershed metrics are better at classifying herring usage for spawning.

Statistical Package for Social Scientists (SPSS) was used to do the PCA and discriminant analyses. For the PCA, components with eigenvalues greater than 1 were chosen for each group. Varimax rotations were used to help create interpretable components by making greater differences in the loadings of individual metrics.

Discriminant analysis requires the variables to have normal distributions and equal covariances (SPSS 1999). Only those components that met these assumptions were chosen to use in a discriminant analysis. As done with the metrics the Kolmogrov-Smirnov and Shapiro Wilk techniques were used to test for normal distributions.

To check for equal covariances, the scores for the all the components were screened in various ways following the suggestions in the *SPSS 9.0 Applications Guide* (1999). Box plots for each component were examined between the absence and presence groups and scatter plots of the scores showed the distribution and trend of the scores for each group. Lastly, covariance matrices for each group were examined. Components were eliminated for discriminant analysis if the values in the covariance matrix differed greatly, either by sign (negative or positive) or by magnitude between the absence and presence groups.

The classification results from the discrimanant analyses were compared among the Watershed, Watershed-Reach and Reach groups to determine which group has the best ability to predict whether the stream supported herring spawning.

Chapter 5

Results

5.1. Icthyoplankton Collection

Eggs or larvae of river herring were found in 17 of the 34 streams sampled, shown in Figure 5.1. Table 5.1 shows the total number of samples taken at each stream and the number of samples that had herring yolk-sac larvae and embryos in 1996 and 1997. Of the streams sampled in both years, most had either eggs and larvae, or none in both years. Five streams, Hazel Run, Little Falls Run, Peedee Creek, Muddy Creek, and Ware Creek showed no evidence of spawning in 1996 whereas eggs and larvae were present in 1997. Uzee and Angermeier (1993) classified most of the same 34 streams as either confirmed or probable, whereas the plankton collections in this study had no indication of spawning in 17. Table 5.2 compares the results of the icthyoplankton sampling and the classification given by Uzee and Angermeier (1993) for river herring. The comparison reveals that for the streams with no eggs or larave, Uzee and Angermeier (1993) classified 3 as probable, 8 as confirmed and 4 as uncertain. For the streams with eggs and larvae, 2 were classified as probable, 14 as confirmed and 1 as uncertain.

Figure 5.1. Map showing the watersheds where presence of spawning was found and watersheds where no evidence of spawning was found. Evidence of spawning was found in 17 watersheds (classified as presence) and no evidence was found in 17 (classified as absence).

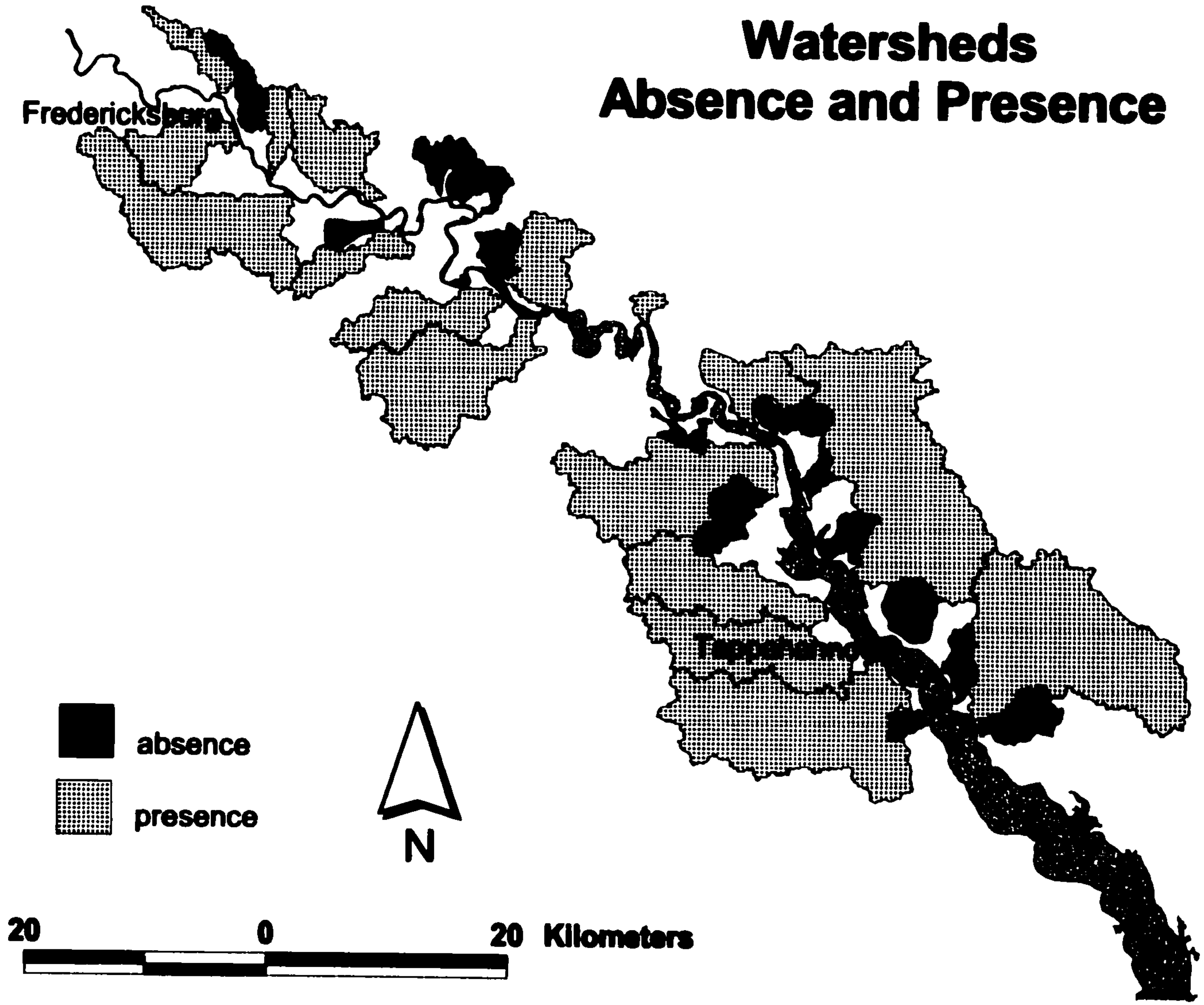

Watersheds
Absence and Presence
Fredericksburg
absence
presence
N
20
0
20 Kilometers

Table 5.1. Total number of samples taken in 1997, the number of samples that had evidence of spawning in 1997, and whether evidence of spawning was found in 1996. NS = Not Sampled.

STREAM	TOTAL SAMPLES TAKEN IN 1997	# SAMPLES WITH LARVAE/EMBRYOS IN 1997	EVIDENCE OF SPAWNING IN 1996
Balls Creek	7	0	NS
Bellview Creek	6	0	NS
Claiborne Run	7	0	no
Colemans Creek	8	0	no
Dicks Creek	7	0	no
Farmers Hall	8	0	no
Hugh Creek	5	0	NS
Jones Creek	7	0	no
Keys Run	6	0	no
Lambs Creek	6	0	no
Little Carter Creek	6	0	NS
Millbank Creek	6	0	no
Pecks Creek	8	0	NS
Richardson Creek	7	0	NS
Saunders Creek	8	0	NS
Waterview Creek	7	0	NS
Brockenbrough Creek	6	0	NS
Falls Run	7	2	yes
Peedee Creek	7	2	yes
Ware Creek	7	2	no
Hoskins Creek	7	3	yes
Muddy Creek	7	3	no
Gingoteague Creek	7	4	yes
Goldenvale Creek	7	4	NS

Table 5.1 (concluded). Total number of samples taken in 1997, the number of samples that had evidence of spawning in 1997, and whether evidence of spawning was found in 1996. NS = Not Sampled.

STREAM	TOTAL SAMPLES IN 1997	# SAMPLES WITH LARVAE/EMBRYOS IN 1997	EVIDENCE OF SPAWNING IN 1996
Hazel Run	8	4	no
Totuskey Creek	6	4	yes
Bristle Mine Run	6	5	NS
Cat Point Creek	7	5	yes
Little Falls Run	7	5	no
Piscataway Creek	7	5	yes
Mount Landing Creek	7	7	yes
Massaponax Creek	1	1	yes
Occupacia Creek	1	1	yes
Peumansend Creek	1	1	yes

The amount of dissolution of the clod cards ranged between 0.03 g/hour and 0.46g/hour with a mean of 0.15g/hour ± 0.04. The small dissolution rates makes estimates of relative velocities and relative volumes of water flowing through the nets questionable. Because of this, no estimates of relative velocities were made.

5.2. Watershed Analysis

5.2.1. Watershed Land Use/Cover

Comparison of Means and Medians

Significantly different land use/cover metrics using either the T-test or the Mann-Whitney U test are shown in Table 5.3. The metrics, %grassland and % deciduous forest, are significantly different for all the buffers and the watershed. The variable, % barren, is significantly different for all the buffers but not for the watershed. The variable, % agriculture, shows differences for the 30-, 90- and 200-meter buffers, whereas % forest is significantly different for the 90- and 200-meter buffers. In addition, % mixed forest is different for the 15- and 30-meter buffers and % emergent wetland is different for the 15- and 90-meter buffers. The 90-meter buffer has the greatest number, seven, metrics with significant differences and the watershed has the least number, three, of significantly different metrics.

Spearman's Rho correlations between %grassland and %deciduous forest, and between %forest and %agriculture are the strongest, -0.753 and -0.863 respectively, shown in Tables 5.4 and 5.5.

Table 5.2. Comparison between the results of this study and Uzee and Angermeier (1993).

STREAM	PLANKTON SAMPLING 1996 AND 1997	UZEE AND ANGERMEIER (1993)
Balls Creek	absence	probable
Bellview Creek	absence	no report
Bristle Mine Run	presence	confirmed
Brockenbrough Creek	absence	confirmed
Cat Point Creek	presence	confirmed
Claiborne Run	absence	uncertain
Colemans Creek	absence	uncertain
Dicks Creek	absence	confirmed
Falls Run	presence	probable
Farmers Hall	absence	confirmed
Gingoteague Creek	presence	probable
Goldenvale Creek	presence	confirmed
Hazel Run	presence	confirmed
Hoskins Creek	presence	confirmed
Hugh Creek (Popcastle Creek)	absence	uncertain
Jones Creek	absence	uncertain
Keys Run	absence	confirmed
Lambs Creek	absence	probable
Little Carter Creek	absence	confirmed
Little Falls Run	presence	uncertain
Massaponax Creek	presence	confirmed
Millbank Creek	absence	confirmed
Mount Landing Creek	presence	confirmed

Table 5.2 (continued). Comparison between the results of this study and Uzee and Angermeier (1993).

STREAM	PLANKTON SAMPLING 1996 AND 1997	UZEE AND ANGERMEIER (1993)
Muddy Creek	presence	confirmed
Occupacia Creek	presence	confirmed
Pecks Creek	absence	probable
Peedee Creek	presence	confirmed
Peumansend Creek	presence	confirmed
Piscataway Creek	presence	confirmed
Richardson Creek	absence	confirmed
Saunders Creek	absence	uncertain
Totuskey Creek	presence	confirmed
Ware Creek	presence	confirmed
Waterview Creek	absence	confirmed

Table 5.3. Land use/cover metrics for the watershed and 15-, 30-, 90-, 200 meter buffers with significant differences ($p < 0.05$). Mean and standard deviation values are shown for the metrics that used the T-test. Median and the 25 and 75 quartile values are shown for the metrics that used the Mann-Whitney U test.

Buffer	**% Land Use/Cover**	**Statistical Test**	**Absence Mean or Median**	**Presence Mean or Median**	**P Value**
15-m Buffer	% deciduous forest	T-Test	20.53 ± 13.26	39.45 ± 16.85	0.001
	% emergent wetland	T-Test	13.73 ± 12.55	6.85 ± 5.51	0.050
	% grasslands	Mann-Whitney U	2.81 0.71 - 6.05	0.71 0.25 - 1.58	0.048
	% mixed forest	Mann-Whitney U	11.23 7.66 - 17.98	7.15 4.57 - 10.70	0.026
30-m Buffer	% deciduous forest	T-Test	24.51 ± 13.78	38.87 ± 17.22	0.011
	% agriculture	T-Test	13.72 ± 11.32	7.10 ± 5.71	0.042
	% grasslands	Mann-Whitney U	3.10 0.93 - 6.47	0.93 0.34 - 1.83	0.022
	% mixed forest	Mann-Whitney U	12.13 8.52 - 19.14	7.53 4.94 - 11.39	0.018
	% barren	Mann-Whitney U	0.00 0.00 - 0.70	0.11 0.00 - 0.70	0.014
90-m Buffer	% grasslands	T-Test	8.30 ± 5.81	2.96 ± 2.70	0.002
	% probable row crop	T-Test	9.15 ± 6.65	5.21 ± 3.68	0.040
	% deciduous	T-Test	27.22 ± 16.50	45.67 ± 10.52	0.001
	% emergent wetland	T-Test	9.00 ± 7.43	4.61 ± 3.79	0.040
	% agriculture	T-Test	20.80 ± 13.01	11.21 ± 7.55	0.014
	% barren	Mann-Whitney U	0.00 0.00 - 0.00	0.29 0.00 - 1.26	0.006
	% forest	Mann-Whitney U	54.31 40.00 - 63.20	60.56 55.45 - 65.47	0.037

Table 5.3 (concluded). Land use/cover metrics for the watershed and 15-, 30-, 90-, 200 meter buffers with significant differences (p< 0.05). Mean and standard deviation values are shown for the metrics that used the T-test. Median and the 25 and 75 quartile values are shown for the metrics that used the Mann-Whitney U test.

Buffer	% Land Use/Cover	Statistical Test	Absence Mean or Median	Presence Mean or Median	P Value
200-m Buffer	% grasslands	T Test	11.69 ± 5.65	5.73 ± 3.76	0.001
	% deciduous	T Test	26.49 ± 17.09	44.62 ± 10.72	0.001
	% agriculture	T Test	28.01 ± 13.16	17.15 ± 8.94	0.008
	% forest	T Test	53.61 ± 16.49	65.34 ± 8.22	0.015
	% barren	Mann-Whitney U	0.00 0.00 - 0.08	0.51 0.02 - 1.83	0.006
Watershed	% grasslands	T Test	16.68 ± 6.06	10.69 ± 5.29	0.004
	% deciduous	T Test	24.38 ± 15.41	37.92 ± 12.97	0.009
	% developed	Mann-Whitney U	1.06 0.05 - 1.67	0.43 0.54 - 5.47	0.048

Table 5.4. Spearman's Rho correlations for the level 2 land use/cover watershed metrics.

	barren	water	low density developed	high density developed	grassland	row crops	probable row crops	conifer/ evergreen forest	mixed forest	deciduous forest	woody wetlands	emergent wetlands
barren	1.000											
water	0.439 0.009	1.000										
low density developed	0.289 0.098	0.111 0.532	1.000									
high density developed	0.284 0.103	0.081 0.648	0.669 0.000	1.000								
grasslands	-0.437 0.010	-0.260 0.138	-0.428 0.012	-0.244 0.164	1.000							
row crops	-0.071 0.690	-0.200 0.256	0.251 0.152	0.159 0.368	0.228 0.196	1.000						
probable row crops	-0.504 0.002	-0.376 0.029	-0.193 0.274	-0.019 0.916	0.373 0.030	0.280 0.109	1.000					
conifer/ evergreen	0.231 0.188	0.143 0.421	-0.196 0.266	-0.124 0.485	0.058 0.746	-0.064 0.717	-0.303 0.081	1.000				
mixed forest	-0.040 0.821	0.075 0.672	-0.632 0.000	-0.167 0.345	0.314 0.071	-0.316 0.068	-0.011 0.949	0.313 0.071	1.000			
deciduous forest	0.337 0.051	0.270 0.122	0.494 0.003	0.041 0.816	-0.753 0.000	-0.188 0.286	-0.479 0.004	-0.246 0.160	-0.572 0.000	1.000		
woody wetlands	-0.173 0.328	0.239 0.173	-0.164 0.353	-0.159 0.370	0.143 0.421	-0.335 0.053	0.105 0.554	-0.017 0.926	-0.037 0.838	0.007 0.968	1.000	
emergent wetlands	-0.195 0.268	0.316 0.069	-0.374 0.029	-0.101 0.569	0.105 0.554	-0.441 0.009	0.111 0.533	0.095 0.595	0.520 0.002	-0.268 0.125	0.514 0.002	1.000

Table 5.5. Spearman's Rho correlations for the level 1 land use/cover watershed metrics.

	developed	agriculture	forest	wetlands
developed	1.000			
agriculture	-0.299 . 0.086	1.000		
forest	0.004 0.980	-0.863 0.000	1.000	
wetlands	-0.279 0.110	0.018 0.921	-0.082 0.645	1.000

Table 5.6 identifies the metrics that are significantly different between the presence and absence streams in the buffer zones and watershed. In general, those watersheds that had evidence of spawning have less area used for agricultural purposes, particularly in %grassland, and greater area covered by forest, particularly deciduous forest, although less mixed forest. In addition, barren areas cover a larger area on average in buffer zones and watersheds with eggs/larvae. However, it should be noted that the percentages are small; the greatest mean is 1.60%. The buffer zones of the streams in the absence group tend to have a greater percentage of emergent forest. Although the percentage is small, those watersheds with evidence of spawning have more development (median = 1.06%).

5.2.2. Watershed Morphology

Table 5.7 shows the metrics that have significantly different means or medians. The watersheds in the presence group are larger both for the entire size and the area above the 5-foot contour. The watersheds also have greater mean elevations and water depths at the creek mouths. The watersheds in the absence group tend to be shaped more like circles and have greater drainage densities. Although the watersheds in the presence group have greater maximum slopes, the overall slopes are greater for the watersheds in the absence group. The slope and elevation standard deviations indicate that the watersheds in the presence group have a greater diversity of elevation and slope.

Table 5.6. A comparison of the significant land use/cover metrics in the watershed and buffer zones.

Land Use/Cover		Buffer width (m)				Watershed
Level 1	Level 2	15	30	90	200	
developed						x
	low intensity developed					
	high intensity developed					
cultivated			x	x	x	
	grasslands	x	x	x	x	x
	row crops			x		
	probable row crops					
upland forests				x	x	
	conifers/ evergreens					
	mixed	x	x			
	deciduous	x	x	x	x	x
wetlands						
	woody wetland					
	emergent wetlands	x		x		
barren		x	x	x	x	

5.3. Stream-Reach Characterization

5.3.1. Water Quality Measurements

Table 5.8 shows the maximum, minimum and median measurements taken for temperature, dissolved oxygen and pH during the 1997 sampling season. The values that are at or outside the acceptable ranges for the habitat requirements (see Table 2.1) shown in Table 5.8 are highlighted. Most values are in the accepted range.

5.3.2. Stream-Reach Morphology

Table 5.9 shows the medians, quartiles and ranges of continuous stream-reach metrics and Table 5.10 shows the results of Mann-Whitney U tests. The results of EPA's rapid habitat assessment are shown in Table 5.11 and 5.12.

Sites where presence of spawning were found to have greater canopy cover and greater number of snags. Although there are no significant differences in the % eroding banks and bank stability between groups, the absence group have greater number of sites with more stable banks and less % eroding banks. There are no significant differences between the percentages of pools and riffles between the groups.

The non-parametric Mann-Whitney U test reveals significant differences between the medians of % silt and clay, % pebbles and cobbles, % sand/pebbles/cobbles and the % organics. The presence group has less clay and silt, greater percentages of pebbles and cobbles, and fewer organics. There are no significant differences for stream-reach width, bankfull maximum depth, bankfull mean depth and % eroding.

Significant differences were found in five of EPA's habitat assessment metrics: epifaunal substrate/available cover, pool substrate characterization, pool variability, sediment deposition, and channel alteration. As well, the total scores were significantly different. In all of the metrics, the absence group had lower median values.

EPA's rapid habitat assessment for high-gradient streams was used for four of the streams: Falls Run, Massaponax Creek, Dicks Creek, and Claiborne Run. These creeks are located near or pass through Fredericksburg at the fall line. Evidence of herring spawning was found in Falls Run Creek and Massaponax Creek. In the high-gradient assessment, the low-gradient metrics, pool substrate, pool variability, channel sinuousity, are replaced with embeddedness, velocity/depth regime and frequency of riffles. The sample size is too small to indicate any patterns. The total scores are lower for Falls Run and Massaponax Creek.

5.3.3. Benthic Results

Of the 87 taxa found in the benthic samples (Table 5.13), 24 were found in only one stream and considered rare. Sixty-seven taxa were identified to genera, 18 to family, and two to order. The samples contained taxa typically found in tidal-freshwater wetlands (Yozzo and Diaz 1999), oligohaline (Draheim 1998; Weisberg *et al.* 1997), and sand (USEPA 1997) and cobble-dominated streams (Barbour 1999). Most sites were dominated by Oligochaeta and Chironomidae; a few sites were dominated either by Hydrobiidae or Polychaeta. Unfortunately, many of the oligochaetes were immature

Table 5.7. Morphology metrics with significant differences ($p < 0.05$). Mean and standard deviation values are shown for the metrics that used the T-test. Median and the 25 and 75 quartile values are shown for the metrics that used the Mann-Whitney U test.

METRIC	STATISTICAL TEST`	ABSENCE MEAN OR MEDIAN	PRESENCE MEAN OR MEDIAN	P VALUE
size (km2)	T-Test	11.03 ± 5.86	70.17 ± 57.63	0.001
area above 5 ft contour (km2)	T-Test	7.15 ± 4.27	49.30 ± 32.68	0.000
shape	T-Test	1.82 ± 0.31	2.39 ± 0.228	0.000
drainage density (stream length/area * 1000)	T-Test	1.31 ± 0.39	0.92 ± 0.12	0.001
slope (degree) maximum	T-Test	10.33 ± 3.77	15.66 ± 4.60	0.001
slope standard deviation	T-Test	1.93 ± 0.68	2.41 ± 0.50	0.026
elevation (m) mean	Mann-Whitney U	24.49 19.19 - 36.71	43.89 35.77 - 47.67	0.000
elevation (m) standard deviation.	Mann-Whitney U	13.31 10.41 - 15.29	16.14 14.70 - 21.47	0.007
overall slope (degree)	Mann-Whitney U	0.32 0.20 - 0.42	0.12 0.05 - 0.24	0.005
depth at mouth (m)	Mann-Whitney U	0.34 0.09 - 0.96	0.83 0.09 - 3.53	0.010

Table 5.8. Maximum, minimum and median values taken for temperature, dissolved oxygen and pH. Highlighted values are outside the suitability ranges for the habitat requirements (see Table 1.1).
* Measurements collected in 1996

	TEMPERATURE			DO			pH		
	Max	Min	Med	Max	Min	Med	Max	Min	Med
Balls Creek	27.0	12.0	19.2	11.1	7.5	9.4	7.7	6.5	6.9
Bellview Creek	20.0	6.6	14.0	9.9	2.7	6.2	8.0	6.4	6.9
Bristle Mine Run	16.2	9.0	12.3	13.2	9.3	10.3	7.6	6.4	6.6
Brockenbrough Creek	23.5	11.5	20.0	10.8	5.3	7.8	7.8	6.5	6.8
Cat Point Creek	22.0	11.0	16.5	10.8	6.4	9.3	7.6	6.7	6.8
Claiborne Run	17.0	10.0	14.0	11.2	9.1	9.9	7.7	6.9	7.0
Colemans Creek	22.1	11.0	15.8	12.0	5.2	9.0	8.7	6.7	7.0
Dicks Creek	16.0	8.0	13.8	11.3	8.0	9.9	6.7	6.2	6.5
Falls Run	17.0	9.0	14.0	11.2	9.4	10.1	7.7	7.1	7.3
Farmers Hall	23.0	12.0	16.2	9.4	4.2	6.7	8.0	6.4	6.8
Gingoteague Creek	22.0	10.0	14.0	14.1	5.1	8.3	7.8	6.4	6.8
Goldenvale Creek	20.0	9.0	15.3	11.2	7.5	8.9	7.3	6.4	6.9
Hazel Run	16.5	8.0	14.0	11.6	9.4	10.1	7.1	5.7	7.0
Hoskins Creek	19.0	10.5	14.5	10.0	7.6	8.7	7.4	6.3	6.5
Hugh Creek	22.0	9.0	15.0	14.4	8.8	9.8	7.4	6.6	7.2
Jones Creek	23.0	11.5	18.0	13.8	5.8	9.1	7.3	6.6	6.9
Keys Run	20.0	10.0	15.0	13.5	8.5	9.6	7.6	6.8	7.1
Lambs Creek	18.0	7.5	13.7	13.9	8.6	9.8	7.3	6.5	6.7
Little Carter Creek	26.0	12.5	21.8	12.6	7.0	9.6	7.8	6.4	6.8
Little Falls Run	18.5	10.0	14.0	11.2	9.0	10.0	7.6	6.6	6.8
Massaponax Creek*	20.2	8.5	16.5	11.2	9.0	9.3	7.1	6.5	6.7
Mount Landing Creek	21.0	7.5	13.4	10.2	6.1	7.4	6.8	6.4	6.5
Millbank Creek non-tidal	21.0	6.5	15.0	11.5	5.0	8.8	7.2	6.7	6.9
Millbank Creek tidal	23.0	13.0	16.0	10.2	8.3	9.3	7.2	6.7	7.0
Muddy Creek	20.5	8.5	15.7	11.0	8.4	9.8	7.7	6.7	7.0
Occupacia Creek	22.5	11.5	14.5	10.7	7.3	8.6	7.8	6.7	6.9

Table 5.8 (concluded). Maximum, minimum and median values taken for temperature, dissolved oxygen and pH. Highlighted values are outside the suitability ranges for the habitat requirements (see Table 1.1).
* Measurements collected in 1996

	TEMPERATURE			DO			pH		
	Max	Min	Med	Max	Min	Med	Max	Min	Med
Peedee downstream	23.0	12.0	17.5	12.4	6.8	8.6	7.8	6.6	6.9
Peedee upstream	21.5	11.0	16.8	14.1	4.1	7.1	7.0	6.4	6.6
Pecks Creek	26.0	11.5	18.3	12.0	6.3	9.6	8.6	6.8	7.1
Peumansend Creek*	20.0	7.0	16.0	11.0	7.5	9.0	7.1	6.1	6.5
Piscataway Creek	19.0	8.0	13.9	10.1	8.0	8.8	8.1	6.8	7.0
Richardson Creek	27.0	11.0	18.3	12.8	5.1	8.5	7.7	6.8	7.0
Saunders Creek	21.8	11.0	16.5	11.6	4.9	9.3	8.6	6.7	7.2
Totuskey Creek	21.0	11.0	18.7	12.0	8.4	9.6	7.7	6.9	7.1
Ware Creek	17.0	9.0	14.0	10.8	8.6	9.7	7.2	6.1	6.4
Waterview Creek	24.0	12.5	18.1	10.8	5.6	7.6	7.0	6.4	6.6

Table 5.9. Medians, quartiles and ranges of stream-reach morphology metrics.

METRIC	ABSENCE	PRESENCE
bankfull width	11.30 7.18 - 16.55 4.11 - 35.39	8.63 6.86 - 12.93 4.73 - 24.08
bankfull maximum depth	1.10 0.85 - 1.45 .68 - 1.89	1.20 0.97 - 1.51 0.71 - 2.97
bankfull mean depth	0.71 0.43 - 0.81 0.24 - 1.06	0.69 0.41 - 0.83 0.17 - 1.95
% clay and silt	45.96 2.37 - 72.15 0.00 - 90.32	4.54 0.04 - 19.04 0.00 - 90.28
% pebbles/cobbles	0 0 - 2.93 0 - 25.40	4.70 0 - 61.30 0 - 100
% sand/pebbles/cobbles	54.04 27.85 - 97.63 9.68 - 100	95.46 80.96 - 99.95 9.72 - 100
% organics	12.15 6.75 - 18.34 0.47 - 32.27	1.39 0.21 - 8.83 0.13 - 11.56
% bank eroded	25 0 - 50 0 - 75	50 10 - 75 5 - 100

Table 5.10. Comparison of medians for stream-reach metrics. Significantly different ($p < 0.05$) metrics are shown in bold.

METRIC	MANN-WHITNEY U RANK STATISTIC	Z SCORE	P VALUE
stream-reach width	120.00	-0.844	0.399
maximum.depth	115.00	-1.016	0.310
mean depth	144.00	-0.017	0.986
% silt and clay	**65.50**	**-2.156**	**0.031**
% pebbles and cobbles	**69.00**	**-2.140**	**0.032**
% sand/pebbles/cobbles	**81.00**	**-2.197**	**0.028**
% organics	**39.00**	**-3.202**	**0.001**
% eroding	55.0	-1.770	0.077

Table 5.11. Median, quartiles and range of low-gradient habitat assessment metrics.

HABITAT METRIC	ABSENCE	PRESENCE
epifaunal substrate/available cover	12.5 10.25 - 14.75 6 - 19	16 14.5 - 17.25 11 - 20
pool substrate characterization	8 8 - 10 5 - 16	16 12.25 - 17.25 10 - 18
pool variability	5 5 - 10.75 3 - 19	15 12.25 - 16 5 - 19
sediment deposition	6 5 - 12.25 3 - 16	14 10 - 18 5 - 19
channel flow status	19 18 - 19 13 - 20	19 19 - 20 13 - 20
channel alteration	16 13.25 - 18.75 13 - 20	19 17 - 20 13 - 20
channel sinuosity	15.5 12.25 - 16 4 - 18	14.5 12.75 - 15 9 - 16
bank stability left	10 8 - 10 6 - 10	9.5 8 - 10 5 - 10
bank stability right	9 8 - 10 6 - 10	9 7 - 10 6 - 10
vegetative protection left	10 8 - 10 2 - 10	10 9 - 10 5 - 10
vegetative protection right	9.5 8 - 10 4 - 10	9 7 - 10 6 - 10

Table 5.11 (concluded). Median, quartiles and range of low-gradient habitat assessment metrics.

HABITAT METRIC	ABSENCE	PRESENCE
riparian vegetative zone width left	9.5 6 - 10 2 - 10	10 9.75 - 10 5 - 10
riparian vegetative zone width right	9 6.25 - 10 5 - 10	10 9.5 - 10 6 - 10
total score	136.5 124.5 - 150 112 - 170	167.5 147.75 - 177 132 - 183

Table 5.12. Comparison of medians for EPA's rapid habitat assessment metrics for low-gradient stream-reaches. Significantly different ($p < 0.05$) metrics are shown in bold.

Metric	Mann-Whitney U Rank Statistic	Z Score	P Value
epifaunal substrate	**48.00**	**-2.861**	**0.004**
pool substrate	**16.00**	**-3.930**	**0.000**
pool variability	**38.00**	**-3.165**	**0.002**
sediment deposition	**46.50**	**-2.768**	**0.006**
channel flow status	98.00	-0.931	0.352
channel alteration	**66.00**	**-2.184**	**0.029**
channel sinuousity	81.00	-1.568	0.117
bank stability left	118.00	-0.086	0.932
bank stability right	108.50	-0.478	0.633
vegetative protection left	118.00	-0.093	0.926
vegetative protection right	109.00	-0.458	0.647
riparian vegetative zone width left	80.00	-1.852	0.064
riparian vegetative zone width right	83.50	-1.612	0.107
total score	**30.50**	**-3.390**	**0.001**

making it impossible to identify the genus. Appendix 2 contains the number of individuals of each taxon by site for the streams. Total numbers of individuals ranged between 13 and 2147 with a median value of 185. Eleven of the sites had total individual counts less than 100. Of the four groups (non-tidal pebble, non-tidal sand, tidal brackish, and tidal fresh), non-tidal sandy sites had the lowest total individual counts with a median count of 72. Figure 5.3 shows box plots of the four groups. Peedee Creek and Waterview Creek are the outliers in the tidal freshwater sites with total counts of 2147 and 892 respectively.

As with the previous analyses, comparisons of medians and means of the absence and presence of herring larvae groups were made for all the benthic metrics shown in Table 3.2. Comparisons were made of the benthic metrics combining all four tidal and substrate groups. A second set of comparisons was made on the largest tidal/substrate group, tidal fresh (TF) with 16 creeks. The significantly different means and medians are shown in Tables 5.14 and 5.15.

Most of the benthic metric values for the absence group indicate "healthier" streams than the values for the presence group. The two exceptions are %*Chironomus* to %Chironomidae and %*Chironomus* to %Chironomini. These two metrics indicate a more degraded environment for the absence group. The percentages of *Chironomus* in the samples are very small, ranging between 0.00% and 33.66% with a median of 0.00%. The ratios of %*Chironomus* to %Chironomidae and %*Chironomus* to %Chironomini both range between 0.00 and 1.00 with a median value of 0.00. The streams with the highest ratios (greater than 0.85) of %*Chironomus* to %Chironomidae and %*Chironomus* to

%Chironomini are Little Carter Creek, Pecks Creek, and Jones Creek. Except for Gingoteague Creek, all 12 streams with ratios greater than 0.00 are in the absence group.

When comparing only the absence and presence groups for tidal freshwater sites the %*Chironomus* to %Chironomidae and %*Chironomus* to %Chironomini metrics again indicate more degraded environments for the absence group. As well, the lack of shredders in the absence group indicates increased degradation. The other metrics indicate the opposite.

Ten sites are classified as non-tidal sandy environments. Of these, only two streams, Keys Run and Lambs Creek, lacked evidence of herring spawning. The values for all the metrics at Keys Run and Lambs Creek do not reveal anything different or unusual than the metric values for the other streams with non-tidal sandy environments that showed evidence of herring spawning.

There are fewer metrics that show significant differences in the tidal-freshwater presence and absence groups than when comparing all sites (6 vs. 11). An examination of the two *Chironomus* metrics for the non-tidal sandy sites (n = 11), reveal 9 of the 11 sites in the presence group had ratios equal to 0.00 whereas Lambs Creek in the absence group had ratios greater than 0.00 for both metrics. Similarly for the tidal freshwater sites (n = 16), 6 of the 7 sites in the presence group had ratios greater than 0.00 whereas only 1 of the 9 sites in the absence group had ratios greater than 0.00.

Four sites, Claiborne Run, Falls Run, Massaponax Creek and Dicks Creek, were sampled in pebble- and cobble-dominated habitats. The benthic community at Claiborne Run shows a large diversity with a comparatively good water quality indicator status. The

Table 5.13. List of taxa found in benthic macroinvertebrate samples.

TAXA

CRUSTACEA
- ISOPODA
  - *Cyathura*
  - *Caecidotea*
  - *Cassidinea*
  - *Edotea*
  - CUMACEA
  - *Almyracuma*
- AMPHIPODA
  - *Corophium*
  - *Crangonyx*
  - *Gammarus*
- DECAPODA
  - Cambaridae
  - *Rithropanopeus*

MOLLUSCA
- GASTROPODA
  - Hydrobiidae
  - Gyralus
  - Viviparidea
- BIVALVIA
  - *Corbicula*
  - Sphaeriidae
  - Unionidae
  - *Rangia*
  - *Macoma*

ANNELIDA
- HIRUDINEA
  - *Helobdella*
  - *Myzobdello*
- POLYCHAETA
  - *Hobsonia*
  - *Laonereis*
  - *Marenzelleria*
  - *Hetermastus*
- OLIGOCHAETA
  - Naididae 1
  - Naididae 2
  - *Dero*

Table 5.13 (continued). List of taxa found in benthic macroinvertebrate samples.

TAXA

OLIGOCHAETA (continued)

Paranais
Pristina
immature without chaetae
Tubificoides
Aulodrilus
Ilydrilus
Limnodrilus
Quistradrilus
Enchytraeidae
Lumbriculidae

PLANARIA

Dugesia

NEMERTEA

INSECTA

DIPTERA

Bezzia
Forcipomyia
Chelifera
Simulidae
Tipula

Chironomidae

Chironomus
Cladopelma
Cryptchironomus
Dicrotendipes
Glyptotendipes
Paracladopelma
Paratendipes
Phaenopsectra
Polypedium
Orthocladinae
Symbiocladius
Boreochlus
Clinotanypus
Pentaneurini
Procladius
Tanypus
Cladotanytarsus
Rheotanytarsus
Tanytarsus

Table 5.13 (concluded). List of taxa found in benthic macroinvertebrate samples.

TAXA

COLEOPTERA
Curculionidae
Dysticidae
Haliplus
Brychius
Berosus
COLLEMBOLA
Isotomidae
Smithuridae
EPHEMEROPTERA
Baetis
Caenis
Stemonema
Hexagenia
Eurylophella
HEMIPTERA
Belostomatidae
Corixidae
MEGALOPTERA
Nigronia
ODONATA
Coenagrionidae
Gomphus
Perithemis
PLECOPTERA
Isoperla
TRICOPTERA
Helicopsychidae
Hydropsyche
Oecetos

HYDRACARINA

Figure 5.3. Box plots of total benthic macroinvertebrate counts. NP = non-tidal pebble, NS = non-tidal sand, TB = tidal brackish, TF = tidal fresh.
Two streams with outlier values are not shown: Peedee Creek has a total individual count of 2147 and Waterview Creek has a total individual count of 892.

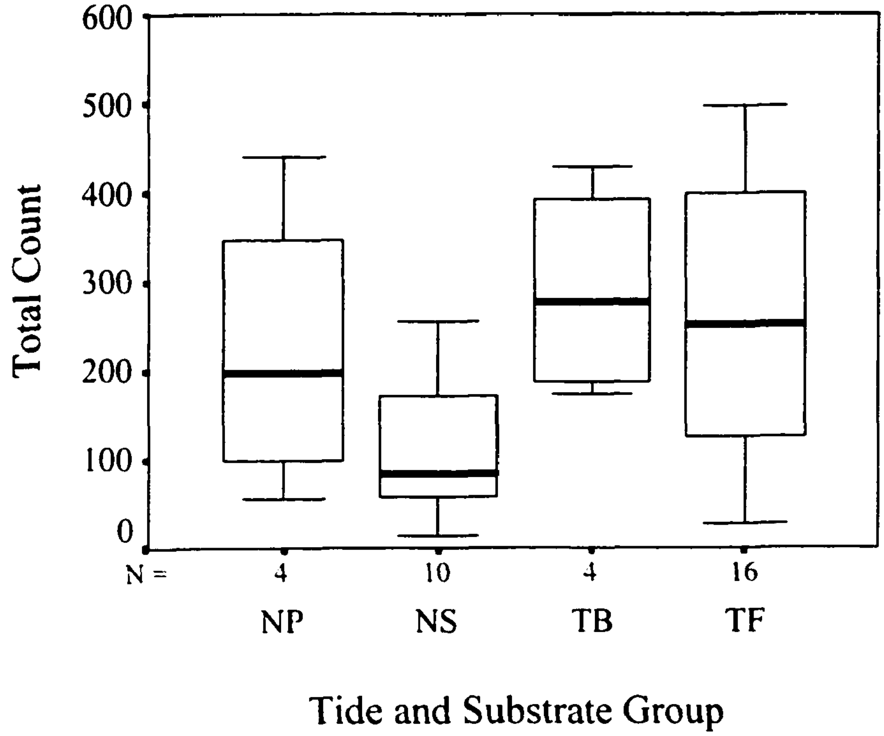

600
500
400
300
200
100
0
Total Count
N =
4
10
4
16
NP
NS
TB
TF
Tide and Substrate Group

Table 5.14. Benthic macroinvertebrate metrics from all sites with significant differences ($p < 0.05$). Mean and standard deviation values are shown for the metrics that used the T-test. Median and the 25 and 75 quartile values are shown for the metrics that used the Mann-Whitney U test.

Benthic Metric	**Statistical Test**	**Absence Mean or Median**	**Presence Mean or Median**	**P Value**
No.Crustacea + Mollusca Taxa	T-Test	3.82 ± 2.43	2.29 ± 1.31	0.029
% Oligochaeta	T-Test	31.93 ± 17.45	53.01 ± 28.14	0.013
Diversity Index	T-Test	2.61 ± 0.58	2.11 ± 0.73	0.037
Total No. Taxa	Mann-Whitney U	16.00 13.50 - 18.50	11.00 9.00 - 14.50	0.003
Total Count	Mann-Whitney U	293.00 185 - 423	87.00 24 - 212	0.003
No. Polychaeta Taxa	Mann-Whitney U	2.00 0.50 - 2.00	0.00 0.00 - 1.00	0.001
No. Oligochaete Taxa	Mann-Whitney U	4.00 2.00 - 4.00	2.00 1.50 - 3.00	0.014
% Polychaeta	Mann-Whitney U	17.00 2.20 - 44.7	0.00 0.00 - 1.25	0.001
% *Chironomus* to % Chironomidae	Mann-Whitney U	0.04 0.00 - 0.21	0.00 0.00 - 0.00	0.001
% *Chironomus* to % Chironomini	Mann-Whitney U	0.10 0.00 - 0.71	0.00 0.00 - 0.00	0.000
Biotic Index	Mann-Whitney U	7.51 7.12 - 8.11	8.53 7.84 - 9.41	0.004

Table 5.15. Benthic macroinvertebrate metrics for tidal freshwater sites with significant differences ($p < 0.05$). Mean and standard deviation values are shown for the metrics that used the T-test. Median and the 25 and 75 quartile values are shown for the metrics that used the Mann-Whitney U test.

Benthic Metric	**Statistical Test**	**Absence Median**	**Presence Median**	**p Value**
No. Polychaeta Taxa	Mann-Whitney U	2.00 1.5 - 3.00	1.00 0.00 - 1.00	0.002
No. Oligochaete Taxa	Mann-Whitney U	4.00 4.00 - 4.50	2.00 2.00 - 3.00	0.007
% Polychaeta	Mann-Whitney U	24.60 8.20 - 47.15	0.20 0.00 - 6.90	0.007
% *Chironomus* to % Chironomidae	Mann-Whitney U	0.06 0.03 - 0.57	0.00 0.00 - 0.00	0.009
% *Chironomus* to % Chironomini	Mann-Whitney U	0.29 0.68 - 0.29	0.00 0.00 - 0.00	0.006
% Shredders	Mann-Whitney U	0.00 0.00 - 1.90	3.30 0.20 - 25.90	0.047

sampling site at Dicks Creek was located in a forested area within a pool and riffle stream reach and the benthic analysis indicates a fairly healthy water quality. Sensitive taxa such as Helgamites were found. All four streams have 0.00 values for the %*Chironomus* / %Chironomidae and %*Chironomus* / %Chironomini.

The macroinvertebrate assemblages at the brackish sites do not show severely degraded environments. All four sites contained pollution-sensitive taxa which would indicate that river herring are not spawning in these streams because of water quality degradation.

5.4. Multivariate Analyses

Watershed

The principal components analysis (PCA) for the Watershed Group produced six components with eigenvalues greater than 1 (Figure 5.4). The six components account for 78.3% of the total variance. After component 6, the values are less than 1 and slowly decrease in value. Table 5.16 shows the eigenvalues and the amount of variance explained by each component for the rotated and non-rotated analyses.

The loadings for the components extracted using a Varimax rotation are shown in Table 5.17. Loading values with less than 0.2 are not shown to visually help identify the larger loadings for each component in the table. Based on the loadings, the components grouped the following metrics together:

Component w1 - mixed forests, deciduous forests and grasslands within the watershed; drainage density; and mean elevation,

Component w2 - low and high intensity developed areas within the watershed; and road density,
Component w3 - size of watershed; area above 5 feet; barren areas within the watershed; shape; and elevation standard deviation,
Component w4 - water, probable row crops and row crops within the watershed,
Component w5 - emergent and woody wetlands within the watershed,
Component w6 - median and standard deviation of slope; and conifers/evergreen forests within the watershed.

The components were examined for normal distributions and covariance, two data requirements for discriminant analysis (SPSS Inc. 1999). All components were found to have normal distributions. A comparison of the covariance matrices for the absence and presence groups reveals that most coefficients either have different signs or magnitudes (Table 5.18). Only the coefficients for w1, w2 and w5 are similar. The scatter plots shown in Figure 5.5 indicate that only components w1 and w5 have similar trends of slope although the spread of data is greater for the absence group. The other scatter plots of pairs of components do not show similar trends of slope and a comparison of the values for each component between the absence and presence groups, shown in the box plots (Figure 5.6), reveals large differences in variances. Based on this examination, two discriminant analyses were performed; one using components w1 and w5 and the other using only component w1. The discriminant analysis using components w1 and w5 had a better prediction of group membership than the analysis using only w1, 88.2% Table 5.19 versus 82.5% (Table 5.20). Because of the better prediction ability, the analysis using both components was selected and the results for it are discussed in more detail.

In SPSS, the Wilks' Lambda is used to test the null hypothesis that the group means are the same for all the components used in a discriminant analysis (SPSS, Inc.

1999). Its value is used to explain the proportion of total variance not explained by differences between the groups. The analysis reveals that about 45% (0.473) of the variance is not explained by group differences. Lambda is transformed to a variable with an approximate chi square distribution. The value, 23.236, indicates that there is a significant difference between the absence and presence group centroids of the discriminant function.

The classification results show that 82.4% of the absence streams were classified correctly in the discriminant model and 94.1% of the presence streams were classified correctly, giving an overall prediction ability of 88.2% (Table 5.19). The streams incorrectly classified are Claiborne Run, Gingoteague Creek, Jones Creek, and Lambs Creek.

Watershed with Land Use/Cover within a 200-m Buffer

The figures and tables for the watershed with land use/cover within a 200-m buffer set of metrics and the other sets of metrics following this section are included in Appendix 4. A PCA for the watershed morphology and land use/cover within a 200-m buffer metrics generated 7 components with eigenvalues greater than 1, shown in Figure A4-1. The 7 components account for 82.56% of the total variance (Table A4-1). The

Figure 5.4. The eigenvalues for the components in a PCA using the watershed land use/cover and morphology metrics. In total 21 metrics were used. Six components resulted with eigenvalues greater than 1.

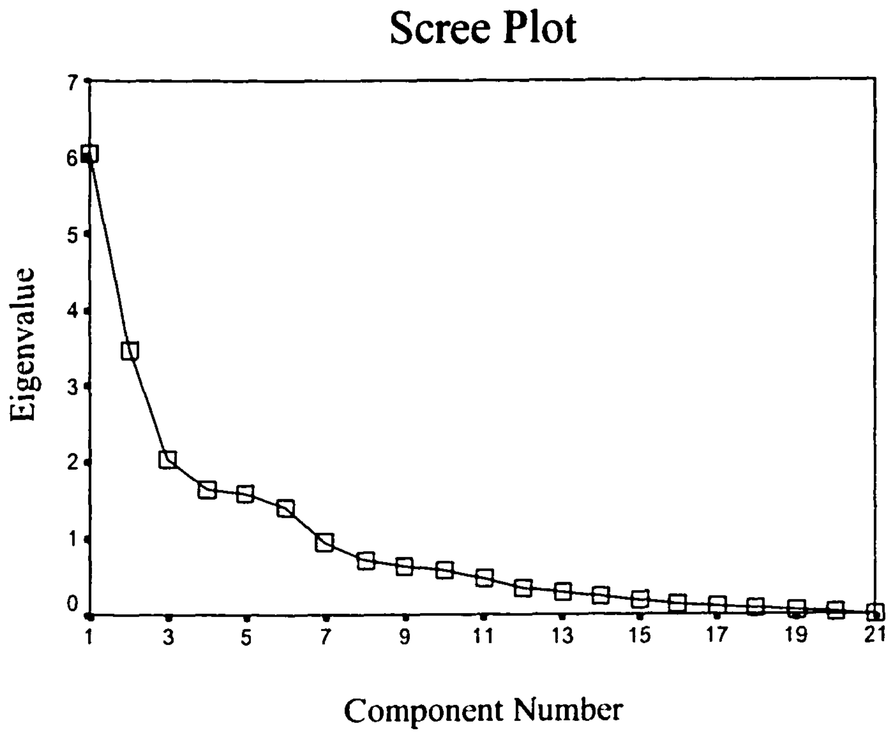

Scree Plot
Eigenvalue
0
1
2
3
4
5
6
7
1
3
5
7
9
11
13
15
17
19
21
Component Number

Table 5.16. The eigenvalues, percent of variance and cumulative percent of variance for the six components with eigenvalues greater than one from the PCA using watershed land use/cover and morphology metrics.

	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
COMPONENT	EIGEN-VALUE	% OF VARIANCE	CUMULATIVE %	EIGEN-VALUE	% OF VARIANCE	CUMULATIVE %
w1	6.032	28.73	28.73	3.400	16.19	16.19
w2	3.468	16.52	45.25	3.225	15.36	31.55
w3	2.033	9.68	54.93	3.075	14.64	46.19
w4	1.645	7.83	62.76	2.232	10.63	56.82
w5	1.583	7.54	70.30	2.156	10.27	67.09
w6	1.402	6.67	76.97	2.075	9.88	76.97

Table 5.17. The component loadings for the watershed land use/cover and morphology metrics. A Varimax rotation was used in the PCA. The shaded values show the variables with the highest loadings for each component.

Metric	**Component**					
	w1	**w2**	**w3**	**w4**	**w5**	**w6**
deciduous forests	0.80[illegible]			0.363		0.264
mixed forests	[illegible]	-0.345		0.242		
elevation, mean	[illegible]	0.535	0.245		0.369	
grasslands	[illegible]		-0.300	-0.402		
drainage density	-0.61[illegible]		-0.287			0.366
high density developed		0.9[illegible]2				
road density		0.90[illegible]				
low density developed	0.227	0.891				
size			0.896			
area above 5 feet	0.278		0.878			
barren		0.308	0.596	0.361		
shape	0.492		0.461	0.302	0.304	
elevation, standard deviation			[illegible]98			0.377
probable row crops	-0.209			-0.838		
row crops	0.267			-0.692	0.359	-0.258
water		-0.261	0.412	0.478		
woody wetlands					-0.900	
emergent wetlands	-0.331				-0.806	
slope, median						0.847
conifers/evergreens forests	-0.252			0.397	0.229	-0.701
slope, standard deviation	0.501		0.235		0.266	0.597

Table 5.18. Covariance matrices for the absence and presence groups of the six components with eigenvalues greater than one. Components w1, w2, and w5 have similar coefficient values. A comparison of the other coefficients reveals different signs or magnitudes.

	COMPONENT	w1	w2	w3	w4	w5	w6
ABSENCE	w1	0.710					
	w2	-0.109	0.385				
	w3	-0.290	0.050				
	w4	-0.122	0.030	1.037			
	w5	-0.255	-0.108	-0.460	0.377	1.508	
	w6	-0.305	-0.126	-0.121	-0.222	-0.324	0.770
PRESENCE	w1	0.415					
	w2	-0.165	1.597				
	w3	0.089	-0.008	0.605			
	w4	0.399	0.051	0.135	0.944		
	w5	-0.120	-0.001	-0.035	-0.267	0.405	
	w6	-0.021	0.036	0.055	0.312	0.202	1.192

Figure 5.5. Scatter plots of the six components with eigenvalues greater than one used in the PCA watershed land use/cover and morphology metrics. The presence group is shown in black; absence group is shown in red. The scatter plot of w1 and w5 shows the best separation of groups with similar slopes.

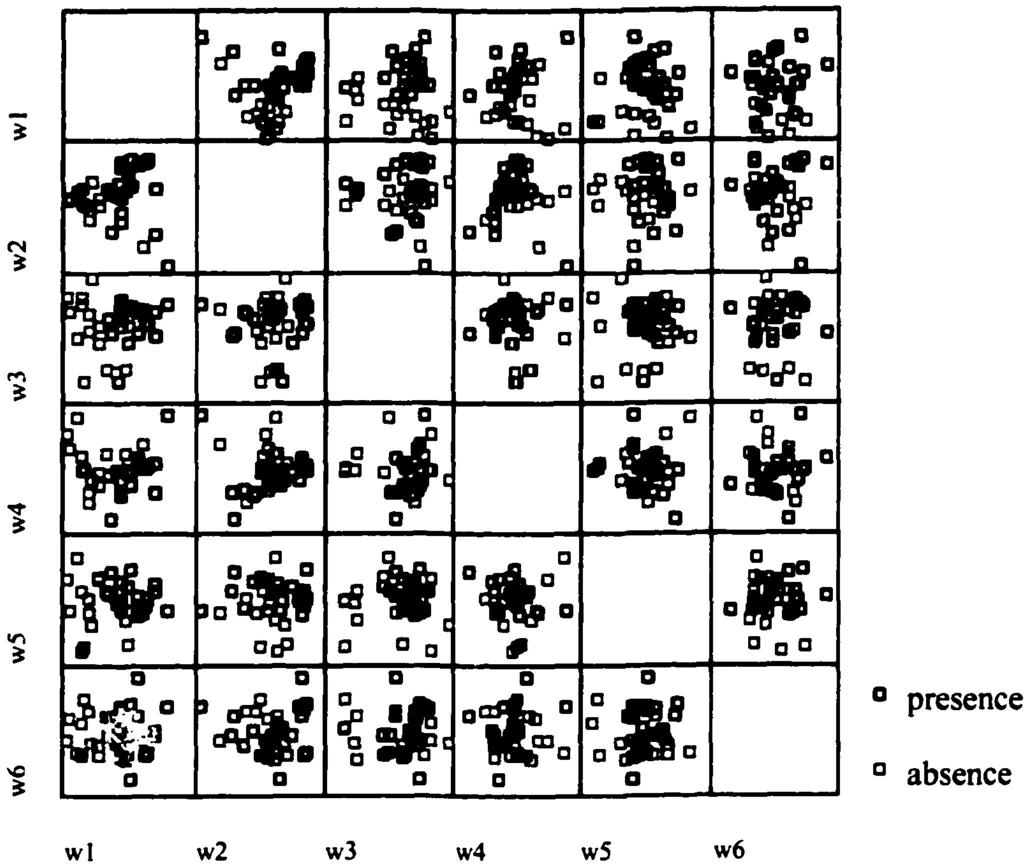

w1
w2
w3
w4
w5
w6
w1
w2
w3
w4
w5
w6
presence
absence

Figure 5.6. Box plots of the components with eigenvalues greater than one resulting from the PCA using watershed land use/cover and morphology metrics. Components w1 and w5 have similar coefficients in the covariance matrices. The spread of the data is greater for component w5.

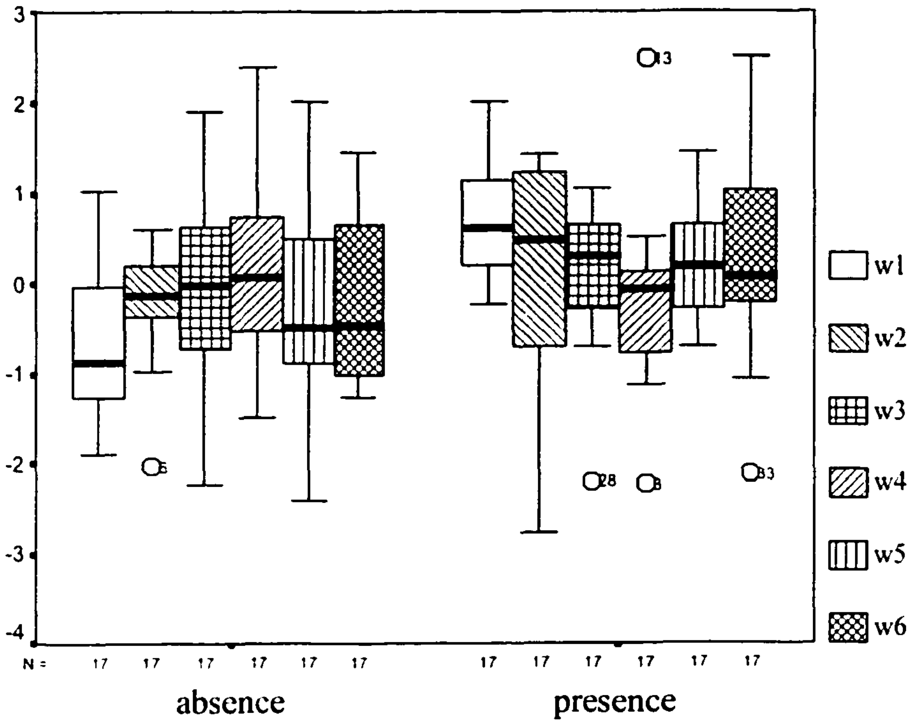

3
2
1
0
-1
-2
-3
-4
N =
17
17
17
17
17
17
17
17
17
17
17
17
absence
presence
w1
w2
w3
w4
w5
w6

Table 5.19. Group prediction results for the discriminant analysis using components w1 and w5.

Table 5.20. Group prediction results for the discriminant analysis using component w1 only.

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	14	3	17
	presence	1	16	17
%	absence	82.4	17.6	100
	presence	5.9	94.1	100

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	13	4	17
	presence	2	15	17
%	absence	76.5	23.5	100
	presence	11.8	88.2	100

loadings for the components extracted using a Varimax rotation are shown in Table A4-2. Based on the loadings, the components grouped the following metrics together:

> **Component w1a** - deciduous forests, probable row crops ,and grasslands within a 200-m buffer; drainage density; shape; and mean elevation,
> **Component w2a** - low and high intensity developed areas within a 200-m buffer; and road density,
> **Component w3a** - mixed forests, conifers/evergreen forests and woody wetlands within a 200-m buffer,
> **Component w4a** - size of watershed; area above 5 feet; and elevation standard deviation,
> **Component w5a** - median and standard deviation of slope,
> **Component w6a** - emergent wetlands and row crops within a 200-m buffer,
> **Component w7a** - water and barren areas within a 200-m buffer.

An examination of the covariance matrices Table A4-3, the box plots (Figure A4-2) and the scatter plots (Figure A4-3) indicates that component w1a only is suitable for discriminant analysis. The other components differ greatly in their shared covariances. Using component w1a in a discriminant analysis resulted in 76.5% of the streams correctly classified with 70.6% of the streams in the absence group correctly classified and 82.4% of the streams in the presence group correctly classified Table A4-3. The incorrectly classified streams are Bristle Mine Run, Brockenbrough Creek, Claiborne Run, Gingoteague Creek, Jones Creek, Keys Run, Lambs Creek, and Little Falls Run.

Watershed and Stream Reach with Land Use/Cover within Watershed

A PCA for the watershed morphology and stream-reach metrics generated 11 components with eigenvalues greater than 1, shown in Figure A4-4. The land use/cover metrics within the watershed were used in this analysis. The 11 components account for

84.27% of the total variance (Table A4-5). The loadings for the components extracted using a Varimax rotation are shown in Table A4-6. Based on the loadings, the components grouped the following metrics together:

Component wr1 - grasslands, water, mixed forests and deciduous forests within a watershed; shape; mean elevation; slope standard deviation; and drainage density,
Component wr2 - median, minimum and maximum temperature; emergent and woody wetlands within a watershed; and % organics,
Component wr3 - high and low intensity developed areas within a watershed; and road density,
Component wr4 - % silt and clay; and stream-reach width,
Component wr5 - mean and maximum stream-reach depth; area above 5 feet; and size,
Component wr6 - minimum, maximum and median pH,
Component wr7 - median slope; and minimum DO,
Component wr8 - elevation standard deviation; and barren areas within a watershed,
Component wr9 - % sand and gravel,
Component wr10 - conifers/evergreen, row and probable row crops within a watershed and,
Component wr11 - median and maximum DO.

An examination of the covariance matrices (Table A4-7), the box plots (Figure A4-5) and the scatter plots (Figure A4-6) indicates that components wr1, wr3 and wr7 are the best candidates for disciminant analysis. Three discriminant analyses were run and compared using wr1 alone, wr1 and wr3, and wr1 and wr7. The coefficients for the absence and presence groups for wr3 and wr7 have different signs. Because of this, these two components were not used in an analysis together.

The Wilks' Lambda test for the three trials are all significantly different indicating that the group centroids for each analysis are significantly different. Two trials, wr1 and wr3 and wr1 and wr7, have the same group predication abilities of 82.4% (Tables A4-8 and A4-9). However, some of the streams incorrectly classified differ. Both analyses incorrectly classified Claiborne Run, Dicks Creek, Gingoteague Creek, Lambs Creek, and Peedee Creek.. The analysis using wr1 and wr3, though, incorrectly classifies Keys Run whereas the analysis using wr1 and wr7 incorrectly classifies Little Totuskey Creek.

The analysis using wr1 only has a weaker group predication ability of 79.4% overall. The incorrectly classified creeks are Claiborne Run, Dicks Creek, Gingoteague Creek, Keys Run, Lambs Creek, Muddy Creek, and Piscataway Creek.

Watershed and Stream Reach with Land Use/Cover within 200-Meter Buffer

A PCA for the watershed morphology and stream-reach metrics generated 10 components with eigenvalues greater than 1, shown in Figure A4-7. The land use/cover metrics within the 200-m buffer were used in this analysis. The 10 components account for 82.38% of the total variance (Table A4-10). The loadings for the components extracted using a Varimax rotation are shown in Table A4-11. Based on the loadings, the components grouped the following metrics together:

Component wr1a - grasslands, row and probable row crops, water and deciduous forests within a 200-m buffer; shape; mean elevation; and area above 5 feet,
Component wr2a - median, minimum and maximum temperature; emergent wetlands within a 200-m buffer; and % organics,
Component wr3a - high and low intensity developed areas within a 200-m buffer; and road density,
Component wr4a - % silt, sand, and clay; and stream-reach width,
Component wr5a - mean and maximum stream-reach depth; and size,
Component wr6a - minimum, maximum and median pH,
Component wr7a - % gravel; slope standard deviation; mixed forests within a 200-m buffer,
Component wr8a - median slope; woody wetlands within 200-m buffer; maximum DO; and drainage density,
Component wr9a - minimum and median DO; and elevation standard deviation

Component wr10a - conifers/evergreen and and barren areas within a 200-m buffer.

An examination of the components analysis above suggests that components wr1a, wr2a, wr3a, and wr8a possibly meet the requirements of normal distributions and equal covariances. The box plots (Figure A4-8) show the most similar variances for the absence and presence groups for components wr1a and wr8a. Except for weak patterns in the scatter plots of components wr1a vs. wr3a, and wr1a vs. wr8a, Figure A4-9 does not reveal patterns for the other pairs of components. The covariance matrices reveal differences in the coefficients between the absence and presence groups except for components wr1a and either wr2a, wr3a or wr8a (Table A4-12). The coefficients for the combinations wr2a and wr3a, wr3a and wr8a, and wr2a and wr8a have different signs. As a result of this preliminary examination, discriminant analyses were performed using the combinations of components: wr1a and wr2a, wr1a and wr3a wr1a and wr8a, and wr1a only.

The classification results of three of the four trials (wr1a only, wr1a and wr8a, and wr1a and wr2a) are the same with an overall prediction ability of 82.4% with 76.5% of the absence streams classified correctly and 88.2% of the presence streams classified correctly (Table A4-13). Using component wr1a only and wr1a and wr8a together results in Claiborne Run, Dicks Creek, Gingoteague Creek, Keys Run, Lambs Creek, and Muddy Creek classified incorrectly. The streams classified incorrectly using wr1a and wr2a are Claiborne Run, Gingoteague Creek, Jones Creek, Keys Run, Lambs Creek, and Muddy Creek.

The combination of wr1a and wr3a has a slightly weaker predication ability of 79.4%. The creeks classified incorrectly using wr1a and wr3a are the same as with wr1a with the addition of Peedee Creek.

In all trials the Wilks' Lambda test reveals a significant difference between the centroids of the absence and presence groups in the discriminant function as shown in Table A4-14 for the discriminant analysis using wr1a only.

Stream Reach

A PCA for the and stream-reach metrics generated 9 components with eigenvalues greater than 1, shown in Figure A4-10. The land use/cover metrics within the 200-m buffer were used in this analysis. The 10 components account for 82.34% of the total variance (Table A4-15). The loadings for the components extracted using a Varimax rotation are shown in Table A4-16. Based on the loadings, the components grouped the following metrics together:

Component r1 -median, minimum and maximum temperature; emergent wetlands within a 200-m buffer; % organics; and stream-reach width,
Component r2 - grasslands, row and probable row crops, water and deciduous forests within a 200-m buffer,
Component r3 - high and low intensity developed areas within a 200-m buffer; minimum and median DO,
Component r4 - minimum, maximum and median pH,
Component r5 - % silt and clay,
Component r6 - mean and maximum stream-reach depth,
Component r7 - % gravel; and mixed forests within a 200-m buffer,
Component r8 - conifers/evergreen and barren areas within a 200-m buffer
Component r9 - woody wetlands within 200-m buffer; and maximum DO.

An examination of the components analysis above suggests that components r1, r2, and r7 possibly meet the requirements of normal distributions and equal covariances. The box plots (Figure A4-11) show similar variances. The scatter plots, though, reveal little patterns (Figure A4-12). The coefficients in covariance matrices reveal similarities between the absence and presence groups for components r1 and either r2 or r7 (Table A4-17). The coefficients for the r2 and r7 have different signs. As a result of this preliminary examination, discriminant analyses were performed using the combinations of components: r1 only, r1 and r2, r1 and r7.

The classification results using the combination of components r1 and r2 is the best with an overall group predication ability of 79.4% (Table A4-18). The groups predication rates of r1 and r1 with r7 are both 76.5%. The creeks classified incorrectly using components r1 and r2 are Bristle Mine Run, Claiborne Run, Dicks Creek, Gingoteague Creek, Keys Run, Lambs Creek and Muddy Creek.

Summary of Multivariate Analyses

A comparison of the discriminant models (Table 5.21) clearly shows that the model using the watershed morphology and land use/cover metrics has the best prediction rate of 88.2%. Including reach substrate and morphology with the watershed morphology weakens the discriminating ability of the models. As well, including the land use/cover within the 200-meter buffer metrics with the watershed morphology decreases the prediction ability to 76.5%; however, land use/cover metrics does not affect the abilities of the two watershed-reach models. Both watershed-reach models have prediction rates of

82.4%. The creeks that are classified incorrectly, though, differ in the two watershed-reach models (Table 5.22). All of the discriminant models consistently incorrectly classify Claiborne Creek, Gingoteague Creek and Lambs Creek.

Table 5.21. A comparison of the discriminant models. The model using the watershed morphology and land use/cover has the best results. The inclusion of reach substrates and morphology weakens the model as does using land use/cover within the 200-meter buffer.

Discriminant Analysis	**Group Predication Results Overall Percentage**
Watershed Morphology and Land Use/Cover	88.2
Watershed with Land Use/Cover within 200-m Buffer	76.5
Watershed-Reach with Land Use/Cover within Watershed	82.4
Watershed-Reach with Land Use/Cover within 200-m Buffer	82.4
Stream-Reach	79.4

Table 5.22. Comparison of the incorrectly classified streams in the five discriminant models. Consistently, Claiborne Creek, Gingoteague Creek and Lambs Creek are classified incorrectly.

STREAM	ABSENCE (0) PRESENCE (1)	WATERSHED	WATERSHED WITH LAND COVER/USE WITHIN 200-M BUFFER	WATERSHED-REACH WITH LAND COVER/USE WITHIN WATERSHED	WATERSHED-REACH WITH LAND COVER/USE WITHIN 200-M BUFFER	STREAM-REACH
Bristle Mine Run	1		X			X
Brockenbrough Creek	0		X			
Claiborne Run	0	X	X	X	X	X
Dicks Creek	0			X	X*	X
Gingoteague Creek	1	X	X	X	X	X
Jones Creek	0	X	X		X*	
Keys Run	0		X	X*	X	X
Lambs Creek	0	X	X	X	X	X
Little Falls Run	1		X			
Little Totuskey Creek	1			X*		
Muddy Creek	1				X	X
Peedee Creek	1			X		

* Separate analyses run. Both analyses had the same number of incorrectly classified streams; however, the incorrectly classified creeks differed slightly. See text for explanation.

Chapter 6

Discussion and Conclusion

Drawing on recent developments in fish habitat research and applying principals of landscape ecology, this study was designed to determine which watershed and stream-reach metrics could be used to indicate potential spawning habitat for river herring. Furthermore, the study examined the relative prediction abilities of the watershed and stream-reach metrics. The results indicate that certain metrics in both the watershed and stream-reach scales are good indicators of herring presence. In addition, the discriminant analyses indicate that the combination of watershed metrics has a better ability to correctly classify which streams are used by river herring for spawning.

Watershed Morphology and Land Use/Cover Metrics

The results of the watershed metric analysis suggest that river herring tend to spawn in larger, elongated watersheds with greater mean elevation and greater habitat complexity within the Rappahannock River watershed. Proportionally less area in the watersheds are within the low-lying areas surrounding the Rappahannock River. The larger watersheds likely have more stable base flows and can maintain suitable spawning habitats even during dry years. Possibly, river herring spawn in certain streams intermittently or spawning sites shift leading to either year-to-year variability or a longer-term trend. Recreational fishers catch river herring each year in streams within larger watersheds, such as Occupacia Creek and Massaponax Creek. The different findings in some of the streams between this study and Uzee and Angermeier (1993) may be due to naturally shifting spawning locations, particularly in the smaller watersheds. An examination of Figure 5.1 clearly shows that the size of a watershed is a good indicator of where river herring spawn. In particular, toward the downstream end of the study area, there is a pronounced difference in the size of the watersheds between the absence and presence groups. The smaller watersheds in this area have less standard deviations of slope and elevation and thus indicate less habitat complexity than the surrounding, larger watersheds.

The watersheds where herring spawning occurred have greater percentages of deciduous forest and developed areas and less grassland areas. If we assume that alteration of the environment by people has a negative impact, then we would expect to see the absence group to have higher percentages of developed and grassland land use/cover. The results of the grassland and deciduous forest metrics confirm our expectation, but the percentages of developed areas in the watersheds do not. The presence group has a higher percentage of developed areas with median value of 1.06% for the presence group versus 0.43% for the absence group.

River herring spawn in most of the watersheds sampled around the city of Fredericksburg (Figure 5.1). This area is where most of the developed land use in the study area is found. The watersheds of Hazel Run, Claiborne Run, and Little Falls Run have the highest percentages of developed land use with 26.08%, 23.81, and 12.20% respectively.

Overall, the study area contains little development. The percentages of developed land use range between 0.02% and 26.08%. Twenty of the 34 watersheds contain less than 1% developed land use. Of the 14 watersheds with developed land use greater than 1%, evidence of herring spawning was found in ten. However, developed area alone is not a good indicator of river herring spawning habitat. The habitat fish perceive is the result of complex interactions of many factors that affect water quality, substrate, stream morphology, and flow regime. As Parrish *et al.* (1998) conclude about factors that have caused the decline in wild Atlantic salmon populations, most factors do not act singly but together and this masks the relative contribution of each factor. In the watersheds in the Fredericksburg area, other features such as size, elevation and habitat complexity are at present more important than the potential negative effects of development.

Although individual watersheds may show large differences in the types of land use/cover, overall the Rappahannock River watershed is dominated by forest and agriculture (Figure 4.2). Historically, deciduous forests dominated this region. The strong Spearman's Rho Correlation of -0.863 ($p < 0.01$) between agriculture and forest indicates the influence of human activity. Furthermore, there is a strong correlation of -0.753 ($p < 0.01$) between deciduous forest and grassland. It is likely that grassland land use has replaced deciduous forests. The other types of forest (mixed and coniferous) and agriculture (row crops and probable row crops) do not show similar strong correlations. Replacement of deciduous forests by agriculture, faster-growing coniferous forests, and developed land affects fish habitat by altering the amount and types of sediments and pollutants entering streams, the amount and types of snags, and by changing tree canopy cover over streams.

In addition to grasslands and deciduous forests, all the buffer zones for the presence group have more barren areas, in particular, areas resulting from clear-cutting forests. One would expect that barren areas, particularly within buffer zones, negatively affect fish habitat as seen in many studies showing the impact of land use changes (primarily due to clear-cutting of forests) on the salmon habitats in the Northwest United States (e.g., Beechie *et al.* 1994, Nehlsen *et al.* 1991). The percentages of barren land, though, are very small, ranging between 0.00% and 5.71% in the Rappahannock River watersheds used in this study. Both developed and barren areas are too small to override the other factors positively influencing river herring habitat.

A variety of studies have examined the relative roles of buffer zones and watershed land use/cover in determining water quality and aquatic habitat quality for macroinvertebrates and fish. For instance, Osborne and Wiley (1988), found greater relationships between water quality (in particular nitrates, soluble phosphorus, and sediments) and land use/cover within buffer zones than entire watersheds. In a macroinvertebrate study, Richards and Host (1994) found causal linkages between land use practices and stream habitat conditions, such as increased sediment load and nutrient inputs resulting from agricultural practices at the watershed scale. Likewise, Roth *et al.* (1996) found stronger correlations between an index of biological integrity (IBI) using fish community data and land use/cover data at the watershed scale.

In the Osborne and Wiley (1988) study, 50% of the forested areas were within 200 feet (approximately 60 meters) whereas in the Richards and Host (1994) study, there was little difference between the composition of the buffer zones and the entire watershed, except for the amount of wetlands. The distribution of land use/cover types in this study revealed little differences between buffer zones and watersheds. The better prediction ability of the discriminant function derived from watershed metrics supports the conclusions by Roth *et al.* (1996) and Richards and Host (1994).

An area of active research is developing ways to determine the required width of buffer zones to help maintain the biological integrity of a stream and minimize negative impacts from human activities. Determining an appropriate width of a buffer zone is a complex problem involving sediment types, land use/cover, topography, and climatic variables such precipitation. Often resource managers are looking for a minimum width that still allows the stream to maintain biological integrity. This allows farmers and other types of land owners to maximize the area being used for their activities.

The literature refers to both riparian and buffer zones. The term, riparian zone, generally refers to the area immediately adjacent to a stream that is influenced by the water in the stream on an annual basis. These areas are critical transition zones between aquatic and terrestrial environments. They can serve a variety of ecological functions such as regulating the movement of materials, maintaining bank stability, contributing carbon inputs, and acting as nutrient filters (Elliott *et al.* 1998, Gumiero and Salmoiraghi 1996). Buffer zones, on the other hand, include more terrestrial area adjacent to a stream. The application of buffer zones along streams is often used to control nutrient, sediment, and pollutant inputs from anthropogenic activities. Other uses for buffer zones include providing wildlife habitats and recreational activities (Large and Petts 1994).

The results of this study do not conclusively support which of the buffer zones examined would be best to maximize anthropogenic land use while maintaining healthy aquatic environments for river herring. Rather, the results of the discriminant analysis suggest that we must consider land use/cover and morphology within the entire watershed and that the cumulative affects within the entire watershed may be as important as the type of land use/cover within buffer zones.

Stream-Reach Metrics

For the stream-reach metrics, the substrates and percent organic matter metrics are significantly different between the two groups. The absence group has a larger amount of organic matter and finer sediments. This is not surprising since these watersheds have lower-gradient stream networks and comparatively more agricultural land use. The presence group prefers sand, pebbles and cobbles in higher-gradient streams.

The greater canopy cover corresponds to the greater percentages of deciduous forests in the presence group. In addition, the larger number of snags in the presence group indicates more trees in the riparian zone. Forested areas provide shading over the streams. However, herring spawning did occur before leaves were fully open, suggesting that shading was not always required. It is likely, though, that as spring progresses and water temperatures increase, the shading keeps water temperatures from rising as quickly as it might in unshaded areas. Although water quality measurements were taken at different times of the day and thus limit comparisons, only two of the temperature values were outside the suitable ranges listed in Table 2.1. These measurements were taken near the end of the spawning season in Balls Creek and Richardson Creek. These two streams are in the absence group.

When comparing the benthic macroinvertebrate metrics between the absence and presence groups, most of the metrics indicate that streams in the presence group have more degraded environments based on the predicted responses shown in Table 3.2. This seems counter-intuitive since one would expect the river herring to prefer "healthier" environments. The two exceptions to the overall trend in the benthic metrics are %*Chironomus* to %Chironomidae and %*Chironomus* to %Chironomini.

Tidal-freshwater, oligohaline, and sandy aquatic habitats are harsh environments for benthic macroinvertebrates. Overall, the abundance values of the samples are low. As is typically found in these habitats, robust taxa such as oligochaetes and chironomids were dominant at most of the sites. Comparisons between the absence and presence groups may be weakened by the natural variability in the communities living in a variety of habitats. Furthermore, the sampling method was different for the cobble-dominated streams.

However, after looking at single habitat types, tidal freshwater and non-tidal sandy, similar results are found. All the benthic metrics excluding the ratios of %*Chironomus* to %Chironomidae and %*Chironomus* to %Chironomini indicate more degraded environments for the presence group. Most of the streams in the presence group have zero values for the *Chironomus* metrics whereas most streams in the absence group have non-zero values. This shows a strong negative correspondence between evidence of spawning and the two *Chironomus* metrics with values greater than zero and suggests that *Chironomus* metrics may be good indicators of degraded habitats in these harsh environments.

The total abundance values for most of the benthic macroinvertebrate samples were low. The Mid-Atlantic Workgroup (EPA 1997) suggests taking a multi-habitat benthic sampling technique to increase abundance values and thus strengthen the analysis. Based on the types of habitats (i.e., channel, bank, snag, pool), one would take proportional samples in the different habitat types to increase overall abundance and diversity in the collection. EPA (1997) concludes that this technique would provide a better representation of the habitat quality. Sampling was only done in a single habitat for this study It would be interesting to compare metrics from multi-habitat with a single channel habitat samples to see if similar results are found. The EPA rapid benthic macroinvertebrate habitat assessment indicates that the absence group has a more degraded environment on average which is different than the metrics indicate, except the two *Chironomus* metrics. One expects the habitat assessment to correspond with the results of the metric analysis. Perhaps with greater abundances found in multi-habitat samples, this would be so.

In pebble and cobble-dominated streams, sampling techniques are standardized and routinely taken in riffles as done in Falls Run, Claiborne Run, Dicks Creek, and Massaponax Creek. The larger values for the metrics, percent dominant taxa and Biotic Index, at the sites in Falls Run and Massaponax Creek indicate more degraded environments. Evidence for herring spawning, however, were found at these two streams and not at Claiborne Run or Dicks Creek. Like with the tidal-freshwater and non-tidal sandy sites, the benthic macroinvertebrate metrics indicate more degraded environments in the presence group, although conclusive statements cannot be made with a small sample size of four streams.

All the brackish sites have sensitive taxa and metric results that indicate "healthy" environments. Bellview Creek is the only stream with %*Chironomus* / %Chironomidae and %*Chironomus* / %Chironomini greater than 0.00. The other three have zero values. Assuming that relative water qualities can be estimated from the benthic macroinvertebrate analysis, river herring did not "choose" the brackish and freshwater cobble sites sampled because of poor water quality. Rather, other factors, such as watershed size, have a greater role in determining where river herring spawn.

Plankton Net Locations

The locations of the plankton nets in the streams may have affected the resultant classification of the Dicks Creek, Lambs Creek, and Claiborne Run watersheds. The plankton nets at Dicks Creek and Lambs Creek were placed farther away from the stream mouths, 1.3 km and 1.8 km respectively, than the other streams. River herring may spawn closer to the mouths than the net locations in these streams. Although the location of the plankton net at Claiborne Run was close to the mouth, 0.3 km upstream, and closer to the mouth than many of the other site locations, there is a small falls (about 2-3 meters at the time of sampling) downstream of the net placement. The falls could limit the migration of river herring and these fish may spawn near the stream mouth.

Three streams, Claiborne Run, Gingoteague Creek, and Lambs Creek, were consistently classified incorrectly in the discriminant analyses. No eggs, embryos or larvae were found in Claiborne Run and Lambs Creek and a placement of the plankton net closer to the stream mouth could have shown presence of river herring spawning. Gingoteague Creek is the only stream that is consistently predicted to belong in the absence group. Despite this incorrect classification, the watershed discriminant model has a nearly 90% prediction ability and might be better if the river herring actually spawn in Claiborne Run and Lambs Creek.

Data accuracy and uncertainty

The spatial resolution of the raster data used in the study is 30 meters and the map scale of vector data (road and stream networks) is 1:100,000. These data sources, or data similar to these, are available in many places throughout the United States for use by resource managers. More detailed data are always desirable for research and input for management decisions, but more detailed data may not be available or may be expensive. In addition, analysis with detailed data requires increased computer processing time, storage, and hardware requirements.

In this study percentages of land use/cover within buffer zones and watersheds were estimated. A data set with a smaller pixel size could increase the accuracy of the estimates of land use/cover types (Comeleo *et al.* 1996, Wehde 1982) and better correlations between water quality and land use may appear with finer resolution data. In particular, fine-scale variation in buffer characteristics could be detected and further resolve the influence of stream buffers on water quality and biotic ecosystems (Richards *et al.* 1996). Likewise, the 30-meter elevation data may have lost subtle changes in the topography, particularly since much of the study area has gentle relief. Studies have shown that small, isolated features in complex landscapes can be lost as data resolution decreases (Meentemeyer and Box 1987).

However, the objective of this was study to identify metrics that could identify potential spawning areas for river herring. The results of the study do show that data used here can effectively predict potential spawning habitats in the developed model. Finer-resolution data along with abundance data may be more useful if the objective of the research is to explore relationships between stream-reach and watershed characteristics, and population dynamics.

Concluding Remarks

This study shows that a model using watershed-scale metrics can be used to predict the streams where river herring spawn. In fact, the discriminant analysis using only watershed metrics has the best prediction ability. Furthermore, the data used to derive the metrics do not require field data-collection. Using only watershed metrics reduces cost of the analysis and requires less time than analyses using stream-reach data.

The amount of developed area in the study area is small. A greater gradient of development may better demonstrate thresholds above which aquatic habitat is affected. It would be interesting to test this model on the James River and the York River. The watershed in the James River has more development than both the York River and Rappahannock River. One could use this model to predict which streams have herring spawning and then conduct field work to assess the strength of the model.

Another question to explore is whether the stream-reach metrics are better predictors of river herring spawning abundance and larval recruitment than absence or presence of herring spawning. The stream-reach metrics may better indicate the quality of the spawning habitats whereas watershed metrics may better indicate potential presence.

Even with limitations of establishing direct cause-effect relationships between aquatic habitat and watershed metrics, the watershed is a logical unit for study for aquatic ecology. The physical boundaries of the watershed allow a researcher or manager to measure inputs and outputs that may affect aquatic environments (Schofield 1992). Studies like this one show differences in aquatic ecology can be inferred from watershed-scale metrics.

Resource managers are faced with many questions and models such as this can help provide scientifically-based solutions. For instance, would it be a better strategy to minimize agriculture expansion in the larger watersheds and lessen the risk of deteriorating river herring habitats? The results from this model suggest that river herring 'prefer' spawning habitats in larger watersheds. The larger watersheds could then safeguard the populations during periods of drought when the base flow in smaller streams may be unfavorable for river herring to spawn.

Another pressing question is: how do we manage increasing populations in the coastal watersheds? To minimize anthropogenic impacts, do we try to encourage people to live in concentrated areas or allow people to evenly spread out throughout the watersheds? The results from this model indicate that we do need to look at the cumulative effects within entire watersheds. So far, the amount of development in the study area is small and has not negatively impacted the presence of river herring. Perhaps river herring habitat has been negatively impacted in places with development but not enough to eliminate all river herring from spawning there. The study did not address the relative qualities of the habitats which could affect abundance values.

However, this study does show a strong correlation between agriculture and forest. If more forests are removed and replaced with either development or agriculture, then land use change will likely negatively impact river herring presence in streams. The model does not indicate, though, how the presence of river herring could be affected by the replacement of agricultural areas with development. More research is needed to estimate the relative impact of developed and agriculture on river herring habitat.

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Appendix 1

Egg and Larvae Data

Table A-1. River herring eggs and larvae found in plankton samples in 1997.

CREEK	# SAMPLES	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8
Balls Creed	7	0	0	0	0	0	0	0	NS
Bellview Creek	6	NS	0	0	0	0	0	0	NS
Bristle Mine Run	6	0	eggs	eggs	eggs	NS	eggs	eggs	NS
Brockenbrough Creek	6	NS	0	0	0	0	0	0	NS
Cat Point Creek	7	4	eggs	52	0	NS	248	8	226
Claiborne Run	7	0	0	0	0	0	0	0	NS
Colemans Creek	8	0	0	0	0	0	0	0	0
Dicks Creek	7	0	0	0	0	0	0	0	NS
Falls Run	7	0	0	0	0	0	eggs	36	NS
Farmers Hall	8	0	0	0	0	0	0	0	0
Gingoteague Creek	7	eggs	3+ eggs	13 + eggs	0	NS	eggs	0	0
Goldenvale Creek	7	3	4	15	12	0	0	0	NS
Hazel Run Creek	8	eggs	0	eggs	eggs	0	0	2 + eggs	0
Hoskins Creek	7	3	1	0	0	eggs	0	0	NS

Table A-1 (continued). River herring eggs and larvae found in plankton samples in 1997.

CREEK	# SAMPLES	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8
Hugh Creek	5	NS	0	NS	0	0	0	0	NS
Jones Creek	7	0	0	0	0	0	0	0	NS
Keys Run	6	NS	0	0	0	0	0	0	NS
Lambs Creek	6	NS	0	0	0	0	0	0	NS
Little Carter Creek	6	NS	0	0	0	0	0	0	NS
Little Falls Run	7	eggs	0	eggs	27 + eggs	0	8 + eggs	3 + eggs	NS
Millbank Creek non-tidal	6	NS	0	0	0	0	0	0	NS
Millbank Creek tidal	6	NS	0	0	0	0	0	0	NS
Mount Landing Creek	7	2 + eggs	eggs	eggs	eggs	eggs	eggs	eggs	NS
Muddy Creek	7	0	0	0	0	0	129	0	NS
Occupacia Creek	8	0	0	0	0	0	0	0	0
Pecks Creek	8	0	0	0	0	0	0	0	0
Peedee Creek downstream	8	0	0	0	0	0	0	9 + eggs	0

Table A1-1 (concluded). River herring eggs and larvae found in plankton samples in 1997.

CREEK	# SAMPLES	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8
Peedee Creek upstream	7	0	0	0	0	235	eggs	0	NS
Piscataway Creek	7	0	eggs	eggs	0	eggs	eggs	eggs	NS
Richardson Creek	7	0	0	0	0	0	0	0	NS
Saunders Creek	8	0	0	0	0	0	0	0	0
Totuskey Creek	6	NS	eggs	eggs	21 + eggs	0	4 + eggs	0	NS
Ware Creek	7	0	3 + eggs	eggs	0	0	0	0	NS
Waterview Creek	7	0	0	0	0	0	0	0	NS
Massaponax Creek	1	eggs							
Occupacia Creek (dipnet site)	1	9 + eggs							
Peumansend Creek	1	2 + eggs							

Appendix 2

Metric Descriptives

Table A2-1. Minimum, maximum, median, mean, and standard deviation values for the watershed morphology metrics.

Watershed Morphology Metrics	Minimum	Maximum	Median	Mean	Standard Deviation
size	3.56	192.15	116.30	40.59	50.280
area above 5-ft contour	1.30	117.13	12.55	28.23	31.374
shape	1.25	2.89	2.08	2.10	0.412
drainage density	0.70	2.37	0.99	1.12	0.345
road density	0.76	5.99	1.42	1.85	1.171
elevation mean	12.25	72.68	36.71	36.22	14.792
elevation standard deviation	5.06	70.64	14.86	17.15	11.327
slope maximum	4.07	27.93	12.68	12.99	4.944
slope median	0.75	2.88	1.39	1.47	0.549
slope standard deviation	0.87	3.50	2.24	2.17	0.635
depth at mouth	-0.12	7.47	0.68	1.36	1.776
width at mouth	3.00	360.72	20.99	70.13	98.339

Table A2-2. Minimum, maximum, median, mean, and standard deviation values for the watershed land use/cover metrics.

Land Use/Cover Watershed Metrics	Minimum	Maximum	Median	Mean	Standard Deviation
water	0.00	3.11	0.91	0.96	0.772
developed low intensity	0.00	21.78	0.50	2.74	5.295
developed high intensity	0.00	6.52	0.23	0.53	1.158
grasslands	0.80	27.03	13.27	13.69	6.372
row crops	0.05	9.25	3.03	3.67	2.632
probable row crops	3.23	37.84	14.10	14.76	7.125
barren	0.00	5.71	0.11	0.963	1.455
forest coniferous/evergreen	1.95	19.14	6.81	7.57	4.118
forest mixed	4.08	51.63	14.96	17.67	9.518
forest deciduous	3.16	63.99	29.71	31.15	15.617
wetlands woody	0.00	17.10	3.81	4.18	3.294
wetlands emergent	0.04	11.75	1.28	2.10	2.726
developed	0.02	26.08	0.77	3.26	6.262
agriculture	4.57	56.90	31.44	32.13	12.158
forest	26.44	85.65	55.62	56.40	13.259
wetlands	0.04	27.99	5.25	6.28	5.486

Table A2-3. Minimum, maximum, median, mean, and standard deviation values for the 200-meter buffer land use/cover metrics.

Land Use/Cover 200-Meter Buffer Metrics	Minimum	Maximum	Median	Mean	Standard Deviation
water	0.00	6.85	1.76	2.29	2.078
developed low intensity	0.00	19.83	0.19	1.64	3.962
developed high intensity	0.00	3.10	0.13	0.39	0.729
grasslands	0.58	21.81	7.79	8.71	5.612
row crops	0.04	11.64	2.70	3.37	2.760
probable row crops	1.85	29.03	10.58	10.49	6.429
forest coniferous/evergreen	1.52	15.58	5.44	6.62	4.047
forest mixed	4.48	55.39	14.52	17.30	10.412
forest deciduous	3.31	65.61	37.47	35.56	16.791
wetlands woody	0.00	16.32	9.36	8.43	4.639
wetlands emergent	0.00	22.28	3.00	4.46	4.879
barren	0.00	4.31	0.05	0.74	1.217
developed	0.00	22.75	0.37	2.072	4.698
agriculture	2.80	45.78	19.94	22.49	12.504
forest	22.90	80.11	62.22	59.42	14.224
wetlands	0.00	32.19	13.24	12.95	7.887

Table A2-4. Minimum, maximum, median, mean, and standard deviation values for the 90-meter buffer land use/cover metrics.

Land Use/Cover 90-Meter Buffer Metrics	Minimum	Maximum	Median	Mean	Standard Deviation
water	0.00	13.81	3.38	4.33	4.014
developed low intensity	0.00	16.86	0.05	1.22	3.321
developed high intensity	0.00	2.75	0.15	0.33	0.584
grasslands	0.16	20.27	3.76	5.63	5.220
row crops	0.00	12.93	2.09	3.20	3.036
probable row crops	1.07	25.20	5.48	7.18	5.658
forest coniferous/evergreen	0.92	13.86	4.20	4.64	3.070
forest mixed	3.84	52.76	12.06	15.16	10.050
forest deciduous	2.21	61.15	35.82	36.44	16.532
wetlands woody	0.00	29.31	14.69	14.52	7.705
wetlands emergent	0.00	22.11	5.49	6.81	6.221
barren	0.00	3.94	0.00	0.52	0.985
developed	0.00	19.03	0.27	1.590	3.889
agriculture	1.50	41.08	12.50	16.03	11.706
forest	21.16	92.29	58.09	56.03	14.235
wetlands	0.00	45.24	21.94	21.44	11.175

Table A2-5. Minimum, maximum, median, mean, and standard deviation values for the 30-meter buffer land use/cover metrics.

Land Use/Cover 30-Meter Buffer Metrics	Minimum	Maximum	Median	Mean	Standard Deviation
water	0.00	30.66	6.70	8.83	8.334
developed low intensity	0.00	12.57	0.00	.872	2.549
developed high intensity	0.00	2.98	0.36	0.48	0.637
grasslands	0.00	16.70	1.42	3.14	3.879
row crops	0.00	12.54	1.35	2.79	2.998
probable row crops	0.00	24.03	2.27	4.53	4.940
forest coniferous/evergreen	0.18	12.42	2.53	3.11	2.505
forest mixed	1.74	40.86	8.76	11.54	8.637
forest deciduous	1.29	74.89	33.46	31.77	17.258
wetlands woody	0.00	45.40	23.55	22.62	11.492
wetlands emergent	0.00	46.92	8.67	9.96	9.941
barren	0.00	3.83	0.00	0.362	0.802
developed	0.00	13.88	0.44	1.35	2.891
agriculture	0.80	32.18	6.44	10.46	9.589
forest	16.59	92.77	46.09	46.42	16.168
wetlands	0.00	66.80	36.39	32.57	17.041

Table A2-6. Minimum, maximum, median, mean, and standard deviation values for the 15-meter buffer land use/cover metrics.

Land Use/Cover 15-Meter Buffer Metrics	Minimum	Maximum	Median	Mean	Standard Deviation
water	0.00	43.74	10.05	10.87	10.432
developed low intensity	0.00	11.07	0.00	0.78	2.354
developed high intensity	0.00	2.05	0.28	0.43	0.557
grasslands	0.00	17.00	1.04	2.72	3.731
row crops	0.00	12.16	1.18	2.57	2.885
probable row crops	0.00	29.46	2.22	4.56	5.922
forest coniferous/evergreen	0.00	11.86	2.08	2.69	2.328
forest mixed	1.17	40.74	8.50	11.01	8.447
forest deciduous	1.19	78.76	30.04	29.77	17.714
wetlands woody	0.00	50.61	24.92	23.90	12.316
wetlands emergent	0.00	49.11	9.24	10.38	10.315
barren	0.00	3.72	0.00	0.31	0.721
developed	0.00	12.48	0.36	1.21	2.720
agriculture	0.44	35.12	5.64	9.85	10.042
forest	15.37	95.58	41.45	43.48	17.231
wetlands	0.00	72.06	38.29	34.28	18.059

Appendix 3

Benthic Macroinvertebrate Data

Table A3-1. Benthic macroinvertebrate count data: Isopoda, Cumacea, Amphipoda and Decopoda.

class	Crustacea										
order		Isopoda				Cumacea	[illegible]			[illegible]	
family		Anthuridea	Asellidae	Sphaeronitea	Idoteidea	Nannastacidae	Corophiidea	Gammaridea		Cambaridae	Xanithidae
genera	tidal / substrate	Cyathura	Caecidotea	Cassidinea	Edotea	Almyracuma	Corophium	Crangonyx	Gammarus		[illegible]
Balls	TB	4	0	1	7	3	2	0	19	0	3
Bellview	TB	4	0	1	0	5	1	0	1	0	8
Bristle Mine Run	TF	0	0	0	0	0	0	0	0	0	0
Brockenbrough	TF	0	3	0	0	0	0	0	4	0	0
Cat Point	NS	0	2	0	0	0	0	0	0	0	0
Claiborne Run	NP	0	1	0	0	0	0	0	0	0	0
Colemans	TF	2	0	0	0	3	0	0	3	0	0
Dicks	NP	0	2	0	0	0	0	1	0	1	0
Falls Run	NP	0	0	0	0	0	0	0	0	0	0
Farmers Hall	TF	0	0	0	0	0	2	0	2	0	0
Gingoteague	TF	0	11	0	0	0	0	0	0	0	0
Goldenvale	TF	0	0	0	0	0	0	0	3	0	0
Hazel Run	NS	0	0	0	0	0	0	0	0	0	0
Hoskins	NS	0	0	0	0	0	0	0	0	0	0
Hugh	TF	0	0	0	0	0	0	0	2	0	0
Jones	TF	1	0	0	0	0	0	0	0	0	0
Keys Run	NS	0	0	0	0	0	0	0	0	0	0
Lambs	NS	0	66	0	0	0	0	0	0	0	0
Little Carter	TF	1	2	0	0	0	1	0	1	0	0
Little Falls Run	NS	0	0	0	0	0	0	0	1	0	0
Massaponax	NP	0	0	0	0	0	0	0	0	0	0
Millbank	TF	0	3	0	0	0	0	0	0	0	0
Mount Landing	NS	0	3	0	0	0	0	0	2	0	0
Muddy	TF	0	21	0	0	0	0	0	4	0	0
Occupacia	NS	0	0	0	0	0	0	0	0	0	0
Pecks	TB	3	0	0	2	1	0	0	1	0	0

Table A3-1 (concluded). Benthic macroinvertebrate count data: Isopoda, Cumacea, Amphipoda and Decopoda.

class	Crustacea										
[illegible]	[illegible]	[illegible]				Cumacea	[illegible]	[illegible]		[illegible]	
family		Anthuridea	Asellidae	Sphaeronitea	Idoteidea	Nannastacidae	Corophiidea	Gammaridea		Cambaridae	Xanithidae
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Peedee	TF	0	33	0	0	0	0	0	40	0	0
Peumansend	NS	0	0	0	0	0	0	0	0	0	0
Piscataway	NS	0	0	0	0	0	0	0	0	0	0
Richardson	TB	14	0	1	0	0	3	0	7	0	0
Saunders	TF	0	0	0	0	0	0	0	0	0	0
Totuskey	TF	0	0	0	0	0	0	0	0	0	0
Ware	NS	0	8	0	0	0	0	0	0	0	0
Waterview	TF	8	1	2	0	9	4	0	3	0	0

Table A3-2. Benthic macroinvertebrate count data: Hirudinea, Polychaeta, and Oligochaeta.

class	Hirudinea		Polychaeta				Oligochaeta			
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
family	Glossiphoniidae	Piscicolidae	Ampharetidae	Nereidae	Spionidea		Naididae			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Dero	[illegible]	[illegible]	[illegible]
Balls	0	1	15	13	6	0	11	0	0	0
Bellview	0	0	133	19	14	0	45	27	0	0
Bristle Mine Run	0	0	0	0	0	0	0	0	0	0
Brockenbrough	1	0	43	0	0	60	12	4	0	0
Cat Point	0	0	0	0	0	0	0	0	0	0
Claiborne	0	0	0	0	0	0	230	0	0	0
Colemans	0	0	14	0	0	1	4	7	0	0
Dicks	0	0	0	0	0	0	0	0	0	0
Falls Run	0	0	0	0	0	0	162	0	0	0
Farmers Hall	0	0	48	0	6	3	16	13	0	0
Gingoteague	0	0	0	0	0	6	1	0	0	0
Goldenvale	0	0	0	0	0	6	0	0	0	0
Hazel Run	0	0	0	0	0	0	0	0	0	0
Hoskins	0	0	0	0	0	0	6	0	5	0
Hugh	3	0	0	0	0	20	2	0	0	0
Jones	4	0	79	0	1	0	0	0	0	0
Keys Run	0	0	0	0	0	0	0	0	0	0
Lambs	0	0	0	0	0	0	0	0	0	0
Little Carter	0	0	5	4	0	0	0	50	0	0
Little Falls Run	0	0	0	0	0	0	0	0	0	0
Massaponax	0	0	0	0	0	0	37	0	0	0
Millbank	1	0	0	0	0	230	24	1	0	0
Mount Landing	0	0	0	0	0	7	0	0	0	0
Muddy	4	0	0	0	0	30	0	0	0	0
Occupacia	0	0	0	0	0	0	0	0	0	0
Pecks	0	3	12	26	50	0	0	0	0	0

Table A3-2 (concluded). Benthic macroinvertebrate count data: Hirudinea, Polychaeta, and Oligochaeta.

class	Hirudinea		Polychaeta				Oligochaeta			
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
family	Glossiphoniidae	Piscicolidae	Ampharetidae	Nereidae	Spionidea		Naididae			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Peedee	4	0	0	0	0	4	0	0	0	2
Peumansend	0	0	0	0	0	0	0	0	0	0
Piscataway	0	0	0	0	0	1	0	1	0	0
Richardson	0	0	214	8	4	0	0	0	0	0
Saunders	0	0	76	0	1	7	4	1	0	0
Totuskey	0	0	0	0	0	0	0	0	0	0
Ware	0	0	0	0	0	0	0	0	0	0
Waterview	0	0	564	9	48	2	17	0	0	0

Table A3-3. Benthic macroinvertebrate count data: Oligochaeta.

class	Oligochaeta									
[illegible]	[illegible]									[illegible]
family	Naididae	Tubificidae							Enchytraeidae	Lumbriculidae
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Limnodrilus hoffmeisteri	[illegible]	[illegible]	[illegible]	[illegible]
Balls	0	10	51	0	0	0	0	0	0	0
Bellview	0	0	153	0	7	0	0	0	0	0
Bristle Mine Run	0	4	0	0	0	0	0	0	0	5
Brockenbrough	0	93	0	18	46	3	0	10	0	0
Cat Point	0	0	0	0	0	0	0	0	34	0
Claiborne	0	2	0	0	0	0	0	0	0	1
Colemans	0	42	0	2	8	0	0	0	0	0
Dicks	0	14	0	0	3	0	0	1	0	0
Falls Run	0	0	0	0	0	0	0	0	0	0
Farmers Hall	0	47	0	0	10	0	0	0	0	0
Gingoteague	0	96	0	3	27	0	0	0	0	0
Goldenvale	1	46	0	0	7	0	0	0	0	0
Hazel Run	0	2	0	0	0	0	0	0	0	11
Hoskins	0	62	0	0	3	0	0	0	0	2
Hugh	0	38	0	0	56	0	0	13	0	0
Jones	0	0	0	0	1	13	0	0	0	0
Keys Run	0	11	0	0	1	0	0	0	0	0
Lambs	0	37	0	0	2	0	0	0	0	0
Little Carter	0	5	0	11	0	25	0	0	0	0
Little Falls Run	0	24	0	0	0	0	0	0	0	0
Massaponax	0	0	0	0	0	0	6	0	0	0
Millbank	0	28	0	0	15	0	0	0	0	0
Mount Landing	0	186	0	1	35	0	0	0	0	0
Muddy	0	51	0	2	28	0	0	0	0	0
Occupacia	0	19	0	0	1	0	0	0	0	0
Pecks	0	1	60	0	0	0	0	0	0	0

Table A3-3 (continued). Benthic macroinvertebrate count data: Oligochaeta.

class	Oligochaeta									
[illegible]	[illegible]									[illegible]
family	Naididae	Tubificidae							Enchytraeidae	Lumbriculidae
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Peedee	0	59	0	0	0	0	0	0	0	0
Peumansend	0	66	0	0	12	0	0	0	0	0
Piscataway	0	46	0	0	16	0	0	0	0	7
Richardson	0	0	90	3	0	0	0	0	0	0
Saunders	0	49	0	0	38	0	0	0	0	0
Totuskey	0	21	0	0	1	0	0	0	0	0
Ware	0	1	0	0	0	0	0	0	0	0
Waterview	0	31	0	0	13	3	0	0	0	0

Table A3-4. Benthic macroinvertebrate count data: Chironomidae.

class	Insecta									
order	Diptera									
family	Chironomidae									
[illegible]	[illegible]	[illegible]	[illegible]	Dicrotendipes	Glyptotendipes	Paracladopelma	[illegible]	[illegible]	[illegible]	[illegible]
Balls	0	0	0	14	0	0	0	0	0	0
Bellview	1	0	0	5	0	0	0	0	0	0
Bristle Mine Run	0	0	1	0	2	0	0	0	8	0
Brockenbrough	4	0	0	21	0	0	0	0	0	0
Cat Point	0	0	3	4	0	0	0	1	1	0
Claiborne	0	0	0	0	0	0	0	0	66	63
Colemans	0	0	0	0	0	0	0	0	0	0
Dicks	0	0	0	0	0	0	0	0	0	8
Falls Run	0	0	0	0	0	0	0	0	0	87
Farmers Hall	2	0	2	3	0	0	0	0	0	2
Gingoteague	4	0	0	19	2	0	0	0	0	1
Goldenvale	0	2	0	0	0	0	0	0	0	0
Hazel Run	0	0	0	0	0	0	0	0	0	0
Hoskins	0	0	7	0	0	0	0	0	0	2
Hugh	1	0	1	2	5	0	0	0	1	0
Jones	138	0	0	1	0	0	0	0	0	0
Keys Run	0	0	1	0	0	0	0	6	18	0
Lambs	1	0	4	7	0	1	2	0	0	0
Little Carter	69	0	0	0	0	0	0	0	0	0
Little Falls Run	0	0	7	0	0	0	0	0	3	6
Massaponax	0	0	2	0	3	0	0	0	1	2
Millbank	1	0	0	0	26	1	0	0	0	0
Mount Landing	0	0	0	1	0	0	0	0	3	15
Muddy	0	0	0	0	0	0	0	0	0	0
Occupacia	0	0	1	0	0	0	0	0	13	24
Pecks	2	0	0	0	0	0	0	0	0	0

Table A3-4 (continued). Benthic macroinvertebrate count data: Chironomidae.

class	Insecta									
order	Diptera									
family	Chironomidae									
[illegible]	[illegible]	[illegible]	[illegible]	Dicrotendipes	Glyptotendipes	Paracladopelma	[illegible]	[illegible]	[illegible]	[illegible]
Peedee	0	0	3	23	5	9	0	6	0	1
Peumansend	0	0	22	1	0	0	0	0	11	8
Piscataway	0	0	0	0	0	0	0	0	10	0
Richardson	0	0	0	4	0	0	0	0	0	0
Saunders	4	0	1	2	0	0	0	0	0	0
Totuskey	0	0	0	0	0	0	0	0	1	0
Ware	0	0	1	1	0	0	15	0	5	0
Waterview	16	0	0	30	0	0	0	0	0	0

Table A3-4 (continued). Benthic macroinvertebrate count data: Chironomidae.

class	Insecta								
order	Diptera								
family	Chironomidae								
subfamily or genera	Symbiocladius	Boreochlus	[illegible]	Pentaneurini	Procladius	Tanypus	[illegible]	[illegible]	Tanytarsus
Balls	0	0	0	0	0	0	0	0	12
Bellview	0	0	0	0	0	0	0	0	1
Bristle Mine Run	0	0	0	0	0	0	0	0	0
Brockenbrough	0	0	0	0	0	85	0	0	7
Cat Point	0	0	0	0	0	0	0	0	1
Claiborne	0	53	0	5	0	0	0	0	2
Colemans	0	0	0	0	14	0	0	0	161
Dicks	0	0	0	0	0	0	0	0	0
Falls Run	0	0	0	0	0	0	0	0	0
Farmers Hall	0	0	0	0	4	0	0	0	2
Gingoteague	0	0	6	0	0	0	0	0	0
Goldenvale	0	0	3	0	0	0	0	0	0
Hazel Run	0	0	0	0	0	0	0	0	0
Hoskins	0	0	0	0	0	1	0	0	2
Hugh	0	0	3	0	3	0	0	0	1
Jones	0	0	0	0	2	0	0	0	20
Keys Run	0	0	0	0	0	0	0	0	0
Lambs	0	0	2	0	0	0	0	0	2
Little Carter	0	0	0	0	0	0	0	0	2
Little Falls Run	0	0	0	0	0	0	17	0	2
Massaponax	0	0	0	0	0	0	0	2	0
Millbank	0	0	0	0	0	0	0	0	0
Mount Landing	0	0	0	0	0	0	0	0	2
Muddy	2	0	0	0	0	0	0	0	3
Occupacia	0	0	0	0	0	0	0	0	1
Pecks	0	0	0	0	0	0	0	0	0

Table A3-4 (concluded). Benthic macroinvertebrate count data: Chironomidae.

class	Insecta								
[illegible]	Diptera								
family	Chironomidae								
[illegible]	[illegible]	[illegible]	[illegible]	Pentaneurini	Procladius	Tanypus	[illegible]	[illegible]	[illegible]
Peedee	0	0	22	0	3	0	0	0	35
Peumansend	0	0	0	0	26	0	0	0	3
Piscataway	0	0	0	0	0	0	0	0	0
Richardson	0	0	0	0	0	0	0	0	3
Saunders	0	0	0	0	11	0	0	0	84
Totuskey	0	0	0	0	0	0	0	0	0
Ware	1	0	0	0	0	0	0	0	14
Waterview	0	0	0	0	0	0	0	0	11

Table A3-5. Benthic macroinvertebrate count data: Coleoptera and Diptera.

class	Insecta									
order	Coleoptera					Diptera				
family	Curculionidae	Dysticidae	Haliplidae		Hydrophiloidae	Ceratopogonidae		Empididae	Simulidae	Tipulidae
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Berosus	Bezzia	Forcipomyia	[illegible]	[illegible]	Tipula
Balls	0	0	0	0	0	0	0	0	0	0
Bellview	0	0	0	0	0	0	0	0	0	0
Bristle Mine Run	0	0	0	1	0	1	1	0	0	0
Brockenbrough	1	0	0	0	0	3	0	0	0	0
Cat Point	0	0	0	0	0	5	0	0	0	0
Claiborne	0	0	3	0	0	0	0	2	2	0
Colemans	0	0	0	0	0	15	0	0	0	0
Dicks	0	0	8	1	0	17	0	1	2	17
Falls Run	0	0	0	0	0	0	0	1	0	0
Farmers Hall	0	0	0	0	0	18	0	0	0	0
Gingoteague	0	0	0	0	0	21	0	0	0	0
Goldenvale	0	0	0	0	0	6	0	0	0	0
Hazel Run	0	0	0	0	0	0	0	0	0	0
Hoskins	0	0	0	0	0	1	0	0	0	0
Hugh	0	0	0	0	0	9	0	0	0	0
Jones	0	0	0	0	0	3	0	0	0	0
Keys Run	0	0	0	0	0	0	0	0	0	0
Lambs	0	1	0	0	0	54	0	0	0	0
Little Carter	0	0	0	0	0	2	0	0	0	0
Little Falls Run	0	8	1	0	0	1	0	0	0	0
Massaponax	0	0	0	0	0	0	0	0	0	0
Millbank	0	0	0	0	0	6	0	0	0	0
Mount Landing	0	0	0	0	0	1	0	0	0	0
Muddy	0	0	2	0	0	6	0	0	0	0
Occupacia	0	0	1	0	0	1	0	0	0	0
Pecks	0	0	0	0	0	0	0	0	0	0

Table A3-5 (concluded). Benthic macroinvertebrate count data: Coleoptera and Diptera.

class										
[illegible]	Coleoptera					Diptera				
family	Curculionidae	Dysticidae	Haliplidae		Hydrophiloidae	Ceratopogonidae		Empididae	Simulidae	Tipulidae
[illegible]	[illegible]	[illegible]	[illegible]	Brychius	Berosus	Bezzia	Forcipomyia	Chelifera	Simulium	Tipula
Peedee	0	0	0	0	2	2	0	0	0	0
Peumansend	0	2	3	0	0	8	0	0	0	0
Piscataway	0	0	0	0	0	1	0	0	0	0
Richardson	0	0	0	0	0	0	0	0	0	0
Saunders	0	0	0	0	0	6	0	0	0	0
Totuskey	0	0	0	0	0	0	0	0	0	0
Ware	0	0	0	0	0	0	0	0	0	0
Waterview	0	0	0	0	0	0	0	0	0	0

Table A3-6. Benthic macroinvertebrate count data: Collembola, Ephemeroptera and Hemiptera.

class	Insecta								
order	Collembola		Ephemeroptera					Hemiptera	
family	Isotomidae	Smithuridae	Baetidae	Caenidae	Heptageniidae	Ephemeridae	Ephemerellidae	Belostomatidae	Corixidae
subfamily or genera			Baetis	Caenis	Stenonema	Hexagenia	Eurylophella		
Balls	0	0	0	0	0	0	0	0	0
Bellview	0	0	0	0	0	0	0	0	0
Bristle Mine Run	2	0	0	0	0	0	0	0	0
Brockenbrough	0	0	0	0	0	0	0	0	0
Cat Point	0	0	0	0	0	0	0	0	0
Claiborne	0	0	0	0	1	0	2	0	0
Colemans	0	0	0	0	0	0	0	0	0
Dicks	1	0	44	0	4	0	8	0	0
Falls Run	0	0	0	0	0	0	0	0	0
Farmers Hall	0	0	0	0	0	0	0	0	2
Gingoteague	0	0	0	2	0	0	0	0	0
Goldenvale	0	0	0	0	0	4	0	0	0
Hazel Run	0	0	0	0	0	0	0	0	0
Hoskins	0	0	0	0	0	0	0	0	0
Hugh	0	0	0	0	0	2	0	0	1
Jones	0	0	0	0	0	0	0	0	0
Keys Run	0	0	0	0	0	0	0	0	0
Lambs	1	0	0	0	0	0	0	0	0
Little Carter	0	1	0	0	0	0	0	8	0
Little Falls Run	0	0	0	0	0	0	0	0	0
Massaponax	0	0	0	0	0	0	0	0	0
Millbank	0	0	0	0	0	0	0	0	0
Mount Landing	0	0	0	0	0	0	0	0	0
Muddy	1	0	0	0	0	1	0	0	0
Occupacia	2	0	0	0	0	0	0	0	0
Pecks	0	0	0	0	0	0	0	0	0

Table A3-6 (concluded). Benthic macroinvertebrate count data: Collembola, Ephemeroptera and Hemiptera.

class	Insecta								
[illegible]	[illegible]		Ephemeroptera					Hemiptera	
family	Isotomidae	Smithuridae	Baetidae	Caenidae	Heptageniidae	Ephemeridae	Ephemerellidae	Belostomatidae	Corixidae
[illegible]	[illegible]	[illegible]	[illegible]	Caenis	Stenonema	Hexagenia	[illegible]	[illegible]	[illegible]
Peedee	0	0	0	58	0	0	0	0	0
Peumansend	0	0	0	0	0	0	0	0	0
Piscataway	0	0	0	0	0	0	0	0	0
Richardson	0	0	0	0	0	0	0	0	0
Saunders	0	0	0	0	0	0	0	0	0
Totuskey	0	0	0	0	0	0	0	0	0
Ware	0	0	0	0	0	0	0	0	0
Waterview	0	0	0	0	0	0	0	0	0

Table A3-7. Benthic macroinvertebrate count data: Megaloptera, Odonata, Plecoptera, Tricoptera, Turbellaria, Nemertea, and Arachnoidea.

class									Turbellaria	Nemertea	Arachnoidea
[illegible]	Megaloptera	Odonata			Plecoptera	Tricoptera			Tricladida		
family	Corydalidae	Coenagrionidae	Gomphidae	Libellulidae	Perlodidae	Helicopsychidae	Hydropsychidae	Leptoceridae	Planaria		Hydracarina
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Isoperla	[illegible]	Hydropsyche	[illegible]	Dugesia		
Balls	0	0	0	0	0	0	0	0	0	1	0
Bellview	0	0	0	0	0	0	0	0	0	0	0
Bristle Mine Run	0	0	0	0	0	0	0	0	0	0	0
Brockenbrough	0	0	0	0	0	0	0	0	0	0	0
Cat Point	0	0	0	0	0	0	0	0	0	0	4
Claiborne	0	0	0	0	0	0	6	0	0	0	1
Colemans	0	0	0	0	0	0	0	0	0	0	0
Dicks	3	0	0	0	0	0	0	5	1	0	0
Falls Run	0	0	0	0	1	0	2	0	0	0	0
Farmers Hall	0	0	0	0	0	0	0	0	0	0	0
Gingoteague	0	0	1	1	0	0	0	0	0	0	0
Goldenvale	0	0	0	0	0	0	0	0	0	0	0
Hazel Run	0	0	0	0	0	0	0	0	0	0	0
Hoskins	0	0	0	0	0	0	0	1	0	0	0
Hugh	0	0	0	0	0	1	0	0	0	0	1
Jones	0	0	0	0	0	0	0	0	0	1	0
Keys Run	0	0	0	0	0	0	0	0	0	0	0
Lambs	0	0	1	0	0	0	0	0	0	0	0
Little Carter	0	0	0	0	0	0	0	0	0	0	11
Little Falls Run	0	0	0	0	0	0	0	0	0	0	0
Massaponax	0	0	0	0	0	0	0	0	0	0	0
Millbank	0	0	0	0	0	0	0	0	0	0	0
Mount Landing	0	0	0	0	0	0	0	0	0	0	0
Muddy	0	0	0	1	0	0	0	0	2	0	0
Occupacia	0	0	0	0	0	0	0	0	0	0	0
Pecks	0	0	0	0	0	0	0	0	0	0	0

Table A3-7 (concluded). Benthic macroinvertebrate count data: Megaloptera, Odonata, Plecoptera, Tricoptera, Turbellaria, Nemertea, and Arachnoidea.

class	Insecta								Turbellaria	Nemertea	Arachnoidea
[illegible]	Megaloptera	Odonata			Plecoptera	Tricoptera			Tricladida		
family	Corydalidae	Coenagrionidae	Gomphidae	Libellulidae	Perlodidae	Helicopsychidae	Hydropsychidae	Leptoceridae	Planaria		Hydracarina
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Isoperla		Hydropsyche	Oecetis	Dugesia		
Peedee	0	1	1	4	0	0	0	3	0	0	0
Peumansend	0	0	0	0	1	0	1	1	0	0	3
Piscataway	0	0	0	0	0	0	0	0	0	0	0
Richardson	0	0	0	0	0	0	0	0	0	0	4
Saunders	0	0	0	0	0	0	0	0	0	0	0
Totuskey	0	0	0	0	0	0	0	0	0	0	0
Ware	0	0	0	0	0	0	0	0	0	0	0
Waterview	0	0	0	0	0	0	0	0	0	0	0

Table A3-8. Benthic macroinvertebrate count data: Mollusca.

phylum	Mollusca							
class	Gastropoda			Bivalvia				
family	Hydrobiidae	Planorbidae	Viviparidea	Corbiculidae	Sphaeriidae	Unionidae	Mactridae	Tellinidea
genus		Gyraulus		Corbicula			Rangia	Macoma
Balls	10	0	0	0	0	0	0	17
Bellview	3	0	0	0	0	0	0	0
Bristle Mine Run	0	0	0	0	2	0	0	0
Brockenbrough	0	0	0	0	0	0	0	0
Cat Point	1	0	0	0	0	0	0	0
Claiborne	0	0	0	0	0	0	0	0
Colemans	42	0	0	0	8	0	0	0
Dicks	0	0	0	0	1	0	0	0
Falls Run	0	0	0	0	0	0	0	0
Farmers Hall	22	0	0	0	0	0	0	0
Gingoteague	172	0	0	0	5	1	0	0
Goldenvale	5	0	0	0	4	0	0	0
Hazel Run	0	0	0	0	0	0	0	0
Hoskins	1	0	0	0	2	0	0	0
Hugh	1	0	0	0	0	0	0	0
Jones	233	0	0	0	0	0	0	0
Keys Run	0	0	0	0	3	0	0	0
Lambs	0	0	0	0	15	0	0	0
Little Carter	7	0	0	0	0	0	0	0
Little Falls Run	0	0	0	0	2	0	0	0
Massaponax	0	0	0	0	1	0	0	0
Millbank	10	0	0	0	2	0	0	0
Mount Landing	0	0	0	0	0	0	0	0
Muddy	3	0	0	0	2	0	0	0
Occupacia	0	0	0	0	6	1	0	0
Pecks	1	0	0	0	0	0	8	4

Table A3-8 (concluded). Benthic macroinvertebrate count data: Mollusca..

phylum	Mollusca							
[illegible]	[illegible]			Bivalvia				
family	Hydrobiidae	Planorbidae	Viviparidea	Corbiculidae	Sphaeriidae	Unionidae	Mactridae	Tellinidea
[illegible]	[illegible]	[illegible]	[illegible]	Corbicula	[illegible]	[illegible]	[illegible]	[illegible]
Peedee	1817	0	0	0	10	0	0	0
Peumansend	3	0	0	0	0	0	0	0
Piscataway	10	2	4	0	11	0	0	0
Richardson	0	0	0	0	0	0	0	0
Saunders	13	0	0	0	1	0	0	0
Totuskey	2	1	0	0	4	0	0	0
Ware	0	0	0	1	12	0	0	0
Waterview	120	0	0	0	1	0	0	0

Appendix 4

PCA and Discriminant Analysis Tables and Figures

Figure A4-1. The eigenvalues for the components in a PCA using the land use/cover within the 200-meter buffer and watershed morphology metrics. In total 21 metrics were used. Seven components resulted with eigenvalues greater than 1.

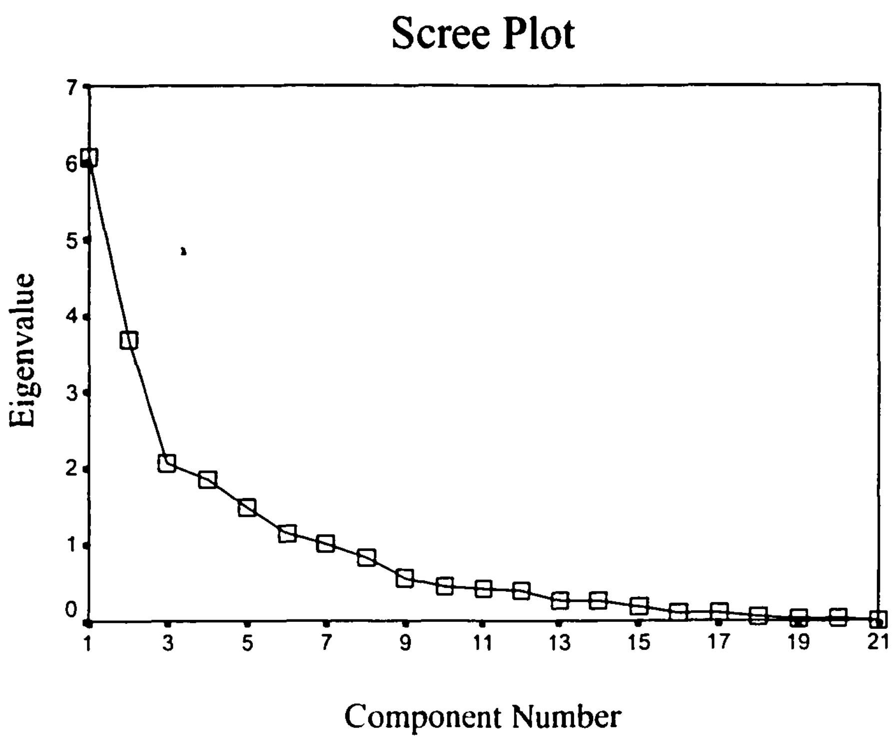

Scree Plot
Eigenvalue
7
6
5
4
3
2
1
0
1
3
5
7
9
11
13
15
17
19
21
Component Number

Table A4-1. The eigenvalues, percent of variance and cumulative percent of variance for the seven components with eigenvalues greater than one from the PCA using land use/cover within a 200-meter buffer and watershed morphology metrics.

	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
COMPONENT	EIGEN-VALUE	% OF VARIANCE	CUMULATIVE %	EIGEN-VALUE	% OF VARIANCE	CUMULATIVE %
w1a	6.076	28.94	28.94	4.485	21.36	21.36
w2a	3.696	17.60	46.54	3.479	16.57	37.923
w3a	2.080	9.91	56.45	1.937	9.22	47.145
w4a	1.859	8.85	65.30	1.929	9.19	56.334
w5a	1.490	7.09	72.39	1.914	9.11	65.45
w6a	1.128	5.37	77.76	1.906	9.07	74.52
w7a	1.007	4.80	82.56	1.688	8.04	82.56

Table A4-2. The component loadings for the land use/cover within a 200-meter buffer and watershed morphology metrics. A Varimax rotation was used in the PCA.

	COMPONENT						
	w1a	w2a	w3a	w4a	w5a	w6a	w7a
grasslands within 200-m buffer	0.887						
probable row crops within 200-m buffer	0.845						-0.272
shape	0.788			0.331			
deciduous forests within 200-m buffer	0.780		0.365		0.275		
elevation, mean	0.696	0.545				0.266	
drainage density	-0.515		-0.359		0.443	-0.251	
high density developed within 200-m buffer		0.949					
road density		0.914					
low density developed within 200-m buffer		0.912					
mixed forests within 200-m buffer		-0.305	-0.859				
conifers/evergreens forests within 200-m buffer			-0.578	-0.405	-0.376		0.387
woody wetlands within 200-m buffer		-0.314	0.572	-0.237	-0.288	-0.485	
elevation, standard deviation				0.722			
area above 5 feet	0.516			[illegible]	-0.238		0.253
size	0.411			[illegible]	-0.303		0.334
slope, median					[illegible]		
slope, standard deviation	0.435		0.330	0.221	[illegible]	0.269	0.228
row crops within 200-m buffer	-0.271					0.849	
emergent wetlands within 200-m buffer	-0.405					-0.732	
barren		0.352					0.797
water within 200-m buffer	0.281	-0.332		0.206		-0.205	[illegible]

Table A4-3. Covariance matrices for the absence and presence groups of the seven components with eigenvalues greater than one. Components w1 and w2 have similar coefficient values. A comparison of the other coefficients reveals different signs or magnitudes.

	COMPONENT	w1a	w2a	w3a	w4a	w5a	w6a	w7a
ABSENCE	w1a	0.728						
	w2a	0.182	0.609					
	w3a	-0.282	0.119	1.413				
	w4a	0.230	-0.176	0.006	1.758			
	w5a	-0.063	0.0696	-0.023	-0.053	1.028		
	w6a	-0.274	0.052	-0.175	-0.027	-0.382	1.229	
	w7a	0.260	-0.150	0.118	-0.034	-0.172	0.229	1.089
PRESENCE	w1a	0.339						
	w2a	0.085	1.382					
	w3a	0.100	-0.070	0.617				
	w4a	-0.049	0.127	0.027	0.271			
	w5a	0.332	-0.142	0.072	0.004	0.961		
	w6a	0.034	0.012	0.131	0.070	0.447	0.776	
	w7a	0.001	0.080	-0.070	-0.013	0.102	-0.167	0.905

Figure A4-2. Scatter plots of the seven components with eigenvalues greater than one used in the PCA land use/cover within a 200-meter buffer and watershed morphology metrics. The presence group is shown in black; absence group is shown in red. None of the scatter plots show good separation of groups, equal variance or similar slopes.

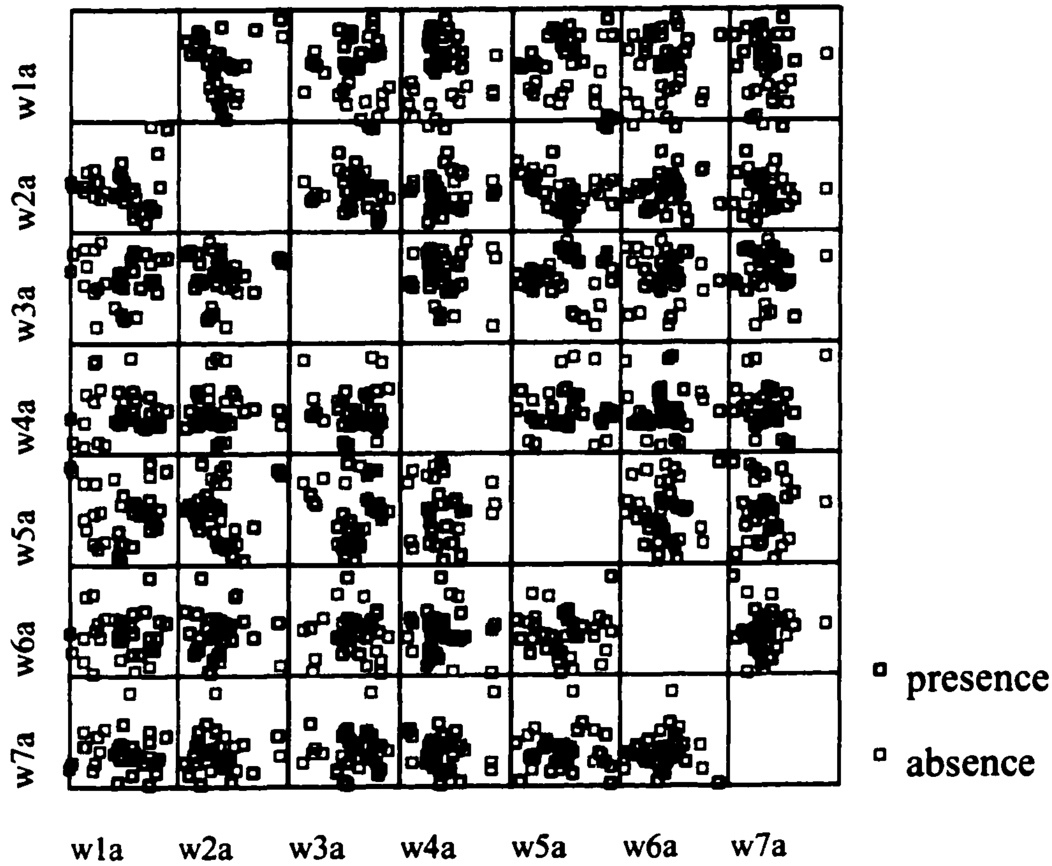
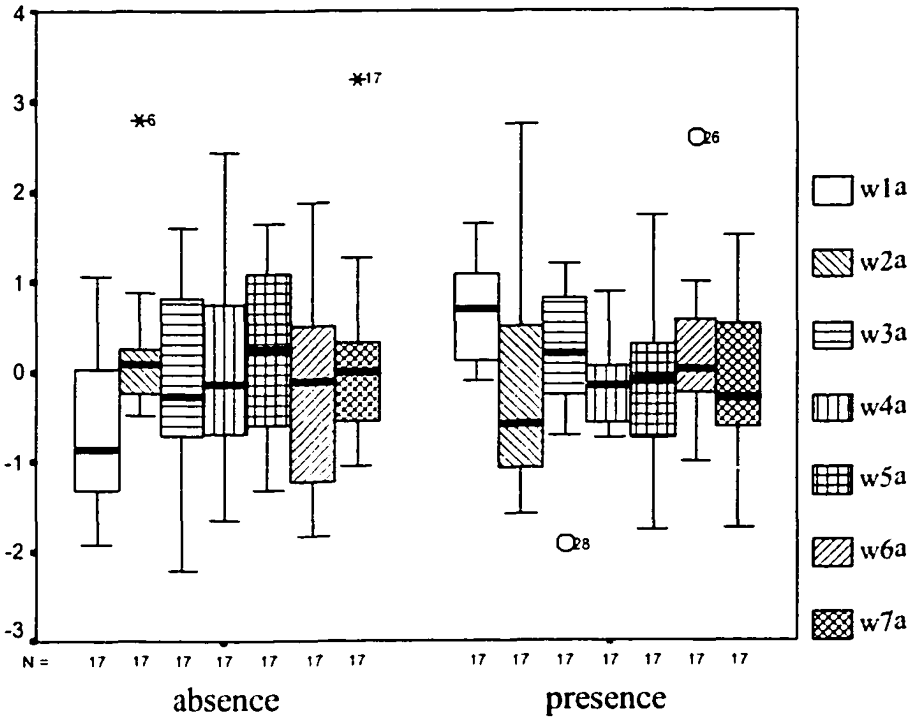

w1a
w2a
w3a
w4a
w5a
w6a
w7a
presence
absence
w1a
w2a
w3a
w4a
w5a
w6a
w7a

Figure A4-3. Box plots of the components with eigenvalues greater than one resulting from the PCA using land use/cover within a 200-meter buffer and watershed morphology metrics.



4
3
2
1
0
-1
-2
-3
*6
*17
○26
○28
N =
17 17 17 17 17 17 17
17 17 17 17 17 17 17
absence
presence
w1a
w2a
w3a
w4a
w5a
w6a
w7a

Table A4-4. Group prediction results for the discriminant analysis using component w1.

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	12	5	17
	presence	3	14	17
%	absence	70.6	29.4	100
	presence	17.6	82.4	100

Figure A4-4. The eigenvalues for the components in a PCA using stream-reach metrics and watershed land use/cover and morphology metrics. In total, 38 metrics were used. Eleven components resulted with eigenvalues greater than 1.

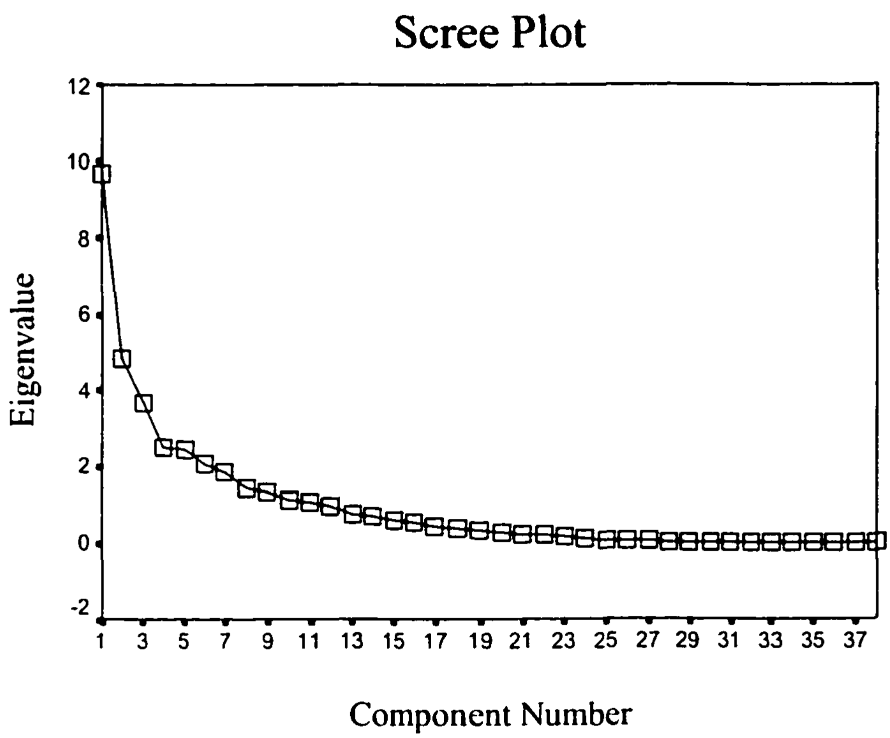

Scree Plot
Eigenvalue
12
10
8
6
4
2
0
-2
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Component Number

Table A4-5. The eigenvalues, percent of variance and cumulative percent of variance for the eleven components with eigenvalues greater than one from the PCA using stream-reach metrics and watershed land use/cover and morphology metrics.

	Initial Eigenvalues			Rotation Sums of Squared Loadings		
Component	Eigen-value	% of Variance	Cumulative %	Eigen-value	% of Variance	Cumulative %
wr1	9.686	25.49	25.49	4.204	11.06	11.06
wr2	4.861	12.79	38.28	4.049	10.66	21.72
wr3	3.663	9.64	47.92	3.881	10.21	31.93
wr4	2.483	6.53	54.45	3.626	9.54	41.47
wr5	2.445	6.43	60.88	2.947	7.75	49.22
wr6	2.068	5.44	66.32	2.743	7.22	56.44
wr7	1.883	4.96	71.28	2.487	6.55	62.99
wr8	1.427	3.76	75.04	2.174	5.72	68.71
wr9	1.315	3.46	78.50	2.069	5.46	74.17
wr10	1.127	2.97	81.47	1.947	5.11	79.28
wr11	1.066	2.80	84.27	1.896	4.99	84.27

Table A4-6. The component loadings for the stream-reach metrics and watershed land use/cover and morphology metrics. A Varimax rotation was used in the PCA.

METRIC	COMPONENT										
	wr1	**wr2**	**wr3**	**wr4**	**wr5**	**wr6**	**wr7**	**wr8**	**wr9**	**wr10**	**wr11**
grasslands within 200-m buffer	**-0.793**	0.206									
deciduous forest within 200-m buffer	**0.757**	-0.376				-0.239	0.220		-0.217		
shape	**0.703**	-0.250		-0.207	0.323			0.299			
elevation, mean	**0.608**	-0.358	0.562						-0.239		
slope, standard deviation	**0.521**			-0.471			0.421		-0.236	0.255	0.248
drainage density	**-0.511**	0.266					0.473	-0.233	0.202		
mixed forests	**-0.479**		-0.317			0.260			0.423	-0.369	
water	**0.381**	0.358	-0.251	-0.274	0.321			0.231		-0.264	0.249
emergent wetlands		**0.798**									-0.229
temperature, median		**0.74[illegible]**		0.331						-0.217	
% organics		**[illegible]**		0.461				-0.282			
temperature, minimum	-0.251	**0.65[illegible]**				0.307	0.248				
temperature, maximum	-0.282	**0.633**	-0.312	0.444						-0.227	
woody wetlands		**0.610**	-0.214			-0.382		-0.269			-0.405

Table A4-6 (continued). The component loadings for the stream-reach metrics and watershed land use/cover and morphology metrics. A Varimax rotation was used in the PCA.

METRIC	COMPONENT										
	wr1	**wr2**	**wr3**	**wr4**	**wr5**	**wr6**	**wr7**	**wr8**	**wr9**	**wr10**	**wr11**
high density, developed			**0.901**								
low density, developed			**0.898**					0.207			
road density		-0.240	**0.867**								
% silt		0.266		**0.852**							
% clay			-0.221	**0.789**		0.248					
stream-reach width		0.297		**0.641**	0.329					0.217	
stream-reach depth, maximum					**0.937**						
stream-reach depth, mean					**0.907**						
size	0.263			-0.306	**0.567**		-0.261	0.508			
area above 5 feet	0.420			-0.223	**0.536**			0.522			
pH, minimum						**0.946**					
pH, median	-0.277		0.282	0.224		**0.779**					
pH, maximum	-0.515			0.268	0.205	**0.545**			0.346		

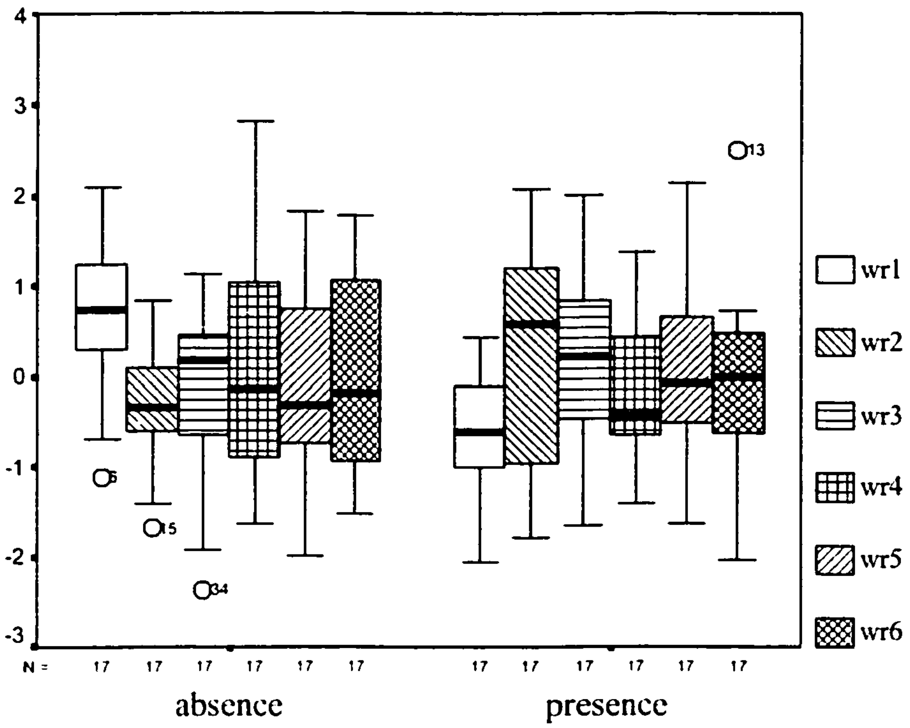
Table A4-6. (concluded). The component loadings for the stream-reach metrics and watershed land use/cover and morphology metrics. A Varimax rotation was used in the PCA.

METRIC	COMPONENT										
	wr1	wr2	wr3	wr4	wr5	wr6	wr7	wr8	wr9	wr10	wr11
slope, median							0.865				
DO, minimum	0.278	-0.245	0.421				-0.540				0.366
elevation, standard deviation							0.218	0.697			-0.348
barren			0.240			-0.213		0.692		-0.231	
% gravel		-0.227	0.268	-0.244					-0.830		
% sand				-0.579					0.759		
probable row crops within 200-m buffer	-0.351			0.244						0.766	
conifers/evergreens forests							-0.496			[illegible]	0.218
row crops		-0.316				0.286	-0.360	-0.233		0.590	0.265
DO, maximum											[illegible]
DO, median		-0.258	0.427				-0.405				[illegible]

Table A4-7. Covariance matrices for the absence and presence groups of the eleven components with eigenvalues greater than one. Components wr1, wr3, and wr7 have similar coefficient values. A comparison of the other coefficients reveals different signs or magnitudes.

	Component	wr1	wr2	wr3	wr4	wr5	wr6	wr7	wr8	wr9	wr10	wr11
Absence	**wr1**	0.805										
	wr2	0.116	0.444									
	wr3	0.133	-0.234	1.095								
	wr4	-0.176	0.255	0.207	1.336							
	wr5	0.345	0.145	-0.107	-0.124	1.114						
	wr6	0.230	-0.003	-0.266	0.009	-0.196	1.149					
	wr7	-0.165	0.025	0.397	-0.213	-0.020	-0.101	1.352				
	wr8	-0.096	-0.030	-0.371	-0.525	0.229	0.125	0.152	0.886			
	wr9	-0.212	0.042	-0.180	0.296	0.095	-0.007	0.080	0.154	0.824		
	wr10	-0.052	0.081	0.138	0.148	0.398	0.145	0.244	0.006	0.177	1.278	
	wr11	0.187	-0.198	0.297	-0.151	0.121	-0.286	0.011	-0.000	0.100	-0.148	0.575
Presence	**wr1**	0.425										
	wr2	0.261	1.448									
	wr3	0.120	0.120	0.891								
	wr4	-0.064	-0.146	-0.134	0.657							
	wr5	-0.243	-0.191	0.076	0.153	0.936						
	wr6	-0.270	0.021	0.278	-0.020	0.200	0.911					
	wr7	-0.158	0.121	-0.299	0.120	0.059	0.086	0.585				
	wr8	0.162	0.000	0.351	0.544	-0.237	-0.121	-0.126	1.172			
	wr9	0.046	0.033	0.230	-0.344	-0.075	-0.000	-0.144	-0.141	1.205		
	wr10	0.109	-0.107	-0.156	-0.132	-0.405	-0.142	-0.222	-0.010	-0.165	0.780	
	wr11	0.076	0.079	-0.377	0.227	-0.153	0.299	0.091	-0.020	-0.047	0.130	1.405

Figure A4-5. Box plots of the components with eigenvalues greater than one resulting from the PCA using stream-reach metrics and watershed land use/cover and morphology metrics.


4
3
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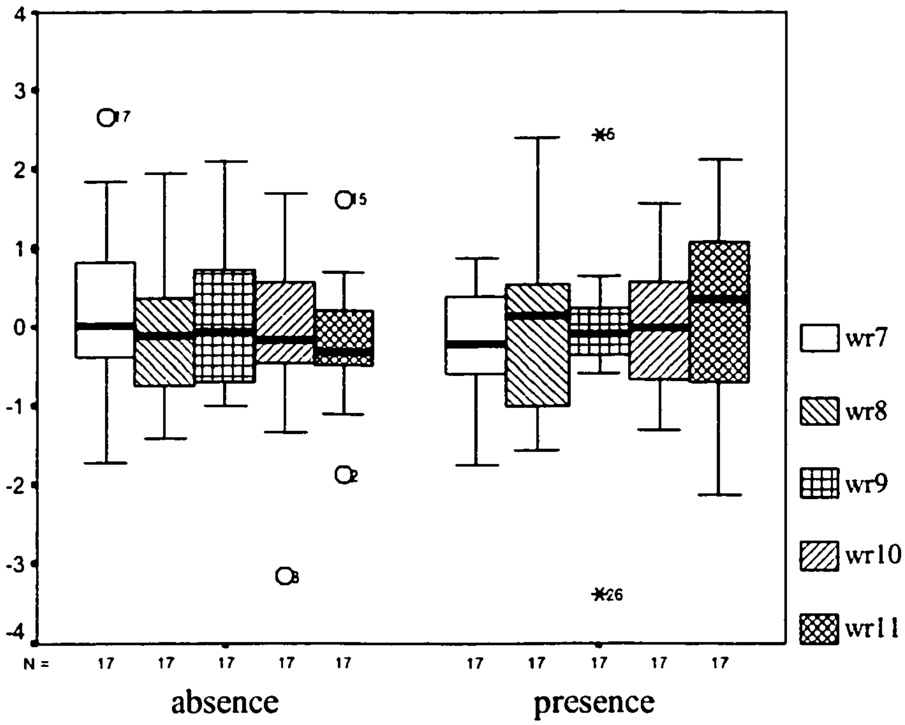
1
0
-1
-2
-3
N =
17
17
17
17
17
17
17
17
17
17
17
17
absence
presence
13
5
15
34
wr1
wr2
wr3
wr4
wr5
wr6


4
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0
-1
-2
-3
-4
N =
17
17
17
17
17
17
17
17
17
17
absence
presence
17
15
2
3
6
26
wr7
wr8
wr9
wr10
wr11

Figure A4-6. Scatter plots of the eleven components with eigenvalues greater than one used in the PCA stream-reach metrics and watershed land use/cover and morphology metrics. The presence group is shown in black; absence group is shown in red.

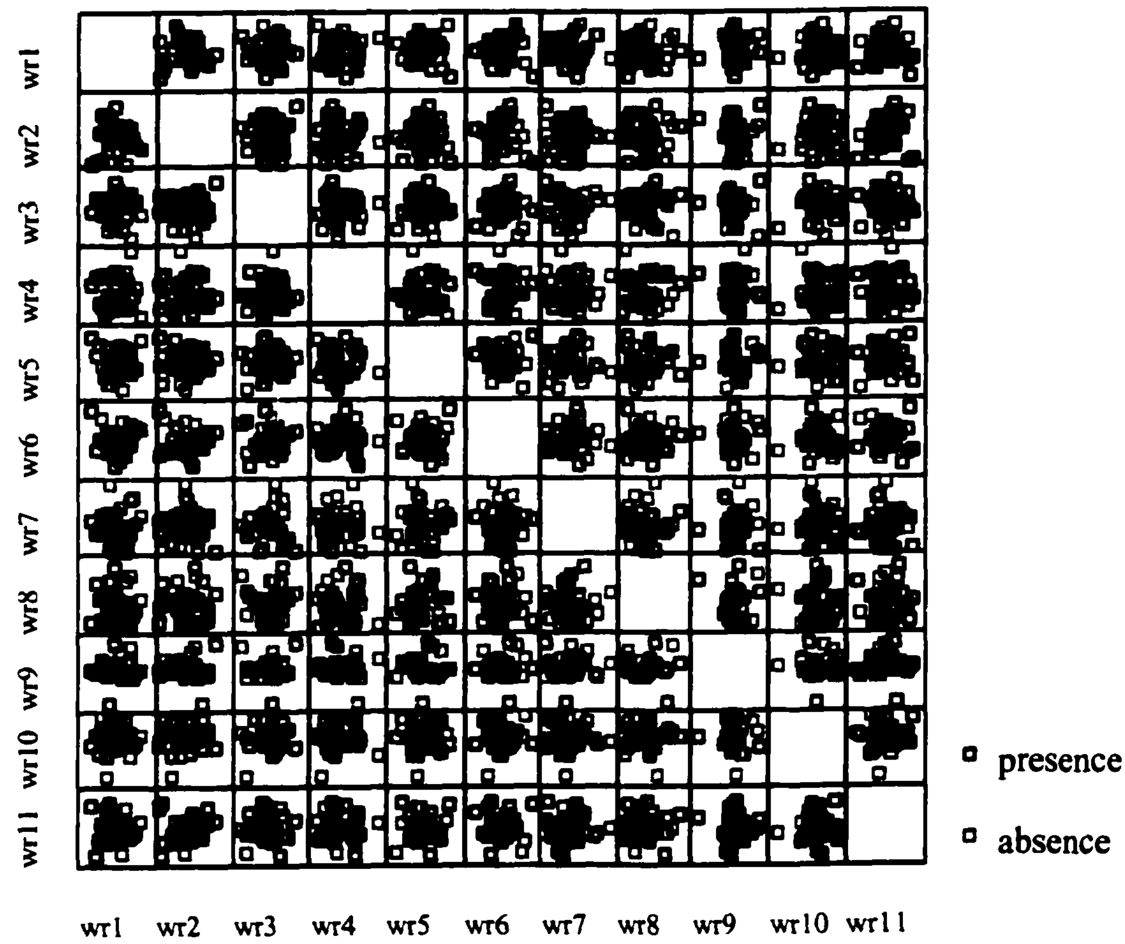

wr1
wr2
wr3
wr4
wr5
wr6
wr7
wr8
wr9
wr10
wr11
presence
absence

Table A4-8. Group prediction results for the discriminant analysis using components wr1 and wr3. The overall prediction ability is 82.4%.

Table A4-9. Group prediction results for the discriminant analysis using components wr1 and wr7. The overall prediction ability is 82.4%, the same as using wr1 and wr3 (shown above).

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	13	4	17
	presence	2	15	17
%	absence	76.5	23.5	100
	presence	11.8	88.2	100

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	14	3	17
	presence	3	14	17
%	absence	82.4	17.6	100
	presence	17.6	82.4	100

Figure A4-7. The eigenvalues for the components in a PCA using stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics. In total, 38 metrics were used. Ten components resulted with eigenvalues greater than 1.

Scree Plot

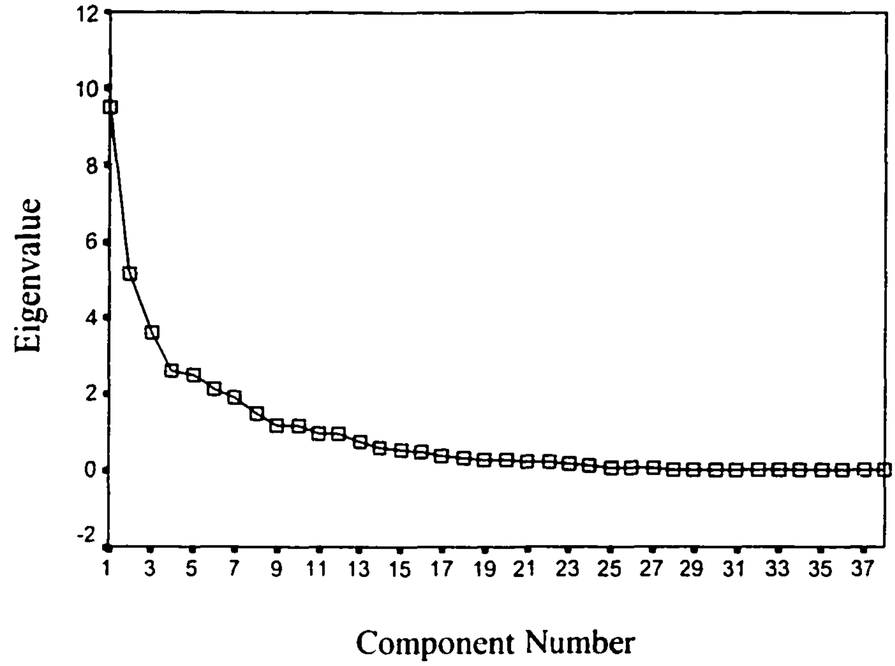

Eigenvalue
12
10
8
6
4
2
0
-2
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Component Number

Table A4-10. The eigenvalues, percent of variance and cumulative percent of variance for the ten components with eigenvalues greater than one from the PCA using stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics.

	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Eigen-value	% of Variance	Cumulative %	Eigen-value	% of Variance	Cumulative %
wr1a	9.501	25.00	25.0	4.892	12.87	12.87
wr2a	5.166	13.60	38.60	4.734	12.46	25.33
wr3a	3.620	9.53	48.13	4.014	10.56	35.89
wr4a	2.619	6.89	55.02	3.059	8.05	43.94
wr5a	2.532	6.66	61.68	2.855	7.51	51.45
wr6a	2.121	5.58	67.26	2.835	7.46	58.91
wr7a	1.900	5.00	72.26	2.777	7.31	66.22
wr8a	1.474	3.88	76.14	2.161	5.69	71.91
wr9a	1.204	3.17	79.31	2.044	5.38	77.29
wr10a	1.164	3.06	82.37	1.934	5.09	82.38

Table A4-11. The component loadings for the stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics. A Varimax rotation was used in the PCA.

METRIC	**COMPONENT**									
	wr1a	**wr2a**	**wr3a**	**wr4a**	**wr5a**	**wr6a**	**wr7a**	**wr8a**	**wr9a**	**wr10a**
grasslands within 200-m buffer	-0.898									
probable row crops within 200-m buffer	-0.799			0.230						
shape	0.749	-0.255			0.286					
deciduous forest within 200-m buffer	0.687	-0.426				-0.221	0.232	0.244		-0.314
elevation, mean	0.585	-0.416	0.537				0.323			
area above 5 feet	0.543			-0.204	0.526		0.241	-0.293	-0.223	
row crops within 200-m buffer	[illegible]	-0.470				0.245			0.386	
water within 200-m buffer	[illegible]	0.294	-0.312	-0.230	0.324		0.330			0.248
temperature, median		[illegible]		0.219						
temperature, minimum		[illegible]	-0.301	0.303						
temperature, maximum		[illegible]				0.319				
emergent wetlands within 200-m buffer		[illegible]						-0.287		
% organics	-0.254	0.705		0.341			-0.237			-0.242

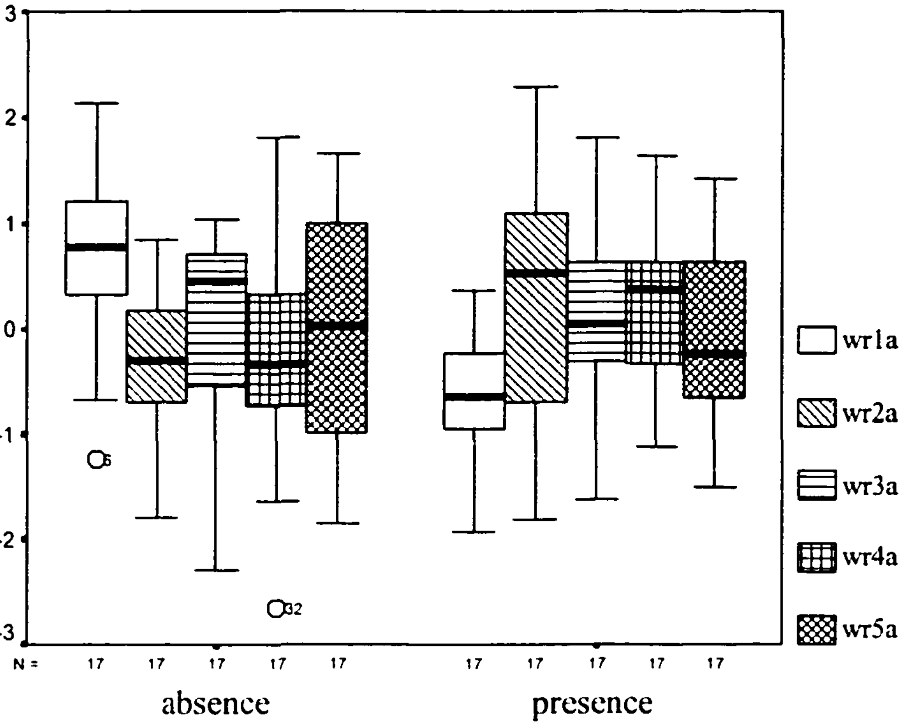
Table A4-11 (continued). The component loadings for the stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics. A Varimax rotation was used in the PCA.

METRIC	COMPONENT									
	wr1a	wr2a	wr3a	wr4a	wr5a	wr6a	wr7a	wr8a	wr9a	wr10a
high intensity developed within 200-m buffer			**0.958**							
low intensity developed within 200-m buffer			**0.888**							
road density		-0.297	**0.852**							0.240
% silt		0.372		**0.803**						
% sand				**-0.754**			-0.534			
% clay		0.311	-0.233	**0.738**		0.269	-0.200			
stream-reach width	-0.306	0.333		**0.553**	0.441					
stream-reach depth, mean					**0.891**					
stream-reach depth, maximum					**0.883**					
size	0.479			-0.308	**0.528**			-0.369		
pH, minimum						**0.91[illegible]**				
pH, median			0.249	0.242		**0.770**				0.203
pH, maximum	-0.330				0.292	**0.585**	-0.512		-0.217	

Table A4-11 (concluded). The component loadings for the stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics. A Varimax rotation was used in the PCA.

Metric	**Component**									
	wr1a	**wr2a**	**wr3a**	**wr4a**	**wr5a**	**wr6a**	**wr7a**	**wr8a**	**wr9a**	**wr10a**
% gravel		-0.375	0.226				**0.728**			
slope, standard deviation	0.447			-0.390			**0.543**	0.373		-0.259
mixed forest within 200-m buffer		0.208	-0.296			0.395	**-0.513**			0.373
slope, median								**0.769**	-0.206	
woody wetlands within 200-m buffer		0.239	-0.315			-0.486		**-0.553**		
DO, maximum				0.238				**-0.497**	0.452	0.305
drainage density	-0.441	0.354					-0.321	[illegible]		
elevation, standard deviation							0.317		[illegible]	
DO, median		-0.267	0.375			0.235			[illegible]	
DO, minimum	0.250	-0.314	0.417				0.305	-0.266	[illegible]	
conifers/evergreen forest within 200-m buffer							-0.259			[illegible]
barren within 200-m buffer	0.226		0.311				0.284			[illegible]

Figure A4-8. Box plots of the components with eigenvalues greater than one resulting from the PCA using stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics.


3
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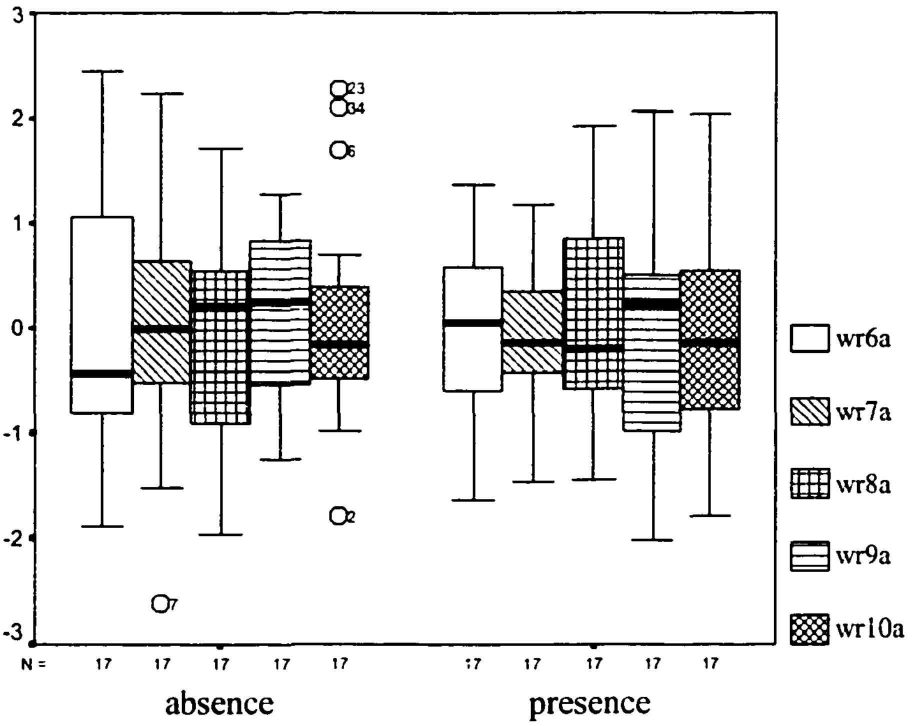
-3
N = 17 17 17 17 17 17 17 17 17 17
absence
presence
wr1a
wr2a
wr3a
wr4a
wr5a


3
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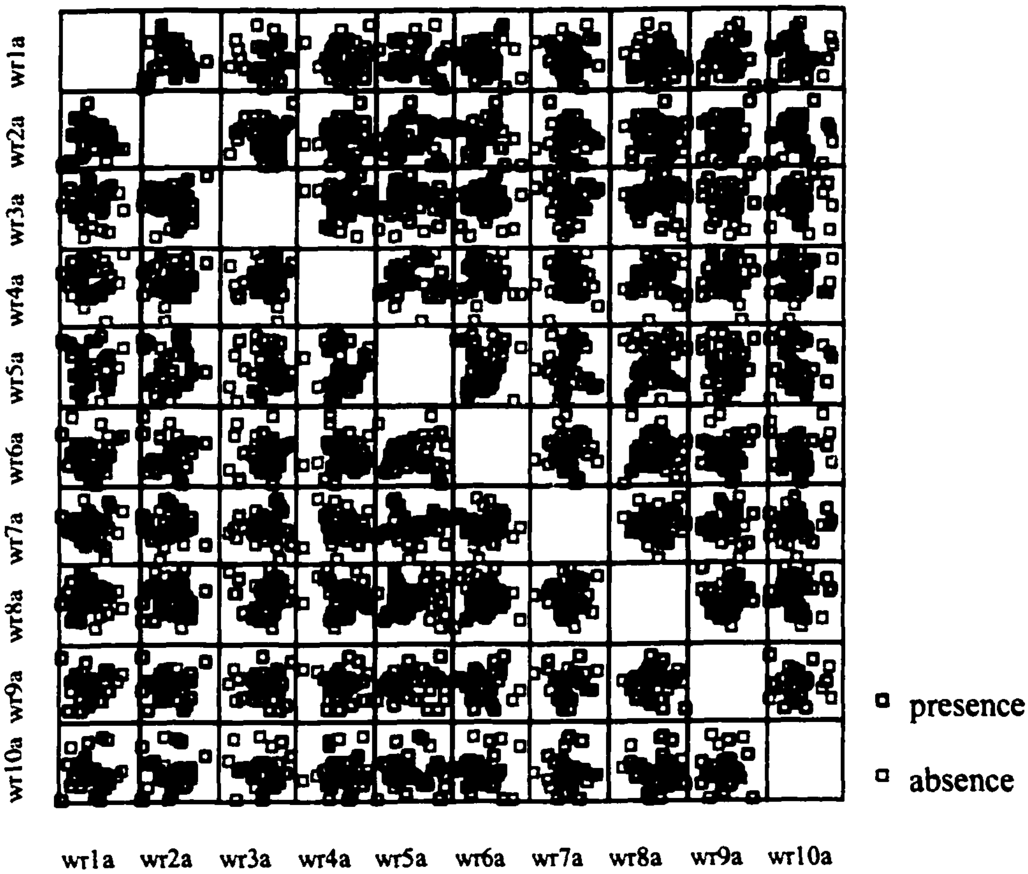
-1
-2
-3
N = 17 17 17 17 17 17 17 17 17 17
absence
presence
wr6a
wr7a
wr8a
wr9a
wr10a

Figure A4-9. Scatter plots of the ten components with eigenvalues greater than one used in the PCA stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics. The presence group is shown in black; absence group is shown in red.



wr1a
wr2a
wr3a
wr4a
wr5a
wr6a
wr7a
wr8a
wr9a
wr10a
presence
absence

Table A4-12. Covariance matrices for the absence and presence groups of the eleven components with eigenvalues greater than one.

	COMPONENT	wr1a	wr2a	wr3a	wr4a	wr5a	wr6a	wr7a	wr8a	wr9a	wr10a
ABSENCE	wr1a	0.817									
	wr2a	0.182	0.526								
	wr3a	0.098	-0.130	1.163							
	wr4a	0.317	-0.181	-0.340	1.196						
	wr5a	0.163	0.256	0.055	0.025	1.224					
	wr6a	0.113	-0.154	-0.280	-0.048	0.005	1.449				
	wr7a	0.015	0.093	0.214	0.322	-0.204	-0.083	1.582			
	wr8a	0.038	-0.096	-0.306	0.201	-0.453	-0.061	-0.152	1.069		
	wr9a	0.091	-0.085	0.142	-0.187	0.027	-0.188	-0.106	0.124	0.703	
	wr10a	-0.258	-0.136	-0.247	0.315	0.362	0.057	0.085	-0.128	0.095	1.179
PRESENCE	wr1a	0.376									
	wr2a	0.244	1.328								
	wr3a	0.056	0.054	0.872							
	wr4a	0.018	0.017	0.281	0.738						
	wr5a	-0.189	-0.243	-0.050	-0.015	0.838					
	wr6a	-0.177	0.186	0.292	0.072	-0.007	0.609				
	wr7a	-0.102	-0.050	-0.198	-0.288	0.202	0.077	0.472			
	wr8a	0.026	0.064	0.295	-0.225	0.455	0.066	0.158	0.988		
	wr9a	-0.158	0.118	-0.131	0.213	-0.029	0.183	0.099	-0.119	1.355	
	wr10a	0.128	0.199	0.270	-0.265	-0.366	-0.066	-0.098	0.137	-0.105	0.864

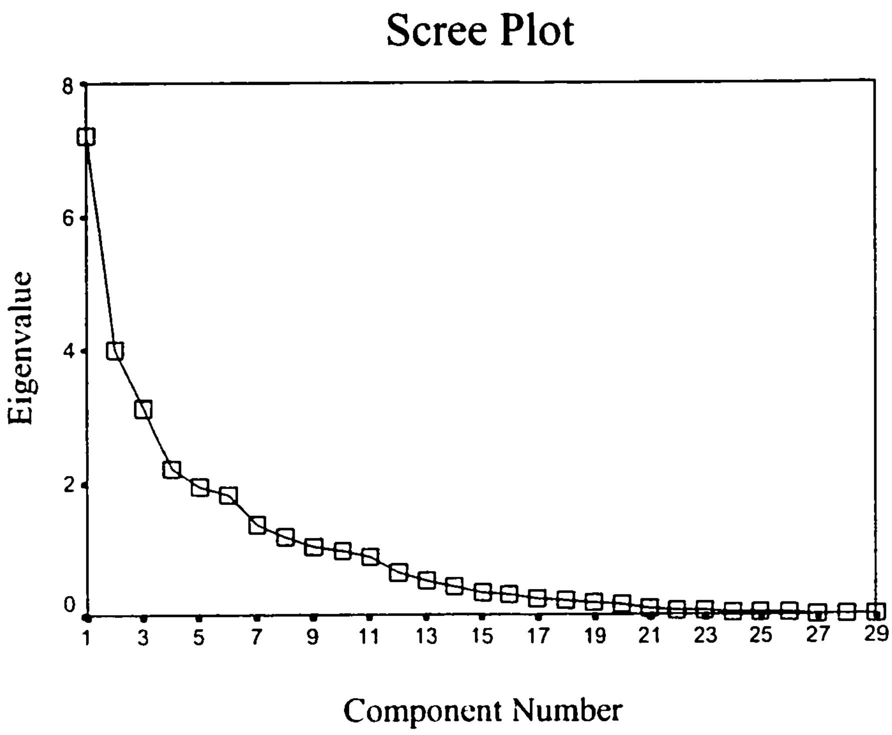
Table A4-13. Group prediction results for the discriminant analyses using components wr1a only, wr1a and wr8a, and wr1a and wr2a. The overall prediction ability of all three trials is 88.2%.

Table A4-14. The Wilks' Lambda test indicates that the centroids of the absence and presence groups are significantly different for all discriminant analyses used for PCA stream-reach metrics and land use/cover within a 200-meter buffer and watershed morphology metrics

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	13	4	17
	presence	2	15	17
%	absence	76.5	23.5	100
	presence	11.8	88.2	100

TEST OF FUNCTION	COMPONENTS	WILKS' LAMBDA	CHI-SQUARE	DF	SIGNIFICANCE
1	wr1a	0.578	17.253	1	0.000
1	wr1a, wr3a	0.565	17.694	2	0.000
1	wr1a, wr8a	0.576	17.102	2	0.000
1	wr1a, wr2a	0.477	22.944	2	0.000

Figure A4-10. The eigenvalues for the components in a PCA using stream-reach metrics. In total, 29 metrics were used. Nine components resulted with eigenvalues greater than 1.


Scree Plot
Eigenvalue
8
6
4
2
0
1
3
5
7
9
11
13
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17
19
21
23
25
27
29
Component Number

Table A4-15. The eigenvalues, percent of variance and cumulative percent of variance for the ten components with eigenvalues greater than one from the PCA using stream-reach metrics.

	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Eigen-value	% of Variance	Cumulative %	Eigen-value	% of Variance	Cumulative %
r1	7.199	24.83	24.83	4.966	17.12	17.12
r2	4.013	13.84	38.67	2.969	10.24	27.36
r3	3.129	10.79	49.46	2.872	9.90	37.26
r4	2.217	7.64	57.10	2.596	8.95	46.21
r5	1.932	6.66	63.76	2.449	8.45	54.66
r6	1.814	6.25	70.01	2.326	8.02	62.68
r7	1.349	4.65	74.66	2.014	6.94	69.62
r8	1.185	4.09	78.75	1.961	6.76	76.38
r9	1.041	3.59	82.34	1.728	5.96	82.34

Table A4-16. The component loadings for the stream-reach metrics. A Varimax rotation was used in the PCA.

Metric	**Component**								
	r1	**r2**	**r3**	**r4**	**r5**	**r6**	**r7**	**r8**	**r9**
temperature, median	0.838								
temperature, maximum	[illegible]		-0.293		0.208				
emergent wetlands within 200-m buffer	[illegible]								-0.296
temperature, minimum	0.734			0.206					
% organics	[illegible]				0.390				
stream-reach width	[illegible]	0.329			0.360	0.449		-0.206	
grasslands within 200-m buffer	0.213	[illegible]						0.209	
probable row crops within 200-m buffer 00	0.348	[illegible]							
row crops within 200-m buffer	-0.449	[illegible]							0.236
water within 200-m buffer		[illegible]	-0.241		-0.218	0.334	0.296		
deciduous forest within 200-m buffer	-0.492	[illegible]						-0.536	

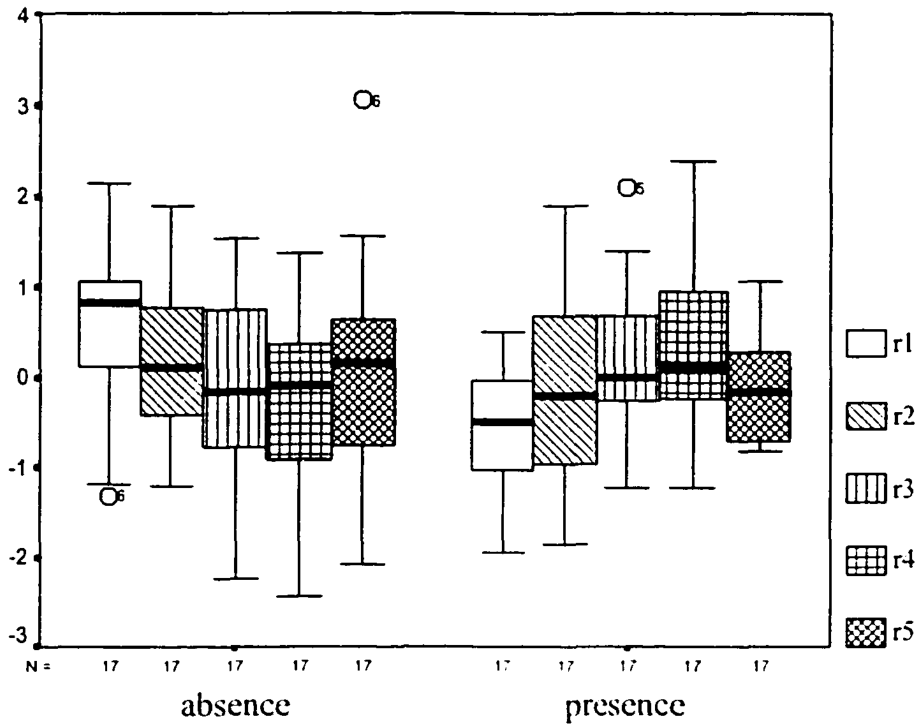
Table A4-16 (continued). The component loadings for the stream-reach metrics. A Varimax rotation was used in the PCA.

METRIC	COMPONENT								
	r1	r2	r3	r4	r5	r6	r7	r8	r9
high intensity developed within 200-m buffer			0.906						
low intensity developed within 200-m buffer			[illegible]	0.213					
DO, minimum	-0.491		[illegible]		0.241			0.357	
DO, median	-0.394		0.653		0.341			0.330	0.344
pH, minimum				0.874					
pH, median			0.243	0.824					
pH, maximum		0.321		0.669		0.268	-0.417		
% clay	0.359			0.244	0.772				
% silt	0.461				0.764				
stream-reach depth, mean						[illegible]			
stream-reach depth, maximum		-0.201				[illegible]			

Table A4-16 (concluded). The component loadings for the stream-reach metrics. A Varimax rotation was used in the PCA.

METRIC	COMPONENT								
	r1	r2	r3	r4	r5	r6	r7	r8	r9
% gravel	-0.359				-0.208		[illegible]		
% sand					-0.555		[illegible]		
mixed forest within 200-m buffer	0.202			0.311			[illegible]	0.488	
conifers/evergreen forest within 200-m buffer				0.207				[illegible]	
Barren within 200-m buffer		-0.296	0.343		-0.395		0.267	[illegible]	0.265
DO, maximum									[illegible]
woody wetlands within 200-m buffer			-0.314	-0.426			0.205		[illegible]

Figure A4-11. Box plots of the components with eigenvalues greater than one resulting from the PCA using stream-reach metrics.


4
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0
-1
-2
-3
N =
17
absence
presence
r1
r2
r3
r4
r5

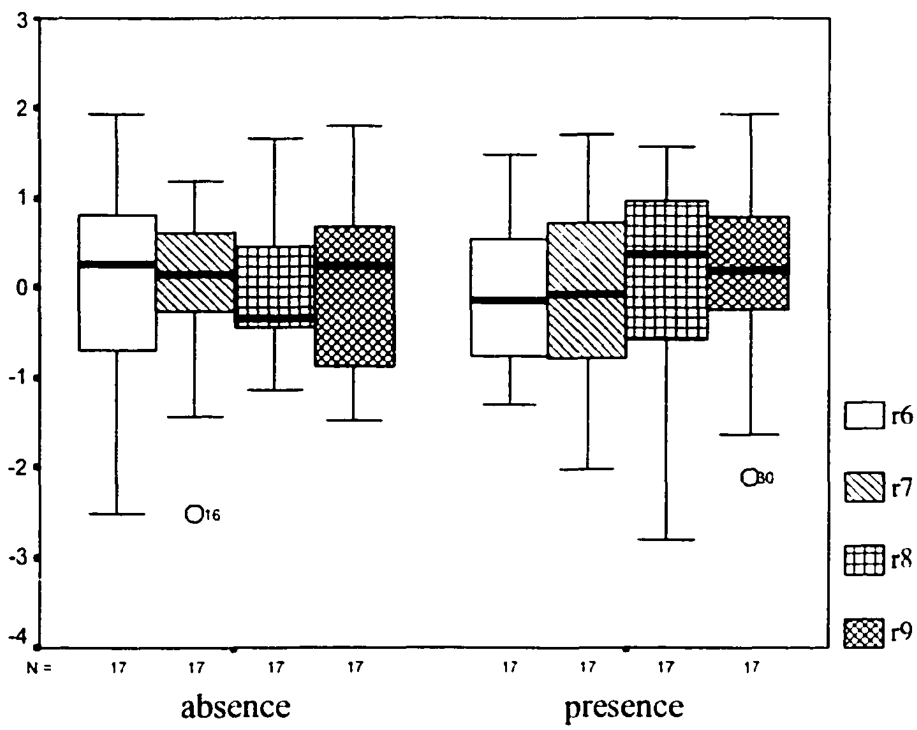
3
2
1
0
-1
-2
-3
-4
N =
17
absence
presence
r6
r7
r8
r9

Figure A4-12. Scatter plots of the nine components with eigenvalues greater than one used in the PCA reach metrics. The presence group is shown in black; absence group is shown in red.

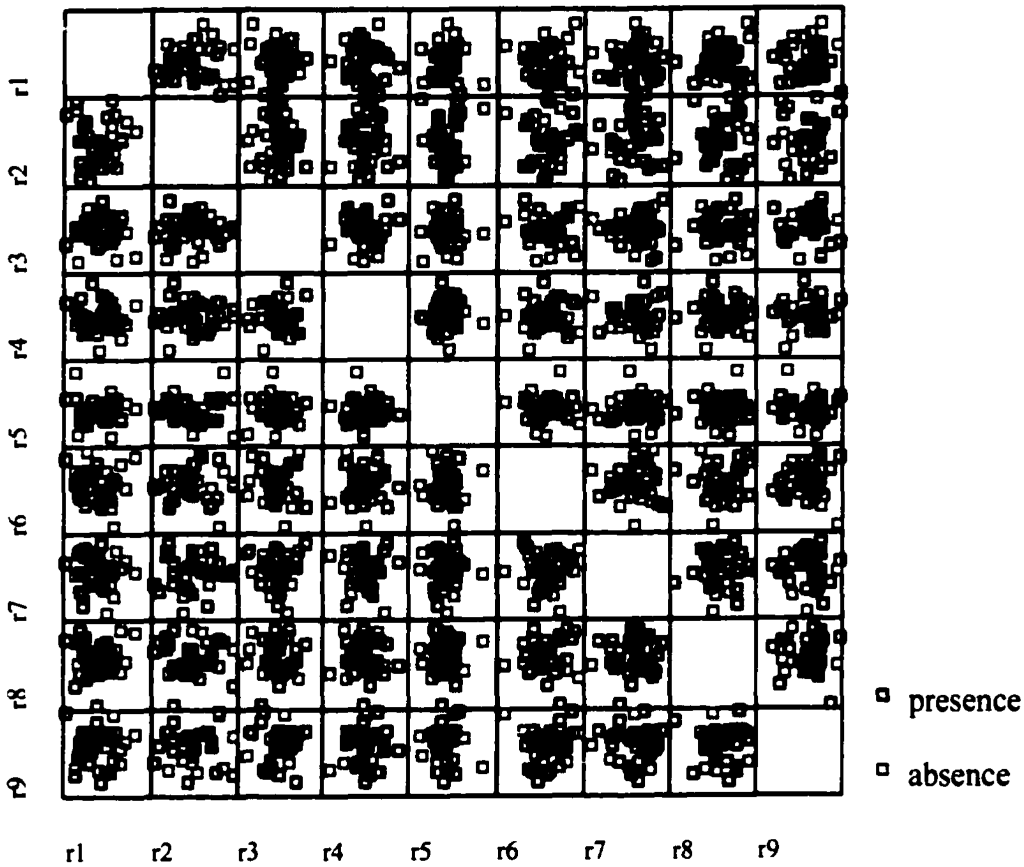
r1
r2
r3
r4
r5
r6
r7
r8
r9
presence
absence

Table A4-17. Covariance matrices for the absence and presence groups of the nine components with eigenvalues greater than one.

	Component	r1	r2	r3	r4	r5	r6	r7	r8	r9
Absence	**r1**	1.011								
	r2	-0.051	0.791							
	r3	-0.009	0.288	1.250						
	r4	0.281	0.103	-0.185	0.949					
	r5	0.056	-0.099	-0.105	0.022	1.637				
	r6	0.133	-0.043	0.171	0.155	-0.262	1.377			
	r7	0.023	-0.068	-0.387	-0.459	-0.165	-0.016	1.037		
	r8	0.156	0.193	-0.225	0.021	0.073	0.308	-0.091	0.685	
	r9	0.233	0.190	0.177	0.093	-0.076	-0.301	-0.001	-0.037	0..876
Presence	**r1**	0.454								
	r2	-0.173	1.188							
	r3	0.230	-0.205	0.731						
	r4	0.034	0.015	0.068	0.948					
	r5	-0.133	0.070	0.134	0.018	0.415				
	r6	-0.194	0.020	-0.149	-0.123	0.254	0.679			
	r7	0.018	0.084	0.371	0.437	0.170	0.019	1.023		
	r8	-0.116	-0.177	0.210	-0.043	-0.068	-0.304	0.088	1.375	
	r9	-0.209	-0.181	-0.186	-0.105	0.079	0.304	-0.000	0.035	1.185

Table A4-18. Group prediction results for the discriminant analyses using components r1 and r2. The overall prediction ability is 79.4%.

		PREDICTED GROUP MEMBERSHIP		TOTAL
		absence	presence	
Count	absence	13	4	17
	presence	3	14	17
%	absence	76.5	23.5	100
	presence	17.6	82.4	100

Vita

Rebecca A. Boger

Earned B.S. in Applied Mathematics from University of Pittsburgh in 1985. Received a M.S. in Geography from Memorial University of Newfoundland in 1994. Started doctoral program in College of William and Mary, School of Marine Science in 1994. Received a Knauss Fellowship in Marine Science in 1998 and worked for an international environmental science and education program called GLOBE. Continued working at GLOBE after the fellowship ended while completing dissertation. Received Ph.D. in Marine Science from College of William and Mary, School of Marine Science in 2002.