Habitat Relationships for Alewives and Blueback Herring in a Virginia Stream

by

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(ABSTRACT)

The relationships between watershed characteristics and stream use by spawning alewife (Alosa pseudoharengus) and blueback herring (Alosa aestivalis) in the Rappahannock River drainage were identified. Trends in fish use of 72 tributaries were determined by consulting eighty-eight people from the Rappahannock River area through a questionnaire. These streams were each given an overall rank based on answers to the questionnaire. The watershed characteristics of these streams were determined from topographic maps, land use data, and digital line graphs. Trends in fish use of streams were associated with stream size, and proportions of forest, agriculture, and wetlands. No negative relationships between urbanization or presence of point-source pollution and fish use of streams were found. Forest was positively associated with stream rank, and agriculture was negatively associated with stream rank. Results indicate that, of the watershed characteristics in the Rappahannock River drainage, forest and agriculture have the strongest associations with stream use by spawning river herring.

Three sites in a tributary of the Rappahannock River were studied to characterize the spawning habitat of river herring. The sites were sampled and their habitat variables were measured throughout the 1992 river herring spawning season. Densities of river herring adults, eggs, and yolk-sac larvae were highest at the upstream site. Densities of post-yolk sac larvae did not differ significantly among the sites. The upstream site differed from the downstream sites in size, vegetation, hydrology, photic zone depth, pH, and vegetation. At times, pH levels in the upstream site were within the range of lethality reported for blueback herring larvae.

Relationships between habitat variables and occurrence of river herring life stages in the upstream site were identified. Effects of tidal condition, time of day, light intensity, and temperature on peaks in densities of river herring life stages in the upstream site were determined by plotting these variables with life stage densities. Trends in water temperature were positively related to peaks in densities of river herring life stages. Logistic regression was used to determine if temperature, light intensity, dissolved oxygen, velocity, depth, and secchi disc transparency predicted occurrence of river herring life stages in the upstream site. Occurrence of alewife early egg stages was positively related to dissolved oxygen and velocity. Occurrences of blueback herring adults and early eggs were positively related to water temperature.

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Introduction

The alewife, Alosa pseudoharengus, and the blueback herring, Alosa aestivalis, are harvested commercially and recreationally in every Atlantic Coast state except Georgia (Street 1970) and in maritime provinces of Canada (Loesch 1987, Scott and Scott 1988). These fish supported relatively important commercial fisheries in Chesapeake Bay until the early 1970's when stocks began to decline dramatically (Klauda et al. 1991). Of all the anadromous fish species harvested in the Chesapeake Bay, they have experienced the most dramatic decline in commercial landings (Speir 1987). For example, fifty years ago in Maryland, 8 million lbs of these fish were caught commercially compared to only 200,000 lbs in 1985, a 97.5% decline. In the past, these fish migrated further upstream than they presently do. Now, for example, they only migrate to river kilometer 250 on the Rappahannock River, compared to river kilometer 326 historically (Mudre et al. 1984). The fisheries have declined for several reasons, one of which is loss of spawning and nursery habitat. Reasons for habitat loss include pollution and migratory impediments such as dams and highway crossings.

River herring, a collective term for both alewives and blueback herring, are a valuable resource in terms of commercial and recreational fishing, and serve as predators, prey, and competitors for various organisms in their communities. Both species are mainly planktivores (Mullen et al. 1986), and as juveniles they partition food items between themselves and other alosids such as the American shad (Crecco and Blake 1983). All stages of both species are important forage items for freshwater and marine fishes, birds, amphibians, reptiles, and mammals (Loesch 1987). They have been important sources of roe, bait, fish meal as a protein supplement in animal feed, fish oil, and are also important for human consumption (Mullen et al. 1986). Considering that these fish rely heavily on freshwater habitats for both spawning and juvenile stages and that these areas are threatened by land use changes, there is a definite need for knowledge of the life history of these fish, especially their early life stages.

The young of these anadromous species spend the first year of life in freshwater and by the end of that first year, migrate seaward (Burbidge 1974, Kissil 1974, Richkus 1975, O'Neill 1980, Loesch 1987), although some juvenile alewife remain in deep estuarine waters through the winter (Hildebrand and Schroeder 1928). They spend the next few years in the ocean, and when old enough, migrate to natal streams to spawn. Late March to late April is the spawning season for the alewife (Jenkins 1992), whose geographical range extends from Newfoundland (Winters et al. 1973) to South Carolina (Berry 1964). Late April to early May is the spawning season for blueback herring (Jenkins 1992), whose geographical range is from Nova Scotia to the St. Johns River, Florida (Hildebrand 1963). Spawning time is triggered mainly by temperature (Cooper 1961) and light (Lund et al. 1970, Saila et al. 1972), and emigration of the adults to the ocean after spawning is triggered by water flow (Huber 1978). After the spawning season the juveniles remain behind, moving upstream in summer (Warinner et al. 1970, Burbidge 1974) and downstream in autumn to areas of higher salinity, and finally, to the ocean (Hildebrand 1963). Juveniles move in response to salinity (Burbidge 1974, Warinner et al. 1970), temperature (Richkus 1975b, Richkus 1975a, O'Leary and Kynard 1986, Davis and Cheek 1966), heavy rainfall (Cooper 1961, Richkus 1975a), stream flow (Kissil 1974, Richkus 1975a, Davis and Cheek 1966) and current (Joseph and Davis 1965, Richkus 1975b).

Some information is available on early life history of these fish in regards to the type of habitat they use for spawning. However, little is known of: 1) effects of watershed characteristics on spawning habitat suitability; 2) interactions between environmental factors that trigger spawning; 3) types of habitats used for spawning in Virginia streams; and 4) early life history in small tributaries. Understanding relationships between watershed characteristics use and spawning success in streams, and habitat parameters that influence spawning, larval abundance, and larval distribution is likely to be essential for development of effective management strategies for anadromous species.

The Rappahannock River drainage in Virginia contains significant alosid spawning and nursery habitat area. The types of habitat available in this drainage and their use by river herring for various early life stages must be known so that these areas can be protected. In this part of their range little is known about river herring spawning habitat. Thus, it is possible that areas contributing significant spawning habitat for these species could be unknowingly altered by various practices such as construction of dams and watershed characteristics such as agriculture or urbanization. Also, since these practices can alter environmental factors that are important triggers for spawning events, it is important to understand how factors interact with one another, and which factors have greater influence on spawning success. Human-made impediments to spawning runs, such as dams and culverts, have been suggested as factors which may have contributed to the decline of river herring populations in Maryland and Virginia (Atran et al. 1983, Speir 1987). There is relatively little information that would directly implicate effects of agriculture as factors contributing to the general decline of river herring in Virginia (Klauda et al. 1991). However, in the Hudson River drainage, urbanization has been found to be associated with a decline in river herring recruitment. Management strategies such as mitigating the negative effects of land uses on spawning and nursery habitat and increasing access to areas used for spawning and nursery habitats may be needed to reverse the declines in these fisheries.

This thesis is divided into two chapters. The first chapter addresses the relationships between watershed characteristics and river herring runs in the Rappahannock River drainage. Watershed characteristics in this drainage and its possible effects on spawning habitat of river herring are discussed. Objectives of this chapter are to identify relationships between watershed characteristics and occurrence of spawning runs, consistency of spawning runs, trends in spawning runs, and stream rank that is based upon use by spawning river herring.

The second chapter addresses the spatio-temporal dynamics of spawning and larval river herring. Knowledge of spatial and temporal patterns for spawning and larval river herring from previous studies are discussed. The objectives of this chapter are to characterize the habitat where river herring spawn, the distribution of yolk-sac and post-yolk sac larvae in a tributary of the Rappahannock River, and to determine the relationships between habitat factors and occurrence of river herring life stages in spawning areas.

Study Area

The Rappahannock River drainage in Virginia is part of the Chesapeake Bay basin, and its mainstem and tributaries support spawning runs of the alewife and blueback herring. This river system, which encompasses 7,000 sq. km in northeastern Virginia, has the third largest area of suitable alosid spawning and nursery habitat (6,500 ha) in Virginia (Davis et al. 1970). Alewife and blueback herring use fresh tidal sections of the Rappahannock River drainage during spawning and as juveniles. Embry Dam at Fredericksburg, located 250 river km upstream from the mouth of the Rappahannock River, is an effective barrier to passage of these and other anadromous fish. The tidal portion of the Rappahannock River extends from the fall line at Fredericksburg 250 river km to the Chesapeake Bay, with salt water intruding upstream 118 river km from the Bay. The average annual discharge at Fredericksburg is 1600 cfs and has ranged from 140000 to 5 cfs. Alewives and blueback herring spawn in tidal freshwater sections of the river (6,500 ha).

Tidal freshwater tributaries also serve as nurseries (Davis et al. 1970). There are at least 125 tributaries that potentially provide spawning and nursery habitat for alosids in this system (nautical mile 31 to Embry Dam at Fredericksburg). Drainages of these tributaries range in size from 11 to 18977 ha.

Chapter One

Watershed characteristics in the Rappahannock River drainage and their importance to river herring

Land uses such as urbanization and agriculture may have negative effects on river herring spawning runs in the Rappahannock River drainage. There is no information suggesting that watershed characteristics affect spawning runs in this system. However, this may be due to lack of knowledge of location of spawning areas in this drainage and, subsequently, effects of watershed characteristics in these areas. There are a variety of land covers in the Rappahannock River drainage. The distribution of land covers in the Rappahannock River drainage and their relationships to spawning runs of both species is important because of this river system's regional importance in providing habitat for river herring. In the Rappahannock River the population of alewife is at a stable, low level of abundance, while that of the blueback herring is stable and moderately abundant (Klauda et al. 1991). Populations in other Chesapeake Bay systems are remnant and/or declining (Klauda et al. 1991). However, knowledge of how watershed characteristics affect the occurrence of spawning runs in the Rappahannock River system may suggest how to remedy the declining trends in the river herring fisheries in other areas.

Agriculture is the primary land cover along the Rappahannock River, whereas farther from the river, agriculture and forest are the main land covers (Davis et al. 1970). Agriculture has many effects on streams, including soil compaction, decreased infiltration, increased runoff and erosion, vegetation changes, riparian canopy loss, bank destabilization, nutrient enrichment, elevated bacterial density, modified hydrology, modified channel morphology, and modified temperature regime from grazing (Platts 1991). Increased rates of wind and water erosion, inhibition of photosynthesis, suffocation of fish eggs and larvae from sedimentation, and diversion of water for irrigation result from row crop agriculture (Ritter 1988).

Both grazing and row crop agriculture are found in the Rappahannock River drainage. Sedimentation, which results from erosion of intensively farmed areas especially during flooding events, can alter dissolved oxygen levels by increasing the oxygen demand required for breakdown of organic matter (Ritter 1988). It can also increase infection rates (from naturally occurring fungi) of alewife and blueback herring eggs (Schubel and Wang 1973) and result in high mortality of blueback herring larvae (Greening et al. 1989). Temperature can be modified by grazing in riparian zones (Platts 1991). There is no evidence that would directly implicate effects of agriculture as factors contributing to the general decline of river herring populations in the Chesapeake Bay or preventing stock recovery (Klauda et al. 1991). Again, this could be due to lack of studies of effects of agriculture on spawning areas in this part of their range. Turbid water conditions and high flows associated with severe flooding cause by hurricane Agnes in June 1972 probably contributed to the decimation of the 1972 year class of alewife in Maryland and altered substrate and depth in many spawning areas (Richkus and DiNardo 1984). Thus, agricultural effects, such as erosion during an intensive flood, could greatly affect stocks of river herring. Therefore, areas of the Rappahannock River that are characterized by agriculture may be poor habitats for river herring life stages.

The Rappahannock River basin also includes scattered patches of wetlands and urban areas (USGS Land Use Land Cover Map). There is no evidence that river herring require wetlands in their spawning habitat. However, submerged aquatic vegetation, of which some wetlands are composed, performs valuable roles within the Chesapeake Bay. These include nutrient absorption and oxygenation of the water column (Boynton and Heck 1982), reduction of resuspension of bottom sediments and shoreline erosion, and promotion of the settlement of suspended sediments (Ward et al. 1984). Thus, if wetlands characterize river herring spawning habitat, this land cover may provide a stable environment for early life stages of fish. Urbanization can affect streams and fish by adding contaminants such as lead, zinc, nutrients, sediments, oil, pesticides, and salt to streams. Also, impervious areas found in urban areas such as streets, sidewalks, parking lots, and roofs will increase frequency and severity of floods, accelerate channel erosion, inhibit groundwater regeneration, alter temperature regimes, and pulse delivery of pollutants (Klein 1979). In the Hudson River basin, dissolved oxygen is more variable near cities, and there is a marked decline in anadromous fish recruitment where urbanization is greater than 10% (Limburg and Schmidt 1990).

Nitrogen and phosphorus are the major enrichments in the Rappahannock River due to industrial effluent from the Fredericksburg area, the major urban area in this drainage. Nitrogen levels decline in concentration downstream of Fredericksburg. Total soluble and total particulate phosphorus concentrations also decline from river kilometer 250 to the mouth of the river (Davis et al. 1970). In 1970 oxygen content of the river was low for approximately 52 river km downstream from Fredericksburg (Davis et al. 1970). The lowest value detected was 10% of saturation in the bottom water. More recent data indicate similar trends in total phosphorus concentrations, with levels declining in concentration downstream of Fredericksburg. Also, one tributary in the Fredericksburg area experienced a significant increase in total phosphorus over an 11-year period. However, dissolved oxygen was within State Water Quality Standard range (>4-5 mg/L) in areas of the Rappahannock River drainage that included Fredericksburg and downstream (Virginia State Water Control Board 1984, VSWCB, pers. comm.). Since habitats of river herring early life stages can be affected negatively by urbanization, spawning streams in an urban area such as Fredericksburg may experience lower spawning success than others. Rulifson et al. (1982) found that low dissolved oxygen, sewage outfalls, and poor water quality as nutrient-related factors that were "possibly important or very important in contributing to the decline of certain populations of alewife in North Carolina. The Rappahannock River is not as urbanized as rivers such as the Potomac, which receives the industrial and domestic effluents of Washington, D.C. area, or the James River, which is polluted by wastes from Richmond. However, relationships between urbanization and declining trends in spawning runs or numbers of river herring in runs in the Rappahannock River system may indicate the significance of urbanization's contribution to trends in these fish stocks.

Although the Rappahannock River drainage is not heavily urbanized, there are many road crossings on various tributaries of this system. Also, new bridge projects are still underway on various tributaries that contribute spawning habitat for river herring (pers. observ.). Road construction and maintenance have many effects on aquatic systems. These include: accelerated erosion rates, mass soil movements, surface erosion, alterations in channel morphology, changes in rainfall-runoff relationships, hillslope drainage, potential for chemical contamination, the amount and type of organic debris in stream channels, and human access to streams and fish populations. Also, road crossing structures can be barriers to migration, usually because of outfall barriers, excessive water velocity, insufficient water depths in culverts, disorienting turbulent flow patterns, lack of resting pools below culverts, or a combination of these conditions (Furniss et al. 1991). If road construction or maintenance occurs on a stream during spawning season, the effects of erosion on turbidity and dissolved oxygen on spawning success can be drastic. Also, access to spawning areas may be decreased if a highway crossing type is not negotiable by anadromous fish. For example, in the James River there are some highway crossing structures that would impede river herring migrations if they could negotiate the stream below these crossings (Odom et al. 1986). Thus, spawning streams with many highway crossings or new road construction may have less fish or declining trends in runs and numbers of fish in runs compared to other streams.

I expect areas in the Rappahannock River basin characterized by point-source pollution, agriculture, urbanization, and road crossings to exhibit negative impacts on river herring spawning habitat. The specific objectives of Chapter One were as follows:

1) to identify relationships between watershed characteristics and occurrence of spawning runs of river herring in tributaries of the Rappahannock River, 2) to identify relationships between watershed characteristics and consistency (presence every year) of spawning runs of river herring in tributaries of the Rappahannock River, 3) to identify relationships between watershed characteristics and trends in spawning runs (size and numbers of runs) in tributaries of the Rappahannock River, and 4) to identify relationships between overall use of streams by river herring (represented by a stream rank that is based upon use by spawning river herring) and watershed characteristics.

Materials and Methods

72 tributaries of the Rappahannock River that are accessible to both species of river herring and whose

watersheds and tributaries contain varying percentages of highway crossings, agriculture, urbanization, forest, and wetlands were categorized as uncertain, probable, or confirmed areas of spawning. Confirmed areas were further divided into a) heavily, b) moderately and/or consistently, or c) inconsistently used areas (categories defined below).

Fish use categories

Categories of fish use of streams, including tributaries of the Rappahannock River and their tributaries, and furthest upstream extent of spawning of fish in these streams were determined by consulting knowledgeable persons (88 total) through a questionnaire. Interviewees included game wardens, anglers, bait shop owners, and landowners during the 1992 spawning season (Feb.-May). Through seven questions I determined: 1) the source of the respondent's familiarity with the fishery; 2) the streams with which the respondent was familiar; 3) the occurrence of river herring in these streams; 4) the consistency of use of these streams; 5) the degree to which streams are used; 6) the trends in use of streams by fish; and 7) the furthest upstream extent of spawning of fish in streams.

The first question consisted of a choice among the aforementioned sources of familiarity with the river herring fishery, which identified the interviewee (Table 1.1). The

Table I.1. Survey used to categorize 71 tributaries of the Rappahannock River by river herring use. A total of 88 people were surveyed during the 1992 river herring spawning season (Feb.-May). These included game wardens, anglers, bait shop owners, and landowners of the Rappahannock River drainage.

QUESTIONS

1. HOW WOULD YOU BEST DESCRIBE YOUR SOURCE OF FAMILIARITY WITH RIVER HERRING AND STREAMS IN THIS AREA (ONES THAT FLOW INTO THE THE RAPPAHANNOCK R.)?

    1 LAW ENFORCEMENT
    2 RECREATIONAL FISHING
    3 LAND OWNERSHIP
    4 BAIT SHOP OWNERSHIP
    5 OTHER (PLEASE SPECIFY)

2. HERE ARE COUNTY MAPS OF THIS AREA. COULD YOU IDENTIFY TRIBUTARIES OF THE RAPPAHANNOCK RIVER WITH WHICH YOU ARE FAMILIAR? THESE STREAMS DO NOT NECESSARILY HAVE TO SUPPORT SPAWNING RUNS OF RIVER HERRING.

THE NEXT QUESTION WILL BE ASKED FOR EACH OF THESE STREAMS THAT YOU IDENTIFIED.

3. HOW WOULD YOU DESCRIBE THIS STREAM IN REGARDS TO RIVER HERRING PRESENCE DURING THE SPAWNING SEASON (NOT NECESSARILY EVERY YEAR)?

    1 FISH ARE PRESENT
    2 FISH ARE PROBABLY PRESENT
    3 I'M NOT SURE IF FISH ARE PRESENT
    4 FISH ARE PROBABLY NOT PRESENT

THE NEXT FOUR QUESTIONS WILL REFER TO THE STREAMS YOU STATED HAD FISH PRESENT DURING THE SPAWNING SEASON.

4. HOW WOULD YOU DESCRIBE CONSISTENCY IN PRESENCE OF RIVER HERRING IN THIS STREAM?

1 FISH ARE PRESENT EVERY YEAR
2 FISH ARE NOT PRESENT EVERY YEAR

5. HOW WOULD YOU BEST DESCRIBE THE SIZE OF THE RUNS OF RIVER HERRING IN THIS STREAM?

1 HIGH NUMBERS OF FISH
2 FAIR TO GOOD NUMBERS OF FISH
3 LOW NUMBERS OF FISH

6.A.HOW WOULD YOU DESCRIBE TRENDS IN FISH SPAWNING RUNS IN REGARDS TO NUMBERS OF RUNS IN THIS STREAM?

1 INCREASING
2 STABLE
3 DECREASING

6.B.HOW WOULD YOU DESCRIBE TRENDS IN FISH SPAWNING RUNS IN REGARDS TO NUMBERS OF FISH IN THE RUNS IN THIS STREAM?

1 INCREASING
2 STABLE
3 DECREASING

7. WHAT IS THE FURTHEST EXTENT OF SPAWNING IN THIS STREAM?

second question asked the respondent to list familiar streams (after showing him/her county maps). By using Likert scales the third, fourth, fifth, and sixth questions asked the respondent to categorize the streams. The streams were categorized as "confirmed" areas of use if respondents to the third question strongly indicated that fish are present during the spawning season. Streams were categorized as "probable" areas of use if respondents indicated that fish may use them. Remaining streams were categorized as "improbable" or "uncertain". Confirmed streams were categorized as "consistent", if respondents to the fourth question indicated that they are used by fish annually, or "inconsistent" streams if they are not. "Heavily used" streams were those confirmed streams that support high density spawning runs, and "moderately" and "slightly used" streams were those that support fairly good-sized and low density spawning runs, respectively. The sixth question asked the respondent to describe the streams as having increasing, decreasing, or stable trends in use by fish. The seventh question asked the respondent if they knew the furthest upstream extent of spawning of fish in the confirmed streams. Respondents were interviewed in person so that they could be shown streams on county maps that are unnamed.

This questionnaire method for categorizing streams was used because data for trends in fish use of streams are not available. Anglers or dippers do not have river herring catch limits and are not required to report the numbers of fish harvested. Therefore, trends in river herring spawning runs in tributaries can only be determined from knowledge of people who have been witnessing the runs.

Sources of watershed characteristics

United States Geological Survey (USGS) topographic maps (1:24000; 1969-1986), Virginia Geographic Information Systems (VIRGIS) land use data (1:24000, 1/9 ha resolution; 1986-1987), and USGS Digital Line Graphs (DLG) data (1:100000; 1969-1986) were used to determine type of land cover in watersheds of tributaries of the Rappahannock River and the size of these watersheds. Important land covers included wetlands, agriculture, urban, forest, and roads. DLG data included streams, shorelines, wetlands, and road crossings. Urban areas were digitized from USGS (1:24000) maps. VIRGIS land use data provided data on agricultural and non-agricultural areas. The percentage of land cover in a particular watershed was estimated by digitizing watershed boundaries and by calculating the size of each land cover, with forest being determined by subtracting the known areas of the other land covers from the total area of each watershed. Density of highway crossings was determined by dividing the number of highway crossings on a stream by area of watershed for that stream. If known, the segments of tributaries in which river herring occur were digitized so that the land use in the watershed that is upstream of or that includes that segment was known. If the segment of a tributary in which river herring occur was not known, then only total watershed area for that tributary was known. Virginia State Water Control Board identified the Rappahannock River tributaries that have point-source pollution in them by identifying streams for which people have VPDES permits (SWCB, pers. comm.).

Due to my reliance on interviews instead of sampling data for categorization of streams by fish use, I had to depend on opinion and perception instead of numbers of eggs and/or spawning river herring adults to indicate how "good" a stream was for providing spawning habitat for river herring. Therefore, although I may have been able to gather information about trends in river herring runs, the information may not be as accurate as if I had been able to sample adults and eggs as indicators of spawning success.

Analyses

In order to demonstrate the variability in responses to my questionnaire, the mean and standard deviation were computed for each question for each stream. The validity of my results was tested by comparing stream ranks derived from my study (method for deriving stream rank is explained below) among stream groups derived from an independent assessment. In a Virginia Institute of Marine Science (VIMS) study (Davis et al. 1970), 20 tributaries of the Rappahannock River were classified as confirmed and 36 were classified as probable areas of alosid spawning from sampling data. Gill nets, seines, and fyke nets were used to sample adults, and plankton nets were used to sample eggs and larvae in these tributaries. If ripe adults were caught or eggs or larvae were taken, sites were designated as confirmed spawning areas. Tributaries entering the tidal freshwater portion of the mainstem but too small to enter by skiff or so shallow as to preclude efficient use of the collecting gear were designated as probable spawning areas providing they were neither severely polluted or had any physical barriers to entry by fish. My streams were reclassified as confirmed, probable, or uncertain streams of spawning according to the VIMS study. My stream ranks were then compared among these three groups using the Kruskal-Wallis Test. If this test was significant, Wilcoxon 2-sample tests were used to see which groups differed from the others.

Since I expected some watershed characteristics to be highly correlated with each other, I analyzed for correlation among all characteristics. I also analyzed for differences in watershed characteristics between streams with point-source pollution and those with none by using Kruskal-Wallis Test.

In the following analyses, both total watershed area, and in the case of a known impediment on a stream (based on answers to Question 7 of the questionnaire), watershed area below that impediment were used to determine relationships between watershed characteristics and stream use by river herring. If upstream extent of river herring runs was not known for a tributary, then total watershed area for this stream was used for analyses involving total watershed area and analyses involving use of impediment information. The purpose of using the two methods was to see if relationships between watershed characteristics and stream use by fish were the same regardless of location of land cover in relation to spawning area. Any relationships between a watershed characteristic and stream use by fish that appeared when some watersheds were modified (that is, when only areas below known impediments in these watersheds were used) would indicate that this watershed characteristic is related to fish use when it occurs in the spawning area.

Stream use by spawning river herring in a tributary was defined by these parameters: occurrence, consistency of occurrence, numbers, and trends in runs (size and numbers of runs) of river herring. Relationships between watershed characteristics in the watershed of a tributary and these parameters were identified: correlations between average answers to questions about trends in stream use by fish and land cover percentages and watershed size for a tributary were tested. The effects of point-source pollution on these parameters were also identified: comparisons of stream use by fish between streams with and without point-source pollution were made using the Kruskal-Wallis test.

Relationships between watershed characteristics and stream rank that is based on use by river herring were identified. Correlations between stream rank and land cover percentages or watershed size were tested. Streams were ranked according to their use by fish, so that streams with lower answers to the questions (for example, those that were categorized as confirmed (Answer 1 to Question 3) and consistent areas of spawning (Answer 1 to Question 4)) were ranked higher than others. Streams were divided into four groups: 1) streams that had the average answer of 1 to Question 3, 2) streams that had average answers of 1-2 for Question 3, 3) streams that had average answers of 2-3 for Question 3, and 4) streams that had average answers of 3-4 for Question 3. Streams that had lower answers to this question were better ranked than those with higher answers. Then, within each of the four groups of streams, streams that had lower answers to Question 4 had better ranks than those with higher answers to this question. Then, within each of the four groups, the average answers to the remaining three questions (5-6b) for each stream were averaged. Streams with a lower value for this average number had better ranks than those with higher values.

The following method was used to determine if streams were included in these analyses (testing correlations between stream rank and watershed characteristics). The frequency distributions of watershed size and land cover were divided into 7 to 9 intervals. The intervals with the smallest percentages of land cover or amounts of watershed area appeared to have a high proportion of streams for all watershed characteristics except forest and agriculture. Streams within these intervals were ignored for all watershed characteristics except forest and agriculture. The ranks of the remaining streams were then correlated with watershed characteristics. For example, if ninety-five streams had 0-7.9% urbanization, two streams had 8-23.9% urbanization, three streams had 24-31.9% urbanization, and two streams had 32-39.9% urbanization, then the ninety-five streams with 0-7.9% urbanization would be disregarded and the ranks of remainder would be correlated with watershed characteristics. By using these criteria, some relationships between stream ranks and watershed characteristics, which could be masked by a large number of streams containing a particular percentage of land cover or amount of watershed area, can be seen.

Groups of streams for each watershed characteristic were identified according to breaks in frequency distribution of the characteristic use or, if there were no obvious breaks, dividing the distribution into thirds. The ranks of these groups were then compared using Kruskal-Wallis test. The ranks of streams with point-source pollution were compared to those with none using the Kruskal-Wallis test. If ranks for groups of streams within a particular watershed characteristic were significantly different, then streams within groups that contained less of this land cover were compared among other watershed characteristic groups using Kruskal-Wallis test. For example, suppose the three groups of streams within the distribution of agriculture (Group A-streams having ≤28.3% agriculture, Group B-streams having >28.3% and ≤56.6%, and Group C-streams having >56.6% agriculture) differed in stream rank. Then, to eliminate the effects of agriculture, only Group A streams (streams having ≤28.3% agriculture) were included in further analyses. Kruskal-Wallis tests were used in these further analyses to identify differences in streams rank among remaining watershed characteristic groups.

Results

Eighty-eight people were interviewed about 72 tributaries in the Rappahannock River drainage. Of these tributaries, 14 were confirmed streams where river herring consistently spawn (every year) and 1 was a confirmed stream where river herring do not consistently spawn. The remaining streams were probable or uncertain areas of river herring spawning, or were probably not used by spawning river herring. No streams had high numbers of fish in their river herring runs. No streams had increasing trends in numbers of river herring runs and numbers of fish in runs.

Stream watersheds ranged in size from 14 to 12873 ha. Streams contained 0 to 59% urbanization, 2 to 26% wetlands, 0 to 4.08 road crossings per ha, 5 to 96% forest, and 5 to 85% agriculture. Nine streams had point-source pollution on them.

Variability in data and validity of results

There were relatively high standard deviations for some answers to the questions about tributaries to the Rappahannock River regarding their use by spawning river herring (Appendix A). However, there were significant differences in my stream ranks among the stream groups categorized from the VIMS study ($p=0.0001$). Confirmed spawning streams had a better average stream rank (23.84) than that of probable spawning streams, 29.7, which in turn, was better than that of uncertain spawning streams, 48.34.

Relationships between watershed characteristics

Agriculture was negatively associated with watershed area ($p=0.0054$, $r=-0.2456$, $N=72$), percentage of urbanization ($p=0.0072$, $r=-0.2375$, $N=72$), and percentage of forest ($p=0.0001$, $r=-0.8548$, $N=72$). Forest was negatively associated with density of highway crossings (p=0.0146, r=-0.2435, N=72) and wetlands (p=0.0030, r=-0.2615, N=72) and positively associated with watershed area (p=0.0031, r=0.2606, N=72). Highway crossings were positively associated with urbanization (p=0.0001, r=0.5469, N=78). Streams with point-source pollution had larger watersheds (p=0.0120, N=105) and higher percentages of wetlands (p=0.0127, N=78) than those with none. Although analyses were not done, there appeared to be no differences in watershed characteristics between areas upstream and downstream of impediments. However, watershed area was always greater upstream than downstream of impediments.

Relationships between land use and different aspects of river herring use of streams

The belief that river herring runs are present in a stream was positively associated with size of watershed (p=0.0001, r=0.4925, N=82), percentage of forest (p=0.0051, r=0.3102, N=80), and negatively associated with percentage of agriculture (p=0.0050, r=-0.3094, N=81) using total watershed. Perception of run consistency was not associated with any land use. Perceived size of river herring runs was positively associated with size of watershed using total watershed (p=0.0272, r=0.4928, N=20). Perceived trends in numbers of spawning runs were positively associated with percentage of urbanization (p=0.0236, r=0.5164, N=19) using total watershed. Perceived trends in size of river herring spawning runs were not associated with any land use.

"Modified watersheds" will mean watershed areas below impediments, if known, and total watershed if furthest upstream extent of fish migrations is not known. There were only a few relationships between fish use and watershed characteristics when total watershed was used that were not seen when modified watersheds were used. There were no relationships between perceived size of river herring runs and watershed area, between perceived trends in numbers of river herring runs and urbanization, and between belief that runs are present and agriculture, when modified watersheds were used. There were only a few relationships between fish use and watershed characteristics when modified watersheds were used that were not seen when total watershed was used. There was a positive association between belief that runs are present and wetlands (p=0.0277, r=0.3562, N=20) and between perceived trends in fish spawning runs and forest when modified watersheds were used (p=0.0182, r=0.5351, N=19). There was a negative association between perceived trends in numbers of spawning runs and agriculture (p=0.0392, r=-0.4643, N=20).

Only the tendency for river herring spawning runs to occur in tributaries was significantly different between streams with point-source pollution and those with none (p=0.0387). However, the average value for Question 3 (which determines occurrence or presence of river herring runs in a stream) was lower for streams with point-source pollution (1.84) than that for others (2.79), indicating that streams with point-source pollution are more likely to have river herring runs in them. Since river herring are likely to use larger tributaries, and streams with point-source pollution were larger than those with none, river herring may be using streams where point-source pollution is permitted. Table I.2 is a summary of relationships between trends in fish use of streams and land use using total watershed.

Relationships between watershed characteristics and stream rank

Figure I.1 shows the frequency distribution of watershed characteristics (percentages of land cover and watershed sizes) using total watershed. Intervals excluding the smallest amounts of watershed characteristic are shown for each characteristic, except for forest and agriculture. When only ranks of these streams (lower rank number represents greater overall use by spawning river herring) were correlated with that watershed characteristic, only percentage forest was positively associated with overall stream use by fish

Table I.2. Summary of relationships between trends in perceived fish use of streams and land use using total watershed. The different aspects of fish use (belief that runs are present, perception of consistency in occurrence of fish runs, perceived size of runs, perceived trends in numbers of fish runs, and perceived trends in size of fish runs) were obtained from interviews conducted in the Rappahannock River drainage (Feb.-May 1992). Total watershed means total watershed for each stream, regardless of impediments to spawning runs on these streams. (+) indicates a positive relationship, (-) indicates a negative relationship, and (NR) indicates that there was no relationship between trends in fish use and land use. (S) indicates that there were significant differences, and (NS) indicates that there were no significant differences in trends in fish use between streams with point-source pollution and those with none.

Land use (units)	Belief that runs are present	Perception of run consistency	Perceived size of runs	Perceived trends in numbers of runs	Perceived trends in size of runs
Watershed area (ha)	+	NR	+	NR	NR
Urbanization (%)	NR	NR	NR	+	NR
Wetlands (%)	NR	NR	NR	NR	NR
Highway crossings(density)	NR	NR	NR	NR	NR
Agriculture (%)	-	NR	NR	NR	NR
Forest (%)	+	NR	NR	NR	NR
Point-source pollution (presence)	S*	NS	NS	NS	NS

* Streams with point-source pollution were believed to have runs present.

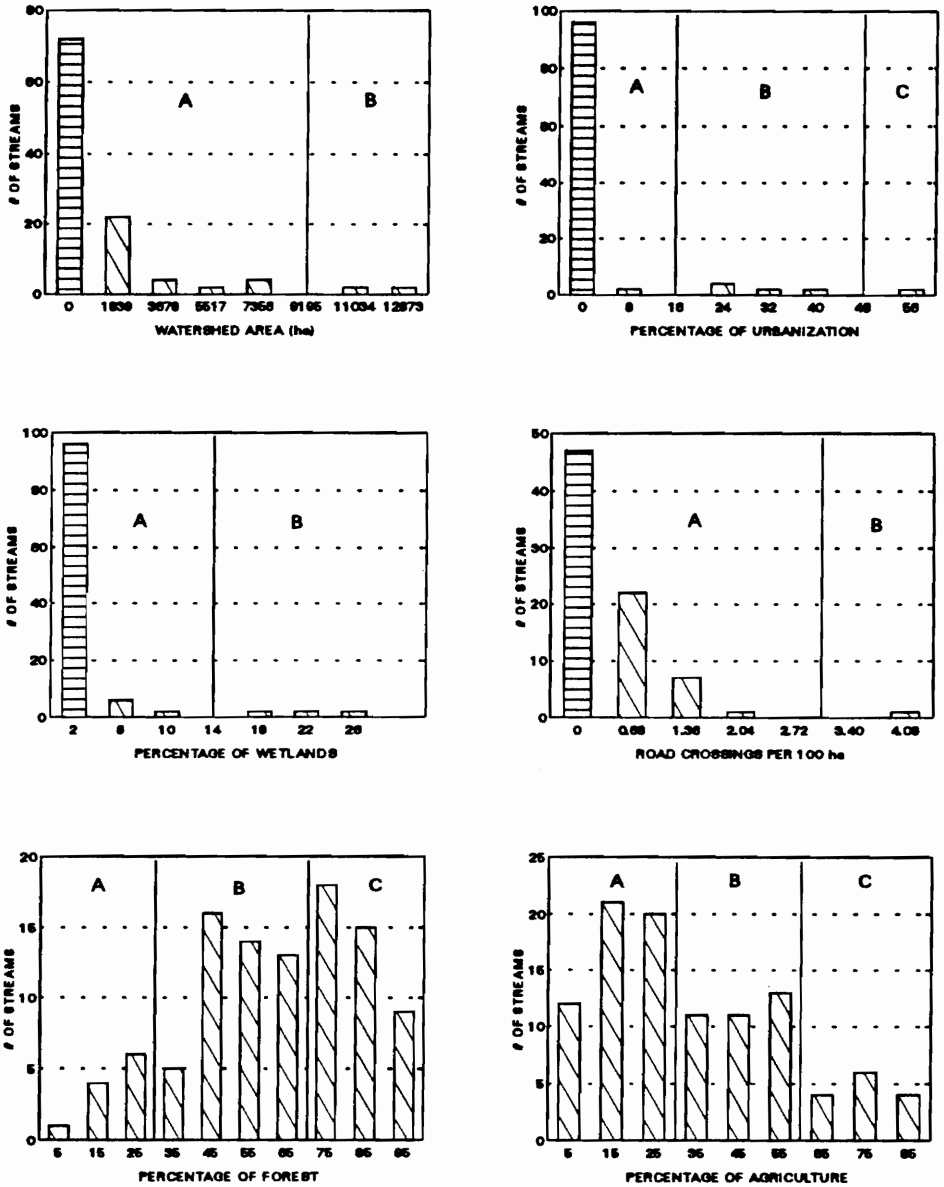
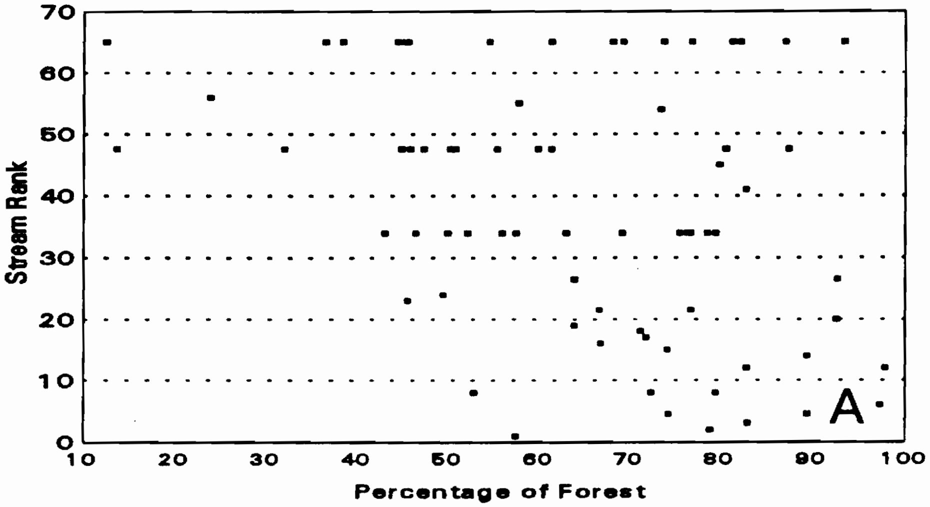


Figure I.1. Frequency distributions of watershed area and percentages of land uses using total watershed. Number under each histogram indicates the minimum value for the range that each histogram represents. Maximum value for that range is shown under histogram to the right. Histograms with horizontal lines indicate streams with the smallest percentages of land use. These were excluded from the analyses that tested correlations between stream rank and land use. Note that streams with the smallest percentages of agriculture and forest were not excluded from these analyses. Letters indicate groups of streams for each land use whose ranks were compared using Kruskal-Wallis tests. Only the differences in stream rank among the three agricultural groups were significant. Group A streams (for agriculture) were better ranked than Group B streams, which were better ranked than Group C streams.

(p=0.0018, r=0.3612, N=72). Percentage agriculture was negatively associated with overall stream use by fish (p=0.0032, r=-0.3401, N=73) using total watershed. The same relationships were seen when modified watersheds were used. Figure I.2 shows percentage of forest and agriculture plotted against stream rank using total watershed. When total watershed was used, there was a 20-30% threshold level for both agriculture and forest where stream rank changed noticeably. In Figure I.2B, asterisks represent the half of the streams that have the greatest watershed areas (≥517 ha), and squares represent the half of the streams that have the smallest watershed areas. The negative association between stream use by fish and percentage agriculture is stronger for larger streams (p=0.0042, r=-0.4648) than for smaller streams (p=0.3467, r=0.1591). Streams having greater than 20-30% forest were either poorly ranked or were highly ranked. If streams had less than 20-30% forest, they had only poor ranks. Streams having less than 20-30% agriculture were either poorly ranked or highly ranked. If streams had greater than 20-30% agriculture, they had only poor ranks. Thus, only percentage of forest and percentage of agriculture are associated with overall stream use by river herring. These relationships are more apparent when agriculture and forest are greater than 20-30% of the land cover in a watershed.

Figure I.1 also shows the different groups of streams for each watershed characteristic distribution (that were based on



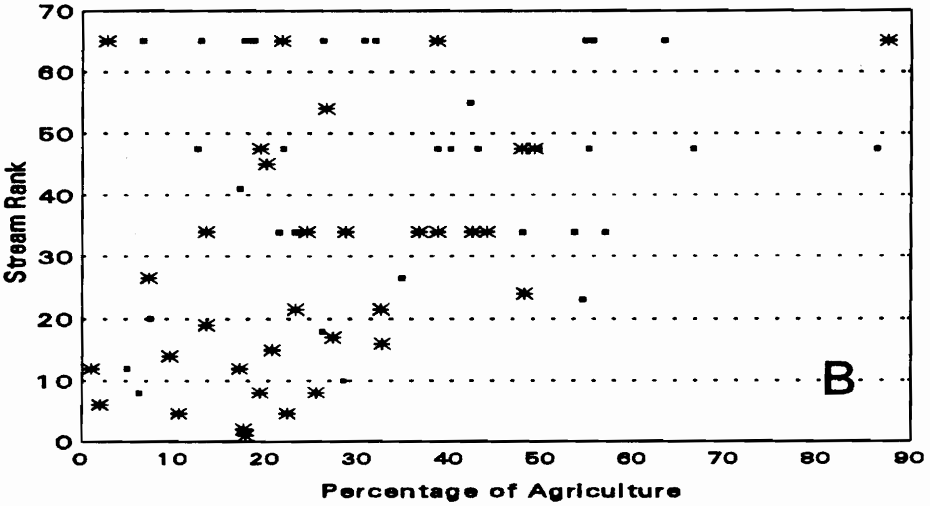


Figure I.2. Percentage of forest and agricultural use in tributaries of the Rappahannock River versus their stream rank using total watershed. Rank was determined from interviews about streams regarding their use by spawning river herring. A) p=0.0018, r=0.3612; B) p=0.0032, r=-0.3401. For Graph B, asterisks represent streams with large watersheds (≥ 862 ha; p=0.0042, r=-0.4648), and squares represent streams with small watersheds (≤ 862 ha; p=0.3467, r=0.1591).

either breaks in distribution or dividing the watershed characteristic distribution into thirds). When groups for each land use were compared using Kruskal-Wallis test, the differences in stream rank among only the three agriculture groups were significant (p=0.0454), using total watershed area. Group A (streams having ≤28.3% agriculture) had a higher average ranking (lower rank number), 32.28, than the two groups of streams with higher percentages of agriculture: B (streams having >28.3% and ≤56.6% agriculture) with an average rank of 40.9, and C (streams having >56.6% agriculture) with an average rank of 52.33. No comparisons of any land use groups using modified watersheds were significant. When Group A streams (for agriculture) were compared among the various groups for other land uses, there were no significant differences in stream rank among any groups. Streams with point-source pollution had significantly better ranks than those with none (p=0.0171).

My results indicate that there are associations between size of watershed, forest, wetlands, urbanization, and point-source pollution, agriculture and individual aspects of stream use by river herring. Of the watershed characteristics studied, however, forest and agriculture had stronger overall relationships with stream use by river herring. Furthermore, agricultural use was correlated with stream rank, and the groups of streams containing different amounts of agriculture were significantly different from each other in overall use by spawning river herring. Since this was not the case with any other watershed characteristic, agriculture may have the strongest relationship with stream use by fish.

Discussion

There were few differences in results obtained from analyzing total watersheds and those obtained from analyzing modified watersheds. The discussion will focus mainly on results obtained when total watershed was used. However, watershed characteristics that are not related to any aspect of fish use when total watershed is used but are related to fish use when modified watersheds are used will be discussed.

Variability in data and validity of results

There was variability in responses to questions about tributaries of the Rappahannock River, and my stream ranks were derived from these data. Streams that I identified as "good" herring streams were those identified as "good" herring streams by the VIMS study. Likewise, streams that I identified as "poor" herring streams were those not identified as "good" herring streams by the VIMS study. My conclusions about Rappahannock River streams (based on opinion) were similar to conclusions about the same streams that were based on sampling data. Therefore, my results, although variable, appear accurate.

Relationships between watershed characteristics and occurrence of river herring runs

The associations between size of watershed, proportion forest, agriculture, and wetlands, and perceived presence of river herring in streams indicate that these land uses are important in determining river herring stream use. Stream size is assumed to be proportional to watershed size. Although the alewife has been found in both large and small systems (Cooper 1961, Loesch 1987, O'Neill 1980, and Kissil 1974), and blueback herring has been found in a diversity of habitats (Frankensteen 1976, Loesch 1987, and Pardue 1983), my results indicate that larger streams are more likely to be used by river herring in the Rappahannock River drainage. Mowrer (1984) found that crowding caused blueback herring adults to move upstream during spawning runs, so possibly river herring use upstream areas of larger streams to escape intraspecific competition for space. Even though moving upstream would put fish in smaller areas, using larger streams would provide more tributary area for spawning of river herring and other species of fish. The Rappahannock River provides spawning habitat for many other species of fish, both diadromous and freshwater.

Some possible predators and competitors of river herring do not use tributaries, use downstream areas of tributaries, or use upstream areas of tributaries at other times. River herring use of upstream areas of larger tributaries in this system may eliminate interspecific competition and predation from these other fish. For example, white perch (Morone americana) prey upon alewife eggs (Edsall 1964, Kissil 1969). However, white perch, whose eggs were found when and where river herring were spawning in a Rappahannock River tributary in 1992 (pers. obs.), may also use mainstems of rivers for spawning habitat (Lippson and Moran 1974). Thus, larger tributaries may provide more spawning area for river herring besides being havens from competition and predation.

There have been no studies indicating that a specific forest buffer or cover is required for spawning habitat of river herring. However, substrates with silt, detritus, and vegetation are considered optimal to provide cover for spawning of both species (Pardue 1983), and these may be provided by leaving streamside vegetation intact. Also, streamside vegetation maintains the integrity of channels, preserves terrestrial-aquatic interactions, provides a diversity of habitat and substrate types, provides nutrients, and helps to control stream temperature, sediment deposition in streams, and light levels (Hicks et al. 1991). Considering requirements of river herring for specific temperatures and levels of dissolved oxygen in spawning habitat, and the possible reactions of early life stages to suspended solids, such as increased infection rates of river herring eggs (Schubel and Wang 1973), maintenance of streamside vegetation along spawning habitat may be important in determining use of streams by these fish.

Results of analysis using total watershed suggest that the negative effects of agriculture on spawning habitat may be significant upstream of spawning areas. The effects that nutrient loading, erosion, bank destabilization, alteration of channel morphology, and other results of agriculture may have on spawning habitat are of importance in the Rappahannock River, because this is the major land use in this drainage. Although there is no information that any effects of agriculture have been the direct cause of decline of river herring stocks, my results suggest that river herring habitat may suffer significantly from this land use. It may be useful to determine if chemicals from agriculture affect spawning habitat of river herring.

There was no relationship between percentage of urbanization and occurrence of river herring runs in tributaries of the Rappahannock River. Limburg and Schmidt (1990) found a marked decline in river herring recruitment where urbanization was 10% or greater in the Hudson River basin. Although there was a high of 59% urbanization in one Rappahannock River watershed, only 8 of the total 81 watersheds contained urbanization. Also, the effects of this land use may be greater in one stream than another, even though two streams contain significant amounts of urbanization. For example, Brehmer (1970) found that the concentration of nitrogen in the James River, which receives nutrient enrichment from the Richmond, Hopewell, and Hampton Roads areas, was 2 to 3 times that found in other Chesapeake Bay rivers, including the Rappahannock River. This indicates that the Rappahannock River may be not be as urbanized as other systems. Contaminants and nutrient loading have not been found to be major causes of declines in river herring stocks in the Chesapeake Bay (Klauda et al. 1991). Therefore, the effects of urbanization in this system may not be as great as that of other activities that affect river herring recruitment (e.g., overfishing) or other factors that affect river herring spawning success (e.g., beaver dams).

There are no studies indicating that river herring use areas associated with wetlands. The positive association between tendency for river herring to be present in streams and wetlands may indicate that river herring runs occur in streams that contain wetlands. This association was seen only when modified watersheds (that is, watershed areas below known impediments) were used. This indicates that river herring use watersheds that are characterized by wetlands when this land cover is in the portion of watershed below impediments. According to local anglers, river herring spawn in marshy areas above Walkers Dam on the Chickahominy River (pers.

comm.). Also, the results of my study of river herring spawning habitat in a Rappahannock River tributary (Chapter 2), indicate that spawning was more significant in an upstream area that may be classified as forested swamps and, consequently, wetlands. Wetlands may stabilize spawning habitat by its positive effects on streams such as reduction of shoreline erosion (Ward et al. 1984). It is not clear what role, if any, wetlands have in river herring spawning habitat. This association between belief that runs are present and wetlands was significant at the 0.05 level (p=0.0277), but other associations between stream use by fish and land use were more significant. Although statistical analyses were not performed, proportion of wetlands appeared to be similar upstream and downstream of impediments, so it is not clear why wetlands was not related to fish use when total watersheds were used. Thus, this association may be weak, and its implications are not clear.

Density of highway crossings was not related to use of streams by river herring, or any other trends in fish use. This indicates that road crossing structures are not greatly affecting use of streams by fish. Odom et al. (1986) found that only 7 highway crossings structures on 54 streams known to have spawning runs were possible or certain impediments to river herring spawning migrations in the lower James River. Uzee and Angermeier (1993) found that dams and stream morphology, not highway crossing structures, were the major impediments to fish migrations in the Rappahannock and Chickahominy Rivers. Therefore, factors other than road crossings may be more significant in deterring fish from using streams in the Rappahannock River drainage.

The greater tendency for river herring to be present in streams that have point-source pollution is probably a result of the greater watershed size in streams with point-source pollution. Of the 15 tributaries of the Rappahannock River drainage that had the largest watershed areas, 7 had point-source pollution and the remaining 8 had none. Neither of these two groups of large streams had a greater tendency for river herring to be present in them. This indicates that, in the areas river herring are more likely to use, point-source pollution is not affecting stream use by fish. I expected point-source pollution to worsen spawning habitat due to its effects on dissolved oxygen and fish health and for this to be reflected by negative relationships with all trends in fish use, but this was not the case. My results indicate that although point-source pollution exists in this river, it may not affect stream use by fish. Therefore, it may not be a distinct cause of decline in river herring stocks.

Relationships between watershed characteristics and size of river herring runs

The association between size of river herring runs and size of watershed indicates that, of the watershed characteristics I studied, only stream size affects the extent to which a stream is used by river herring. Various watershed characteristics were related to occurrence of river herring runs, and I expected that these characteristics would be related to how many fish use a stream. This was not the case, however. Since fish are more likely to use larger tributaries of this system, as my results indicate, runs will probably be larger in these better habitats.

Relationships between watershed characteristics and trends in river herring runs

The associations between forest, agriculture, and urbanization and trends in numbers of herring runs in streams indicate that these watershed characteristics have effects on recent trends in the Rappahannock River populations of river herring. I did not expect urbanization to be positively related to trends in runs. However, as before, this may be an indication that the effects of urbanization in the Rappahannock River are not that great. Considering that agriculture and forest are the two major land covers in this drainage, the associations between these two land covers and trends in runs are of great importance. I expected that trends in fish use would be related to recent trends in watersheds such as land cover, not a characteristic such as watershed size, and this was the case. However, as the land cover in the Rappahannock River drainage probably has not experienced dramatic changes in the last years (VDGIF game wardens and landowners in the Rappahannock River area, pers. comm.), I did not expect that forest and agriculture would contribute to recent trends in river herring runs.

Agriculture's negative association to trends in numbers of runs indicates that there may be cumulative agricultural effects, such as sedimentation, or recent practices in agriculture, such as use of new fertilizers or pesticides, which are contributing to a decline in fish runs. Cultivation and fertilization of fields in the Rappahannock River drainage occurs during the river herring spawning season (pers. observ.). Pesticides, which can be applied during the spawning season, can affect fish health and may significantly affect river herring spawning success. Effects of agriculture on river herring spawning habitat should be understood so that they can be minimized.

Relationships between watershed characteristics and stream rank

Watershed characteristics that were associated with individual aspects of fish use of streams were not always related to overall fish use of streams. I felt that associations between any watershed characteristics and stream rank based on all aspects of fish use would indicate that these characteristics are the most significant in affecting fish use of streams in the Rappahannock River drainage. The associations between stream rank and forest and agriculture, using both total watershed and modified watersheds, indicate that these land covers are overall more significant in affecting spawning streams than any other watershed characteristic. These associations between stream rank and forest and agriculture were valid regardless of the associations between stream size and river herring use of streams and between percentages of agriculture and forest and stream size. Streams were divided into 2 groups (the half having largest watershed areas and the half having the smallest watershed areas). The association between agriculture and stream rank was significant when only the streams with large watersheds ($\geq$517 ha) were used in analyses. Percentage agriculture was negatively associated with greater stream use by fish (p=0.0042, r=-0.4648, N=36) when only large streams were examined. However, percentage agriculture was not related to stream use by fish (p=0.3467, N=35) when only small streams were examined. Where fish are more likely to be present, the larger streams, agriculture appears to be affecting stream use by fish. Furthermore, the significant differences in stream rank among groups of streams by agricultural intensity suggests that agriculture is the most important watershed characteristic in affecting spawning habitat of river herring. Once again, this is important considering the extent to which this area is farmed. Since stream use by spawning river herring may change noticeably if agriculture is greater than 20-30% in a watershed, small amounts of this land use may affect river herring stocks in the Rappahannock River. River herring appear to use larger tributaries in this system, and these streams are more likely to have greater amounts of forest than agriculture in their watersheds. However, small amounts of agriculture in these watersheds may still have dramatic effects on river herring stocks.

It appears that agriculture affects stream use by river herring, regardless of associations between this land use and stream size and topography. The land cover distributions in the Rappahannock River drainage are possibly a result of the topography of this region. It appears that agriculture is more likely to occur in flatter areas, which occur in downstream portions of watersheds. Forest is more likely to occur in steeper areas that are not farmed. This could explain the positive association between stream size and forest and the negative association between stream size and agriculture. In watersheds of large streams there is more forest than agriculture because these large watersheds include steep terrain. I found that high velocity, which is due to a steep gradient, is an important trigger of alewife spawning (See Chapter Two-Results and Discussion-Habitat variables affecting occurrence river herring life stages in spawning area). However, river herring can spawn in different sized and types of habitat in other parts of their ranges. Also, the topography in the Rappahannock River drainage below Fredericksburg is relatively flat compared to upstream areas of this system. Effects of topography on stream use by fish may need to be further studied. My results indicate that agriculture may have a significant effect on stream use by river herring.

Management implications and further research

Of the watershed characteristics studied, some had definite associations with certain aspects of stream use by fish, while others had none. Urbanization and point-source pollution were positively related to aspects of stream use by fish. Thus, these watershed characteristics should not be considered major factors in contributing to the decline of river herring recruitment in the Rappahannock River drainage through decreased spawning success. Urbanization and point-source pollution may affect other river herring life stages, such as juveniles, that do not use the spawning habitat but use other freshwater areas of the Rappahannock

River. Also, higher amounts of urbanization and point-source pollution could affect spawning success. Thus, these land uses should not be disregarded as factors affecting other aspects of river herring recruitment. These land uses could affect spawning success if they were more abundant in this system. Negative effects of these land uses should be minimized by 1) maintaining buffer and riparian zones along streams in urbanized areas, and 2) monitoring effects of point-source pollution. These practices require knowledge of appropriate buffer and riparian zones and possibly limiting pollution discharges that are allowed in this drainage. At this time, the Chesapeake Bay Act requires a 100 ft riparian zone for streams in development areas. Lands with agriculture and forestry practices are exempt from this requirement. It is not known if this required zone is an appropriate buffer for habitat of river herring early life stages, so this must be studied.

Watershed characteristics other than urbanization and point-source pollution have stronger associations with individual aspects of stream use by river herring. Management of these other characteristics are important for recovery for river herring runs in tributaries of the Rappahannock River. Managers should protect larger watersheds by establishing appropriate buffer zones within them and providing fish access to them. Land covers that may have positive effects on stream use by fish such as wetlands should be studied to see how they affect river herring runs. If a positive effect is determined, they should be maintained in streams that provide spawning habitat for river herring.

Since agriculture and forest may have the strongest effects on river herring use of tributaries in the Rappahannock River system, management of these land covers should be of highest priority. Once again, riparian zone requirements for habitats that river herring early life stages use are not known. This knowledge is required before appropriate riparian zones and buffer zones between agriculture and streams can be established and maintained in river herring spawning areas in this drainage. Threshold levels (20-30%) for both agriculture and forest may cause dramatic changes in overall stream use by spawning river herring. Knowledge of how these two land covers interact above these levels is needed to manage their effects. Managing for greater than 20-30% forest and minimizing the effects of agriculture that is at or above this amount may be additional strategies for protecting river herring fisheries in the Rappahannock River.

Thus, forest should be considered the most important land cover for contributing positively to stream use by river herring. Likewise, agriculture should be considered the same for contributing negatively to stream use by river herring. Forest is more predominant in larger watersheds, and river herring are more likely to use larger watersheds than smaller ones. However, agriculture may be affecting stream use by fish even in these larger streams. An understanding of how watershed characteristics interact to effect spawning runs is needed before watersheds can be managed. Also, the effects of gradient on suitability of river herring spawning habitat should be understood. All land covers should be monitored, their negative effects mitigated, and positive effects enhanced, especially those of agriculture and forest. However, other practices, such as recreational and/or commercial fishing, and other factors such as beaver dams should be studied to see how they affect river herring runs in streams of the Rappahannock River drainage.

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Chapter Two

Spatio-temporal dynamics of spawning and larval river herring

Because of the decline of river herring stocks in recent years and their importance to other organisms and to humans, for commercial and recreational fishing, there is a need to determine causes of their decline. The critical life history stages of river herring include the egg, yolk-sac larvae, and post-yolk sac larvae. These stages occur in freshwater, inland habitats. The location of these habitats makes these stages susceptible to human perturbations that could alter environmental factors. In the Chesapeake Bay, there is a lack of knowledge of spawning habitat for river herring. Also lacking is knowledge of how environmental factors interact to affect occurrence of river herring life stages in upstream site. Therefore, spawning habitat and the influence of environmental parameters on spawning dynamics need to be studied.

Spatial patterns for spawning and larval river herring

Research has shown that, throughout their ranges, river herring use different types of habitat for spawning. Physical characteristics of available habitat such as area, velocity, depth, and substrate composition determine if adult alewives and blueback herring can or will utilize an area for spawning. Blueback herring can move upstream into shallow areas by swimming on their sides and will spawn in water with velocity less than 1.2 m/s, where streams are 4.6 m or greater in width (Mowrer 1984). In a Prince Edward Island stream, blueback herring eggs and larvae are found where water depth is 1 to 2 m, and stream width is 15 to 20 m (Johnston and Cheverie 1988). Blueback herring are found in areas of fast moving water with hard substratum (Loesch and Lund 1977), although they also spawn in a diversity of habitats including channel sections of fresh and brackish tidal rivers, Atlantic coastal ponds, seasonally flooded rice fields, cypress swamps, and oxbows (Frankensteen 1976; Loesch 1987; Pardue 1983). Pardue (1983) concluded that substrata with 75% silt or other soft materials containing detritus and vegetation and sluggish flows are considered optimal to provide cover for spawning river herring and their eggs and larvae. Freshly fertilized eggs adhere to substrate until water hardening (the uptake of water by eggs; 24 h after fertilization) occurs. After water hardening, eggs are less adhesive and are pelagic, but demersal in still water (Loesch and Lund 1977). Alewives have been reported to spawn in small streams with hardly enough water to cover their bodies (Cooper 1961). They spawn in a diversity of habitats including large rivers, small streams and ponds, over a range of substrata such as gravel, sand, detritus and submerged vegetation, and in areas with sluggish water flows and depths ranging from about 0.2 to 3 m (Cooper 1961; Loesch 1987; O'Neill 1980; Kissil 1974). They also spawn in big lakes and reservoirs (Jones et al. 1978, Nigro and Ney 1982).

Research has shown that where the two species' ranges overlap, they occur in different spawning habitats. Blueback herring prefer lotic spawning sites and alewives spawn in lotic areas in the north, where the two species are sympatric. In the south where the blueback herring is more prevalent, this species uses lotic or lentic sites. Loesch (1987) suggests that this is a clinal spawning pattern that may reduce competition with alewife for spawning habitat when the two species are sympatric. The spawning behavior of blueback herring and alewife near the middle portion of their ranges (e.g., Chesapeake Bay) has not been studied to support this hypothesis (Klauda et al. 1991). In the Chesapeake Bay area where the two species overlap, the blueback herring and alewife should show habitat partitioning. Knowledge of the spawning habitats of the two species of river herring in the Rappahannock River may help explain how they partition resources in the middle portion of their ranges.

Salinity is a major factor influencing where alewives and blueback herring spawn. Spawning habitat typically occurs above the zone between fresh and salt in tidal freshwater portions of the mainstem of a river. River herring spawn in freshwater (salinity < 1 ppt). Blueback herring in Maryland spawn no more than 3-5 km upstream of tides (Mowrer 1984). Alewife eggs were collected in areas of the upper Chesapeake Bay where salinities ranged from 0 to 2 ppt: 99% of the eggs were collected in strictly freshwater (Dovel 1971). Larvae and juveniles were collected in areas that ranged from 0 to 8 ppt; 98% were collected in areas that ranged from 0 to 3 ppt and 82% were collected in fresh water. Pardue (1983) concluded that salinities of 5 ppt or less were optimal for the alewife and blueback herring. However, blueback herring eggs in various stages of development and prolarvae can survive in estuaries of a Prince Edward Island coastal stream of 18-22 ppt salinity (Johnston and Cheverie 1988). Thus, the salinity tolerances of the eggs and larvae depend on habitat conditions to which the population is subjected.

Dissolved oxygen concentrations and pH conditions also determine where both species of river herring spawn. Minimum dissolved oxygen requirements are 5.0 mg/L for alewife eggs and larvae and 3.6 mg/L for adults (Jones et al. 1988). There is no information on dissolved oxygen optima or tolerance for blueback herring eggs (Klauda et al. 1991), but larvae and adult blueback herring require dissolved oxygen of at least 5.0 mg/L (Jones et al. 1978). For alewife eggs and yolk-sac larvae, pH 5.0-8.0 and 5.5-8.5 is considered suitable. For blueback herring eggs, pH 5.7-8.5 is considered suitable and pH 6.0-8.0 is optimal. For blueback herring yolk-sac larvae, pH 6.2-8.5 is considered suitable and pH 6.5-8.0 is optimal (Klauda et al. 1991). Thus, blueback herring require higher pH levels. Also, larvae of both species seem more sensitive to pH levels than eggs. Practices that affect dissolved oxygen or pH levels in spawning habitat and nursery areas, such as industrialization, urbanization, and agriculture could have significant negative effects on habitat for spawning river herring.

Temperature is another important habitat parameter in that it affects egg incubation and larval survival. Alewife eggs from Lake Michigan hatch between 7 and 29°C, with an optimum hatching temperature of 16°C (Edsall 1970). Survival time of unfed larvae held at incubation temperature increases from 3.8 days at 10.5°C to 7.6 days at 14.5-15°C, then decreases to 2.4 days at 26.5-28°C (Edsall 1970). Deformity rates of 100% of blueback herring larvae from Canaan River, New Brunswick, Canada were seen in laboratory studies when temperature reached 34°C (Koo and Johnston 1978). Thus, temperature plays an important role in timing of hatching and survival of larvae, and, therefore, affects where successful spawning can take place. Habitat alteration that affects temperature such as pond formation upstream of spawning areas or clear-cutting along spawning habitat could have dramatic effects on the success of spawning in that area.

Spawning habitat for river herring depends on type of habitat available and degree of sympatry of the river herring. In a coastal stream on Prince Edward Island, blueback herring spawn above the head of tide in an area that has a predominant saltwater wedge (Johnston and Cheverie 1988). In the Connecticut River, blueback herring spawn in fresh water in areas of swift current (Loesch and Lund 1977). In southeastern U.S. blueback herring spawn in ricefields, in swampy areas, and in small tributaries upstream from the tidal zone (Christie et al. 1981, Loesch 1987, Meador et al. 1984, Rulifson et al. 1982). In the Connecticut River, where river herring are sympatric and their spawning seasons overlap, the alewife spawns in lentic areas, different from spawning areas of the blueback herring (Loesch and Lund 1977). In southeastern U.S., where the alewife does not occur, the blueback herring spawns in lentic areas. There is little knowledge of spawning habitat for river herring in the Chesapeake Bay, where the blueback herring is more abundant than the alewife. An understanding of where river herring spawn in the Rappahannock River would show which parameters are important for habitat selection by these species in this part of their range.

Temporal patterns for spawning and larval river herring

Besides affecting where river herring spawn, stream size and stream velocities will influence timing of spawning. Crowding causes fish to move further upstream (Mowrer 1984). High flows with sediment push river herring downstream of suitable spawning habitat (Mowrer 1984) or result in lower abundances of blueback herring larvae (Meador et al. 1984), but adult fish will return when the area is clear (Mowrer 1984). After spawning, adult alewives and blueback herring rely on increasing water flows to trigger their emigration back to the sea (Huber 1978). The effects of tide on spawning have not been documented, but anglers and game wardens in the Rappahannock River area report that fish enter spawning areas on high tide, mainly at night, and leave the streams on low tide. Also, rain and high flows inhibit spawning runs (pers. comm.). Thus, physical habitat parameters that change dielly or unpredictably can influence the timing of occurrence of life stages in spawning areas.

Temperature also influences timing of spawning of alewife and blueback herring. Both species depend on an increase in water temperature to trigger spawning in the spring. Spawning time of the alewives begins 3 to 4 weeks before that of blueback herring in the same areas. Spawning peaks of the two species are usually 2 to 3 weeks apart (Jones et al. 1978). Minimum water temperature at which spawning begins is 10.5°C for alewife (Cianci 1969) and 14°C for blueback herring (Loesch and Lund 1977). Therefore, the temporal difference in spawning for these fish enables them to use the same areas at different times. This may serve to minimize competition for spawning sites that exists between these two species. Hatching of blueback herring eggs in a Prince Edward Island stream occurs after 3 to 20 days, depending on water temperature, and the periodicity of night-time hatching is obscured when water temperature increases (Johnson and Cheverie 1988). The 1991 river herring spawning runs into tributaries of the Rappahannock occurred from mid-April to mid-May (pers. obs.; Knox Turnbull, VDGIF, pers. comm.). Anglers and game wardens reported that spawning runs occurred during late April, after 1-2 days of high temperature. Thus, temperature plays an important role in affecting timing of occurrence of life stages in spawning areas.

Both light intensity and temperature can determine when adults enter spawning grounds and when spawning occurs. Migratory activity of alewives is closely associated with solar radiation and with diurnal periodicity in fish activity (Saila et al. 1972). Light intensity also influences entry of adults into freshwater (Lund et al. 1970; Cooper 1961) and movement upstream during a 24-hr period (Lund et al. 1970). However, stream temperature also determines date of adult alewife entry and their rate of movement into freshwater (Cooper 1961). Alewives avoid light during the initial stages of spawning (Cooper 1961; Rothschild 1966), but they eventually overcome their aversion to light (Cooper 1961). An understanding of how light and/or temperature determine time of entry and movement of adults in freshwater during the spawning period would be helpful in predicting when spawning will occur in a habitat.

Drift of eggs and larvae and spawning activity exhibit diel patterns. Johnston and Cheverie (1988) found that the peak period of blueback herring spawning activity is between 12 and 1 a.m. in a Prince Edward Island stream, and drift of eggs and/or larvae increases at night to dawn (Johnston and Cheverie 1988; Meador et al. 1984; Jessop 1990). However, spawning activity and peak periods of drift of eggs and/or larvae are asynchronous (Johnston and Cheverie 1988; Meador et al. 1984). The appearance of large numbers of larvae at night suggests that hatching occurs at this time since larvae have limited swimming ability (Johnston and Cheverie 1988). Peak periods for daily activity of spawning alewives can occur at different times of the day (Tyus 1974), as can their entry into streams (Cooper 1961). Diel periodicity in spawning dynamics may, therefore, determine timing of events such as spawning activity and the appearance of eggs and larvae. In the Rappahannock River river herring runs during the 1991 season lasted 2-3 days, and in one tributary, only two relatively strong runs occurred (Knox Turnbull, VDGIF, pers. comm.). An understanding of this diel periodicity in spawning dynamics would be useful in predicting occurrence of eggs in spawning areas.

Therefore, there are many environmental factors that influence the timing of river herring spawning. A knowledge of how these factors influence spawning in the Rappahannock River is needed in order to maintain the integrity of spawning in this portion of their range.

In summary, there is some knowledge of habitat selection by spawning alewife and blueback herring, but little is known from Virginia streams and smaller systems regarding how physical parameters and light intensity, diel periodicity, tides, rain, and temperature, affect habitat selection and spawning dynamics. In this portion of their range where blueback herring are more prevalent, competition between the two species may affect habitat selection and timing of occurrence of life stages in spawning areas. Knowledge of the physical characteristics of a habitat, the daily and seasonal changes in those characteristics, and the effect that these factors have on blueback herring and alewife is necessary in order to understand the temporal dynamics of their spawning. This knowledge of habitat selection and influence of habitat factors on occurrence of adults and eggs in spawning areas is needed in order to protect early life stages of these fish. The specific objectives of Chapter Two were as follows:

1) to characterize the habitat where river herring spawn and the spatial distribution of yolk-sac larvae in a tributary of the Rappahannock River

2) to determine importance of environmental factors in influencing occurrence of life stages in spawning areas

3) to characterize the habitat where post-yolk sac larvae are found.

Materials and Methods

Sampling of river herring adults, eggs, and larvae

Eggs, yolk-sac larvae, and spawning adults were sampled during the 1992 spawning season (Feb.18 to May 13) in Occupacia Creek, a stream in Essex Co., VA, where river herring spawn every year (see Chapter 1-Materials and Methods for method of determining consistency in spawning). This stream, located 44 nautical miles above the mouth of the Rappahannock River, has a watershed area of 7075 ha that is 25% agriculture and 72% forest. Three sites (each 50 m long) were chosen that represent a small upstream and two wider and deeper downstream sections of this tributary (Figure II.1).

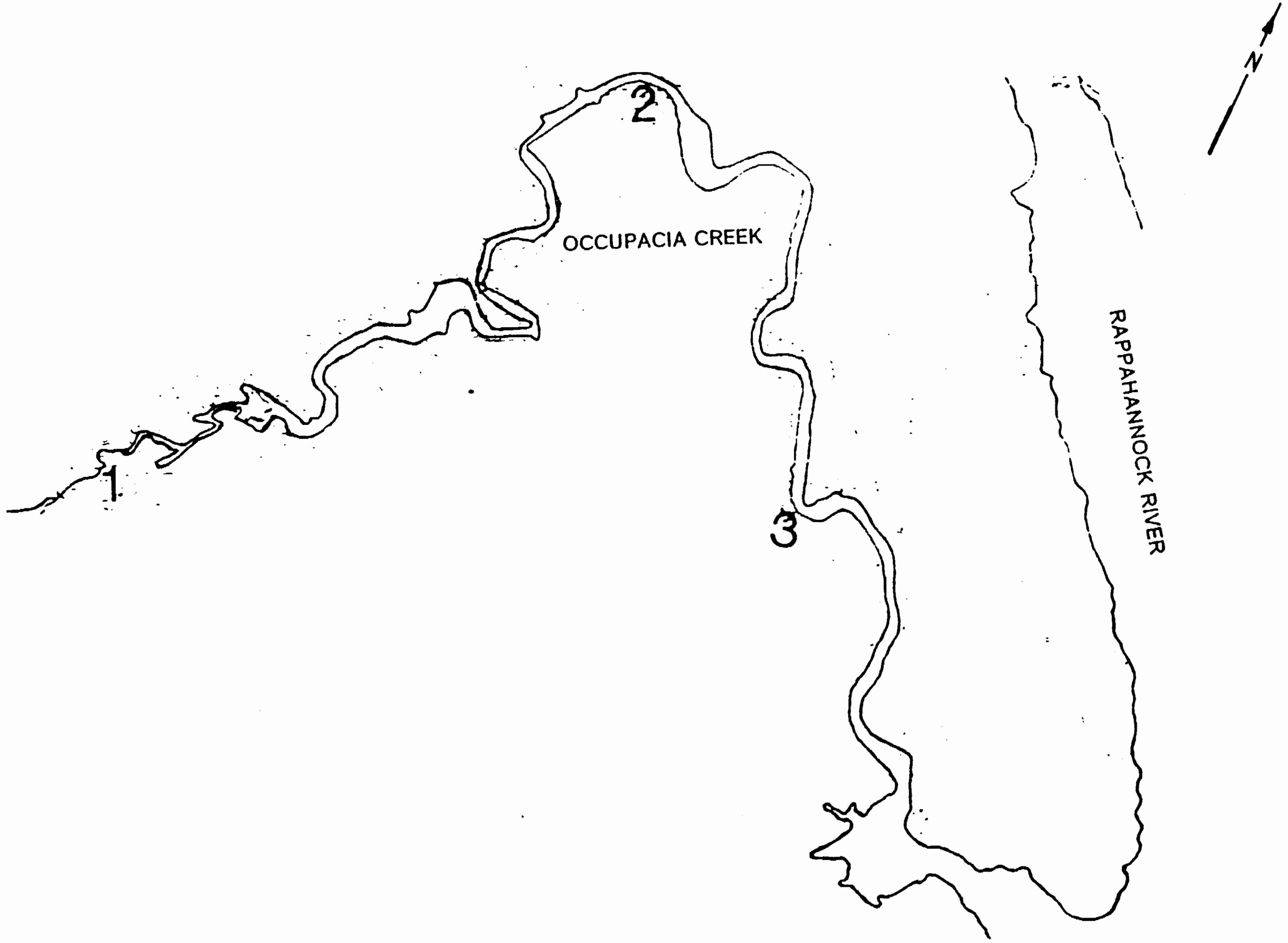


Figure II.1. The three sites on Occupacia Creek, Essex Co., VA. that were sampled during the 1992 spawning season for river herring.

The upstream site, Site 1, was 16 km from the mouth of Occupacia Creek. Sites 2 and 3, the two downstream sites, were 9 and 5 km from the mouth of this stream. Sites were sampled on a 5-day, 4-time interval rotation: on Day 1 the upstream site was sampled at dawn, the middle site at midday, the downstream site at dusk, and the next two time intervals (midnight and dawn) were skipped. On Day 2, the upstream site was sampled at midday, the middle site at dusk, the downstream site at midnight, and the remaining next two time intervals were skipped. The sampling schedule for the rest of the 5-day rotation followed a similar pattern (see Appendix B). Thus, in a 5-day rotation each site was sampled once at each of the four time intervals.

Three 363-micron-mesh (35x47cm mouth) drift nets were set at mid-channel (at the bottom) in the upstream site, and two sets of two drift nets were set vertically (at the bottom and at the surface) along the mid-channel in the two deeper, downstream sites, in areas of swiftest current (Figure II.2). When the sampling period occurred during incoming tide at the two downstream sites, drift nets were towed 2 times by boat along the mid-channel at the surface. Larvae and eggs were sampled with drift nets for 20 minute intervals during each sample period, from one week before runs appeared in the tributary until the cessation of runs. Sites 1, 2, and 3 were sampled 63, 48, and 37 times throughout the river herring spawning season.

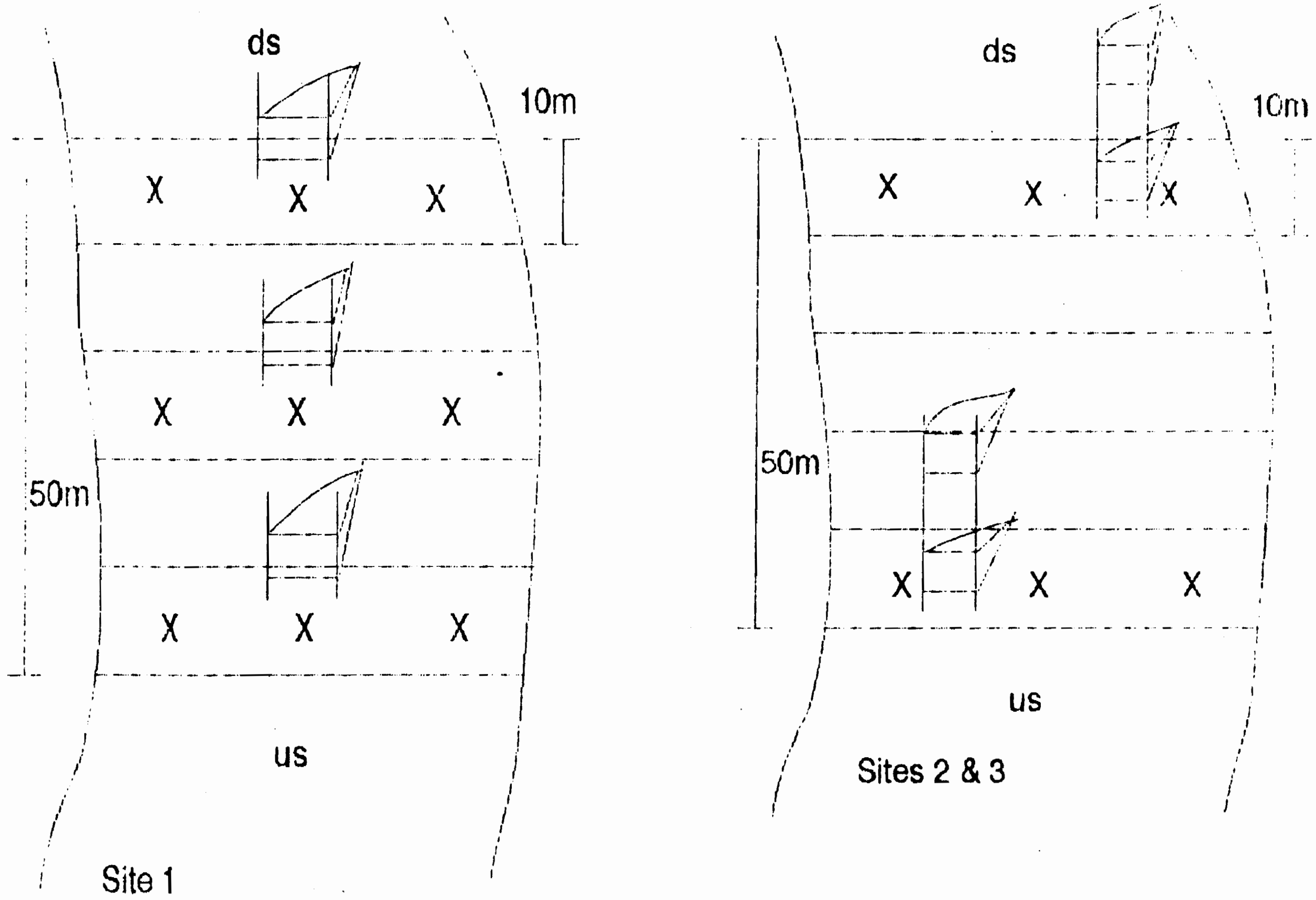


Figure II.2. Transect scheme for Site 1 and Sites 2 and 3 for sampling eggs and yolk-sac larvae and measuring habitat variables. Net configurations represent placement of drift nets in sites. "X"'s represent points at 25%, 50%, and 75% of the stream width within each transect where habitat variables were measured. "us" represents upstream and "ds" represents downstream.

The technique for sampling eggs and yolk-sac larvae was similar to that used by Limburg and Schmidt (1990). Current velocity (cm/s) was measured by placing a flowmeter in the mouth of the drift net. Water volume (cm^3) passing through the net was estimated from data on the net's mouth area and current velocity. Densities of eggs or larvae (per volume water) were estimated for each sampling interval. Eggs were described as adhesive or nonadhesive upon sampling and both eggs and larvae were subsequently preserved in a borax-buffered 10% formalin solution in order to stage (age) the eggs and larvae. Since there are difficulties in distinguishing between the two species before they are 15 mm post-yolk sac larvae (Ed Sismour, VIMS, pers. comm.), identification of the species of river herring adults in the stream at the time of egg or larval capture was used to identify these stages. Eggs and yolk-sac larvae were later staged in the laboratory. Eggs were staged as "b" eggs if they were unfertilized and "c" eggs if they were less than an hour old (Mansueti and Hardy 1967). Densities of later egg stages were combined with densities of the "b" and "c" stages to determine total egg densities. Yolk-sac larvae were staged as "a" if they were no greater than 3.5 mm and "c" if they were over 3.5 mm (Mansueti and Hardy 1967).

Adults were sampled during the drift sampling period by continuously dipping for them (for 20 minute interval) with a 1 m diameter dip net of 1-inch chicken-wire mesh. Since gizzard shad larvae were sampled along with eggs and larvae of river herring during the 1991 spawning season and there are difficulties in distinguishing among eggs and larvae of river herring and gizzard shad, sampling for adult spawners during the egg and larval period identified which spawning species were present and their movement in or out of the stream. Adults were identified in the field by eye diameter, operculum shape, and peritoneum color (O'Neill 1980). Spawning readiness, sex, and length (mm) of alewife and blueback herring adults were recorded upon capture.

After sampling for eggs, yolk-sac larvae, and adults, post-yolk sac larvae were sampled by towing a 500-micron-mesh modified plankton sampler (53 cm diam) by foot in the upstream site (approximate speed=3.6 km/hr) by boat in the downstream sites (approximate speed=3.0 km/hr). The sampler was towed at the surface along the banks and mid-channel for a total of 3 tows at each site. Velocity (cm/s) of water passing through the net was measured by a flowmeter attached to the mouth of the net. Water volume (cm^3) passing through the net was estimated from data on the net's mouth area and this velocity. Densities of post-yolk sac larvae (per volume of water) were estimated for each sampling period. Post-yolk sac larvae were preserved in a borax-buffered formalin solution. They were later staged in the laboratory (Mansueti and Hardy 1976). Post yolk-sac larvae were designated as "a" if the caudal finfold was not separate from the dorsal finfold and "b" if the caudal finfold was separate from the dorsal finfold.

Measurement of habitat parameters

Three transects bands (each 10 m x stream width) were established at the upper, middle, and lower portions of the upstream site, and two transects were established at the upper and lower ends of the middle and downstream site. Within each transect, three points were established at 25%, 50%, and 75% of the stream width (Figure II.2). After each 20 minute sampling period, light intensity, temperature, velocity, water depth, salinity, and DO were measured at each point. Acidity (pH) was measured one time at one point after each sampling period. The transects were also divided into thirds across the stream, and percentage of substrate type and aquatic vegetation of each portion of transect were determined for each sampling period.

Light intensity (lux) above the water was measured with a light meter (Model 214, General Electric). A secchi disk measured photic zone depth (cm) and secchi disc transparency (cm) in the water. Since the photic zone is the subsurface zone where 1.0% of incident surface light remains, the amount of light intensity available to fish in this area was known. Temperature (°C) and salinity (ppt) were measured using a YSI S-C-T meter. Velocity (cm/s) was measured using Marsh-McBirney analog and digital flow meters. Water depth (cm) was measured using a meter stick. Substratum was visually described using the Wentworth scale. DO (mg/L) was measured using a YSI dissolved oxygen meter. Acidity (pH) was measured using a Markson Dip-N-Read pH meter. The distribution of vegetation was recorded for each portion of the transects as well as along the banks of the stream. Stream width was measured across each transect using a 50 meter tape. Time of day and tidal condition (outgoing, low, incoming, or high tide) were also recorded for each sampling period.

Analyses

Spawning habitat

The mean value of each parameter was computed for all sampling periods at every site. Number of adults/min. and average number of eggs/100m^3, yolk-sac larvae/100m^3, and post-yolk sac larvae/100m^3 were determined for each sampling period. These mean values were used in all analyses involving habitat variables and densities of river herring life stages described below.

Habitat parameters were analyzed for differences among the sites and throughout the river herring spawning season. I divided the habitat and life stage data into four seasons: 1) before alewife spawning, 2) during alewife spawning, 3) when both species were spawning, and 4) during blueback herring spawning. Mean values for habitat variables for each of the three sites over the seasons were compared by two-way analysis of variance (ANOVA) using the general linear model to see if there were any season x site interactions. If there was a season x site interaction for any variable, then a one-way ANOVA using the general linear model was used to test for differences among sites over the seasons and among seasons over the sites for that variable. Values for habitat variables without season x site interaction for each of the three sites over the seasons were compared using Kruskal-Wallis test. If this test was significant ($p<0.05$), pairwise site comparisons were made using Wilcoxon 2-sample test. Likewise, values for habitat variables without season x site interaction for each of the four seasons over the sites were compared using Kruskal-Wallis test. If this test was significant, pairwise season comparisons were made using Wilcoxon 2-sample test. If any habitat variables were different among seasons, these variables were compared among sites for each season to see how sites differed from each other in each season. Mean values for each variable for sites and seasons were obtained from general linear model.

In the following analyses involving densities of river herring life stages, only data from samples taken during the time intervals when these stages were at any of the three sites were used, unless otherwise mentioned.

Densities of adults, the two egg stages, the two yolk-sac larval stages, and all egg stages for both species in the three sites were compared using Kruskal-Wallis tests to see if occurrences of eggs and adults and yolk-sac larval stages, as indicated by densities, differed significantly among the sites. Mean values for densities for each site were provided by the general linear model.

Densities of both stages of eggs for both species were plotted together to see if proportions of stages were similar over the time that they were in Site 1. If proportions differed, presence of unfertilized eggs (the "b" stage) would not necessarily indicate successful spawning in this area.

Timing of occurrence of river herring life stages

Habitat variables affecting occurrence of life stages in spawning areas

To determine if tidal condition or time of day affected occurrence of life stages in significant spawning areas (sites where densities of eggs, adults, and yolk-sac larvae were significantly higher than other sites), densities of adults and egg stages for both species at each tidal condition [(1) high tide (2) low tide (3) outgoing tide, and (4) incoming tide] in these area(s) were compared using the Kruskal-Wallis test. This test was also used to compare densities of these life stages at each time of day [(1) dawn (2) noon (3) dusk and (4) midnight]. Also, life stage densities of both species were plotted with tidal condition, time of day, and light intensity and temperature (factors associated with time of day) to search for trends.

Habitat variables affecting occurrence of life stages in the spawning area

Before I determined if any habitat variables affected occurrence of life stages in significant spawning areas, I examined habitat variables in these areas for differences over the sampling season and for relationships among them. I also wanted to determine how occurrence of adults and egg stages in the spawning area were related to each other. I compared values for habitat variables in significant spawning areas among the four seasons and among 5-day cycles using a Kruskal-Wallis test. Correlations between habitat variables and cycle were tested to see how variables changed throughout the sampling season. Correlations between habitat variables were also tested. Likewise, correlations between densities of adults and densities of each egg stage and between densities of each egg stage were tested to determine relationships between occurrences of these life stages.

Habitat variables that varied significantly among seasons or cycles or that have been found in other studies to trigger or affect occurrences of river herring life stages in spawning areas were then separately related to occurrence of eggs and adults in spawning areas by using logistic regression (Harrell 1985). This analysis generated a model that predicted occurrence of a river herring life stage in the spawning area from habitat variables. Occurrence of a river herring life stage is a binary variable (1=presence and 2=absence), and habitat variables are continuous. Habitat variables were related individually to occurrence of each life stage of river herring. In this analysis, data from Site 1 over the entire sampling interval were used. The p-value for chi-square for covariates indicated the likelihood for fitting a model (that predicts presence of each life stage) with an intercept and each habitat variable (Harrell 1985).

Stepwise logistic regression was then used to generate models to predict occurrence of life stages in spawning area from habitat variables that had p-values for chi-square for covariates <0.05. The p-values for Wald chi-squares for each parameter indicated which parameters were entered or removed from the models in stepwise logistic regression (Harrell 1985).

Finally, variables that entered and remained in the logistic regression models were used to generate final models. Parameter estimates for these variables and p-values for chi-square for covariates were found from fitting these variables into the models. The final model determined probability values for occurrence of a river herring life stages from variable values. Classification tables at 0.500 probability level were also generated for each model. I chose the 0.500 probability as a "cutoff" level for these models.

A model predicted presence (p=1, presence) of a life stage if the probability determined by variable value is above 0.500. The model predicted absence (p=0, absence) of a life stage if probability is below 0.500. The classification table is a frequency table of observed and predicted responses at a given probability, in this case at the 0.500 "cutoff" probability. It consists of the following five values: 1) percentage correct, the percentage of my observations of the river herring life stage that were the same as model predictions (using the 0.500 "cutoff" level); 2) sensitivity, the proportion of observed occurrences of the life stages predicted to be occurrences; 3) specificity, the proportion of observed non-occurrences of the life stage predicted to be non-occurrences; 4) false positive rate, the proportion of predicted occurrences that were observed as non-occurrences; and 5) the false negative rate, the proportion of predicted non-occurrences that were observed to be occurrences. The final models for predicting occurrence of river herring life stages using parameter estimates for habitat variables accepted into the models were also determined. From these models, variables were plotted against probabilities of occurrences of these life stages to indicate values of these variables at the 0.500 level of probability.

Post-yolk sac larvae habitat

Densities of post-yolk sac larvae for each of the three sites were compared using a Kruskal-Wallis test to see if this stage was more abundant at one site than another.

Results

Spawning habitat

The three sites that were sampled for river herring life stages differed from each other over the seasons in depth, velocity, pH, secchi disc transparency, salinity, % marsh that is within the site (WS), % tree (WS), % log (WS), % brush (WS), % clay, % mud, % sand, width, % marsh that is surrounding the site (SS), % tree (SS), % log (SS), % non-wood (SS), and % brush (SS) (Table II.1). Light intensity, temperature, and dissolved oxygen, and % non-woody vegetation (WS) were not significantly different among sites. The upstream site was shallower, narrower, more acidic, clearer, less marshy (both within the site and surrounding the site), and had greater velocity, more brush, logs, and trees within the site and more trees and brush surrounding the site, a muddier substrate, more clay, and less sand than the middle and downstream sites. The middle site was narrower, less

TABLE II.1. Results of Kruskal-Wallis tests or analyses of variance (ANOVA's, using the general linear model (glm)) comparing values of habitat variables for Sites 1, 2, and 3 over all seasons. * indicates that glm was used when there was season x site interaction (based on ANOVA) for the variable. P-values represent significance of either Kruskal-Wallis tests or ANOVA's. Mean value, sample size (N), and standard deviation (sd) are shown for each habitat variable, except ph^1 For pH, the median and interquartile range are shown. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests or mean values in glm ANOVA tests for habitat variables are not significantly different at 0.05 level.

Habitat variable	P	Mean (N,sd) Site 1	Mean (N,sd) Site 2	Mean (N,sd) Site 3
Depth(cm)	0.0001	64.96a (62,17.57)	201.68b (43,34.19)	219.39b (32,46.10)
Velocity(cm/s)	0.0002	9.14a (61,5.34)	4.44b (41,9.84)	2.66b (31,7.34)
pH^1	0.0002	5.98a (28,0.60)	6.37b (27,0.37)	6.35b (15,0.39)
Light intensity(lux)	0.1849	564a (54,1082)	953a (44,1886)	1403a (34,2247)
Secchi disc transparency(cm)	0.0054	40.11a (54,33.07)	23.23b (42,20.34)	25.27b (33,17.21)
Salinity(ppt)*	0.0001	0.0a (63,0)	0.0a (48,0)	0.2b (37,0.4)
Dissolved oxygen(mg/l)*	0.2580	9.40a (61,1.76)	9.17a (47,1.43)	9.69a (37,1.26)
Temperature(°C)	0.7682	12.2a (63,4.4)	12.6a (48,4.8)	11.8a (37,4.4)
% Marsh(WS)	0.0001	0.00a (62,0)	2.99b (44,3.36)	4.11c (33,3.31)
% Tree(WS)	0.0001	0.13a (62,0.69)	0.09b (44,0.13)	0.00a (33,0)

% Log(WS)	0.0001	23.72a (62,0.08)	0.00b (44,0)	0.00b (33,0)
% Brush(WS)	0.0001	1.68a (62,0.22)	0.00b (44,0)	0.00b (33,0)
% Clay	0.0001	11.81a (63,3.93)	13.85b (48,2.71)	26.70c (37,0)
% Mud	0.0001	73.37a (63,2.95)	62.88b (48,2.02)	53.30c (37,0)
% Sand	0.0001	14.82a (63,0.98)	23.16b (48,0.67)	20.00c (37,0)
Width(m)	0.0001	9.85a (49,2.35)	39.55b (42,4.48)	45.45c (33,2.59)
% Marsh(SS)	0.0001	0.00a (61,0)	23.86b (44,26.93)	63.64c (33,27.3)
% Tree(SS)	0.0001	18.40a (61,0)	1.77b (44,2.03)	3.35c (33,1.77)
% Log(SS)	0.0001	0.00a (61,0)	0.56b (44,0.71)	0.00a (33,0)
% Non-wood(SS)	0.0001	0.00a (61,0)	0.56b (44,0.71)	0.00a (33,0)
% Brush(SS)	0.0001	11.08a (61,0)	4.01b (44,5.05)	0.00c (33,0)

WS = within site
SS = surrounding site

marshy (within and surrounding the site), had more trees within but fewer surrounding the site, had more logs, non-woody vegetation, and brush surrounding the site and had less clay but more sand and mud than the downstream site. Thus, the upstream site differed from the other sites in size, hydrology, pH, turbidity, substrate, and vegetation. The two downstream sites differed in width, substrate, vegetation, and salinity. Results of Kruskal-Wallis tests or general linear model ANOVA's (for dissolved oxygen and salinity) comparing habitat variables among the sites over seasons are shown in Table II.1.

Only velocity, pH, salinity, dissolved oxygen, and temperature differed among seasons (over all the sites; Table II.2). Velocity, pH, and salinity fluctuated and dissolved oxygen and temperature decreased and increased, as expected, throughout the sampling interval. Salinity was higher downstream than at the other two sites before alewife spawned. Velocity was higher upstream than at the other two sites and pH was lower upstream than at the other two sites during the alewife spawning season. No habitat variables that differed among the season differed significantly among sites when both species were spawning. Acidity was significantly higher upstream and salinity was significantly higher downstream than in the other two sites during the blueback herring spawning season (Table II.3). Thus, of the variables that changed over the seasons, only those that were different among the sites

TABLE II.2. Results of Kruskal-Wallis tests or analyses of variance (ANOVA's, using the general linear model (glm)) comparing values of habitat variables for Seasons 1, 2, 3, and 4 over all sites. * indicates that glm was used when there was a season x site interaction (based on ANOVA) for the variable. P-values represent significance of either Kruskal-Wallis tests or ANOVA's. Mean value, sample size (N), and standard deviation (sd) are shown for each habitat variable, except pH[1] For pH, the median and interquartile range are shown. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests or mean values in glm ANOVA tests for habitat variables are not significantly different at the 0.05 level.

Habitat variable	P	Mean (N,sd) Seas. 1	Mean (N,sd) Seas. 2	Mean (N,sd) Seas. 3	Mean. (N,sd) Seas. 4
Depth(cm)	0.6888	130.23a (11,68.13)	146.05a (81,81.04)	157.38a (21,77.77)	131.34a (24,78.94)
Velocity(cm/s)	0.0145	12.27a (9,6.95)	6.59bd (79,7.11)	2.36ce (21,7.31)	5.885ade (24,9.77)
pH[1]	0.0002	6.36a (6,0.25)	6.10ab (35,0.37)	6.43ac (11,0.16)	6.48ac (18,0.57)
Light intensity(lux)	0.9764	808a (12,1635)	956a (88,1845)	831a (16,1465)	811a (16,1594)
Secchi disc transparency(cm)	0.5136	24.80a (10,24.12)	29.58a (88,25.57)	32.98a (15,32.83)	39.78a (16,30.02)
Salinity(ppt)	0.0084	0.2a (12,0.4)	0.0b (90,0.2)	0.0b (21,0.2)	0.0b (25,0.0)
Dissolved oxygen(mg/l)	0.0001	10.82a (12,0.50)	9.93b (88,1.24)	8.61c (20,0.95)	7.46d (25,1.15)
Temperature(°C)	0.0001	7.9a (12,1.4)	10.1b (90,3.1)	16.7c (21,2.0)	18.0c (25,2.4)
% Marsh(WS)	0.8547	1.97a (7,3.37)	1.81a (87,2.98)	2.35a (24,3.08)	1.95a (21,3.30)
% Tree(WS)	0.8964	0.04a (7,0.10)	0.11a (87,0.59)	0.03a (24,0.10)	0.05a (21,0.08)

% Log(WS)	0.5668	13.57a (7,12.69)	10.09a (87,11.79)	9.04a (24,12.08)	12.86a (21,11.81)
% Brush(WS)	0.6529	0.94a (7,0.87)	0.73a (87,0.87)	0.63a (24,0.83)	0.89a (21,0.82)
% Clay	0.2262	17.03a (12,7.20)	16.46a (90,7.02)	17.57a (25,5.01)	13.68a (21,7.39)
% Mud	0.2250	63.50a (12,8.79)	64.20a (90,8.37)	63.53a (25,7.39)	68.04a (21,9.21)
% Sand	0.8363	19.43a (12,3.56)	18.88a (90,3.82)	18.88a (25,3.88)	18.26a (21,3.38)
Width(m)	0.2171	43.33a (3,3.75)	29.23a (79,16.21)	32.83a (23,16.79)	25.27a (19,16.54)
% Marsh(SS)	0.7255	17.86a (7,31.34)	22.38a (86,32.32)	29.76a (24,29.47)	19.79a (21,35.90)
% Tree(SS)	0.5820	11.78a (7,8.39)	9.01a (86,8.17)	8.75a (24,8.06)	11.24a (21,7.93)
% Log(SS)	0.6551	0.21a (7,0.57)	0.16a (86,0.45)	0.14a (24,0.58)	0.28a (21,0.45)
% Non-wood(SS)	0.6551	0.21a (7,0.57)	0.16a (86,0.45)	0.14a (24,0.58)	0.28a (21,0.45)
% Brush(SS)	0.3067	7.86a (7,5.37)	5.76a (86,5.47)	5.24a (24,4.86)	8.01a (21,5.63)

WS = within site
SS = surrounding site

TABLE II.3. Results of Kruskal-Wallis tests comparing values of habitat variables that were significantly different among seasons (over all sites) for Sites 1, 2, and 3 at each season. P-values represent significance of Kruskal-Wallis tests. Mean value, sample size (N), and standard deviation (sd) are shown for each habitat variable, except pH^1 For pH, the median and interquartile range are shown. Mean values with the letter indicate that median values in Wilcoxon 2-Sample tests for habitat variables are not significantly different at 0.05 level.

Habitat variable	P	Mean (N,sd) Site 1	Mean (N,sd) Site 2	Mean (N,sd) Site 3
Season 1				
Velocity(cm/s)	0.2466	11.46a (4,5.60)	16.82a (3,6.04)	7.09a (2,10.02)
pH^1	0.1173	6.16a (3,0.47)	6.37a (1,.)	6.52a (2,0.22)
Salinity(ppt)	0.0279	0.0a (4,0)	0.0a (4,0)	0.7b (4,0.5)
Dissolved oxygen(mg/l)	0.6964	10.75a (4,0.36)	10.98a (4,0.43)	10.75a (4,0.75)
Temperature(°C)	0.9390	8.2a (4,1.6)	7.8a (4,0.9)	7.8a (4,1.9)
Season 2				
Velocity(cm/s)	0.0002	10.43a (35,5.64)	3.74b (24,7.26)	3.29b (20,6.14)
pH^1	0.0011	5.85a (13,0.34)	6.16b (13,0.16)	6.25b (9,0.29)
Salinity(ppt)	0.0620	0.0a (37,0)	0.0a (29,0)	0.1a (24,0.4)
Dissolved oxygen(mg/l)	0.0799	10.28a (36,1.15)	9.61a (28,1.20)	9.78a (24,1.33)
Temperature(°C)	0.8761	10.0a	10.3a	10.3a

		(37,3.2)	(29,3.0)	(24,3.1)
Season 3				
Velocity(cm/s)	0.0907	6.65a (8,2.70)	-0.06a (7,10.05)	-0.56a (6,5.86)
pH[1]	0.2454	6.27a (2,0.11)	6.46a (6,0.10)	6.43a (3,0.34)
Salinity(ppt)	0.0724	0.0a (8,0)	0.0a (7,0)	0.1a (6,0.3)
Dissolved oxygen(mg/l)	0.1619	8.86a (7,1.28)	8.08a (7,0.52)	8.94a (6,0.73)
Temperature(°C)	0.4416	16.0a (8,1.9)	17.4a (7,2.0)	16.9a (6,2.1)
Season 4				
Velocity(cm/s)	0.6619	6.66a (14,4.54)	6.02a (7,15.03)	1.94a (3,16.12)
pH[1]	0.0215	6.27a (10,0.79)	6.68b (7,0.35)	6.93b (1,.)
Salinity(ppt)	0.0256	0.0a (14,0)	0.0ac (8,0)	0.1bc (3,0.1)
Dissolved oxygen(mg/l)	0.0565	7.01a (14,0.93)	7.67a (8,1.08)	8.96a (3,1.12)
Temperature(°C)	0.1321	17.1a (14,2.3)	19.1a (8,2.3)	19.1a (3,1.8)

overall (velocity, pH, and salinity) were also different among sites at certain seasons. Values for most variables during the time intervals that river herring egg and yolk-sac larvae were at these sites were within ranges where these stages have been found, are suitable and/or are optimum for these life stages. However, temperature at all three sites was sometimes below the reported suitable range for alewife eggs when this stage was present in the stream. Also, pH in the upstream site was sometimes within the range of lethality reported for blueback herring yolk-sac larvae when this stage was present in this area.

Alewife adults were present in the stream from February 24 to April 15, while blueback herring spawned from April 13 to May 13. Densities of both stages of alewife eggs, all egg stages combined, and yolk-sac "c" larvae were significantly different among the sites when these stages were present in the stream. Densities of all stages of eggs and yolk-sac larvae of the blueback herring as well as blueback herring adults and total egg densities were significantly different among sites when these stages were present in the stream. When densities of life stages were different, Site 1 generally had higher densities than Sites 2 and 3, where densities were similar. Average values for densities are given in Table II.4. Site 1 had significantly higher densities than the other two sites in all stages of eggs, total egg densities, yolk-sac larvae, and adults of both species, indicating that

TABLE II.4. Results of Kruskal-Wallis tests comparing the values of alewife and blueback herring adult, "b" and "c" stage egg, total egg, and "a" and "c" stage yolk-sac larvae densities for Sites 1, 2, and 3 during the intervals when these stages were in the stream. P-values represent significance of the Kruskal-Wallis tests. Mean value, sample size (N), and standard deviation (sd) are shown for densities of each life stage. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests for densities are not significantly different at 0.05 level.

Alewife

Life stage	P	Mean (N,sd) Site 1	Mean (N,sd) Site 2	Mean (N,sd) Site 3
Adults [1]	0.1398	0.02a (12,0.04)	0.01a (10,0.02)	0.00a (7,0)
Egg "b" [2]	0.0001	36.98a (39,55.15)	1.06b (30,3.28)	3.37b (26,17.20)
Egg "c" [2]	0.0001	20.66a (39,30.53)	0.30b (30,1.15)	0.00b (26,0)
Total egg [2]	0.0001	80.49a (39,100.40)	1.55b (31,3.82)	3.24b (27,16.88)
Yolk-sac "a" [2]	0.0708	.69a (20,1.73)	0.00a (18,0)	0.00a (16,0)
Yolk-sac "c" [2]	0.0003	54.89a (20,117.95)	4.45b (18,18.88)	0.00b (16,0)

Blueback Herring

Life stage	P	Mean value Site 1	Mean value Site 2	Mean value Site 3
Adults [1]	0.0096	0.10a (21,0.16)	0.00b (8,0)	0.00b (7,0)
Egg "b" [2]	0.0016	285.90a (17,711.46)	3.11b (11,9.73)	0.00b (6,0)
Egg "c" [2]	0.0024	460.70a	0.35b	0.00b

		(17,1525.5)	(11,0.99)	(6,0)
Total egg [2]	0.0002	875.60a (17,2194.3)	3.81b (10,11.23)	0.00b (5,0)
Yolk-sac "a" [2]	0.0070	213.00a (17,503.57)	0.00bc (11,0)	0.00ac (6,0)
Yolk-sac "c" [2]	0.0002	1594.00a (17,4040.3)	0.00b (11,0)	0.00b (11,0)

[1] = No./minute.
[2] = No./100m^3

Site 1 provides significant spawning habitat and habitat for early life stages of river herring.

When the two egg stages were plotted together for Site 1, the proportions of fertilized to unfertilized eggs were not always the same for either species (Figure II.3). When unfertilized alewife eggs were present during the early part of the sampling season, densities of this stage were higher than that of the fertilized stage. However, densities of the unfertilized egg stage were lower than that of the fertilized stage toward the end of the alewife spawning period. During the one peak period of blueback herring spawning, densities of the unfertilized egg stage were higher and then lower than that of the fertilized stage. However, in most cases when the unfertilized egg stage was present, the fertilized egg stage was also present, for both species. Thus, the analysis of both stages of eggs separately was warranted, because presence of unfertilized eggs may represent early or unsuccessful spawning. Regardless of this, densities of unfertilized and fertilized eggs were highest in the upstream site.

There were differences among the three Occupacia Creek sites in habitat variables and densities of river herring life stages. The upstream site had significantly higher densities of all river herring life stages and was the most distinct with respect to habitat configuration.

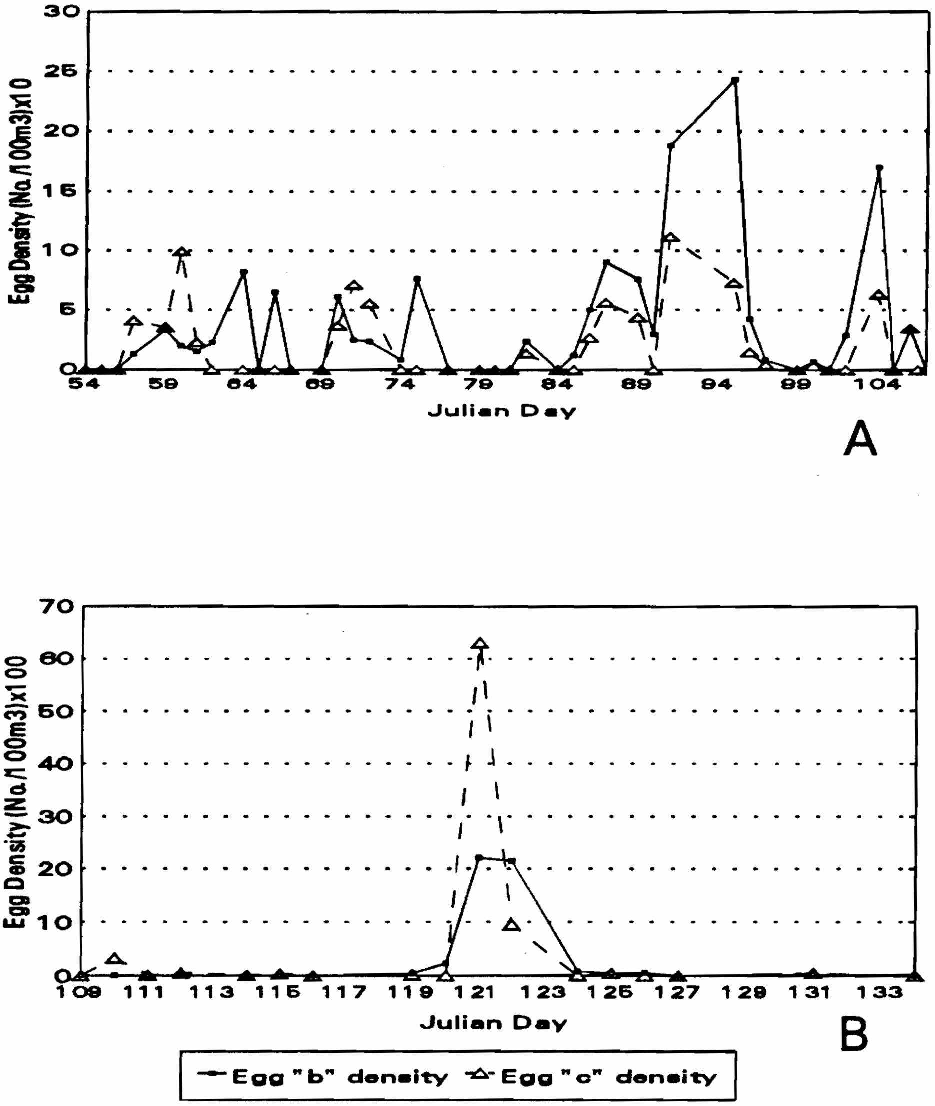


Figure II.3. Plots of densities of two egg stages of A) alewife and B) blueback herring versus Julian day. Eggs were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

Temporal dynamics of spawning

Habitat variables affecting trends in occurrences of life stages in spawning areas

Only densities of alewife "c" eggs were significantly different among tidal conditions in Site 1; densities at high and outgoing tides were lower than densities at low and incoming tides (Table II.5). For the alewife adult stage, peaks in densities occurred at high and low tide. Densities of both egg stages had peaks at all tidal conditions (Figure II.4). Densities of all blueback herring life stages had peaks at different tidal conditions (Figure II.5). Thus, occurrence of adults and early egg stages of both species was not related to tide.

Differences in densities of all river herring life stages among all times of the day were insignificant (Table II.6). There were trends in only alewife adult densities with time of day, with peaks occurring every 90 hr (Figure II.6). Although no analyses were performed, peaks in densities of all alewife life stages did not correspond to peaks in light intensity (Figure II.8). There were no trends in densities of any blueback herring life stage with time of day (Figure II.7). Although no analyses were performed, peaks in densities of all blueback herring life stages did not correspond to peaks in light intensity (Figure II.9). Although no analyses were

Table II.5. Results of Kruskal-Wallis tests comparing values of alewife and blueback herring adult and "b" and "c" stage egg densities for tidal conditions 1, 2, 3, and 4 (high, low, incoming, and outgoing) in Site 1. P-values represent significance of the Kruskal-Wallis tests. Mean value, sample size (N) and deviation (sd) are shown for densities. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests for densities are not significantly different at 0.05 level.

Alewife

Life stage	P	Mean val. (N,sd) High tide	Mean val. (N,sd) Low tide	Mean val. (N,sd) Incoming tide	Mean val. (N,sd) Outgoing tide
Adults[1]	0.1205	0.003a (3,0.06)	0.075a (2,0.04)	0.000a (4,0)	0.003a (3,0.01)
Egg "b"[2]	0.0777	20.86a (5,33.06)	34.84a (5,26.49)	59.50a (13,60.36)	29.05a (13,66.22)
Egg "c"[2]	0.0137	0.00a (5,0)	23.82b (5,15.83)	36.55b (13,38.85)	13.12a (13,27.12)

Blueback herring

Life stage	P	Mean val. High tide	Mean val. Low tide	Mean val. Incoming tide	Mean val. Outgoing tide
Adults[1]	0.5166	0.000a (1,.)	0.233a (3,0.25)	0.100a (10,0.17)	0.064a (7,0.07)
Egg "b"[2]	0.8179	(2,25.53)	29.65a (9,726.09)	265.30a (6,856.08)	402.10a
Egg "c"[2]	0.2811	(2,205.06)	189.00a (9,2100.2)	710.00a (6,379.40)	17.80a

[1] = No./minute
[2] = No./100m^3

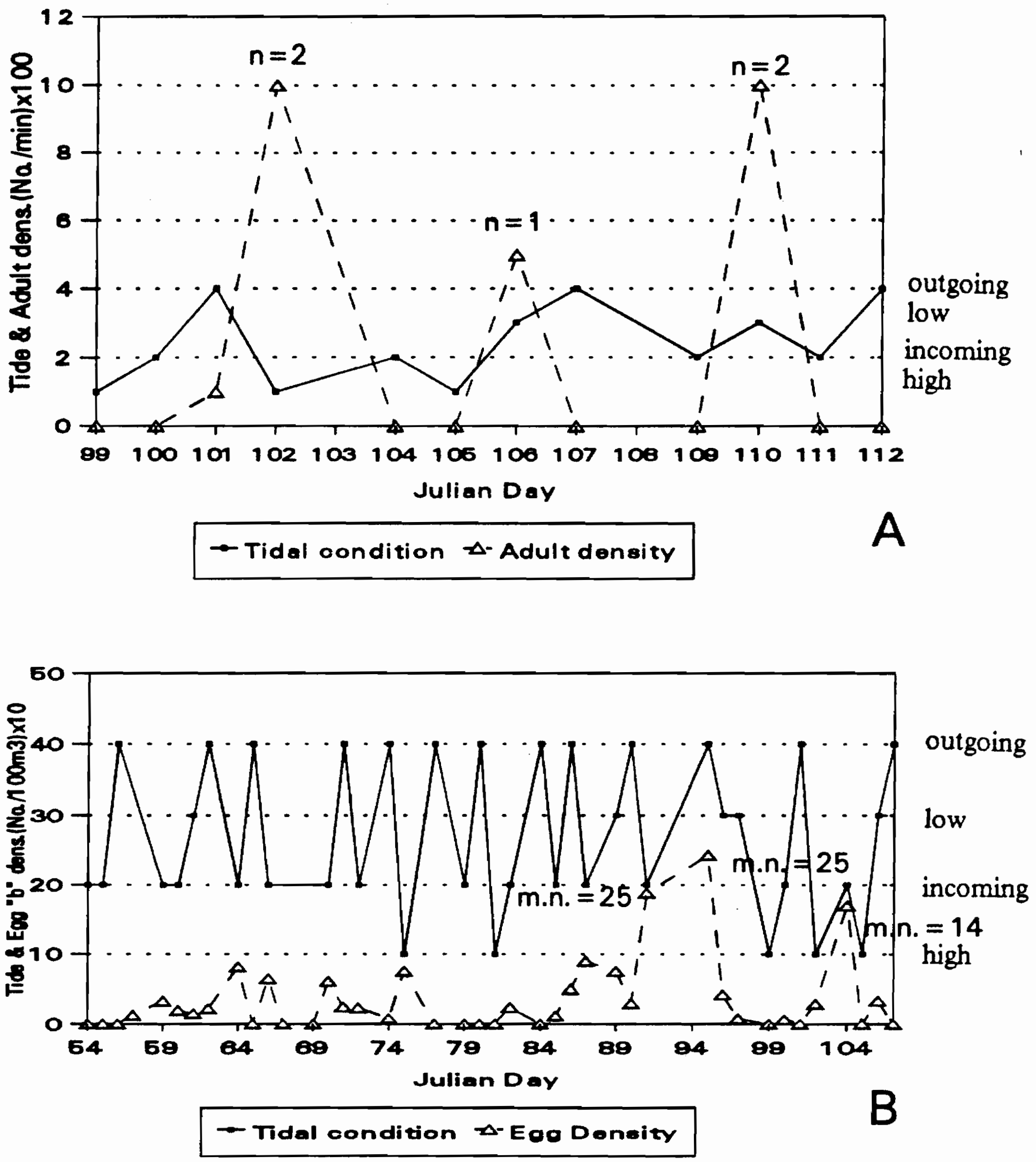


Figure II.4. Densities of alewife A) adults and B) stage "b" eggs and tidal condition (outgoing, low, incoming, and high tides) versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season. For Graph A, the "n" for each density peak represents the number of adults caught. For Graph B, "m.n." for each density peak represents the mean number of eggs (averaged over the number of drift nets used) caught.

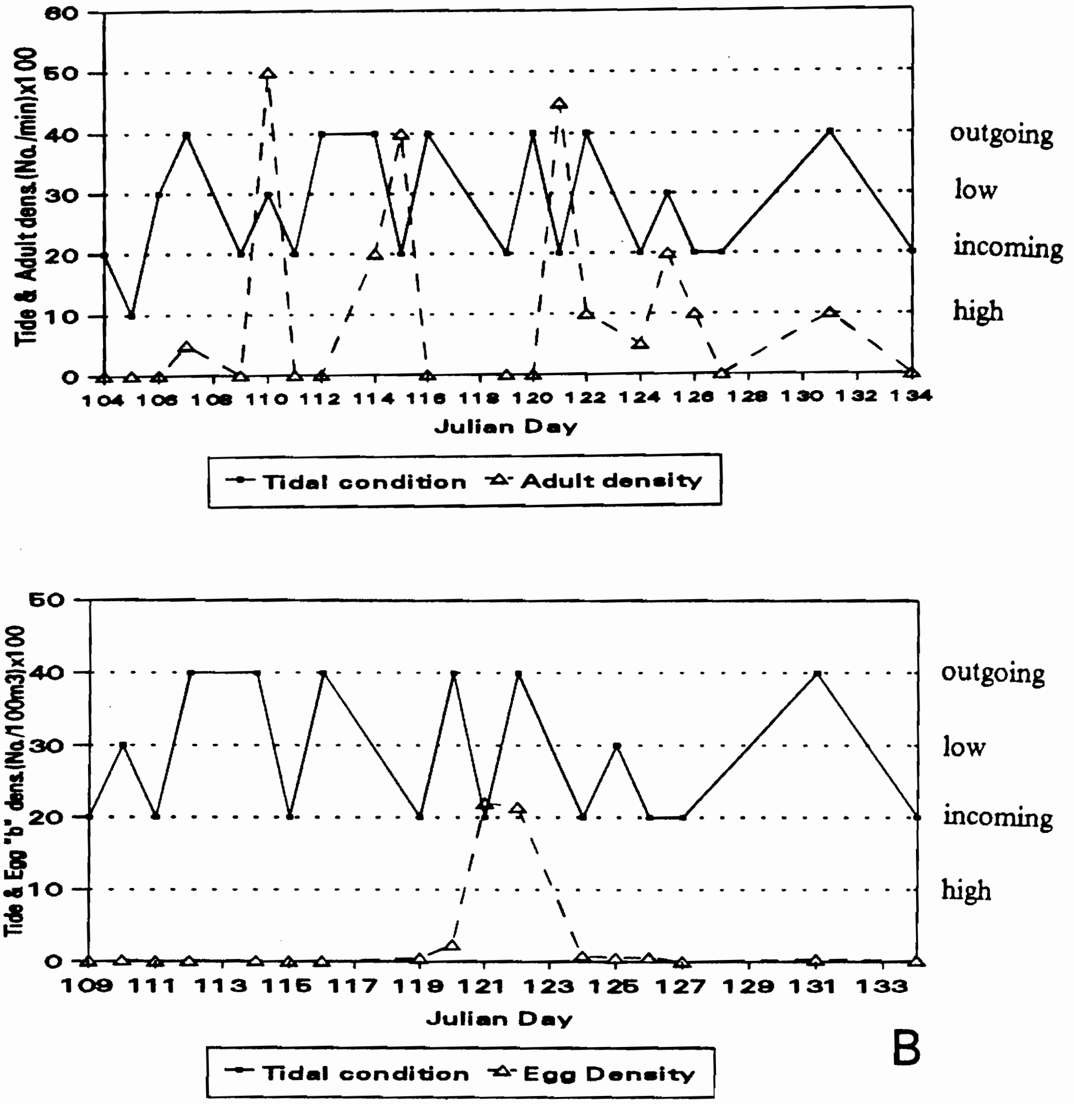


Figure II.5. Densities of blueback herring A) adults and B) stage "b" eggs and tidal condition (outgoing, low, incoming, and high tides) versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

Table II.6. Results of Kruskal-Wallis tests comparing values of alewife and blueback herring adult and "b" and "c" stage egg densities for time of day 1, 2, 3, and 4 (dawn, noon, dusk, and midnight) in Site 1. P-values represent significance of Kruskal-Wallis tests. Mean value, sample size (N), and standard deviation (sd) are shown for each density. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests for densities are not significantly different at 0.05 level.

Alewife

Life stage	P	Mean val. Dawn	Mean val. Noon	Mean val. Dusk	Mean val. Midnight
Adults [1]	0.5786	0.000a (3,0)	0.033a (3,0.06)	0.020a (3,0.03)	0.033a (3,0.06)
Egg "b" [2]	0.8797	40.92a (9,58.48)	48.38a (10,74.51)	41.86a (10,56.06)	20.84a (10,26.69)
Egg "c" [2]	0.8152	15.83a (9,24.80)	21.20a (10,36.60)	28.12a (10,36.99)	17.00a (10,24.07)

Blueback herring

Life stage	P	Mean val. Dawn	Mean val. Noon	Mean val. Dusk	Mean val. Midnight
Adults [1]	0.5349	0.042a (6,0.08)	0.220a (5,0.23)	0.108a (6,0.17)	0.038a (4,0.05)
Egg "b" [2]	0.9850	28.08a (5,32.56)	93.57a (4,108.53)	456.40a (5,974.99)	715.20a (3,1233.9)
Egg "c" [2]	0.5164	0.00a (5,8.54)	104.00a (4,154.74)	1275.00a (5,2814.9)	335.00a (3,533.97)

[1] = No./min.
[2] = No./100m^3

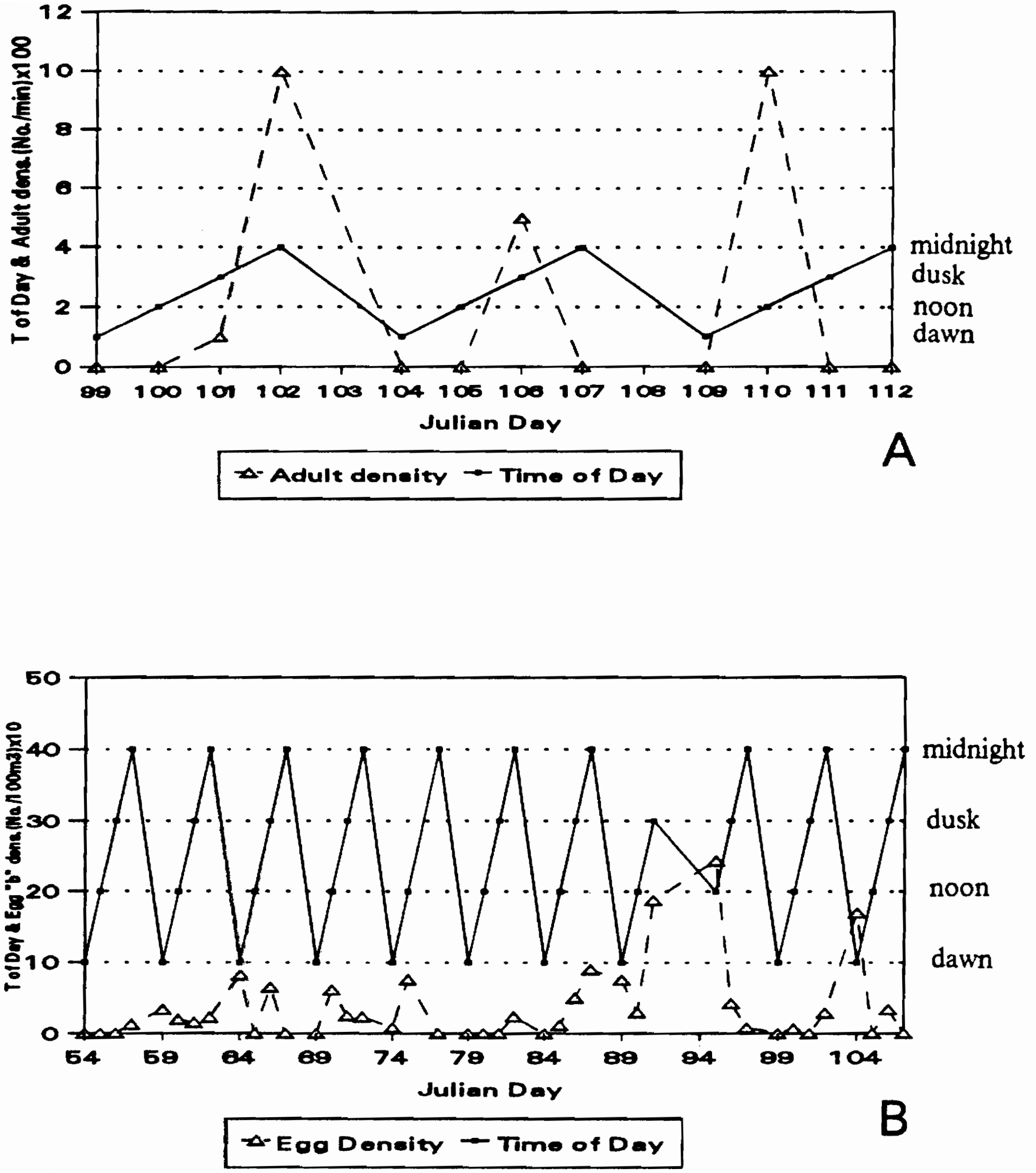


Figure II.6. Densities of alewife A) adults and B) stage "b" eggs and time of day (dawn, noon, dusk, and midnight) versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

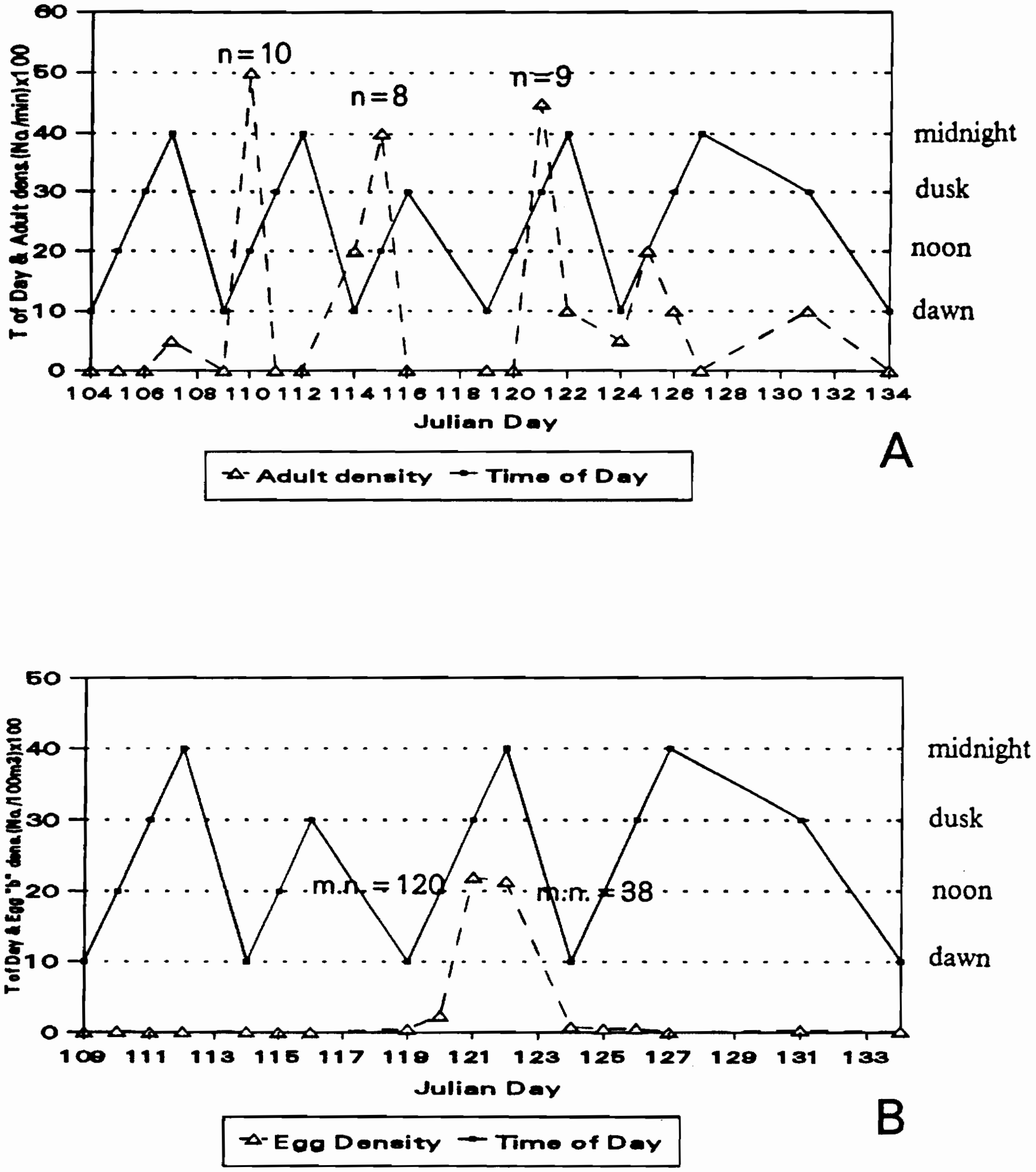


Figure II.7. Densities of blueback herring A) adults and B) stage "b" eggs and time of day (dawn, noon, dusk, and midnight) versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season. For Graph A, the "n" for each density peak represents the number of adults caught. For Graph B, "m.n." for each density peak represents the mean number of eggs (averaged over the number of drift nets used) caught.

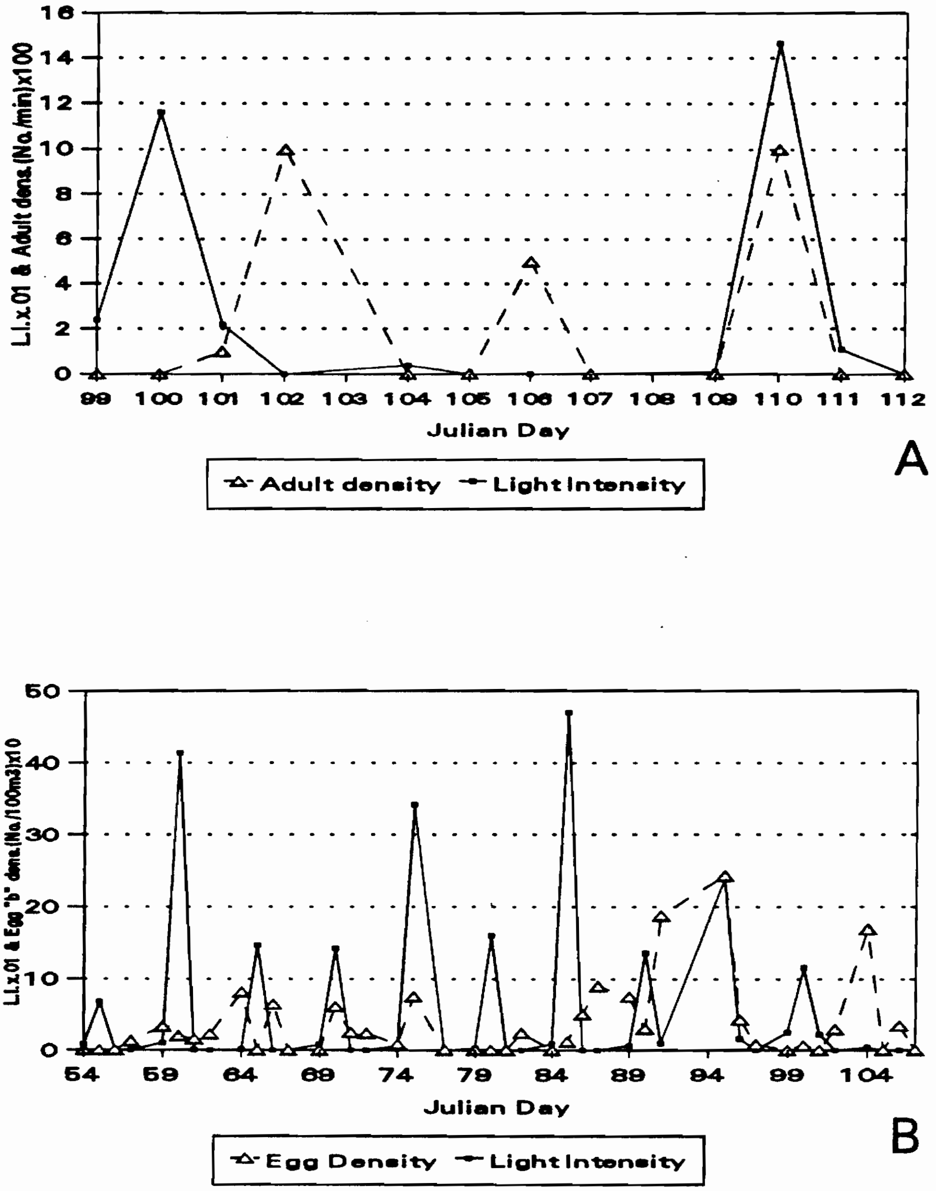


Figure II.8. Densities of alewife A) adults and B) stage "b" eggs and light intensity versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

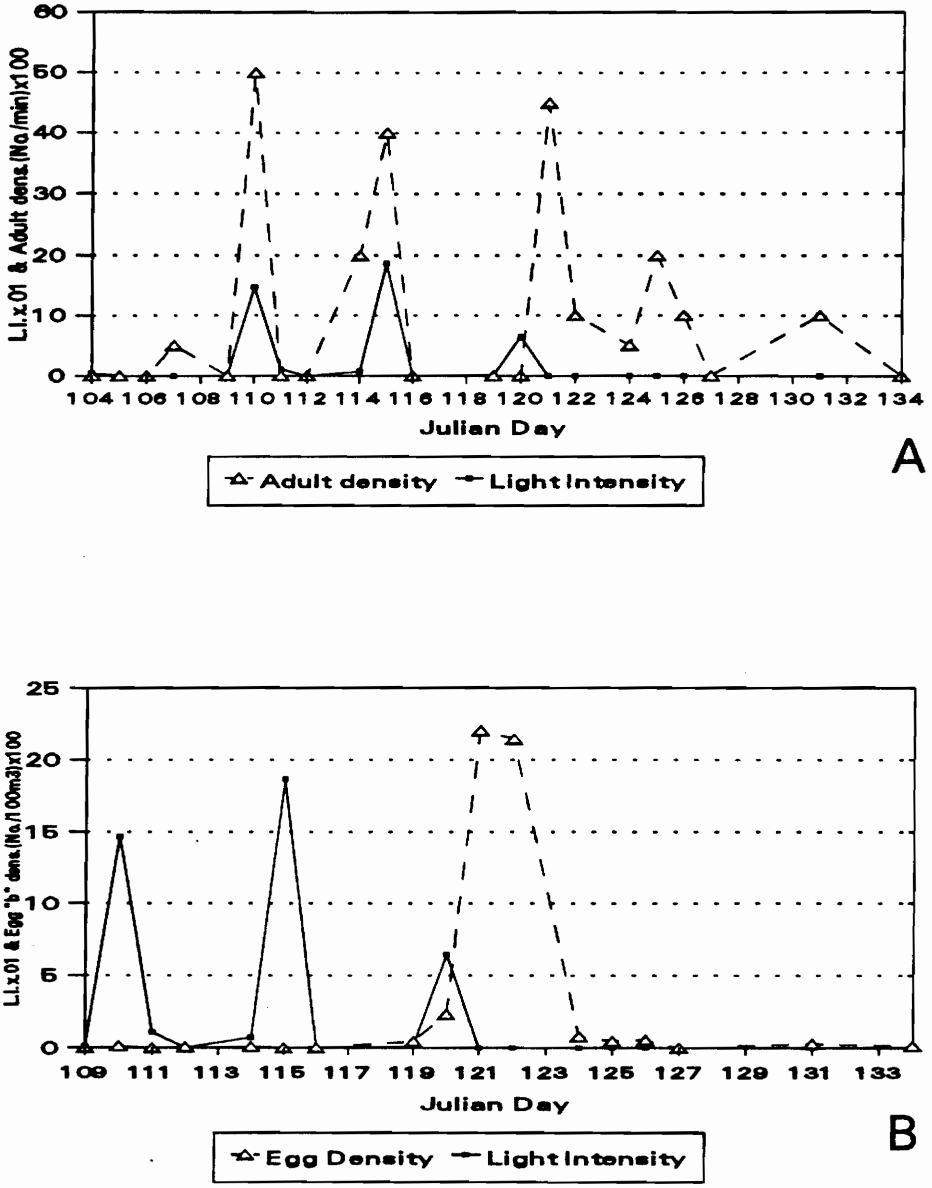
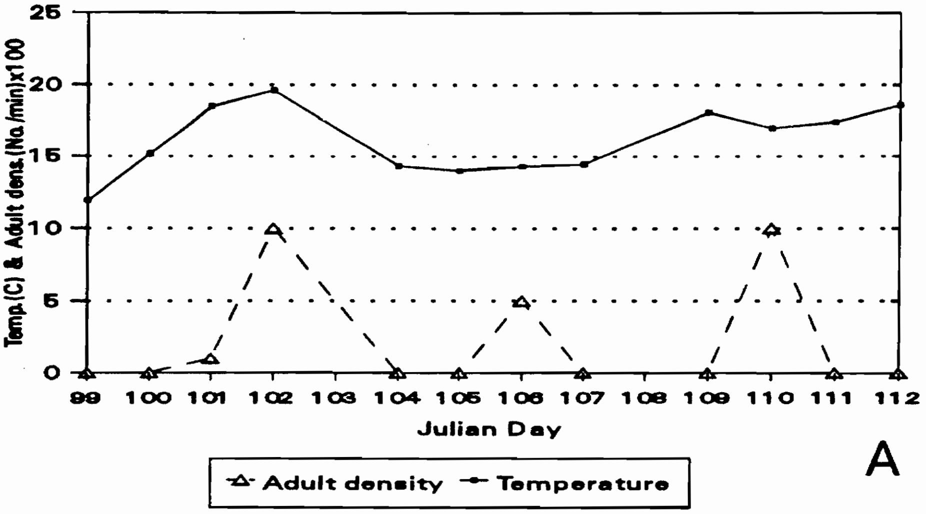


Figure II.9. Densities of blueback herring A) adults and B) stage "b" eggs and light intensity versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

performed, the two highest peaks in densities of alewife adults were at greater temperatures than the lower peak. Also, peaks in the densities of the two stages of alewife eggs corresponded somewhat to peaks in temperature (Figure II.10). Of the blueback herring life stages, only the peaks in densities of adult corresponded somewhat to peaks in temperature (Figure II.11). The trends in densities of both egg stages (for both species) were similar across all variables. Therefore, the graphs of densities of egg "b" stages represent trends for both egg stages. Table II.7 summarizes these comparisons of densities of life stages among tidal conditions and times of day and trends in densities of life stages with tidal condition, time of day, light intensity, and temperature. Overall, temperature appeared to have a greater effect on peaks in densities of adults and early egg stages than diel periodicity. However, this effect was not strong.

Habitat variables triggering occurrence of life stages in spawning areas

Only dissolved oxygen (p=.0002) and temperature (p=.0001) differed significantly among the seasons in Site 1. Oxygen decreased and temperature increased from season to season (Table II.8). Only velocity (p=0.0269), dissolved oxygen (p=0.0002), and temperature (p=0.0001) differed significantly among cycles of the sampling interval. Likewise, there were



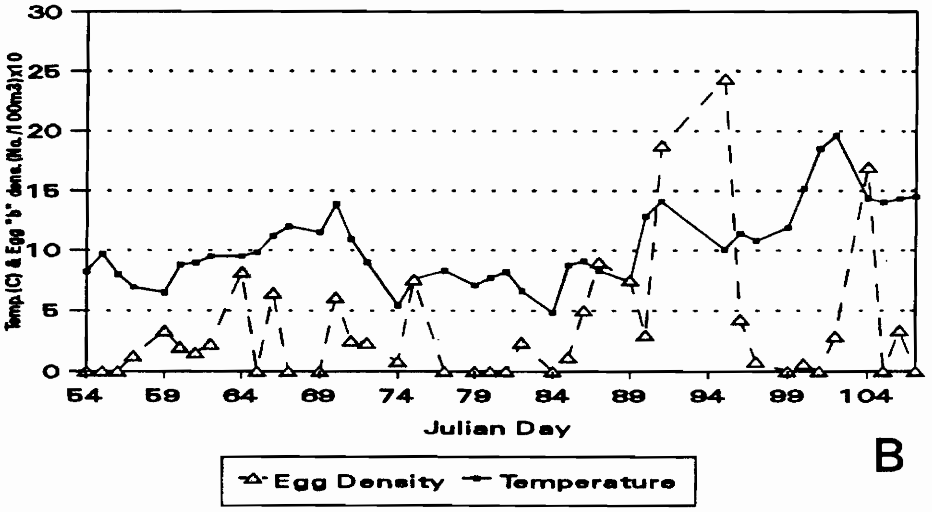


Figure II.10. Densities of alewife A) adults and B) stage "b" eggs and temperature versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

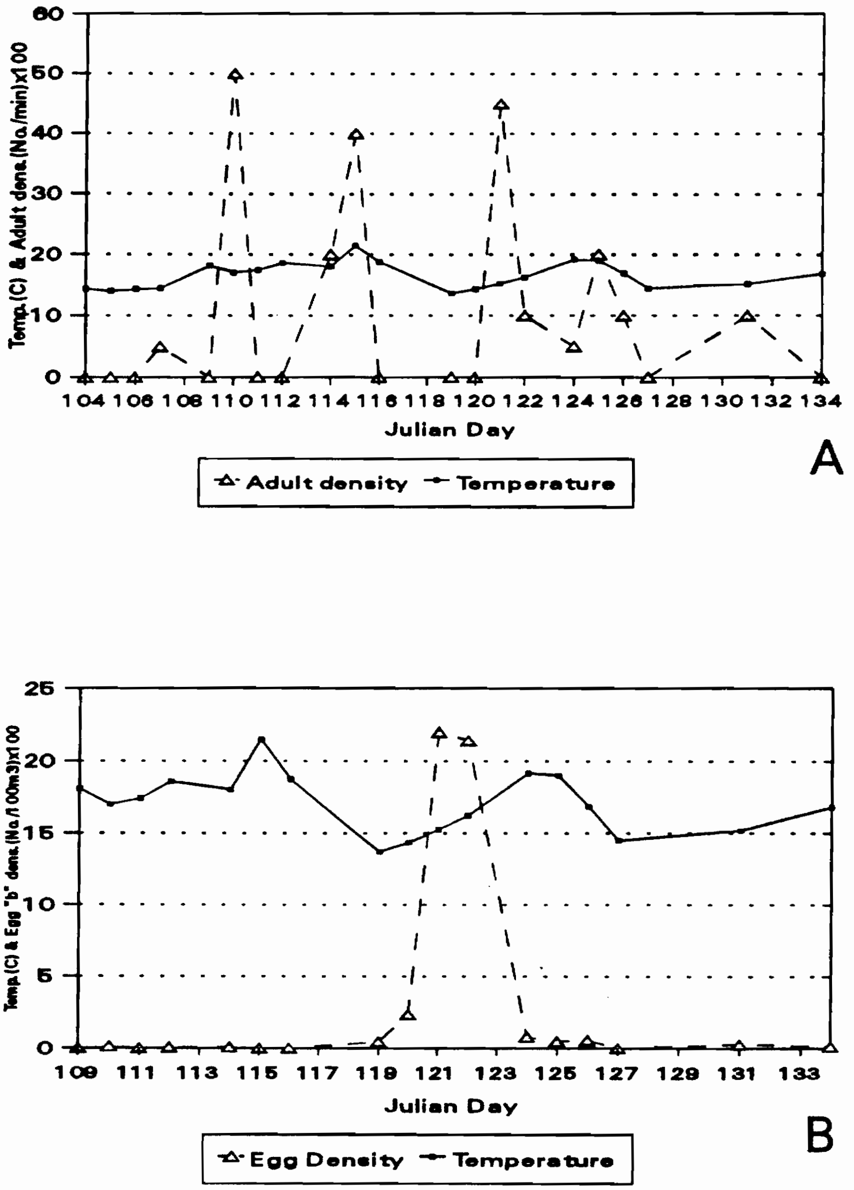


Figure II.11. Densities of blueback herring A) adults and B) stage "b" eggs and temperature versus Julian day. Eggs and adults were sampled in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season.

Table II.7. Summary of differences in densities of river herring life stages among tidal conditions and times of day and trends in densities with tide, time of day, light intensity, and temperature at Site 1. NS indicates that there were no significant differences in densities of life stages among tidal conditions or times of day. NT indicates that there were no trends in densities of life stages with variables.

Alewife

Life stage	Tide significance	Time of day significance	Tide Trend	Time of day Trend	l.intens. Trend	temp. Trend
Adults	NS	NS	peaks at high and low tides	peaks every 18 hr	NT	2 highest peaks at high temps.
Egg "b"	NS	NS	NT	NT	NT	peaks correspond somewhat to temp. peaks
Egg "c"	lower at high and outgoing tides	NS	NT	NT	NT	peaks correspond somewhat to temp. peaks

Blueback herring

Life stage	Tide significance	Time significance	Tide Trend	Time Trend	l.intens. Trend	temp. Trend
Adults	NS	NS	NT	NT	NT	peaks correspond somewhat to temp. peaks
Egg "b"	NS	NS	NT	NT	NT	NT
Egg "c"	NS	NS	NT	NT	NT	NT

l.intens. = light intensity
temp. = temperature

TABLE II.8. Results of Kruskal-Wallis tests comparing values of habitat variables for Site 1 for Seasons 1, 2, 3, and 4 (pre-alewife spawning, during alewife spawning, during both species spawning, during blueback herring spawning). P-values indicate significance of Kruskal-Wallis tests. Mean value, sample size (N), and standard deviation (sd) are shown for each habitat variable, except pH[1] For pH, the median and interquartile range are shown. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests for habitat variables are not significantly different at 0.05 level.

Habitat variable	P	Mean (N,sd) Seas. 1	Mean (N,sd) Seas. 2	Mean (N,sd) Seas. 3	Mean (N,sd) Seas. 4
Depth(cm)	0.4629	51.35a (4,21.52)	64.60a (36,15.17)	64.68a (8,21.57)	69.90a (14,19.70)
Velocity(cm/s)	0.0832	11.50a (4,5.60)	10.40a (35,5.64)	6.65a (8,2.70)	6.66a (14,4.54)
pH[1]	0.0814	6.16a (3,0.47)	5.85a (13,0.34)	6.27a (2,0.11)	6.27a (10,0.79)
Light intensity(lux)	0.9516	666a (4,1172)	637a (37,1204)	271a (6,587)	371a (7,700)
Secchi disc transparency(cm)	0.7864	30.40a (4,28.09)	38.57a (37,32.28)	44.05a (6,39.85)	50.40a (7,38.38)
Salinity(ppt)	1.0000	0.0a (4,0)	0.0a (37,0)	0.0a (8,0)	0.0a (14,0)
Dissolved oxygen(mg/l)	0.0001	10.75a (4,0.36)	10.28a (36,1.15)	8.86b (7,1.28)	7.01c (14,0.93)
Temperature(°C)	0.0001	8.2a (4,1.6)	10.0a (37,3.2)	16.0b (8,1.9)	17.1b (14,2.3)
% Marsh(WS)	1.0000	0.00a (4,0)	0.00a (37,0)	0.00a (8,0)	0.00a (13,0)
% Tree(WS)	0.7117	0.00a (4,0)	0.21a (37,0.89)	0.00a (8,0)	0.00a (13,0)
% Log(WS)	0.7117	23.74a	23.71a	23.74a	23.74a

		(4,0)	(37,0.10)	(8,0)	(13,0)
% Brush(WS)	0.7117	1.64a	1.71a	1.64a	1.64a
		(4,0)	(37,0.28)	(8,0)	(13,0)
% Clay	0.6989	11.10a	12.30a	11.10a	11.10a
		(4,0)	(37,5.10)	(8,0)	(14,0)
% Mud	0.6989	73.90a	73.00a	73.90a	73.90a
		(4,0)	(37,3.82)	(8,0)	(14,0)
% Sand	0.6989	15.00a	14.62a	15.00a	15.00a
		(4,0)	(37,1.27)	(8,0)	(14,0)
Width(m)	0.9334		9.92a	9.55a	9.85a
		(0,.)	(31,2.77)	(6,1.51)	(12,1.41)
% Marsh(SS)	1.0000	0.00a	0.00a	0.00a	0.00a
		(4,0)	(36,0)	(13,0)	(8,0)
% Tree(SS)	1.0000	18.40a	18.40a	18.40a	18.40a
		(4,0)	(36,0)	(13,0)	(8,0)
% Log(SS)	1.0000	0.00a	0.00a	0.00a	0.00a
		(4,0)	(36,0)	(13,0)	(8,0)
% Non-wood(SS)	1.0000	0.00a	0.00a	0.00a	0.00a
		(4,0)	(36,0)	(13,0)	(8,0)
% Brush(SS)	1.0000	11.08a	11.08a	11.08a	11.08a
		(4,0)	(36,0)	(13,0)	(8,0)

SS = surrounding site
WS = within site

only correlations between velocity (p=0.0037, r=-0.3658), dissolved oxygen (p=0.0001, r=-0.6370), and temperature (p=0.0001, r=0.7937) and cycle. This indicates that velocity and dissolved oxygen decreased and temperature increased over the 5-day cycles (time).

Depth and secchi disc transparency, velocity and dissolved oxygen, velocity and secchi disc transparency, velocity and temperature, dissolved oxygen and temperature, and light intensity and secchi disc transparency were correlated with each other (Table II.9). The two stages of eggs were positively correlated with each other for both alewife (r=0.6380) and blueback herring (r=0.7882), indicating that for both species, trends in densities of both egg stages were similar. However, in general, the densities of adults were not correlated with densities of either egg stage. This indicates that for both species adults may not necessarily be spawning the entire time they are at the spawning site or higher densities of adults may not indicate increased spawning.

Logistic regression was used to relate presence of river herring adult and early eggs separately with temperature, depth, velocity, light intensity, dissolved oxygen, and secchi disc transparency. No habitat variable was a strong predictor of alewife adult presence. Alewife early egg presence was significantly related to temperature, depth, velocity, and dissolved oxygen. Blueback herring adult presence in Site 1

TABLE II.9. Correlation matrix of mean values of habitat variables for Site 1. The coefficient of correlation (r) is shown for variables that were significantly correlated ($P < 0.05$).

r	Velocity	Dissolved oxygen	Light intensity	Secchi disc transparency	Temperature
Depth	-0.460	—	—	0.278	—
Velocity		0.315	—	-0.368	-0.409
Dissolved oxygen			—	—	-0.723
Light intensity				0.321	—
Secchi disc transparency					—
Temperature					

was related only with temperature and dissolved oxygen, as was blueback herring early egg presence (Table II.10).

Stepwise logistic regression tests were used to test these variables together to determine which were the best predictors of occurrence of river herring life stages in the upstream site. Not all variables that separately were strong predictors of life stage occurrence were strong predictors when other variables were included in the regression model. Dissolved oxygen and velocity were the strongest predictors of alewife early egg presence; temperature was the strongest predictor of blueback herring adult and early egg presence (Table II.11).

Tables II.12-II.14 show results of logistic regression for predicting alewife early egg presence and blueback herring adult and early egg presence using the variables that were found (by stepwise logistic regression) to be the strongest predictors of occurrence of these life stages. Alewife early egg presence was positively correlated with dissolved oxygen and velocity, and blueback herring adult and early egg presence were positively related to temperature. Thus, these variables were better predictors of presence of these stages than others. The percentages of my observations that were the same as model-predictions (at the 0.500 probability level) for all models were high: 78.2, 79.3, and 77.6 for models predicting alewife early egg, blueback herring adult, and blueback herring early egg presence, respectively. However,

TABLE II.10. Results of logistic regression relating alewife and blueback herring adult and early egg presence with temperature, depth, velocity, light intensity, dissolved oxygen, and secchi disc transparency, separately in Site 1. The p-value for chi-square for covariates indicates the likelihood of fitting a model with an intercept and each variable that would predict presence of each life stage. AW indicates alewife and BBH indicates blueback herring.

p-value for Chi-Square for covariates	AW,Adult	AW,Early egg	BBH,Adult	BBH,Early egg
Temperature	0.0696	0.0014	0.0001	0.0001
Depth	0.5206	0.0149	0.5934	0.5154
Velocity	0.2582	0.0003	0.3107	0.0690
Light intensity	0.6639	0.1713	0.8004	0.9201
Dissolved oxygen	0.9613	0.0002	0.0002	0.0001
Secchi disc transparency	0.8366	0.0895	0.7316	0.2534

TABLE II.11. Results of stepwise logistic regression relating alewife early egg and blueback herring adult and early egg presence to variables that were separately significant in predicting presence of these stages. Stepwise logistic regression entered and removed variables from models for predicting presence of each life stage. Entering and removing variables was determined by strength of these variables (in combination with other variables previously entered into the model) as predictors of life stage presence. The p-values for Wald Chi-Square for each parameter indicate if the parameter was entered into and/or removed from models. AW indicates alewife and BBH indicates blueback herring.

Life sp.,stage	Habitat variable	Entered or Removed	p-value
AW,Early egg	Dissolved oxygen	Entered	0.0004
	Velocity	Entered	0.0071
BBH,Adult	Temperature	Entered	0.0001
BBH,Early egg	Temperature	Entered	0.0001

TABLE II.12. Habitat variables, parameter estimates, p-values for Wald chi-square statistics, p-value for chi-square statistics for covariates, classification table at 0.500, and final model for predicting alewife early egg presence by dissolved oxygen and velocity. The p-values for Wald chi-square statistics indicate significance of each variable in the model. The p-value for chi-square statistics for covariates indicates the likelihood of fitting a model with an intercept and these variables. The sensitivity and specificity percentages indicate proportions of observed occurrences or non-occurrences of this life stage that were predicted correctly at the 0.500 level of probability. The false positive and false negative percentages indicate those that were predicted incorrectly.

Habitat variable	Parameter estimates	p-value for W.chi-square	p-value for chi-square for covariates
Dissolved oxygen	0.5691	0.0100	0.0001
Velocity	0.1863	0.0125	
Intercept	-7.3160	0.0010	

Classification Table

			Percentages		
Probability level	Correct	Sensitivity	Specificity	False Positive	False Negative
0.500	78.2	76.0	80.0	24.0	20.0

Final equation:

$\text{Probability} = 1/(1 + \exp(7.3160-0.5691(\text{dissolved oxygen})-0.1863(\text{velocity})))$

TABLE II.13. Habitat variables, parameter estimates, p-values for Wald chi-square statistics, p-value for chi-square statistics for covariates, classification table at 0.500, and final model for predicting blueback herring adult presence by temperature. The p-values for Wald chi-square statistics indicate significance of each variable in the model. The p-value for chi-square statistics for covariates indicates the likelihood of fitting a model with an intercept and this variable. The sensitivity and sensitivity percentages indicate proportions of observed occurrences or non-occurrences of this life stage that were predicted correctly at 0.500 level of probability. The false positive and false negative percentages indicate those that were predicted incorrectly.

Habitat variable	Parameter estimates	p-value for W.chi-square	p-value for chi-square for covariates
Temperature	0.4187	0.0021	0.0001
Intercept	-7.7172	0.0006	

Classification Table

	Percentages				
Probability level	Correct	Sensitivity	Specificity	False Positive	False Negative
0.500	79.3	30.0	89.6	62.5	14.0

Final equation:
Probability=1/(1 + exp(7.7172-0.4187(temperature)))

TABLE II.14. Habitat variables, parameter estimates, p-values for Wald chi-square statistics, p-values for chi-square statistics for covariates, classification table at 0.500, and final model for predicting blueback herring early egg presence by temperature. The p-values for Wald chi-square statistics indicate significance of each variable in the model. The p-value for chi-squared statistics for covariates indicates the likelihood of for fitting a model with an intercept and this variable. The sensitivity and specificity percentages indicate proportions of observed occurrences or non-occurrences of this life stage that were predicted correctly at 0.500 level of probability. The false positive and false negative percentages indicate those that were predicted incorrectly.

Habitat variable	Parameter estimates	p-value for W.chi-square	p-value for chi-square for covariates
Temperature	0.4649	0.0004	0.0001
Intercept	-7.8107	0.0002	

Classification Table

Probability level	Percentages				
	Correct	Sensitivity	Specificity	False Positive	False Negative
0.500	77.6	42.9	88.6	45.5	17.0

Final equation:
Probability=1/(1 + exp(7.8107-0.4649(temperature)))

sensitivities were low for the models predicting blueback herring adult and early egg presence, indicated by correspondingly high false positive rates. In other words, observed occurrences of blueback herring adult and early egg stages were not very similar to model-predicted occurrences of these stages at the 0.500 probability level. Thus, the models for predicting alewife early egg use are more accurate than those for predicting blueback herring adult and early egg use. Figures II.12-II.14 plot dissolved oxygen and velocity versus probability of alewife early egg presence and temperature versus probability of blueback herring adult and early egg presence in Site 1. Dissolved oxygen values between 8 and 11 mg/l and velocity values between 6 and 16 cm/s are required to produce a 0.5 probability of alewife early egg occurrence in the upstream site. Temperature was at 18.8° and 16.8°C for occurrence of blueback herring adult and early egg stages. These numbers indicate the minimum levels required for presence of these life stages in spawning areas of Occupacia Creek.

Therefore, temperature appears to have a greater effect on trends in occurrences of river herring life stages than tidal condition, time of day, and other factors associated with time of day. However, while temperature may be important in determining when blueback herring adults are present and spawning occurs, dissolved oxygen and velocity may be important in determining when alewife spawning occurs.

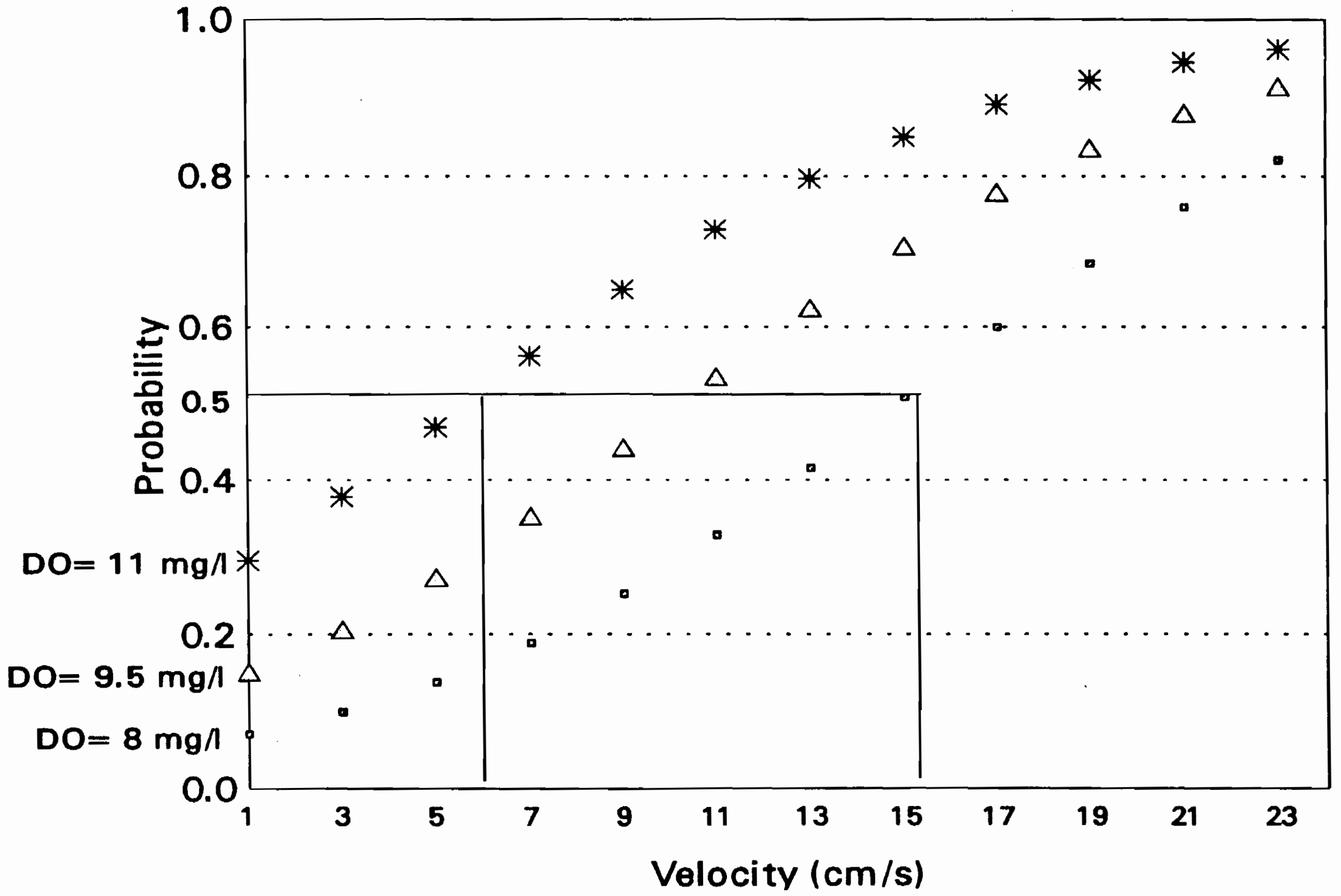


Figure II.12. Probability of alewife early egg presence versus velocity at 3 different dissolved oxygen (DO) levels as estimated from the logistic regression model. Model was based on relating values of dissolved oxygen and velocity to occurrence of alewife early eggs in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season (Feb.-May). Values for velocity represent the range of velocities observed in the upstream site during this time. Dissolved oxygen values of 8 to 11 mg/l and velocity values between 6 and 16 cm/s are required to produce a 0.5 probability that this life stage will occur in the upstream site.

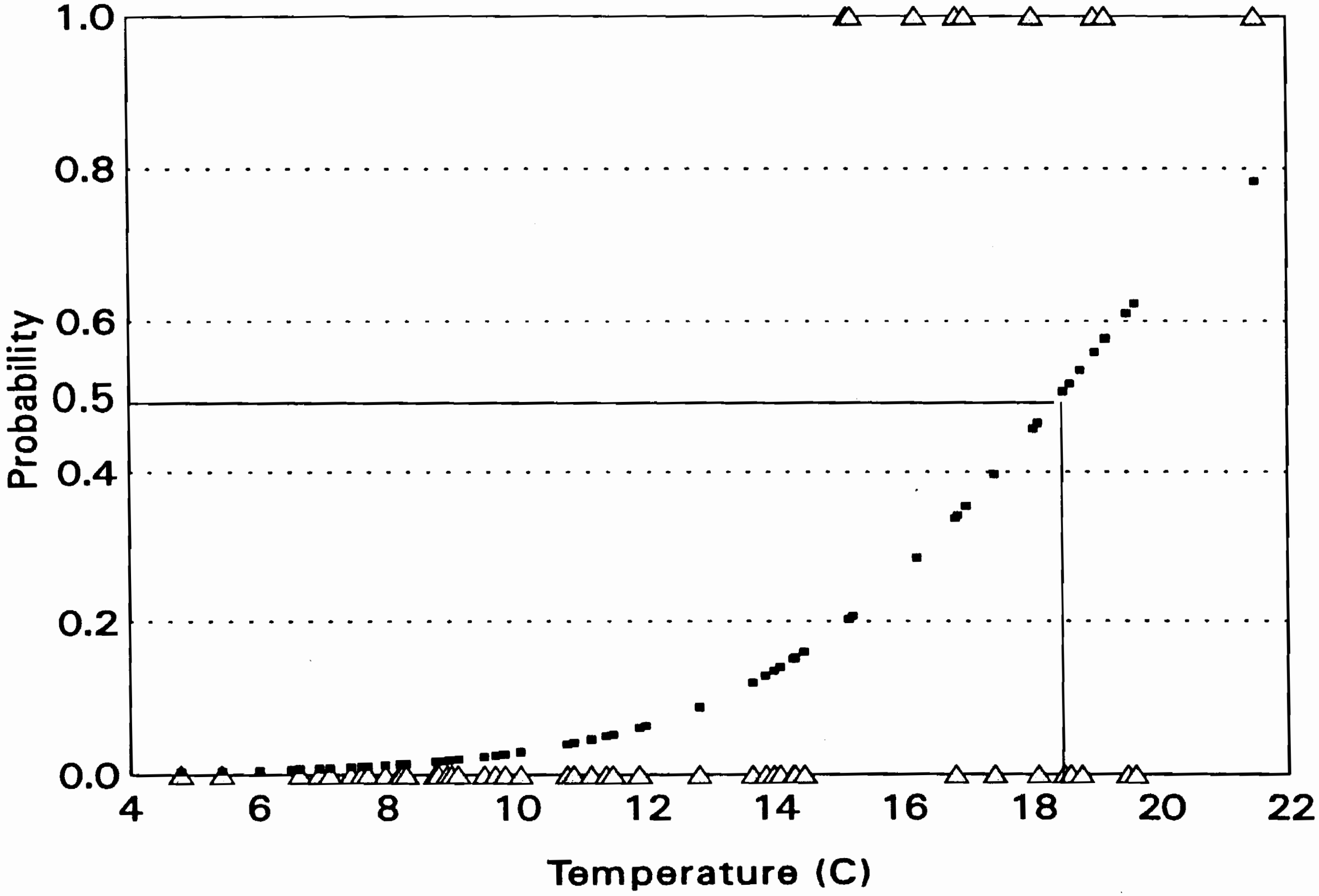


Figure II.13. Probability of blueback herring adult presence versus temperature as estimated from the logistic regression model. Model was based on relating values of temperature to occurrence of blueback herring adults in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season (Feb.-May). Squares represent probabilities predicted from the model. Triangles represent my observations of this life stage at these temperature values. A temperature of 18.8°C is required to produce a 0.5 probability that this life stage will occur in the upstream site.

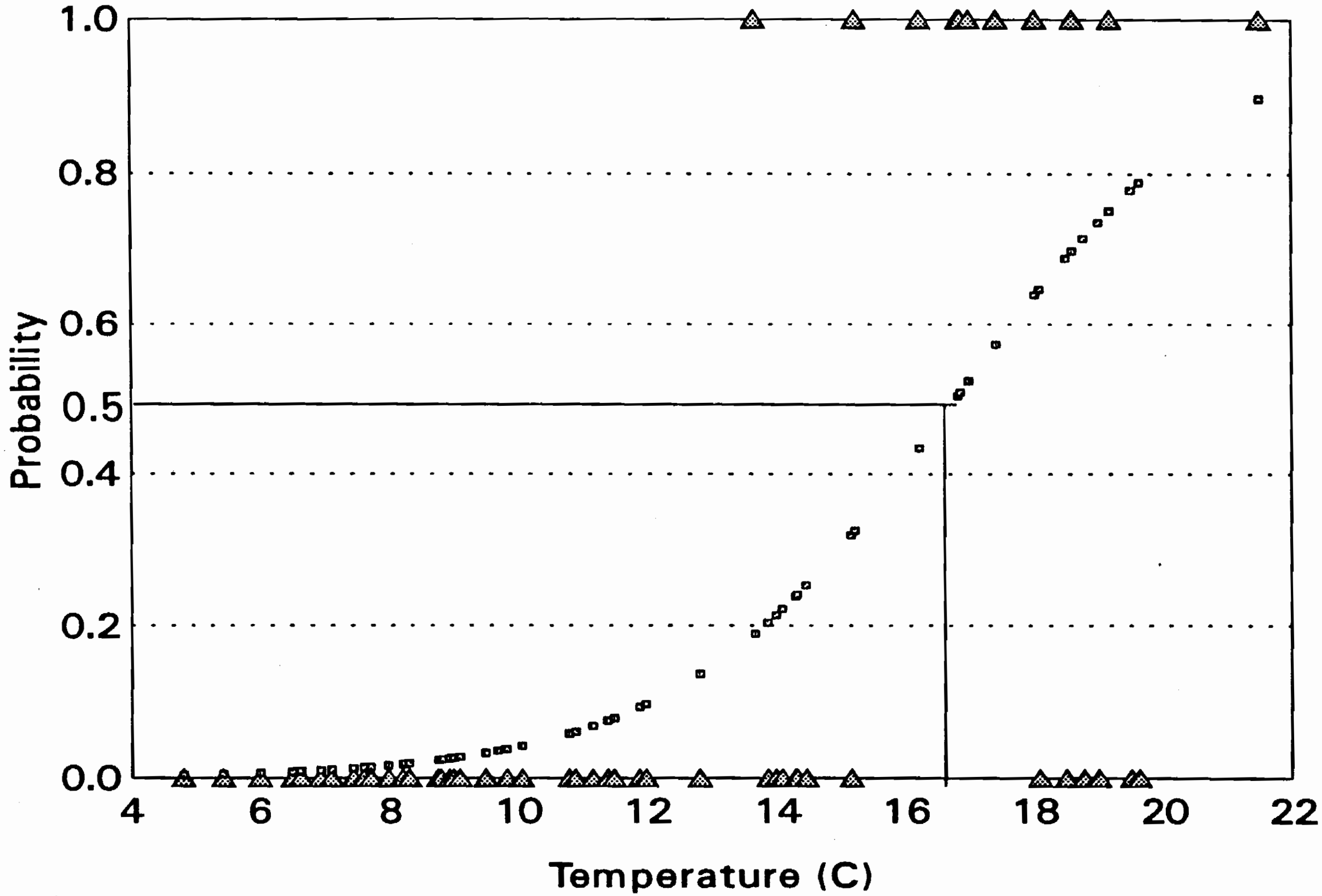


Figure II.14. Probability of blueback herring early egg presence versus temperature as estimated from the logistic regression model. Model was based on relating values of temperature to occurrence of blueback herring early eggs in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season (Feb.-May). Squares represent probabilities predicted from the model. Triangles represent my observations of this life stage at these temperature values. A temperature of 16.8°C is required to produce a 0.5 probability that this life stage will occur in the upstream site.

Post-yolk sac larvae habitat

Densities of alewife stage "a" and "b" post-yolk sac larvae (averaged from tows) were not significantly different among the three sites, (p=0.5377 and 0.4066, respectively). Likewise, densities of blueback herring stage "a" and "b" post-yolk sac larvae were not significantly different among sites (p=0.6318 and 0.4129, respectively). Average values of post-yolk sac larvae densities are shown in Table II.15. These results indicate that the post yolk-sac larvae stages occur throughout this stream. However, the highest densities of the younger post-yolk sac stage for both species occurred at Site 1. Also, the highest densities of the older post-yolk sac stage for both species occurred at Site 2.

Discussion

Spawning habitat

The area in Occupacia Creek that had the greatest densities of river herring spawning adults and early life stages was different from other areas in this stream and provided new information about where river herring can spawn. Requirements for substrate (clay, mud, and sand), vegetation

TABLE II.15. Results of Kruskal-Wallis test comparing values of alewife and blueback herring "a" and "b" stage post-yolk sac larvae densities for Sites 1, 2, and 3. P-values represent significance of Kruskal-Wallis tests. Mean value, sample size (N), and standard deviation (sd) are shown for densities. Mean values with the same letter indicate that median values in Wilcoxon 2-Sample tests for densities are not significantly different at 0.05 level.

Alewife

Life stage	P	Mean (N,sd) Site 1	Mean (N,sd) Site 2	Mean (N,sd) Site 3
Post-yolk sac "a" [1]	0.5377	3.02a (15,30.34)	0.82a (15,5.84)	0.53a (12,6.29)
Post-yolk sac "b" [1]	0.4066	0.00a (15,0)	0.21a (15,2.76)	0.00a (12,0)

Blueback Herring

Life stage	P	Mean value (N,sd) Site 1	Mean value (N,sd) Site 2	Mean value (N,sd) Site 3
Post-yolk sac "a" [1]	0.6318	7.50a (16,68.64)	0.47a (13,6.49)	0.20a (7,3.17)
Post-yolk sac "b" [1]	0.4129	0.00a (16,0)	0.39a (13,5.38)	0.00a (7,0)

[1] = No./100m^3

type, and secchi disc transparency have not been reported for these life stages. The upstream site, an area characterized by mud, trees, and low turbidity, had significantly higher densities of river herring life stages than the other two sites. In all sites and seasons, the other habitat variables measured, except for pH and temperature, were within ranges where spawning and early life stages of river herring have been found.

The average pH value in all sites was above the minimum (4.5) for successful spawning of alewives (Byrne 1988), during the time that alewives were spawning in Occupacia Creek (seasons 2 and 3). However, the median pH values in the upstream site during the time when blueback herring were spawning (6.27 for seasons 3 and 4) have been found to be unacceptable for blueback herring larvae. These values were within the range where mortality has been induced in blueback herring larvae in the laboratory (5.7-6.5) and was below a 96 hr LC_{50} of 6.37 for this life stage (Klauda et al. 1987).

Reasons for use of this habitat by river herring are not known. Blueback herring often migrate far upstream to spawn (Jones et al. 1978), and their distribution is a function of habitat suitability and hydrologic conditions permitting access to these sites (Loesch and Lund 1977). Therefore, it is possible that river herring are spawning in these conditions only because they characterize the furthest area to which these species have access. There was a series of beaver dams just above this site and an old mill dam upstream of these dams which apparently served as impediments to migrations of these fish (pers. obs.).

Another reason for river herring using the upstream habitat may be more successful spawning. Spawning in the upstream habitat may eliminate competition or predation between river herring and other organisms. Many possible predators, such as striped bass (Scott and Scott 1988) and osprey (Colby 1973), do not use this area. White perch, which prey upon alewife eggs (Edsall 1964, Kissil 1969), use mainstems of rivers for spawning habitat besides shallow areas such as the upstream site (Lippson and Moran 1974). Thus, the upstream site may serve as a safe area for river herring spawning due to the lack of predation and competition with other organisms.

Yet another reason for spawning in the upstream habitat may be that river herring have certain habitat requirements such as substrate, vegetation, and turbidity that are unique to this area of Occupacia Creek or requirements that are unique to upstream habitats in general: faster velocity and smaller area. Since substrata containing vegetation are considered optimal for spawning habitat of river herring (Pardue 1983), the abundance of forest in the upstream site may provide some measure of cover for eggs and larvae of these species. Also the larger riparian zone may be important for maintaining stream channel and diverse habitat, and controlling sedimentation and stream temperature in this site. Sedimentation may increase rates of egg infections of both species of river herring and negatively affect blueback herring larvae (Schubel and Wang 1973). Temperature is important due to its effects on location and timing of river herring spawning (see Chapter Two-Discussion-Temporal Dynamics of Spawning). I will explain below (Chapter Two-Discussion-Temporal Dynamics of Spawning) that velocity and dissolved oxygen may affect timing of occurrence of alewife eggs in the spawning site. The clearer water and faster velocity of the upstream site may be important in affecting dissolved oxygen and, subsequently, timing of alewife spawning in this area. Therefore, besides its location, characteristics of the upstream site such as substrate type, vegetation, lack of turbidity, and faster velocity may also affect spawning habitat quality for the river herring.

Regardless of the reasons for choosing the upstream spawning site, my results indicate that pH in this area was, at times, unacceptable for blueback herring larvae. Values for pH in other areas of the Rappahannock River near Occupacia Ck. were within State Water Quality Standard range (6 to 9) during a 12 to 13 year period (State Water Control Board 1984, State Water Control Board, pers. comm.). The low pH in the upstream site may be due to a number of factors. Low pH may have resulted from leaching of tannins from trees during rain events and decomposition of organic materials in this smaller area. In coastal streams in Maryland, acidic conditions were thought to be caused by episodic rain events and were not related to organic sources of acidity (Hall et al. 1993). Coastal streams generally have low acid neutralizing capacity (ANC). Thus, these areas may be more subject to fluctuations in pH. Because Occupacia Creek is apparently an important historical area of spawning for river herring, unacceptable pH ranges in this stream are unlikely to have resulted from natural causes. Acid rain may be a better explanation of recent trends in pH in this stream than natural effects of organic composition. The effects of pH on larvae in Occupacia Creek during the 1992 spawning season were not clear. Deformities in yolk-sac larvae were not apparent. Blueback herring post-yolk sac larvae for this species were found in this stream, indicating that larvae survived to this stage, at least. Acidity may be one cause of decline in blueback herring populations, but more study is required for proof of this.

Since higher densities of both species of river herring were found in the upstream site than in the other two sites, there is no indication that they are choosing different habitats to avoid competition. Blueback herring eggs and larvae were more abundant than that of the alewife, indicating that blueback herring use the stream more than the alewife. However, the alewife uses the stream over a longer time period than the blueback herring. Thus, fewer alewife eggs can be spawned at a time over a longer period of time, while the blueback herring spawns in higher numbers over a shorter period of time. Besides the difference in length of their spawning seasons, the blueback herring and alewife spawning seasons overlapped for only 3 days (April 13-15) during the 1992 season, and this temporal separation of spawning of the two species may serve to eliminate competition between them. Thus, use of diverse habitats differing in substrate type or velocity by the two species was not seen in Occupacia Creek. In this part of their range, river herring overlap only spatially, not temporally, in their spawning habitat, so they are not completely sympatric. If their ranges and spawning seasons overlapped in this part of their range, I would expect them to use different areas of Occupacia Creek.

In summary, the area in Occupacia Creek where river herring spawn was different from other areas in this stream, but, except for pH and temperature, habitat variables at all sites were within ranges where river herring spawning and early life stages have been found. Reasons for choice of the upstream habitat may be twofold: 1) fish may be migrating as far upstream as possible in this stream to avoid predation and competition by other organisms during the spawning season; or 2) characteristics of this upstream habitat such as substrate type, vegetation, and photic zone depth or of upstream sites in general, such as velocity and size may greatly affect spawning success of these fish. Because pH reached levels that are not acceptable for blueback herring larvae, negative effects of acidity may be a cause of decline in stocks of this species. Because both species of river herring use this upstream site more than other areas in this stream, there is need for knowledge of why this area is used and how it can be protected. Alterations of this habitat could affect habitat variables for which river herring have specific requirements, such as pH, and lead to further decline of these fish.

Temporal dynamics of spawning

Habitat variables affecting densities of river herring life stages

Because both species use the upstream area for spawning and this site experiences a greater relative fluctuation in depth with tide than the two downstream sites (the average depths in Site 1 can fluctuate by as much as 60 cm; Figure II.15), areas such as the upstream site may be inaccessible to spawning fish if runs occur at low tide. My results generally indicate that occurrence of adults and early eggs in the spawning site are equally likely to occur at all tidal conditions. Even though the average densities of alewife stage "c" eggs were higher at low and incoming tides, these two tidal conditions affect depth differently. Thus, river herring adult migrations into the spawning area and spawning

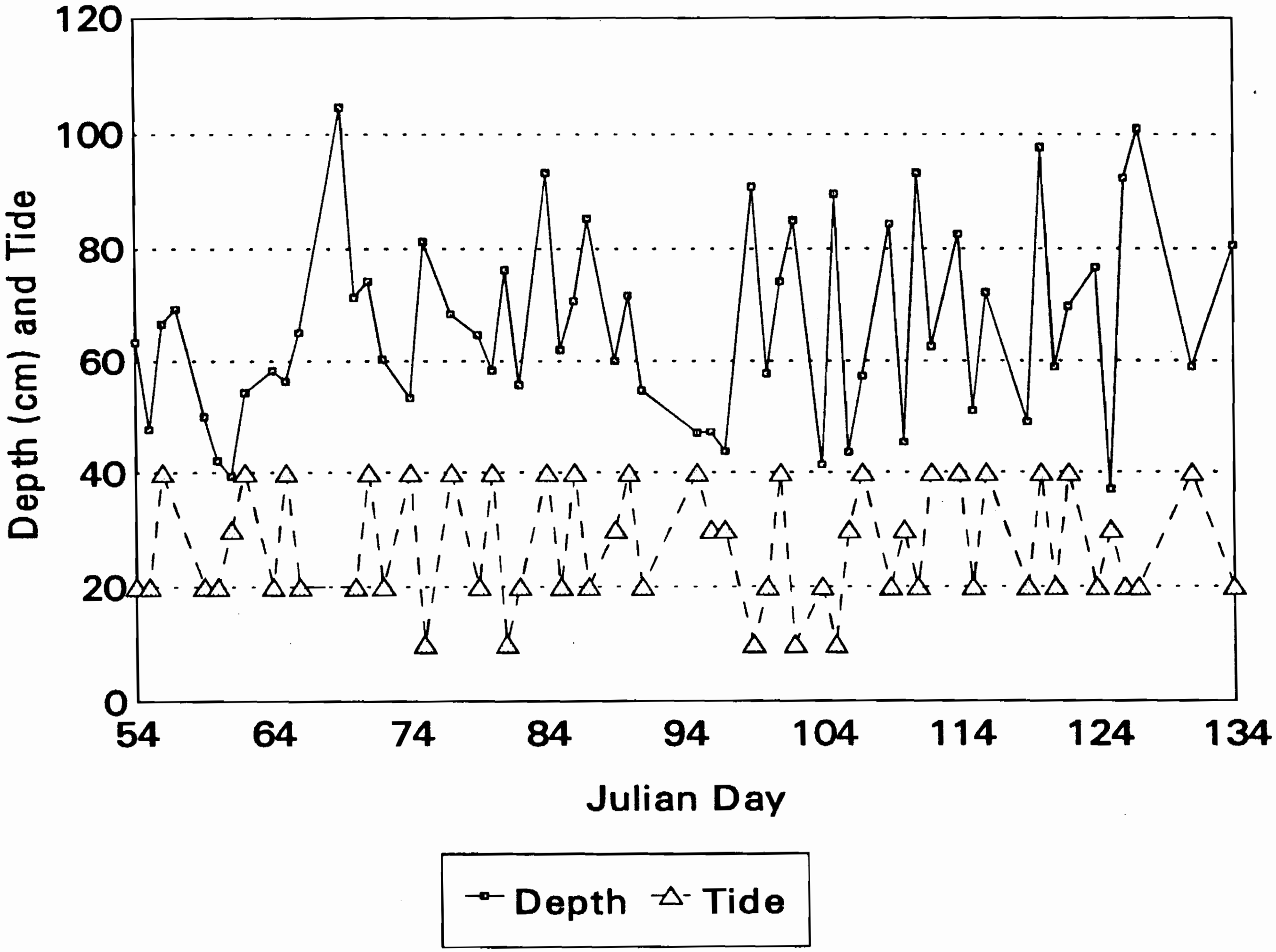


Figure II.15. Depth and tidal condition (outgoing, low, incoming, and high tides) versus Julian day in the upstream site of Occupacia Creek, Essex Co., Virginia during the 1992 river herring spawning season (Feb.-May).

may occur in varying water depths. Structures such as dams and highway crossings may, therefore, have even more potential to be migratory impediments. According to local game wardens, recreational dippers, fisheries biologists, and studies conducted during 1992, this year's river herring spawning season was the lowest in terms of numbers of adult herring in the runs. In studies conducted in 1984 in a Prince Edward Island stream, the peak density of blueback herring stage "b" eggs was $6000/100m^3$ (Johnston and Cheverie 1988) compared to our study's peak of $2300/100m^3$ (Figure II.11). Thus, since this year was atypically low in terms of numbers of river herring adults and, consequently, spawning success, I may have been able to detect tidal effects if numbers were higher. Temperature appeared to have a greater effect on densities of alewife life stages than other variables. The two highest density peaks of alewife adults occurred at temperatures within the optimal range for eggs (16-21°C; Klauda et al. 1991). Also, the two highest peaks in alewife egg "b" densities occurred at temperatures within the suitable range for this life stage (11-28°C; Klauda et al. 1991). Effects of light intensity and time of day on spawning migrations of alewife adults and spawning activity of alewives which have been found in other studies (Cooper 1961, Saila et al. 1972, Tyus 1974, Collins 1952, Richkus 1974, and Graham 1956) were not seen in my study. This may indicate that temperature plays a primary role in determining times when peak numbers of adults are in a spawning area, and under which light intensities and time of day. In my study, I sampled Site 1 every day and at a different time of day, so I did not have continuous information during spawning runs. Thus, some variations in densities of river herring life stages with time of day and light intensity may not have been seen. The trend in peaks of alewife adult densities every 90 hr indicates that there may be a pattern with time of day and appearance of adults, but it may not be a strong one or may be masked by the low number of samples we collected.

Trends in blueback herring adult densities appeared to be related only to temperature, and light intensity and time of day had no effect on densities of adults or egg stages. Of the three highest peaks in density of blueback herring adults, one occurred within the optimal range (20-24°C) and two occurred within the suitable range of temperature for blueback herring eggs (14-26&deg.C; Klauda et al. 1991). One of the two peaks in density of blueback herring eggs occurred at less than suitable temperatures for this life stage. Studies have shown that spawning migrations of blueback herring are influenced by several physical and chemical factors, with temperature playing a major role (Klauda et al. 1991). However, Johnston and Cheverie found that peak spawning activity of blueback herring occurs between 12 and 1 a.m., and drift of eggs increases at night to dawn (Johnston and Cheverie 1988; Meador et al. 1984; Jessop 1990). My data did not exhibit these patterns. My data also did not show any trends in blueback herring spawning with temperature, which has been found to affect the nighttime periodicity seen in the Johnston and Cheverie (1988) study. Therefore, my results indicate that, for peak densities of blueback herring life stages, only densities of adults were affected by temperature. spawning migrations of blueback herring. Once again, due to low numbers of adult river herring in the runs for the 1992 season, the effects of diel periodicity in spawning may have not been seen.

One reason for this lack of diel periodicity in spawning migrations and spawning activity of the river herring is that the low amount of predation (from osprey and striped bass) and deeper photic zone in the upstream site (that could result in increased vision by spawning individuals) may allow the river herring to spawn at all times of day. Thus, if diel periodicity is relatively unimportant in affecting occurrence of river herring life stages in spawning areas can occur throughout the day.

Although temperature appeared to have the strongest relationships with trends in densities of river herring life stages, this relationship was not a strong one. Temperature, by itself may not be a strong predictor of peaks in river herring runs and spawning activity in Occupacia Creek. Again due to the low number of samples we had and low numbers of adults in the runs, a stronger relationship may not have been seen. Further study and analysis needs to be done to clarify any relationships between temperature and peaks in densities of river herring life stages in this part of their range.

Habitat variables affecting occurrence of river herring life stages in the spawning area

Factors that affect trends in densities of life stages were not always important in determining when life stages would occur in the upstream site. Temperature was most significant in affecting trends in densities of all river herring life stages, except blueback herring early egg stages. However, temperature was important in influencing when blueback adults were present in the spawning habitat, and when they spawned, but did not appear to determine when any alewife life stages occur in spawning areas. Diel factors that did not affect trends in densities of river herring life stages (time of day, light intensity, and secchi disc transparency) correspondingly did not determine occurrence of any life stages in the spawning area.

Since there was correlation between the densities of early egg stages (within species) but not between densities of eggs and adults (Table II.12), I felt that presence in Site 1 of both adults and early eggs (either stage) was adequate for indicating presence of life stages in spawning area. My findings (that adult presence or activity is not necessarily correlated with spawning) indicate that spawning does not always occur when adults are moving into the spawning area. Similarly, other studies have found that most movement of adult alewives occurs during the daylight hours (Collins 1952; Richkus 1974), but spawning activity of alewives is greater at night (Graham 1956).

Habitat variables that changed over the entire spawning interval (over the 5-day cycles and over the spawning seasons), or that have been found in other studies to affect spawning, included habitat variables that change dielly. I expected that only these changing habitat variables could influence timing of occurrence of river herring life stages in spawning area of Occupacia Creek. Average values of depth, velocity, and dissolved oxygen, which separately were found to be significant in predicting alewife early egg presence, and temperature and dissolved oxygen which separately were found to be significant in predicting blueback herring adult and early egg presence, were all within ranges where these stages have been found. I did not expect these variables to be strong predictors of when river herring life stages were present in the upstream site, but they were. This indicates that the ranges of variables that trigger spawning in Occupacia Creek are different from ranges in other areas. One reason for these differences may be that effects of these variables on occurrence of river herring life stages in spawning areas are not well-studied. Also, river herring may be adapted to different variable levels here since these levels are available in this system.

No habitat variables were good predictors of alewife adult presence in the upstream site. Since peaks in temperature corresponded to peaks in alewife adult densities, I thought that this variable might trigger adult movement into the spawning grounds, but this was not the case. Perhaps they migrate in a wider range of temperatures, since they have a longer spawning season than the blueback herring. Therefore, the alewife may be adapted to more fluctuations in temperature during their spawning migrations.

Likewise, temperature was not the best predictor of when alewife early egg occur in the spawning area. Temperatures over the entire sampling period never reached those of critical thermal maximum (CTM) for alewife eggs, 35.6°C (Koo et al. 1976), and the average values for all seasons were within the range where alewife eggs can hatch (Edsall 1970). However, studies have shown that at incubation temperatures below 11°C, 69% of newly hatched alewife larvae are deformed (Edsall 1970), a value higher than my average values for Seasons 2 and 3, when alewife adults were present and/or spawning in Site 1. I expected spawning to occur only when temperatures were acceptable for alewife larvae and that temperature would be a good predictor of alewife spawning. However, this was not the case. The optimal and suitable temperatures for alewife spawning found in other studies may not be same for all populations of alewife (including that in Occupacia Creek). Temperature during in the 1992 spawning season (for the alewife) experienced wide fluctuations. Thus, fish may have had to spawn under less than suitable temperature conditions.

The final model for predicting alewife early egg presence indicates that alewives will probably not spawn in the upstream site when water contains dissolved oxygen that is below 10 mg/L or when water velocity is below 8 cm/s. Values for both dissolved oxygen and velocity, found in my study, were always either higher than the minimum for alewife or within range where alewife have been reported to spawn elsewhere. My model predicted that at lower values of these variables, alewives will not spawn. The alewife, in this part of its range (i.e. Occupacia Creek), is possibly adapted to greater levels of dissolved oxygen and higher velocities, than in other areas. Since velocity and dissolved oxygen were positively correlated over the sampling period, the higher velocities may significantly increase dissolved oxygen to levels that are required for alewife spawning. Therefore, my results indicate that dissolved oxygen and velocity are important in determining when alewife spawning occurs and that certain minimum levels of dissolved oxygen and velocity are required for spawning to occur.

Although dissolved oxygen and temperature were found separately to be good predictors of presence of blueback herring life stages in the upstream site, temperature was the strongest determinant of adult presence at the spawning site and spawning. Blueback herring eggs have been found in water temperatures ranging from 7-14°C in the upper Chesapeake Bay, with most being collected at 14°C (Dovel 1971). The temperatures over the entire sampling period never reached temperatures where a significant reduction in hatching success occurs, 32.9-36.1°C., or where 100% deformity of larvae occurs, 34°C. Temperature's significance in predicting presence of blueback herring life stages in the spawning area is unexpected since it was not significant presence of alewife life stages. My results indicate that blueback herring adult require temperatures of 18.8°C for movement into the spawning site of Occupacia Creek and 16.8°C to spawn. Suitable and optimum temperature ranges for blueback herring eggs (from habitat suitability index models (Pardue 1983) based on data from the Chesapeake Bay (Dovel 1974) and New Brunswick (Koo and Johnston 1978) areas) have been found to be 14-26°C and 20-24°C (Klauda et al. 1991). Thus, temperature ranges that are suitable for blueback herring spawning in other areas are suitable in this part of their range.

There were differences in predictors of presence of life stages in the spawning area for the two river herring species. The suitable and optimum ranges of temperature for blueback herring eggs are narrower than those for alewife (Klauda et al. 1991). Blueback herring may be more sensitive to temperature fluctuations than alewives during the spawning season. Temperature may, therefore, have a greater influence on occurrence of blueback herring life stages than on occurrence of alewife life stages in the upstream area. Because of temperature's influence on blueback herring during the spawning season, other variables may not be as important. Reasons for importance of dissolved oxygen and velocity for alewife spawning are not clear. Further study of how important these variables are for spawning alewife may be needed.

There were fairly high percentages of my observations that were the same as predictions from models for alewife early egg, and blueback herring adult and early egg presence in the upstream site. However, observed occurrences of blueback herring adult and early egg stages were not very similar to model-predicted occurrences of these stages. Thus, predictions of occurrences of these life stages from temperature conditions may not necessarily be accurate. The predicted occurrences of alewife early egg presence from dissolved oxygen and velocity were similar to my observations. Thus, the model for predicting presence of this alewife life stage seems more accurate than those predicting presence of blueback herring life stages.

The models predicting presence of blueback herring life stages had cutoff values (minimum values that these life stages require) for temperature that were within suitable ranges for blueback herring eggs. My models predicted that blueback herring adults would be present and spawning would occur (early eggs would be present) in the upstream site when temperature reached values that were suitable for spawning of this species elsewhere. Thus, these models may be applicable to other populations of blueback herring. There is little information on optimal ranges of dissolved oxygen for alewife life stages, and my model-determined cutoff value for this variable was much higher than the minimum required for alewife eggs. Alewives may be limited by oxygen levels in Occupacia Creek. However, the general importance of high dissolved oxygen levels for this species should be examined more closely. The model predicting alewife egg presence from dissolved oxygen may not be applicable elsewhere.

In summary, trends in movement of adult river herring into the spawning area and spawning activity and occurrences of adults and eggs are related to certain habitat variables. Tidal condition, time of day, and factors associated with time of day (light intensity and secchi disc transparency) do not affect the degree to which life stages occur. There are weak relationships between densities of river herring life stages and temperature. Alewife adult presence in the spawning site was not strongly related to any habitat factor, indicating that the alewife adult may be more generalized as to when it will move into the spawning site. However, alewife spawning appears to require specific dissolved oxygen and velocity levels indicating that in this part of their range certain dissolved oxygen and velocity levels are important requirements for these fish. There appear to be specific temperature requirements for occurrences of blueback herring life stages in the spawning area. This may be a result of the restricted temperature range that blueback herring require for spawning.

Post-yolk sac larvae

The mean values of post-yolk sac larvae densities indicate that this stage occurs at all three sites in Occupacia Creek equally. There is limited data on habitat requirements of this life stage. There is virtually no information on velocity, dissolved oxygen, pH, or physical habitat requirements for this stage of river herring (Klauda et al. 1991). Values for temperature, salinity, and dissolved oxygen at all three sites during the time that this life stage was in the stream were generally within suitable or optimal ranges for both species of river herring. In a study conducted during the 1992 spawning season, larvae 4.1-20.1 mm were caught in surface tows in the mainstem of the Rappahannock River, indicating that both yolk-sac and post-yolk sac larvae use will occur in larger areas than my three sites (Raabe and Wieland 1993). Larvae were collected from mile 67 to mile 92, an area upstream of Occupacia Creek, so it is not known if post-yolk sac larvae use mainstem areas surrounding this stream. Since post-yolk sac larvae use both mainstem areas and areas throughout a tributary, they may have a wide range of values for habitat variables where they can occur. My results indicate that small areas can offer habitat for post-yolk sac larvae as well as larger areas such as the mainstem of a river. However, importance of these small areas, relative to larger areas, for this life stage is not known.

Management implications and further research

Spawning habitat

Both species of river herring use upstream areas of Occupacia Creek for spawning, and these areas appear to be used more than downstream areas. Upstream areas in similar tributaries of the Rappahannock River must be accessible to fish to insure successful river herring spawning. Spawning river herring have been seen to migrate past some of the mill dams that are present in the Rappahannock River tributaries, but spawning does not appear to be successful in these areas (landowner in Rappahannock River area, pers. comm.). Present policies that prohibit construction or licensing of dams without fish passage facilities should also include provisions for dams such as mill dams that are now inoperative but still present throughout rivers such as the Rappahannock. These provisions should include 1) breaching of dams or 2) study of spawning habitat quality in areas upstream of dams if dams are not removed but fish passage is restored.

My results indicate that tidal conditions do not effect timing of river herring migrations into upstream areas. Thus, fish may be denied access to spawning areas if water depths are low at a potential impediment, such as mill dams. This indicates that access to spawning areas should be maintained at all tidal conditions.

Past and recent research has indicated that some highway crossings in river systems such the James River and the Rappahannock River are potential impediments to river herring migrations. Highway crossings in the Rappahannock River drainage did not appear to be affecting trends in use of tributaries by spawning river herring (see Chapter One). Because of the few crossings that are impediments to spawning in this system and in others, present policies should be continued. These policies include 1) identifying and removing of highway crossings that are impediments and 2) avoiding construction of new impediments.

The values for pH in the upstream site were not suitable for river herring spawning, according to previous studies. Sources of acidity in Occupacia Creek and the effects on survivability of early life stages of blueback herring need to be understood. Acid rain or other possible causes of acidity in spawning areas such as that in Occupacia Creek and/or their effects should be minimized.

There is a need for further study of the reasons why river herring use upstream areas. Reasons for use of these areas would explain how spawning success could be insured. Importance of avoiding competition and predation from other organisms needs to be understood, so that balances between organisms can be maintained. Importance of vegetation, riparian zone, substrate type, and photic zone depth in a spawning habitat also needs to be understood. Upstream areas should be protected by establishing buffers between land uses, such as agriculture and urbanization, and spawning streams. These buffers would maintain the integrity of spawning streams. As mentioned before (see Chapter One-Management Implications), appropriate riparian and buffer zones for river herring spawning streams need to be determined.

Timing of spawning

Habitat variables that have been found to be important in influencing trends in densities and occurrences of river herring life stages should be protected. Also, further study of how temperature affects peak spawning times of river herring needs to be done. Dissolved oxygen levels of at least

10 mg/L and velocities of 8 cm/s are required for alewife spawning. Further study of how dissolved oxygen triggers occurrence of alewife spawning needs to be done. Blueback herring spawning adults and eggs require temperatures of 18.8 and 16.8°C. Appropriate riparian zone buffers between land uses, such as agriculture or urbanization, and spawning streams should be established so that required temperature and dissolved oxygen levels are maintained in streams. Removal of dams or other impediments would result in faster-flowing, more highly oxygenated waters. Removal of dams would also insure that high temperatures do not occur too early in spawning areas during the spawning season.

Post-yolk sac larvae habitat

Since post-yolk sac larvae are found throughout Occupacia Creek, all of these areas should be considered habitat for this life stage. There is a need for more knowledge about habitat requirements for this life stage so that this life stage can be protected. Since this life stage has been found in both the mainstem and a tributary of the Rappahannock River, a comparison of both areas should be made to see if these habitats differ in use by this life stage. If both habitats are equally important in providing habitat for the post-yolk sac larvae stage, then mainstem areas and tributaries, both of which are affected to different degrees by human alterations, must be protected. Once again, appropriate buffers between streams and land uses should be established so that habitat quality for this life stage is maintained.

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Synthesis/Conclusions

In the Rappahannock River drainage, watershed size, agriculture, forest, and wetlands were related to use of streams by spawning river herring. Urbanization and point-source pollution did not appear to affect river herring spawning runs in this system. An appropriate buffer zone between land uses, such as agriculture and urbanization, and point-source pollution and spawning streams should be established. Wetlands and forest should be maintained in spawning areas, since they appear to enhance river herring spawning runs.

Of the watershed characteristics studied, agriculture and forest had the strongest relationships with use of streams by spawning river herring. Larger streams in the Rappahannock River drainage have more forest than agriculture. However, low levels of both land uses can affect stream use by fish. An understanding of how varying levels of agriculture and forest interact to affect stream use by fish is needed to protect spawning areas. Establishment of buffer zones between agriculture and spawning areas should be of highest priority for managers, since this land use has the greatest effect on spawning runs.

Upstream areas in Occupacia Creek, a tributary of the Rappahannock River, are more important for river herring spawning than downstream areas. Reasons for use of upstream areas, such as importance of substrate, vegetation, and photic zone depth, or avoidance of competition and predation from other organisms, should be understood. These areas may be inaccessible to fish because of structures that serve as impediments to migration, especially at low tide. These impediments should be eliminated.

In the upstream site of Occupacia Creek, pH may have been inappropriate for blueback herring larvae. Causes of this acidity should be known so that acidity can be minimized.

Occurrences of river herring life stages in spawning area are may be affected by temperature, dissolved oxygen, and velocity. Further study of effects of dissolved oxygen on river spawning may be needed. Appropriate levels of variables that are important for river herring life stages during the spawning season should be protected. This can be accomplished by maintaining appropriate buffers between land uses and spawning streams and removing impediments that could negatively affect variables.

Post-yolk sac larvae occurred throughout Occupacia Creek. This stage also occurs in the mainstem of Rappahannock River. Relative importance of these habitats should be understood so that this life stage can be protected.

Appendix A. Average Answers to Questions about Rappahannock River Tributaries

Mean answer, sample size (N), and standard deviation (sd) for answers to questions about tributaries of the Rappahannock River regarding trends in their use by spawning river herring. Tributaries are ordered by their stream rank which was determined by these answers. The location of the mouth of each tributary (MAM; nautical miles above the mouth of the Rappahannock River) is shown. Game wardens, anglers, bait shop owners, and land owners from the Rappahannock River area, who were consulted through a questionnaire during the 1992 spawning season for river herring (Feb.-May), provided answers to these questions. An answer of $\geq$2.33 to the first question (about belief that runs are present) indicates that runs are not likely to be present in a stream. Therefore, the remaining questions (about trends in spawning runs) do not apply to streams with answers of$\geq$2.33 to the first question.

	Questions				
	Belief that runs are present	Perception of run consistency	Perceived size of runs	Perceived trends in numbers of runs	Perceived trends in size of runs
Stream rank/MAM Name	Mean answer (N,sd)	Mean answer (N,sd)	Mean answer (N,sd)	Mean answer (N,sd)	Mean answer (N,sd)
1/93 Deep Run	1.00 (2,0.00)	1.00 (2,0.00)	2.00 (2,1.41)	2.00 (1,.)	2.00 (1,.)
2/37 Hoskins Ck.	1.00 (4,0.00)	1.00 (4,0.00)	2.00 (4,0.82)	2.50 (4,0.58)	2.38 (4,0.48)
3/89 Massaponax Ck.	1.00 (3,0.00)	1.00 (3,0.00)	2.00 (1,.)	2.00 (2,0.00)	3.00 (2,0.00)

4.5/35 Piscataway Ck.	1.00 (4,0.00)	1.00 (3,0.00)	2.17 (3,1.04)	2.33 (3,1.15)	3.00 (2,0)
4.5/82 Ware Ck.	1.00 (4,0.00)	1.00 (4,0.00)	2.50 (4,0.58)	2.50 (4,1.00)	2.50 (4,1.00)
6/67 Peumansend Ck.	1.00 (8,0.00)	1.00 (8,0.00)	2.25 (8,0.89)	2.50 (6,0.84)	2.87 (7,0.38)
8/44 Occupacia Ck.	1.00 (12,0.00)	1.00 (12,0.00)	2.27 (11,0.79)	2.91 (11,0.30)	2.82 (11,0.40)
8/94.5 Unnamed Ck.	1.00 (1,.)	1.00 (1,.)	3.00 (1,.)	2.00 (1,.)	3.00 (1,.)
10/39 Cat Point Ck.	1.00 (9,0.00)	1.00 (9,0.00)	2.60 (5,0.89)	2.78 (9,0.44)	2.78 (9,0.44)
12/72.5 Unnamed Ck.	1.00 (2,0.00)	1.00 (1,.)	2.50 (1,.)	3.00 (1,.)	3.00 (1,.)
12/73 Mount Ck.	1.00 (3,0.00)	1.00 (3,0.00)	2.50 (2,0.71)	3.00 (2,0.00)	3.00 (2,0.00)
12/77 Keys Run	1.00 (2,0.00)	1.00 (2,0.00)	2.50 (2,0.71)	3.00 (2,0.00)	3.00 (2,0.00)
14/68 Goldenvale Ck.	1.00 (3,0.00)	1.00 (3,0.00)	2.67 (3,0.58)	3.00 (3,0.00)	3.00 (3,0.00)
15/39 Mt.Landing Ck.	1.00 (2,0.00)	1.00 (1,.)	3.00 (1,.)	3.00 (1,.)	3.00 (1,.)
16/91 Little Falls Run	1.00 (1,.)	2.00 (1,.)			

17/32 Totuskey Ck.	1.33 (6,0.82)	1.00 (5,0.00)	2.33 (3,1.15)	2.67 (3,0.58)	3.00 (3,0.00)
18/62 Jetts Run	1.50 (2,0.71)	1.00 (1,.)	2.00 (1,.)	3.00 (1,.)	3.00 (1,.)
19/94 Hazel Run	2.00 (3,1.73)	1.00 (2,0.00)	3.00 (1,.)	3.00 (2,0.00)	3.00 (2,0)
20/71.5 Unnamed Ck.	2.00 (2,1.41)	2.00 (1,.)	3.00 (1,.)	3.00 (1,.)	3.00 (1,.)
21.5/49 Peedee Ck.	2.33 (3,0.58)				
21.5/44 Jones Ck.	2.33 (3,1.15)				
23/75 Jones Top Ck.	2.50 (2,2.12)	1.00 (1,.)	3.00 (1,0)	3.00 (1,.)	3.00 (1,.)
24/40 Doctors Ck.	2.50 (2,0.71)				
25/57 Troy Ck.	2.67 (3,0.58)				
26.5/64 Portobago Ck.	2.75 (4,0.50)				
26.5/68 Gingoteague Ck.	2.75 (4,0.96)				
34/42 Broad Run	3.00 (2,0)				

34/43 Sluice Run	3.00 (1,.)
34/44 Farmers Hall Ck.	3.00 (1,.)
34/67 Roys Run	3.00 (3,0.00)
34/84.3 Dicks Ck.	3.00 (3,1.73)
34/79 Birchwood Ck.	3.00 (1,.)
34/77 Dogue Run	3.00 (1,.)
34/61 Unnamed Ck.	3.00 (2,1.41)
34/59.4 Bristol Mine Run	3.00 (2,1.41)
34/35 Little Carters Ck.	3.00 (2,1.41)
34/34 Balls Ck.	3.00 (2,0.00)
34/31 Richardson Ck.	3.00 (2,0.00)
41/80.5 Unnamed Ck.	3.33 (3,2.08)

47.5/37.5 Unnamed Ck.	3.50 (2,0.71)
47.5/64 Unnamed Ck.	3.50 (2,0.71)
47.5/64.5 Unnamed Ck.	3.50 (2,0.71)
47.5/65 Unnamed Ck.	3.50 (2,0.71)
47.5/65.5 Unnamed Ck.	3.50 (2,0.71)
47.5/69 Unnamed Ck.	3.50 (2,0.71)
47.5/74 Unnamed Ck.	3.50 (2,0.71)
47.5/79 Lamb Ck.	3.50 (2,0.71)
47.5/78 Unnamed Ck.	3.50 (2,0.71)
47.5/69 Millbank Ck.	3.50 (2,0.71)
47.5/58.4 Unnamed Ck.	3.50 (2,0.71)
47.5/33 Pecks Ck.	3.50 (2,0.71)

54/87 Snow Ck.	3.60 (5,0.55)
55/29 Unnamed Ck.	3.67 (3,0.58)
56/84.5 Unnamed Ck.	3.75 (4,0.50)
65/81.5 Unnamed Ck.	4.00 (2,0)
65/94.7 Unnamed Ck.	4.00 (1,.)
65/94.6 Falls Run	4.00 (1,.)
65/91.5 Unnamed Ck.	4.00 (1,.)
65/85 Muddy Ck.	4.00 (3,0.00)
65/76.8 Unnamed Ck.	4.00 (1,.)
65/69 Unnamed Ck.	4.00 (1,.)
65/62 Unnamed Ck.	4.00 (1,.)
65/52 Unnamed Ck.	4.00 (1,.)

65/47 Unnamed Ck.	4.00 (1,.)
65/46.8 Unnamed Ck.	4.00 (1,.)
65/46.6 Unnamed Ck.	4.00 (1,.)
65/44 Barnett Ck.	4.00 (1,.)
65/44 Wilna Ck.	4.00 (1,.)
65/34 Jugs Ck.	4.00 (3,0)
65/27.5 Unnamed Ck.	4.00 (1,.)

Appendix B. Sampling Schedule.

Five-day, 4-time interval rotation for sampling river herring adults, eggs, and larvae in three sites in Occupacia Creek. Sites were sampled from one week before spawning runs appeared in this stream until the cessation of runs. us, ms, and ds represent the upstream, middle, and downstream sites.

day	dawn	midday	dusk	midnight
1	us	ms	ds	
2		us	ms	ds
3			us	ms
4	ds			us
5	ms	ds		

Vita

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