ABSTRACT

Title of Document: AN RNA:DNA-BASED INDEX OF GROWTH IN JUVENILE ATLANTIC MENHADEN (*BREVOORTIA TYRANNUS*): LABORATORY CALIBRATION AND FIELD ASSESSMENT

Jason Lee Edwards, Master of Science, 2009

Directed By: Professor Thomas J. Miller, University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory

Atlantic menhaden (*Brevoortia tyrannus*) is an ecologically and economically important species in the mid-Atlantic coastal ecosystem. Its population dynamics are influenced by growth and survival during juvenile occupancy in estuarine nursery habitats. Therefore, quantifying production of potential nursery areas is important to understanding population processes and defining essential fish habitat for this species. Based on laboratory growth experiments, an RNA:DNA-based growth model was developed for young-of-the-year menhaden. The temporal response of RNA:DNA to changes in feeding condition was also quantified in the laboratory. Results of these investigations indicate RNA:DNA as a reliable tool for estimating recent growth and condition in relation to habitat residency. RNA:DNA-based estimates of growth were combined with site-specific abundance estimates to evaluate the spatiotemporal variability in production of potential menhaden nursery habitats. Site-specific production estimates exhibited high spatiotemporal variability suggesting menhaden utilize a mosaic of habitats to promote production, rather than specific sites consistently generating high levels of production.

AN RNA:DNA-BASED INDEX OF GROWTH IN JUVENILE ATLANTIC MENHADEN (*BREVOORTIA TYRANNUS*): LABORATORY CALIBRATION AND FIELD ASSESSMENT

By

Jason Lee Edwards

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2009

Advisory Committee:
Professor Thomas J. Miller, Chair
Professor Edward D. Houde
Professor David G. Kimmel
Professor Timothy E. Targett

© Copyright by
Jason Lee Edwards
2009

Dedication

This work is dedicated to my mother and father, who questioned me in nothing and supported me in everything. Thank you.

Acknowledgements

First and foremost, I would like to thank my advisor, Dr. Thomas J. Miller. The combination of guidance, support and independence he has provided has truly made this a worthwhile experience. Special thanks must go to my committee for their valuable input on my education and research. Also, I would like to thank the Miller lab group including David Loewensteiner, Janet Nye and Adam Peer. I would not have made it through this process without them. Many thanks to all who helped with the field, lab and conceptual components of this research including Tom Ihde, Mike Wilberg, Kara Schroepfer, Sarah Michaels, Megan Gluth, Chris Cammarata, Jamie Smith and Rebecca Wingate. I would also like to thank Tim Targett's lab, especially Ben Ciotti and Catherine House for their help with sample collection and RNA:DNA analysis. I must thank Bud Millsaps for his help with the seawater facility during my experiments. I would also like to express my sincere gratitude to Joe Drach and Patricia Mickelson for their great generosity to CBL and their support of my endeavor to "Save the Bay." With the help individuals like them, we may actually do just that. I must also thank my friends both at CBL and afar who have provided lots of support, encouragement and laughs over the past three years. Special thanks must go to Jaime Aulson who always made me smile, even when science wasn't nice to me. Thank you for sticking with me through all this. Lastly, I must thank the 2008 year-class of Atlantic menhaden. Without them, none of this would have been possible. Thanks to everyone for all you have done. It has been greatly appreciated.

Table of Contents

Dedication ii
Acknowledgements iii
Table of Contents iv
List of Tables vi
List of Figures vii
Chapter 1: 1
Rationale 1
Introduction 2
Objectives 13
Chapter 2: 15
An RNA:DNA-based model for estimating growth rate of juvenile Atlantic menhaden *Brevoortia tyrannus* 15
Abstract 16
Introduction 17
Materials and Methods 21
Growth experiments 21
Biochemical analyses 22
Statistical analyses 24
Results 24
Discussion 26
Chapter 3: 42
Temporal response (latency) of RNA-DNA ratio to changes in feeding regime in juvenile Atlantic menhaden *Brevoortia tyrannus* 42
Abstract 43
Introduction 44
Materials and Methods 49
Latency experiments 49
Biochemical analyses 50
Statistical analyses 51
Results 51
Discussion 54
Chapter 4: 69
A preliminary assessment of broad- and fine-scale patterns in RNA:DNA-based growth, abundance and production of juvenile Atlantic menhaden in the Chesapeake and Delaware Bays 69
Abstract 70
Introduction 71
Materials and Methods 75
Field 75
Laboratory 78
Statistics 79

Results 81
Discussion 86
Chapter 5: 169
Conclusions, limitations and future work 169
Appendix A: 177
Site-specific monthly instantaneous growth for 2007 177
Appendix B: 183
Site-specific monthly abundance for 2007 183
Appendix C: 190
Site-specific monthly production for 2007 190
Appendix D: 196
Site-specific monthly instantaneous growth for 2008 196
Appendix E: 202
Site-specific monthly abundance for 2008 202
Appendix F: 209
Site-specific monthly production for 2008 209
Bibliography 215

List of Tables

Table 2.1 Summary of design of laboratory growth experiments on juvenile Atlantic menhaden……..33

Table 2.2 Pearson product moment correlation results for juvenile Atlantic menhaden calibration experiments……..34

Table 2.3 Estimation of parameters in model relationship between instantaneous growth (G, d^{-1}) and experimental ration (r, % body wt.d^{-1})……35

Table 2.4 Growth equations developed using multiple linear regression for juvenile Atlantic menhaden…….36

Table 4.1 Site-specific data from each sampling event in 2007……..95

Table 4.2 Site-specific data from each sampling event in 2008……112

Table 4.3 Site-specific *Z*-score and relative ranking for instantaneous growth, abundance and production in 2007..……..129

Table 4.4 Site-specific *Z*-score and relative ranking for instantaneous growth, abundance and production in 2007..……..133

Table 4.5 Pearson product moment correlation results for 2007 field site means……139

Table 4.6 Pearson product moment correlation results for 2008 field site means……140

List of Figures

Figure 1.1. Historical geometric mean catch per haul of juvenile Atlantic menhaden from the Maryland Department of Natural Resources juvenile striped bass seine survey……14

Figure 2.1 Relationship between ration and instantaneous growth (*G*) in juvenile Atlantic menhaden……...37

Figure 2.2 Relationship between ration and RNA:DNA in juvenile Atlantic menhaden…….38

Figure 2.3 Relationship between tank mean RNA:DNA and instantaneous growth (*G*) in juvenile Atlantic menhaden……...39

Figure 2.4 RNA:DNA-growth relationship at each temperature treatment for juvenile Atlantic menhaden…….40

Figure 2.5 Relationship at each temperature treatment between tank mean RNA:DNA and instantaneous growth rate of juvenile menhaden…….41

Figure 3.1 Response of RNA:DNA to changes in feeding condition in juvenile Atlantic menhaden…….65

Figure 3.2 Response of RNA content and DNA content to changes in feeding condition in juvenile Atlantic menhaden…….66

Figure 3.3 Regression of experimental treatments from the onset of starvation until either feeding was resumed (2S – 18F) or RNA:DNA values became significantly different from the control……...67

Figure 3.4 Regression of experimental treatments from the reintroduction of food until RNA:DNA values were no longer significantly different from the control……..68

Figure 4.1 Map of 2007 and 2008 sampling locations……141

Figure 4.2 Frequency diagram of A) RNA:DNA values of field-collected individuals and B) RNA:DNA values of individuals from laboratory calibration experiment……...142

Figure 4.3 Frequency diagram of A) RNA:DNA-based estimates of instantaneous growth rates of field-collected individuals and B) Measured growth rates of individuals from laboratory calibration experiment…….143

Figure 4.4 Site-specific mean instantaneous growth throughout season in 2007 and 2008…….144

Figure 4.5 Box plots of the distribution of Z-score transformed instantaneous growth by system in 2007 Z-scores in 2007……..……145

Figure 4.6 Box plots of the distribution of Z-score transformed instantaneous growth by system in 2008……..……146

Figure 4.7. Box plots of the distribution of Z-score transformed instantaneous growth by site in 2007..……..147

Figure 4.8 Box plots of the distribution of Z-score transformed instantaneous growth by site in 2008 …...……148

Figure 4.9 Relationship of instantaneous growth *Z*-scores between 2007 and 2008 for those sites at which data were available from multiple biweekly sampling events and available in both years……..149

Figure 4.10 Site-specific abundance throughout season in 2007 and 2008……..150

Figure 4.11 Box plots of the distribution of Z-score transformed menhaden abundances by system in 2007……..……..151

Figure 4.12 Box plots of the distribution of Z-score transformed menhaden abundances by system in 2008……..……..152

Figure 4.13 Box plots of the distribution of Z-score transformed menhaden abundance by site in...……153

Figure 4.14 Box plots of the distribution of Z-score transformed menhaden abundance by site in 2008…..……154

Figure 4.15 Relationship of abundance *Z*-scores between 2007 and 2008 for those sites at which data were available from multiple biweekly sampling events and available in both years……..….155

Figure 4.16 Site-specific production throughout season in 2007 and 2008.…….156

Figure 4.17 Box plots of the distribution of Z-score transformed menhaden production by system in 2007……157

Figure 4.18 Box plots of the distribution of Z-score transformed menhaden production by system in 2008……158

Figure 4.19 Box plots of the distribution of Z-score transformed menhaden production by site in 2007 ….……159

Figure 4.20 Box plots of the distribution of Z-score transformed menhaden production by site in 2008….……160

Figure 4.21 Relationship of production *Z*-scores between 2007 and 2008 for those sites at which data were available from multiple biweekly sampling events and available in both years…….161

Figure 4.22 Relationship between site-specific abundance and instantaneous growth rate in 2007……162

Figure 4.23 Relationship between site-specific abundance and instantaneous growth rate in 2008……163

Figure 4.24 Relationship between site-specific instantaneous growth rate and production in 2007…….164

Figure 4.25 Relationship between site-specific instantaneous growth rate and production in 2008…….165

Figure 4.26 Relationship between site-specific abundance and production in 2007……166

Figure 4.27 Relationship between site-specific abundance and production in 2008……167

Figure 4.28 Relationships between temperature and salinity and site-specific abundance, instantaneous growth and production…….168

Chapter 1:

Rationale

Introduction

Estuarine environments provide important nursery habitats for many ecologically and economically important fishes during critical periods of early life (June & Chamberlain 1959, Weinstein 1979, Nixon 1980, Hoss & Thayer 1993, Able & Fahay 1998, Beck et al. 2001, Minello et al. 2003). Estuarine nursery habitats are generally characterized as providing favorable physicochemical conditions (e.g. temperature, salinity, dissolved oxygen), abundant and/or high quality prey resources and decreased predation risk. Many of these factors influence growth or survival of fish early life stages (Miller et al. 1985, Beck et al. 2001). Furthermore, variability in growth during early life stages can have considerable influence on survival and subsequent recruitment of fishes (Houde 1987). For example, increased growth rates normally confer a survival advantage in larval and juvenile fishes by ushering individuals more quickly through size-selective predation fields (reduced stage-duration) and decreasing over-winter mortality (Houde 1987, Post & Evans 1989a, Post & Evans 1989b, Rice et al. 1993a, Rice et al. 1993b, Meekan & Fortier 1996, Conover & Schultz 1997, Sogard 1997, Takasuka et al. 2004, Takahashi et al. 2008). Growth and survival of fish early life stages, and the interaction of these two processes can have complex and nonlinear impacts on the potential of different estuarine habitats to serve as nursery areas.

To date, insufficient consideration has been given to the criteria for designation of specific estuarine environments as nursery habitats. Beck et al. (2001) assert that the custom of indiscriminately classifying all juvenile habitats as nurseries serves no purpose in focusing conservation and management efforts. Furthermore,

many studies examining nursery areas have ignored fundamental factors contributing to the relative importance of specific nursery habitats. Within and among estuaries, nursery habitats are not uniformly productive. Beck et al. (2001) suggest the importance of a nursery area is determined by the relative contribution it makes to the recruitment of individuals to the adult population and therefore, defined a nursery as a habitat that, on average, produces disproportionately more recruits per unit area than do other habitats in which individuals of a particular species occur. Beck et al. (2001) identify the following four factors that combine to influence the relative contribution a specific nursery habitat makes to recruitment: (1) abundance, (2) growth, (3) survival, and (4) movement of individuals. Few studies, however, have incorporated information on these factors in a formal quantitative examination of relative contribution of different nursery habitats. For instance, habitat-specific abundance estimates (number of individuals per unit area) have often been used as an indicator of habitat quality; although, this measurement alone provides no information on the proportion of individuals surviving to adulthood. Because the contribution a habitat makes to adult recruitment is a product of multiple variables, Beck et al. (2001) affirm that an integrated measure of some, if not all of the aforementioned factors is necessary to assess potential nursery habitats. An integrated habitat metric can be used to determine which juvenile habitats serve as nurseries, facilitating the prioritization of spatially-explicit management, restoration and conservation efforts. Additionally, comparing relative habitats values will aid in the identification of biotic and abiotic factors contributing to site-specific spatiotemporal variability in habitat

production, which may improve our understanding of population and recruitment dynamics.

The concept of essential fish habitat (EFH) provides a framework to identify and evaluate the contribution of different estuarine nursery areas. The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (MSFCMRA - 2007) defined EFH as *those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity* (NOAA 2007). The National Marine Fisheries Service (NMFS) has developed four levels of resolution in defining EFH as mandated by the MSFCMRA (NMFS 1997). The first two levels of EFH require information on presence/absence and relative abundance data of a species or life history stage, respectively (Able 1999). The third level of EFH requires data regarding habitat-related growth, reproduction and/or survival by life history stage, adding that habitats exhibiting the highest production should support the highest levels of these measures (Able 1999). The fourth level of EFH requires a quantitative description of habitat production, defining essential fish habitats as those necessary to maintain fish production consistent with a sustainable fishery and healthy ecosystem (Able 1999).

While all levels of information outlined by the NMFS are potentially important in determining EFH, the categories that specifically facilitate quantification of habitat production to accurately define and compare EFH are perhaps most valuable. The two highest levels of EFH designation rely on quantification of habitat-specific growth. Growth during early life stages influences survival and recruitment (Rice et al. 1993b). Habitats promoting rapid growth are therefore likely important to

recruitment in fishes. In turn, because growth responds to habitat characteristics such as physicochemical factors (Fry 1971) and prey availability (Graeb et al. 2004), *in situ* growth rates likely reflect habitat quality (Sogard 1992, Meng et al. 2000, Nislow & Folt 2000, Le Pape et al. 2003, Amara et al. 2007, Glass et al. 2008). Ultimately, to meet the highest level of EFH designation, estimates of growth ($g.t^{-1}$) must be combined with estimates of abundance to provide an index of relative production, hereafter production. Inherently, these solitary production estimates exclude the impact of mortality on habitat contribution; however, estimates generated from the coupling of these measures provide "snapshots" of site-specific production. Therefore, mortality influences these snapshots by reducing abundance between sampling events. Estimates of habitat-specific abundance, defined as the number of individuals per unit area (m^{-2}), can provide important information regarding relative habitat use by fishes (Able 1999, Beck et al. 2001) and are an integral part of estimating production. Unfortunately, the quantification of habitat-specific production ($g.m^{-2}.t^{-1}$) has posed a major challenge to investigators (Edgar & Shaw 1995, Able 1999, Beck et al. 2001, Gillanders et al. 2003).

Reliable estimates of habitat-specific abundance data can be obtained without difficultly. However, most traditional methods of estimating growth, such as size-at-age and otolith-based techniques integrate past growth over protracted time periods. Therefore, these approaches to estimating growth in mobile organisms, such as juvenile fishes, likely integrate growth over multiple habitats. Consequently, such growth estimates may not match, spatially or temporally, estimates of relative habitat-specific abundance, potentially providing unreliable estimates of habitat-specific

production. Thus, a central problem in producing estimates of production of specific habitats is the availability of growth estimates at relevant spatial and temporal scales such that they reliably reflect recent growth in the habitat of interest.

Nucleic acids levels within tissues can provide an index of growth. The underlying principle of the approach is that the amount of deoxyribonucleic acid (DNA) remains constant within individual cells of an organism. Conversely, ribonucleic acid (RNA) levels fluctuate in response to activity of the protein synthetic machinery on the ribosomes. Thus, during periods of increased growth and cellular division, RNA levels increase while DNA amounts remain invariable, producing relatively higher RNA:DNA (Bulow 1970, Buckley et al. 1984, Ferron & Leggett 1994). RNA-DNA ratios have been used as an index of growth in cell and tissue cultures (Dortch et al. 1983), and in whole organisms (Sutcliffe 1970). In fishes, RNA-DNA ratios have been found to reliably estimate growth of larval (e.g., Wright & Martin 1985, Rooker & Holt 1996, Heyer et al. 2001) and juvenile fish (Malloy & Targett 1994a, Suthers et al. 1996, Smith & Buckley 2003). Because RNA levels reflect physiological conditions, RNA levels respond over relatively short time scales. Thus, RNA-DNA ratios can be associated with environmental conditions observed at the time of sampling events (Buckley 1984, Bulow 1987, Ferron & Leggett 1994, Buckley et al. 1999). Importantly for estimating habitat-specific growth rates, RNA-DNA ratios have also been found to respond to changes in feeding and growth on the order of hours to days, making them a valuable resource for measuring habitat-specific growth (Wright & Martin 1985, Bulow 1987, Ferron & Leggett 1994, Malloy & Targett 1994b, Arndt et al. 1996, Kono et al. 2003, Catalan et al. 2007, Stierhoff et

al. 2009). RNA:DNA offers a valuable tool for identifying and understanding the relationships between recent growth, production and environmental factors of estuarine nursery habitats.

However, the principal challenge in the application of RNA:DNA-based approaches in estimating habitat-specific production is that RNA-DNA ratios provide an index of growth and not an absolute estimate. Various studies have quantified the relationship between RNA:DNA and growth rate to estimate condition and growth of laboratory and field collected fish (Buckley 1982, Buckley et al. 1984, Caldarone 2005, Mercaldo-Allen et al. 2006, Mercaldo-Allen et al. 2008). Because activity of ribosomal RNA increases with temperature (Buckley 1982, Buckley et al. 1999), some relationships developed to estimate growth from RNA:DNA have been improved by the inclusion of temperature in the model (Buckley 1982, Buckley et al. 1984, Caldarone et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006). The majority of relationships between RNA:DNA and growth have been found to be species-specific, meaning that relationships determined for one species may not be reliably applied to another. These findings suggest that any proposed application of an RNA:DNA-based growth index to previously untested species requires laboratory quantification of the relationship between RNA:DNA, temperature and growth rate. Once a laboratory-based predictive model has been developed, inputs of RNA:DNA from field-caught individuals and observed temperatures from sampling sites may be used to estimate growth of resident fish and the associated production of estuarine nursery habitats.

Several different biochemical approaches to quantifying nucleic acids have been published. The majority of these techniques involve binding a fluorescent dye or fluorochrome to the nucleic acids (Clemmesen 1993). The techniques differ in the detergents used to break down the lipoprotein membranes that surround the cell and in the fluorochromes used. It is known that these different protocols affect the RNA:DNA values calculated (Caldarone et al. 2006). Thus, different protocols will yield different absolute RNA:DNA values for the same sample. Recently, Caldarone et al. (2006) demonstrated an approach that standardizes RNA:DNA values calculated by different protocols. The approach uses the slopes of the calibration curves that express fluorescence as a function of known nucleic acid concentrations to standardize the sensitivity of each protocol to different nucleic acid concentrations.

Here I apply RNA:DNA-indices of growth to quantify production in juvenile Atlantic menhaden (*Brevoortia tyrannus*) during periods of estuarine residency. Atlantic menhaden (hereafter menhaden) is an ecologically and economically important species in the mid-Atlantic ecosystem, providing important ecosystem services as a filter feeder and forage species and supporting a valuable commercial fishery (ASMFC 2006). Menhaden is a schooling, obligate filter-feeding planktivore which consumes a mixture of phytoplankton, zooplankton and detritus in proportion to concentrations found in the environment (Jeffries 1975). Menhaden schools filter large quantities of water, potentially limiting phytoplankton blooms and increasing water clarity. These ecosystem services can be especially valuable when anthropogenic sources of nutrient inputs stress marine environments. In turn, menhaden juveniles and adults represent an important prey for many piscivorous

fishes (Sykes & Manooch 1979, Hartman 2003, Uphoff 2003), birds (Spitzer 1989) and marine mammals (Hildebrand 1963). Thus, menhaden represents an important trophic link between primary and secondary production and higher trophic levels, circulating and redistributing considerable amounts of energy throughout the mid-Atlantic ecosystem (Peters & Schaaf 1981, Lewis & Peters 1984).

Economically, menhaden supports valuable commercial reduction and bait industries. In 2007, the commercial harvest of Atlantic menhaden was 215,506 metric tons valued at nearly 32 million dollars (NMFS 2008). The reduction fishery utilizes purse-seining gear to harvest vast numbers of menhaden which are subsequently processed into fish meal, fish oil and condensed fish solubles for products such as agri- and aquaculture feed, food additives, paints, cosmetics, health supplements and fertilizers (Smith 1991). A relatively smaller bait industry exists for menhaden; although, landings of this sector have become more important to the total catch in recent years (ASMFC 2006).

Atlantic menhaden ranges from Nova Scotia to central Florida (Reintjes 1969, Ahrenholz 1991). During the summer, adult menhaden are stratified by age and size, with the oldest, largest individuals found at the highest latitudes (Nicholson 1978, Ahrenholz 1991). In fall, menhaden begin their southern migration. Some spawning occurs year round (Higham & Nicholson 1964, Judy & Lewis 1983, Warlen 1994), but the most intense spawning is believed to occur from December through March south of Cape Hatteras, North Carolina (Higham & Nicholson 1964, Reintjes & Pacheco 1966, Judy & Lewis 1983). After spawning peaks, schools migrate north beginning in late March/early April. During the northern migration, spawning occurs

at a decreasing rate and progressively farther inshore (Rogers & Van Den Avyle 1989). By May, most spawning is restricted to areas north of Cape Hatteras (Judy & Lewis 1983). Spawning reaches its minimum in June when individuals are again dispersed from Maine to Florida (Judy & Lewis 1983).

Estuarine systems along the Atlantic seaboard are important habitats for juvenile menhaden. Eggs typically hatch at sea between 2.5 – 2.9 days at 15.5°C (Hettler 1981) with a size at hatch between 3 – 4 mm (Powell & Phonlor 1986, Maillet & Checkley 1990, Warlen 1992). Menhaden larvae are transported from their coastal spawning sites to estuarine habitats by a combination of physical processes and behavioral responses, arriving at various estuaries along the coast at different times depending upon factors such as spawning time and location (Reintjes & Pacheco 1966, Nelson et al. 1977, Checkley et al. 1988, Warlen 1994, Quinlan et al. 1999, Hare et al. 2005). Menhaden typically spend 1-3 months at sea and are normally still larvae (8-42 mm total length [TL]) when they ingress into estuarine environments (June & Chamberlain 1959, Reintjes & Pacheco 1966). The mean age and standard length of larvae recruiting to the New Port River estuary, N.C. was 61 days and 24.6 mm over seven spawning seasons (Warlen 1994). Ingress generally occurs during May – October in the North Atlantic, October – June in the Mid-Atlantic, and November – May in the South Atlantic (Reintjes & Pacheco 1966, Wilkens & Lewis 1971). Once in the estuaries, menhaden prefer shallow, low salinity environments in which they metamorphose to the juvenile stage (Wilkens & Lewis 1971, Weinstein 1979, Rogers et al. 1984, Murdy et al. 1997).

The transition from the larval to the juvenile stage occurs at around 38 mm (Lewis et al 1972) and is characterized by a morphological change in feeding apparatus, allowing a dietary shift from individual zooplankton prey to filter-feeding on plankton and other suspended organic matter (June & Carlson 1971). Generally, juveniles experience rapid and variable growth rates during estuarine residency, influenced primarily by environmental conditions and prey availability. Juveniles have shown growth rates approaching 1 mm/day in the field (Reintjes 1969, Kroger et al. 1974). During fall, growth is effectively halted when temperatures drop below 15°C (Kroger et al. 1974) when most will leave the estuarine environment and join the adult stock on their southward migration. Lengths of emigrating juveniles typically range from approximately 55 to 140 mm TL (Nicholson 1978).

Estuarine nursery habitats are critical to the growth and survival of early life history stages of Atlantic menhaden. The most recent ASMFC stock assessment showed that coastwide juvenile menhaden abundance indices have declined since the 1970s, although the adult spawning population remains healthy (ASMFC 2006). Specifically in the Chesapeake Bay, bay-wide indices of juvenile abundance have experienced similar declines (Durell & Weedon 2007 – Figure 1.1). The causes of the recent menhaden recruitment declines have yet to be determined, but may be attributed to environmental influences (Wood 2000). In the Chesapeake Bay, decreased survival during estuarine residency has been cited as a potential cause of recent poor recruitment episodes (ASMFC 2004). Using a matrix modeling approach, Quinlan & Crowder (1999) identified growth and mortality dynamics in the late larval and juvenile stages to be most important to population growth rates of

menhaden. These life stages coincide with periods of estuarine residency, suggesting that processes occurring during juvenile occupancy of estuarine nursery habitats may have great influence on menhaden population dynamics. Therefore, examination of nursery ground processes and their effects on juvenile menhaden could provide valuable information for understanding menhaden population dynamics, improving recruitment predictions, defining essential fish habitat and developing effective management strategies for this species.

Information on the abundance of juvenile menhaden in mid-Atlantic estuaries is important not only for understanding the dynamics of its own species, but also for the dynamics of a major predator, striped bass (*Morone saxatilis*). Several studies have documented the importance of Atlantic menhaden to the diet of striped bass (Hartman & Brandt 1995, Walter & Austin 2003, Walter et al. 2003). While menhaden numbers have been declining, striped bass abundance is currently at historically high levels, increasing the relative demand for menhaden as prey. In fact, recent observations of emaciation and occurrences of mycobacteriosis in striped bass may be a result of insufficient numbers of menhaden as forage (Uphoff 2003). Thus, understanding the dynamics of menhaden has important consequences for advancing ecosystem-based approaches to fisheries management.

In this study, I have attempted to evaluate the spatial and temporal dynamics of estuarine nursery habitats of Atlantic menhaden by quantifying site-specific habitat production in Chesapeake and Delaware Bays. Potential nursery habitat production was determined by combining nucleic acid-based estimates of growth with fishery-independent abundance data. Relative habitat production was then compared over a

range of scales both spatially and temporally to better define essential fish habitat and investigate the potential factors determining recruitment success for this species.

Objectives

The objectives of this study were to 1) develop an RNA:DNA-based index for estimating growth rate in juvenile Atlantic menhaden by experimentally quantifying the relationship between growth rate, temperature and RNA:DNA, 2) determine the temporal response (latency) of nucleic acid-based condition to changes in feeding status in juvenile Atlantic menhaden, 3) combine nucleic-acid based growth estimates with fishery-independent abundance data to compare relative nursery habitat production on both broad- and fine-scales for juvenile Atlantic menhaden in the Chesapeake and Delaware Bays. Each objective is addressed in a subsequent chapter of my thesis, with each chapter prepared as a draft manuscript intended for submission for publication to peer-reviewed journals. I will be senior author on all publications derived from this thesis. The target journals have yet to be defined.

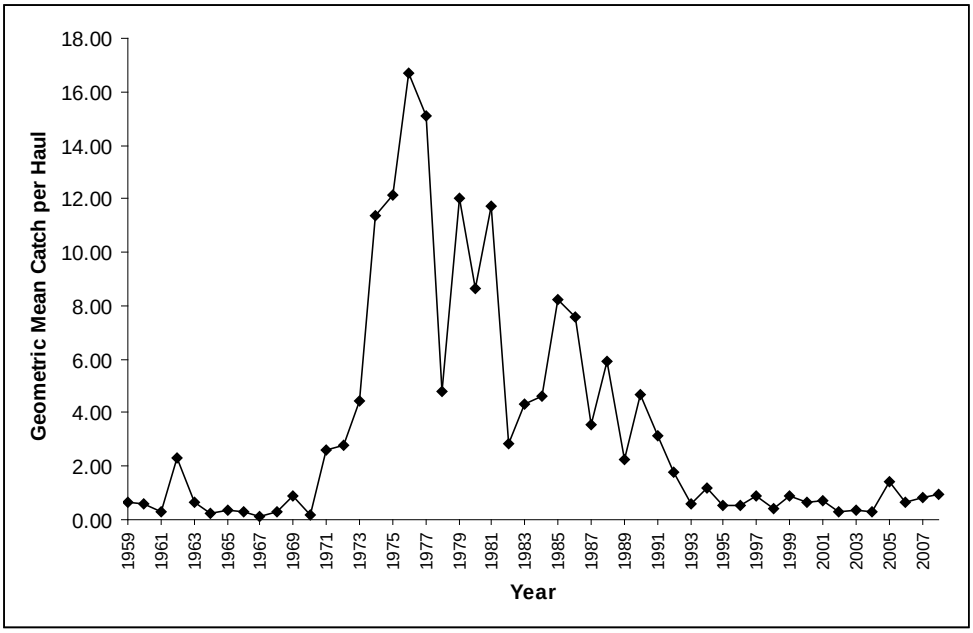


Figure 1.1. Historical geometric mean catch per haul of juvenile Atlantic menhaden from the Maryland Department of Natural Resources juvenile striped bass seine survey

Chapter 2:

An RNA:DNA-based model for estimating growth rate of juvenile Atlantic menhaden *Brevoortia tyrannus*

Abstract

Fluorometric techniques were used to develop a nucleic acid-based index for estimating instantaneous growth rate in young-of-the-year Atlantic menhaden. A series of 10-day laboratory growth experiments consisting of different temperatures and food rations was conducted. Weight-specific instantaneous growth rate and nucleic acid measurements (RNA content, DNA content, RNA:DNA) were obtained from individual fish. RNA:DNA was most correlated with instantaneous growth (G) ($r = 0.81$; $p < 0.0001$). Using multiple linear regression, RNA:DNA and temperature explained 76% of the variability in growth, producing the following predictive model: $G = 0.01021(\text{RNA:DNA}) + 0.00199(T) - 0.09929$. This model can be applied to field-caught individuals to estimate relative growth in potential nursery habitats for juvenile Atlantic menhaden.

Introduction

Estuarine environments provide important nursery habitats for many ecologically and economically important fish species (June & Chamberlain 1959, Weinstein 1979, Nixon 1980, Hoss & Thayer 1993, Able & Fahay 1998, Minello et al. 2003). Estuarine nursery habitats are believed to foster increased growth and survival of early life stages by providing favorable abiotic conditions, sufficient prey resources and decreased predation risk (Miller et al. 1985). The nursery-role concept proposed by Beck et al. (2001) defined nurseries as habitats that contribute disproportionately more recruits to the adult population than other habitats by providing favorable conditions for growth and survival during early life stages. However, the quality and relative value of nursery habitats within and among estuaries is not homogeneous. Determining which habitats constitute nurseries may help to identify the factors influencing spatiotemporal habitat variability, potentially increasing our understanding of recruitment dynamics and improving management strategies for estuarine dependent fish species.

Identification of which habitats may function as nurseries requires quantification of habitat-specific production. Production ($g.m^{-2}.d^{-1}$) is typically defined as the product of abundance in the habitat (number of individuals), the area of the habitat (m^{-2}) and the net individual growth rate in the habitat ($g.d^{-1}$). However, growth and production likely do not vary proportionally as a result of the complex and potentially nonlinear relationship between growth during early life stages and survival and subsequent recruitment of fishes (Rice et al. 1993b). Increased growth rate normally confers a survival advantage in larval and juvenile fishes by reducing

stage-duration and decreasing mortality (Houde 1987, Post & Evans 1989a, Post & Evans 1989b, Rice et al. 1993a, Rice et al. 1993b, Conover & Schultz 1997, Sogard 1997). Also, because growth responds to variability in nursery habitat characteristics such as physicochemical factors (Fry 1971) and prey availability (Graeb et al. 2004), growth indices may provide a useful measure of habitat-specific production or quality (Sogard 1992, Meng et al. 2000, Nislow & Folt 2000, Le Pape et al. 2003, Amara et al. 2007, Glass et al. 2008).

For estimates of growth rates to be of utility in quantifying habitat-specific production, it is critical that only growth achieved while the animals are in the specific habitat be measured. Biases in the estimates of habitat-specific production can be introduced if growth that occurred while the animals are in different habitats is incorporated into the estimated growth and hence, into estimates of production. Thus, the approach used to estimate growth must have a temporal resolution shorter than the period of residency of the animals in the habitat, but must integrate the temporal variability in the characteristics of the habitat itself. Many traditional methods of estimating growth, such as size-at-age and otolith-based techniques integrate past growth over protracted time periods and potentially, multiple habitats. These estimates likely do not correspond to site-specific abundance estimates, potentially providing unreliable estimates of habitat-specific production.

Nucleic acid-based condition indices offer a means to estimate growth over short temporal scales, thereby providing a higher spatial resolution corresponding to site-specific abundance estimates. The underlying principle behind the use of RNA:DNA indices is that DNA content remains relatively constant per cell, reflecting

cell number. Conversely, RNA content fluctuates in response to the amount protein synthetic machinery and ribosomal activity, providing a measure of relative condition and potential growth of individuals (Bulow 1970, Buckley et al. 1984, Ferron & Leggett 1994). RNA:DNA has been used historically to estimate growth in cell and tissue cultures (Dortsch et al. 1983), and in whole organisms (Sutcliffe 1970). Because environmental variables (e.g. temperature, salinity, dissolved oxygen) and site-specific availability of potential prey vary over small spatial and temporal scales, RNA:DNA offers a valuable tool for identifying and understanding the relationships between recent growth, production and environmental factors of estuarine nursery habitats.

Numerous studies have quantified the relationship between RNA:DNA and growth rate to estimate condition and growth of laboratory and field collected fish (e.g., Buckley 1982, Buckley et al. 1984, Caldarone 2005, Mercaldo-Allen et al. 2006, Mercaldo-Allen et al. 2008). RNA-DNA ratios have been found to reliably estimate recent feeding and growth of larval and juvenile fish (Wright & Martin 1985, Malloy & Targett 1994a, Malloy & Targett 1994b, Rooker & Holt 1996, Suthers et al. 1996, Smith & Buckley 2003). Because activity of ribosomal RNA increases with temperature (Buckley 1982, Buckley et al. 1999), some relationships developed to estimate growth from RNA:DNA have been improved by the inclusion of temperature in the model (Buckley 1982, Buckley et al. 1984, Caldarone et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006). Additionally, relationships between RNA:DNA and growth have normally been found to be species specific, meaning that relationships determined for one species may not be reliably applied to another.

These findings suggest that any proposed application of an RNA:DNA-based growth index to previously untested species requires laboratory quantification of the potential relationships between RNA:DNA, temperature and growth rate. Once a laboratory-based predictive model has been developed, inputs of RNA:DNA from field-caught individuals and observed temperatures from sampling sites can be used to estimate growth of resident fish and the associated production of estuarine nursery habitats.

In this study, I conducted laboratory experiments to determine the relationship between RNA:DNA, temperature and growth rate of juvenile Atlantic menhaden (*Brevoortia tyrann*us) using a fluorometric 1-dye/2-enzyme microplate assay. Menhaden is an ecologically and economically important species in mid-Atlantic ecosystems, providing important ecosystem services as a filter feeder (Peters & Schaaf 1981, Lewis & Peters 1984) and forage species (Uphoff 2003) and supporting a valuable commercial fishery (Ahrenholz et al. 1987). Menhaden generally spawn in continental shelf waters (Higham & Nicholson 1964, Judy & Lewis 1983) and larvae are transported to various estuaries along the Atlantic coast (Quinlan et al. 1999). Juvenile menhaden are estuarine-dependent during their first year of life, and processes affecting the juvenile stage likely have major influence upon population growth rates (Quinlan & Crowder 1999). Recent stock assessments have shown that juvenile menhaden abundance indices have declined since the 1970s (ASMFC 2006), suggesting the need for investigation into the potential mechanisms contributing to decreased recruitment success. Examination of nursery ground processes and their effects on juvenile menhaden could provide valuable information for understanding

menhaden recruitment variability, defining essential fish habitat and developing effective management strategies for this species.

Materials and Methods

Growth experiments

Experiments were conducted using young-of-the-year, juvenile Atlantic menhaden collected by beach seine from littoral habitats in the Patuxent River, MD. Fish were held for at least seven days to allow recovery from transportation or handling-induced stress, and acclimated to experimental temperatures for at least an additional five days before undergoing experimentation. During this period, fish were fed pelleted food (Zeigler Finfish Starter Meal, Gardners, PA, 0.42- 0.595 mm) *ad libitum* four times daily. Individuals showing signs of injury or disease were not used in the experiments. A photoperiod of 14 hr light – 10 hr dark was imposed throughout all phases of the research.

A laboratory growth experiment involving four, 10-day growth trials incorporating a range of temperature and feeding regimes was conducted between May 23 and September 8, 2008. Fish used in the experiments ranged from 0.76 – 36.94 g (Table 2.1). Temperature and food ration levels were chosen to elicit a wide range of growth rates and to simulate the approximate thermal regime that juvenile menhaden experience during estuarine residence in the Chesapeake Bay and other mid-Atlantic estuaries. Treatment combinations used in trials were established using a response surface methodological approach. This design consisted of a core set of levels of each factor (i.e., temperatures: 20, 24, 28°C and rations: 0, 5, 20% body wt.day^{-1}) conducted as a two-factor randomized complete block design with

additional levels incorporated to fully quantify relationships between temperature, ration, growth and RNA:DNA. Trials 1 and 2 consisted of three levels of temperature (20, 24 and 28°C) and three food rations (0, 5 and 20% body wt.day^{-1}). Trials 3 and 4 consisted of four levels of temperature (20, 24, 28 and 30°C) and three food rations (0, 5 and 20% body wt.·day^{-1}). To ensure the feeding regime produced a wide spectrum of growth rates, the second trial included an additional ration level of 50% body wt.day^{-1}.

Each trial employed 12 circular, 511-l fiberglass tanks. Each tank was provided with flow through water from the Patuxent River. Because menhaden is a planktonic filter-feeder, serial filtration (10, 5 and 1 µm) of inflowing water was utilized to ensure reliable ration treatments were maintained. Water quality was monitored regularly during the experiment. To begin an experiment, 7-8 fish were randomly assigned to each tank. Prior to addition to the tank individual menhaden were anesthetized with 60mg.l^{-1} MS-222, weighed, measured, and fin clipped for identification at the end of the experiment. Fish were fed their assigned ration level at regular intervals 4 times daily. After 10 d, fish from each tank were measured and weighed. Food was not withheld on day 10 so as to maintain treatment-related differences in biochemical indices. Fish were immediately frozen on dry ice and stored at -80°C after measuring and weighing for subsequent biochemical analyses.

Biochemical analyses

Nucleic acid concentrations were determined using a 1 fluorochrome (ethidium bromide) / 2 enzyme (RNase and DNase) fluorometric protocol adapted from Caldarone et al. (2001) for use with juvenile fish. Three subsamples of epaxial

muscle tissue above the lateral line were removed from each fish. Each subsample was placed in 1% N-lauroylsarcosine for extraction, vortexed for 60 minutes, sonicated and vortexed again for 30 minutes to ensure complete dissociation of nucleoproteins. Subsamples were further diluted with tris-EDTA buffer and centrifuged to precipitate cellular debris. Aliquots were pipetted into a 96-well microplate. The fluorochrome ethidium bromide was added to each well and total nucleic acid fluorescence was measured using a spectrofluorometer (Spectramax II, Molecular Devices Inc., Sunnyvale, CA). The excitation wavelength was 525 nm and the emission wavelength was 600 nm. RNase and DNase were used to enzymatically digest RNA and DNA, respectively. Fluorescence values of RNA and DNA were determined via subtraction after the enzymatic digestion of each nucleic acid, respectively. Samples were run in triplicate in a randomized order on 81-well microplates. Calibration curves were produced for each plate using serially diluted commercial preparations of 18S + 28S Ribosomal RNA (Sigma R-0889) and calf thymus DNA (Sigma D-1501). Fitted calibration curves were never less than R^2=0.99. RNA and DNA fluorescences for individual samples were converted to RNA and DNA concentrations by comparison with their respective calibration curve and the standardization procedure in Caldarone et al. (2006) which adjusts the fluorescence for the slope of the calibration curve. A standard control homogenate of surplus fish was prepared and analyzed with each plate to verify the accuracy of the run. All nucleic acid data were reported and analyzed as the average of the triplicate samples.

Statistical analyses

Weight-specific instantaneous growth rate (G, d^{-1}) was calculated for each fish using the equation: $G = [(\ln Wt_f - \ln Wt_i)\ d^{-1}]$; where Wt_f = final wet weight, Wt_i = initial wet weight and d = number of days between measurements. Estimates of body mass, G, RNA content, DNA content and RNA:DNA were available for each individual fish sampled. However, to avoid pseudoreplication, all statistical analyses were conducted using tank mean values. Pearson product moment correlation analysis was used to examine the relationships between RNA:DNA, RNA content, DNA content, temperature, body mass and instantaneous growth rate. Two-way analysis of variance (ANOVA) was used to determine the effects of experimental temperature, ration level and their interactions on both instantaneous growth rate and RNA:DNA of juvenile menhaden. Subsequently, when statistically significant effects of growth on RNA:DNA were detected, stepwise multiple linear regression was employed to develop a predictive model for growth of juvenile Atlantic menhaden. Variables tested included RNA:DNA, temperature and body mass. Variables were selected for the model if they met the significance criteria for inclusion ($p < 0.05$). All statistical analyses were conducted using SAS 9.1 (*SAS* Institute, Cary, NC, USA) and SYSTAT 11 (SYSTAT Software, Inc., Point Richmond, CA, USA).

Results

Only five of the 336 fish used to quantify the relationship between growth and nucleic acid concentration died during this study. Menhaden used in experiments exhibited growth from -0.11 to 0.07 d^{-1} over 10 d trials. Tank mean instantaneous growth (± S.E.) varied from -0.05 ± 0.005 to 0.03 ± 0.006 d^{-1} (Figure 2.1). Measured

RNA levels in individual samples ranged from 0.43 to 4.34 $\mu g.ml^{-1}$ while DNA levels ranged from 0.10 to 0.72 $\mu g.ml^{-1}$. Individual RNA:DNA values ranged from 1.57 to 12.03. Tank mean RNA:DNA (± S.E.) varied from 2.26 ± 0.14 to 8.60 ± 0.68 (Figure 2.2).

Pearson product moment correlation analysis showed a significant positive correlation between RNA and DNA content ($r = 0.38$; $p = 0.0071$ - Table 2.2). RNA:DNA was also significantly positively correlated with RNA ($r = 0.70$; $p < 0.0001$), but showed a significant negative relationship to DNA ($r = -0.33$; $p < 0.022$). Results indicated a significant ($p < 0.0001$) positive correlation between RNA:DNA and instantaneous growth rate (d^{-1}), which produced the strongest relationship of all the variables examined ($r = 0.81$). Additionally, both RNA ($r = -0.54$; $p < 0.0001$) and RNA:DNA ($r = -0.42$; $p = 0.003$) were significantly negatively correlated with temperature.

Analysis of variance indicated a significant effect of experimental ration on both instantaneous growth rate ($p < 0.0001$) and RNA:DNA ($p < 0.0001$) in juvenile menhaden. Experimental temperature had a significant effect on RNA:DNA ($p < 0.0001$), but did not significantly affect instantaneous growth ($p > 0.05$). No significant interactions between ration and temperature were observed on either growth rate ($p > 0.05$) or RNA:DNA ($p > 0.05$).

Growth was non-linear, but significantly related to experimental ration (Fig 2.1). The data were fitted to the equation:

$$G = y_0 + \alpha(1 - e^{-\beta r})$$

where G and r = instantaneous growth rate and ration, respectively; α, β and y_0 = constants. Parameter estimates are given in Table 2.3. Similarly, RNA:DNA and ration were also significantly, but non-linearly related (Fig. 2.2).

An inverse relationship was developed to estimate juvenile menhaden growth from RNA:DNA. A relatively strong linear relationship was observed between tank mean RNA:DNA and instantaneous growth rate (adj $R^2 = 0.64$) (Figure 2.3), even without accounting for the effect of temperature treatment. Inclusion of temperature effects further improved the relationship between RNA:DNA and instantaneous growth (Figure 2.4). RNA:DNA was not found to increase with increasing temperature. Rather, as temperature increased, increased growth was observed at lower RNA:DNA values.

Step-wise multiple linear regression was employed to develop a predictive model for growth of juvenile Atlantic menhaden. Of the variables examined, RNA:DNA was most strongly related to instantaneous growth (Table 2.2) and was the first variable included in the model (adj $R^2 = 0.64$, $p<0.0001$, Table 2.4). Temperature was selected next (adj $R^2 = 0.12$, $p<0.0001$). No other variables met the required significance level for entry. The best equation for predicting growth was:

$G = 0.01021(\text{RNA:DNA}) + 0.00199(T) - 0.09929$ (adj $R^2 = 0.76$, $p<0.0001$).

This predictive model can be used to estimate instantaneous growth of juvenile Atlantic menhaden with inputs of RNA:DNA and temperature (Figure 2.5).

Discussion

My results indicated that RNA:DNA, along with associated effects of temperature, may serve as a reliable predictor of growth rate in juvenile Atlantic

menhaden. The model developed from the experimental data indicated that 76% of the variability in juvenile menhaden growth could be explained by RNA:DNA and temperature. Most of the variability is accounted for by the nucleic acid ratio (64%), with temperature accounting for 12% of the remaining variability. Results indicated that RNA:DNA is linearly related to growth, regardless of whether overall growth is negative or positive. Similar relationships have been found between RNA:DNA and growth in other species of fishes (Rooker & Holt 1996, Fukuda et al 2001, Peck et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006, Mercaldo-Allen et al. 2008). RNA and DNA content were also found to be significantly correlated with growth; however, the relationship between each of these biochemical indices and growth was not nearly as strong as to that of RNA:DNA. This suggests that RNA:DNA could provide growth estimates of sufficient reliability to be of use in calculating habitat-specific growth rates of juvenile Atlantic menhaden.

The strength of the relationship between RNA:DNA and growth is comparable to similar relationships reported in other larval and juvenile stages of fishes (Buckley et al. 1984, Caldarone 2005, Mercaldo-Allen et al. 2006, Mercaldo-Allen et al. 2008). Other studies have similarly observed that the inclusion of temperature has strengthened the relationship of RNA:DNA-growth models (Buckley 1982, Buckley et al. 1984, Caldarone et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006). This is the result of enhanced metabolic activity of fish with increasing temperature, and a corresponding increase in the rate of protein synthesis and ribosomal activity (Mathers et al. 1992). However, increased growth at higher temperatures is generally not associated with increased RNA:DNA, but instead,

higher temperatures produce increased growth rates at a given RNA:DNA compared to lower temperatures (Buckley 1982, Goolish et al. 1984, Buckley et al.1999, Caldarone et al. 2003, Caldarone 2005). Correlation analysis supports this pattern by indicating a significant negative relationship between temperature and RNA:DNA in juvenile Atlantic menhaden. Although this relationship indicates that RNA:DNA and temperature are not strictly independent, a violation of an assumption of linear regression; the relative strength of the correlation is acceptable for inclusion of both variables in the prediction model.

Instantaneous growth rate was significantly affected by experimental ration. As anticipated, in all experiments growth increased with increasing ration level. However, individuals in tanks subjected to the 50% body wt.d^{-1} ration treatment did not experience considerably increased growth beyond that of our 20% body wt.d^{-1} level, suggesting that ration levels were appropriate for producing a sufficiently broad growth spectrum. Similar asymptotic relationships between growth rate and feeding have been observed in previous studies (O'Connell & Raymond 1970, Wurtsbaugh & Davis 1977, Checkley 1984, Kiørboe et al. 1987). Specifically, Keller et al. (1990) observed a curvilinear relationship in Atlantic menhaden in which growth rates approached a maximum in relation to experimental feeding levels in a mesocosm study. Durbin & Durbin (1983) found similar asymptotic relationships between growth and plankton concentration in Atlantic menhaden. However, it is possible that the saturation of growth with respect to feeding level observed in this study is not a result of individual menhaden approaching maximum growth rates. Instead, the trend produced may be due to an inability of experimental individuals to entirely consume

their assigned ration. Menhaden are planktonic filter feeders and therefore acquire food by sieving prey particles from the water column. In my study, prey was not ubiquitous, but was instead provided at regular intervals each day of the experiment. If sinking rates of food occurred more quickly than individuals could acquire it, individuals may not be able to achieve maximum ingestion. I attempted to eliminate this concern by feeding four times throughout the day, but insufficient ingestion may still have occurred. For the purposes of this study, however, the question of whether maximum growth was achieved may be unimportant as the saturation occurred at ration levels above those expected in the field.

Temperature, however, did not have a significant affect on growth rates. Generally, under maximum consumption conditions, increases in temperature will produce increased growth until temperature reaches a threshold at which growth will begin to decline, whereas, at low consumption, growth declines as temperature increases (Wooten 1998). Other studies have observed the effect of temperature on early life stages of Atlantic menhaden (Lewis & Hettler 1968, Hettler 1976, McNatt & Rice 2004). In my study, however, individuals were subjected to a range of temperature treatments designed to approximately simulate the thermal regime experienced by juvenile menhaden during estuarine residence time in the Chesapeake and Delaware Bays. Brandt & Mason (2003) state that at high feeding levels, juvenile menhaden have a relatively broad scope for growth, ranging from 21-30°C, and that variation in temperature within this range will have little effect on growth rate. The experimental temperatures employed in this study (20, 24, 28 and 30°C)

fall within this range, potentially explaining the lack of a significant effect of temperature on growth in this study.

RNA:DNA was significantly affected by both experimental ration and temperature. Several studies have documented the rapid response of RNA:DNA to changes in feeding and nutritional condition (Malloy & Targett 1994b, Chung et al. 1998, Stierhoff et al. 2009). RNA content fluctuates in accordance with potential for protein synthesis and subsequent growth. During early life stages, the majority of prey consumed is converted into energy for somatic growth; therefore, nucleic acid indices can provide a reliable indicator of recent feeding and potential growth in fish. Additionally, RNA:DNA in individual summer flounder (*Paralichthys dentatus* - Malloy & Targett 1994b), red drum (*Sciaenops ocellatus* – Rooker & Holt 1996) and weakfish (*Cynoscion regalis* – Stierhoff et al. 2009) has been shown to respond on the order of hours to days. Results of this study support previous observations of the quick response of RNA:DNA to recent feeding and nutritional status. Based on our findings, the response of RNA:DNA to feeding in juvenile Atlantic menhaden is equal to or less than 10 days.

The objective of the predictive growth model developed in this study was to estimate growth of field-caught individuals to quantify and compare relative habitat-specific production of juvenile menhaden. Because menhaden is a mobile, pelagic fish, estimated growth rates must be relevant to short temporal scales so that growth and subsequent production can be directly related to specific habitats and associated biotic and abiotic variables. Therefore, the temporal response of nucleic acids to changes in feeding and condition must be established to ensure the quantification of

reliable habitat-specific growth estimates. Thus, additional laboratory-based latency experiments are needed to more precisely define the rate of response of RNA:DNA to changes in feeding and other stimuli to determine the degree of temporal resolution our model provides.

The effect of temperature on RNA:DNA observed in this study has also been observed in several studies on other species of fish (Buckley 1982, Buckley et al. 1984, Caldarone et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006). Because biochemical activity increases with increased temperature, the relationship between nucleic acids and growth is often temperature dependent. The significant effect observed in this study suggests the potential importance of including temperature in our predictive RNA:DNA-growth model for juvenile menhaden.

Relationships between RNA:DNA and growth rate in fish can be affected by size and ontogenetic changes (Buckley et al. 1999). As fish grow and develop, energy is allocated to other metabolic activities besides somatic growth, potentially providing unreliable estimates of nucleic acid-based growth rates. Therefore, caution must be exercised when applying predictive models to older or more developed individuals. This study incorporated individuals over a range of sizes corresponding to those observed during estuarine residency time of juvenile Atlantic menhaden. Pearson product moment correlation analysis did not indicate a significant relationship between body mass and any of the variables included in our model (instantaneous growth, RNA:DNA, temperature). Additionally, body mass did not meet the 0.05 significance level required for entry into the model and was therefore not included. Finally, residuals of our model plotted against body mass exhibited no

apparent trend and were randomly distributed. These finding suggest that our model can be reliably applied to individuals within the size range used in this study, and more importantly, to field-caught individuals sampled during estuarine residency.

The predictive model developed by this study can be used to estimate growth rates of juvenile Atlantic menhaden with inputs of RNA:DNA and temperature. The relatively strong relationship between these factors suggests that the model can provide a reliable method for estimating growth of field-caught individuals. Using this index, growth and subsequent production of potential estuarine nursery habitats can be quantified in order to spatially and temporally assess the quality of potential estuarine nursery habitats for this species. This information can be beneficial to managers in evaluating relative nursery habitat contribution, improving understanding of recruitment processes, and focusing management, conservation and restoration efforts for Atlantic menhaden.

Table 2.1. Summary of design of laboratory growth experiments on juvenile Atlantic menhaden. Each value in the temperature column represents an individual tank mean and standard error based on daily measurements taken over the 10 d experimental period.

Experiment no.	Size range (g)	Temperature (°C) (± S.E)	Ration (% body wt. d^{-1})
1	0.76 – 5.90	19.76 (0.15), 19.81 (0.15), 19.66 (0.15)	0, 5, 20
		20.61 (0.15), 20.42 (0.08), 20.47 (0.17)	0, 5, 20
		24.01 (0.17), 23.65 (0.17), 23.54 (0.12)	0, 5, 20
		27.73 (0.15), 27.82 (0.24), 27.92 (0.10)	0, 5, 20
2	1.14 – 3.34	20.21 (0.13), 20.1 (0.15), 20.17 (0.16)	0, 5, 20
		24.07 (0.18), 24.16 (0.16), 24.03 (0.28)	0, 5, 20
		23.63 (0.26), 23.85 (0.17), 24.11 (0.17)	50, 50, 50
		27.7 (0.18), 28.06 (0.07), 28.0 (0.13)	0, 5, 20
3	1.91 – 9.07	20.2 (0.11), 20.3 (0.10), 20.41 (0.10)	0, 5, 20
		23.69 (0.23), 23.73 (0.13), 23.97 (0.13)	0, 5, 20
		28.02 (0.14), 27.97 (0.15), 28.11 (0.14)	0, 5, 20
		30.04 (0.15), 29.96 (0.20), 30.22 (0.07)	0, 5, 20
4	13.00 – 36.94	20.76 (0.17), 20.96 (0.17), 20.72 (0.19)	0, 5, 20
		23.94 (0.10), 24.04 (0.12), 24.0 (0.17)	0, 5, 20
		27.97 (0.06), 28.21 (0.06), 27.7 (0.09)	0, 5, 20
		30.07 (0.07), 30.24 (0.06), 29.88 (0.11)	0, 5, 20
Overall	0.76 – 36.94	20.3 (0.10) 23.9 (0.05) 27.9 (0.05) 30.1 (0.06)	0, 5, 20, 50

Table 2.2. Pearson product moment correlation results for juvenile Atlantic menhaden calibration experiments

Variable	RNA	DNA	Temperature	*G*	body mass
RNA:DNA	0.70238 (**<.0001**)	-0.32997 (**0.0220**)	-0.41941 (**0.0030**)	0.80547 (**<.0001**)	-0.18136 (0.2173)
RNA (μg/mg wet tissue wt.)		0.38393 (**0.0071**)	-0.53931 (**<.0001**)	0.41716 (**0.0032**)	-0.66407 (**<.0001**)
DNA (μg/mg wet tissue wt.)			-0.14081 (0.3398)	-0.52299 (**<.0001**)	-0.72287 (**<.0001**)
Temperature (°C)				-0.02725 (0.8541)	0.18827 (0.2000)
G					0.01322 (0.9289)

Pearson product moment correlation (*r*) for variables (RNA:DNA, RNA, DNA, temperature and *G* (instantaneous growth rate) ($n = 48$). All *p*-values are shown in parentheses. Statistically significant ($p < 0.05$) values are in boldface.

Table 2.3. Estimation of parameters (± S.E.) in model relationship between instantaneous growth (G, d^{-1}) and experimental ration (*r*, % body wt.d^{-1}).

Model	Parameter estimates	r^2	p
$G = y_0 + \alpha(1 - e^{-\beta r})$	α = 0.0448 (± 0.005) β = 0.0979 (± 0.0295) y_0 = -0.0212 (± 0.0026)	0.73	< 0.0001

Table 2.4. Growth equations for juvenile Atlantic menhaden

y	x^1	x^2	Equation	adj R^2	p-value
G	RNA:DNA	-	$y = 0.00853(\text{RNA:DNA}) - 0.04243$	0.64	<0.0001
G	RNA:DNA	Temp	$y = 0.01021(\text{RNA:DNA}) + 0.00199(T) - 0.09929$	0.76	<0.0001

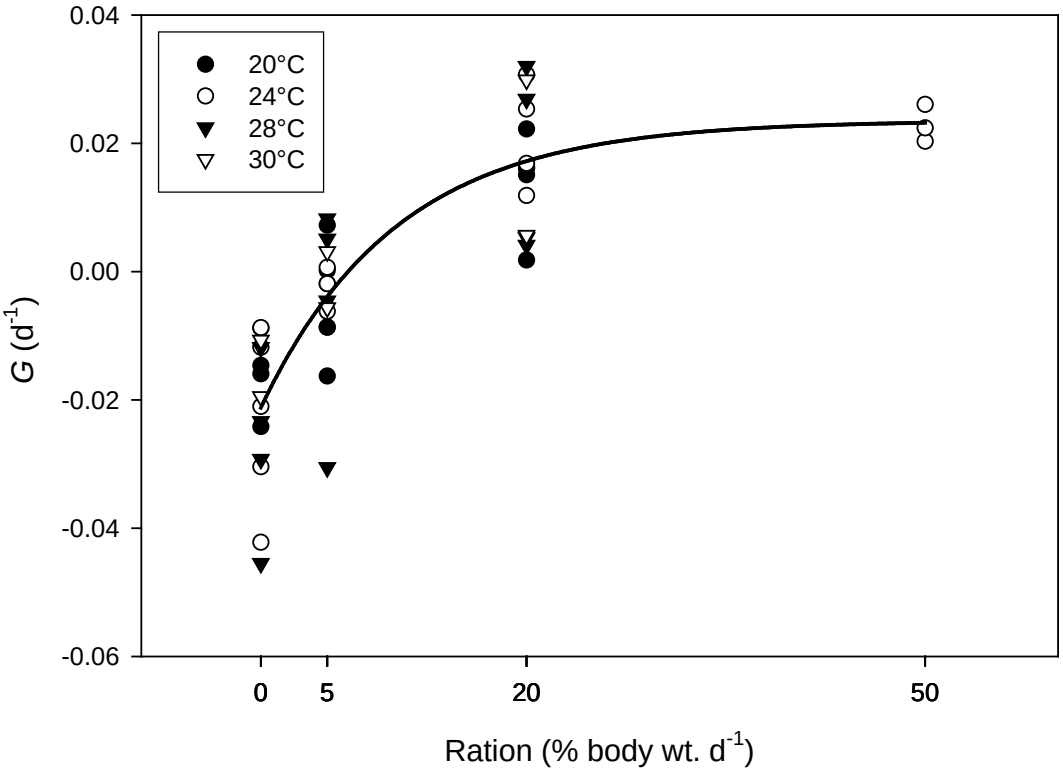


Figure 2.1. Relationship between ration and instantaneous growth (*G*) in juvenile Atlantic menhaden.

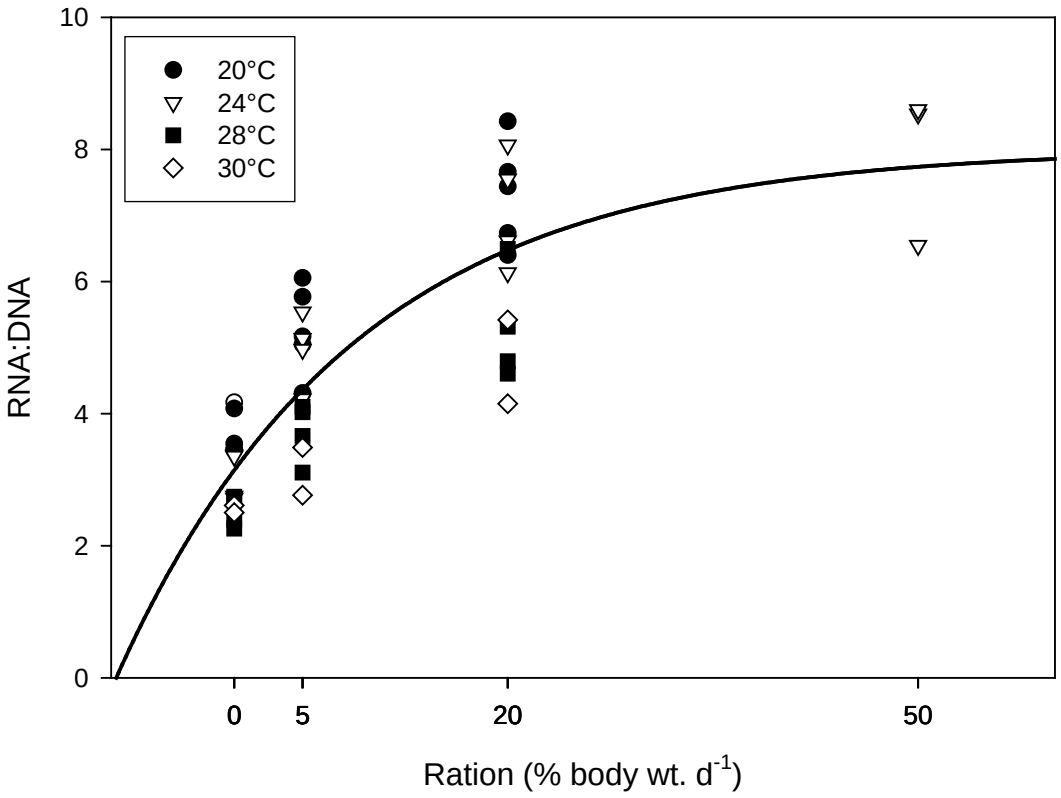


Figure 2.2. Relationship between ration and RNA:DNA in juvenile Atlantic menhaden

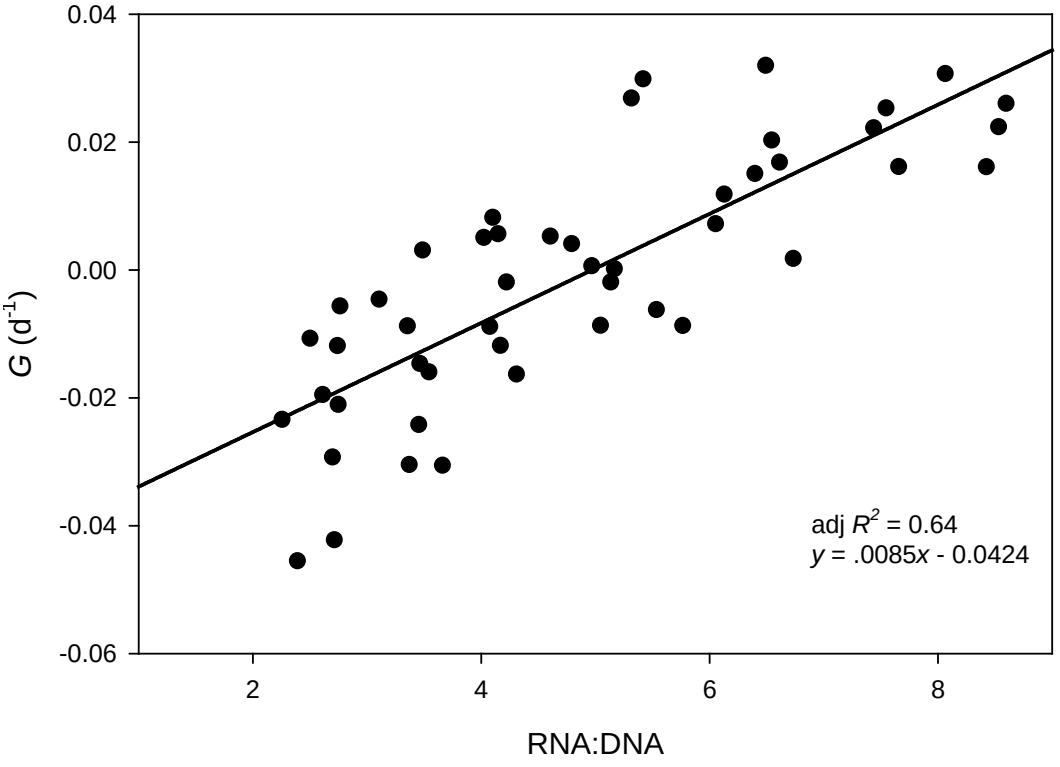


Figure 2.3. Relationship between tank mean RNA:DNA and instantaneous growth (*G*) in juvenile Atlantic menhaden

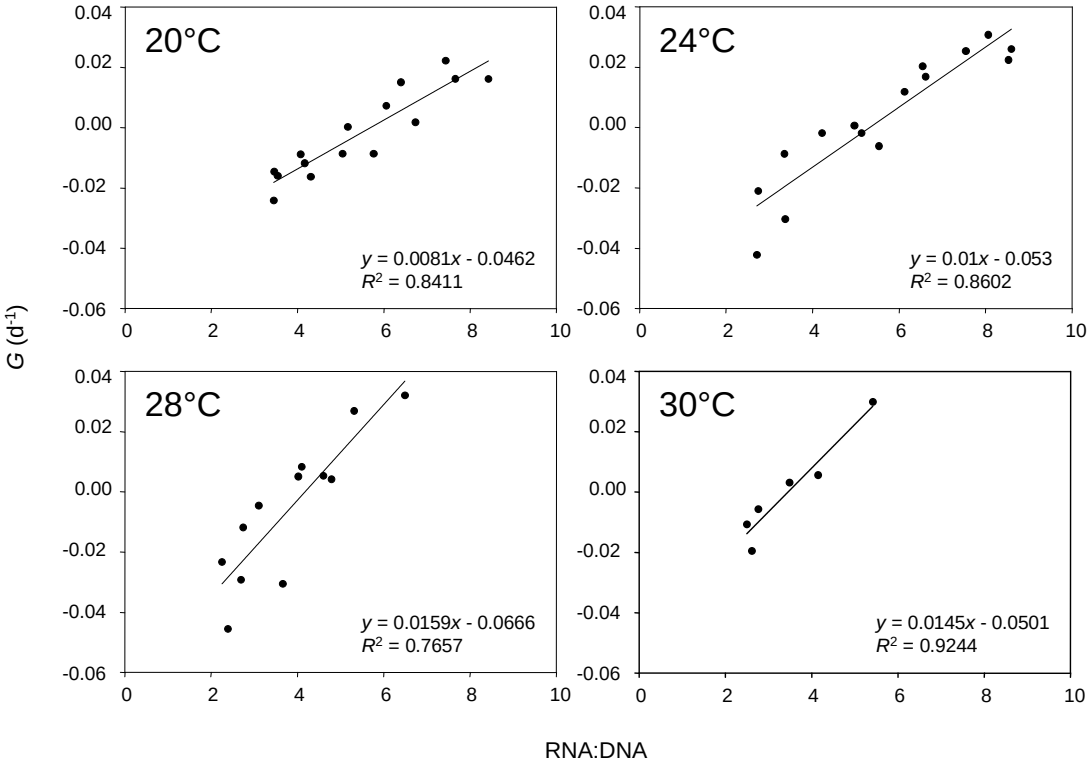


Figure 2.4. RNA:DNA-growth relationship at each temperature treatment for juvenile Atlantic menhaden

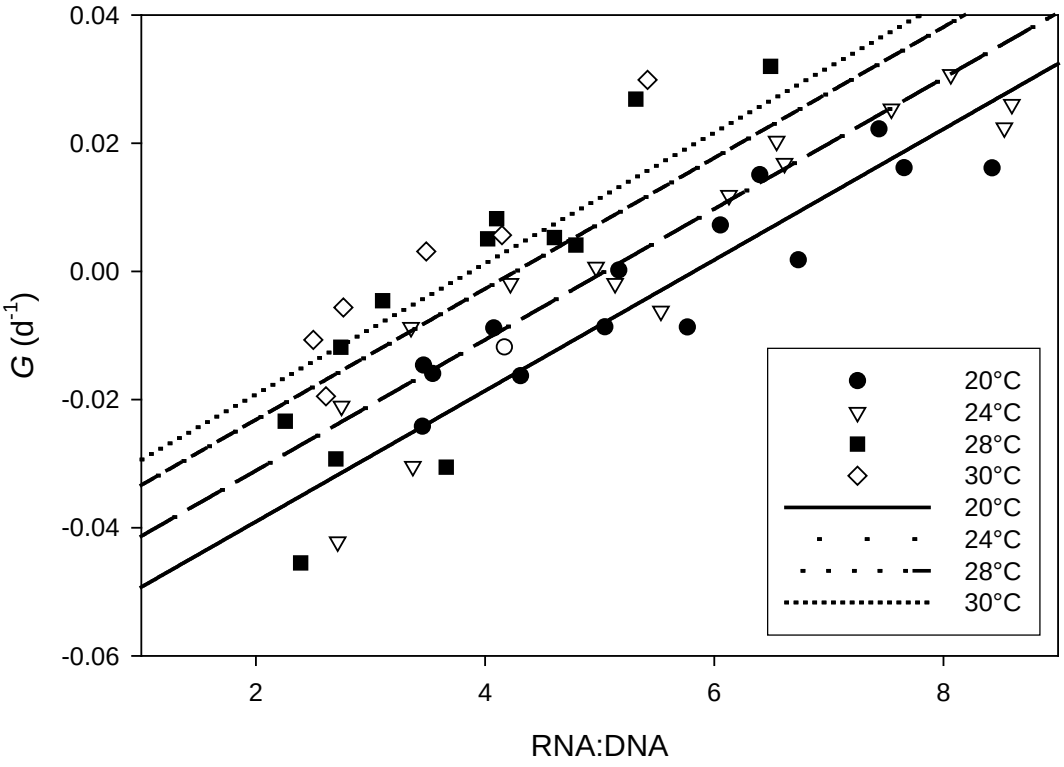


Figure 2.5. Relationship at each temperature treatment between tank mean RNA:DNA and instantaneous growth rate of juvenile menhaden. The regression lines illustrated are predicted from the model by substituting 20, 24, 28 or 30 as the temperature term

Chapter 3:

Temporal response (latency) of RNA-DNA ratio to changes in feeding regime in juvenile Atlantic menhaden *Brevoortia tyrannus*

Abstract

Fluorometric techniques were used to measure RNA:DNA values to evaluate the temporal response (latency) of nucleic-acid based condition to changes in feeding regime of juvenile Atlantic menhaden (*Brevoortia tyrannus*). The 20-day experiment consisted of a completely randomized design involving a fully fed control treatment and three additional treatments of varying starvation duration before reintroduction of food. Individuals were sampled at regular intervals throughout the experiment, and the time for a significant change in RNA:DNA to be observed and the rate of change following removal and reintroduction of food were determined. Following changes in feeding regime, RNA:DNA responded rapidly. After removal of food, RNA:DNA declined within 2 days, becoming significantly different from the control within 4-6 days. Following the reintroduction of food, RNA:DNA responded within 2 days; however, there was evidence of hysteresis after prolonged periods of starvation. By quantifying the temporal response of RNA:DNA in this species, reliable inferences regarding the temporal and spatial scale of nucleic-acid based estimates of condition and growth from field-collected individual can be made.

Introduction

Enhanced knowledge and understanding of growth dynamics is a priority for fisheries research and a vital component of fisheries management efforts. Increased growth rates during larval and juvenile life stages are typically associated with increased survivorship by reducing stage-duration (Houde 1987, Rice et al. 1993a, Rice et al. 1993b) and decreasing over-winter mortality of early life stages (Post & Evans 1989a, Post & Evans 1989b, Conover & Schultz 1997, Sogard 1997). Small variations in growth can lead to variation in mortality that has substantial impacts on recruitment success (Houde 1987).

Individual growth can be influenced by a range of factors including prey quality (Mazur et al. 2007), prey availability (Paperno et al. 2000, Graeb et al. 2004) and abiotic variables such as temperature, salinity and dissolved oxygen (Hettler 1976, Manderson et al. 2002, McNatt & Rice 2004). Knowledge regarding the relationships between environmental factors and growth may aid in the identification and improve our understanding of important biotic and abiotic processes regulating recruitment of fishes. For juvenile stages, these influencing factors and resultant growth rates often vary over small spatial and temporal scales, making indices of growth a frequently used metric to assess habitat quality (Sogard 1992, Meng et al. 2000, Nislow & Folt 2000, Le Pape et al. 2003, Amara et al. 2007, Glass et al. 2008). Moreover, it has been proposed that the relative value of a potential nursery habitat is determined by the contribution individuals residing in the habitat make to the ultimate level of recruitment (Beck et al. 2001). Because this contribution is a function of both the size and number of individuals surviving to adulthood (Beck et al. 2001),

growth rate estimates can be coupled with site-specific abundance to quantify relative habitat production in order to evaluate juvenile nursery habitats and identify relationships to environmental variables.

Due to the dynamic nature of aquatic environments and the vagility of juveniles of many fishes, measures of growth must be determined at fine spatial and temporal scales if environmental conditions observed at the time of sampling events are to be reliably associated to growth rates in specific habitats. To achieve this objective, the technique used to estimate growth must have a temporal resolution sufficiently small to provide information only on the growth achieved during recent habitat residency. The technique must also respond to the temporal variability of the environmental conditions in the habitat. Few conventional methods of estimating growth meet these standards. Caging studies have been used extensively to obtain information on growth rates of fishes (Duffy-Anderson & Able 1999, Phelan et al. 2000, Kellison et al. 2003). However, this technique prevents the natural movement of individuals into areas that would otherwise produce different rates of growth (Phelan et al. 2000), thereby potentially biasing estimates. Mark-recapture, size-at-age approaches to estimating growth integrate past growth over extended time periods and hence likely, multiple habitats and environmental conditions. Otolith-based growth estimates may be unsuitable for this application because of the potential lagged response of between somatic and otolith growth rates (Neilson & Geen 1985, Molony & Choat 1990, Rooker & Holt 1997). Furthermore, somatic and otolith growth can become uncoupled during periods of slow growth (Secor & Dean 1989,

Szedlmayer 1998). These two features of otolith-based approaches make them potentially unsuitable for this application.

Biochemical estimates are considered to be the most sensitive and effective means of estimating recent growth of larval and juvenile fish because of the rapid response at the cellular level to changes in external conditions (Robinson & Ware 1988, Ferron & Legget 1994, Theilacker & Shen 2001). In particular, nucleic acid-based indices have been used extensively to estimate recent growth (Chapter 2 and Bulow 1970, Buckley 1982, Buckley 1984, Bulow 1987, Foster et al. 1993, Malloy & Targett 1994a, Malloy et al. 1996, Rooker & Holt 1996, Caldarone 2005, Mercaldo-Allen et al. 2006, Mercaldo-Allen et al. 2008). Nucleic acid-based approaches have also been used to quantify the relative health or condition of larval and juvenile fishes (Buckley 1980, Wright & Martin 1985, Clemmesen 1987, Kimura et al. 2000, Fukuda et al. 2001, Kono et al. 2003). The ratio of RNA to DNA is often found to be the most sensitive indicator of changes in recent feeding and growth (Buckley 1979, Clemmesen 1987, Canino 1994, Suneetha et al. 1999, Catalan et al. 2007). The amount of DNA, remains relatively constant per cell and is a characteristic of individual species. Changes in DNA levels are indicative of changes in cell number. In contrast, RNA content fluctuates in response to ribosomal numbers and the level of protein synthesis (Bulow 1970, Buckley et al. 1984, Ferron & Leggett 1994). Therefore, the ratio of RNA to DNA levels provides a standardized measure of the protein synthetic capacity of cells, with higher RNA:DNA values suggesting increased potential for growth and enhanced condition.

Nucleic acids, particularly RNA:DNA values have been shown to respond to changes in feeding and condition on the order of hours to days (Wright & Martin 1985, Bulow 1987, Malloy & Targett 1994b, Arndt et al. 1996, Kono et al. 2003, Catalan et al. 2007). The rapid response of RNA:DNA can provide valuable information on spatial and temporal scales relevant to conditions at the time of sampling, allowing investigation of the relationship between biotic and abiotic factors and the variability in growth of larval and juvenile fishes. However, the temporal response of nucleic acid-based indices may be species-specific and often varies as a result of multiple factors including ontogenetic stage (Richard et al. 1991, Rooker & Holt 1996), feeding regime (Johnson et al. 2002), and temperature (Kono et al. 2003). If the assumption of rapid response is incorrect, inferred linkages between growth rates and environmental variables may be erroneous. Additionally, without determination of the temporal response of a measured nucleic acid parameter, neither the temporal nor spatial scale of index-based, habitat-specific growth estimates can be established. Therefore, quantification of the temporal response of a selected nucleic acid parameter to a change in condition is necessary to reliably apply a nucleic acid-based growth index to field caught individuals.

One species that may benefit from an enhanced understanding of relationships with the environment is Atlantic menhaden (*Brevoortia tyrannus*, hereafter menhaden). Menhaden is a highly abundant, obligate filter-feeding planktivore frequently occurring in dense schools ranging from Nova Scotia to central Florida. Ecologically, menhaden is a filter feeder (Durbin & Durbin 1975, Peters & Schaaf 1981, Lewis & Peters 1984, Friedland et al. 2006) and represent an important dietary

component for many species of fish (Sykes & Manooch 1979, Hartman & Brandt 1995, Overton et al. 2008), birds (Spitzer 1989) and marine mammals (Hildebrand 1963). Menhaden, therefore, occupy a central position in estuarine and coastal ecosystems (Baird & Ulanowicz 1989). Economically, this species supports valuable commercial reduction and bait industries (Ahrenholz et al. 1987).

Adult menhaden spawn in the coastal ocean. Larvae are transported to estuarine environments (Quinlan et al. 1999) where juveniles reside during their first year of life. Juvenile abundance indices for the Chesapeake Bay have declined since the 1970s (ASMFC 2006). The cause for the observed decline is uncertain. The adult stock is purportedly healthy (ASMFC 2006). Hypotheses related to changes in the adult age structure and oceanographic climate have been proposed (ASMFC 2004). Quinlan & Crowder (1999) identified processes occurring during the juvenile stage, coinciding with estuarine-residence as being the life history stage that is most important to determining population growth. Thus, it has also been hypothesized that poor juvenile growth and survival may account for the observed decline in the recruitment indices. Therefore, information regarding the growth and survival dynamics of estuarine-resident menhaden may be valuable to understand recruitment patterns and developing effective management strategies. To this end, in Chapter 2, I developed a predictive RNA:DNA-based index to estimate growth of field-caught menhaden. These growth estimates can be coupled with abundance data from fishery independent surveys to quantify and compare habitat-specific production of potential menhaden nursery habitats, and ultimately evaluate the abiotic and biotic factors influencing estuarine productivity dynamics for this species. However, to reliably

relate growth rate estimates to site-specific habitat residency and associated environmental factors, knowledge of the temporal response of RNA:DNA to changes in nutritional condition is required. Here, I report on laboratory experiments that investigated the temporal sensitivity of RNA:DNA in juvenile menhaden by quantifying the latency of RNA:DNA estimates to changes in feeding regime. The results of this study will help determine the temporal and spatial scales at which the previously developed RNA:DNA-based growth index can be applicable.

Materials and Methods

Latency experiments

The laboratory experiment was conducted using young-of-the-year, juvenile menhaden collected by beach seine from littoral habitats in the Patuxent River, MD. Fish were held for at least seven days in holding tanks to allow recovery from transportation and handling-induced stress, and acclimated to the experimental conditions for at least fourteen additional days before being used in experiments. During this period, fish were fed *ad libitum* pelleted food hourly, nine times daily (Zeigler Finfish Starter Meal, Gardners, PA, 0.42- 0.595 mm). Individual fish showing signs of injury or disease were not used in the experiments. A photoperiod of 14 hr light – 10 hr dark was employed throughout all phases of the work.

The temporal response experiment was conducted at 24°C over a period of 20 days from July 25 - August 14, 2008. The experiment was conducted as a completely randomized design involving four starvation period treatments of different duration. Experimental treatments consisted of a control fed *ad libitum* throughout the duration of the experiment and three starved/refed treatments. Each treatment was replicated

three times. All treatment groups had received consistent rations prior to use in the experiment to limit variation in initial RNA:DNA concentrations. To begin the experiment, 45 fish from the common stock tank were randomly assigned to each experimental tank. Subsequently, fish in fed treatments were fed nine times daily at the amount calculated to give a ration of 11% body weight.d^{-1}.$fish^{-1}$. Based on preliminary experiments and observations, this ration is above maintenance and close to *ad libitum*. At the beginning of the experiment fish in all tanks except those in the control treatment (0S – 20F) were starved. The refeeding treatments commenced after 2 (2S – 18F), 4 (4S – 16F), and 8 (8S – 12F) days. A sample of fish (n=5) was removed from each tank on days 0, 2, 4, 6, 8, 10, 12, 16 and 20. Subsequently, ration was adjusted to maintain a constant 11% body weight.d^{-1}.$fish^{-1}$. Immediately after sampling, each fish was euthanized, measured, weighed and stored at -80°C for subsequent biochemical analysis.

Fish used in the experiments ranged from 7.8 – 22.5g. The experiment used 12 circular, 511-l fiberglass tanks. Each tank was provided with flow through water from the Patuxent River. Because menhaden is a planktonic filter-feeder, serial filtration (10, 5 and 1 µm) of inflowing water was utilized to ensure reliable ration treatments were maintained. Water quality was monitored regularly and all tanks were maintained at 24°C throughout the experiment.

Biochemical analyses

The RNA:DNA levels of menhaden sampled during the experiment were analyzed following the protocol described in Chapter 2. I verified that sample degradation does not occur as a result of storage at -80C. Briefly, epaxial muscle was

dissected from individual fish and the RNA and DNA content of these muscle samples were quantified using the 1 dye/2 enzyme microplate fluorometric assay. Triplicate samples of muscle from each fish were analyzed in a random order. RNA:DNA values were calculated based on calibration curves developed for each microplate. Calibration relationships never explained less than 99% of the variation in the data.

Statistical analyses

Tank mean RNA:DNA levels were calculated from the mean of individual fish samples taken from each tank on each sampling day. Tank means were considered as replicates for each time point. Tukey's HSD tests were employed to determine the time point at which treatments became significantly different from the control (0S – 20F) after the onset of starvation and following reintroduction of food. To determine the rate of change of RNA:DNA to different periods of starvation, Fisher's LSD test was used to compare regression coefficients between treatments from the onset of starvation until either feeding was resumed or values became significantly different from the control treatment (0S – 20F). Similarly, regression coefficients were compared from the reintroduction of food until RNA:DNA values were no longer significantly different from the control treatment (0S – 20F).

Results

Response of RNA:DNA corresponded to changes in feeding conditions in juvenile Atlantic menhaden. Fish fed constantly throughout the 20 day experiment (0S -20F) maintained consistent RNA:DNA values until day 20 when values became

significantly lower from those observed on day 0 (Figure 3.1, $p = 0.03$). The 2S – 18F treatment mean RNA:DNA decreased from 5.63 ± 0.59 (mean ± S.E.) to 4.14 ± 0.05 (a 26.5 % reduction) after 2 days of starvation. The tank mean RNA:DNA subsequently increased to 4.96 ± 0.10 (19.8 % increase) by day 4 following refeeding (Figure 3.1 - A). However, RNA:DNA in the 2S – 18F treatment did not differ significantly from the 0S – 20F treatment during the experiment. In contrast significant differences between treatment and control RNA:DNA values were observed in the other treatments. During the 4d starvation treatment (4S-16F treatment), average RNA:DNA levels declined from 6.07 ± 0.52 (mean ± S.E.) to 3.77 ± 0.13 (a 37.9 % reduction) after 4 days of starvation (Figure 3.1 - B, $p = 0.03$). Following refeeding, the 4S – 16F treatment mean RNA:DNA increased to 4.69 ± 0.24 by day 6 (a 24.4 % increase) and was no longer significantly different from the control (Figure 3.1 - B). During the 8d starvation treatment (8S-12F), average RNA:DNA levels declined from 6.49 ± 0.49 (mean ± S.E.) to 3.45 ± 0.14 (a 46.8 % reduction) after 8 days of starvation (Figure 3.1 – C). Treatment RNA:DNA values were significantly different from the control after 6 days ($p = 0.01$). Following refeeding, the 8S – 12F treatment mean RNA:DNA increased to 4.74 ± 0.56 by day 16 (a 37.4 % increase) and was no longer significantly different from the control (Figure 3.1 – C).

RNA:DNA appeared to be a more sensitive index of feeding condition in juvenile menhaden than either RNA content or DNA content (Figure 3.2). Periods of starvation were characterized by a general decrease in RNA content and a concomitant increase in DNA content. Likewise, following refeeding, RNA content

increased while DNA content generally declined. These joint fluctuations of RNA and DNA content in response to periods of starvation and refeeding amplified the RNA:DNA signal in this study, making this measure most responsive to changes in feeding condition.

The rate of change of RNA:DNA to changes in feeding condition did not differ significantly between treatments. Regression coefficients describing the rate of decline of RNA:DNA from the onset of starvation until the point of significant difference from the control treatment (0S – 20F) of -0.745, -0.574 and -0.451 were estimated for treatments 2S – 18F, 4S – 16F and 8S -12F, respectively, (Figure 3.3). Regression coefficients describing the decline in RNA-DNA ratios among treatments did not differ significantly during periods of starvation in juvenile Atlantic menhaden. However, there was a tendency for slopes describing the response to longer starvation periods to be less steep than those describing shorter starvation periods. Likewise, regression coefficients of 0.407, 0.460 and 0.168 were observed for treatments 2S – 18F, 4S – 16F and 8S – 12F, respectively, from the reintroduction of food until RNA:DNA values were statistically indistinguishable from the control (0S-20F) treatment (Figure 3.4). The regression coefficients describing change in RNA:DNA to reintroduction of food did not differ significantly among treatments. Data describing recovery following 2 and 4 d of starvation were more similar than those describing recovery from the longer 8 d starvation period, and are suggestive of hysteresis in RNA:DNA levels.

Discussion

My results show that RNA:DNA responds rapidly to changes in feeding condition in juvenile Atlantic menhaden, supporting the utility of this index to quantify recent growth conditions for menhaden in the field. When food was removed, RNA:DNA values in all treatments declined by the next sampling period (2 days), suggesting a rapid response to changes in feeding conditions and the consequent response of RNA:DNA levels. When compared to those fish held under approximately *ad libitum* feeding conditions, statistically significant changes in RNA:DNA were detectable within 4 days of starvation. Though the overall rate of decrease in RNA:DNA slowed with increased starvation duration, potentially due to an RNA:DNA threshold under starvation conditions, the rates of decline of RNA:DNA did not differ significantly among starvation treatments. Equally, when food was reintroduced, RNA:DNA levels exhibited increases by the following sampling period (2 days) in treatments starved for only 2 and 4 days, becoming statistically indistinguishable from the control treatment. However, fish subjected to 8 days starvation required 6 days to exhibit increased RNA:DNA, suggesting a potential carry-over i.e., hysteresis effect to an extended period of starvation. However, regardless of starvation duration, RNA:DNA values eventually recovered to and were statistically indistinguishable from control values following the reintroduction of food in juvenile Atlantic menhaden.

An improved understanding and quantification of the temporal response (latency) of a selected condition or growth index is critical to obtaining accurate data regarding fish growth and to reliably evaluating relationships between growth and

environmental conditions in specific habitats at the time of sampling events (Ferron & Leggett 1994, Arndt et al. 1996, Buckley et al. 1999, Caldarone 2005). In their review of indices of growth and condition in fish, Ferron & Leggett (1994) identified three attributes of a "good" index: reliability, sensitivity and latency. They define reliability of an index as a measure of its accuracy and repeatability. I have shown previously that RNA:DNA is a reliable growth index for menhaden (Chapter 2). The results of Chapter 2 with regard to the high precision of the analyses also indicates that RNA:DNA is likely to be a sensitive growth index. Indeed, nucleic acid-based indices have been found to be among the most sensitive measures of recent growth, condition and feeding in larval and juvenile fish (Bulow 1970, Buckley 1979, Buckley 1980, Buckley 1984, Wright & Martin 1985, Fukuda et al. 1986, Bulow 1987, Clemmesen 1987, Robinson & Ware 1988, Ferron & Leggett 1994, Clemmesen 1994, Clemmesen & Doan 1996, Buckley et al., 1999). The experiment reported herein sought to evaluate the latency of the RNA:DNA index. Ferron & Leggett (1994) defined latency as the time required for a given change in food availability to be reflected as a significant change in the index of condition used. Because fish in the natural environment typically experience fluctuations in food availability occurring on short temporal scales, indices characterized by the shortest latency are of most utility to field studies (McLaughlin et al. 1995, Suneetha et al. 1999).

Many studies have investigated the response of nucleic acid-based measures to changes in feeding regime (Buckley 1979, Wright & Martin 1985, Jurss et al. 1986, Bastrop et al. 1991, Richard et al. 1991, Clemmesen 1994, McLaughlin et al. 1995, Arndt et al. 1996, Chung et al. 1998, Gwak & Tanaka 2001, Johnson et al. 2002,

Caldarone 2005). Studies that compared different nucleic acid-based indices have established RNA:DNA as the most responsive (Clemmesen 1987, Canino 1994, Suneetha et al. 1999, Catalan et al. 2007). My findings of a significant change in RNA:DNA within four days in response to either initiation of starvation or reintroduction of food falls within the range of previous results found in other studies (Wright & Martin 1985, Clemmesen 1987, Mugiya & Oka 1991, Canino 1994, Clemmesen 1994, Rooker & Holt 1996, Stuck et al. 1996, Suneetha et al. 1999, Kimura et al. 2000, Vidal et al. 2006, Catalan et al. 2007, Stierhoff et al. 2009). Further work is required to quantify the temporal response of RNA:DNA in juvenile menhaden at even shorter time scales, as some research has established changes in RNA:DNA within hours of a change in feeding regime (Wright & Martin 1985).

The decreases in RNA:DNA observed in response to starvation were produced by immediate reductions in RNA content and accompanied by a slight increase in DNA content under starved conditions, similar to results found in previous studies (Buckley 1979, Stuck et al. 1996, Chung et al. 1998, Suneetha et al. 1999, Gwak & Tanaka 2001). Starvation typically results in degradation of all types of RNA and often a concomitant increase in DNA content per unit tissue weight. The observed increase in DNA is the result of an increased number of cells per unit tissue caused by catabolism of intracellular constituents, reduction of cytoplasmic volume and decreased cell weight under starved conditions (Mustafa & Mittal 1982). After reintroduction of food, pre-starvation cellular conditions are restored, resulting in larger cells per unit tissue mass and subsequent decline in DNA concentration (Mustafa & Mittal. 1982). The apparent conservation of DNA under periods of stress

in fish allows for RNA measurements to be standardized to cell number, making measurements of RNA:DNA highly sensitive to starvation conditions (Buckley et al. 1999).

The relatively immediate response of RNA content to changes in feeding supports the utility of our RNA:DNA-based growth index to detect recent changes in growth and condition in juvenile menhaden. Several studies have observed a considerable lag between changes in short-term feeding regime and the response of RNA content. These studies indicate that changes in rates of protein synthesis precede changes in RNA concentration (Loughna & Goldspink 1984, McMillan & Houlihan 1988). Because changes in protein synthesis occur in response to changes in both the number of ribosomes and in the activity of those ribosomes (Young 1970, Henshaw et al. 1971, Loughna & Goldspink 1984), these findings have been attributed to changes in ribosomal activity as opposed to increases or decreases in RNA concentration. My results are contrary to these findings, showing no substantial delayed response time.

Statistical comparison of the rates of change of RNA:DNA in response to changes in feeding conditions detected no significant differences among treatments. However, the rate of decline decreased with increasing starvation duration. This diminishing rate of decline may be attributable to RNA:DNA levels approaching a lower limit, or threshold value during prolonged periods of starvation, as RNA:DNA levels of fish starved for 8 days appeared to stabilize. The juvenile menhaden in this study exhibited a mean basal RNA:DNA ≈ 3.5 after three days of food deprivation. Similarly, Mugiya & Oka (1991) observed RNA:DNA values maintained at a basal

level after 3 days starvation in rainbow trout *Oncorhynchus mykiss*. After the reintroduction of food, menhaden starved for 2 and 4 days showed immediate increases in RNA:DNA values by the next sampling period. RNA:DNA values of menhaden starved for 8 days, however, did not respond as rapidly. The rate of change of the 8S – 12F treatment following refeeding, although statistically similar, was reduced compared to fish starved for lesser time periods, suggesting the temporal response of RNA:DNA in juvenile menhaden may decline after prolonged periods of starvation or exposure to other stressors. Additionally, although RNA:DNA values of treatments 2S - 18F and 4S – 16F became statistically indistinguishable from the control treatment only 2 days following refeeding, RNA:DNA levels of starved treatments remained below that of the control until day 16, at which point RNA:DNA levels of the control had declined, possibly for reasons described below.

I did not find evidence of a compensatory response of RNA:DNA to changes in ration, as has been shown in other research (Miglavs & Jobling 1989, Malloy & Targett 1994a, Catalan et al. 2007). Following refeeding, Malloy & Targett (1994a) observed RNA:DNA values increase to levels above those observed prior to starvation in summer flounder. Furthermore, Catalan et al. (2007) found that the response of RNA:DNA following reintroduction of food was positively related to the duration of starvation. Miglavs & Jobling (1989) attribute the compensatory response to hyperphagic feeding or enhanced conversion efficiency following reintroduction of food after a period of malnourishment. It is conceivable that my method of feeding during the experiment prohibited menhaden from acquiring food at elevated levels required to produce a compensatory response. Because menhaden obtain food by

filtering particles from the water column, coupled with the sinking nature of the fish meal used in my study, fish would have to ingest sufficient quantities of food before it sank to the floor of the experimental tank, where it would become unavailable to the menhaden. I attempted to counteract this limitation by feeding nine times throughout the day; however, it is possible that individuals may not have been able to take full advantage of all food offered. Alternatively, the decreased response of RNA:DNA after starvation may be due to an inefficiency to ingest food or convert to required energy after a period of decreased food intake. Perhaps juvenile menhaden require a period of acclimation to return to levels of feeding and conversion efficiency maintained prior to undernourishment. Regardless, the rate of response of RNA:DNA in juvenile menhaden following reintroduction of food appears to be dependent upon the duration of the food deprivation.

RNA:DNA values of fish subjected to the control treatment (0S – 20F) remained relatively consistent until day 16 when they began to decline. In comparison to values observed on day 0, RNA:DNA became significantly different on day 20. I expected that under *ad libitum* feeding conditions, RNA:DNA values should have remained constant throughout the experiment. There are several possible explanations. I believe that the periodic removal of individuals from experimental tanks during each sampling period may have been responsible for the observed declines in RNA:DNA near the end of the experiment. As mentioned, at each sampling period five individuals were removed for biochemical analysis from each experimental tank. Therefore, by day 16, only 5 – 10 fish remained in each tank. Menhaden is a schooling species and prefers to congregate in aggregations. The low

number of individuals in each tank compared to earlier in the experiment may have imposed stress on remaining individuals, ultimately lowering RNA:DNA. Similarly, with fewer individuals composing schools within a tank, the time required to detect food was likely slower, and competition for food between individuals lower by the end of the experiment. Potentially slower recognition of food and/or decreased feeding rates may have contributed to decreased ingestion of food before particles sank to the floor of the tank, becoming unavailable for consumption. Additionally, as fish were removed for subsequent analysis, food was supplied to the tanks in proportion to the weight of remaining individuals. Thus lower concentrations of food were added over the course of the experiment. However, the size of the experimental tanks remained constant. Therefore, as the experiment progressed, fewer individuals were required to search the same volume of water to encounter lower concentrations of food. Durbin & Durbin (1983) found a direct relationship between menhaden swimming speed and the concentration of plankton in the environment. Therefore, individuals remaining by day 16 were likely swimming more slowly, consuming less food, which contributed to a lower positive energy balance (Macy et al. 1990), and decreased RNA:DNA values. It is possible that any of these factors or a combination may have contributed to the decline in RNA:DNA seen in the control treatment by the end of the experiment.

This study represents the first examination of the latency of RNA:DNA in response to changes in ration in juvenile Atlantic menhaden. Although my results support the ability of RNA:DNA to detect short-term changes in condition and hence, provide a means of measuring growth potential on recent time scales, further research

is desired to more comprehensively describe the temporal dynamics of RNA:DNA in this species. Investigation of several factors and their relationship to the utility of RNA-DNA ratios in menhaden is warranted.

My study was conducted at 24°C. This temperature was chosen to reflect the median temperature experienced by juvenile menhaden during estuarine residence in Chesapeake and Delaware Bays. Had experiments been conducted at temperatures above or below this level, potentially different results regarding the response time of RNA:DNA may have resulted. Further experimentation on the response of RNA:DNA at different thermal regimes is required for full elucidation of RNA:DNA-temperature dynamics. Relationships between RNA:DNA and growth rate have been found to be temperature dependent in several studies (Buckley 1982, Buckley et al. 1984, Caldarone et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006) and specifically in juvenile Atlantic menhaden (Chapter 2). Typically, as temperature increases, lower RNA:DNA values are associated with increased rates of growth. This has been attributed to a compensatory mechanism of increasing ribosomal numbers at lower temperatures (Goolish et al. 1984, Houlihan 1991). Suneetha et al. (1999) and Kono et al. (2003) observed higher responsiveness of RNA:DNA to starvation at increased temperatures, and Jurss et al. (1987) noted higher RNA:DNA in both fed and starved fish at lower temperatures. Conversely, in response to changes in feeding conditions, RNA:DNA changed more rapidly at lower temperatures in juvenile summer flounder (Malloy & Targett 1994a). The observed unpredictability in the response of RNA:DNA to variable temperatures requires the quantification of the temporal response over a range of potential thermal scenarios.

Because juvenile Atlantic menhaden will experience a range of thermal conditions during estuarine residence time, a thorough understanding of the effect of temperature on the temporal response of RNA:DNA is required to obtain reliable nucleic acid-based estimates of growth in the field. Together, these studies indicate that the temperature-dependence of the sensitivity and latency of RNA:DNA indices (sensu Ferron & Leggett) remains undescribed.

Similarly, the response of RNA:DNA to feeding conditions and other factors is often dependent upon size and ontogenetic stage (Buckley et al. 1999). Throughout growth and development, energy will be allocated to various metabolic pathways and as such, the response of RNA:DNA may be variable during different life history stages. The predictive RNA:DNA-growth model developed in Chapter 2 was intended for juvenile menhaden, approximately 35 – 140 mm TL, residing in estuarine habitats during their first year of life. Individuals in this study were 90 – 129 mm TL; and therefore, do not fully encompass the range of sizes present during estuarine residency. The response of growth and RNA:DNA to starvation and other stressors is likely different between menhaden of different size classes. For example, larger individuals found later in the growing season may possess enhanced energy reserves that serve to dampen the negative effects of starvation, thereby lessening observed declines in RNA:DNA levels. Rooker & Holt (1996) found that RNA:DNA in red drum was less responsive to starvation with increasing age. Conversely, smaller menhaden collected shortly following ingress will likely possess greater growth potential than larger individuals found later in the season, and therefore exhibit a greater range of RNA:DNA in response to feeding and growth conditions.

To fully understand the temporal response dynamics of juvenile menhaden throughout growth and development, further experimentation should be conducted which expands the size range of experimental individuals to that which is found in the estuarine environment during their first year of life. By quantifying the temporal response dynamics over all size ranges of estuarine-dependent individuals, more reliable associations can be determined between RNA:DNA, growth and environmental factors observed at the time of sampling events.

This study quantified the responsiveness of RNA:DNA to the abrupt change in feeding from *ad libitum* to starvation conditions. However, in the natural environment changes in feeding regime are likely less drastic, and as such, the response of RNA:DNA less pronounced. Therefore, quantification of the temporal sensitivity to intermediate changes in feeding is desired to ensure reliable estimates of growth and condition in the field. For instance, Johnson et al. (2002) observed that intermediate feeding levels maintained relatively constant RNA:DNA levels, suggesting that this biochemical measure may be unable to detect subtle changes in feeding condition in the wild. Elucidation of such detection limits is necessary to make reliable inferences regarding the condition and growth of field-caught individuals. Further experimentation including treatments of intermediate feeding similar to Wright & Martin (1985), Arndt et al. (1996) and Johnson et al. (2002) may help to fully characterize the temporal response of RNA:DNA to realistic changes in feeding and growth conditions in juvenile Atlantic menhaden.

Quantification of the temporal response of any laboratory-derived index is a necessary prerequisite to the field application of a selected parameter as a measure of

growth or condition. The results of the present study suggest that RNA:DNA provides a highly sensitive measure of recent feeding, and thus a reliable measure of potential growth in juvenile Atlantic menhaden. The description of the temporal dynamics of RNA:DNA obtained from this study will allow valid inferences to be made regarding RNA:DNA, growth and their relationships to specific habitats and environmental variables.

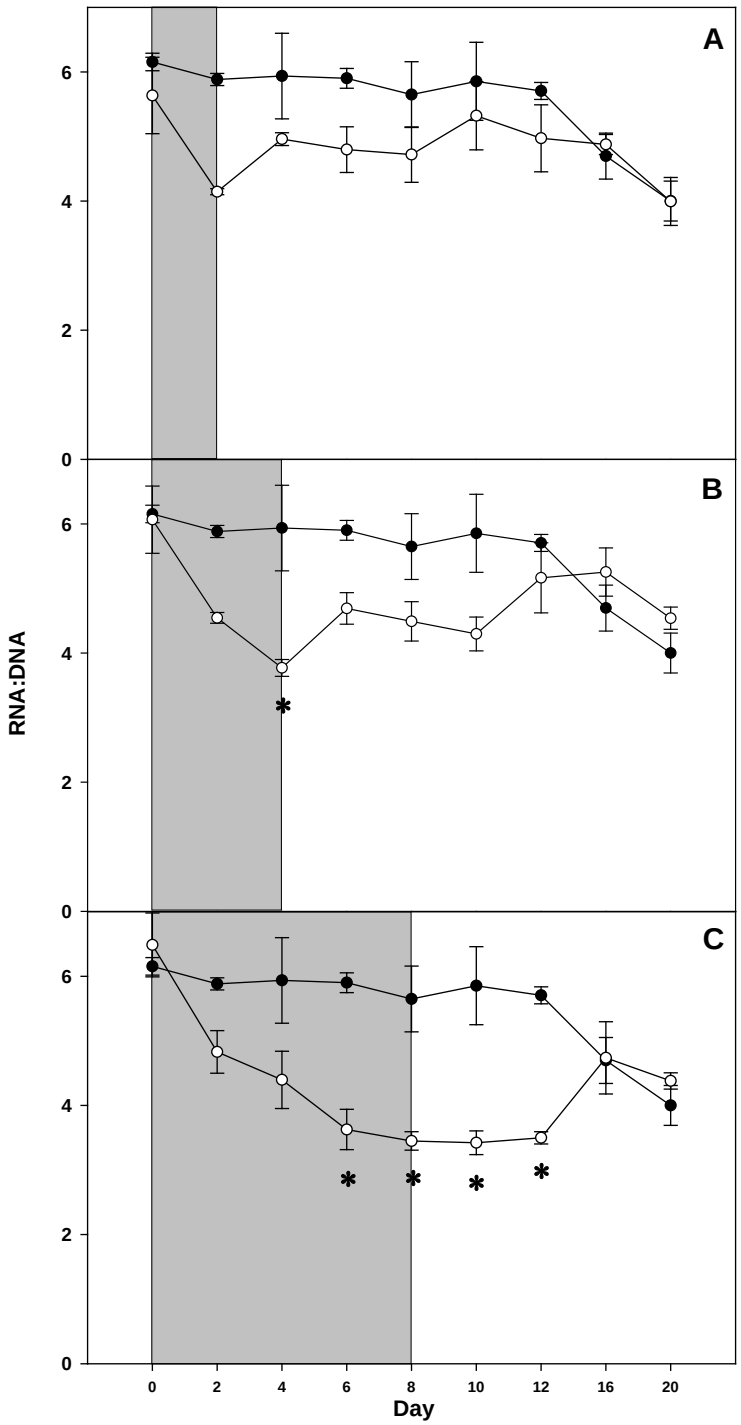


Figure 3.1. Response of RNA:DNA to changes in feeding condition in juvenile Atlantic menhaden. Treatment mean RNA:DNA (± S.E.) in continuously fed control treatment (closed circles) compared to starved/refed treatments (open circles): A) 2S – 18F, B) 4S – 16F and C) 8S – 12F. Shaded area represents period of starvation. Significant differences in RNA:DNA between treatment and control at a given sampling event represented by asterisks

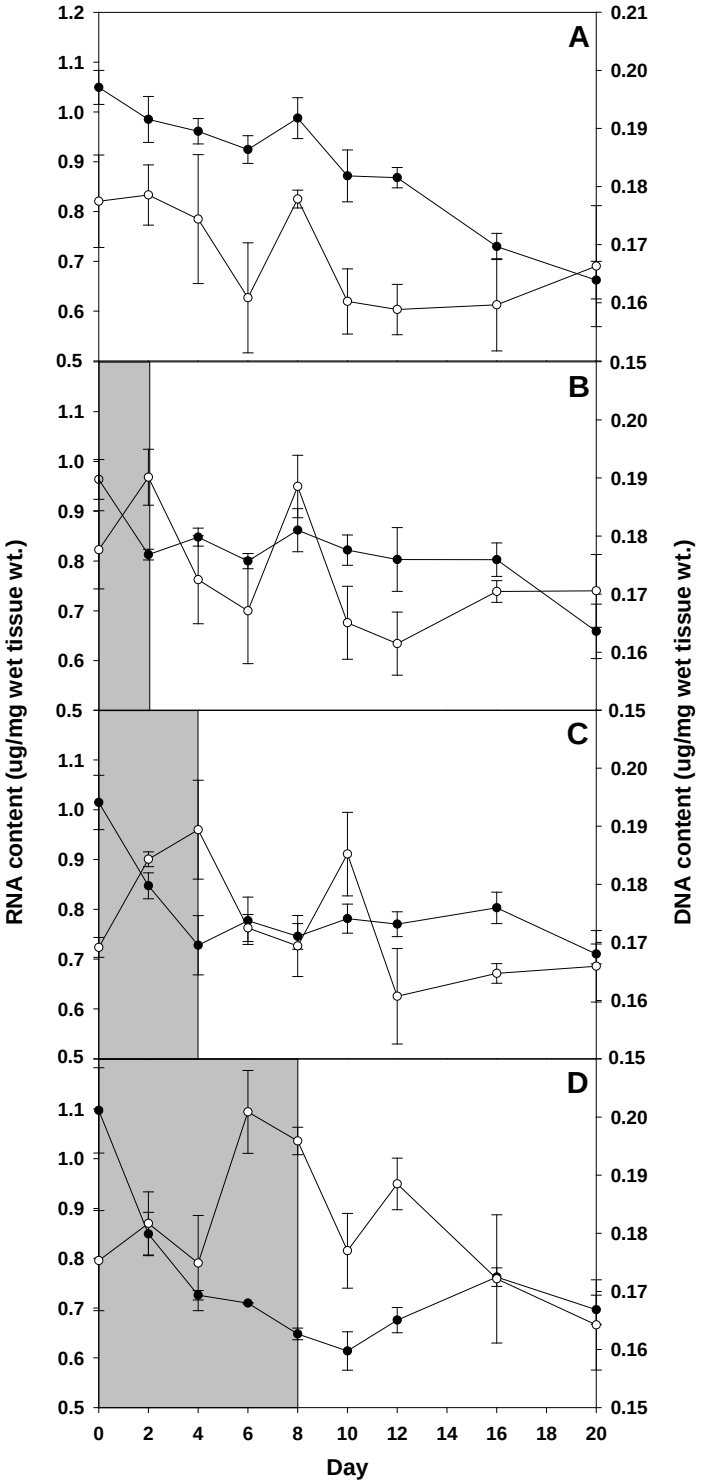


Figure 3.2. Response of RNA content (closed circles) and DNA content (open circles) to changes in feeding condition in juvenile Atlantic menhaden. Treatment mean RNA and DNA content (± S.E.) in A) control, B) 2S – 18F, C) 4S – 16F and D) 8S – 12F treatments. Shaded area represents period of starvation.

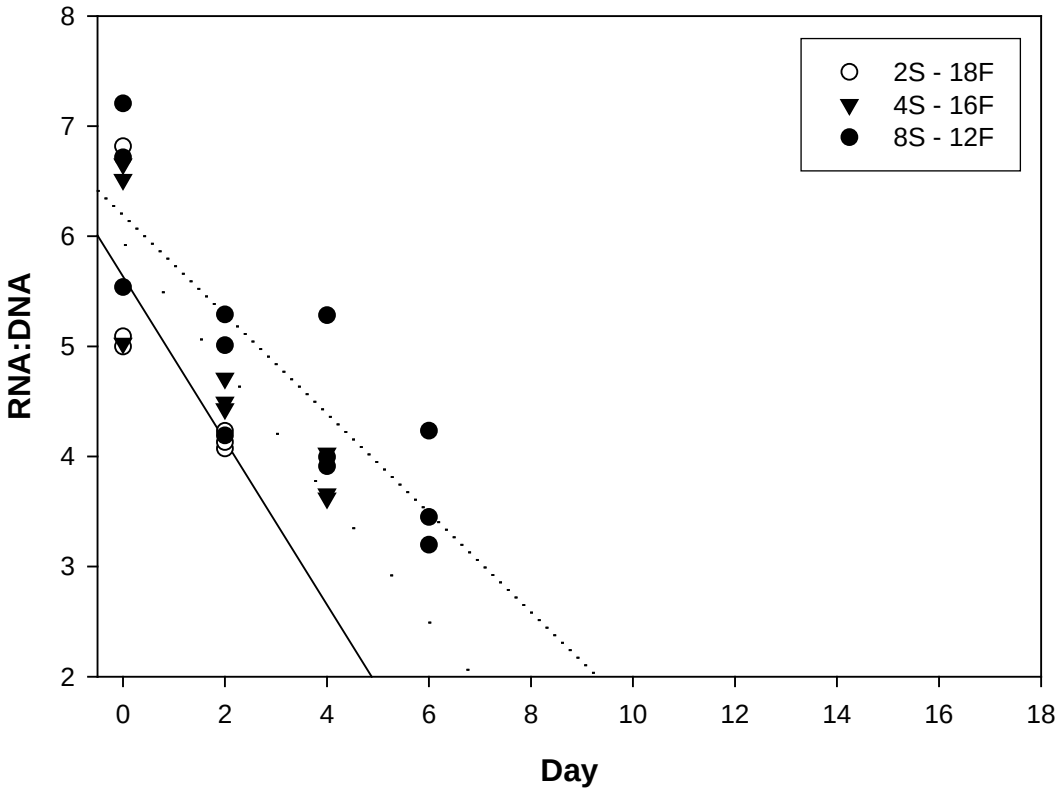


Figure 3.3. Regression of experimental treatments from the onset of starvation until either feeding was resumed (2S – 18F) or RNA:DNA values became significantly different from the control. Regression lines for the 2S – 18F (solid), 4S – 16F (dashed) and 8S – 12F (dotted) treatments shown.

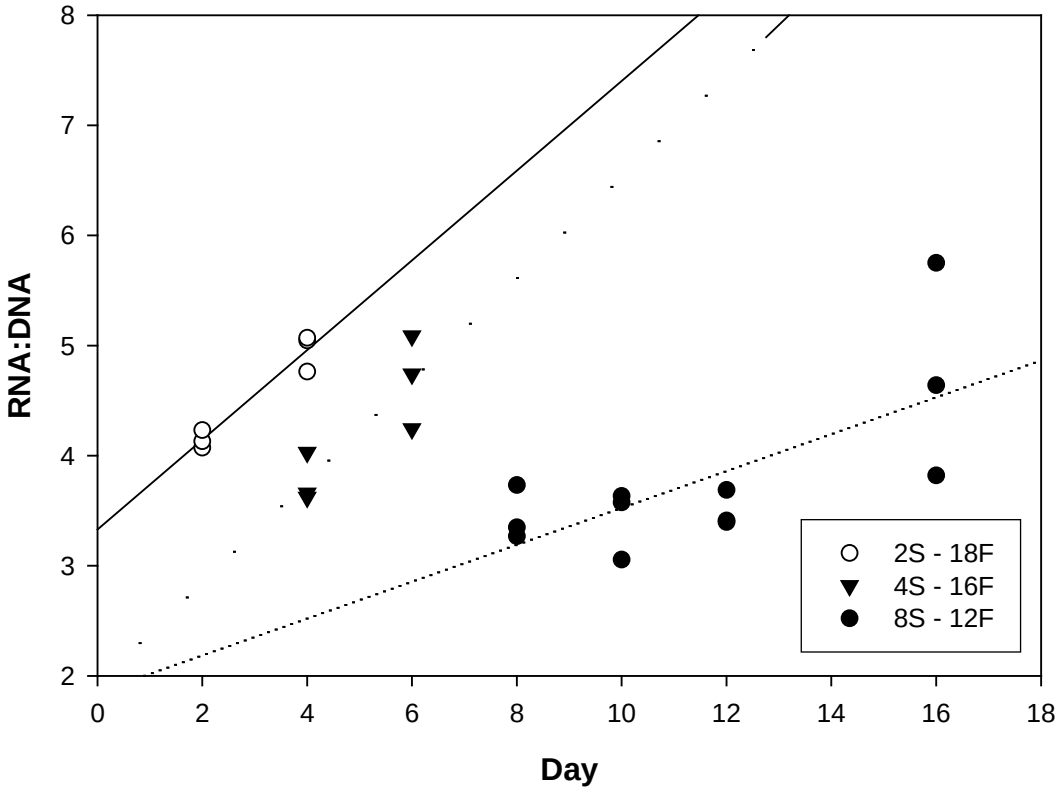


Figure 3.4. Regression of experimental treatments from the reintroduction of food until RNA:DNA values were no longer significantly different from the control. Regression lines for the 2S – 18F (solid), 4S – 16F (dashed) and 8S – 12F (dotted) treatments shown.

Chapter 4:

A preliminary assessment of broad- and fine-scale patterns in RNA:DNA-based growth, abundance and production of juvenile Atlantic menhaden in the Chesapeake and Delaware Bays

Abstract

RNA:DNA-based estimates of instantaneous growth in the field were combined with site-specific abundance estimates to calculate the production of habitats within the Chesapeake and Delaware Bay estuaries. High spatiotemporal variability characterized both broad-scale (system-level) and fine-scale (site-level) estimates of growth, abundance and production. Z-scores indicated specific sites that exhibited growth consistently above- or below-average within years in both 2007 and 2008; however, the high frequency of zero hauls generally dampened potential site-specific differences in abundance and production. These results suggest specific sites do not provide sufficient consistency to be classified as nurseries, but rather juvenile menhaden utilize a mosaic of sites within estuaries to promote growth, survival and production. Therefore, designation of essential fish habitat for the purposes of conservation and restoration may prove difficult; however, the identification of environmental variables related to observed patterns in site-specific production may provide valuable insight for the management of this species.

Introduction

Many fish species utilize estuarine nursery habitats during early-life stages (June & Chamberlain 1959, Weinstein 1979, Nixon 1980, Hoss & Thayer 1993, Able & Fahay 1998, Able 1999, Minello et al. 2003). Estuaries offer a variety of habitat types for shelter and protection from predators, and provide favorable physicochemical conditions and prey resources. These attributes, along with the highly productive nature of the estuarine environment, make nursery habitats critical to the growth and survival of estuarine-dependent fish species (Miller et al. 1985, Beck et al. 2001). However, the productivity of nursery habitats is generally not homogenous within or among estuaries. Beck et al (2001) define a habitat as a nursery if it produces disproportionately more recruits per unit area than do other habitats. The number of recruits that a nursery habitat contributes to the population is controlled by factors that vary both spatially and temporally (Manderson et al. 2002). Identifying which factors influence the relative production of nursery habitats and how these factors vary over space and time will increase our understanding of population dynamics and recruitment, and aid in the design and assessment of management efforts for estuarine fishes.

A recent priority of fisheries management is the designation of essential fish habitat (EFH), defined by the Magnuson-Stevens Act as *those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity* (NOAA 2007). The criteria used to classify areas as EFH require site-specific information regarding abundance, growth, survival and production, all of which can be used to assess the relative contribution of nursery habitats. The abundance of individuals

within a habitat may provide valuable information regarding the ability of a habitat to serve as EFH for a specific species. However, these data alone cannot reliably be used to estimate the contribution of a specific habitat, because it is often uncertain as to whether or not individuals residing in a particular habitat will survive to adulthood (Beck et al. 2001). Because fish growth rates are generally positively associated with survival, estimates of growth when combined with habitat-specific abundances can provide an indicator of habitat quality (Sogard 1992, Meng et al. 2000, Nislow & Folt 2000, Le Pape et al. 2003, Amara et al. 2007, Glass et al. 2008). Rapid growth is thought to increase the probability of survival in larval and juvenile fishes by decreasing the time spent in size-selective predation ranges (reduced stage-duration) and lowering over-winter mortality rates (Houde 1987, Miller et al. 1988, Post & Evans 1989a, Post & Evans 1989b, Rice et al. 1993a, Rice et al. 1993b, Conover & Schultz 1997, Sogard 1997, Grant & Tonn 2002, Huss et al. 2008). Beck et al. (2001) describe the contribution of a habitat as a function of both the size and number of individuals recruiting to the adult spawning population. Therefore, the quantification of nursery habitat production requires data regarding site-specific abundance and growth rates of individuals. Coupling these values will generate a site-specific production estimate which can be used to assess relative habitat contribution and identify potential factors influencing variability in nursery habitat contribution.

Although reliable site-specific abundance estimates can usually be acquired without difficulty, growth rate estimates on the same spatial and temporal scales are more difficult to obtain. Established techniques for estimating growth such as size-at-age and otolith-based measures are retrospective, and may integrate past growth over

multiple habitats, particularly in relatively mobile fish species. These growth estimation methods may provide unreliable estimates due to the potential lagged response of otolith growth to short term somatic growth rates (Neilson & Geen 1985, Molony & Choat 1990, Rooker & Holt 1997). Additionally, correlations between incremental growth of otoliths and short term somatic growth rates can become dissociated or uncoupled, particularly during periods of reduced growth (Secor & Dean 1989, Szedlmayer 1998). For example, Ahrenholz et al. 1995 reported that deposition of otolith growth increments in Atlantic menhaden (*Brevoortia tyrannus*) was less than daily at growth rates less that 0.3 mm. d^{-1}, making predictions of somatic growth from increment width potentially unreliable. These limitations reveal the need for a measure of growth that responds on the same spatial and temporal scale as respective site-specific abundance estimates.

Nucleic acid-based growth indices represent a reliable tool for estimating recent somatic growth in relation to specific habitat residence. Nucleic acid-based measures have been shown to respond to recent feeding and growth of larval and juvenile fish (Chapters 2 and 3, and see also Wright & Martin 1985, Malloy & Targett 1994a, Rooker & Holt 1996, Suthers et al. 1996, Smith & Buckley 2003). In early life stages, a major proportion of consumed energy is allocated to somatic growth (Houde & Zastrow 1993). Because ribonucleic acid (RNA) content fluctuates in response to the amount of protein synthetic machinery and ribosomal activity, it represents an indirect measure of feeding and growth rate (Bulow 1970, Buckley et al. 1984, Ferron & Leggett 1994). In contrast, deoxyribonucleic acid (DNA) content within cells remains relatively constant. Thus, RNA can be normalized with DNA

(RNA:DNA) to account for changes in cell number to yield a growth index. These nucleic acid measures respond rapidly, on the order of hours to days (Foster et al. 1993, Malloy & Targett 1994b, Rooker & Holt 1996, Stierhoff et al. 2009), providing a recent measure of condition and growth, corresponding to habitat specific abundance estimates and environmental conditions (Buckley 1984, Bulow 1987, Ferron & Leggett 1994, Buckley et al. 1999). Because estuarine environments exhibit small-scale spatial and temporal variability, the rapid response of nucleic acid-based growth indices can provide a valuable tool for evaluating growth and production of nursery habitats and associated abiotic factors.

Atlantic menhaden (*Brevoortia tyrannus* – hereafter menhaden) is considered an important species both ecologically and economically to the mid-Atlantic ecosystem. Ecologically, menhaden functions as a planktivorous filter feeder. Its dense schools can filter large amounts of plankton and organic detritus, potentially improving water quality (Durbin & Durbin 1998). Menhaden also serve as an important forage species to many piscivores such as striped bass, weakfish and bluefish, representing an important trophic link between primary production and higher trophic levels (Baird & Ulanowicz 1989). Economically, menhaden supports valuable commercial reduction and bait industries along the Atlantic coast.

Menhaden spawns predominantly in coastal ocean environments and larvae are transported to estuarine nursery habitats (Quinlan et al. 1999) where they grow and develop during their first year of life (Ahrenholz 1991). Since the 1970s, juvenile menhaden have experienced declines, as indicated by coastwide juvenile abundance indices (ASMFC 2006). In particular, declines in the Chesapeake Bay may be a

result of reduced survival of early-life stages during estuarine residency (ASMFC 2004). Quinlan & Crowder (1999) identified survival during those early life stages corresponding to periods of estuarine residence as the most important in determining population growth rates of Atlantic menhaden. The ASMFC (2004) identified estuarine habitats as those most critical to menhaden development and survival, as well as most vulnerable to anthropogenic alteration. Both the quantity and quality of estuarine menhaden habitat may have been altered by increased development and consequent increases in nutrient and chemical pollutants and habitat modification (ASMFC 2004). These concerns have prompted recognition of the need for identification, conservation and restoration of habitats critical to Atlantic menhaden survival and recruitment.

The objective of this study is to combine site-specific abundance and growth rate estimates to quantify relative habitat production in the Chesapeake and Delaware Bays. These values can be used to compare relative habitat qualities for Atlantic menhaden as well as investigate associations between juvenile menhaden dynamics and environmental factors. A central goal was to determine whether there are specific sites that promote consistently high production and represent high quality habitats.

Materials and Methods

Field

Field sampling for young-of-the-year Atlantic menhaden was conducted periodically between June 6 – November 20, 2007 and between June 11 – November 17, 2008. Sampling was conducted by scientists from the Chesapeake Biological

Laboratory (CBL), the New Jersey Department of Environmental Protection (NJDEP), the Maryland Department of Natural Resources (MDNR), the Virginia Institute of Marine Science (VIMS) and the University of Delaware (UD). Sampling protocols were standardized among institutions. In the Delaware Bay, sampling was conducted in the lower Delaware River and upper Delaware Bay (Figure 4.1). In the Chesapeake Bay, samples were collected from the Northeast River, Susquehanna Flats, Bohemia River, Elk River, Sassafras River, Worton Creek, Chester River, Tuckahoe Creek, Choptank River, Patuxent River, Nanticoke River, Potomac River and James River (Figure 4.1). In our analysis, the Northeast River, Susquehanna Flats, Bohemia River, Elk River, Sassafras River and Worton Creek were classified as Upper Bay. Thus analyses involved eight distinct systems: Delaware Bay, Upper Chesapeake Bay, and the Chester, Choptank, Patuxent, Nanticoke, Potomac and James Rivers.

NJDEP sampling sites included both fixed and stratified random station locations throughout the Delaware River (Figure 4.1) sampled periodically from June – November in 2007 and 2008. At each sampling site, a 30.5 m beach seine with 6.4 mm mesh was deployed and the number of age-0 menhaden captured in each haul was quantified. A random subsample of up to ten menhaden from each catch was preserved on dry ice, then stored at -80°C for subsequent biochemical analysis. For subsequent abundance calculations, a value of 729 m^2 was used as the area swept by each seine haul. Surface water temperature, salinity and dissolved oxygen were also measured.

MDNR sampling sites consisted of fixed locations in the upper Chesapeake Bay, and the Choptank, Patuxent, Nanticoke and Potomac River systems (Figure 4.1). These sites were sampled monthly from July – September in 2007. MDNR did not provide any samples in 2008. At each site, samples were collected using duplicate hauls of a 30.5 m beach seine with 6.4 mm mesh. The number of age-0 menhaden in each haul was quantified. A random subsample of ten menhaden from each catch was preserved on dry ice, then stored at -80°C for subsequent biochemical analysis. For abundance calculations, a value of 729 m^2 was used for the area of each haul. Time of first haul, maximum distance from shore, weather, maximum depth, surface water temperature, tidal stage, surface salinity, dissolved oxygen, pH and turbidity measurements were recorded at each site.

VIMS sampling sites were located in the James River (Figure 4.1) and were sampled periodically from July – September 2008. At each site, duplicate hauls of a 30.5 m beach seine with 6.4 mm mesh were deployed perpendicular to the shoreline (either until the net was fully extended or a depth of approximately four feet was encountered) and then leaving the onshore brail in a fixed position while pulling the offshore end down current and back to the shore, resulting in the sweeping of a quarter circle quadrant (Hewitt et al. 2008). The number of age-0 menhaden in each haul was quantified and a random subsample of up to ten menhaden from each haul was preserved on dry ice, then stored at -80°C for subsequent biochemical analysis. A haul area of 729 m^2 was used for abundance calculations. Water temperature, salinity, dissolved oxygen, pH, sampling time, tidal stage and weather conditions were recorded.

CBL sampling sites consisted of 12 sites in the Patuxent River, MD (Figure 4.1) which were sampled at least monthly between June - November in both 2007 and 2008. Additionally, CBL project staff conducted seining in the Choptank, Chester and upper Chesapeake Bay tributary systems monthly July – November 2008 (Figure 4.1). At each site a 30.5 m beach seine with 6.4 mm mesh was deployed. The shore length of the haul as well as maximum seine extension distance from shore was recorded and used to calculated the area (m^2) swept by each haul. The number of young-of-the-year menhaden collected in each haul was quantified. A random subsample of up to ten menhaden from each haul was preserved in liquid nitrogen, then stored at -80°C for subsequent biochemical analysis. Water temperature, salinity and dissolved oxygen were measured using a YSI Professional Plus (Yellow Springs, OH) and time of haul and tidal stage were recorded.

University of Delaware personnel sampled in multiple sites in the Delaware estuary (Figure 4.1) periodically August – October 2008. At each site, a 30.5 m beach seine with 6.3 mm mesh was deployed at two locations, separated by approximately 500 m. An area swept of 729 m^2 was assumed for each haul. The number of menhaden collected in each haul was quantified. A subsample of menhaden from each catch was taken at random and preserved on dry ice, then stored at -80°C for subsequent biochemical analysis.

Laboratory

The RNA:DNA levels of samples collected from the field were analyzed following the protocol described in Chapter 2. Briefly, RNA and DNA content of white muscle tissue were quantified using the 1 dye/2 enzyme microplate

fluorometric assay. I verified that sample degradation does not occur as a result of storage at -80C. I determined the relationship between RNA:DNA, temperature and growth rate (manipulated through feeding treatments) in laboratory experiments (Chapter 2). The instantaneous growth rate of juvenile Atlantic menhaden was predicted as:

$$G = 0.01021(RNA{:}DNA) + 0.00199(Temp) - 0.09929,\ n = 48,\ \text{adj } R^2 = 0.76 \qquad (1)$$

Statistics

The predicted growth rates of all individuals collected at a site during a specific sampling event were averaged to estimate the site-specific mean instantaneous growth rate (G, d^{-1}). The abundance (A, number of fish. m^{-2}) of each sampling site was calculated, as well as the mean body mass ($\overline{W}$, g) of individuals at each site. Using these, instantaneous site-specific production (P, g. m^{-2}. d^{-1}) was calculated as:

$$P = G \cdot \overline{W} \cdot A \qquad (2)$$

Due to unavoidable logistical constraints, estimates of growth, abundance and subsequent production were not available for all sites at all sampling periods, producing an unbalanced inventory of habitat estimates. This precluded the use of parametric statistical methods. Because a central goal of our analyses was to identify whether individual sites consistently supported high levels of production, I chose to use a *Z*-score transformation of the data that allowed the relative ranking of each sample to be assessed. Z-scores are standardized values obtained by dividing the difference between the population mean and an individual value by the population standard deviation. This transformation allows comparison of values from different

distributions. Because these values are standardized in units of standard deviation, positive z-scores represent values above the mean, negative scores represent values below the mean and a score of zero represents no deviation from the mean. Comparisons between sites and systems were conducted using standard scores (*Z*-scores). Sampling was conducted on a biweekly basis, and thus *Z*-scores estimates were scaled using half-monthly increments. This ensures that *Z*-score values of sites were calculated from only a single sampling event. For sites sampled within a given half-monthly period, estimates of growth, abundance and production were standardized using the equation:

$$Z_{ijk} = \frac{X_{ijk} - \overline{X}_{ijk}}{\sigma_{X_k}} \tag{3}$$

Where X is the site-specific habitat estimate, $\overline{X}$ is the mean of the distribution of all site-specific habitat estimates from the given half-monthly period and σ is standard deviation of the mean site-specific habitat estimates. This transformation allows for a relative comparison of site-specific estimates based on an average habitat score ($\overline{Z}_k = 0$).

Pearson product moment correlation analysis was used to examine the relationships between site mean instantaneous growth rate, abundance, mean body mass and production. Pearson correlation analysis was also used to examine relationships between site mean instantaneous growth rate, abundance and production and corresponding temperature and salinity measurements recorded at the time of sampling events.

Results

A total of 328 and 715 individual fish were analyzed for RNA:DNA and subsequent growth in 2007 and 2008, respectively. Between June – November 2007, seining was conducted at 74 distinct sampling sites across six systems in the Chesapeake and Delaware Bays: Delaware Bay (n = 32), Upper Bay (n = 12), Choptank (n = 4), Patuxent (n = 15), Nanticoke (n = 4) and Potomac (n = 7) (Table 4.1). In 2008, seining was conducted at 100 sites across seven systems: Delaware Bay (n = 39), Upper Bay (n = 9), Chester (n = 11), Choptank (n = 15), Patuxent (n = 12), Nanticoke (n = 3) and James (n = 11) (Table 4.2). In both years, site-specific mean instantaneous growth (n_{07} = 47, n_{08} = 96), abundance (n_{07} = 513, n_{08} = 526) and production (n_{07} = 430, n_{08} = 434) were estimated for each sampling event (Tables 4.1 & 4.2).

Field based estimates of RNA:DNA were broadly similar to those measured in laboratory calibration experiments (Fig. 4.2), and thus resultant estimates of growth were derived from interpolation of Eq. 1 rather than extrapolation. RNA:DNA levels in individual menhaden ranged from 1.759 – 11.817 (Figure 4.2.A). RNA:DNA-based predicted instantaneous growth rates of individual menhaden were between -0.035 – 0.078 d^{-1}, and as with RNA:DNA values, were similar to those measured in the laboratory (Figure 4.3).

Individual site-specific mean growth (d^{-1}, ± S.E.) varied from -0.023 ± 0.005 – 0.030 ± 0.003 in 2007 and -0.022 ± 0.004 – 0.048 ± 0.008 in 2008 (Tables 4.1 & 4.2). In both years, individual site mean instantaneous growth declined throughout the season (Figure 4.4); however, the majority of instantaneous growth rates were

positive in 2007 (57.4%) and 2008 (62.5%). No perceivable pattern in relation to a latitudinal gradient existed in either year (Appendix A & D). In 2007, system-level growth estimates were available for the Delaware Bay, Choptank and Patuxent systems, although the Choptank was only represented by a single site. Generally, juvenile menhaden in the Patuxent outperformed those in the Delaware Bay in terms of instantaneous growth in 2007 (Figure 4.5). In 2008, the availability of growth estimates was more spatially extensive. Based upon the distribution of standard *Z*-score estimates, the Upper Bay, Chester and Patuxent systems typically supported lower growth while the Delaware, Choptank, Nanticoke and James generally exhibited higher growth (Figure 4.6). It should be noted that relatively high growth estimates from the Nanticoke are likely a result of having only three samples from early in the season, and the James system is represented by only one sampling site.

Site-specific instantaneous growth in both years was variable (Figures 4.7 & 4.8). In 2007, eight sites from the Delaware, Choptank and Patuxent systems were represented by an estimate of growth from a single biweekly sampling event, and thus do not provide a reliable basis by which to determine if these sites exhibited a consistent ranking with respect to growth. Estimates of growth from multiple biweekly sampling events were available for 12 sites from the Delaware and Patuxent systems in 2007. These data indicate that individual sites within these systems tended to be either highly variable or consistently low in the relative growth they supported. For example, growth estimates for the Chester Island (CI) site in the Delaware Bay were either the most highly ranked during one biweekly sampling period, or one of the lowest ranked during another biweekly sampling (Figure 4.7, Table 4.3). In

contrast, growth estimates for the Helms Cove (HC) site in the Delaware Bay system when sampled were consistently 0.5 - 1 standard deviation units below the median for all sites sampled in the respective biweekly periods (Figure 4.7, Table 4.3). In 2008, estimates of growth from single biweekly sampling events were represented by 23 sites, and multiple biweekly sampling events were also available for 23 sites (Table 4.4). A similar pattern was observed in 2008 as individual site relative growth was either highly variable or consistently low (Figure 4.8).

There was no relationship between the *Z*-scores for instantaneous growth in 2007 and 2008 for sites at which data were available from multiple biweekly sampling events and available in both years (Figure 4.9). However, this finding is strongly influenced by data from a single site in Delaware Bay (Augustine Beach – AB). This site supported the lowest average growth in 2007 and one of the highest average growths in 2008 of those sites sampled consistently in both years. If the AB data are considered anomalous, then the correlation between site-specific average growth in the two years is significant ($R^2 = 0.388$, $p<0.05$, n=10).

The number of menhaden collected in seine hauls varied from 0 – 1,330 in 2007 and 0 – 5,050 in 2008. Individual site-specific mean abundances varied from 0 – 0.95 fish.m^{-2} in 2007 and 0 – 7.65 fish.m^{-2} in 2008 (Tables 4.1 and 4.2). Menhaden abundance varied without trend in both years, but was generally more variable in 2008 (Figure 4.10). In neither 2007 nor 2008 was a latitudinal gradient in fish abundance observed (Appendix B & E). System-level comparisons of abundance are complicated by the high frequency of zero catches. Given this caveat, median abundance estimates for 2007 exhibited little variation among systems; however, the

Nanticoke system was generally the highest, with the Patuxent and Delaware Bay systems exhibiting the most variability (Figure 4.11). System-level abundances in 2008 displayed patterns similar to the preceding year; however, as with growth, the Nanticoke system abundance is driven by limited sampling occurring only in June (Figure 4.12).

As noted with system-level abundance comparison, site-specific comparisons of abundance are also complicated by the high frequency of zero catches. This attribute of the data tends to dampen potential differences in medians among sites. Given this, it was particularly striking that in 2007 three sites in the Nanticoke (LL – Lewis Landing, CP – Chapter Point, TB – Tyaskin Beach) and one site in the Choptank (NS – North Shore) exhibited consistently high levels of relative abundance of juvenile menhaden (Figure 4.13, Table 4.3). In 2008, site-specific median abundance levels were broadly similar (Figure 4.14, Table 4.4).

There was no relationship between the Z-scores for abundance in 2007 and 2008 for sites at which data were available from multiple biweekly sampling events and available in both years (Figure 4.15). Only at sites Fort Mott (FM) in the Delaware Bay and Cage Stables (CS) in the Patuxent did relative abundance increase from below- to above-average.

Based on RNA:DNA-based estimates of the instantaneous growth rates of individual menhaden, their size and estimated abundances within specific habitats, site-specific production was calculated using Eq. 2. Site mean production ranged from -0.183 – 0.038 $g.m^{-2}.d^{-1}$ in 2007 and -0.437 – 0.744 $g.m^{-2}.d^{-1}$ in 2008 (Tables 4.1 & 4.2), and was relatively variable in 2008 (Figure 4.16). As with growth and

abundance estimates, no trends in monthly habitat-specific production related to latitude were distinguishable (Appendix C & F). Aside from the production estimate for the Nanticoke system in 2008, which was inflated because the dominance of early season sampling, there was limited variability in system-specific levels of production in either year (Figures 4.17 & 4.18).

Similar to abundance, site-specific production estimates were influenced by the prevalence of zero-abundance sampling events, although *Z*-scores did identify some sites with relatively increased or decreased production throughout the season (Figures 4.19 & 4.20). In particular, consistently low levels of relative production were observed in some Delaware Bay sites previously identified as supporting consistently low growth rates in 2007 (HC - Helms Cove, NC – Newcastle)(Figure 4.19, Table 4.3). In 2008, inter-site variability in growth was not sufficient to alter the template for production established by patterns in abundance (Figure 4.20, Table 4.4).

The comparison of site-specific production for sites at which data were available in both years and multiple biweekly sampling events is complicated by the extremely high relative production observed in Tim's Creek in the Upper Bay in 2008. However, with or without this site, no clear correlation exists between site-specific productions in the two years (Figure 4.21).

Pearson product moment correlation analysis showed similar relationships among estimates of growth, abundance and production in 2007 and 2008 (Tables 4.5 & 4.6). A nonsignificant positive correlation was observed between instantaneous growth rate and abundance in both years ($r_{07} = 0.228$; $p_{07} = 0.1234$; $r_{08} = 0.152$; $p_{08} =$

0.1381 – Figures 4.22 & 4.23). There were significant negative relationships between growth and mean weight (r_{07} = -0.526; $p_{07} < 0.001$; r_{08} = -0.384; $p_{08} < 0.0001$). Growth rates and production were also significantly correlated in 2007 and 2008 (r_{07} = 0.348; p_{07} = 0.0164; r_{08} = 0.422; $p_{08} < 0.0001$ – Figures 4.24 & 4.25). In 2007, a significant negative correlation was found between abundance and production (r = -0.139; p = 0.0038 – Figure 4.26); however, a significant positive relationship was present in 2008 (r = 0.279; $p < 0.0001$ – Figure 4.27). In both years mean weight and production were negatively correlated (r_{07} = -0.415; p_{07} = 0.0037; r_{08} = -0.242; p_{08} = 0.0178).

Pearson product moment correlation analysis found temperature and salinity to be significantly correlated to site specific abundance and instantaneous growth rate, but not to production (Figure 4.28). Positive significant correlations were observed between temperature and both abundance (r = 0.068; p = 0.03) and growth (r = 0.486; $p < 0.0001$). However, temperature and production were not significantly correlated (r = 0.06; p = 0.074). Similarly, salinity was significantly correlated to abundance (r = 0.103; p = 0.001) and growth (r = -0.226; p = 0.0065), but not to production (r = -0.017; p = 0.62).

Discussion

Several studies have incorporated biochemical indices (RNA:DNA) into their habitat evaluation; however, most have used these measures as either a qualitative proxy for condition (Gilliers et al. 2004, Fonseca et al. 2006, Meng et al. 2008, Vinagre et al. 2008, Vasconcelos et al. 2009) or to generate a correlative growth rate as an exclusive indicator of habitat quality (Malloy et al. 1996, Yamashita et al. 2003,

Stierhoff et al. 2009). By coupling RNA:DNA-based estimates of growth and field-based abundance estimates, this study represents one of the few to formally quantify habitat-specific production to assess spatiotemporal variability in habitat quality. To our knowledge, this is the first study to examine habitat-specific production in Atlantic menhaden.

Most RNA:DNA and instantaneous growth measurements collected from the field fell within range of those observed in the laboratory. Fish in the field will often grow faster than those under laboratory conditions, and this can be a source of bias in growth and production estimates (Folkvord 2005). The results of this study indicate that the spectrum of RNA:DNA and growth produced in the laboratory was sufficiently broad to encompass the vast majority of growth conditions experienced by juvenile menhaden in the environment, and thereby provide an appropriate foundation from which to estimate production.

In both 2007 and 2008, broad-scale (system-level) estimates of growth, abundance and production exhibited considerable temporal and spatial variability. Generally, system-wide growth rates declined throughout the growing season; whereas abundance displayed no apparent trend over time. As a result, abundance tended to drive variability of production estimates. System-specific patterns in production were difficult to quantify because of the impact of numerous zero catches in the data. However, site-specific comparison did reveal some sites that appeared to support consistently high levels of production compared to other sites in 2007. Site-specific differences in production were less evident in 2008. For all estimates (growth, abundance and production) no latitudinal gradients within a system were

apparent, neither was there evidence of gradation extending from a central point of high production. In fact, in some instances sampling sites located sequentially along the latitudinal gradient could produce vastly different estimates of growth, abundance and production.

A central goal of this research was to explore whether individual sites consistently exhibited relatively high levels of menhaden production. The results presented here indicate that although there was substantial spatial and temporal variability in menhaden production in 2007 and 2008, no single site consistently exhibited the highest level of production. Our analyses do not support the notion that individual sites defined at a small spatial resolution within broad estuarine areas serve as nurseries *sensu* Beck et al (2001). I suggest it is more likely that juvenile menhaden utilize a mosaic of sites within broad estuarine areas to promote growth, survival and production. Friedland et al. (1996) suggest the distribution of juvenile menhaden may vary over space and time in relation to various factors, most notably phytoplankton concentrations. Although associations with environmental factors have yet to be comprehensively examined in our study, it is possible that complex interactions between biotic and abiotic factors may influence the observed habitat-specific estimates of growth, abundance and production. These factors themselves can exhibit high spatiotemporal variability throughout the estuarine environment, and thus may contribute to the high variability in our site-specific estimates.

If juvenile menhaden rely on a mosaic of habitats to promote production as suggested by our results, defining those habitats that are “essential” will require sampling that is both spatially and temporally intensive. Simply stated, fisheries

biologists and managers cannot rank and compare the relative value of sites for production of menhaden based on a limited spatial or temporal sampling scheme. Given the high spatiotemporal variability of menhaden production throughout the estuarine environment, defining essential fisheries habitat for the purposes of protection or restoration of specific areas may prove problematic. The results of this investigation suggest that the designation of specific geographic areas within estuaries as preferred nursery habitats for juvenile menhaden may be difficult, if not impossible. Perhaps more useful to management objectives would be the identification of factors contributing to the site-specific variability observed in menhaden production, as echoed by Beck et al. (2001). If driving factors can be reliably determined and the spatiotemporal behavior in these factors can be predicted throughout the estuarine environment, the patterns of menhaden production may be simulated to provide a more dynamic assessment of important nursery habitats.

Based upon coefficient of variation (CV), the variation in 2007 site-specific production estimates was driven in nearly equal magnitude by instantaneous growth rates (CV = 5.06) and site-specific abundance (CV = 5.45). Conversely, 2008 production estimates were influenced more by abundance (CV = 6.74) than by growth rates (CV = 2.10). Similar high levels of variability in abundance have been observed for Atlantic menhaden in other studies (Wingate & Secor 2008). Mean individual body weight contributed relatively little to the observed variation in production in both years ($CV_{2007} = 0.91$, $CV_{2008} = 0.60$). Nonsignificant positive correlations were observed between instantaneous growth and abundance in both years, suggesting that growth rate is independent of fish abundance in menhaden at fine spatial and

temporal scales. In both years, growth rate and mean body weight were negatively correlated, likely a result of decreased potential for somatic growth with increasing body mass coupled with decreasing water temperatures as the growing season progressed. Correlations between production and any one of the factors used to estimate it are inherently influenced by one another due to the multiplicative properties of the production equation; however, aside from the relationship between abundance and production in 2007, similar patterns were observed between years. A significant negative correlation was observed between abundance and production in 2007. This pattern is likely driven by a single data point observed late in the growing season (10/11/07) consisting of several large individuals experiencing relatively low growth. If this data point is removed, there is a positive correlation between abundance and production, as was observed in 2008.

It is important to note that my conclusions regarding temporal and spatial variability in production are heavily dependent on interpretation of zero catches in the biweekly sampling in the surveys. I interpreted zero hauls as true zero values, giving them full weight in my analyses. The high frequency of zero hauls served to constrain estimates of the median abundance and thus of the median levels of production. I believe this is the most conservative approach. However, I recognize that a zero haul does not necessarily reflect the absence of menhaden in the habitat. Several factors may cause a zero haul even when menhaden are present. Most fisheries sampling inherently assumes that fish are randomly distributed, with each individual having an equal probability of being caught. Menhaden's schooling behavior violates this assumption and tends to produce catches that are bimodally

distributed. This precluded the use of parametric statistics, but application of *Z*-transformations may still be susceptible to this source of bias, potentially inflating or deflating estimates. Additionally, a beach seine is likely not the optimal gear for sampling juvenile menhaden. The depth restriction on seining may have reduced the likelihood of sampling menhaden, particularly later in the year.

Due to the importance of estuarine environments to the growth and survival of fish early life stages and subsequent year class success, as well as the ever-increasing vulnerability of estuarine habitats to anthropogenic disturbance, the identification and classification of essential fish habitat has become a priority in fisheries research. Defining EFH requires data on habitat-specific abundance, growth, survival and production; the latter proving the most difficult to obtain (Able 1999). Numerous studies have attempted to assess and evaluate habitat quality by comparing relative growth (Sogard 1992, Malloy et al. 1996, Able et al. 1999, Duffy-Anderson & Able 1999, Meng et al. 2000, Nislow & Folt 2000, Phelan et al. 2000, Manderson et al. 2002, Amara et al. 2007, Glass et al. 2008, Meng et al. 2008), fish size (Le Pape et al. 2003), abundance (Fodrie & Mendoza 2006, Courrat et al. 2009), or a combination of growth and abundance estimates (Gilliers et al. 2006**,** Taylor et al. 2007). However, few have attempted to evaluate fish habitat by calculating potential production or contribution (Kraus & Secor 2005), which has been suggested as the most useful measure of nursery quality (Beck et al. 2001).

The estuarine environment is highly dynamic in terms of the biotic and abiotic factors and related processes influencing the growth, abundance and subsequent production of juvenile fish nursery habitats. Therefore, methods used to quantify

habitat-specific production must operate on similar fine spatial and temporal scales. However, year-class success and overall contribution to the adult populations are based on the cumulative input from habitats over large spatial and temporal scales. To examine such population-level processes, estimates of production from putative nursery habitats must be available over a sufficiently broad range to encompass dynamics relevant to the population of interest. Gilliers et al. (2006) suggest a meso-scale approach to examine general trends followed by a more precise investigation on the local scale to understand causative dynamics. The highly variable estimates observed at both broad- and fine-scale levels in this study suggest the need to quantify potential abiotic and biotic factors influencing production in the estuarine environment. The high spatial and temporal variability observed at the site-specific level in this study may be attributed to fine-scale spatiotemporal variation of numerous environmental factors, characteristic of the estuarine environment.

A number of studies have noted associations between areas of increased phytoplankton production and menhaden abundance and growth (Friedland et al. 1989, Friedland et al. 1996, Luo et al. 2001, Brandt & Mason 2003, Love et al. 2006). These areas of high phytoplankton biomass have been found to move in relation to changes in flow rates as the season progresses in the estuary mainstem as well as associated tributaries (Friedland et al. 1996). Additionally, as menhaden grow, morphological changes in feeding apparatus, swimming speed and energetic requirements shift feeding strategies away from high concentrations of nanophytoplankton, located in the upper estuary, to larger and less concentrated plankton found in lower estuary and coastal areas, potentially driving menhaden

down estuary (Friedland et al. 1996). The interactions between spatiotemporal variability in phytoplankton biomass and changes in menhaden behavior will likely influence the growth, abundance and production during juvenile occupancy and may partly explain the high variability observed in our results. Salinity has also been offered as a potential factor influencing the growth and distribution of juvenile Atlantic menhaden. It has been proposed that menhaden during early-life prefer low salinity environments in which to metamorphose to juvenile stages (Wilkens & Lewis 1971, Weinstein 1979, Rogers et al. 1984, Murdy et al. 1997) after which they are increasingly found in higher salinity areas (Lewis et al. 1972). In laboratory experiments, Hettler (1976) also found that juvenile menhaden in lower salinities outperformed their conspecifics raised in higher salinities. However, Love et al. (2006) failed to observe a pattern in distribution of menhaden in relation to salinity. Although latitudinal patterns (an imprecise proxy for salinity) were not apparent, significant correlations were observed between salinity and both site-specific abundance and growth in this study. However, more comprehensive examinations of trends with salinity are desired. Anthropogenic disturbances have the potential to alter nursery habitat in estuarine environments, and such disturbances have been suggested as a possible culprit of site-specific declines in menhaden recruitment (Love et al. 2006). It is possible that local land-use patterns may be at least partly responsible for the observed site-specific variability observed in this study. An investigation of potential human-induced habitat alteration in relation to specific nursery areas may help to elucidate relationships. Ultimately, the patterns of habitat use by juvenile Atlantic menhaden are likely driven by a combination of numerous

environmental factors known to influence the growth and production of fishes. Manderson et al. (2002) found that habitat suitability in terms of growth of juvenile winter flounder varied greatly in space and time and that the highest quality areas coincided with areas of optimal temperature and salinity intersection. Future work to link observed patterns in growth, abundance and production of juvenile menhaden nursery habitats may help to identify the environmental conditions influencing nursery habitat contribution and recruitment success. Evaluating these mechanisms may improve management and increase understanding of the population dynamics of this ecologically and economically important species.

Table 4.1. Site-specific data from each sampling event in 2007.

System	Site Code	Latitude	Longitude	Date	Temperature (°C)	Salinity (ppt)	Abundance (fish.m^{-2})	Weight (g)		RNA:DNA		*G* (d^{-1})		Production (g.m^{-2}.d^{-1})
								Mean	S.E.	Mean	S.E.	Mean	S.E.	
Patuxent	DNR	38.702500	-76.693610	6/6/2007	24.4	0.40	0.0226	2.808	0.072	7.337	0.200	0.02418	0.002	0.001535
Patuxent	EH	38.571667	-76.681667	6/6/2007	28.4	4.90	0.1376	2.155	0.339	5.864	0.302	0.01710	0.003	0.005070
Patuxent	GG	38.538056	-76.668890	6/6/2007	27.1	6.10	0.0102	2.787	0.510	5.189	0.430	0.00881	0.004	0.000250
Patuxent	GK	38.633226	-76.691428	6/6/2007	26.3	0.80	0.1091	2.643	0.126	7.532	0.256	0.02995	0.003	0.008631
Patuxent	LM	38.658958	-76.682418	6/6/2007	25.7	0.70	0.2529	2.060	0.123	6.649	0.433	0.01973	0.004	0.010282
Patuxent	SL	38.752801	-76.699864	6/6/2007	24.4	0.20	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	6/7/2007	26.0	9.90	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	6/7/2007	24.0	8.60	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	6/7/2007	28.0	9.90	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	6/7/2007	23.0	8.70	0.0028							
Patuxent	SP	38.467200	-76.644720	6/7/2007	23.6	8.80	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	6/8/2007	26.4	10.80	0.0018							
Patuxent	DNR	38.702500	-76.693610	6/20/2007	26.8	0.70	0.0904	6.295	0.869	5.837	0.164	0.01364	0.002	0.007764
Patuxent	EH	38.571667	-76.681667	6/20/2007	28.8	4.30	0.0000							0.000000
Patuxent	GG	38.538056	-76.668890	6/20/2007	26.9	7.60	0.0023							
Patuxent	GK	38.633226	-76.691428	6/20/2007	27.9	1.40	0.0548	8.349	0.273	5.766	0.206	0.01510	0.002	0.006914
Patuxent	LM	38.658958	-76.682418	6/20/2007	27.8	1.20	0.1603	2.742	0.243	6.108	0.448	0.01839	0.005	0.008081
Patuxent	SL	38.752801	-76.699864	6/20/2007	27.3	0.40	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	6/21/2007	27.9	10.50	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	6/21/2007	28.6	8.70	0.0073	1.510	0.268	3.470	0.120	-0.00695	0.001	-0.000076
Patuxent	CS	38.412990	-76.524300	6/21/2007	30.4	10.50	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	6/21/2007	25.9	9.00	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	6/21/2007	26.4	9.20	0.0010							
Patuxent	SB	38.324720	-76.462200	6/22/2007	27.1	11.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	6/25/2007	25.3	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	6/25/2007	24.9	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	6/25/2007	25.0	0.10	0.0000							0.000000

Delaware Bay	HI	40.045333	-74.975233	6/25/2007	24.1	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	6/25/2007	25.1	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	6/25/2007	24.7	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	6/25/2007	24.2	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	6/25/2007	23.8	0.10	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	6/26/2007	26.0	6.30	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	6/26/2007	26.6	4.80	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	6/26/2007	25.0	1.10	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	6/26/2007	27.3	3.50	0.0014							
Delaware Bay	GAG	39.638600	-75.598050	6/26/2007	26.3	2.30	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	6/26/2007	25.6	2.10	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	6/26/2007	26.7	3.60	0.0754							
Delaware Bay	PN	39.648467	-75.532600	6/26/2007	27.2	1.70	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	6/27/2007	27.2	0.20	0.6612							
Delaware Bay	HC	39.723917	-75.476783	6/27/2007	25.0	0.70	0.0027							
Delaware Bay	NM	39.796033	-75.452267	6/27/2007	26.8	0.30	0.0974							
Delaware Bay	OC	39.826833	-75.354017	6/27/2007	26.7	0.20	0.0096							
Delaware Bay	OP	39.762633	-75.461550	6/27/2007	26.6	0.50	0.0027							
Delaware Bay	RC	39.811033	-75.381133	6/27/2007	27.0	0.20	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	6/27/2007	26.3	0.60	0.0233							
Delaware Bay	SD	39.842183	-75.311200	6/27/2007	28.0	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	6/28/2007	28.0		0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	6/28/2007	25.5		0.0178							
Delaware Bay	MC	39.852917	-75.225000	6/28/2007	26.5		0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	6/28/2007	28.0		0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	6/28/2007	26.0		0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	6/28/2007	29.0		0.0110							
Delaware Bay	TT	39.852200	-75.280600	6/28/2007	28.0		0.0041							
Delaware Bay	UPS	39.857383	-75.256783	6/28/2007	28.5		0.0151							
Delaware Bay	AB	39.505917	-75.578433	7/3/2007	26.0	6.80	0.0041	22.167	7.216	5.006	0.313	0.00356	0.003	0.000325
Delaware Bay	CB	39.515700	-75.527167	7/3/2007	26.1	4.80	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	7/3/2007	25.5	2.60	0.0000							0.000000

Delaware Bay	FM	39.601433	-75.552167	7/3/2007	26.0	3.70	0.0055	8.650	0.593	5.733	0.509	0.01099	0.005	0.000521
Delaware Bay	GAG	39.638600	-75.598050	7/3/2007	27.4	2.80	0.3855	9.431	1.255	5.414	0.309	0.01051	0.003	0.038218
Delaware Bay	NC	39.657033	-75.566400	7/3/2007	27.6	2.40	0.0041	8.210	0.526	5.050	0.226	0.00719	0.002	0.000243
Delaware Bay	OB	39.556967	-75.517983	7/3/2007	26.6	1.90	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	7/3/2007	24.7	2.80	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	7/3/2007	27.5	0.60	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	7/3/2007	28.6	7.70	0.0091	3.843	0.304	5.909	0.283	0.01796	0.003	0.000630
Patuxent	GG	38.538056	-76.668890	7/3/2007	25.5	9.10	0.0006	5.575	3.745	5.210	1.948	0.00465	0.020	0.000015
Patuxent	GK	38.633226	-76.691428	7/3/2007	27.2	2.50	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	7/3/2007	28.4	1.70	0.0291	4.999	0.562	4.838	0.359	0.00662	0.004	0.000963
Patuxent	SL	38.752801	-76.699864	7/3/2007	27.0	0.20	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	7/5/2007	24.7	11.70	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	7/5/2007	24.4	10.80	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	7/5/2007	26.0	11.70	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	7/5/2007	23.9	10.60	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	7/5/2007	26.2	12.90	0.0006							
Patuxent	SP	38.467200	-76.644720	7/5/2007	24.8	10.70	0.0000							0.000000
Choptank	CH	38.626667	-76.163333	7/9/2007	26.9	11.12	0.0000							0.000000
Choptank	JP	38.611667	-75.986667	7/9/2007	27.3	7.52	0.0103							
Choptank	MT	38.815000	-75.896667	7/9/2007	28.3	1.59	0.0007							
Choptank	NS	38.608333	-76.066667	7/9/2007	27.3	9.34	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	7/10/2007	27.0	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	7/10/2007	27.3	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	7/10/2007	27.7	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	7/10/2007	27.3	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	7/10/2007	27.3	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	7/10/2007	28.9	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	7/10/2007	26.6	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	7/10/2007	27.1	0.10	0.0000							0.000000
Nanticoke	CP	38.380000	-75.866667	7/10/2007	28.2	6.90	0.2037							
Nanticoke	LL	38.418333	-75.850000	7/10/2007	27.8	4.62	0.0000							0.000000
Nanticoke	SH	38.538333	-75.726667	7/10/2007	29.7	0.45	0.0000							0.000000

Nanticoke	TB	38.326667	-75.876667	7/10/2007	28.7	9.60	0.0206							
Delaware Bay	CI	39.840367	-75.342317	7/11/2007	27.8	0.20	0.1331	6.317	0.622	6.232	0.485	0.01966	0.005	0.016525
Delaware Bay	HC	39.723917	-75.476783	7/11/2007	26.9	1.10	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	7/11/2007	29.2	0.40	0.0151							
Delaware Bay	OC	39.826833	-75.354017	7/11/2007	27.4	0.20	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	7/11/2007	27.2	0.80	0.4815	6.732	0.662	5.099	0.623	0.00690	0.006	0.022360
Delaware Bay	RC	39.811033	-75.381133	7/11/2007	27.4	0.20	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	7/11/2007	29.2	0.40	0.0274							
Delaware Bay	SD	39.842183	-75.311200	7/11/2007	27.8	0.20	0.0000							0.000000
Potomac	BL	38.408333	-77.111667	7/11/2007	26.5	5.23	0.0014							
Potomac	HP	38.638333	-77.131667	7/11/2007	28.9	0.16	0.0000							0.000000
Potomac	IH	38.600000	-77.185000	7/11/2007	28.2	0.16	0.0000							0.000000
Potomac	LP	38.458333	-77.268333	7/11/2007	27.3	1.66	0.0000							0.000000
Potomac	MO	38.361667	-76.983333	7/12/2007	26.1	9.15	0.0000							0.000000
Potomac	RP	38.273333	-76.833333	7/12/2007	26.7	10.84	0.0000							0.000000
Potomac	SG	38.136667	-76.500000	7/12/2007	26.9	13.36	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	7/16/2007	28.4	0.20	0.0027	2.620	0.110	5.405	0.388	0.01241	0.004	0.000089
Delaware Bay	EA	39.878083	-75.177450	7/16/2007	26.2	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	7/16/2007	26.3	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	7/16/2007	26.7	0.20	0.0014	1.960		5.865		0.01373		0.000037
Delaware Bay	PEB	39.874966	-75.192950	7/16/2007	26.2	0.20	0.0041	7.300	1.652	5.236	0.377	0.00631	0.004	0.000189
Delaware Bay	TK	39.854500	-75.272666	7/16/2007	28.4	0.20	0.0014	6.440	0.782	5.286	0.326	0.00921	0.003	0.000081
Delaware Bay	TT	39.852200	-75.280600	7/16/2007	27.4	0.20	0.0137							
Delaware Bay	UPS	39.857383	-75.256783	7/16/2007	28.4	0.20	0.0000							0.000000
Upper Bay	HW	39.371667	-76.105000	7/16/2007	27.4	2.55	0.0000							0.000000
Upper Bay	SF	39.371600	-75.992470	7/16/2007	28.6	1.34	0.0000							0.000000
Upper Bay	TC	39.289317	-76.169117	7/16/2007	26.8	5.19	0.0000							0.000000
Upper Bay	TO	39.213333	-76.245000	7/16/2007	25.6	6.59	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	7/17/2007	27.9	6.20	0.0014							
Delaware Bay	CB	39.515700	-75.527167	7/17/2007	27.9	5.10	0.0041							
Delaware Bay	CT	39.670767	-75.513167	7/17/2007	27.3	2.80	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	7/17/2007	27.6	3.90	0.0096							

Delaware Bay	GAG	39.638600	-75.598050	7/17/2007	28.8	3.40	0.0096							
Delaware Bay	NC	39.657033	-75.566400	7/17/2007	28.8	2.70	0.0082							
Delaware Bay	OB	39.556967	-75.517983	7/17/2007	28.2	4.30	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	7/17/2007	26.7	3.00	0.0014							
Upper Bay	EN	39.475583	74.006200	7/17/2007	25.4	0.15	0.0000							0.000000
Upper Bay	PR	39.471767	-75.873215	7/17/2007	29.5	0.75	0.0007							
Upper Bay	WP	39.527250	-75.880967	7/17/2007	28.9	1.19	0.0000							0.000000
Upper Bay	YP	39.505000	-75.928333	7/17/2007	27.7	0.86	0.0007							
Upper Bay	CA	39.540000	-76.003333	7/18/2007	27.8	0.14	0.0000							0.000000
Upper Bay	PL	39.486667	-76.113333	7/18/2007	28.3	0.15	0.0014							
Upper Bay	SI	39.503333	-76.096667	7/18/2007	27.3	0.15	0.0000							0.000000
Upper Bay	TE	39.508333	-76.111667	7/18/2007	28.3	0.14	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	7/19/2007	31.5	12.20	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	7/19/2007	29.9	11.50	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	7/19/2007	31.1	12.40	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	7/19/2007	29.7	9.28	0.0398							
Patuxent	GG	38.538056	-76.668890	7/19/2007	28.7	9.90	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	7/19/2007	29.4	11.20	0.0000							0.000000
Patuxent	MI	38.638333	-76.695000	7/19/2007	29.5	5.08	0.0041							
Patuxent	NT	38.713107	-76.701882	7/19/2007	29.2	1.58	0.0329							
Patuxent	PP	38.388333	-76.506667	7/19/2007	27.4	12.57	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	7/19/2007	29.1	0.79	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	7/19/2007	27.7	11.24	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	7/24/2007	26.6	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	7/24/2007	26.2	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	7/24/2007	26.5	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	7/24/2007	25.4	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	7/24/2007	26.9	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	7/24/2007	26.8	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	7/24/2007	25.1	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	7/24/2007	24.8	0.10	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	7/26/2007	27.3	0.20	0.0027	23.330		3.959		-0.00454		-0.000291

Delaware Bay	HC	39.723917	-75.476783	7/26/2007	25.4	1.70	0.0892	11.223	1.104	4.971	0.376	0.00201	0.004	0.002016
Delaware Bay	NM	39.796033	-75.452267	7/26/2007	28.1	0.60	0.0041							
Delaware Bay	OC	39.826833	-75.354017	7/26/2007	26.3	0.30	0.0041							
Delaware Bay	OP	39.762633	-75.461550	7/26/2007	25.7	1.20	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	7/26/2007	26.3	0.30	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	7/26/2007	27.8	1.30	0.0041							
Delaware Bay	SD	39.842183	-75.311200	7/26/2007	26.7	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	7/30/2007	28.0	0.20	0.0014							
Delaware Bay	EA	39.878083	-75.177450	7/30/2007	26.6	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	7/30/2007	27.8	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	7/30/2007	27.2	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	7/30/2007	27.5	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	7/30/2007	28.4	0.20	0.0123							
Delaware Bay	TT	39.852200	-75.280600	7/30/2007	28.1	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	7/30/2007	27.6	0.20	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	8/1/2007	30.1	1.80	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	8/1/2007	30.8	8.90	0.0041	7.640	1.411	5.406	0.257	0.01720	0.003	0.000540
Patuxent	GG	38.538056	-76.668890	8/1/2007	28.4	10.20	0.0000							0.000000
Patuxent	GK	38.633226	-76.691428	8/1/2007	29.2	4.50	0.0127	10.095	0.829	3.556	0.134	-0.00487	0.001	-0.000624
Patuxent	LM	38.658958	-76.682418	8/1/2007	29.8	3.10	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	8/1/2007	29.2	0.60	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	8/2/2007	28.9	8.10	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	8/2/2007	29.1	6.40	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	8/2/2007	28.1	3.60	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	8/2/2007	28.1	3.60	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	8/2/2007	29.5	4.00	0.0110							
Delaware Bay	NC	39.657033	-75.566400	8/2/2007	29.9	3.50	0.0151							
Delaware Bay	OB	39.556967	-75.517983	8/2/2007	29.3	5.60	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	8/2/2007	27.4	4.10	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	8/2/2007	29.5	13.10	0.0011	9.940		5.437		0.01493		0.000165
Patuxent	CR	38.434797	-76.640113	8/2/2007	29.8	12.10	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	8/2/2007	27.5	13.20	0.0000							0.000000

Patuxent	MH	38.475000	-76.641667	8/2/2007	32.3	12.00	0.0801	24.687	0.593	4.497	0.200	0.01090	0.002	0.021566
Patuxent	SB	38.324720	-76.462200	8/2/2007	27.1	13.80	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	8/2/2007	31.3	12.10	0.0000							0.000000
Choptank	CH	38.626667	-76.163333	8/6/2007	27.2	13.19	0.0000							0.000000
Choptank	JP	38.611667	-75.986667	8/6/2007	28.1	10.26	0.0316	18.955	1.376	4.144	0.180	-0.00106	0.002	-0.000634
Choptank	MT	38.815000	-75.896667	8/6/2007	29.3	2.86	0.0000							0.000000
Choptank	NS	38.608333	-76.066667	8/6/2007	27.0	11.84	0.0686							
Delaware Bay	BN	40.087033	-74.856583	8/6/2007	28.2	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	8/6/2007	28.1	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	8/6/2007	28.3	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	8/6/2007	28.5	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	8/6/2007	29.1	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	8/6/2007	28.0	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	8/6/2007	28.3	0.10	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	8/7/2007	27.6	0.00	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	8/7/2007	29.5	0.20	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	8/7/2007	27.8	0.10	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	8/7/2007	29.7	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	8/7/2007	28.5	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	8/7/2007	28.2	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	8/7/2007	28.7	0.20	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	8/7/2007	28.3	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	8/7/2007	29.0	0.20	0.0000							0.000000
Nanticoke	CP	38.380000	-75.866667	8/7/2007	29.3	7.99	0.1283							
Nanticoke	LL	38.418333	-75.850000	8/7/2007	28.9	5.94	0.0556							
Nanticoke	SH	38.538333	-75.726667	8/7/2007	28.5	0.65	0.0000							0.000000
Nanticoke	TB	38.326667	-75.876667	8/7/2007	30.1	10.07	0.9499							
Potomac	BL	38.408333	-77.111667	8/8/2007	28.9	5.74	0.0226							
Potomac	HP	38.638333	-77.131667	8/8/2007	31.5	0.23	0.0000							0.000000
Potomac	IH	38.600000	-77.185000	8/8/2007	29.7	0.52	0.0000							0.000000
Potomac	LP	38.458333	-77.268333	8/8/2007	28.5	2.64	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	8/9/2007	30.0	13.20	0.0000							0.000000

Patuxent	CR	38.434797	-76.640113	8/9/2007	30.5	12.60	0.0006	19.550		3.876		0.00097		0.000011
Patuxent	CS	38.412990	-76.524300	8/9/2007	29.5	13.20	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	8/9/2007	31.8	2.80	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	8/9/2007	32.2	8.30	0.0099	13.684	1.644	4.155	0.232	0.00721	0.002	0.000981
Patuxent	GG	38.538056	-76.668890	8/9/2007	31.8	10.90	0.0000							0.000000
Patuxent	GK	38.633226	-76.691428	8/9/2007	31.4	6.30	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	8/9/2007	31.2	4.70	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	8/9/2007	31.1	12.50	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	8/9/2007	29.0	14.00	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	8/9/2007	31.5	0.80	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	8/9/2007	30.8	12.60	0.0000							0.000000
Potomac	MO	38.361667	-76.983333	8/9/2007	31.3	9.27	0.0000							0.000000
Potomac	RP	38.273333	-76.833333	8/9/2007	29.4	10.90	0.0000							0.000000
Potomac	SG	38.136667	-76.500000	8/9/2007	30.5	13.08	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	8/13/2007	28.2	0.30	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	8/13/2007	30.3	1.50	0.0082	13.955	1.773	3.286	0.300	-0.00544	0.003	-0.000625
Delaware Bay	NM	39.796033	-75.452267	8/13/2007	29.6	1.00	0.6571							
Delaware Bay	OC	39.826833	-75.354017	8/13/2007	28.3	0.30	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	8/13/2007	28.8	1.20	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	8/13/2007	27.8	0.40	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	8/13/2007	27.2	1.40	0.0014							
Delaware Bay	SD	39.842183	-75.311200	8/13/2007	28.4	0.30	0.0000							0.000000
Upper Bay	HW	39.371667	-76.105000	8/13/2007	27.9	4.20	0.0000							0.000000
Upper Bay	SF	39.371600	-75.992470	8/13/2007	29.0	2.94	0.0000							0.000000
Upper Bay	TC	39.289317	-76.169117	8/13/2007	27.2	6.52	0.0000							0.000000
Upper Bay	TO	39.213333	-76.245000	8/13/2007	27.0	8.42	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	8/14/2007	26.9	7.80	0.0014	7.610		2.811		-0.01706		-0.000178
Delaware Bay	CB	39.515700	-75.527167	8/14/2007	27.5	6.20	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	8/14/2007	26.7	3.50	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	8/14/2007	28.1	5.20	0.0192	19.306	1.213	3.603	0.204	-0.00659	0.002	-0.002442
Delaware Bay	GAG	39.638600	-75.598050	8/14/2007	27.2	3.90	0.0027	10.455	0.175	3.231	0.332	-0.01217	0.003	-0.000349
Delaware Bay	NC	39.657033	-75.566400	8/14/2007	27.1	3.60	0.0206	13.547	1.056	3.846	0.398	-0.00609	0.004	-0.001698

Delaware Bay	OB	39.556967	-75.517983	8/14/2007	28.2	4.90	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	8/14/2007	25.6	1.90	0.0000							0.000000
Upper Bay	EN	39.475583	74.006200	8/14/2007	25.7	0.35	0.0000							0.000000
Upper Bay	PR	39.471767	-75.873215	8/14/2007	28.4	1.90	0.0219							
Upper Bay	WP	39.527250	-75.880967	8/14/2007	29.1	3.71	0.0000							0.000000
Upper Bay	YP	39.505000	-75.928333	8/14/2007	27.5	3.07	0.0000							0.000000
Upper Bay	CA	39.540000	-76.003333	8/15/2007	26.9	0.16	0.0000							0.000000
Upper Bay	PL	39.486667	-76.113333	8/15/2007	26.3	0.17	0.0014							
Upper Bay	SI	39.503333	-76.096667	8/15/2007	26.4	0.17	0.0000							0.000000
Upper Bay	TE	39.508333	-76.111667	8/15/2007	26.0	0.17	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	8/20/2007	25.9	10.48	0.0000							0.000000
Patuxent	MI	38.638333	-76.695000	8/20/2007	26.7	6.80	0.0000							0.000000
Patuxent	NT	38.713107	-76.701882	8/20/2007	25.5	2.86	0.0000							0.000000
Patuxent	PP	38.388333	-76.506667	8/20/2007	25.8	15.95	0.0988							
Patuxent	SL	38.752801	-76.699864	8/20/2007	24.9	1.17	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	8/20/2007	26.3	15.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	8/22/2007	22.8	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	8/22/2007	24.1	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	8/22/2007	23.4	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	8/22/2007	24.2	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	8/22/2007	24.5	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	8/22/2007	23.7	0.20	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	8/22/2007	23.8	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	8/22/2007	23.7	0.20	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	8/22/2007	23.8	2.30	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	8/22/2007	24.7	8.50	0.0000							0.000000
Patuxent	GG	38.538056	-76.668890	8/22/2007	25.1	11.50	0.0000							0.000000
Patuxent	GK	38.633226	-76.691428	8/22/2007	25.2	5.50	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	8/22/2007	25.0	4.50	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	8/22/2007	22.7	0.50	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	8/23/2007	23.0	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	8/23/2007	23.1	0.10	0.0000							0.000000

Delaware Bay	EP	40.072750	-74.890000	8/23/2007	22.9	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	8/23/2007	22.6	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	8/23/2007	22.9	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	8/23/2007	21.0	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	8/23/2007	23.5	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	8/23/2007	23.7	0.10	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	8/23/2007	25.7	13.80	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	8/23/2007	24.7	12.40	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	8/23/2007	25.1	14.30	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	8/23/2007	24.8	12.80	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	8/23/2007	25.5	14.90	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	8/23/2007	25.8	13.00	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	8/27/2007	24.0	0.80	0.0027	12.585	1.525	3.292	0.033	-0.01792	0.000	-0.000619
Delaware Bay	RH	39.740417	-75.471017	8/27/2007	24.6	0.90	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	8/28/2007	26.2	0.20	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	8/28/2007	25.1	0.00	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	8/28/2007	25.8	0.20	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	8/28/2007	24.5	0.80	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	8/28/2007	25.6	0.20	0.0590							
Delaware Bay	SD	39.842183	-75.311200	8/28/2007	26.5	0.00	0.0000							0.000000
Choptank	CH	38.626667	-76.163333	9/4/2007	25.5	15.26	0.0000							0.000000
Choptank	JP	38.611667	-75.986667	9/4/2007	26.4	11.34	0.0000							0.000000
Choptank	MT	38.815000	-75.896667	9/4/2007	26.9	3.52	0.0000							0.000000
Choptank	NS	38.608333	-76.066667	9/4/2007	25.5	13.36	0.0171							
Delaware Bay	BN	40.087033	-74.856583	9/4/2007	25.6	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	9/4/2007	25.2	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	9/4/2007	25.0	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	9/4/2007	24.2	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	9/4/2007	25.5	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	9/4/2007	25.9	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	9/4/2007	24.1	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	9/4/2007	23.9	0.10	0.0000							0.000000

Nanticoke	CP	38.380000	-75.866667	9/5/2007	26.9	10.40	0.0082							
Nanticoke	LL	38.418333	-75.850000	9/5/2007	26.0	8.00	0.0110							
Nanticoke	SH	38.538333	-75.726667	9/5/2007	25.4	1.03	0.0000							0.000000
Nanticoke	TB	38.326667	-75.876667	9/5/2007	27.7	12.16	0.0069							
Delaware Bay	BP	39.841417	-75.269650	9/6/2007	25.4	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	9/6/2007	24.4	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	9/6/2007	24.9	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	9/6/2007	25.4	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	9/6/2007	24.8	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	9/6/2007	26.9	0.20	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	9/6/2007	25.9	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	9/6/2007	26.6	0.20	0.0000							0.000000
Potomac	BL	38.408333	-77.111667	9/6/2007	25.7	6.30	0.0000							0.000000
Potomac	HP	38.638333	-77.131667	9/6/2007	27.4	0.28	0.0000							0.000000
Potomac	IH	38.600000	-77.185000	9/6/2007	26.7	0.49	0.0000							0.000000
Potomac	LP	38.458333	-77.268333	9/6/2007	26.3	2.39	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	9/7/2007	24.9	2.50	0.0041	20.540	0.733	3.653	0.633	-0.01245	0.006	-0.001052
Delaware Bay	OP	39.762633	-75.461550	9/7/2007	25.2	1.80	0.0027							
Potomac	MO	38.361667	-76.983333	9/7/2007	27.6	10.82	0.0000							0.000000
Potomac	RP	38.273333	-76.833333	9/7/2007	26.6	12.59	0.0000							0.000000
Potomac	SG	38.136667	-76.500000	9/7/2007	27.4	15.54	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	9/10/2007	27.0	0.40	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	9/10/2007	27.2	3.00	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	9/10/2007	26.4	11.20	0.0014							
Delaware Bay	OC	39.826833	-75.354017	9/10/2007	26.4	0.40	0.0137							
Delaware Bay	RC	39.811033	-75.381133	9/10/2007	26.4	0.40	0.0508							
Delaware Bay	RH	39.740417	-75.471017	9/10/2007	26.3	2.00	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	9/10/2007	26.8	0.30	0.0096							
Upper Bay	HW	39.371667	-76.105000	9/10/2007	26.9	5.33	0.0000							0.000000
Upper Bay	SF	39.371600	-75.992470	9/10/2007	26.9	3.29	0.0000							0.000000
Upper Bay	TC	39.289317	-76.169117	9/10/2007	26.8	7.52	0.0000							0.000000
Upper Bay	TO	39.213333	-76.245000	9/10/2007	25.3	9.11	0.0000							0.000000

Delaware Bay	AB	39.505917	-75.578433	9/11/2007	26.2	7.80	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	9/11/2007	26.6	7.20	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	9/11/2007	26.5	5.30	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	9/11/2007	26.0	4.30	0.0206	18.324	1.176	4.036	0.099	-0.00634	0.001	-0.002390
Delaware Bay	NC	39.657033	-75.566400	9/11/2007	25.8	4.10	0.0302	17.690	1.090	3.959	0.199	-0.00752	0.002	-0.004017
Delaware Bay	OB	39.556967	-75.517983	9/11/2007	26.5	5.60	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	9/11/2007	25.9	3.50	0.0000							0.000000
Upper Bay	EN	39.475583	74.006200	9/11/2007	26.4	0.76	0.0000							0.000000
Upper Bay	PR	39.471767	-75.873215	9/11/2007	26.7	2.70	0.0021							
Upper Bay	WP	39.527250	-75.880967	9/11/2007	26.7	3.17	0.0000							0.000000
Upper Bay	YP	39.505000	-75.928333	9/11/2007	26.3	2.94	0.0000							0.000000
Upper Bay	CA	39.540000	-76.003333	9/12/2007	24.7	0.18	0.0000							0.000000
Upper Bay	PL	39.486667	-76.113333	9/12/2007	25.1	0.30	0.0000							0.000000
Upper Bay	SI	39.503333	-76.096667	9/12/2007	24.3	0.22	0.0000							0.000000
Upper Bay	TE	39.508333	-76.111667	9/12/2007	24.8	0.19	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	9/13/2007	26.5	13.47	0.0000							0.000000
Patuxent	MI	38.638333	-76.695000	9/13/2007	26.2	8.98	0.0000							0.000000
Patuxent	NT	38.713107	-76.701882	9/13/2007	24.7	3.15	0.0000							0.000000
Patuxent	PP	38.388333	-76.506667	9/13/2007	26.3	17.66	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	9/13/2007	24.7	1.43	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	9/13/2007	26.9	16.43	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	9/18/2007	23.5	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	9/18/2007	23.5	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	9/18/2007	22.3	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	9/18/2007	23.0	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	9/18/2007	23.3	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	9/18/2007	21.6	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	9/18/2007	22.9	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	9/18/2007	22.7	0.10	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	9/19/2007	22.5	7.80	0.0014							
Delaware Bay	CB	39.515700	-75.527167	9/19/2007	23.2	7.60	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	9/19/2007	22.2	3.10	0.0000							0.000000

Delaware Bay	FM	39.601433	-75.552167	9/19/2007	24.7	6.00	0.0041	19.188	1.108	3.536	0.689	-0.01404	0.007	-0.001108
Delaware Bay	GAG	39.638600	-75.598050	9/19/2007	21.3	7.60	0.0055	16.233	1.170	3.346	0.442	-0.02274	0.005	-0.002025
Delaware Bay	NC	39.657033	-75.566400	9/19/2007	22.1	4.00	0.0110	19.033	1.465	3.579	0.192	-0.01877	0.002	-0.003921
Delaware Bay	OB	39.556967	-75.517983	9/19/2007	23.1	5.60	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	9/19/2007	21.8	3.50	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	9/24/2007	23.7	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	9/24/2007	22.0	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	9/24/2007	23.2	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	9/24/2007	23.2	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	9/24/2007	23.2	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	9/24/2007	24.1	0.20	0.0027							
Delaware Bay	TT	39.852200	-75.280600	9/24/2007	24.4	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	9/24/2007	24.6	0.20	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	9/25/2007	24.3	0.40	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	9/25/2007	22.0	2.40	0.0014							
Delaware Bay	NM	39.796033	-75.452267	9/25/2007	23.0	1.20	0.0014							
Delaware Bay	OC	39.826833	-75.354017	9/25/2007	23.5	0.50	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	9/25/2007	22.0	2.00	0.0274							
Delaware Bay	RC	39.811033	-75.381133	9/25/2007	23.8	0.50	0.0219							
Delaware Bay	RH	39.740417	-75.471017	9/25/2007	22.5	2.10	0.0055							
Delaware Bay	SD	39.842183	-75.311200	9/25/2007	24.4	0.40	0.0110							
Patuxent	BI	38.401389	-76.550000	9/27/2007	24.4	15.80	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	9/27/2007	23.6	16.70	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	10/1/2007	22.3	8.80	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	10/1/2007	22.2	7.90	0.0014							
Delaware Bay	CT	39.670767	-75.513167	10/1/2007	22.6	4.90	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	10/1/2007	22.4	6.60	0.0027							
Delaware Bay	GAG	39.638600	-75.598050	10/1/2007	21.7	5.30	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	10/1/2007	22.1	4.40	0.0027							
Delaware Bay	OB	39.556967	-75.517983	10/1/2007	22.4	6.60	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	10/1/2007	21.8	5.30	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	10/2/2007	22.5	0.10	0.0000							0.000000

Delaware Bay	BN	40.087033	-74.856583	10/2/2007	22.5	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	10/2/2007	22.2	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	10/2/2007	21.8	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	10/2/2007	21.5	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	10/2/2007	22.4	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	10/2/2007	21.7	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	10/2/2007	21.4	0.10	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	10/3/2007	24.1	0.60	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	10/3/2007	22.7	2.60	0.3374							
Delaware Bay	NM	39.796033	-75.452267	10/3/2007	23.1	1.10	0.0014							
Delaware Bay	OC	39.826833	-75.354017	10/3/2007	23.1	0.70	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	10/3/2007	22.6	2.40	0.0027							
Delaware Bay	RC	39.811033	-75.381133	10/3/2007	24.4	0.80	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	10/3/2007	25.5	2.60	0.0014							
Delaware Bay	SD	39.842183	-75.311200	10/3/2007	24.1	0.60	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	10/11/2007	24.0	16.50	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	10/11/2007	22.5	15.60	0.0050	51.713	1.397	4.881	0.060	-0.00468	0.001	-0.001221
Patuxent	DNR	38.702500	-76.693610	10/11/2007	22.0	4.40	0.0017	16.540		4.250		-0.01212		-0.000348
Patuxent	EH	38.571667	-76.681667	10/11/2007	23.2	13.00	0.3076	36.128	3.494	3.588	0.231	-0.01649	0.002	-0.183261
Patuxent	GG	38.538056	-76.668890	10/11/2007	22.4	14.20	0.0488	60.308	3.387	4.283	0.305	-0.01098	0.003	-0.032344
Patuxent	GK	38.633226	-76.691428	10/11/2007	23.1	8.70	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	10/11/2007	23.4	6.80	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	10/11/2007	22.1	15.60	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	10/11/2007	22.3	1.80	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	10/16/2007			0.0069							
Delaware Bay	EA	39.878083	-75.177450	10/16/2007			0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	10/16/2007			0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	10/16/2007			0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	10/16/2007			0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	10/16/2007			0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	10/16/2007			0.0014							
Delaware Bay	UPS	39.857383	-75.256783	10/16/2007			0.0000							0.000000

Patuxent	SB	38.324720	-76.462200	10/16/2007	22.6	17.70	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	10/17/2007	21.5	10.50	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	10/17/2007	21.0	6.50	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	10/17/2007	21.0	8.00	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	10/17/2007	23.0	7.00	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	10/17/2007	23.0	6.00	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	10/17/2007	20.5	9.50	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	10/17/2007	20.5	9.50	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	10/17/2007	20.0	6.00	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	10/22/2007	17.9	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	10/22/2007	17.9	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	10/22/2007	17.5	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	10/22/2007	17.9	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	10/22/2007	17.9	0.00	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	10/22/2007	18.9	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	10/22/2007	18.9	0.00	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	10/22/2007	18.4	0.10	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	10/30/2007	17.7	0.20	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	10/30/2007	17.7	0.60	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	10/30/2007	18.5	0.30	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	10/30/2007	15.6	0.20	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	10/30/2007	18.3	0.40	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	10/30/2007	17.1	0.20	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	10/30/2007	13.9	0.50	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	10/30/2007	16.6	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	10/31/2007	15.4	0.10	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	10/31/2007	17.3	0.10	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	10/31/2007	17.1	0.10	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	10/31/2007	17.0	0.10	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	10/31/2007	17.0	0.10	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	10/31/2007	16.8	0.10	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	10/31/2007	16.2	0.10	0.0000							0.000000

Delaware Bay	UPS	39.857383	-75.256783	10/31/2007	17.0	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	11/5/2007	11.3	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	11/5/2007	12.3	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	11/5/2007	11.1	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	11/5/2007			0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	11/5/2007	10.8	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	11/5/2007	10.4	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	11/5/2007	11.6	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	11/5/2007	13.0	0.10	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	11/8/2007	12.9	16.70	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	11/8/2007	9.5	14.70	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	11/8/2007	11.9	16.80	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	11/8/2007	11.3	14.30	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	11/8/2007	12.0	15.30	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	11/9/2007	12.2	6.40	0.0055							
Delaware Bay	CB	39.515700	-75.527167	11/9/2007	13.4	7.40	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	11/9/2007	12.6	0.90	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	11/9/2007	12.8	3.70	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	11/9/2007	10.5	2.30	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	11/9/2007	11.9	1.90	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	11/9/2007	12.6	4.40	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	11/9/2007	13.0	2.70	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	11/14/2007	12.2	0.10	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	11/14/2007	12.3	0.70	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	11/14/2007	12.3	0.20	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	11/14/2007	11.9	0.10	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	11/14/2007	12.0	0.40	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	11/14/2007	12.1	0.10	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	11/14/2007	12.0	0.50	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	11/14/2007	12.1	0.10	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	11/20/2007	9.3	0.10	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	11/20/2007	9.0	0.10	0.0000							0.000000

Delaware Bay	MC	39.852917	-75.225000	11/20/2007			0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	11/20/2007	9.3	0.10	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	11/20/2007	9.3	0.10	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	11/20/2007	9.5	0.10	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	11/20/2007	9.3	0.10	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	11/20/2007	9.3	0.10	0.0000							0.000000

Table 4.2. Site-specific data from each sampling event in 2008.

System	Site Code	Latitude	Longitude	Date	Temperature (°C)	Salinity (ppt)	Abundance (fish.m^{-2})	Weight (g)		RNA:DNA		*G* (d^{-1})		Production (g.m^{-2}.d^{-1})
								Mean	S.E.	Mean	S.E.	Mean	S.E.	
Patuxent	SL	38.752801	-76.699864	6/11/2008	27.2	0.10	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	6/11/2008	28.2	0.90	0.0060	1.717	0.252	8.961	0.748	0.04832	0.008	0.000576
Patuxent	GK	38.633226	-76.691428	6/11/2008	28.8	0.16	0.0017	0.760		3.775		-0.00344		-0.000005
Patuxent	LM	38.658958	-76.682418	6/11/2008	28.8	0.10	0.0795	0.819	0.046	7.465	0.440	0.03424	0.004	0.002916
Patuxent	EH	38.571667	-76.681667	6/11/2008	29.0	0.70	0.0157	1.050	0.089	6.342	0.627	0.02318	0.006	0.000381
Patuxent	GG	38.538056	-76.668890	6/11/2008	28.0	4.60	0.1825	3.726	0.435	7.366	0.257	0.03164	0.003	0.012008
Patuxent	SP	38.467200	-76.644720	6/11/2008	26.7	6.93	0.0009							
Patuxent	MH	38.475000	-76.641667	6/11/2008	27.7	6.18	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	6/11/2008	30.8	5.35	0.0015	1.500	0.250	3.532	0.115	-0.00194	0.001	-0.000004
Patuxent	BI	38.401389	-76.550000	6/11/2008	29.9	7.70	0.5312	2.528	0.162	7.723	0.286	0.03906	0.003	0.058824
Patuxent	SB	38.324720	-76.462200	6/11/2008	28.8	7.87	4.6995	1.655	0.161	6.790	0.344	0.02735	0.004	0.210125
Choptank	MT	38.815000	-75.896667	6/16/2008	29.3	0.20	0.0009	1.575	0.269	6.794	0.604	0.02839	0.006	0.000041
Delaware Bay	HC	39.723917	-75.476783	6/16/2008	24.9	0.30	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	6/16/2008	25.3	0.30	0.0027							
Delaware Bay	OP	39.762633	-75.461550	6/16/2008	25.1	0.20	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	6/16/2008	25.4	0.20	0.0082							
Delaware Bay	RC	39.811033	-75.381133	6/16/2008	26.5	0.10	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	6/16/2008	26.3	0.10	0.0014							
Delaware Bay	CI	39.840367	-75.342317	6/16/2008	26.5	0.10	0.0055							
Delaware Bay	SD	39.842183	-75.311200	6/16/2008	26.2	0.10	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	6/16/2008	26.3	0.10	0.0027							
Nanticoke	TB	38.326667	-75.876667	6/16/2008	27.9	5.60	6.9273	3.460	0.121	7.327	0.237	0.03104	0.002	0.744003
Nanticoke	CP	38.380000	-75.866667	6/16/2008	29.1	4.10	2.4966	3.872	0.300	7.935	0.220	0.03964	0.002	0.383159
Nanticoke	LL	38.418333	-75.850000	6/16/2008	29.3	0.20	0.9287	5.496	0.420	7.992	0.315	0.04061	0.003	0.207291
Choptank	NS	38.608333	-76.066667	6/17/2008	26.6	7.70	1.9801	6.102	0.402	7.172	0.142	0.02687	0.001	0.324677
Delaware Bay	TT	39.852200	-75.280600	6/18/2008	24.2	0.10	0.0055							
Delaware Bay	TK	39.854500	-75.272666	6/18/2008	25.5	0.10	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	6/18/2008	23.4	0.20	0.0000							0.000000

Delaware Bay	PB	39.850516	-75.244516	6/18/2008	24.5	0.10	0.0082							
Delaware Bay	MC	39.852917	-75.225000	6/18/2008	25.4	0.10	0.0069							
Delaware Bay	PEB	39.874966	-75.192950	6/18/2008	25.5	0.10	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	6/18/2008	24.5	0.10	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	6/23/2008	25.7	1.90	0.0041							
Delaware Bay	AB	39.505917	-75.578433	6/23/2008	25.4	5.10	0.0261							
Delaware Bay	NC	39.657033	-75.566400	6/23/2008	25.0	1.60	0.0110							
Delaware Bay	FM	39.601433	-75.552167	6/23/2008	26.5	2.70	0.3443							
Delaware Bay	PN	39.648467	-75.532600	6/23/2008	24.9	1.90	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	6/23/2008	25.8	3.80	0.0096							
Delaware Bay	OB	39.556967	-75.517983	6/23/2008	26.3	3.30	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	6/23/2008	25.1	1.50	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	6/23/2008	30.0	4.20	0.0262	8.667	0.572	6.631	0.218	0.02811	0.002	0.006373
Patuxent	GG	38.538056	-76.668890	6/23/2008	28.5	4.93	0.0003	14.800		3.501		-0.00683		-0.000033
Patuxent	SP	38.467200	-76.644720	6/23/2008	27.4	7.02	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	6/23/2008	26.4	5.57	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	6/23/2008	25.7	7.38	0.0387	4.996	0.431	3.957	0.304	-0.00775	0.003	-0.002026
Patuxent	BI	38.401389	-76.550000	6/23/2008	26.4	8.04	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	6/23/2008	25.8	7.71	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	6/23/2008	26.9	9.01	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	6/24/2008	24.6	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	6/24/2008	24.8	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	6/24/2008	25.3	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	6/24/2008	25.5	0.00	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	6/24/2008	25.5	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	6/24/2008	27.0	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	6/24/2008	25.4	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	6/24/2008	26.6	0.10	0.0014							
Delaware Bay	HC	39.723917	-75.476783	7/1/2008	25.8	0.70	0.0027							
Delaware Bay	RH	39.740417	-75.471017	7/1/2008	26.1	0.60	0.0905							
Delaware Bay	OP	39.762633	-75.461550	7/1/2008	26.0	0.60	0.3951							
Delaware Bay	NM	39.796033	-75.452267	7/1/2008	26.8	0.40	0.0549							

Delaware Bay	RC	39.811033	-75.381133	7/1/2008	27.0	0.20	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	7/1/2008	27.1	0.20	0.0014							
Delaware Bay	CI	39.840367	-75.342317	7/1/2008	27.7	0.20	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	7/1/2008	27.3	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	7/1/2008	28.2	0.20	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	7/1/2008	25.5	0.11	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	7/1/2008	27.2	0.12	0.0006	2.090		2.803		-0.01396		-0.000017
Patuxent	GK	38.633226	-76.691428	7/1/2008	29.0	0.22	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	7/1/2008	28.6	0.16	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	7/2/2008	27.1	0.20	0.0041							
Delaware Bay	TK	39.854500	-75.272666	7/2/2008	28.1	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	7/2/2008	27.2	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	7/2/2008	26.3	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	7/2/2008	27.2	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	7/2/2008	27.0	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	7/2/2008	27.2	0.20	0.0000							0.000000
James	JA0077	37.420200	-77.396200	7/3/2008	30.4	0.20	0.0000							0.000000
James	JA0068	37.350700	-77.271300	7/3/2008	30.8	0.20	0.0000							0.000000
James	JA0062	37.310200	-77.222300	7/3/2008	29.3	0.20	0.0000							0.000000
James	JA0056	37.303500	-77.091800	7/3/2008	27.4	0.10	0.0000							0.000000
James	JA0051	37.285000	-77.035200	7/3/2008	27.7	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	7/8/2008	25.9	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	7/8/2008	26.2	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	7/8/2008			0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	7/8/2008			0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	7/8/2008			0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	7/8/2008			0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	7/8/2008			0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	7/8/2008			0.0000							0.000000
James	JA0046	37.270800	-76.989800	7/8/2008	28.2	0.50	0.0075							
James	JA0042	37.209300	-76.916500	7/8/2008	28.4	1.60	0.0000							0.000000
James	JA0036	37.221700	-76.788300	7/8/2008	26.1	3.00	0.0000							0.000000

James	JA0029	37.218300	-76.691300	7/8/2008	31.3	5.40	0.0014							
Delaware Bay	GAG	39.638600	-75.598050	7/10/2008	26.4	3.00	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	7/10/2008	27.5	5.30	0.0604	4.387	0.854	5.356	0.329	0.01012	0.003	0.002680
Delaware Bay	NC	39.657033	-75.566400	7/10/2008	26.4	2.60	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	7/10/2008	28.2	3.40	0.0055	1.750	0.215	4.847	0.133	0.00632	0.001	0.000061
Delaware Bay	CB	39.515700	-75.527167	7/10/2008	26.9	4.80	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	7/10/2008	28.1	3.50	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	7/10/2008	26.0	1.60	0.0000							0.000000
James	JA0022	37.137700	-76.619700	7/11/2008	30.4	9.00	0.0014							
James	JA0012	37.038000	-76.486500	7/11/2008	29.3	17.20	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	7/16/2008	27.4	2.80	0.0110	10.842	0.924	5.413	0.715	0.01050	0.007	0.001249
Delaware Bay	AB	39.505917	-75.578433	7/16/2008	27.7	6.60	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	7/16/2008	27.1	2.60	0.0027	9.890	3.820	7.018	0.940	0.02630	0.010	0.000714
Delaware Bay	FM	39.601433	-75.552167	7/16/2008	28.8	3.50	0.0000							0.000000
Delaware Bay	PN	39.648467	-75.532600	7/16/2008	26.9	2.10	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	7/16/2008	28.2	4.80	0.0137	13.650	0.587	7.799	0.440	0.03646	0.004	0.006826
Delaware Bay	OB	39.556967	-75.517983	7/16/2008	28.9	3.50	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	7/16/2008	27.2	1.70	0.0000							0.000000
Choptank	CH	38.626667	-76.163333	7/17/2008	32.0	9.08	0.0000							0.000000
Choptank	HN	38.592321	-76.129154	7/17/2008	31.3	7.83	0.0000							0.000000
Choptank	HB	38.592252	-76.084492	7/17/2008	28.9	7.37	0.0000							0.000000
Choptank	TY	38.755867	-76.000417	7/17/2008	29.2	1.30	0.0000							0.000000
Choptank	TY	38.755867	-76.000417	7/17/2008	29.2	1.30	0.0000							0.000000
Choptank	WC	38.613317	-75.971517	7/17/2008	29.8	5.42	0.7316	11.542	0.641	6.092	0.154	0.02222	0.002	0.172885
Choptank	HU	38.678433	-75.940917	7/17/2008	30.8	3.25	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	7/17/2008	29.4	0.20	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	7/17/2008	29.4	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	7/17/2008	29.7	0.20	0.3155	3.062	0.339	6.480	0.215	0.02598	0.002	0.025095
Delaware Bay	BP	39.841417	-75.269650	7/17/2008	30.2	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	7/17/2008	29.1	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	7/17/2008	28.4	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	7/17/2008	27.8	0.20	0.0000							0.000000

Delaware Bay	PEB	39.874966	-75.192950	7/17/2008	27.6	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	7/17/2008	27.0	0.20	0.0000							0.000000
Chester	LV	39.021917	-76.290100	7/18/2008	27.5	7.53	0.0082	43.887	4.755	4.640	0.620	0.00281	0.006	0.001011
Chester	EI	39.009342	-76.209700	7/18/2008	28.2	6.93	0.0921	20.032	1.090	5.946	0.259	0.01754	0.003	0.027280
Chester	NP	39.103900	-76.161250	7/18/2008	28.7	5.68	0.0000							0.000000
Chester	SA	39.093500	-76.144533	7/18/2008	28.2	5.79	0.0000							0.000000
Chester	CQ	39.098378	-76.135062	7/18/2008	29.4	5.70	0.0108	23.139	1.407	5.465	0.316	0.01501	0.003	0.003739
Chester	CN	39.181237	-76.061323	7/18/2008	30.9	3.40	0.3361	4.962	0.075	7.379	0.235	0.03754	0.002	0.062603
Chester	RW	39.229600	-76.018100	7/18/2008	29.9	1.73	0.0000							0.000000
James	JA0077	37.420200	-77.396200	7/18/2008	30.8	0.20	0.0000							0.000000
James	JA0068	37.350700	-77.271300	7/18/2008	31.2	0.10	0.0000							0.000000
James	JA0062	37.310200	-77.222300	7/18/2008	31.8	0.20	0.0000							0.000000
James	JA0056	37.303500	-77.091800	7/18/2008	27.6	0.20	0.0000							0.000000
James	JA0051	37.285000	-77.035200	7/18/2008	27.5	0.20	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	7/21/2008	32.7	1.30	0.0178	6.010	0.456	7.766	0.730	0.04507	0.007	0.004831
Delaware Bay	RH	39.740417	-75.471017	7/21/2008	29.8	1.10	0.0206							
Delaware Bay	OP	39.762633	-75.461550	7/21/2008	31.1	1.10	0.0302	10.136	1.301	7.020	0.429	0.03427	0.004	0.010484
Delaware Bay	NM	39.796033	-75.452267	7/21/2008	31.1	0.90	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	7/21/2008	29.2	0.30	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	7/21/2008	28.7	0.30	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	7/21/2008	29.4	0.30	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	7/21/2008	28.1	0.13	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	7/21/2008	29.4	0.26	0.1460	14.172	1.725	5.060	0.360	0.01088	0.004	0.019503
Patuxent	GK	38.633226	-76.691428	7/21/2008	31.0	1.75	0.0108	14.911	0.635	4.722	0.332	0.01061	0.003	0.001716
Patuxent	LM	38.658958	-76.682418	7/21/2008	30.1	0.81	0.0113	11.264	1.377	4.583	0.408	0.00740	0.004	0.001022
Patuxent	EH	38.571667	-76.681667	7/21/2008	32.5	5.80	0.0000							0.000000
Patuxent	GG	38.538056	-76.668890	7/21/2008	31.9	7.02	0.1970	15.031	1.132	4.591	0.300	0.01107	0.003	0.032152
Patuxent	SP	38.467200	-76.644720	7/21/2008	30.3	8.85	0.0267	17.069	0.952	5.651	0.274	0.01870	0.003	0.009511
Patuxent	MH	38.475000	-76.641667	7/21/2008	32.7	8.63	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	7/21/2008	31.8	8.91	0.0000							0.000000
Patuxent	BI	38.401389	-76.550000	7/21/2008	32.4	9.63	1.2085	11.663	0.652	4.401	0.245	0.01012	0.003	0.142589
Patuxent	CS	38.412990	-76.524300	7/21/2008	30.0	9.81	1.6850	13.513	0.647	5.088	0.225	0.01235	0.002	0.232204

Patuxent	SB	38.324720	-76.462200	7/21/2008	29.4	9.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	7/22/2008	27.8	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	7/22/2008	28.2	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	7/22/2008	28.6	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	7/22/2008	29.0	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	7/22/2008	29.1	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	7/22/2008	30.4	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	7/22/2008	29.8	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	7/22/2008	30.5	0.10	0.0000							0.000000
James	JA0046	37.270800	-76.989800	7/22/2008	31.5	0.70	0.0000							0.000000
James	JA0042	37.209300	-76.916500	7/22/2008	32.3	2.10	0.0000							0.000000
James	JA0036	37.221700	-76.788300	7/22/2008	28.1	4.00	0.0000							0.000000
James	JA0029	37.218300	-76.691300	7/22/2008	32.1	7.40	0.0000							0.000000
James	JA0022	37.137700	-76.619700	7/25/2008	30.7	11.40	0.0000							0.000000
James	JA0012	37.038000	-76.486500	7/25/2008	28.0	19.10	0.0000							0.000000
Upper Bay	TC	39.289317	-76.169117	7/31/2008	28.6	2.69	0.0041	25.915	5.259	4.608	0.606	0.00467	0.006	0.000496
Upper Bay	HW	39.371667	-76.105000	7/31/2008	27.4	1.06	0.0000							0.000000
Upper Bay	AP	39.154098	-76.079372	7/31/2008	28.1	0.21	0.0000							0.000000
Upper Bay	LG	39.371550	-75.978467	7/31/2008	28.4	0.22	0.0000							0.000000
Upper Bay	WP	39.527250	-75.880967	7/31/2008	28.5	0.20	0.0000							0.000000
Upper Bay	PR	39.471767	-75.873215	7/31/2008	28.7	0.22	0.0753	7.771	0.846	4.896	0.288	0.00781	0.003	0.004111
Upper Bay	EN	39.475583	-74.006200	7/31/2008	28.0	0.14	0.0000							0.000000
James	JA0077	37.420200	-77.396200	8/1/2008	30.5	0.20	0.0000							0.000000
James	JA0068	37.350700	-77.271300	8/1/2008	32.2	0.20	0.0000							0.000000
James	JA0062	37.310200	-77.222300	8/1/2008	30.0	0.20	0.0000							0.000000
James	JA0056	37.303500	-77.091800	8/1/2008	28.1	0.20	0.0000							0.000000
James	JA0051	37.285000	-77.035200	8/1/2008	29.8	0.50	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	8/4/2008	27.7	2.40	0.0055	10.653	1.970	3.501	0.484	-0.00842	0.005	-0.000492
Delaware Bay	AB	39.505917	-75.578433	8/4/2008	27.4	5.50	0.0069	13.854	1.695	5.050	0.608	0.00679	0.006	0.000646
Delaware Bay	NC	39.657033	-75.566400	8/4/2008	28.3	2.40	0.2414	14.606	0.835	5.141	0.315	0.00952	0.003	0.033568
Delaware Bay	FM	39.601433	-75.552167	8/4/2008	26.6	2.90	0.0027	5.090	0.650	4.701	1.111	0.00164	0.011	0.000023
Delaware Bay	PV	39.649783	-75.531783	8/4/2008	28.2	1.70	0.0055							

Delaware Bay	CB	39.515700	-75.527167	8/4/2008	26.7	3.80	0.0219	12.436	1.171	4.047	0.213	-0.00483	0.002	-0.001319
Delaware Bay	OB	39.556967	-75.517983	8/4/2008	26.5	3.20	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	8/4/2008	28.2	1.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	8/5/2008	25.5	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	8/5/2008	25.7	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	8/5/2008	25.9	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	8/5/2008	26.5	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	8/5/2008	26.6	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	8/5/2008	27.6	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	8/5/2008	27.3	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	8/5/2008	27.6	0.10	0.0000							0.000000
James	JA0046	37.270800	-76.989800	8/5/2008	30.9	1.60	0.0027							
James	JA0042	37.209300	-76.916500	8/5/2008	31.2	3.10	0.0000							0.000000
James	JA0036	37.221700	-76.788300	8/5/2008	28.1	5.90	0.0000							0.000000
James	JA0029	37.218300	-76.691300	8/5/2008	31.6	8.60	0.0000							0.000000
James	JA0022	37.137700	-76.619700	8/8/2008	28.2	12.00	0.0000							0.000000
James	JA0012	37.038000	-76.486500	8/8/2008	29.5	19.80	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	8/12/2008	22.4	0.80	0.0192	11.501	1.022	3.781	0.204	-0.01611	0.002	-0.003558
Delaware Bay	RH	39.740417	-75.471017	8/12/2008	24.0	0.60	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	8/12/2008	23.9	0.50	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	8/12/2008	25.4	0.40	0.0123							
Delaware Bay	RC	39.811033	-75.381133	8/12/2008	25.9	0.20	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	8/12/2008	25.7	0.20	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	8/12/2008	26.4	0.20	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	8/12/2008	25.1	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	8/12/2008	25.9	0.20	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	8/13/2008	25.4	0.17	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	8/13/2008	25.5	0.43	0.0367	12.198	0.996	4.229	0.395	-0.00537	0.004	-0.002403
Patuxent	GK	38.633226	-76.691428	8/13/2008	26.6	2.14	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	8/13/2008	26.4	1.11	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	8/13/2008	27.4	5.36	0.0017							
Patuxent	GG	38.538056	-76.668890	8/13/2008	27.2	8.30	0.0803	17.629	1.002	5.279	0.607	0.00874	0.006	0.011820

Patuxent	SP	38.467200	-76.644720	8/13/2008	26.6	9.63	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	8/13/2008	26.6	9.48	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	8/13/2008	27.1	9.68	1.2979	12.699	0.647	4.101	0.244	-0.00349	0.002	-0.059377
Patuxent	BI	38.401389	-76.550000	8/13/2008	28.3	10.65	3.6926	14.843	0.813	3.778	0.282	-0.00440	0.003	-0.259099
Patuxent	CS	38.412990	-76.524300	8/13/2008	28.2	10.70	0.2696	13.154	0.747	3.310	0.305	-0.00938	0.003	-0.032123
Patuxent	SB	38.324720	-76.462200	8/13/2008	28.0	11.42	0.2599	15.972	1.067	4.579	0.472	0.00318	0.005	0.013212
Delaware Bay	TT	39.852200	-75.280600	8/18/2008	25.6	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	8/18/2008	28.4	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	8/18/2008	26.7	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	8/18/2008	25.4	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	8/18/2008	27.6	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	8/18/2008	26.6	0.10	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	8/18/2008	25.2	0.10	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	8/19/2008	26.3	4.60	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	8/19/2008	26.4	8.80	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	8/19/2008	26.4	3.50	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	8/19/2008	27.0	5.60	0.0082	12.650	2.287	5.621	0.699	0.01183	0.007	0.001232
Delaware Bay	PV	39.649783	-75.531783	8/19/2008	25.3	4.10	0.0027	12.975	0.325	5.531	0.814	0.00753	0.008	0.000268
Delaware Bay	CB	39.515700	-75.527167	8/19/2008	26.6	6.70	0.0055	10.450		3.593		-0.00967		-0.000555
Delaware Bay	OB	39.556967	-75.517983	8/19/2008	27.3	5.40	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	8/19/2008	26.1	3.70	0.0000							0.000000
James	JA0077	37.420200	-77.396200	8/19/2008	30.2	0.30	0.0000							0.000000
James	JA0068	37.350700	-77.271300	8/19/2008	29.2	0.20	0.0000							0.000000
James	JA0062	37.310200	-77.222300	8/19/2008	28.4	0.30	0.0000							0.000000
James	JA0056	37.303500	-77.091800	8/19/2008	26.5	0.60	0.0000							0.000000
James	JA0051	37.285000	-77.035200	8/19/2008	26.7	1.20	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	8/21/2008	27.2	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	8/21/2008	25.7	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	8/21/2008	24.1	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	8/21/2008	24.8	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	8/21/2008	24.5	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	8/21/2008	26.2	0.10	0.0000							0.000000

Delaware Bay	LC	40.104600	-74.832500	8/21/2008	24.7	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	8/21/2008	25.5	0.10	0.0000							0.000000
James	JA0046	37.270800	-76.989800	8/21/2008	28.2	3.20	0.0007							
James	JA0042	37.209300	-76.916500	8/21/2008	26.5	4.90	0.0000							0.000000
James	JA0036	37.221700	-76.788300	8/21/2008	25.1	7.80	0.0021							
James	JA0029	37.218300	-76.691300	8/21/2008	28.3	10.70	0.0007							
Choptank	CH	38.626667	-76.163333	8/25/2008	26.4	11.05	0.0000							0.000000
Choptank	HN	38.592321	-76.129154	8/25/2008	25.7	10.60	0.0000							0.000000
Choptank	HB	38.592252	-76.084492	8/25/2008	26.2	9.16	0.0000							0.000000
Choptank	RD	38.619200	-76.082378	8/25/2008	29.5	9.18	0.0000							0.000000
Choptank	LT	38.739530	-75.993013	8/25/2008	28.0	4.34	0.1861	17.708	0.563	4.370	0.283	0.00104	0.003	0.003645
Choptank	CW	38.640640	-75.976952	8/25/2008	26.9	6.97	0.0219	18.257	0.766	4.346	0.329	-0.00139	0.003	-0.000586
Choptank	WC	38.613317	-75.971517	8/25/2008	26.7	7.19	0.0000							0.000000
Choptank	CY	38.777292	-75.950377	8/25/2008	27.8	2.92	0.4204	14.694	0.723	4.574	0.310	0.00274	0.003	0.017102
Delaware Bay	TT	39.852200	-75.280600	8/25/2008	26.1	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	8/25/2008	27.1	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	8/25/2008	25.8	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	8/25/2008	26.7	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	8/25/2008	26.0	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	8/25/2008	25.5	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	8/25/2008	25.8	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	8/25/2008	25.3	0.20	0.0000							0.000000
Chester	EI	39.009342	-76.209700	8/26/2008	23.9	9.86	0.0022	21.423	2.344	2.916	0.344	-0.02195	0.004	-0.001034
Chester	CQ	39.098378	-76.135062	8/26/2008	23.6	8.62	0.0008	29.710	1.850	4.628	0.553	-0.00508	0.006	-0.000127
Chester	BC	39.154262	-76.079158	8/26/2008	25.6	7.34	0.0019	13.408	1.433	5.131	0.217	0.00404	0.002	0.000102
Chester	CN	39.181237	-76.061323	8/26/2008	26.0	4.48	0.0002	15.530		5.023		0.00374		0.000012
Chester	SK	39.178218	-76.046317	8/26/2008	26.7	4.94	0.0000							0.000000
James	JA0022	37.137700	-76.619700	8/26/2008	27.0	13.60	0.0219	32.753	1.257	5.825	0.221	0.01391	0.002	0.010001
James	JA0012	37.038000	-76.486500	8/26/2008	27.9	21.50	0.0000							0.000000
Delaware Bay	AA	39.503970	-75.580890	8/27/2008	27.1	8.80	0.0027	11.675	0.485	5.635	0.514	0.01217	0.005	0.000390
Delaware Bay	AC	39.506401	-75.578495	8/27/2008	27.1	8.80	0.0206	16.168	1.505	6.515	0.492	0.02116	0.005	0.007039
Delaware Bay	NA	39.657170	-75.566160	8/27/2008	26.5	4.50	0.0206	10.802	0.638	6.391	0.460	0.01870	0.005	0.004157

Delaware Bay	WA	39.331422	-75.470196	8/27/2008	25.4	14.10	0.1674	21.760	1.876	7.348	0.214	0.02628	0.002	0.095715
Delaware Bay	WB	39.330920	-75.468617	8/27/2008	25.4	14.10	0.0425	22.387	1.664	6.838	0.454	0.02107	0.005	0.020056
Patuxent	SL	38.752801	-76.699864	8/27/2008	25.7	0.35	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	8/27/2008	25.9	1.10	0.0067							
Patuxent	GK	38.633226	-76.691428	8/27/2008	26.3	3.51	0.2819	13.587	1.602	4.953	0.245	0.00362	0.003	0.015401
Patuxent	LM	38.658958	-76.682418	8/27/2008	26.4	2.37	0.0023	13.785	1.115	2.835	0.043	-0.01780	0.000	-0.000574
Patuxent	EH	38.571667	-76.681667	8/27/2008	27.1	7.86	0.1287	15.751	1.246	4.312	0.443	-0.00134	0.005	-0.002917
Patuxent	GG	38.538056	-76.668890	8/27/2008	26.2	10.59	0.0112	18.702	0.676	4.816	0.264	0.00202	0.003	0.000423
Patuxent	SP	38.467200	-76.644720	8/27/2008	25.6	11.64	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	8/27/2008	25.9	11.38	0.0496	18.817	0.587	4.366	0.327	-0.00317	0.003	-0.002954
Patuxent	CR	38.434797	-76.640113	8/27/2008	24.8	11.35	0.0072	15.840	1.001	3.082	0.731	-0.01847	0.007	-0.002099
Patuxent	BI	38.401389	-76.550000	8/27/2008	25.7	12.59	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	8/27/2008	25.5	12.93	7.6536	14.820	1.173	4.394	0.307	-0.00368	0.003	-0.437497
Patuxent	SB	38.324720	-76.462200	8/27/2008	25.6	13.72	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	8/28/2008	24.9	2.40	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	8/28/2008	25.0	2.50	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	8/28/2008	24.7	2.30	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	8/28/2008	25.0	1.10	0.0014							
Delaware Bay	RC	39.811033	-75.381133	8/28/2008	25.3	0.80	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	8/28/2008	25.1	0.50	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	8/28/2008	25.1	0.40	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	8/28/2008	24.7	0.40	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	9/2/2008	24.9	5.30	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	9/2/2008	24.9	8.90	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	9/2/2008	24.9	4.50	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	9/2/2008	25.7	6.40	0.0562							
Delaware Bay	PV	39.649783	-75.531783	9/2/2008	24.0	5.20	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	9/2/2008	25.6	7.60	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	9/2/2008	25.7	6.30	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	9/2/2008	24.2	4.60	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	9/3/2008	24.3	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	9/3/2008	24.4	0.10	0.0000							0.000000

Delaware Bay	HI	40.045333	-74.975233	9/3/2008	25.1	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	9/3/2008	27.9	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	9/3/2008	24.9	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	9/3/2008	28.1	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	9/3/2008	26.0	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	9/3/2008	26.5	0.10	0.0000							0.000000
James	JA0077	37.420200	-77.396200	9/3/2008	27.1	0.10	0.0000							0.000000
James	JA0068	37.350700	-77.271300	9/3/2008	29.7	0.20	0.0000							0.000000
James	JA0062	37.310200	-77.222300	9/3/2008	29.7	0.30	0.0000							0.000000
James	JA0056	37.303500	-77.091800	9/3/2008	26.9	0.40	0.0000							0.000000
James	JA0051	37.285000	-77.035200	9/3/2008	26.7	0.80	0.0000							0.000000
Upper Bay	WT	39.295167	-76.169583	9/4/2008	25.2	7.15	0.0000							0.000000
Upper Bay	HW	39.371667	-76.105000	9/4/2008	25.1	5.47	0.0000							0.000000
Upper Bay	AP	39.154098	-76.079372	9/4/2008	26.0	2.72	0.0000							0.000000
Upper Bay	PD	39.455083	-75.992957	9/4/2008	27.4	3.00	0.0000							0.000000
Upper Bay	LG	39.371550	-75.978467	9/4/2008	27.1	1.98	0.0000							0.000000
Upper Bay	WP	39.527250	-75.880967	9/4/2008	27.0	4.08	0.0007	14.120		3.016		-0.01477		-0.000146
Upper Bay	PR	39.471767	-75.873215	9/4/2008	27.2	1.31	0.1124	9.487	0.621	4.061	0.312	-0.00369	0.003	-0.003705
Upper Bay	EN	39.475583	-74.006200	9/4/2008	25.6	1.08	0.0000							0.000000
Delaware Bay	WA	39.331422	-75.470196	9/5/2008	24.6	14.80	0.0014							
Delaware Bay	WB	39.330920	-75.468617	9/5/2008	24.6	14.80	0.0069							
James	JA0046	37.270800	-76.989800	9/5/2008	28.9	1.90	0.0007							
James	JA0036	37.221700	-76.788300	9/5/2008	25.9	6.60	0.0000							0.000000
James	JA0029	37.218300	-76.691300	9/5/2008	28.0	9.70	0.0014							
Delaware Bay	BP	39.841417	-75.269650	9/9/2008	24.9	0.30	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	9/9/2008	25.3	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	9/9/2008	25.1	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	9/9/2008	25.2	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	9/9/2008	24.9	0.20	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	9/10/2008	25.7	0.70	0.0137							
Delaware Bay	RC	39.811033	-75.381133	9/10/2008	25.3	0.50	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	9/10/2008	24.9	0.40	0.0000							0.000000

Delaware Bay	CI	39.840367	-75.342317	9/10/2008	25.3	0.40	0.0041							
Delaware Bay	SD	39.842183	-75.311200	9/10/2008	23.9	0.40	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	9/10/2008	24.9	0.20	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	9/10/2008	23.4	0.20	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	9/10/2008	23.8	0.20	0.0000							0.000000
James	JA0022	37.137700	-76.619700	9/10/2008	25.6	10.60	0.0000							0.000000
James	JA0012	37.038000	-76.486500	9/10/2008	26.1	17.70	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	9/12/2008	23.5	2.20	0.0892	12.101	0.781	4.205	0.346	-0.00960	0.004	-0.010353
Delaware Bay	RH	39.740417	-75.471017	9/12/2008	24.1	1.90	0.0027							
Delaware Bay	OP	39.762633	-75.461550	9/12/2008	24.0	1.80	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	9/15/2008	25.1	0.30	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	9/15/2008	25.6	0.20	0.0123							
Delaware Bay	BP	39.841417	-75.269650	9/15/2008	25.3	0.30	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	9/15/2008	25.4	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	9/15/2008	24.7	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	9/15/2008	25.7	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	9/15/2008	25.4	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	9/15/2008	24.7	0.20	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	9/16/2008	24.1	1.60	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	9/16/2008	21.6	1.30	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	9/16/2008	22.2	1.00	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	9/16/2008	23.8	0.90	0.0014							
Delaware Bay	RC	39.811033	-75.381133	9/16/2008	24.5	0.30	0.0082	17.257	1.974	4.119	0.513	-0.00848	0.005	-0.001204
Delaware Bay	OC	39.826833	-75.354017	9/16/2008	24.1	0.30	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	9/16/2008	24.6	0.30	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	9/16/2008	23.8	0.30	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	9/17/2008	24.2	4.00	0.0027	22.085	2.985	3.688	0.629	-0.01347	0.006	-0.000816
Delaware Bay	AB	39.505917	-75.578433	9/17/2008	23.7	7.70	0.1015	13.251	1.000	4.649	0.223	-0.00466	0.002	-0.006265
Delaware Bay	NC	39.657033	-75.566400	9/17/2008	24.6	3.60	0.0302	11.573	1.027	4.449	0.202	-0.00492	0.002	-0.001717
Delaware Bay	FM	39.601433	-75.552167	9/17/2008	23.3	5.00	0.0041	9.237	1.917	5.456	0.409	0.00278	0.004	0.000106
Delaware Bay	PV	39.649783	-75.531783	9/17/2008	24.9	3.30	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	9/17/2008	23.3	6.00	0.0014	26.110		4.501		-0.00697		-0.000250

Delaware Bay	OB	39.556967	-75.517983	9/17/2008	22.4	5.40	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	9/17/2008	25.1	2.40	0.0000							0.000000
Delaware Bay	WA	39.331422	-75.470196	9/17/2008	19.9	13.50	0.0000							0.000000
Delaware Bay	WB	39.330920	-75.468617	9/17/2008	19.9	13.50	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	9/22/2008	22.4	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	9/22/2008	21.9	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	9/22/2008	21.6	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	9/22/2008	22.4	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	9/22/2008	22.1	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	9/22/2008	23.0	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	9/22/2008	22.3	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	9/22/2008	21.2	0.10	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	9/23/2008	21.6	0.26	0.0037							
Patuxent	DNR	38.702500	-76.693610	9/23/2008	22.2	1.30	0.0135							
Patuxent	GK	38.633226	-76.691428	9/23/2008	22.7	4.92	0.0095	24.765	2.845	5.850	0.315	0.00561	0.003	0.001323
Patuxent	LM	38.658958	-76.682418	9/23/2008	22.8	3.83	0.0086							
Patuxent	EH	38.571667	-76.681667	9/23/2008	23.1	7.90	0.3739	20.689	0.971	4.712	0.138	-0.00521	0.001	-0.040280
Patuxent	GG	38.538056	-76.668890	9/23/2008	23.0	11.21	0.2968	18.741	0.819	4.556	0.355	-0.00701	0.004	-0.039559
Patuxent	SP	38.467200	-76.644720	9/23/2008	23.7	12.67	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	9/23/2008	23.9	12.28	0.0025	20.590		4.294		-0.00788		-0.000403
Patuxent	CR	38.434797	-76.640113	9/23/2008	23.1	12.35	1.0375	18.832	0.701	4.135	0.348	-0.01110	0.004	-0.214914
Patuxent	BI	38.401389	-76.550000	9/23/2008	24.4	13.55	0.0370	32.059	0.798	4.750	0.288	-0.00223	0.003	-0.003253
Patuxent	CS	38.412990	-76.524300	9/23/2008	24.7	13.64	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	9/23/2008	24.5	14.31	0.0000							0.000000
Delaware Bay	NB	39.656010	-75.568881	9/27/2008	26.5	4.50	0.0000							0.000000
Choptank	DB	38.617867	-76.084883	9/29/2008	22.3	12.61	0.0000							0.000000
Choptank	HB	38.592252	-76.084492	9/29/2008	21.4	12.34	0.9078	17.939	1.464	6.391	0.295	0.00855	0.003	0.139269
Choptank	LT	38.739530	-75.993013	9/29/2008	22.5	5.29	0.0128							
Choptank	WC	38.613317	-75.971517	9/29/2008	21.6	10.23	0.0000							0.000000
Choptank	PT	38.678173	-75.964735	9/29/2008	21.6	7.96	0.0000							0.000000
Choptank	AT	38.810828	-75.877500	9/29/2008	22.1	1.82	0.0017							
Chester	EI	39.009342	-76.209700	9/30/2008	20.5	12.37	0.0000							0.000000

Chester	CQ	39.098378	-76.135062	9/30/2008	20.7	10.58	0.0000							0.000000
Chester	BC	39.154262	-76.079158	9/30/2008	21.4	9.64	0.0052	9.120		6.254		0.00715		0.000340
Chester	PS	39.247533	-76.006848	9/30/2008	21.0	5.11	0.0394	9.375	0.294	6.024	1.016	0.00400	0.010	0.001478
Chester	UC	39.249113	-75.893775	9/30/2008	21.2	1.67	0.6068	12.162	0.358	7.611	0.388	0.02060	0.004	0.148354
Delaware Bay	WA	39.331422	-75.470196	10/1/2008	19.5	14.50	0.0096	13.924	1.778	5.151	0.431	-0.00789	0.004	-0.001055
Delaware Bay	WB	39.330920	-75.468617	10/1/2008	19.5	14.50	0.0316	13.836	0.804	5.089	0.227	-0.00853	0.002	-0.003723
Upper Bay	WT	39.295167	-76.169583	10/1/2008	20.6	9.68	0.0000							0.000000
Upper Bay	AP	39.154098	-76.079372	10/1/2008	21.4	6.02	0.0000							0.000000
Upper Bay	PD	39.455083	-75.992957	10/1/2008	20.6	5.55	0.0006							
Upper Bay	LG	39.371550	-75.978467	10/1/2008	21.5	6.66	0.0000							0.000000
Upper Bay	WP	39.527250	-75.880967	10/1/2008	22.2	7.65	0.0000							0.000000
Upper Bay	PR	39.471767	-75.873215	10/1/2008	21.2	5.99	0.0948	12.016	0.856	6.557	0.801	0.00985	0.008	0.011217
Upper Bay	EN	39.475583	-74.006200	10/1/2008	20.7	1.82	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	10/6/2008	19.8	0.20	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	10/6/2008	18.7	0.30	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	10/6/2008	19.4	0.20	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	10/6/2008	19.5	0.20	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	10/6/2008	19.1	0.20	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	10/6/2008	19.4	0.20	0.0000							0.000000
Delaware Bay	RC	39.811033	-75.381133	10/7/2008	19.2	0.40	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	10/7/2008	18.4	0.30	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	10/7/2008	19.8	0.30	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	10/7/2008	17.9	0.20	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	10/7/2008	18.2	0.20	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	10/7/2008	18.8	0.20	0.0000							0.000000
Delaware Bay	PV	39.649783	-75.531783	10/8/2008	18.9	4.10	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	10/8/2008	19.2	3.90	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	10/8/2008	17.2	2.30	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	10/8/2008	17.8	0.20	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	10/8/2008	18.0	1.50	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	10/8/2008	18.7	0.80	0.0027							
Delaware Bay	GAG	39.638600	-75.598050	10/14/2008	18.8	5.40	0.0000							0.000000

Delaware Bay	AB	39.505917	-75.578433	10/14/2008	18.9	10.10	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	10/14/2008	19.0	4.50	0.0014							
Delaware Bay	FM	39.601433	-75.552167	10/14/2008	20.0	6.70	0.2016							
Delaware Bay	CB	39.515700	-75.527167	10/14/2008	19.8	9.30	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	10/14/2008	19.7	7.50	0.0000							0.000000
Delaware Bay	WA	39.331422	-75.470196	10/14/2008	20.7	15.10	0.0000							0.000000
Delaware Bay	WB	39.330920	-75.468617	10/14/2008	20.6	15.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	10/15/2008	18.7	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	10/15/2008	18.3	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	10/15/2008	18.4	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	10/15/2008	18.7	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	10/15/2008	19.1	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	10/15/2008	18.6	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	10/15/2008	18.5	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	10/15/2008	18.2	0.10	0.0000							0.000000
Delaware Bay	GAG	39.638600	-75.598050	11/3/2008	12.5	2.90	0.0000							0.000000
Delaware Bay	AB	39.505917	-75.578433	11/3/2008	11.9	7.60	0.0000							0.000000
Delaware Bay	NC	39.657033	-75.566400	11/3/2008	12.6	2.50	0.0000							0.000000
Delaware Bay	FM	39.601433	-75.552167	11/3/2008	12.2	5.10	0.0000							0.000000
Delaware Bay	PV	39.649783	-75.531783	11/3/2008	13.0	1.10	0.0000							0.000000
Delaware Bay	CB	39.515700	-75.527167	11/3/2008	12.0	6.20	0.0000							0.000000
Delaware Bay	OB	39.556967	-75.517983	11/3/2008	11.6	4.70	0.0000							0.000000
Delaware Bay	CT	39.670767	-75.513167	11/3/2008	13.2	1.10	0.0000							0.000000
Patuxent	SL	38.752801	-76.699864	11/3/2008	11.3	0.22	0.0000							0.000000
Patuxent	DNR	38.702500	-76.693610	11/3/2008	11.4	1.45	0.0000							0.000000
Patuxent	GK	38.633226	-76.691428	11/3/2008	12.3	5.24	0.0000							0.000000
Patuxent	LM	38.658958	-76.682418	11/3/2008	11.9	3.63	0.0000							0.000000
Patuxent	EH	38.571667	-76.681667	11/3/2008	13.7	9.95	0.0006							
Patuxent	GG	38.538056	-76.668890	11/3/2008	13.4	11.54	0.0000							0.000000
Patuxent	SP	38.467200	-76.644720	11/3/2008	13.9	14.74	0.0000							0.000000
Patuxent	MH	38.475000	-76.641667	11/3/2008	13.5	13.86	0.0000							0.000000
Patuxent	CR	38.434797	-76.640113	11/3/2008	13.9	13.58	0.0023							

Patuxent	BI	38.401389	-76.550000	11/3/2008	14.2	15.00	0.0000							0.000000
Patuxent	CS	38.412990	-76.524300	11/3/2008	15.0	15.46	0.0000							0.000000
Patuxent	SB	38.324720	-76.462200	11/3/2008	15.1	16.04	0.0000							0.000000
Choptank	DB	38.617867	-76.084883	11/5/2008	12.9	14.11	0.0000							0.000000
Choptank	HB	38.592252	-76.084492	11/5/2008	13.0	13.58	0.0000							0.000000
Choptank	LT	38.739530	-75.993013	11/5/2008	12.8	7.19	0.0000							0.000000
Choptank	WC	38.613317	-75.971517	11/5/2008	12.4	12.69	0.0000							0.000000
Choptank	AT	38.810828	-75.877500	11/5/2008	13.1	3.38	0.0000							0.000000
Chester	EI	39.009342	-76.209700	11/6/2008	13.8	13.27	0.0000							0.000000
Chester	CQ	39.098378	-76.135062	11/6/2008	13.2	11.75	0.0000							0.000000
Chester	BC	39.154262	-76.079158	11/6/2008	12.7	10.11	0.0010							
Chester	PS	39.247533	-76.006848	11/6/2008	13.0	4.76	0.0000							0.000000
Upper Bay	WT	39.295167	-76.169583	11/7/2008	13.3	7.58	0.0000							0.000000
Upper Bay	HW	39.371667	-76.105000	11/7/2008	13.1	6.58	0.0000							0.000000
Upper Bay	AP	39.154098	-76.079372	11/7/2008	15.1	5.36	0.0000							0.000000
Upper Bay	PD	39.455083	-75.992957	11/7/2008	14.8	5.11	0.0000							0.000000
Upper Bay	LG	39.371550	-75.978467	11/7/2008	14.2	5.22	0.0000							0.000000
Upper Bay	WP	39.527250	-75.880967	11/7/2008	13.7	6.58	0.0000							0.000000
Upper Bay	PR	39.471767	-75.873215	11/7/2008	13.8	4.78	0.0000							0.000000
Upper Bay	EN	39.475583	-74.006200	11/7/2008	14.6	4.98	0.0000							0.000000
Delaware Bay	TT	39.852200	-75.280600	11/10/2008	10.9	0.10	0.0000							0.000000
Delaware Bay	TK	39.854500	-75.272666	11/10/2008	10.5	0.10	0.0000							0.000000
Delaware Bay	BP	39.841417	-75.269650	11/10/2008	10.2	0.10	0.0000							0.000000
Delaware Bay	UPS	39.857383	-75.256783	11/10/2008	11.1	0.10	0.0000							0.000000
Delaware Bay	PB	39.850516	-75.244516	11/10/2008	11.0	0.10	0.0000							0.000000
Delaware Bay	MC	39.852917	-75.225000	11/10/2008	11.2	0.10	0.0000							0.000000
Delaware Bay	PEB	39.874966	-75.192950	11/10/2008	11.0	0.10	0.0000							0.000000
Delaware Bay	EA	39.878083	-75.177450	11/10/2008	10.5	0.10	0.0000							0.000000
Delaware Bay	HC	39.723917	-75.476783	11/12/2008	10.6	1.10	0.0000							0.000000
Delaware Bay	RH	39.740417	-75.471017	11/12/2008	10.8	0.80	0.0000							0.000000
Delaware Bay	OP	39.762633	-75.461550	11/12/2008	10.6	0.60	0.0000							0.000000
Delaware Bay	NM	39.796033	-75.452267	11/12/2008	11.4	0.60	0.0000							0.000000

Delaware Bay	RC	39.811033	-75.381133	11/12/2008	11.3	0.20	0.0000							0.000000
Delaware Bay	OC	39.826833	-75.354017	11/12/2008	10.8	0.10	0.0000							0.000000
Delaware Bay	CI	39.840367	-75.342317	11/12/2008	10.5	0.10	0.0000							0.000000
Delaware Bay	SD	39.842183	-75.311200	11/12/2008	10.5	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	11/14/2008	11.8	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	11/14/2008	10.7	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	11/14/2008	11.0	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	11/14/2008	11.4	0.10	0.0000							0.000000
Delaware Bay	EP	40.072750	-74.890000	11/14/2008	11.5	0.10	0.0000							0.000000
Delaware Bay	BN	40.087033	-74.856583	11/14/2008	10.9	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	11/14/2008	10.6	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	11/14/2008	10.1	0.10	0.0000							0.000000
Delaware Bay	PC	39.998167	-75.053100	11/17/2008	8.7	0.10	0.0000							0.000000
Delaware Bay	PO	40.020617	-75.006617	11/17/2008	9.2	0.10	0.0000							0.000000
Delaware Bay	HI	40.045333	-74.975233	11/17/2008	9.5	0.10	0.0000							0.000000
Delaware Bay	CO	40.073583	-74.917817	11/17/2008	10.6	0.10	0.0000							0.000000
Delaware Bay	LC	40.104600	-74.832500	11/17/2008	10.6	0.10	0.0000							0.000000
Delaware Bay	NI	40.127850	-74.767833	11/17/2008	10.3	0.10	0.0000							0.000000

Table 4.3. Site-specific *Z*-score and relative ranking for instantaneous growth, abundance and production in 2007.

2007 GROWTH				
SYSTEM	**SITE**	**N**	**Rank**	***G z*-score**
Patuxent	BI	1	1	1.408495
Delaware Bay	PB	1	2	1.048084
Patuxent	MH	1	3	1.032831
Delaware Bay	BP	1	4	0.855955
Patuxent	EH	5	5	0.689036
Patuxent	GK	3	6	0.439393
Delaware Bay	TK	1	7	0.3904
Patuxent	DNR	3	8	0.31236
Delaware Bay	FM	3	9	0.212819
Patuxent	CR	3	10	0.107001
Delaware Bay	CI	2	11	0.068263
Patuxent	LM	3	12	-0.02777
Delaware Bay	PEB	1	13	-0.03104
Choptank	JP	1	14	-0.08277
Delaware Bay	NC	4	15	-0.25809
Delaware Bay	GAG	4	16	-0.42012
Delaware Bay	OP	1	17	-0.50922
Delaware Bay	HC	3	18	-0.65525
Patuxent	GG	3	19	-0.9061
Delaware Bay	AB	2	20	-1.33692
2007 ABUNDANCE				
SYSTEM	**SITE**	**N**	**Rank**	**A *z*-score**
Nanticoke	CP	3	1	0.866681
Nanticoke	TB	3	2	0.504342
Choptank	NS	3	3	0.37371
Nanticoke	LL	3	4	0.26605
Upper Bay	PR	3	5	-0.08406
Delaware Bay	NC	10	6	-0.12646
Delaware Bay	GAG	10	7	-0.13626
Delaware Bay	HC	10	8	-0.15479
Patuxent	EH	10	9	-0.17362
Choptank	JP	3	10	-0.17544
Delaware Bay	NM	10	11	-0.17639
Delaware Bay	RH	10	12	-0.18312
Delaware Bay	TK	9	13	-0.18466
Delaware Bay	FM	10	14	-0.18931
Delaware Bay	CI	10	14	-0.18931
Delaware Bay	OP	10	14	-0.18931
Delaware Bay	OC	10	14	-0.18931

Delaware Bay	RC	10	14	-0.18931
Patuxent	GK	7	15	-0.19292
Patuxent	LM	7	15	-0.19292
Delaware Bay	OB	11	15	-0.19292
Delaware Bay	SD	10	16	-0.20533
Delaware Bay	BP	9	17	-0.20774
Upper Bay	PL	3	17	-0.20774
Patuxent	CR	9	18	-0.21188
Delaware Bay	AB	10	19	-0.21274
Delaware Bay	PB	9	20	-0.21774
Patuxent	DNR	7	20	-0.21774
Delaware Bay	PEB	9	20	-0.21774
Delaware Bay	UPS	9	20	-0.21774
Delaware Bay	TT	9	20	-0.21774
Delaware Bay	EA	9	20	-0.21774
Patuxent	NT	3	20	-0.21774
Patuxent	MI	3	20	-0.21774
Patuxent	GG	8	21	-0.23432
Delaware Bay	PN	10	22	-0.24051
Patuxent	SP	10	23	-0.24056
Patuxent	CS	8	24	-0.24551
Patuxent	SB	8	24	-0.24551
Delaware Bay	CB	9	25	-0.25886
Upper Bay	YP	3	26	-0.26094
Patuxent	MH	9	27	-0.27329
Delaware Bay	MC	9	27	-0.27329
Delaware Bay	LC	9	27	-0.27329
Potomac	BL	3	28	-0.27423
Patuxent	BI	10	29	-0.27485
Delaware Bay	NI	10	29	-0.27485
Delaware Bay	CT	10	29	-0.27485
Delaware Bay	CO	10	29	-0.27485
Delaware Bay	EP	10	29	-0.27485
Delaware Bay	HI	10	29	-0.27485
Delaware Bay	PO	10	29	-0.27485
Delaware Bay	PC	10	29	-0.27485
Patuxent	SL	10	29	-0.27485
Delaware Bay	BN	11	30	-0.27641
Choptank	MT	3	31	-0.28183
Choptank	CH	3	32	-0.28943
Nanticoke	SH	3	32	-0.28943
Potomac	HP	3	32	-0.28943
Potomac	IH	3	32	-0.28943
Potomac	LP	3	32	-0.28943
Potomac	MO	3	32	-0.28943
Potomac	RP	3	32	-0.28943
Potomac	SG	3	32	-0.28943
Patuxent	PP	3	33	-0.31414

Upper Bay	SF	3	33	-0.31414
Upper Bay	TC	3	33	-0.31414
Upper Bay	TO	3	33	-0.31414
Upper Bay	CA	3	33	-0.31414
Upper Bay	WP	3	33	-0.31414
Upper Bay	TE	3	33	-0.31414
Upper Bay	SI	3	33	-0.31414
Upper Bay	EN	3	33	-0.31414
Upper Bay	HW	3	33	-0.31414

2007 PRODUCTION

SYSTEM	SITE	N	Rank	P *z-score*
Delaware Bay	CI	7	1	0.212751
Upper Bay	PL	1	1	0.212751
Potomac	BL	1	1	0.212751
Delaware Bay	RH	2	2	0.185433
Patuxent	NT	2	2	0.185433
Patuxent	MI	2	2	0.185433
Patuxent	EH	9	3	0.158114
Delaware Bay	NM	1	3	0.158114
Delaware Bay	OC	5	3	0.158114
Patuxent	GK	7	3	0.158114
Patuxent	LM	7	3	0.158114
Delaware Bay	PEB	7	3	0.158114
Delaware Bay	TT	5	3	0.158114
Delaware Bay	BN	9	3	0.158114
Delaware Bay	BP	6	4	0.147897
Delaware Bay	TK	4	5	0.135021
Upper Bay	YP	2	6	0.063693
Choptank	MT	2	6	0.063693
Delaware Bay	OP	4	7	0.036374
Delaware Bay	UPS	6	7	0.036374
Delaware Bay	EA	6	7	0.036374
Delaware Bay	NI	8	7	0.036374
Delaware Bay	CO	8	7	0.036374
Delaware Bay	EP	8	7	0.036374
Delaware Bay	HI	8	7	0.036374
Delaware Bay	PO	8	7	0.036374
Delaware Bay	PC	8	7	0.036374
Patuxent	PP	2	8	0.029126
Delaware Bay	PB	7	9	-0.03357
Choptank	JP	2	10	-0.06589
Delaware Bay	OB	7	11	-0.08537
Patuxent	DNR	7	11	-0.08537
Delaware Bay	PN	7	11	-0.08537
Patuxent	SP	8	11	-0.08537
Patuxent	SB	5	11	-0.08537

Delaware Bay	CB	6	11	-0.08537
Patuxent	MH	7	11	-0.08537
Delaware Bay	MC	7	11	-0.08537
Delaware Bay	LC	7	11	-0.08537
Patuxent	BI	9	11	-0.08537
Delaware Bay	CT	8	11	-0.08537
Patuxent	SL	10	11	-0.08537
Choptank	CH	3	11	-0.08537
Nanticoke	SH	3	11	-0.08537
Potomac	HP	3	11	-0.08537
Potomac	IH	3	11	-0.08537
Potomac	LP	3	11	-0.08537
Potomac	MO	3	11	-0.08537
Potomac	RP	3	11	-0.08537
Potomac	SG	3	11	-0.08537
Upper Bay	SF	3	11	-0.08537
Upper Bay	TC	3	11	-0.08537
Upper Bay	TO	3	11	-0.08537
Upper Bay	CA	3	11	-0.08537
Upper Bay	WP	3	11	-0.08537
Upper Bay	TE	3	11	-0.08537
Upper Bay	SI	3	11	-0.08537
Upper Bay	EN	3	11	-0.08537
Upper Bay	HW	3	11	-0.08537
Delaware Bay	SD	6	12	-0.11993
Patuxent	CR	8	12	-0.11993
Delaware Bay	AB	6	13	-0.12175
Delaware Bay	RC	5	14	-0.1545
Patuxent	GG	7	14	-0.1545
Patuxent	CS	7	14	-0.1545
Delaware Bay	FM	5	15	-0.18928
Choptank	NS	1	16	-0.26325
Nanticoke	LL	1	16	-0.26325
Delaware Bay	GAG	6	17	-0.2769
Delaware Bay	HC	5	18	-0.34087
Delaware Bay	NC	5	19	-0.77947

Table 4.4. Site-specific *Z*-score and relative ranking for instantaneous growth, abundance and production in 2008.

2008 GROWTH				
SYSTEM	**SITE**	**N**	**Rank**	***G z*-score**
Nanticoke	CP	1	1	2.022874
Delaware Bay	OP	1	2	1.730331
Nanticoke	TB	1	3	1.66547
Nanticoke	LL	1	4	1.55248
Choptank	MT	1	5	1.408965
Choptank	WC	1	6	1.282293
Choptank	NS	1	7	1.261301
Delaware Bay	TK	1	8	1.056792
Chester	CN	2	9	0.967837
Patuxent	SP	1	10	0.846433
James	JA0022	1	11	0.592604
Patuxent	SB	2	12	0.49889
Delaware Bay	AC	1	13	0.477369
Chester	UC	1	14	0.446758
Delaware Bay	AA	1	15	0.330039
Delaware Bay	FM	4	16	0.229459
Choptank	HB	1	17	0.179387
Delaware Bay	AB	3	18	0.146805
Delaware Bay	PV	1	19	0.036113
Upper Bay	PR	3	20	0.032959
Delaware Bay	WA	2	21	-0.00626
Chester	PS	1	22	-0.02818
Patuxent	BI	4	23	-0.03186
Chester	EI	2	24	-0.07136
Patuxent	GK	4	25	-0.07831
Chester	CQ	2	26	-0.07939
Patuxent	DNR	4	27	-0.10619
Delaware Bay	WB	2	28	-0.12985
Patuxent	EH	4	29	-0.14576
Chester	BC	2	30	-0.20704
Patuxent	LM	3	31	-0.28266
Choptank	CY	1	32	-0.28462
Choptank	LT	1	33	-0.31421
Patuxent	GG	6	34	-0.42959
Delaware Bay	CB	4	35	-0.47735
Chester	LV	1	36	-0.48878
Delaware Bay	NC	3	37	-0.56378
Patuxent	CS	3	38	-0.62456
Choptank	CW	1	39	-0.76855
Patuxent	MH	2	40	-0.81968

Patuxent	CR	5	41	-0.89227
Delaware Bay	GAG	3	42	-0.97449
Delaware Bay	RC	1	43	-0.97815
Delaware Bay	HC	3	44	-1.15776
Upper Bay	WP	1	45	-1.35356

2008 ABUNDANCE

SYSTEM	SITE	N	Rank	A *z*-score
Nanticoke	TB	1	1	9.114495
Choptank	NS	1	2	6.479136
Nanticoke	LL	1	3	4.147211
Nanticoke	CP	1	4	3.36101
Upper Bay	TC	1	5	3.328201
Chester	UC	1	6	2.60979
Choptank	CY	1	7	0.368509
Chester	CN	2	8	0.046259
Delaware Bay	FM	9	9	0.027862
Patuxent	CS	6	10	0.016371
Chester	EI	4	11	-0.00228
Patuxent	GG	7	12	-0.0566
Choptank	LT	3	13	-0.09426
Patuxent	BI	7	14	-0.11459
Upper Bay	PR	4	15	-0.11618
Patuxent	EH	7	16	-0.12641
Delaware Bay	AA	1	17	-0.15153
Chester	PS	2	18	-0.1525
Delaware Bay	NM	9	19	-0.15315
Choptank	PT	1	20	-0.16073
Patuxent	CR	7	21	-0.16104
Patuxent	LM	7	21	-0.16104
Delaware Bay	NC	9	22	-0.16233
James	JA0022	5	23	-0.16417
Patuxent	SB	7	23	-0.16417
Delaware Bay	PV	6	23	-0.16417
Delaware Bay	WA	5	23	-0.16417
Patuxent	GK	7	23	-0.16417
Delaware Bay	CB	9	23	-0.16417
Delaware Bay	HC	9	23	-0.16417
Chester	NP	1	23	-0.16417
Chester	SA	1	23	-0.16417
Upper Bay	WP	4	24	-0.17857
Choptank	CW	1	25	-0.18355
Delaware Bay	GAG	9	26	-0.18729
Delaware Bay	AC	1	27	-0.18967
Chester	BC	3	28	-0.19185
Delaware Bay	WB	5	29	-0.19204
Upper Bay	PD	3	30	-0.19311
Delaware Bay	TK	9	31	-0.19364

Patuxent	SP	7	31	-0.19364
Delaware Bay	AB	9	31	-0.19364
Patuxent	MH	7	31	-0.19364
James	JA0077	5	31	-0.19364
Upper Bay	EN	4	31	-0.19364
Upper Bay	HW	3	31	-0.19364
Choptank	CH	2	32	-0.20084
Chester	CQ	4	33	-0.21045
Chester	LV	1	34	-0.21322
Choptank	MT	1	35	-0.21611
Choptank	HB	4	36	-0.21931
Delaware Bay	PB	9	37	-0.21958
Delaware Bay	RH	9	37	-0.21958
Delaware Bay	CT	9	37	-0.21958
Delaware Bay	OB	9	37	-0.21958
James	JA0068	5	37	-0.21958
James	JA0062	5	37	-0.21958
James	JA0051	5	37	-0.21958
James	JA0036	5	37	-0.21958
Choptank	AT	2	38	-0.22151
Patuxent	DNR	7	39	-0.23015
Choptank	DB	2	40	-0.23405
Delaware Bay	PN	2	40	-0.23405
Choptank	TY	2	41	-0.23637
James	JA0046	5	42	-0.23652
James	JA0029	5	42	-0.23652
Delaware Bay	OP	9	43	-0.23751
Delaware Bay	TT	9	43	-0.23751
Delaware Bay	BP	9	43	-0.23751
Delaware Bay	CI	9	43	-0.23751
Delaware Bay	OC	9	43	-0.23751
Delaware Bay	BN	9	43	-0.23751
Delaware Bay	EP	9	43	-0.23751
Delaware Bay	EA	9	43	-0.23751
James	JA0056	5	43	-0.23751
Choptank	WC	4	44	-0.2454
Delaware Bay	NI	10	45	-0.25437
Delaware Bay	LC	10	45	-0.25437
Delaware Bay	CO	10	45	-0.25437
Delaware Bay	MC	9	46	-0.25518
Delaware Bay	HI	10	47	-0.25598
Delaware Bay	PO	10	47	-0.25598
Delaware Bay	PC	10	47	-0.25598
Choptank	HN	2	48	-0.26272
James	JA0042	4	49	-0.26407
Delaware Bay	RC	9	50	-0.27122
Choptank	HU	1	50	-0.27122
Delaware Bay	SD	9	50	-0.27122

James	JA0012	5	50	-0.27122
Patuxent	SL	7	50	-0.27122
Delaware Bay	PEB	9	51	-0.27445
Delaware Bay	UPS	9	51	-0.27445
Upper Bay	LG	4	52	-0.27735
Upper Bay	WT	3	52	-0.27735
Upper Bay	AP	4	52	-0.27735
Chester	RW	1	53	-0.28793
Chester	SK	1	53	-0.28793
Choptank	RD	1	54	-0.30857
Delaware Bay	NB	1	55	-0.32649

2008 PRODUCTION

SYSTEM	SITE	N	Rank	P *z*-score
Nanticoke	TB	1	1	8.604067
Choptank	NS	1	2	6.081561
Nanticoke	CP	1	3	5.658837
Nanticoke	LL	1	4	3.902272
Upper Bay	TC	1	5	3.328201
Chester	UC	1	6	2.759971
Chester	CN	2	7	0.359521
Chester	LV	1	8	0.177753
Choptank	MT	1	9	0.167172
Choptank	HU	1	10	0.147882
Patuxent	SL	6	11	0.08028
Choptank	RD	1	11	0.08028
Choptank	LT	2	12	0.036124
Choptank	WC	4	13	0.026308
Choptank	CY	1	14	0.024478
Delaware Bay	AC	1	15	0.02102
Chester	BC	2	16	0.003543
Chester	PS	2	17	0.000634
Delaware Bay	NM	2	18	-0.0005
Delaware Bay	CB	8	19	-0.00292
Upper Bay	EN	4	20	-0.00804
Delaware Bay	WA	4	21	-0.02511
Choptank	HB	4	21	-0.02511
James	JA0036	4	21	-0.02511
Choptank	TY	2	21	-0.02511
Delaware Bay	OP	8	22	-0.02958
Patuxent	SB	7	23	-0.0354
Delaware Bay	WB	4	24	-0.0648
Chester	EI	4	25	-0.07155
Choptank	DB	2	25	-0.07155
Delaware Bay	PN	2	25	-0.07155
Delaware Bay	RH	5	26	-0.09527
Delaware Bay	TT	7	26	-0.09527
Delaware Bay	NB	1	26	-0.09527

Patuxent	DNR	5	27	-0.10423
Delaware Bay	FM	6	27	-0.10431
Delaware Bay	BP	8	28	-0.10533
Delaware Bay	MC	8	29	-0.11288
Delaware Bay	UPS	8	29	-0.11288
Patuxent	GK	7	30	-0.1154
Patuxent	SP	6	30	-0.1154
Delaware Bay	AB	8	30	-0.1154
Patuxent	MH	7	30	-0.1154
Choptank	AT	1	30	-0.1154
Delaware Bay	BN	9	30	-0.1154
Delaware Bay	NI	9	30	-0.1154
Delaware Bay	RC	9	30	-0.1154
Delaware Bay	SD	9	30	-0.1154
Chester	RW	1	30	-0.1154
Chester	SK	1	30	-0.1154
Patuxent	LM	6	31	-0.11641
James	JA0022	4	32	-0.12295
Delaware Bay	HC	8	32	-0.12295
Delaware Bay	GAG	8	32	-0.12295
Delaware Bay	LC	10	32	-0.12295
Delaware Bay	CO	10	32	-0.12295
Patuxent	CR	6	33	-0.12297
Patuxent	GG	7	34	-0.12553
Choptank	CW	1	35	-0.12676
Delaware Bay	PEB	8	36	-0.13044
Delaware Bay	NC	7	37	-0.1305
Delaware Bay	PV	5	37	-0.1305
Chester	NP	1	37	-0.1305
Chester	SA	1	37	-0.1305
Upper Bay	WP	4	37	-0.1305
Delaware Bay	TK	7	37	-0.1305
James	JA0077	5	37	-0.1305
Upper Bay	HW	3	37	-0.1305
Delaware Bay	OB	9	37	-0.1305
James	JA0062	5	37	-0.1305
James	JA0051	5	37	-0.1305
Delaware Bay	CI	7	37	-0.1305
Delaware Bay	OC	7	37	-0.1305
Delaware Bay	HI	9	37	-0.1305
Delaware Bay	PO	9	37	-0.1305
Delaware Bay	PC	9	37	-0.1305
James	JA0029	2	38	-0.14051
Chester	CQ	4	39	-0.14173
Delaware Bay	PB	8	40	-0.14805
Delaware Bay	EA	8	40	-0.14805
Delaware Bay	AA	1	41	-0.15811
Choptank	PT	1	42	-0.16561

Delaware Bay	CT	9	42	-0.16561
James	JA0068	5	42	-0.16561
James	JA0046	1	42	-0.16561
Delaware Bay	EP	9	42	-0.16561
James	JA0056	5	42	-0.16561
James	JA0012	5	42	-0.16561
Patuxent	BI	7	43	-0.16869
James	JA0042	4	44	-0.17019
Upper Bay	PR	4	45	-0.17474
Choptank	HN	2	46	-0.17708
Patuxent	CS	6	47	-0.18463
Upper Bay	PD	2	47	-0.18463
Choptank	CH	2	47	-0.18463
Patuxent	EH	5	48	-0.20988
Upper Bay	LG	4	49	-0.27735
Upper Bay	WT	3	49	-0.27735
Upper Bay	AP	4	49	-0.27735

Table 4.5. Pearson product moment correlation results for 2007 field site means. All *p*-values are shown in parentheses. Statistically significant ($p < 0.05$) values are in boldface.

Variable	Abundance (fish.m^{-2})	Mean Weight (g)	Production (g.m^{-2}.d^{-1})
G (d^{-1})	0.22790 (0.1234)	-0.52597 (<**0.0001**)	0.34836 (**0.0164**)
Abundance (fish.m^{-2})		-0.05781 (0.6995)	-0.13923 (**0.0038**)
Mean Weight (g)			-0.41534 (**0.0037**)

Table 4.6. Pearson product moment correlation results for 2008 field site means. All *p*-values are shown in parentheses. Statistically significant ($p < 0.05$) values are in boldface.

Variable	Abundance (fish.m^{-2})	Mean Weight (g)	Production (g.m^{-2}.d^{-1})
G (d^{-1})	0.15246 (0.1381)	-0.38428 (<**0.0001**)	0.42235 (<**0.0001**)
Abundance (fish.m^{-2})		-0.15349 (0.1354)	0.27953 (<**0.0001**)
Mean Weight (g)			-0.24150 (**0.0178**)

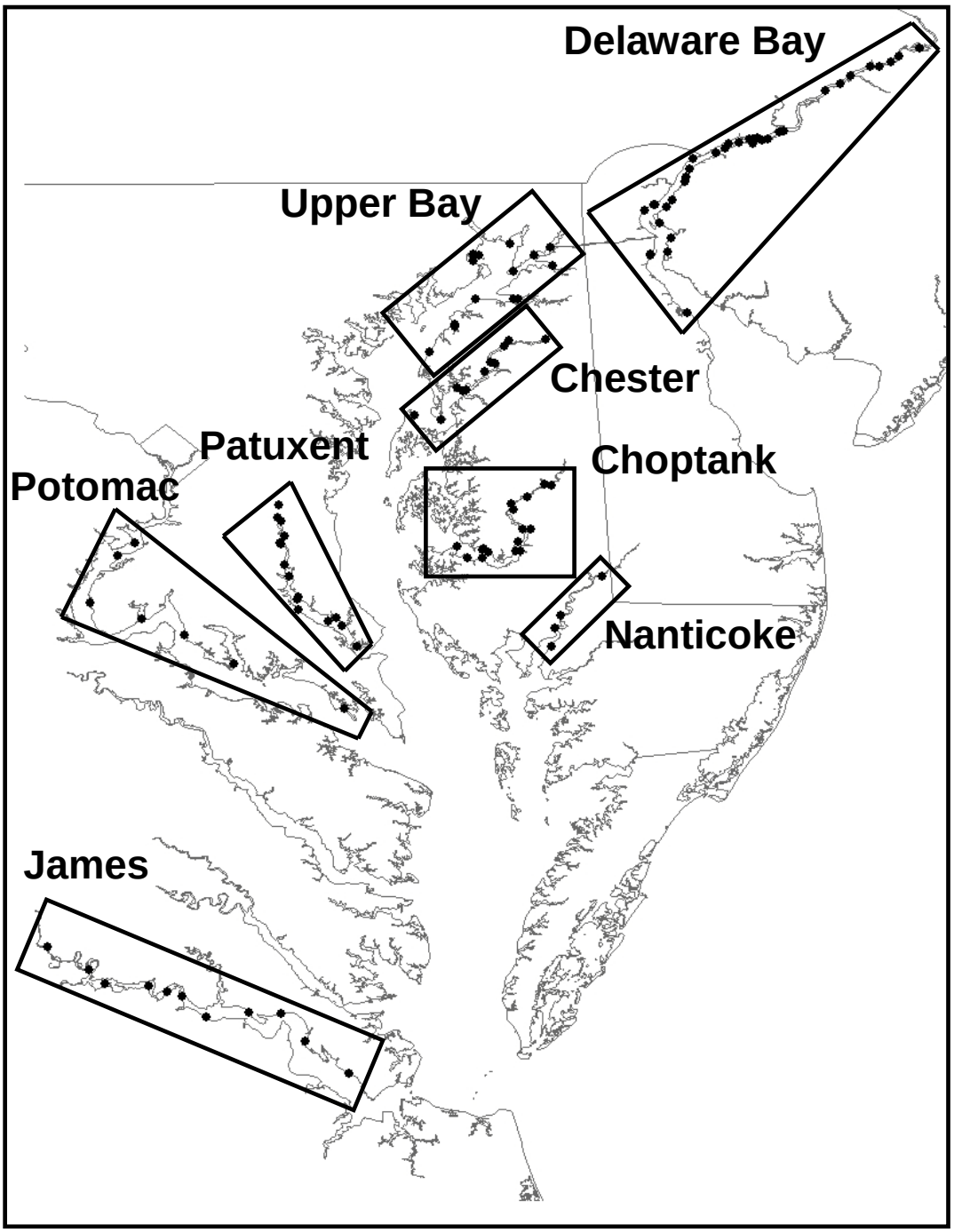


Figure 4.1. Map of 2007 and 2008 sampling locations.

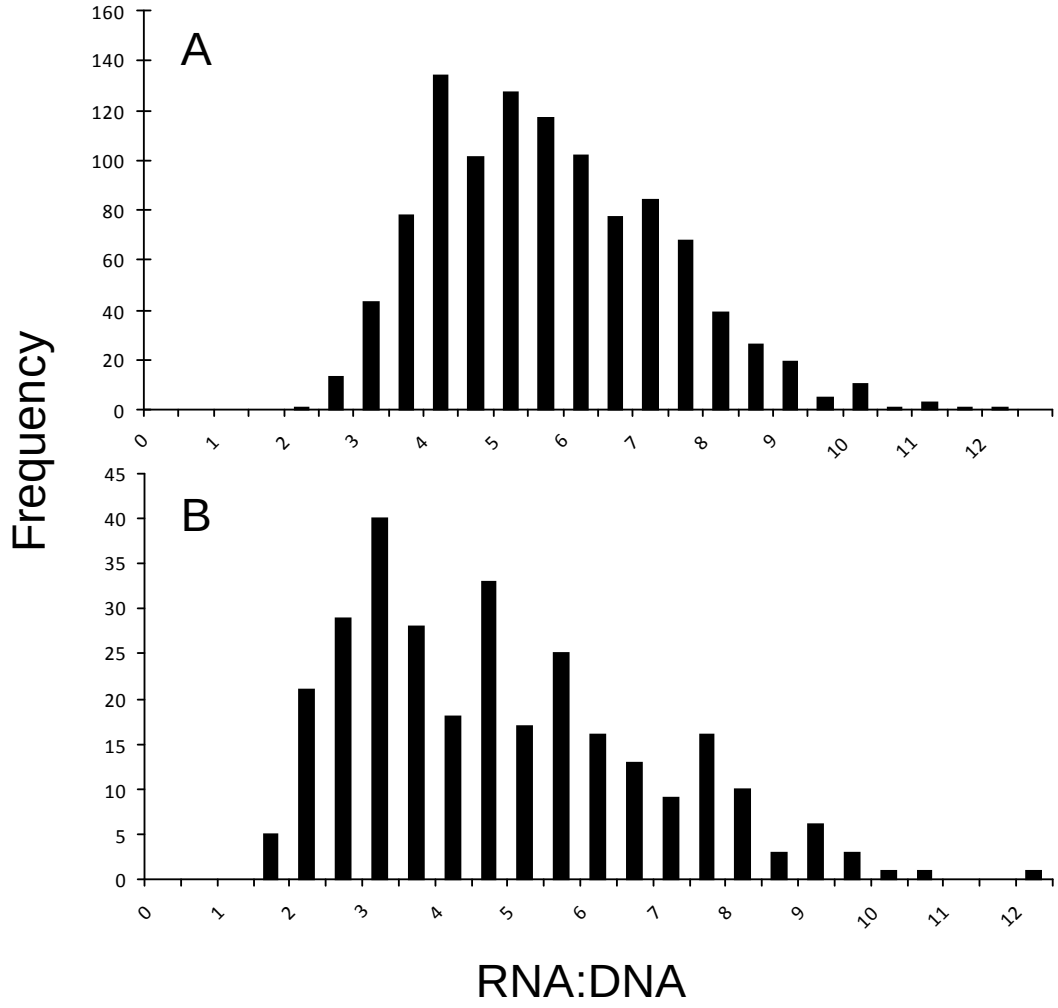


Figure 4.2. Frequency diagram of A) RNA:DNA values of field-collected individuals and B) RNA:DNA values of individuals from laboratory calibration experiment.

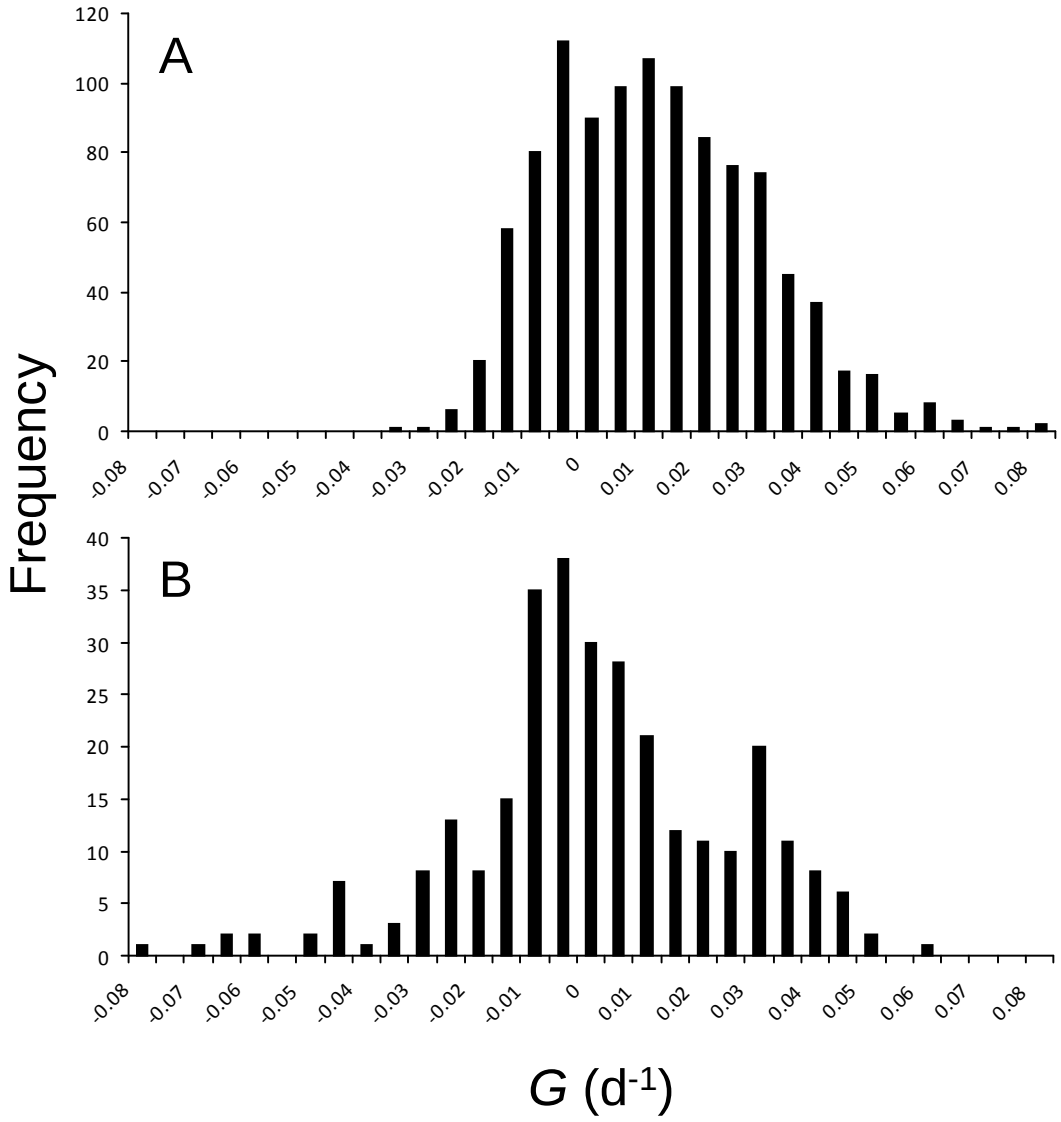


Figure 4.3. Frequency diagram of A) RNA:DNA-based estimates of instantaneous growth rates of field-collected individuals and B) Measured growth rates of individuals from laboratory calibration experiment.

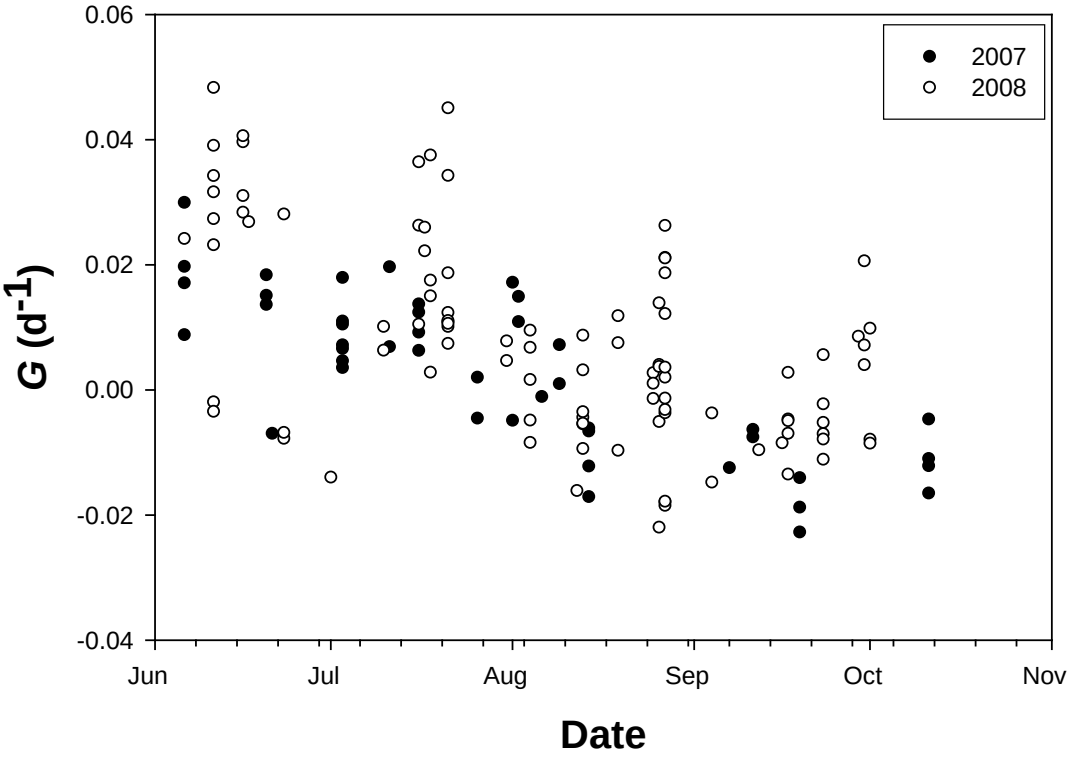


Figure 4.4. Site-specific mean instantaneous growth throughout season in 2007 (closed circles) and 2008 (open circles).

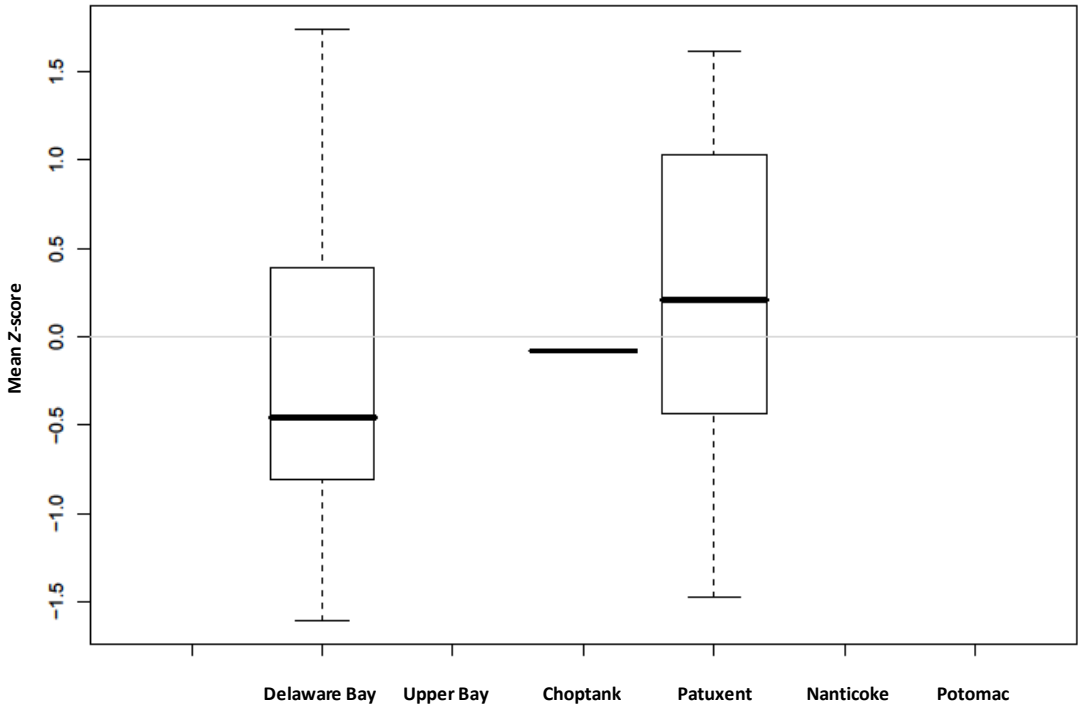


Figure 4.5. Box plots of the distribution of Z-score transformed instantaneous growth by system in 2007. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box. Single median lines represent instances with insufficient data to generate box plots.

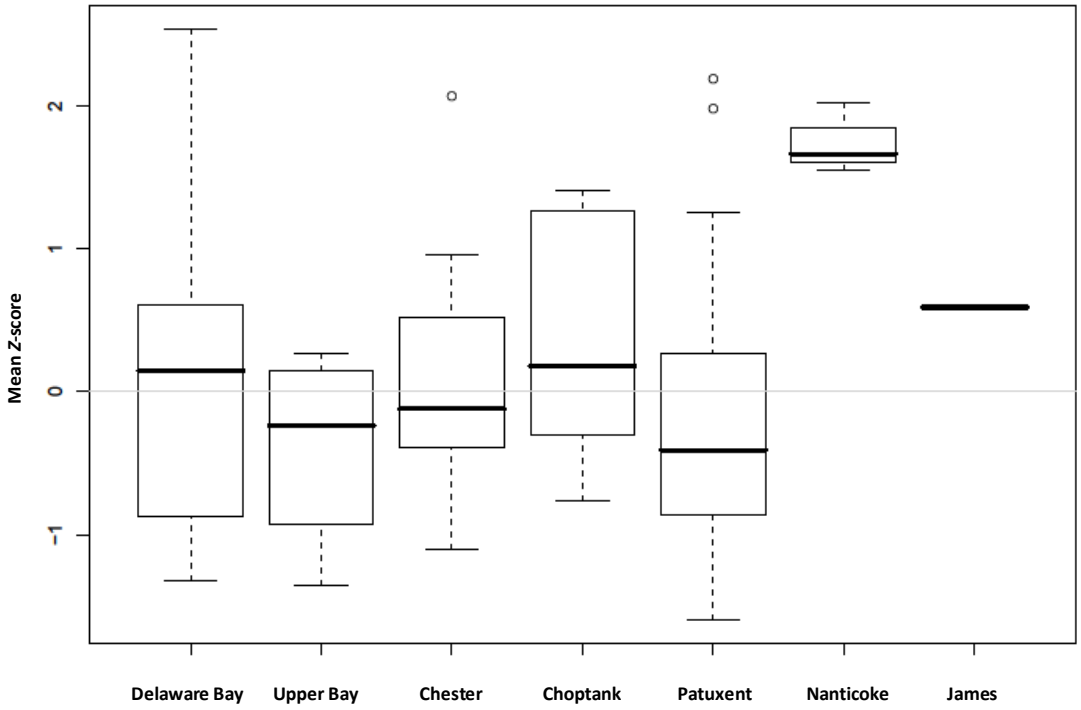


Figure 4.6. Box plots of the distribution of Z-score transformed instantaneous growth by system in 2008. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box. Single median lines represent instances with insufficient data to generate box plots.

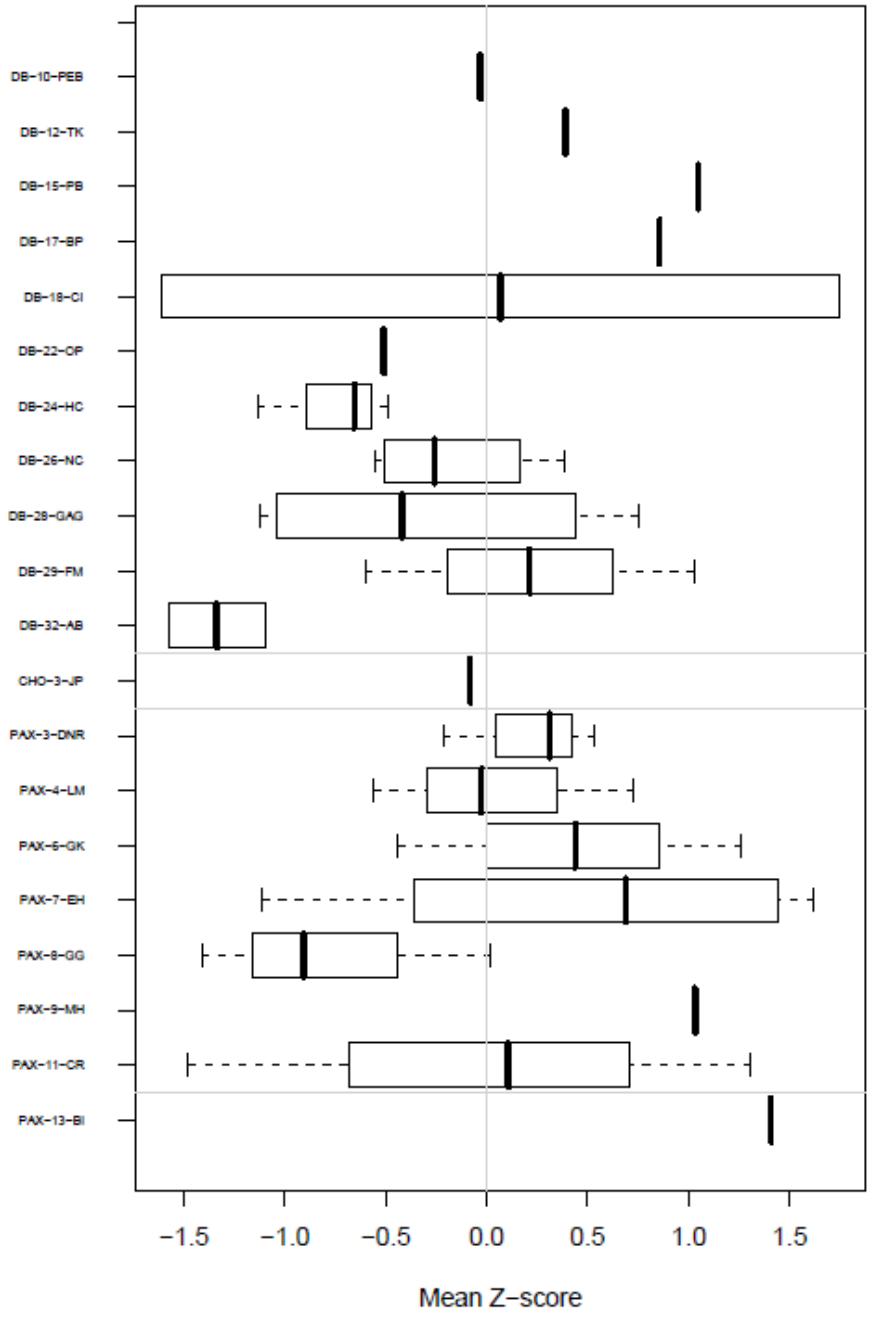


Figure 4.7. Box plots of the distribution of Z-score transformed instantaneous growth by site in 2007 for Delaware Bay (DB), Upper Bay (UB), Choptank (CHO), Patuxent (PAX), Nanticoke (NAN) and Potomac (POT) systems. Within each system, the sites are plotted in order of decreasing latitude from top to bottom. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box. Single median lines represent instances with insufficient data to generate box plots.

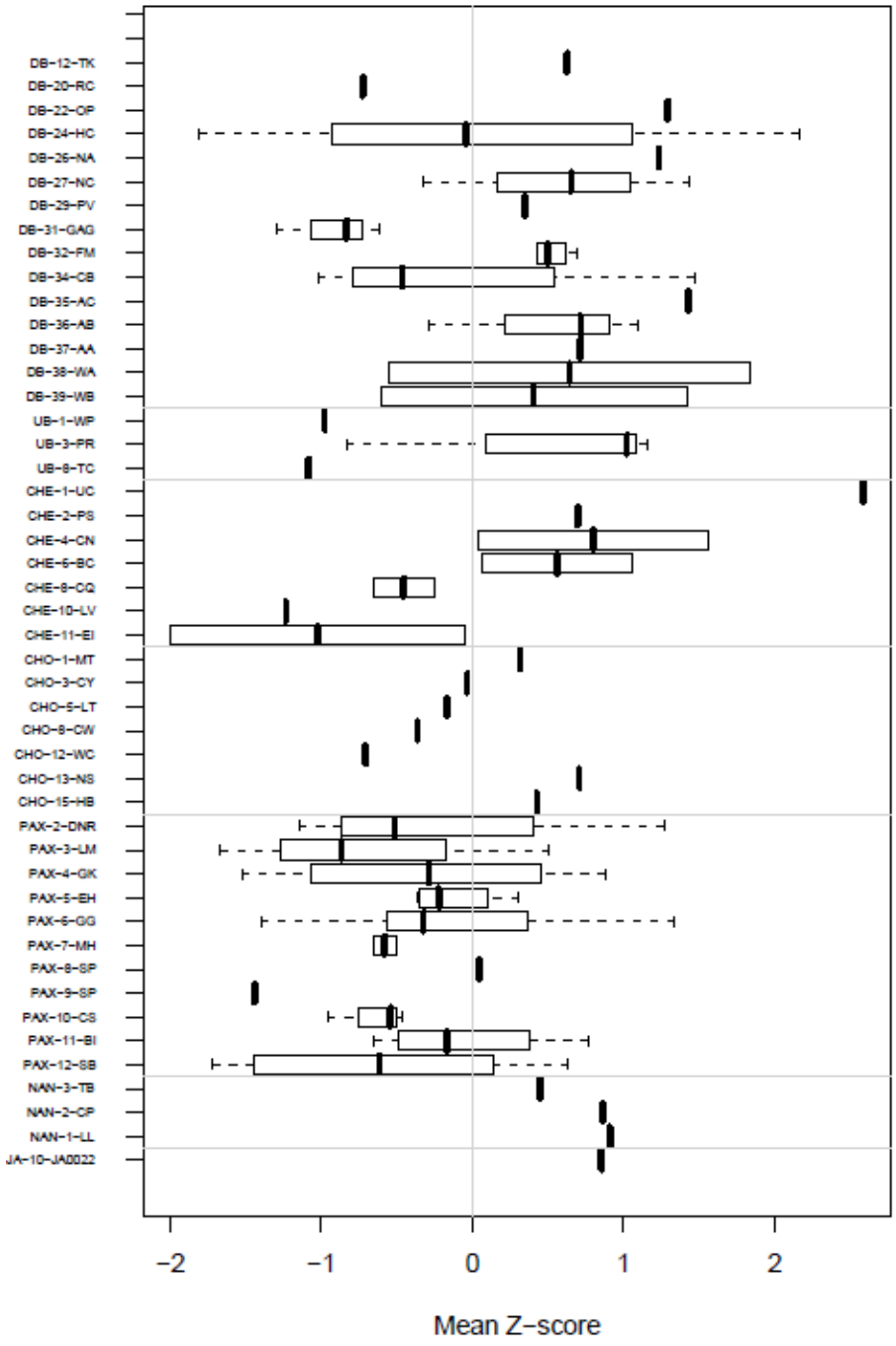


Figure 4.8. Box plots of the distribution of Z-score transformed instantaneous growth by site in 2008 for Delaware Bay (DB), Upper Bay (UB), Chester (CHE), Choptank (CHO), Patuxent (PAX), Nanticoke (NAN) and James (JA) systems. Within each system, the sites are plotted in order of decreasing latitude from top to bottom. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box. Single median lines represent instances with insufficient data to generate box plots.

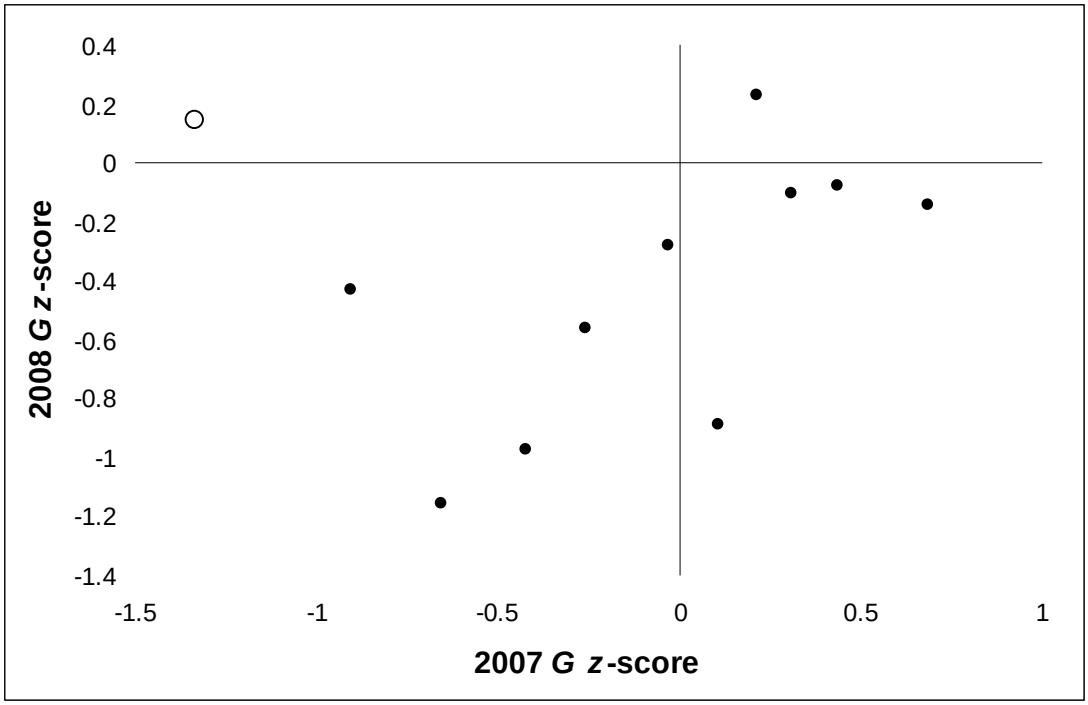


Figure 4.9. Relationship of instantaneous growth *Z*-scores between 2007 and 2008 for those sites at which data were available from multiple biweekly sampling events and available in both years. Potential outlier, Augustine Beach (AB) denoted as open circle.

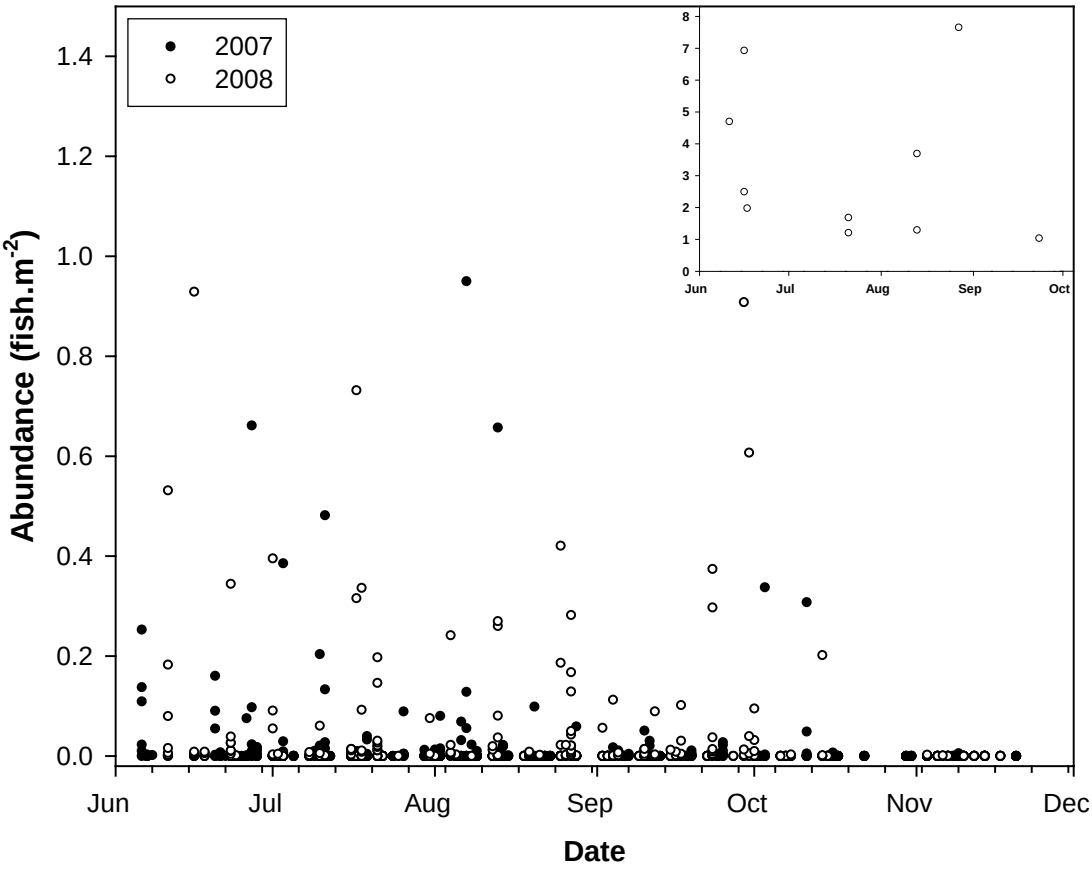


Figure 4.10. Site-specific abundance throughout season in 2007 (closed circles) and 2008 (open circles).

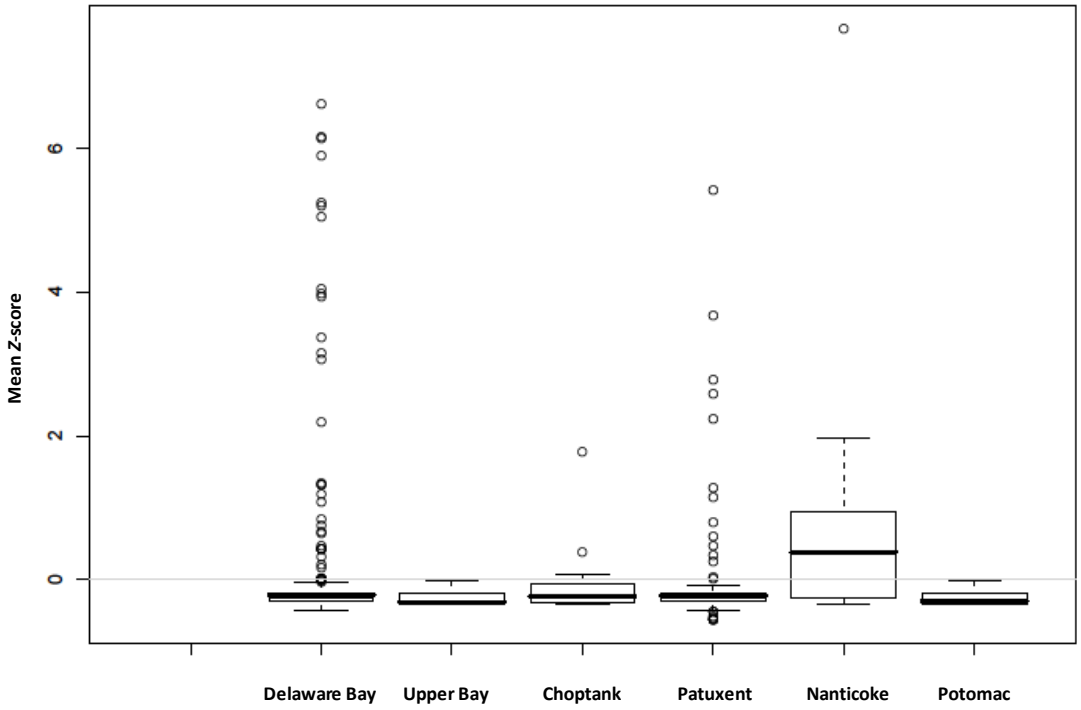


Figure 4.11. Box plots of the distribution of Z-score transformed menhaden abundances by system in 2007. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box.

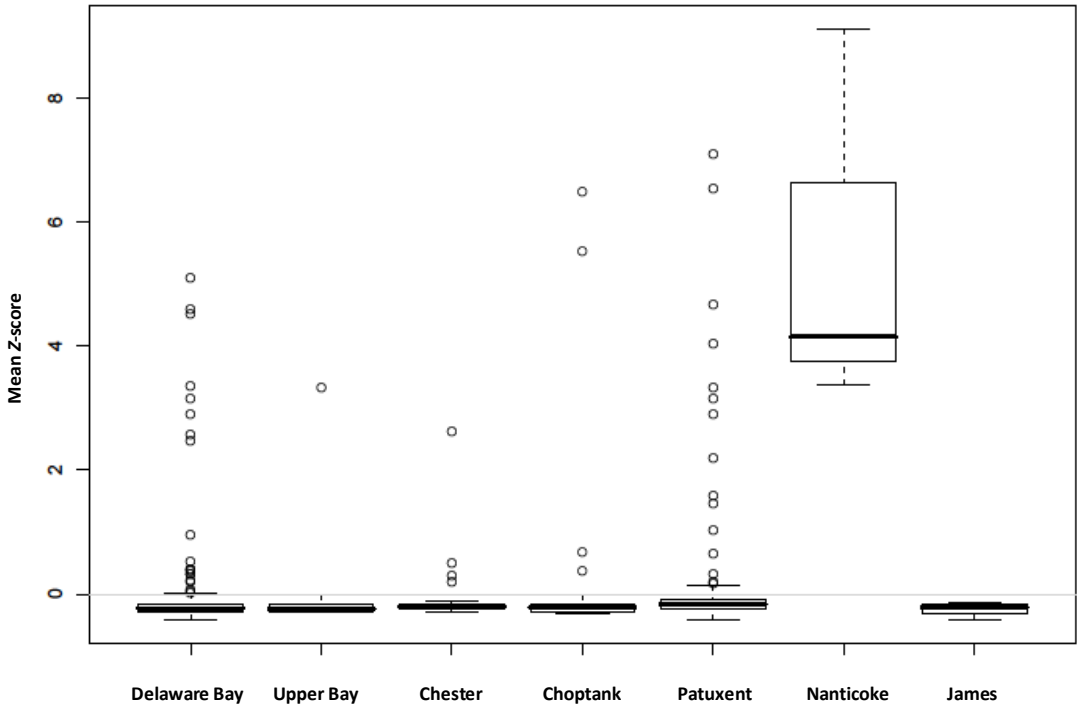


Figure 4.12. Box plots of the distribution of Z-score transformed menhaden abundances by system in 2008. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box.

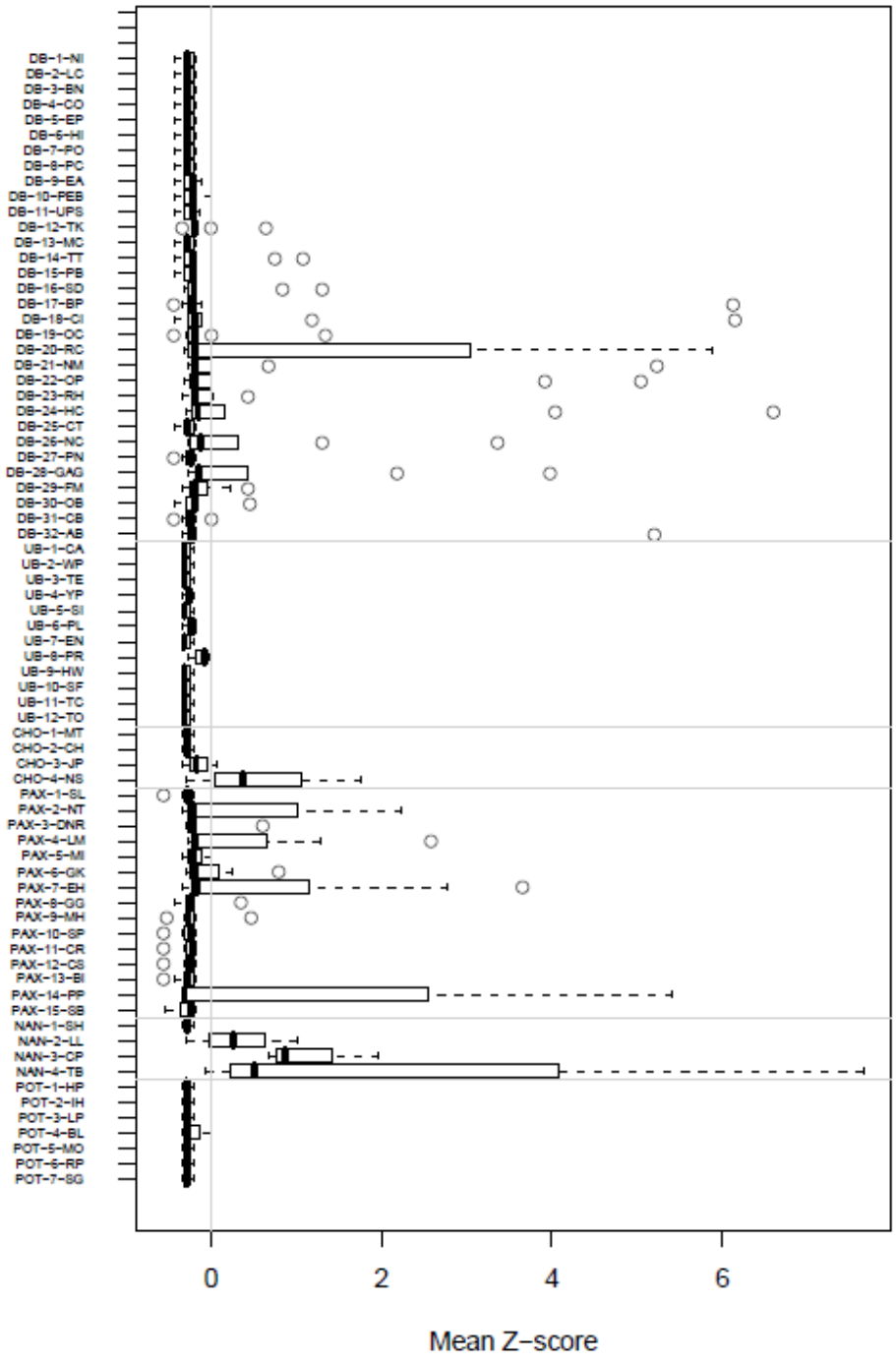


Figure 4.13. Box plots of the distribution of Z-score transformed menhaden abundance by site in 2007 for Delaware Bay (DB), Upper Bay (UB), Choptank (CHO), Patuxent (PAX), Nanticoke (NAN) and Potomac (POT) systems. Within each system, the sites are plotted in order of decreasing latitude from top to bottom. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box.

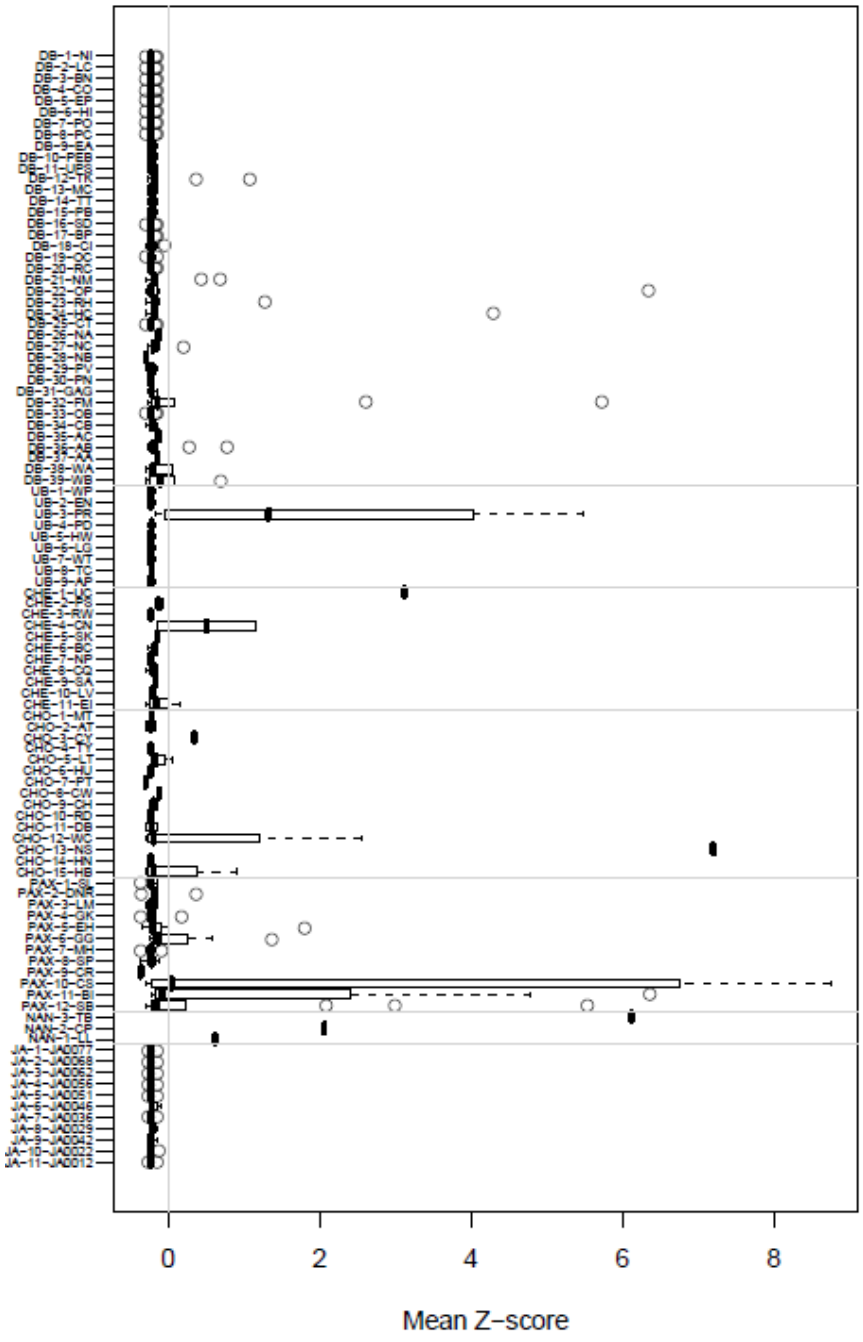


Figure 4.14 - Box plots of the distribution of Z-score transformed menhaden abundance by site in 2008 for Delaware Bay (DB), Upper Bay (UB), Chester (CHE), Choptank (CHO), Patuxent (PAX), Nanticoke (NAN) and James (JA) systems. Within each system, the sites are plotted in order of decreasing latitude from top to bottom. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box. Single median lines represent instances with insufficient data to generate box plots.

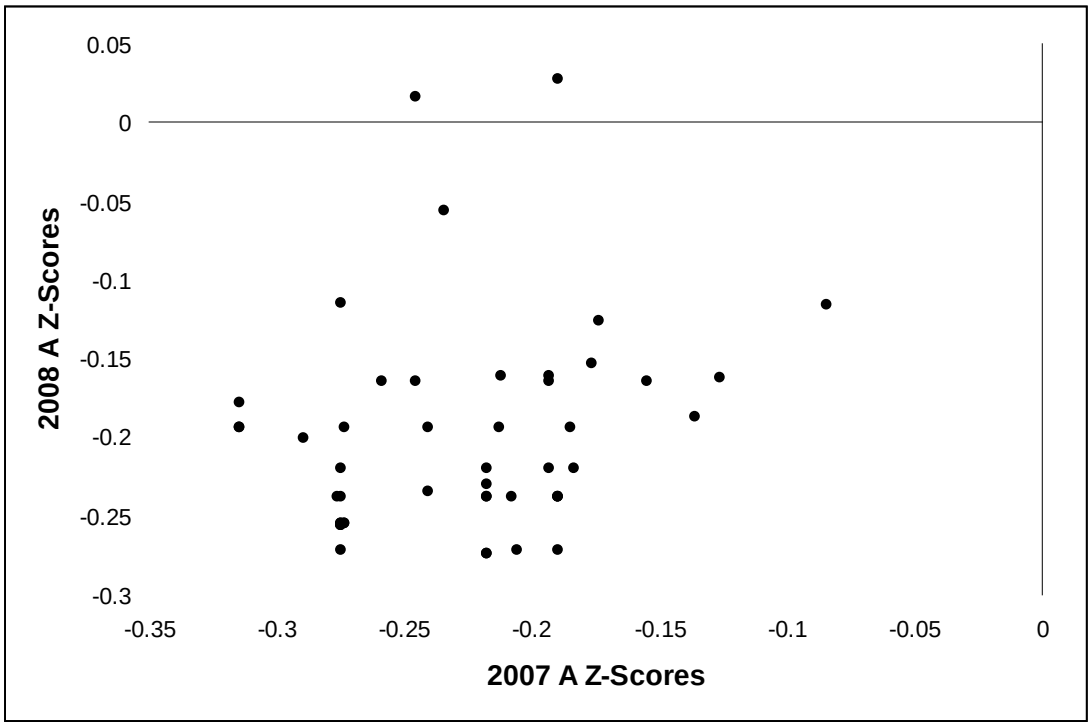


Figure 4.15. Relationship of abundance *Z*-scores between 2007 and 2008 for those sites at which data were available from multiple biweekly sampling events and available in both years.

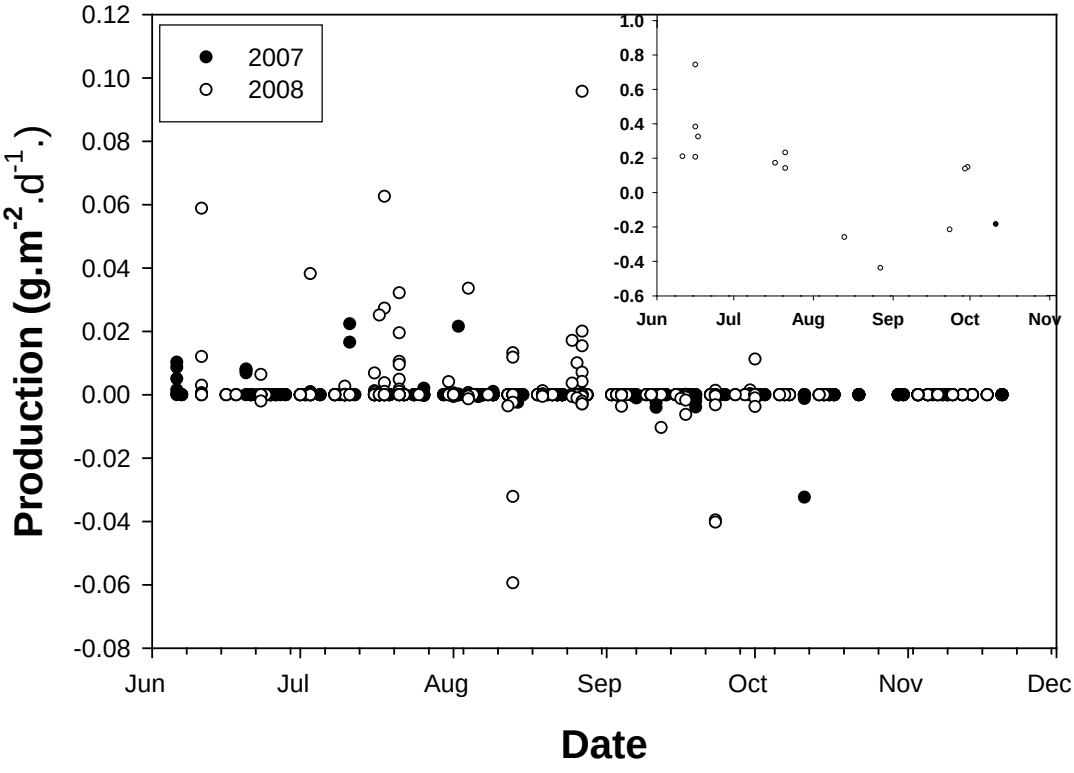


Figure 4.16. Site-specific production throughout season in 2007 (closed circles) and 2008 (open circles).

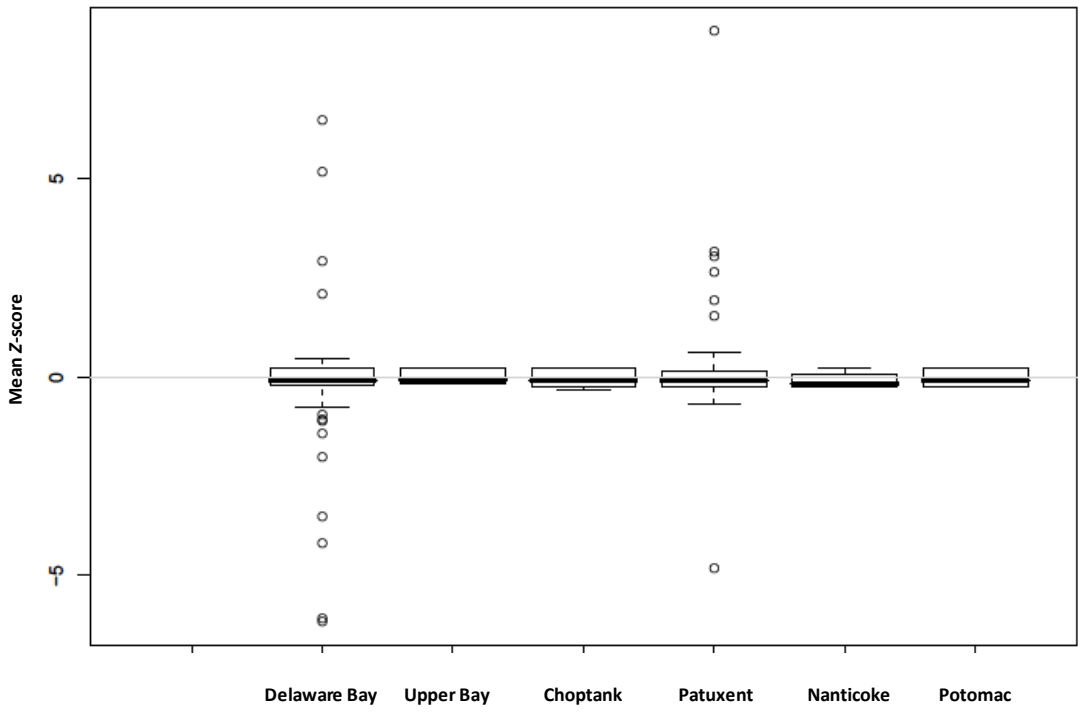


Figure 4.17. Box plots of the distribution of Z-score transformed menhaden production by system in 2007. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box.

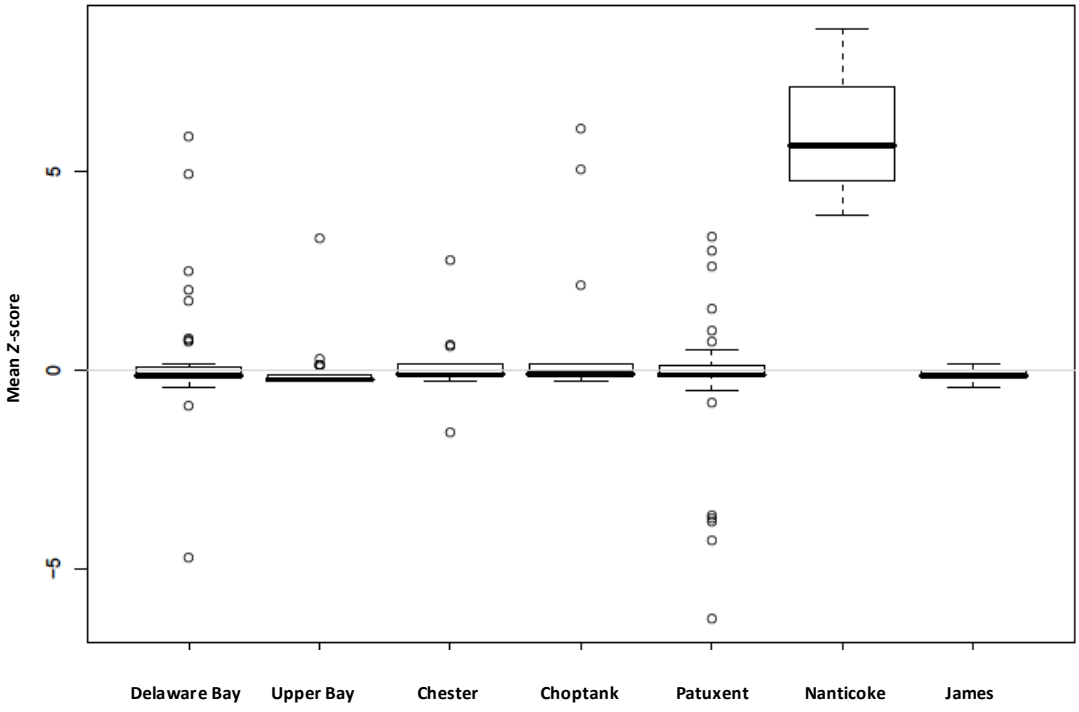


Figure 4.18 - Box plots of the distribution of Z-score transformed menhaden production by system in 2008. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box.

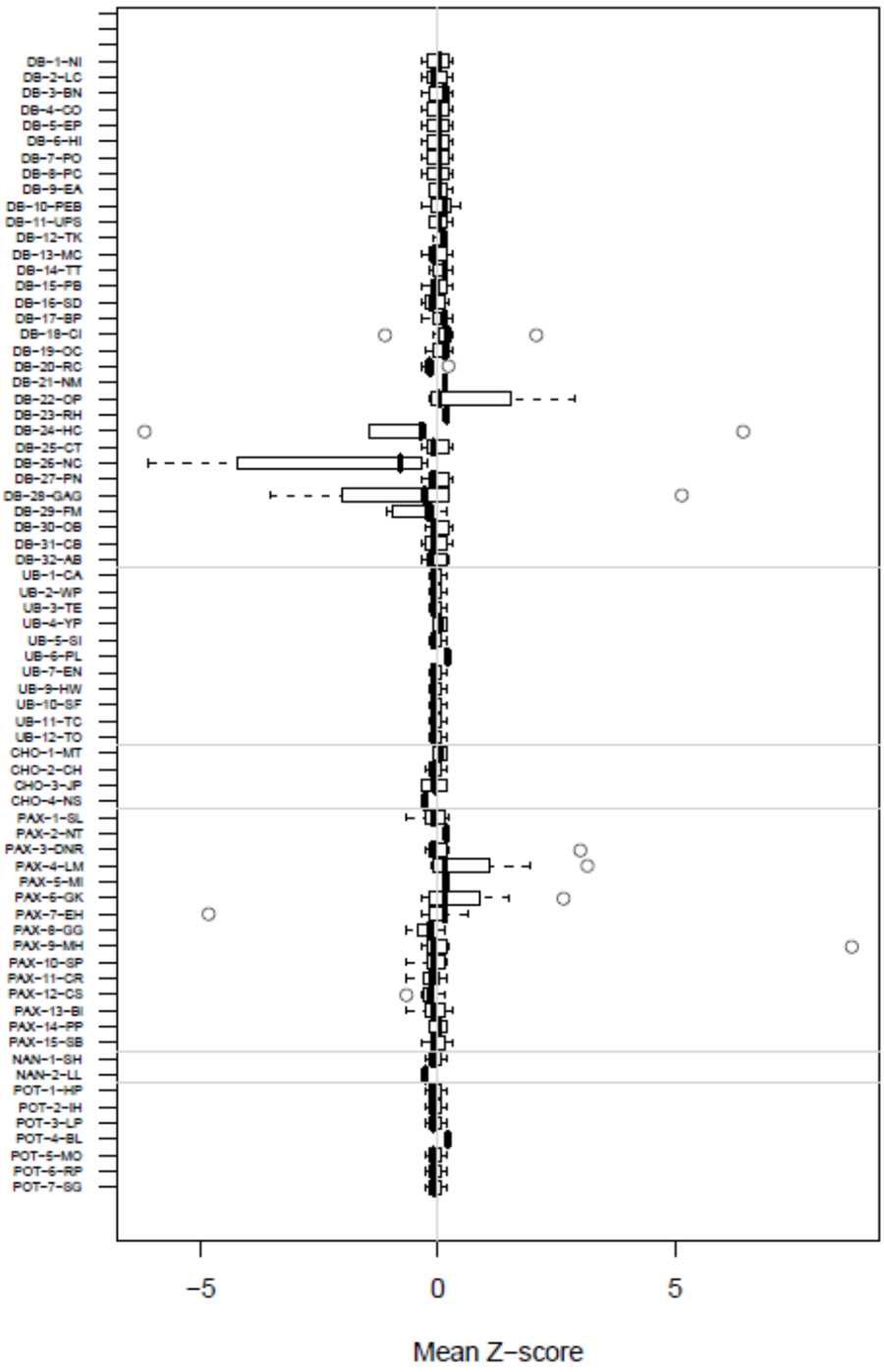


Figure 4.19. Box plots of the distribution of Z-score transformed menhaden production by site in 2007 for Delaware Bay (DB), Upper Bay (UB), Choptank (CHO), Patuxent (PAX), Nanticoke (NAN) and Potomac (POT) systems. Within each system, the sites are plotted in order of decreasing latitude from top to bottom. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box.

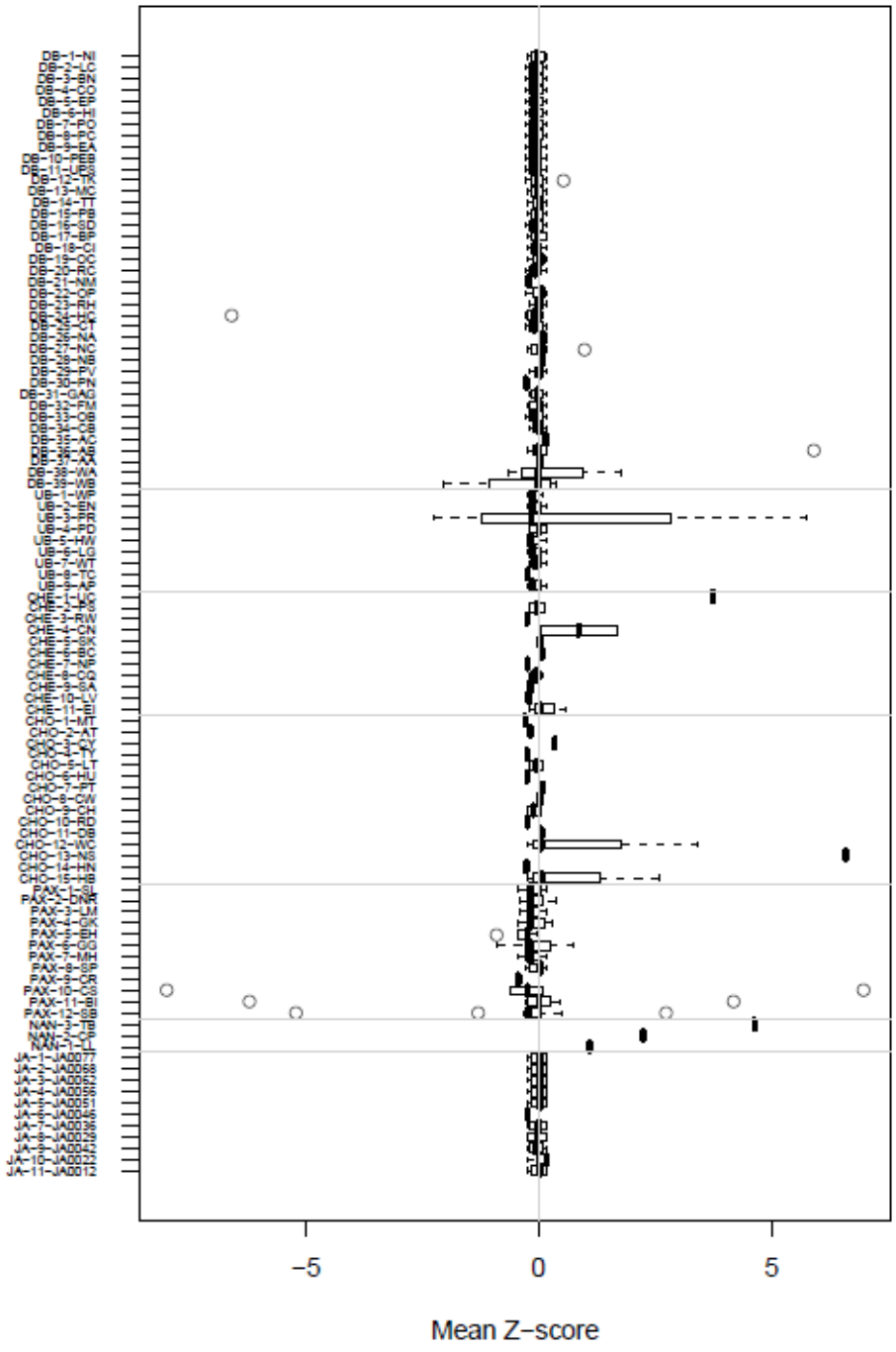


Figure 4.20. Box plots of the distribution of Z-score transformed menhaden production by site in 2008 for Delaware Bay (DB), Upper Bay (UB), Chester (CHE), Choptank (CHO), Patuxent (PAX), Nanticoke (NAN) and James (JA) systems. Within each system, the sites are plotted in order of decreasing latitude from top to bottom. The boxes show the median (thick horizontal line) and the 25th and 75th percentiles of the distribution (box limits). The whiskers extend to the data point that is no more than 1.5 * interquartile range from the box. Single median lines represent instances with insufficient data to generate box plots.

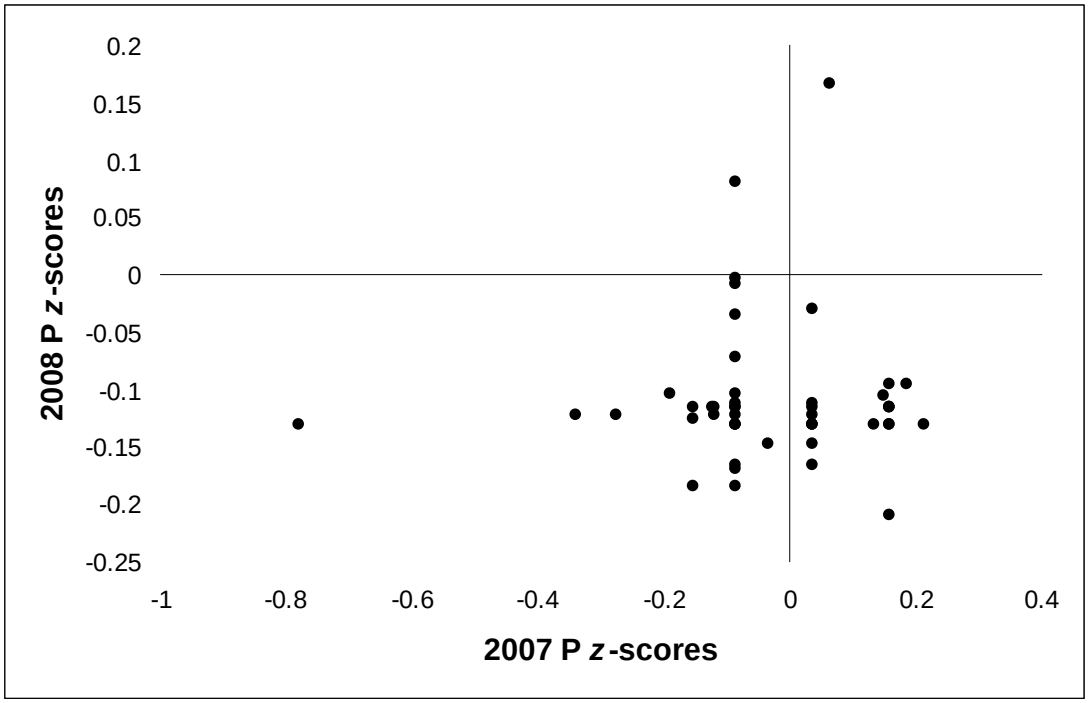


Figure 4.21. Relationship of production *Z*-scores between 2007 and 2008 for those sites at which data were available from multiple biweekly sampling events and available in both years.

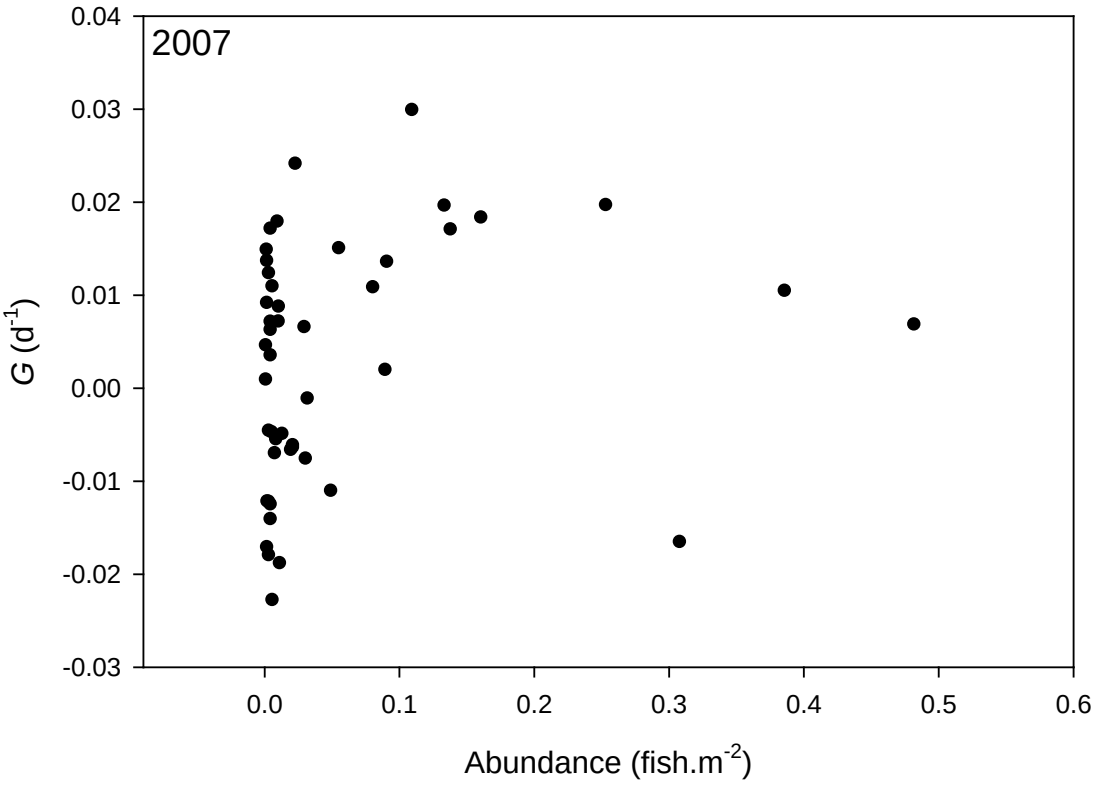


Figure 4.22. Relationship between site-specific abundance and instantaneous growth rate in 2007.

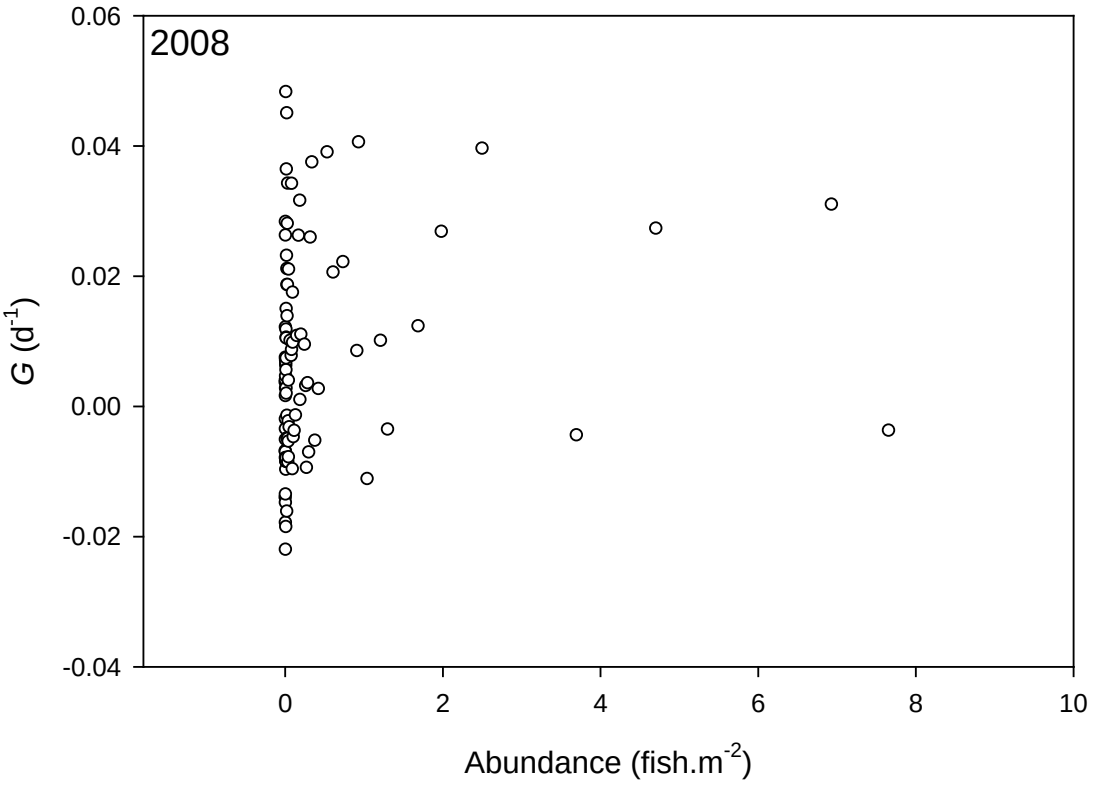


Figure 4.23. Relationship between site-specific abundance and instantaneous growth rate in 2008.

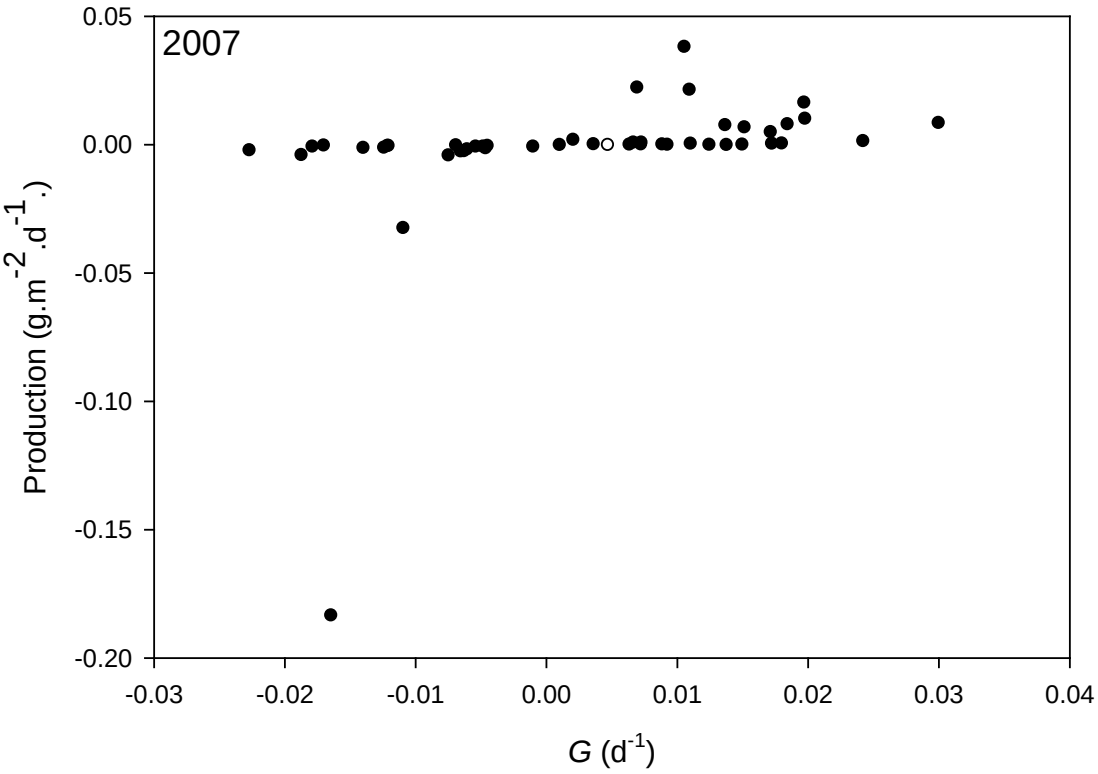


Figure 4.24. Relationship between site-specific instantaneous growth rate and production in 2007.

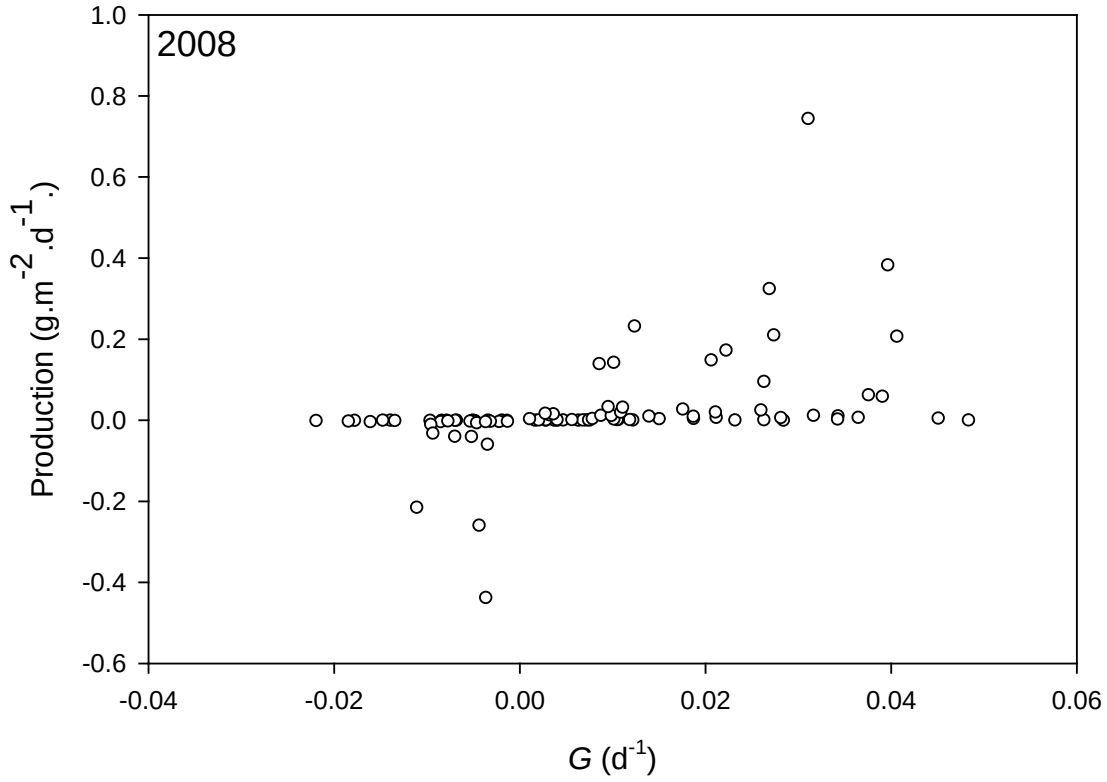


Figure 4.25. Relationship between site-specific instantaneous growth rate and production in 2008.

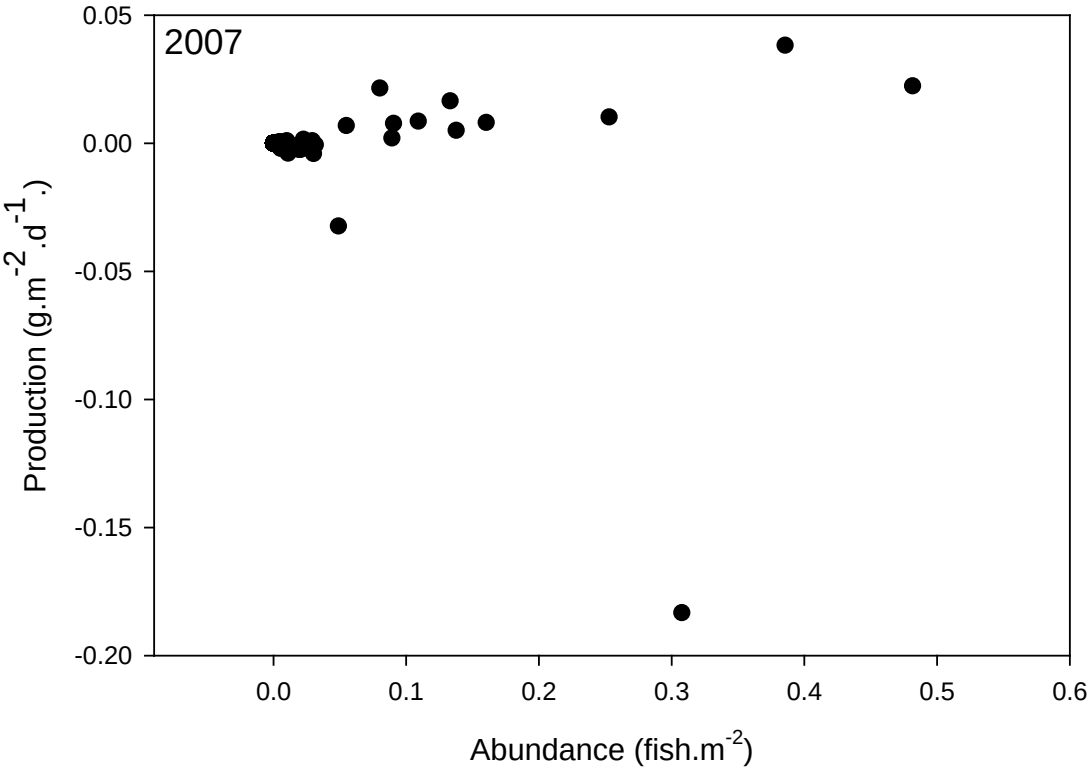


Figure 4.26. Relationship between site-specific abundance and production in 2007.

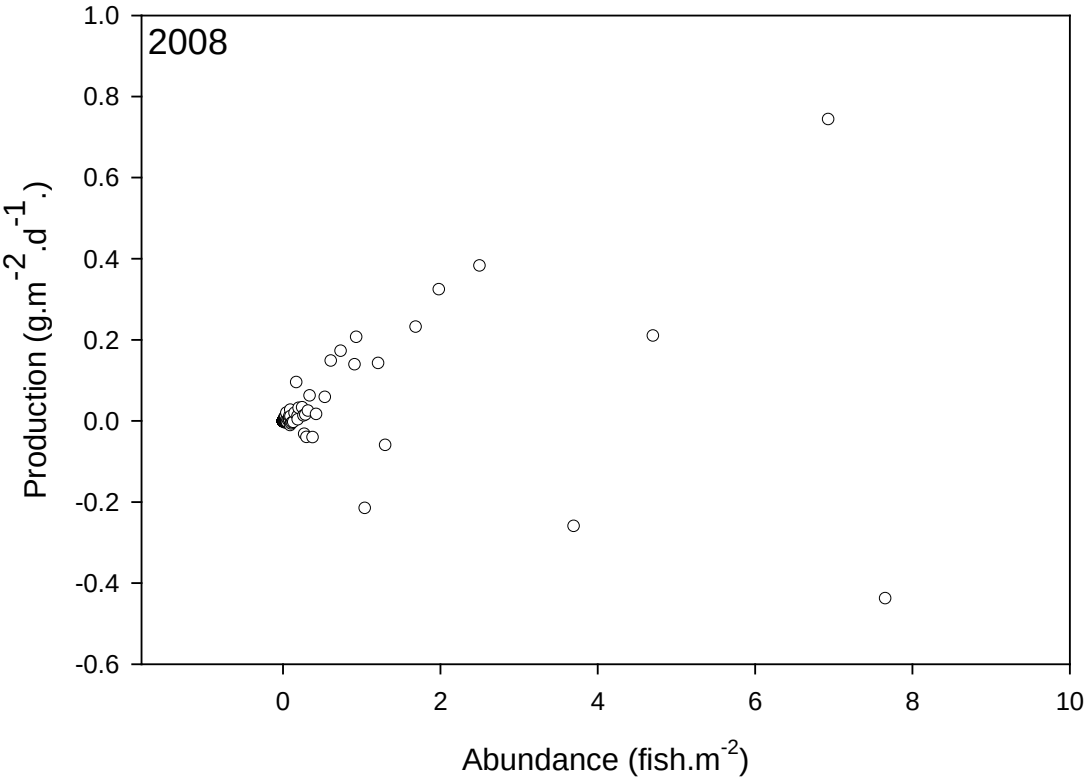


Figure 4.27. Relationship between site-specific abundance and production in 2008.

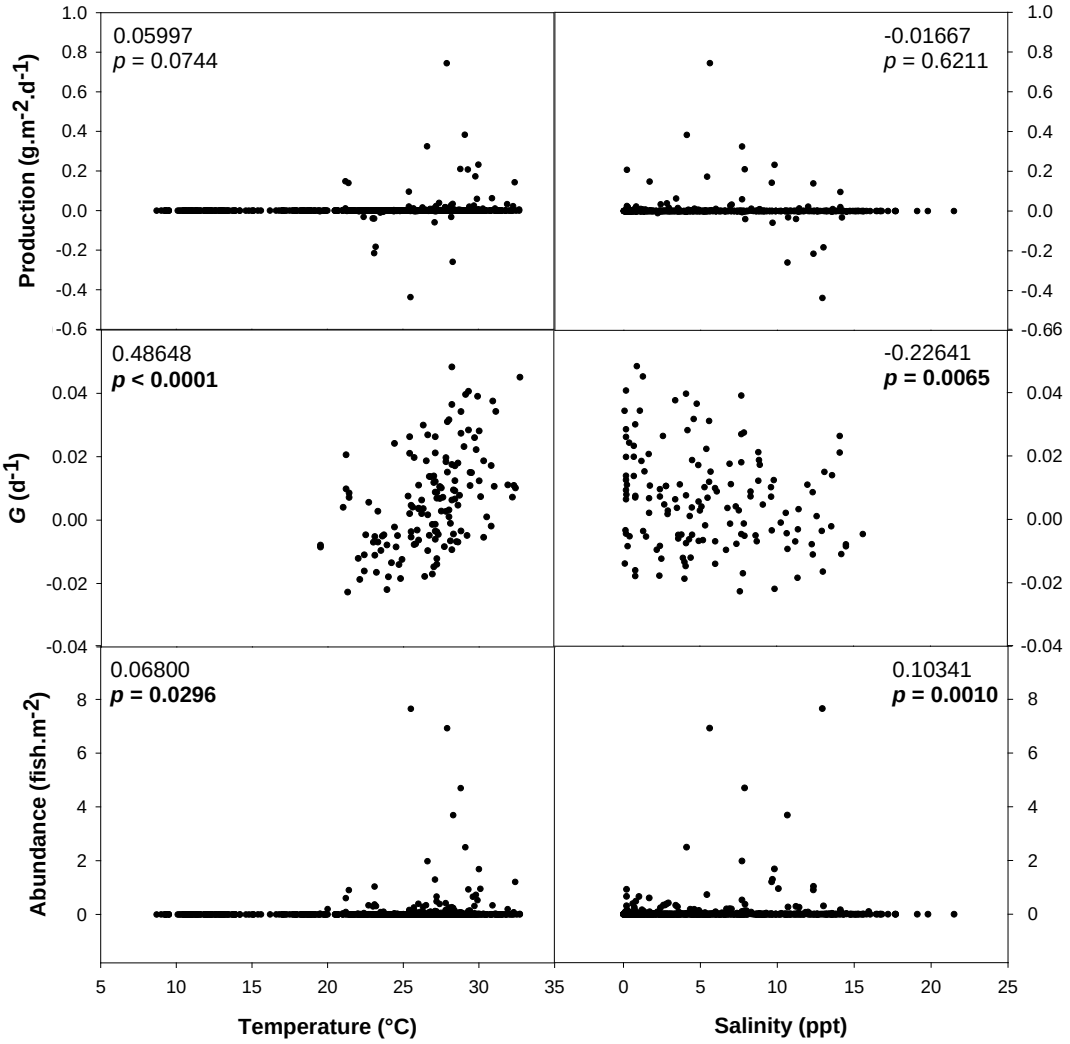


Figure 4.28. Relationships between temperature and salinity and site-specific abundance, instantaneous growth and production. Pearson correlation coefficient and *p*-values are shown for each respective relationship. Statistically significant ($p < 0.05$) values are in boldface.

Chapter 5:

Conclusions, limitations and future work

The objective of this chapter is to integrate the information presented in the previous four chapters, identify potential limitations of the study and describe future research objectives. Chapter 1 introduced the objectives of the projects included in this thesis. It reviewed the nursery-role hypothesis and the need for reliable estimates of site-specific production to identify essential fish habitats. A nucleic acid-based index, specifically RNA:DNA, was identified as a potential measure of assessing growth on spatial and temporal scales relevant to habitat residency. The life history of Atlantic menhaden was described, as well as the importance of identifying mechanisms influencing the success of this species during estuarine residency. Chapter 2 "An RNA:DNA-based model for estimating growth rate of juvenile Atlantic menhaden *Brevoortia tyrannus*" used laboratory experiments to quantify the relationships between RNA:DNA, temperature, feeding and growth rate, and developed a predictive RNA:DNA-based model for use on field-collected individuals. Chapter 3 "Temporal response (latency) of RNA-DNA ratio to changes in feeding regime in juvenile Atlantic menhaden *Brevoortia tyrannus*" investigated the utility of a predictive model to assess habitat-specific growth and production by using laboratory experiments to quantify the temporal reponse of RNA:DNA to changes in feeding. Finally, Chapter 4 "A preliminary assessment of broad- and fine-scale patterns in RNA:DNA-based growth, abundance and production of juvenile Atlantic menhaden in the Chesapeake and Delaware Bays" investigated the applicability of the model developed in Chapter 2 to field-collected individuals, and examined the spatiotemporal variability in juvenile Atlantic menhaden growth, abundance and production at the system- and site-level.

The focal point of the second chapter, "Relationship of RNA-DNA ratio and water temperature to growth rates in juvenile Atlantic menhaden *Brevoortia tyrannus*" was the development of an RNA:DNA-based predictive model of growth for juvenile Atlantic menhaden. Recruitment success of this species is likely greatly influenced during periods of early life (Quinlan & Crowder 1999) and defining essential fish habitat as well as identifying factors affecting juveniles during estuarine residency will provide a more comprehensive understanding of the recruitment dynamics of this species. The predictive model developed in this study provides a means of quantifying growth and subsequent production in relation to biotic and abiotic factors present at the time of sampling events. This tool allows for the relative comparison of juvenile menhaden habitat quality in the estuarine environment, assessment of the spatiotemporal variability of menhaden growth and production, and the identification of factors potentially influencing observed variability.

Due to unavoidable logistical constraints in terms of experimental design some important factors potentially influencing the RNA:DNA-growth relationship could not be investigated. Some studies have suggested food quality (Lied & Rosenlund 1984), food quantity (Goolish et al. 1984, McMillan & Houlihan 1988) and salinity (Kim et al. 2008) as potential influential factors in nucleic acid-growth relationships. Menhaden are obligate filter-feeders which consume plankton in the natural environment (Jeffries 1975). However, to maintain consistent ration treatments during experimentation, fish were fed a finfish starter meal similar to other laboratory studies on this species (McNatt & Rice 2004). Differences in energetic quality between natural prey for juvenile menhaden and food provided in experiments

may produce different rates of growth; however, I feel confident my methods did not bias results as feeding-related influences on the RNA:DNA-growth model were not quantified. Additionally, reliable estimates of food concentration in the field would likely prove difficult to obtain and thus, were excluded from the predictive model. Salinity represents an important factor influencing the vital rates of fishes in a variety of ways (Wooten 1998); however, effects of salinity are often ignored in RNA:DNA-growth relationships. Hettler (1976) noted effects of salinity on the growth and metabolic rates of juvenile menhaden. It is possible that salinity could influence my model; however potential affects could not be quantified in the present study.

Despite these limitations, the model developed in this study explained a considerable amount of the variability in growth (76%), comparable to nucleic acid-based growth indices produced in other studies. However, the model has yet to be tested on subjects with known growth rates from an independent sample. Model validation is desired where known measurements of growth from independent trials are directly compared with model predictions. Such testing may help to identify potential biases and improve model development.

Chapter 3, "Temporal response (latency) of RNA-DNA ratio to changes in feeding regime in juvenile Atlantic menhaden *Brevoortia tyrannus*" quantified the responsiveness of RNA:DNA to nutritional condition in this species. The utility of RNA:DNA-based growth indices lies in their ability to estimate recent growth in relation to specific-habitat residency and related environmental factors. However, to reliably associate patterns in RNA:DNA-based growth to specific sites and/or biotic and abiotic variables, the temporal response of RNA:DNA must first be determined.

This study detected changes in RNA:DNA in response to feeding conditions within two days and significant differences were observed in as little as four days. These results support the ability of my predictive model to estimate growth on small temporal scales relative to specific habitat residency. However, further work is desired to more comprehensively quantify the latency dynamics of juvenile menhaden.

Due to logistical constraints, only one temperature could be employed to produce sufficient replication of treatments conditions. To represent an approximate median temperature of Chesapeake and Delaware Bays during menhaden estuarine residency, 24°C was chosen. However, the temperature dynamics in estuarine environments are both spatially and temporally variable and juvenile menhaden will ultimately experience a spectrum of thermal regimes. Because RNA:DNA-growth relationships are often influenced by temperature (Buckley 1982, Buckley et al. 1984, Caldarone et al. 2003, Caldarone 2005, Mercaldo-Allen et al. 2006), it is possible that the temporal response of RNA:DNA in menhaden will vary at different temperatures, as seen previously in other fishes (Jurss et al. 1987, Malloy & Targett 1994a). Further experimentation incorporating a range of possible thermal scenarios may help to elucidate potential interactions between temperature and the latency of RNA:DNA in juvenile menhaden.

The predictive model developed in Chapter 2 was intended for use throughout the entire size range of young-of-the-year menhaden during estuarine residence. However, the size range incorporated in our temporal response experiment was less broad. Menhaden of varying sizes will likely display variable responses to stressors,

such as changes in feeding conditions, due to differential energy reserves and metabolic requirements. For example, Rooker & Holt (1996) found that RNA:DNA in red drum was less responsive to starvation as fish became older. Differential temporal responses of RNA:DNA between individuals may lead to incorrect assumptions regarding the scale of observed RNA:DNA-based estimates. Further quantification of the latency of RNA:DNA of individuals within a more complete size spectrum is desired to determine if inferences regarding the scale of RNA:DNA-based estimates can be reliably applied to all size-classes of juveniles found in the estuarine environment.

It is entirely likely that changes in condition (e.g. feeding) in the natural environment are less pronounced than those experienced by individuals in my latency trial. If so, changes in growth and subsequent RNA:DNA values in the field may be more subtle. To reliably assess site-specific growth and associated environmental factors, my RNA:DNA-index must be sufficiently sensitive to detect such minuscule changes. Johnson et al. (2002) observed declines in RNA:DNA in response to relatively large changes in feeding level, but failed to detect changes at intermediate feeding regimes. This inability to detect subtle changes may bias field-based estimates and fail to fully capture the dynamics of the system being investigated. To address this concern, further experimentation is desired incorporating intermediate feeding similar to Wright & Martin (1985), Arndt et al. (1996) and Johnson et al. (2002).

Despite inherent limitations, this study has successfully established the rapid response of RNA:DNA to changes in feeding in juvenile Atlantic menhaden. These

finding suggest the utility of the predictive model to assess short term growth and production and provides a preliminary foundation for further investigation of the latency of RNA:DNA under other scenarios for this species.

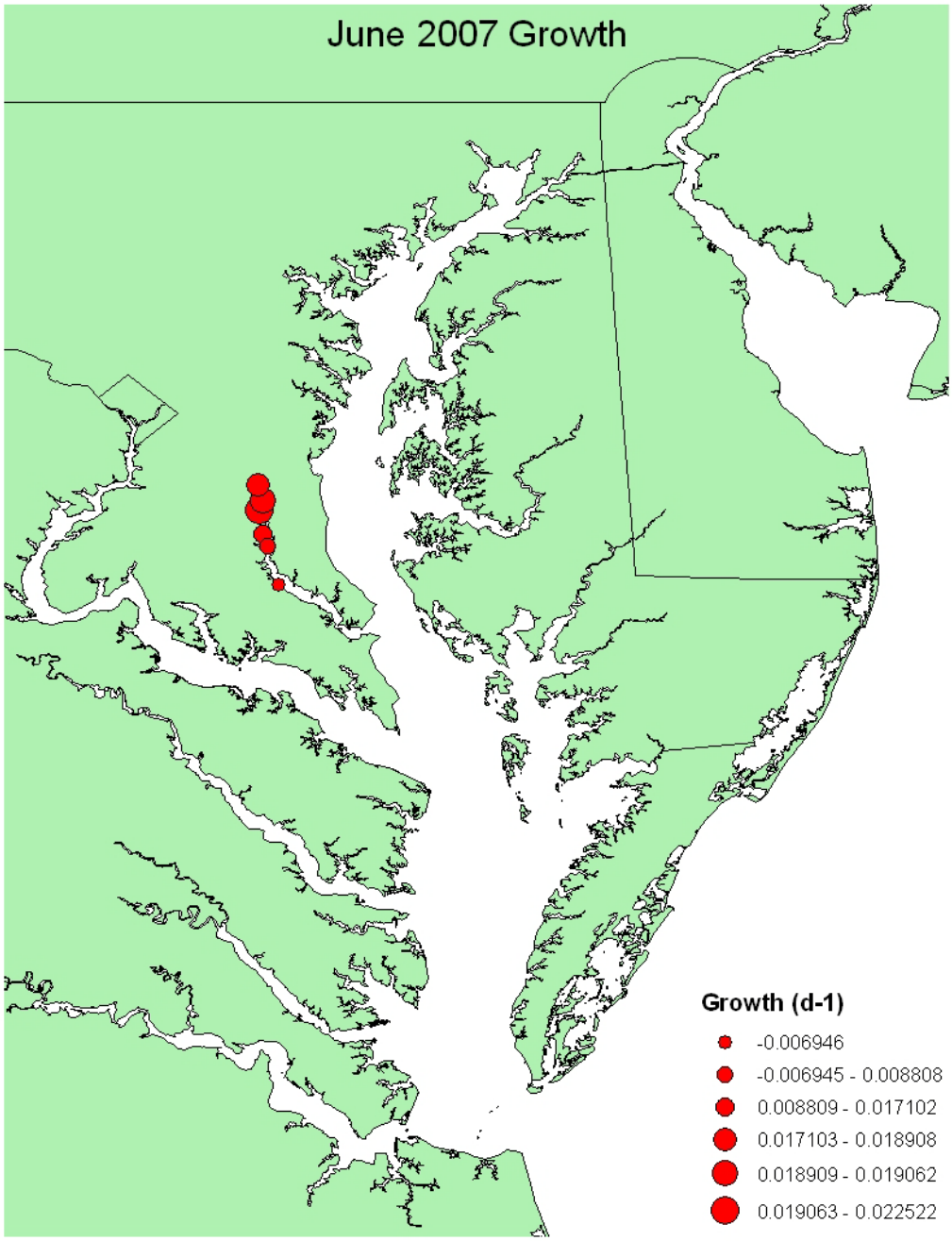
Chapter 4, "A preliminary assessment of broad- and fine-scale patterns in RNA:DNA-based growth, abundance and production of juvenile Atlantic menhaden in the Chesapeake and Delaware Bays" assessed the spatiotemporally variability of potential juvenile Atlantic menhaden nursery habitats. By combining RNA:DNA-based estimates of growth from field-collected individuals and site-specific abundance estimates from surveys, production of sites within the Chesapeake and Delaware Bays was calculated. This chapter explored the central objective of the research – to determine whether specific sites within the estuarine environment consistently exhibited high levels of menhaden production. Beck et al. (2001) propose that nursery habitats are those areas that on average contribute disproportionately more recruits than others, and suggest production as the best integrative measure to evaluate this contribution. The results of my investigation suggest that juvenile menhaden contribution is not simply a result of consistently high production of specific-sites, but rather, the utilization of many sites by menhaden over space and time. These findings have important implications to management and the definition of essential fisheries habitat for this species. High spatiotemporal variability in menhaden production throughout estuaries may preclude the designation of specific-sites as EFH. However, identifying the causative factors and understanding mechanisms contributing to observed variability in production may provide valuable insights into the population dynamics of this species. If the

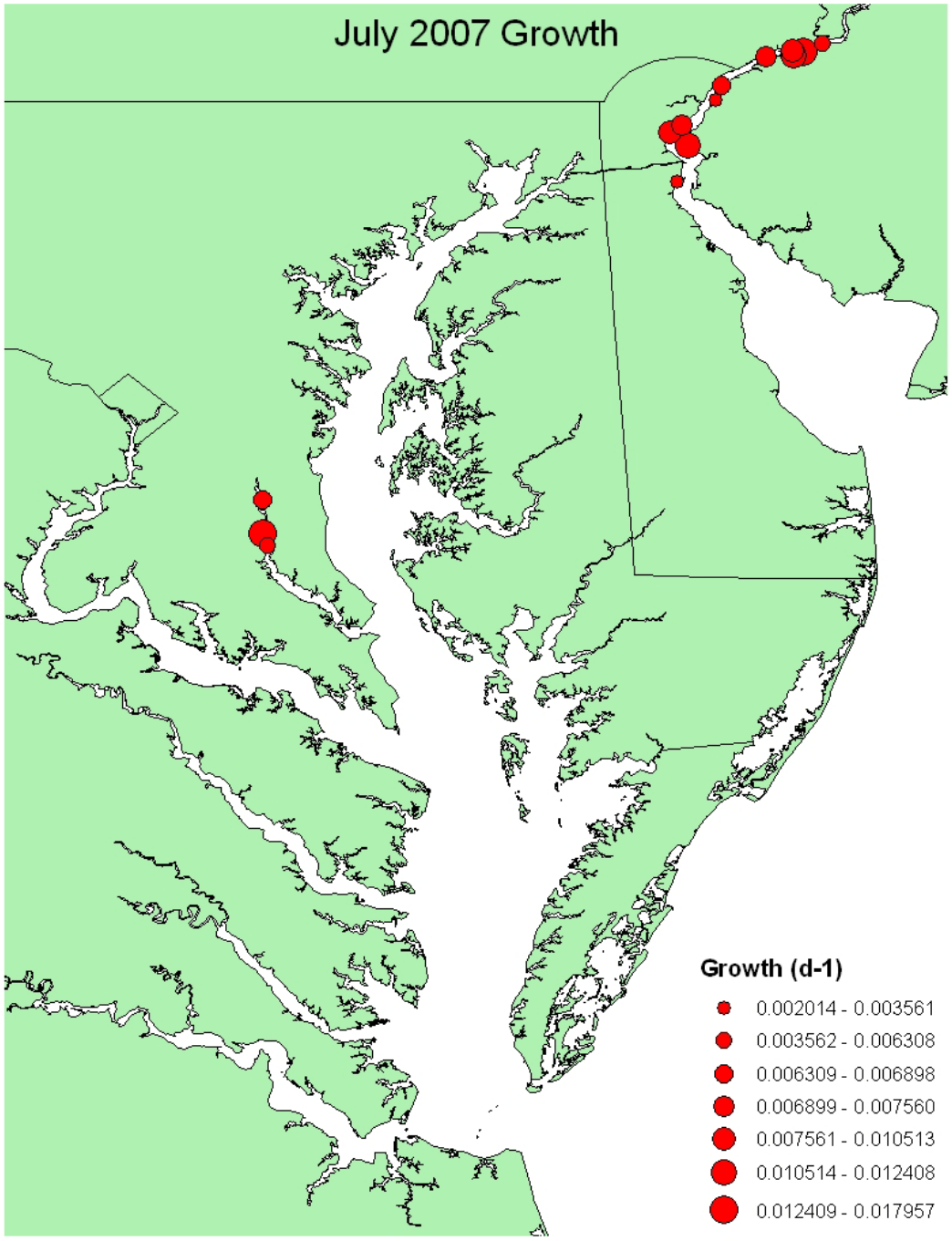
spatiotemporal variability of important factors can be accurately predicted, mapping of potential juvenile menhaden production throughout the estuarine environment may be achieved, producing a spatiotemporally dynamic depiction of relative habitat quality and assisting in the forecasting of recruitment outcomes.

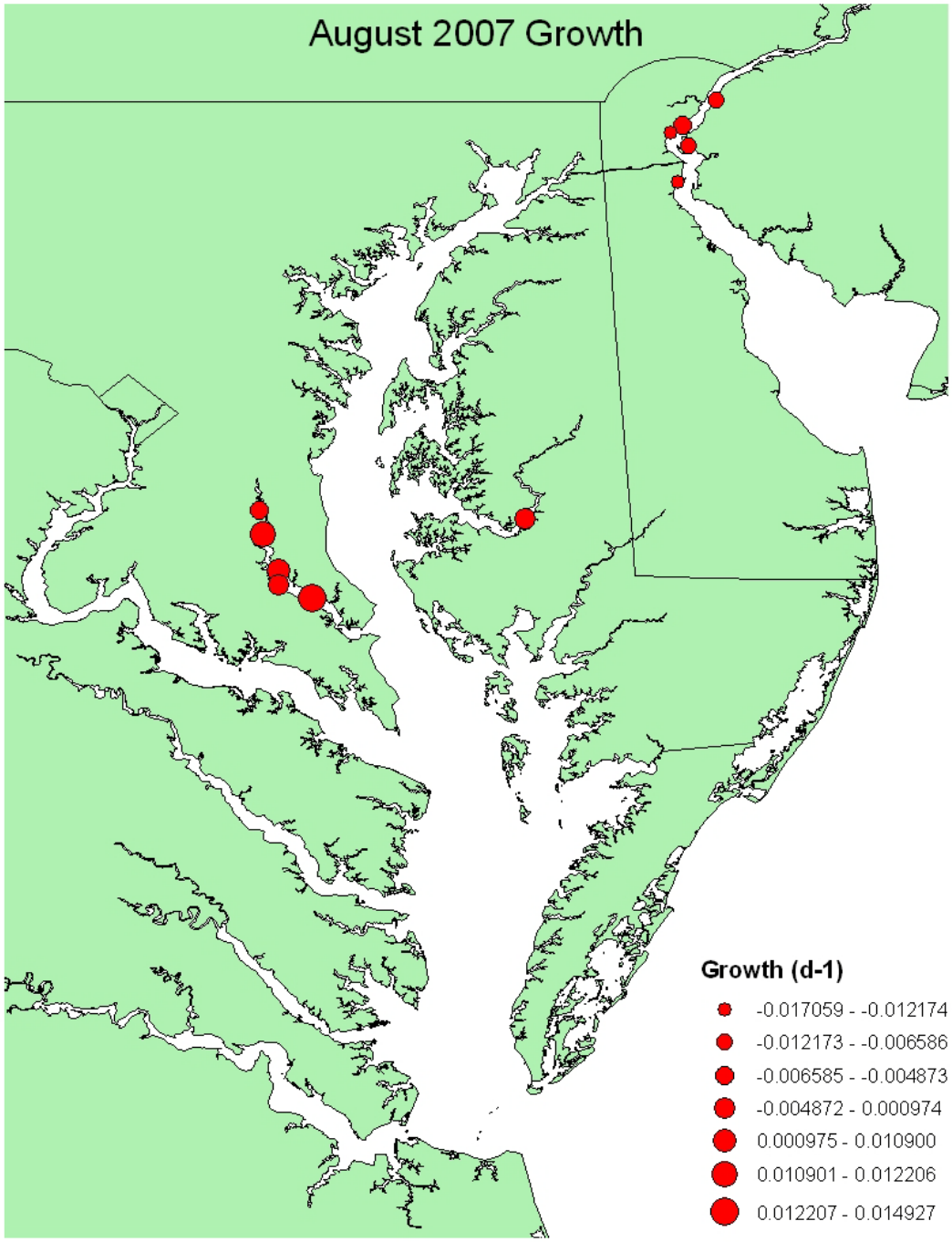
In conclusion, my research has provided a foundation for further investigation into the production dynamics of juvenile Atlantic menhaden in the estuarine environment. The RNA:DNA-based index of growth developed in Chapter 2 and the quantification of the temporal response of RNA:DNA in Chapter 3 provide a potentially valuable tool for estimating short term growth of menhaden in relation to specific habitat residency. Using the estimates derived from this model, a preliminary assessment of the spatial and temporal variability in juvenile menhaden production was conducted in Chapter 4. Results of this investigation suggest a highly variable utilization of estuarine habitats over space and time, exemplifying the need to identify the causative agents driving observed variability in juvenile menhaden production. Future research may improve our understanding of the relationships between menhaden production and important biotic and abiotic factors, potentially enhancing our knowledge of population dynamics and improving management strategies for Atlantic menhaden.

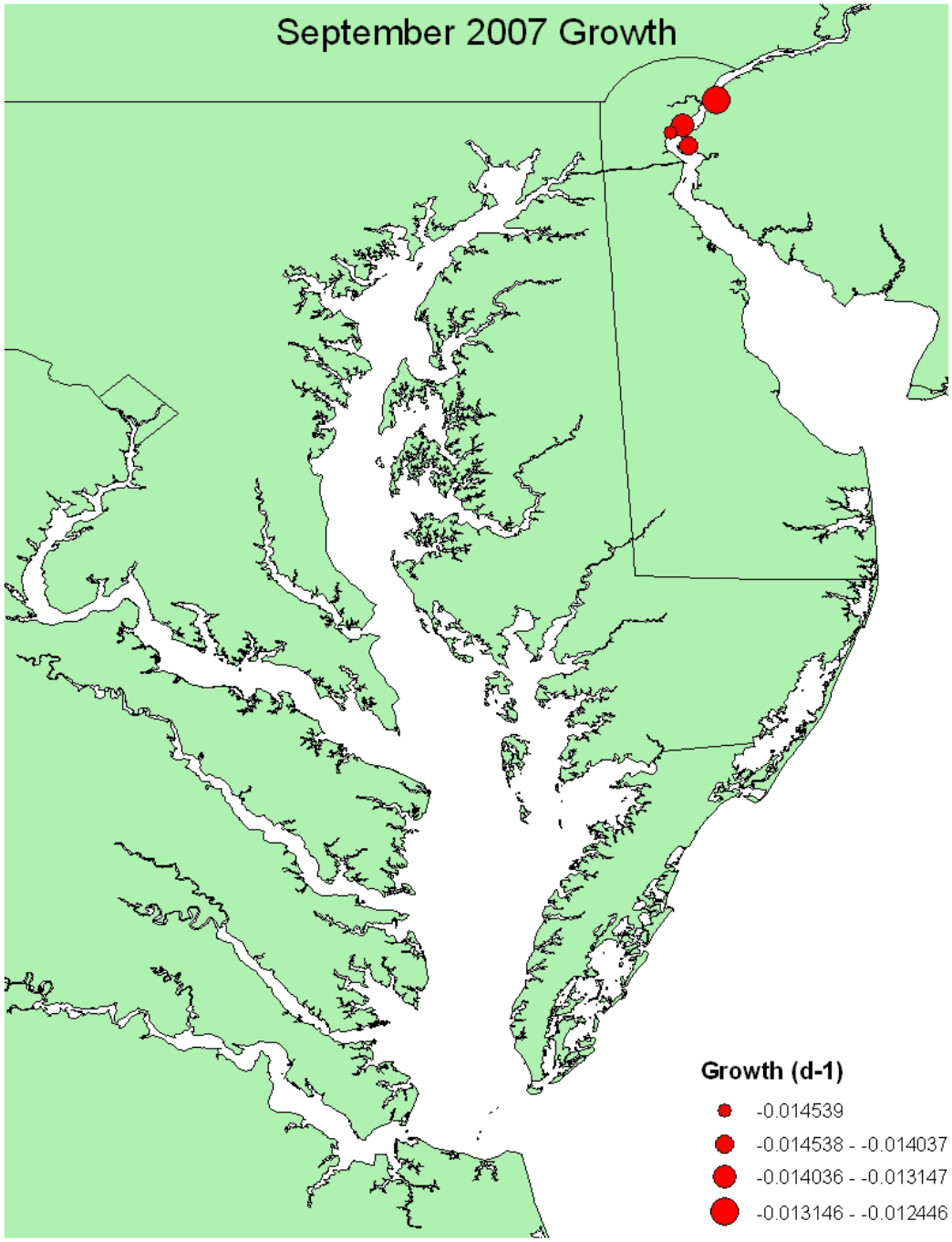
Appendix A:

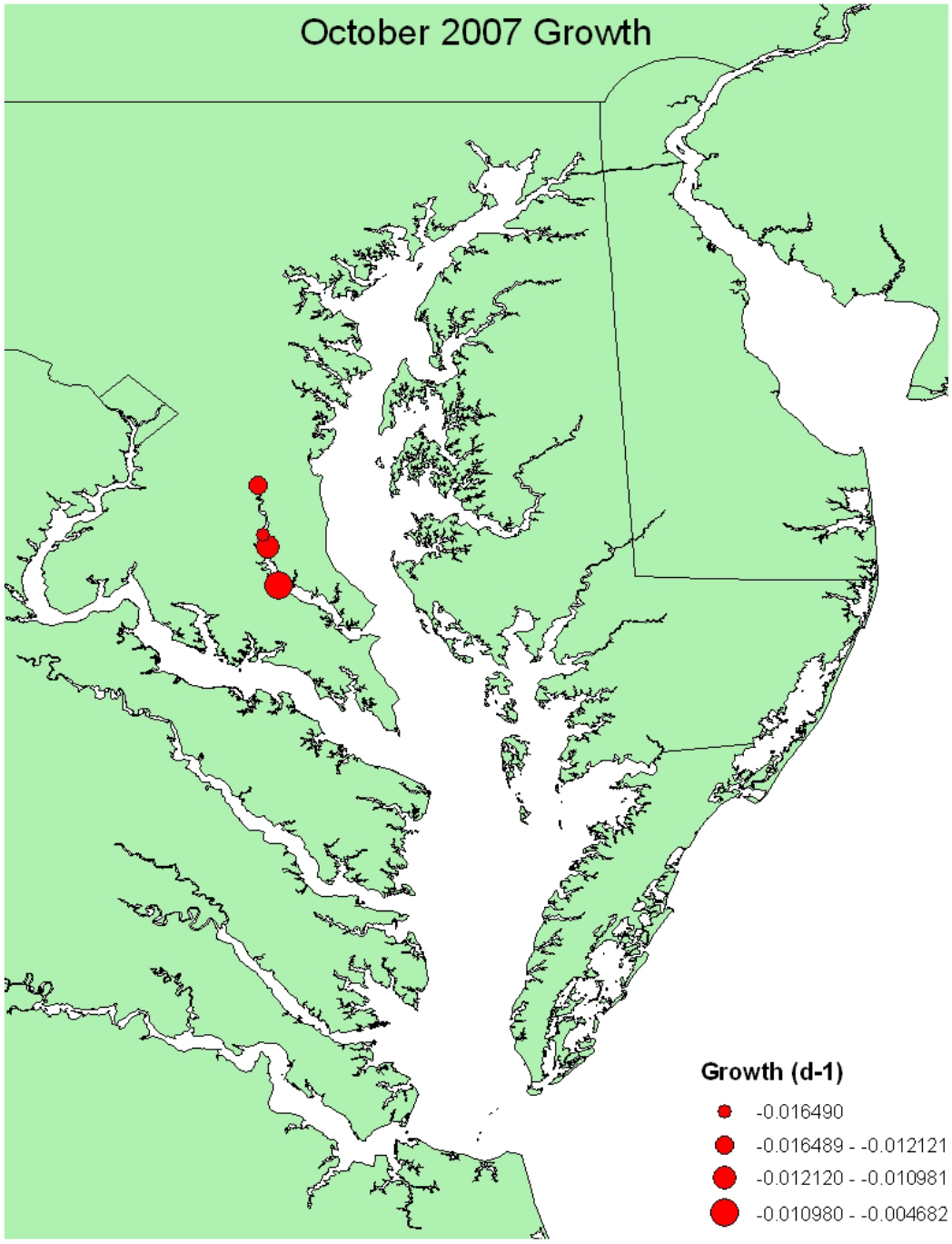
Site-specific monthly instantaneous growth for 2007


June 2007 Growth
Growth (d-1)
-0.006946
-0.006945 - 0.008808
0.008809 - 0.017102
0.017103 - 0.018908
0.018909 - 0.019062
0.019063 - 0.022522


July 2007 Growth
Growth (d-1)
0.002014 - 0.003561
0.003562 - 0.006308
0.006309 - 0.006898
0.006899 - 0.007560
0.007561 - 0.010513
0.010514 - 0.012408
0.012409 - 0.017957

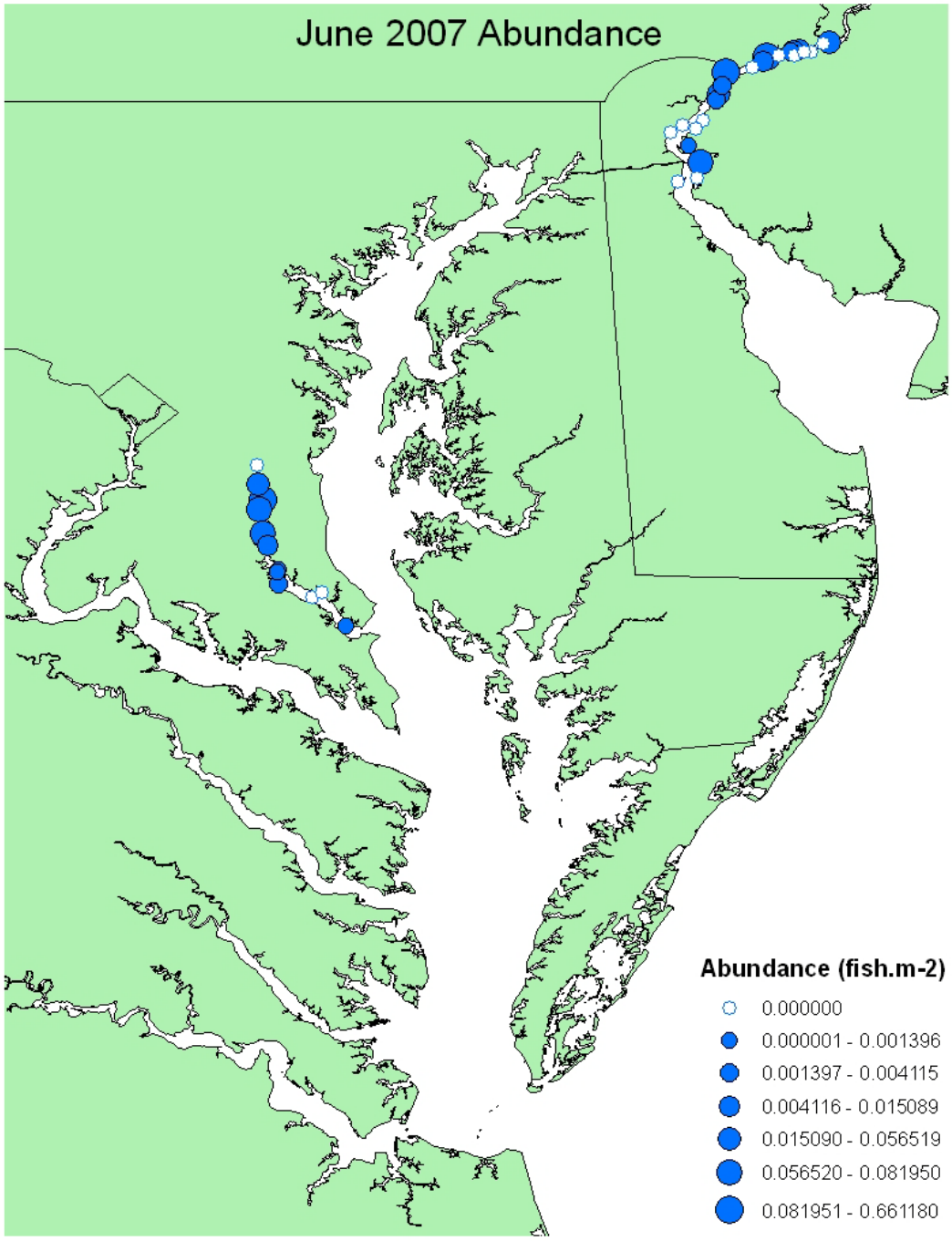

August 2007 Growth
Growth (d-1)
-0.017059 - -0.012174
-0.012173 - -0.006586
-0.006585 - -0.004873
-0.004872 - 0.000974
0.000975 - 0.010900
0.010901 - 0.012206
0.012207 - 0.014927

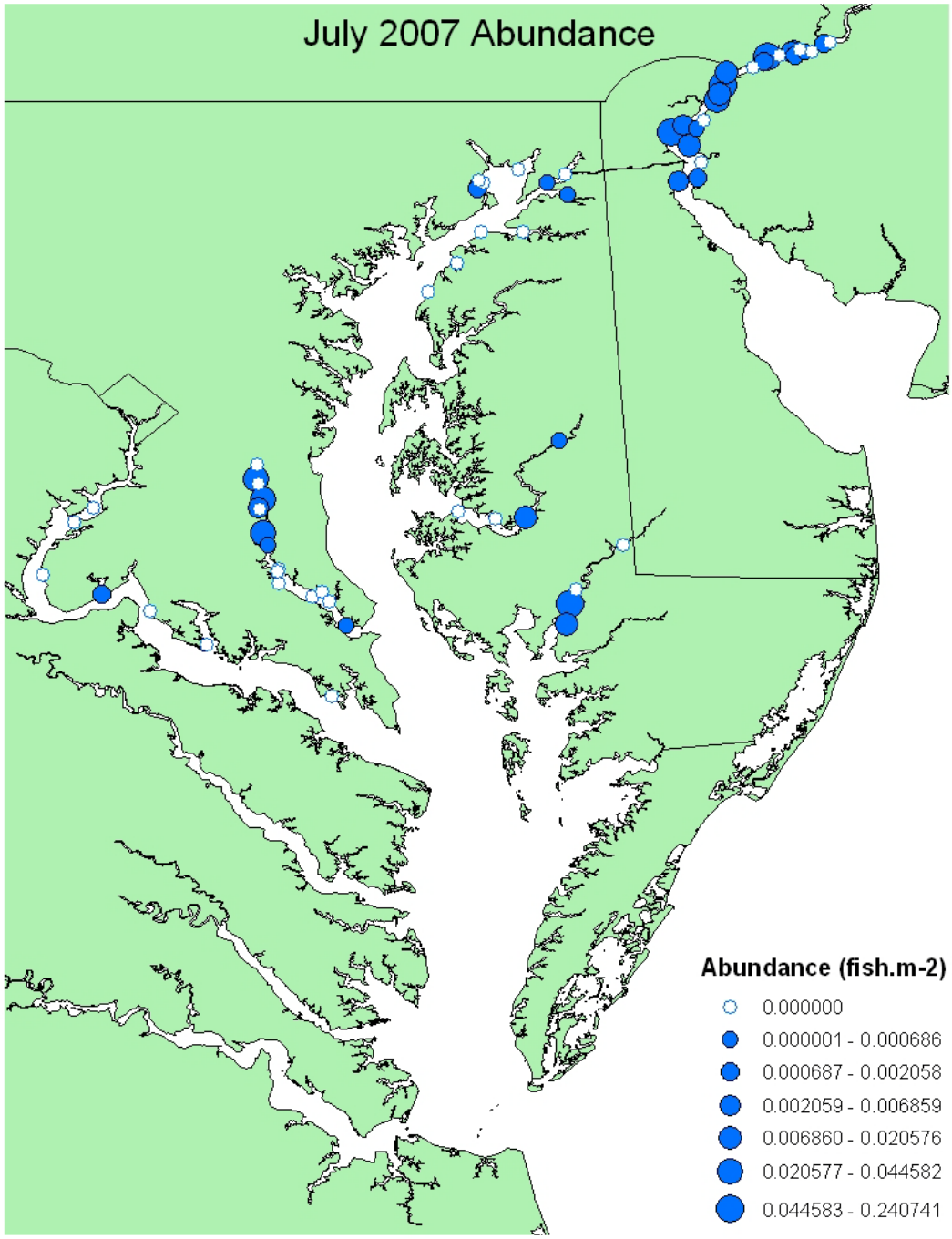

September 2007 Growth
Growth (d-1)
-0.014539
-0.014538 - -0.014037
-0.014036 - -0.013147
-0.013146 - -0.012446

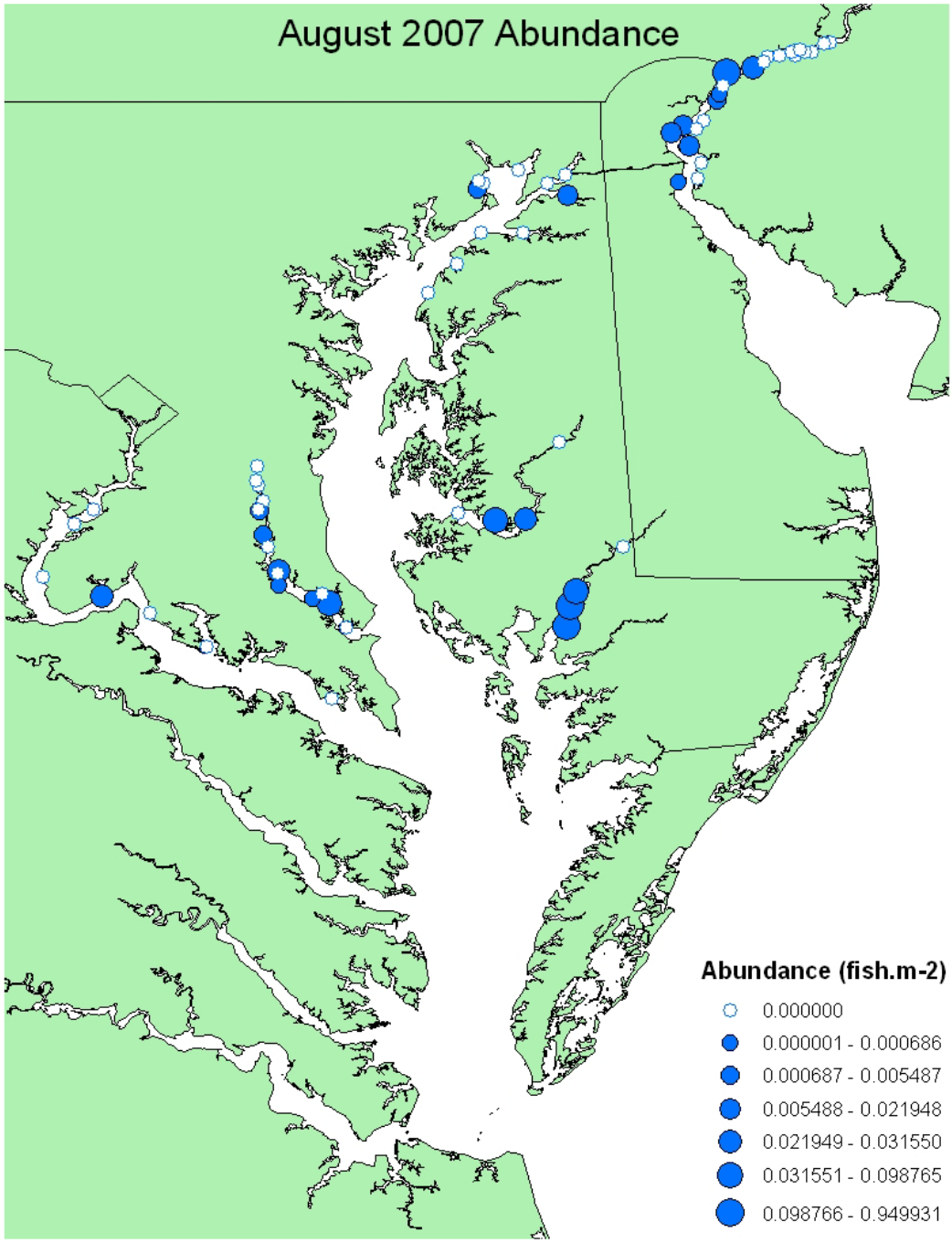

October 2007 Growth
Growth (d-1)
-0.016490
-0.016489 - -0.012121
-0.012120 - -0.010981
-0.010980 - -0.004682

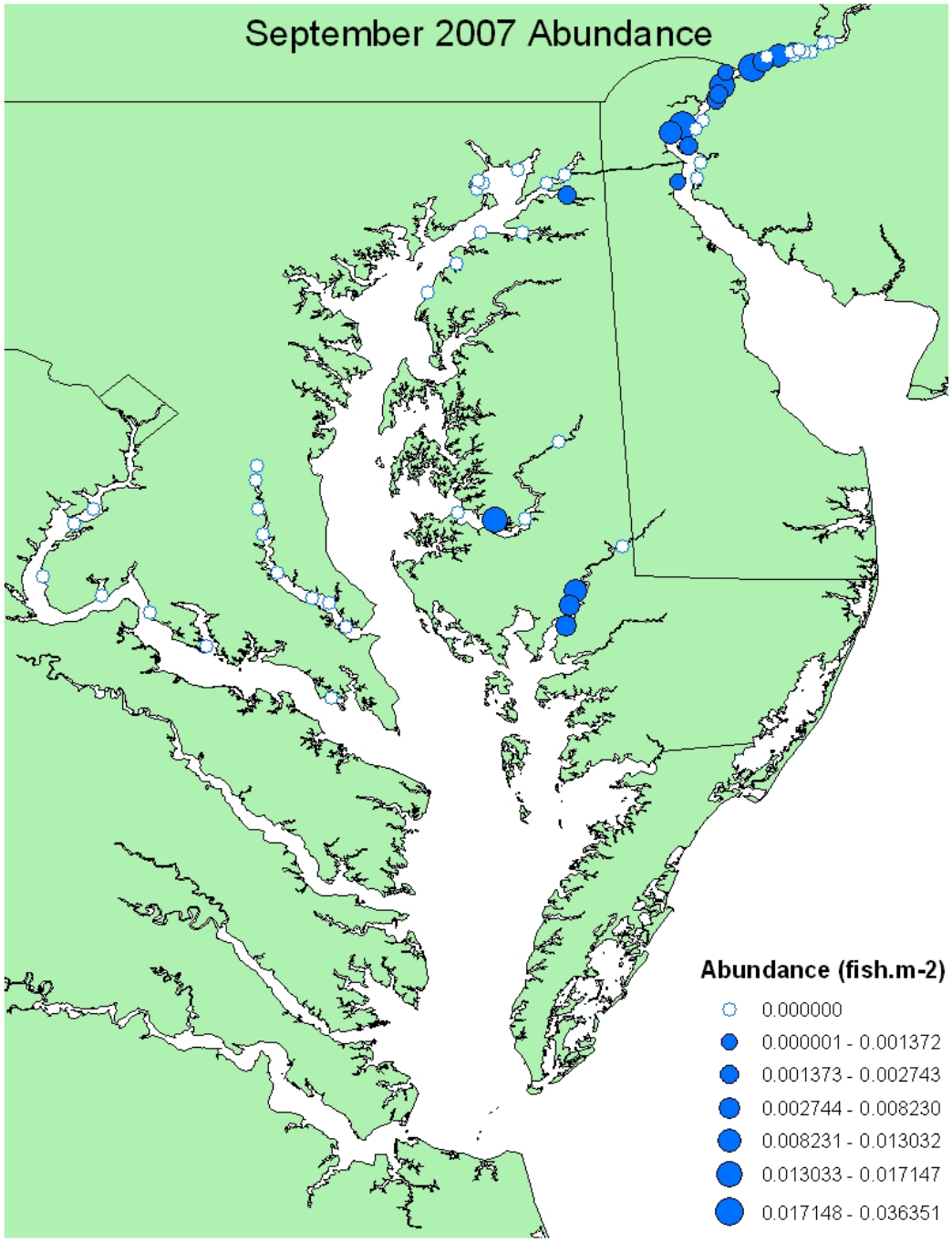
Appendix B:

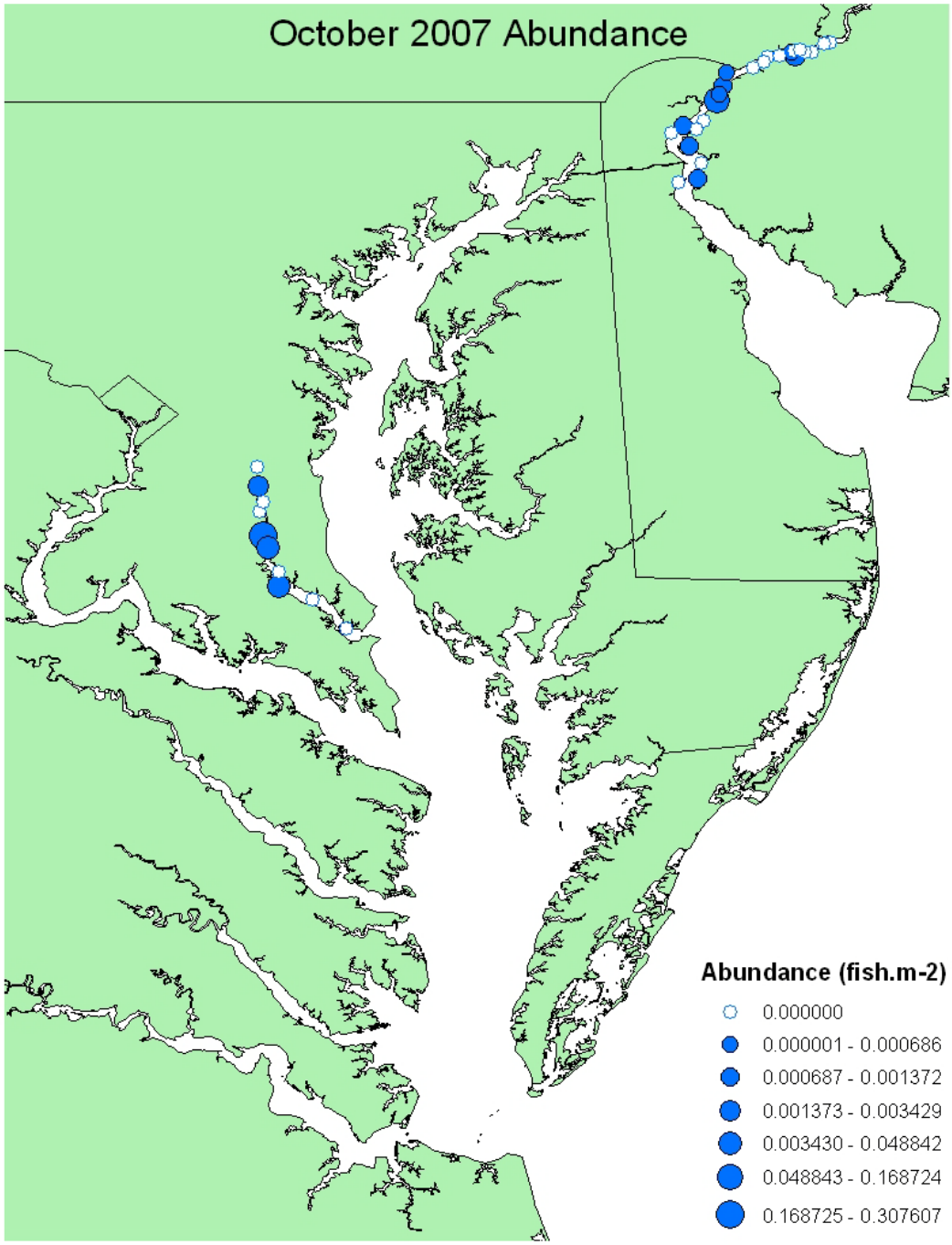
Site-specific monthly abundance for 2007

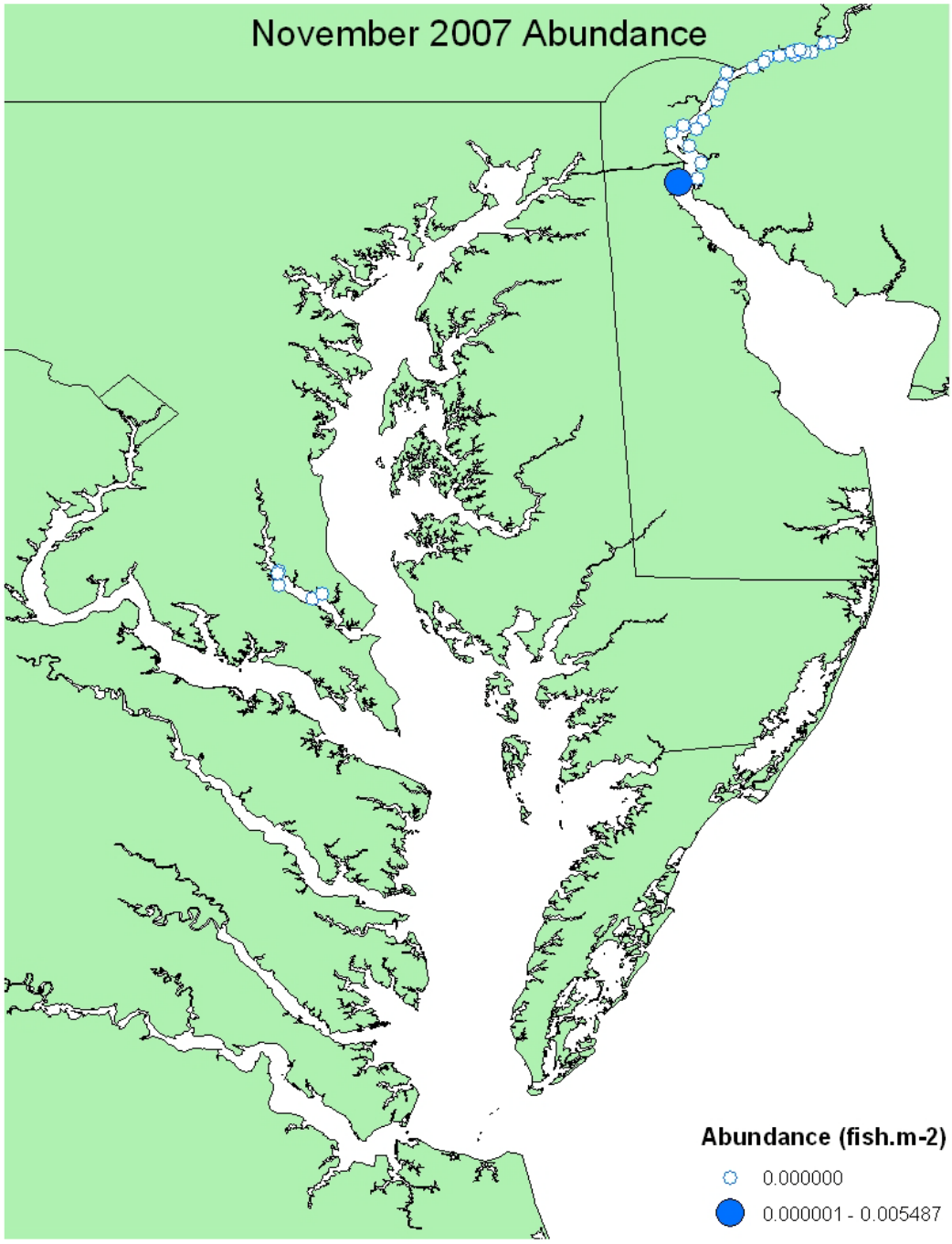

June 2007 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.001396
0.001397 - 0.004115
0.004116 - 0.015089
0.015090 - 0.056519
0.056520 - 0.081950
0.081951 - 0.661180


July 2007 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.000686
0.000687 - 0.002058
0.002059 - 0.006859
0.006860 - 0.020576
0.020577 - 0.044582
0.044583 - 0.240741


August 2007 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.000686
0.000687 - 0.005487
0.005488 - 0.021948
0.021949 - 0.031550
0.031551 - 0.098765
0.098766 - 0.949931

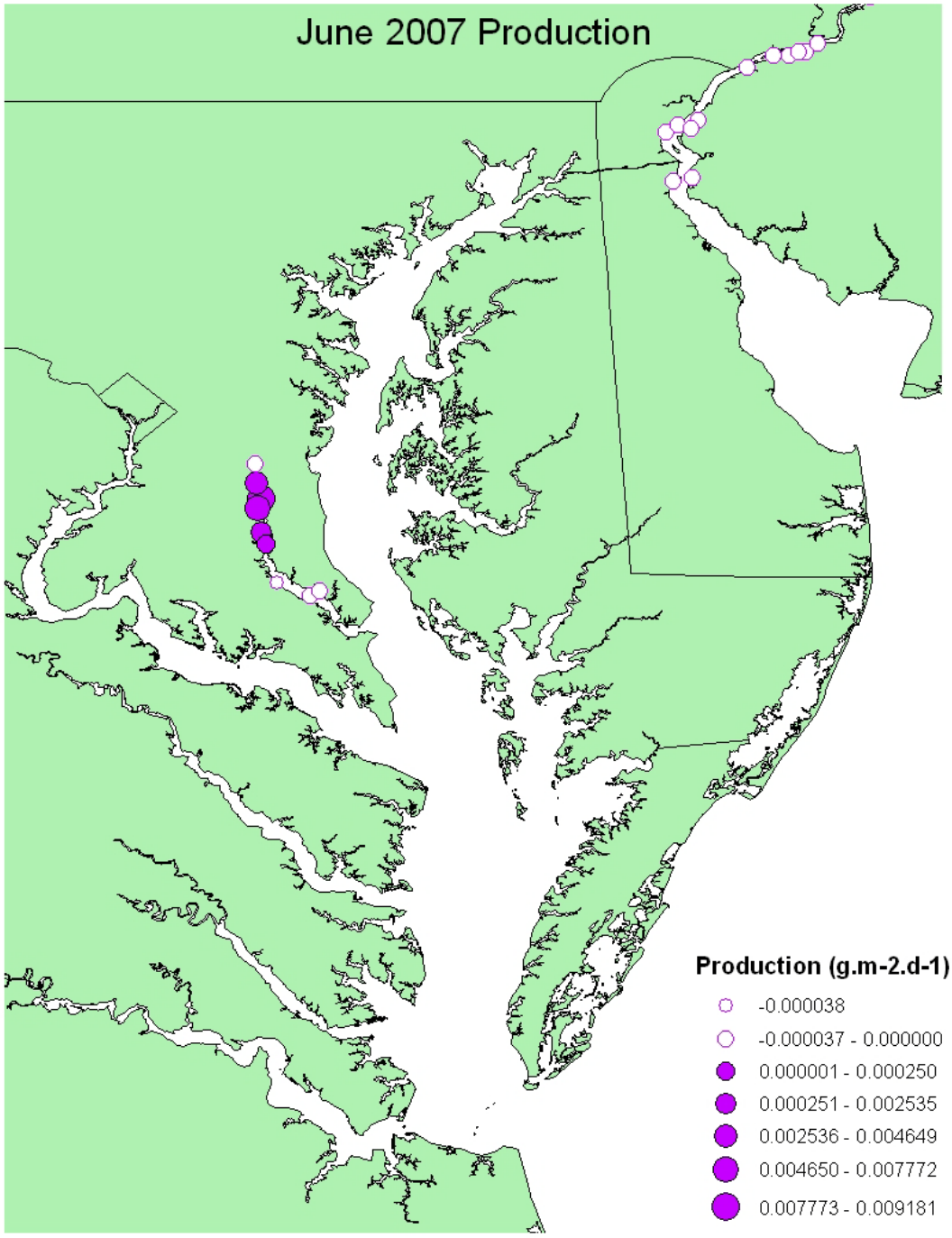

September 2007 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.001372
0.001373 - 0.002743
0.002744 - 0.008230
0.008231 - 0.013032
0.013033 - 0.017147
0.017148 - 0.036351

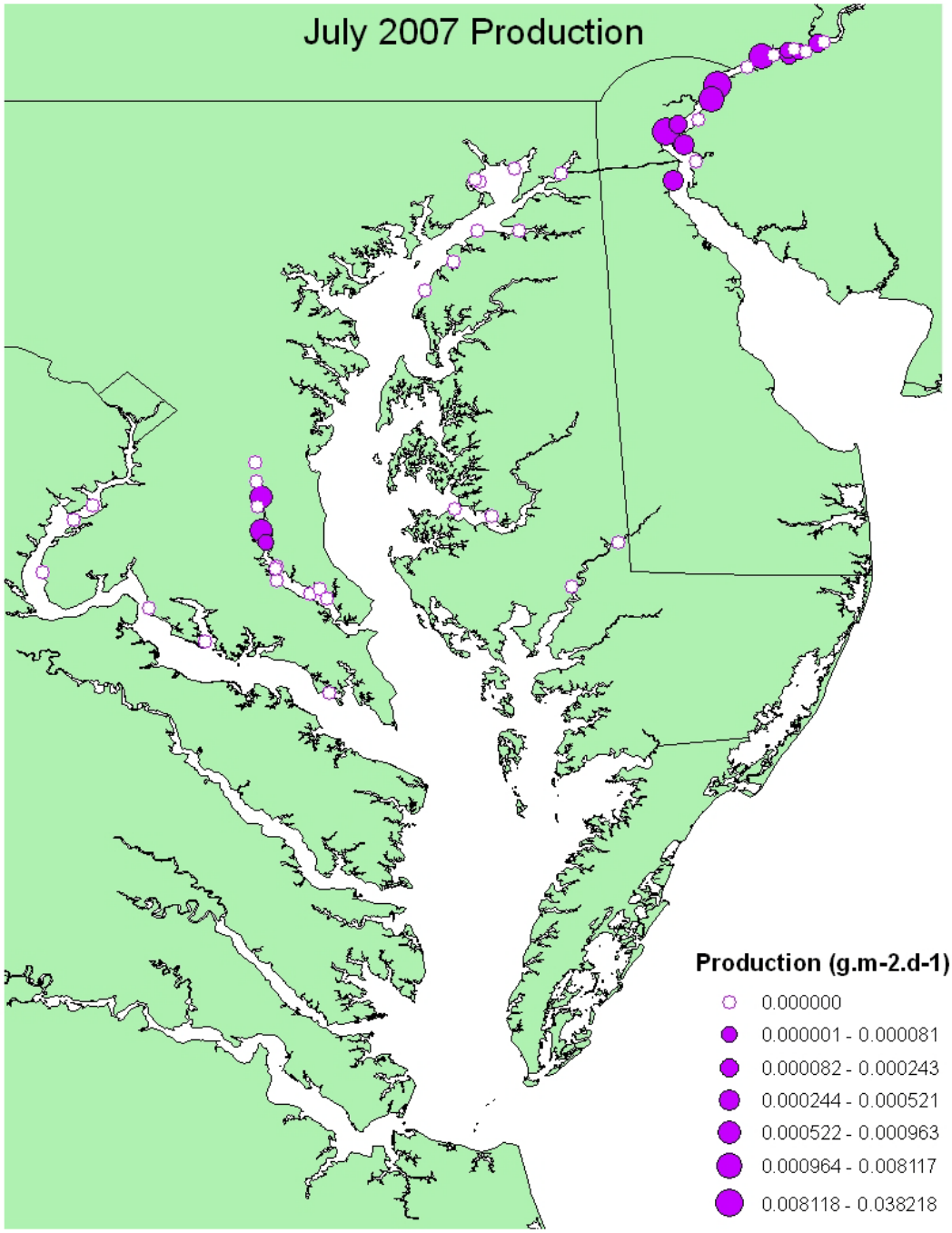

October 2007 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.000686
0.000687 - 0.001372
0.001373 - 0.003429
0.003430 - 0.048842
0.048843 - 0.168724
0.168725 - 0.307607

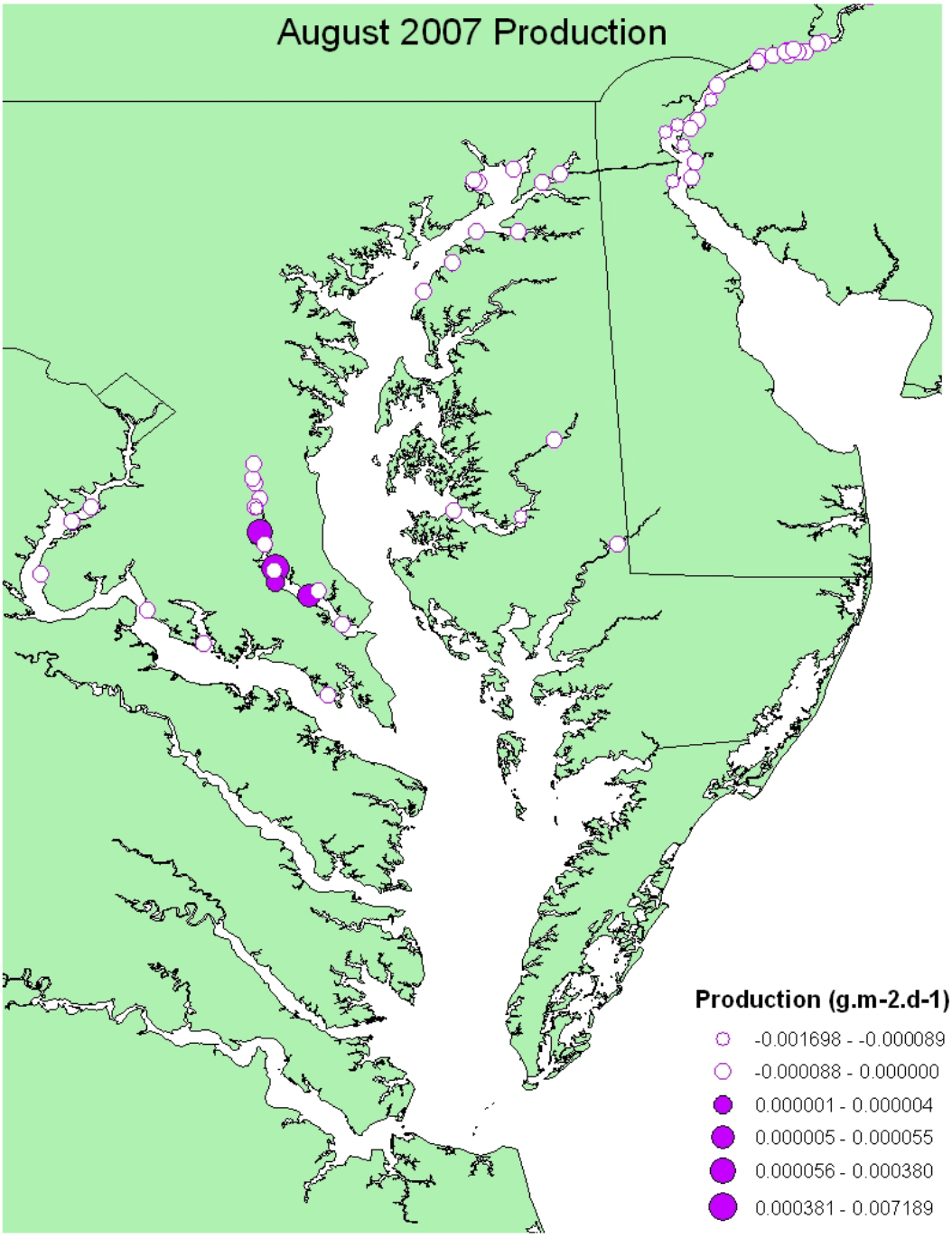

November 2007 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.005487

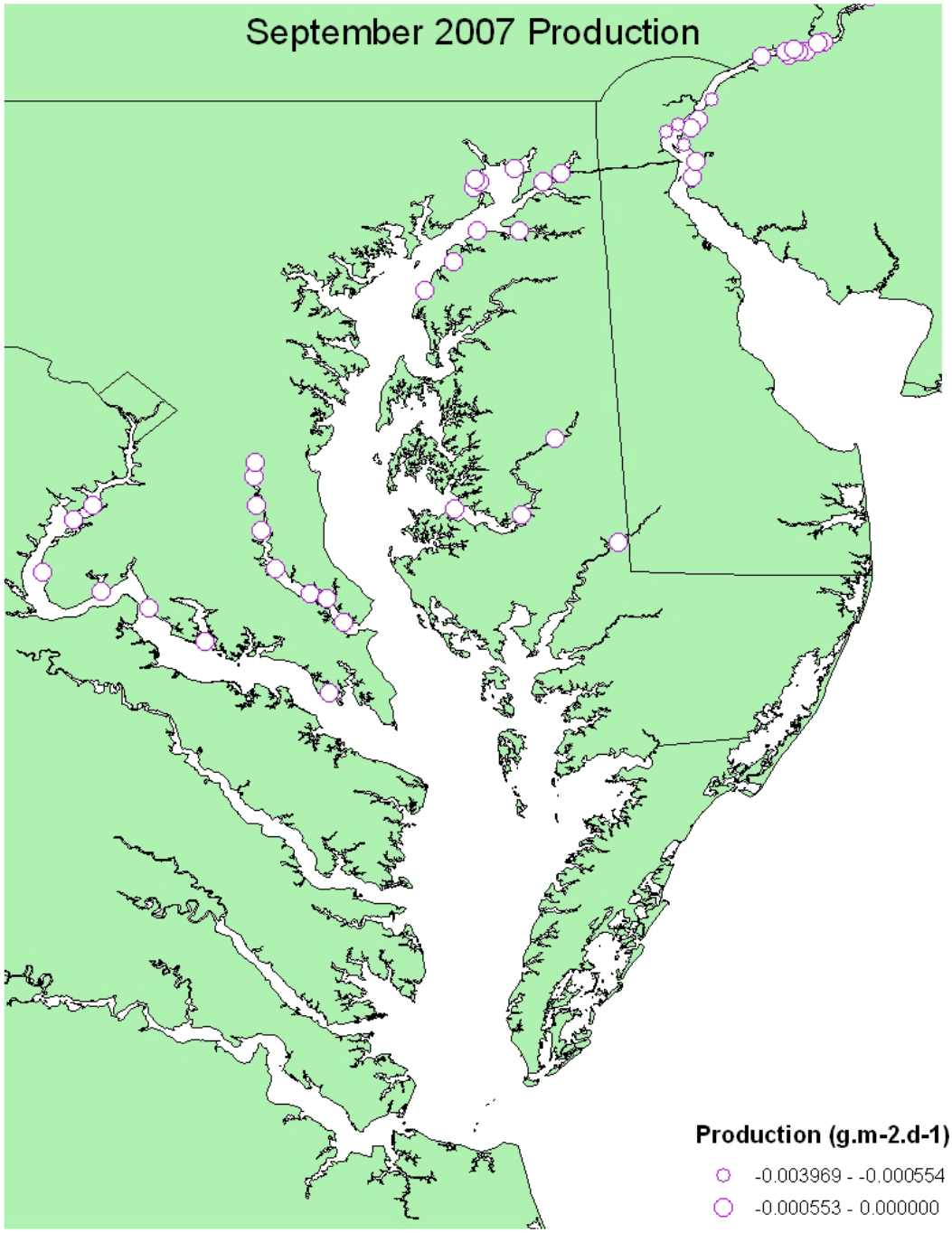
Appendix C:

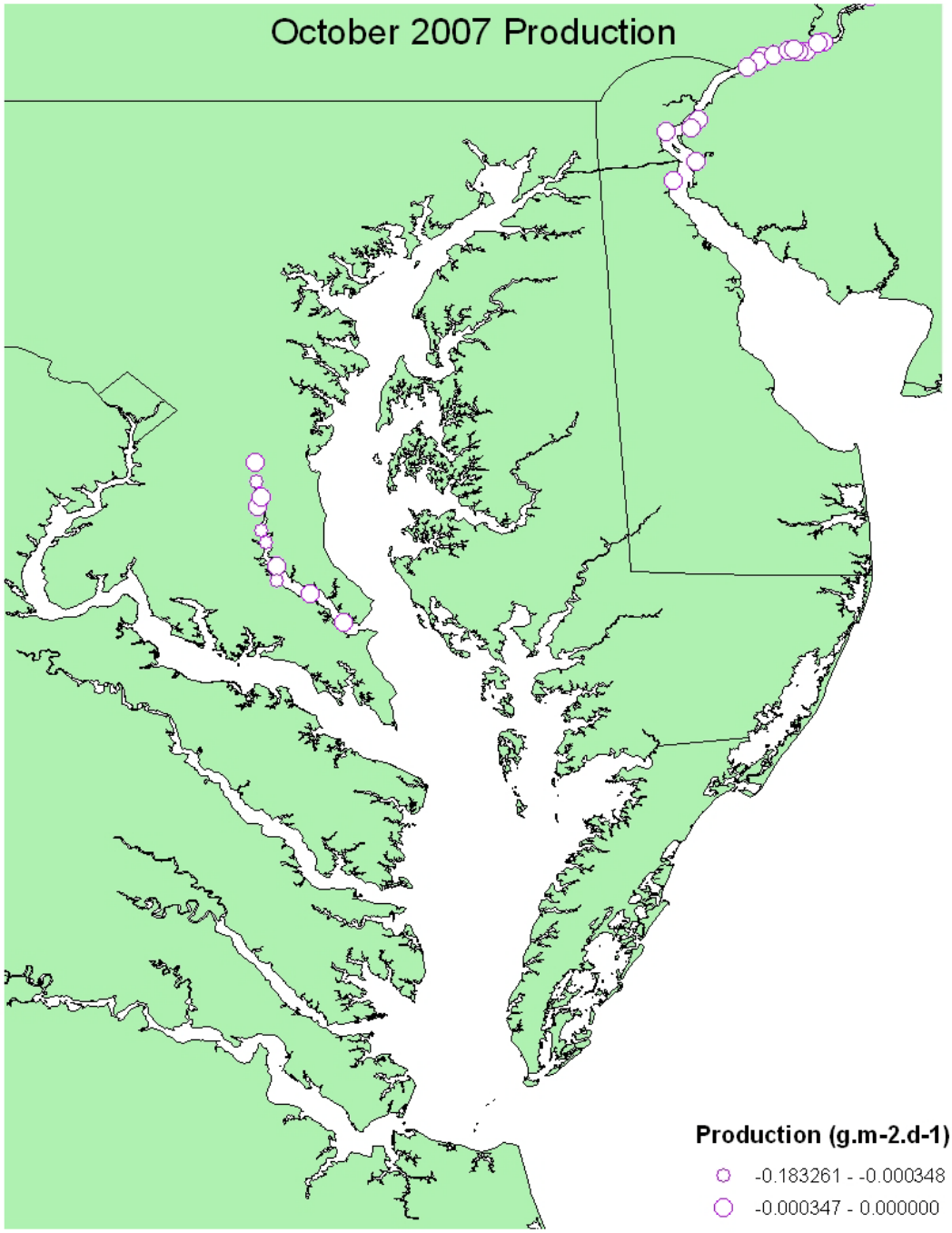
Site-specific monthly production for 2007


June 2007 Production
Production (g.m-2.d-1)
-0.000038
-0.000037 - 0.000000
0.000001 - 0.000250
0.000251 - 0.002535
0.002536 - 0.004649
0.004650 - 0.007772
0.007773 - 0.009181


July 2007 Production
Production (g.m-2.d-1)
0.000000
0.000001 - 0.000081
0.000082 - 0.000243
0.000244 - 0.000521
0.000522 - 0.000963
0.000964 - 0.008117
0.008118 - 0.038218

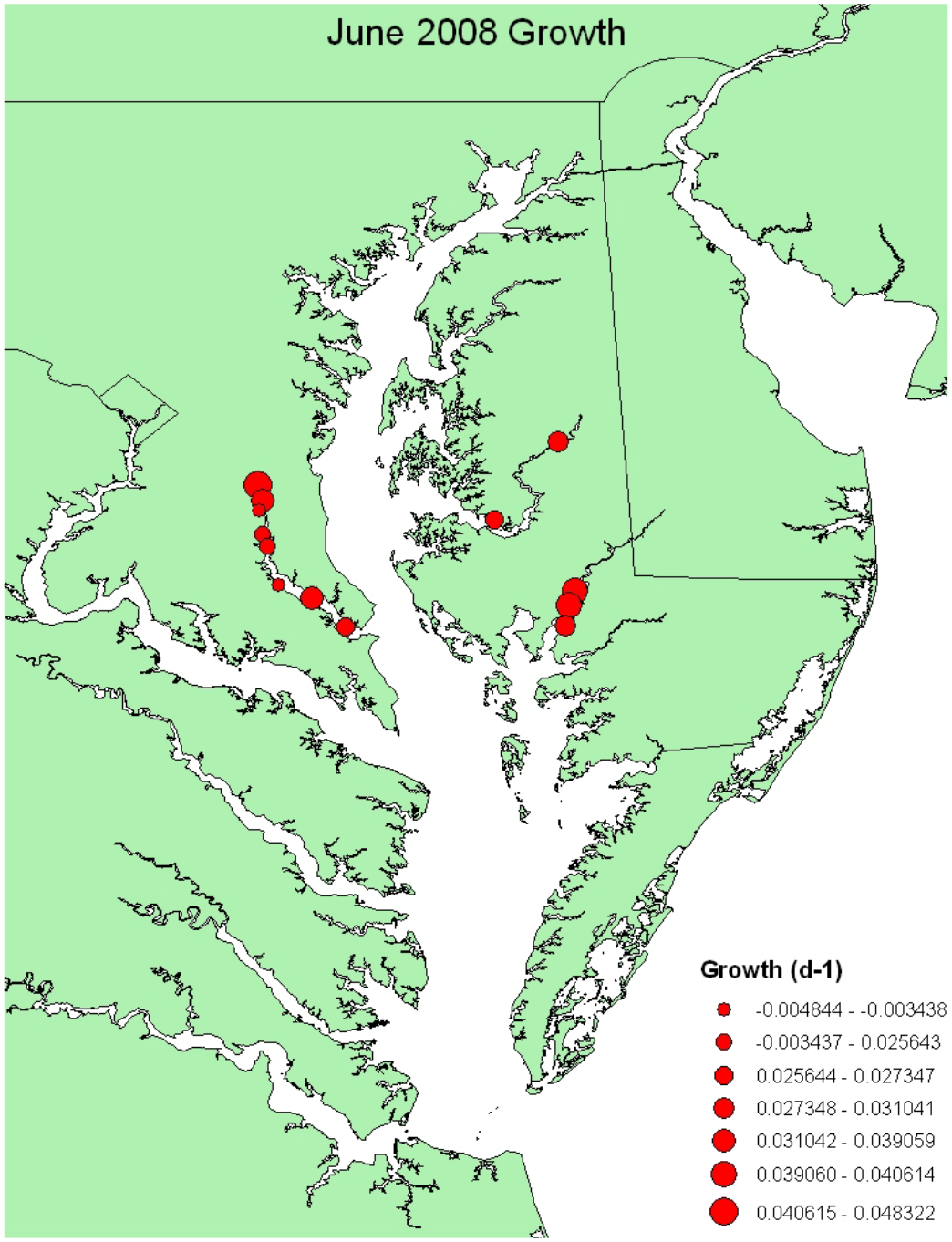

August 2007 Production
Production (g.m-2.d-1)
-0.001698 - -0.000089
-0.000088 - 0.000000
0.000001 - 0.000004
0.000005 - 0.000055
0.000056 - 0.000380
0.000381 - 0.007189

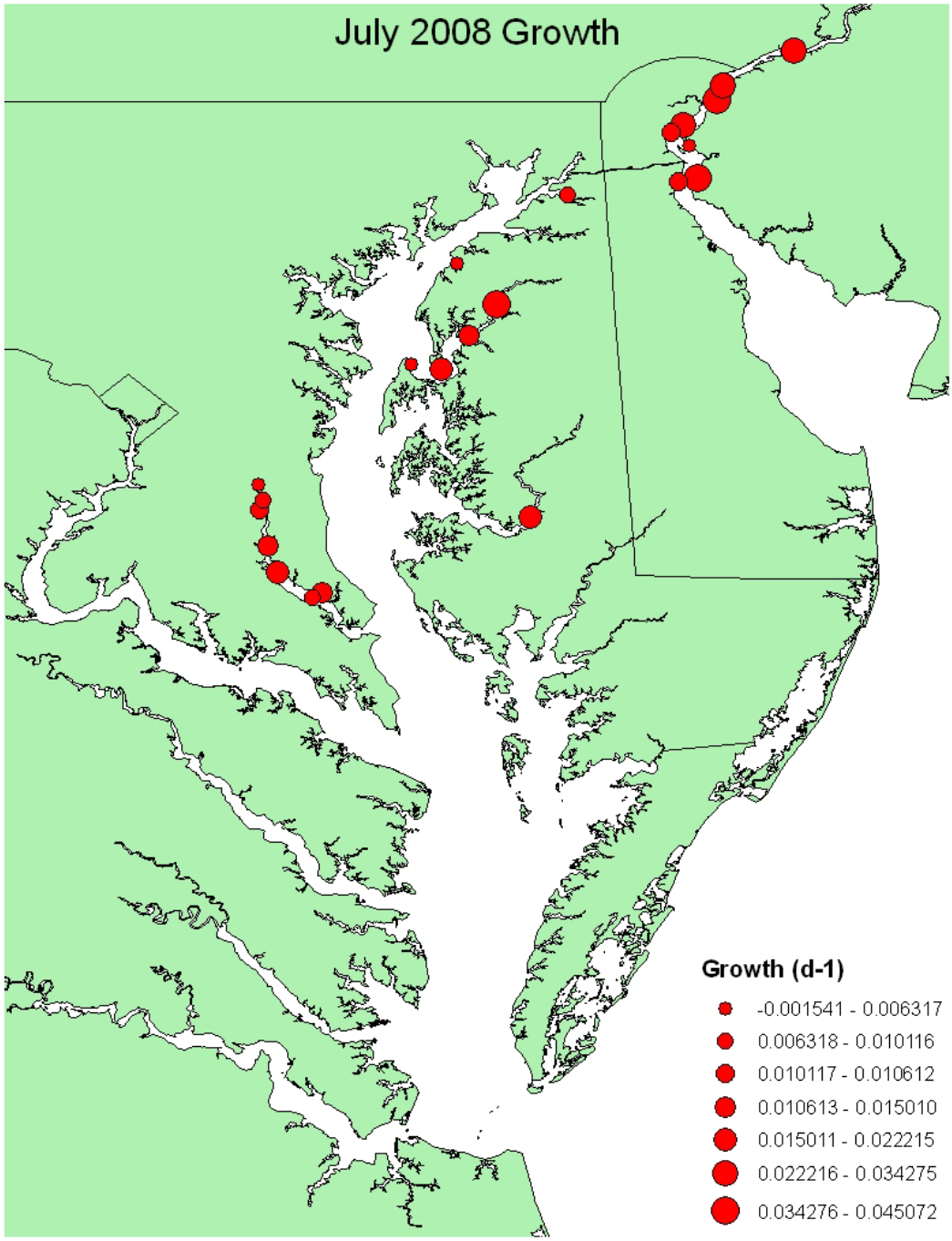

September 2007 Production
Production (g.m-2.d-1)
-0.003969 - -0.000554
-0.000553 - 0.000000

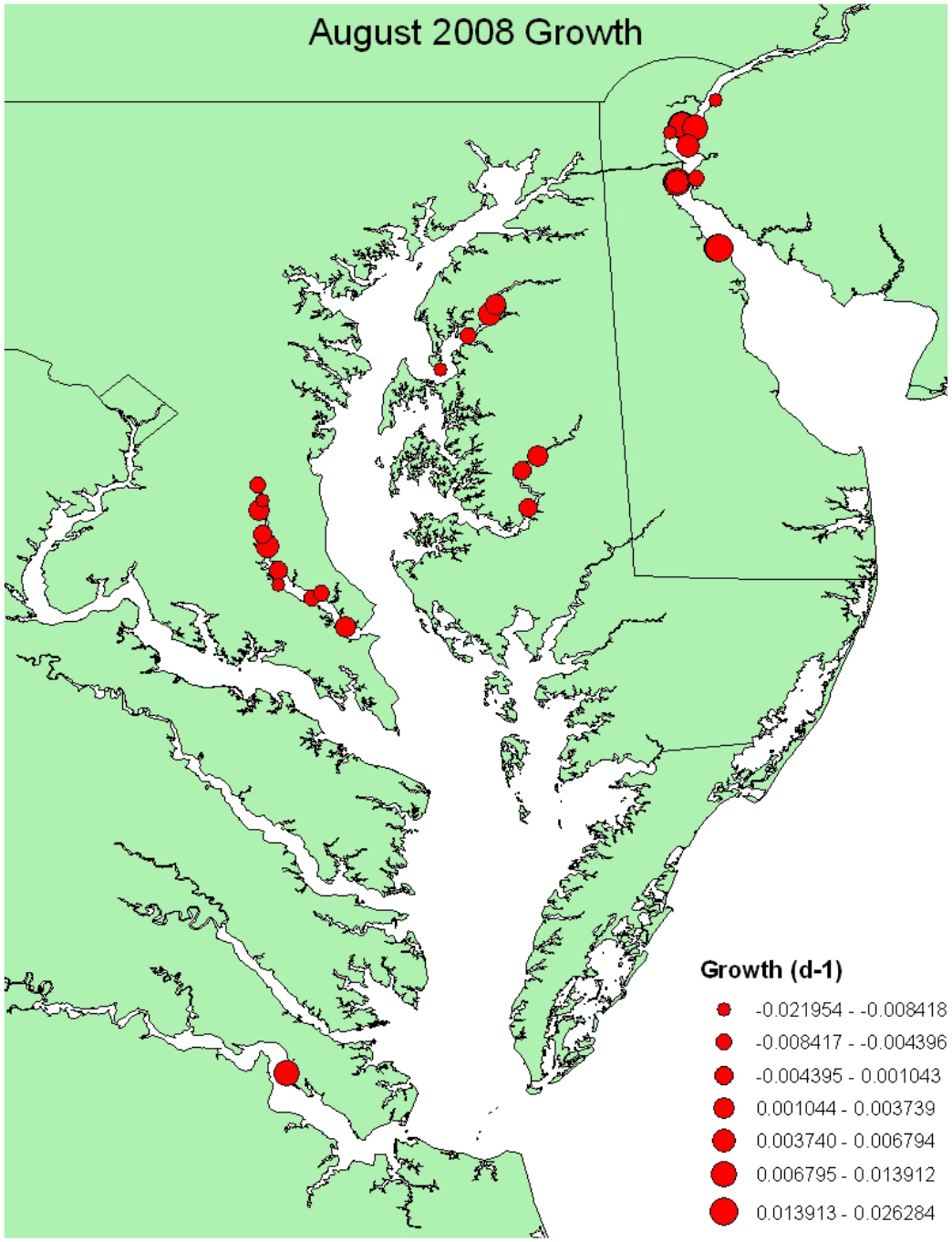

October 2007 Production
Production (g.m-2.d-1)
-0.183261 - -0.000348
-0.000347 - 0.000000

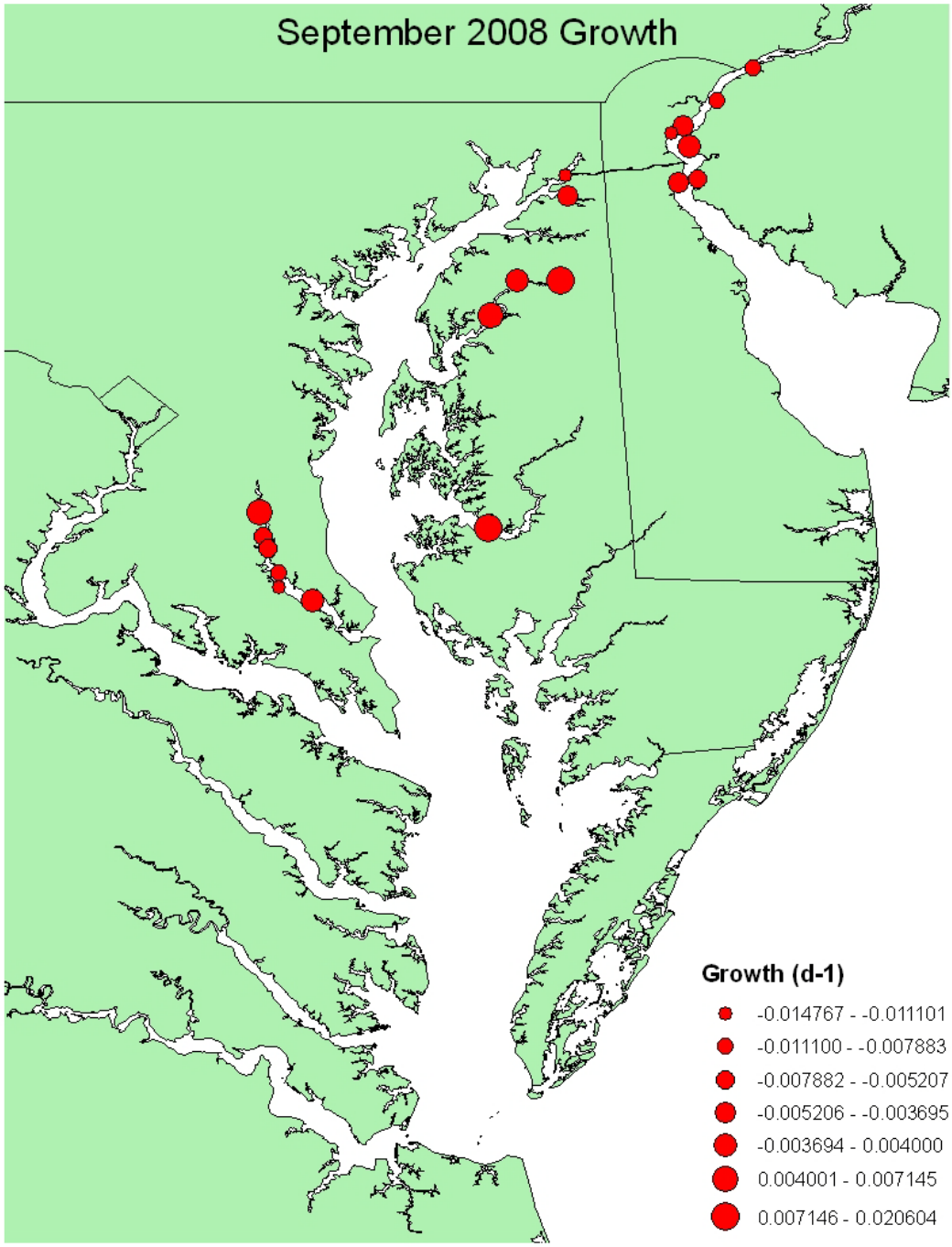
Appendix D:

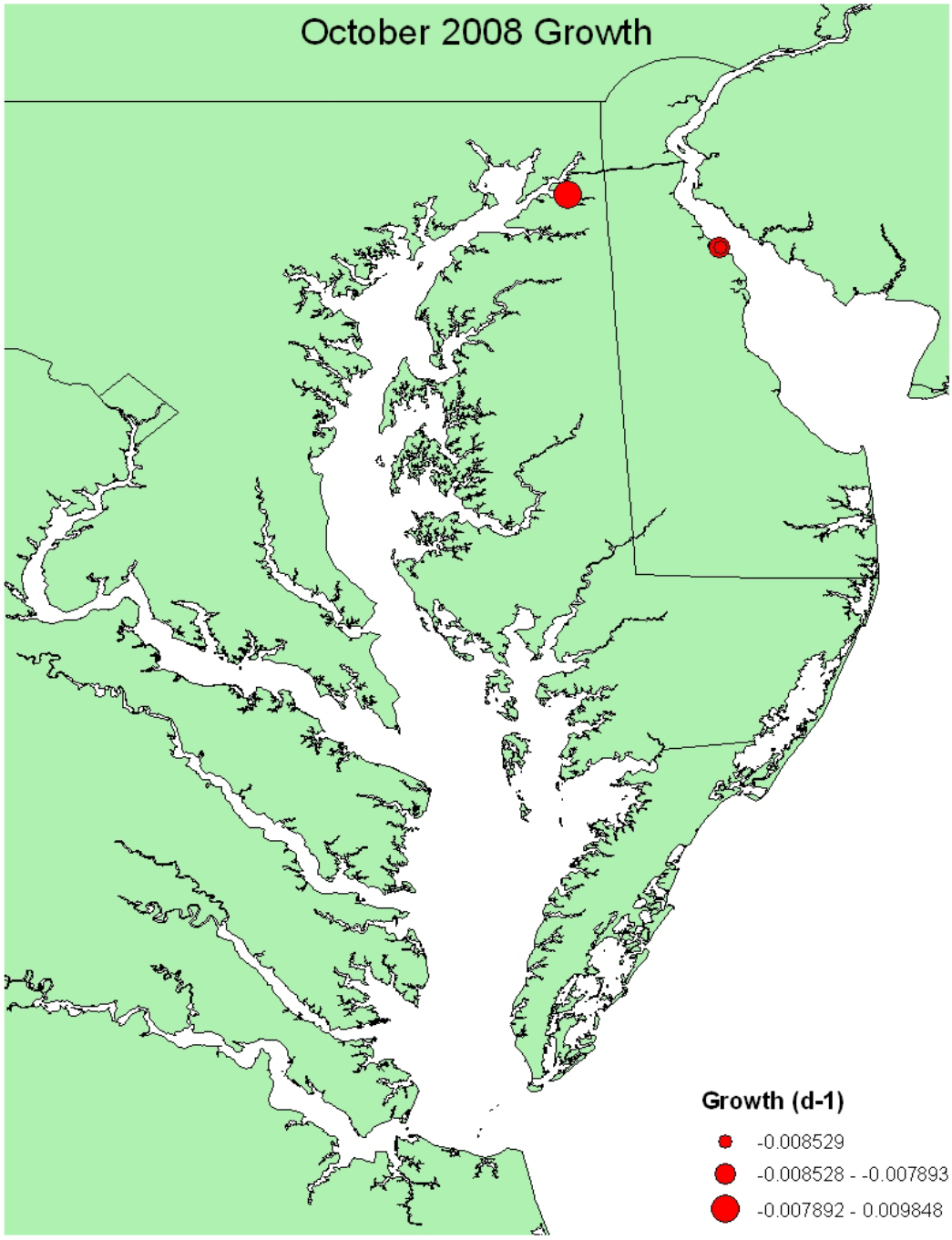
Site-specific monthly instantaneous growth for 2008


June 2008 Growth
Growth (d-1)
-0.004844 - -0.003438
-0.003437 - 0.025643
0.025644 - 0.027347
0.027348 - 0.031041
0.031042 - 0.039059
0.039060 - 0.040614
0.040615 - 0.048322


July 2008 Growth
Growth (d-1)
-0.001541 - 0.006317
0.006318 - 0.010116
0.010117 - 0.010612
0.010613 - 0.015010
0.015011 - 0.022215
0.022216 - 0.034275
0.034276 - 0.045072

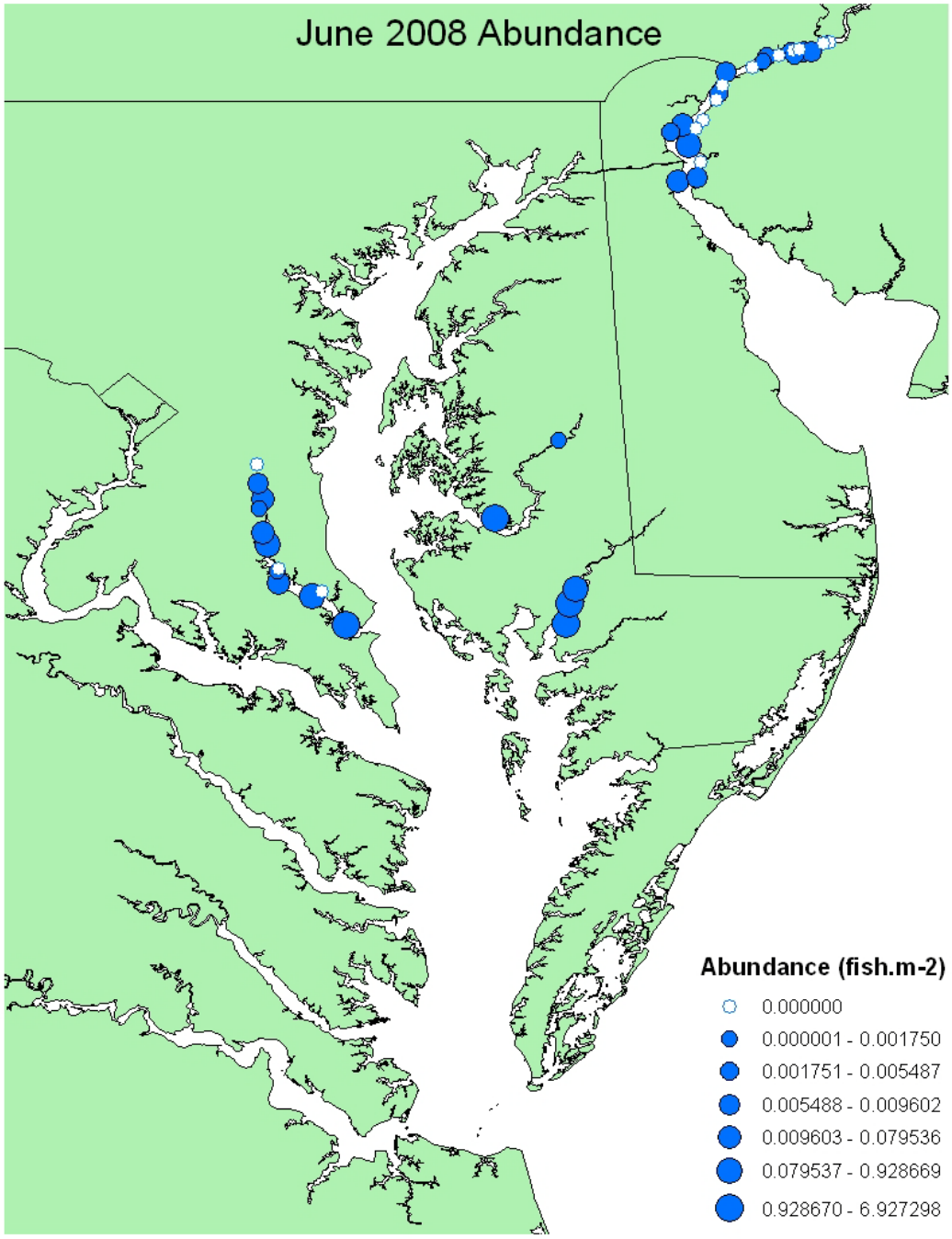

August 2008 Growth
Growth (d-1)
-0.021954 - -0.008418
-0.008417 - -0.004396
-0.004395 - 0.001043
0.001044 - 0.003739
0.003740 - 0.006794
0.006795 - 0.013912
0.013913 - 0.026284

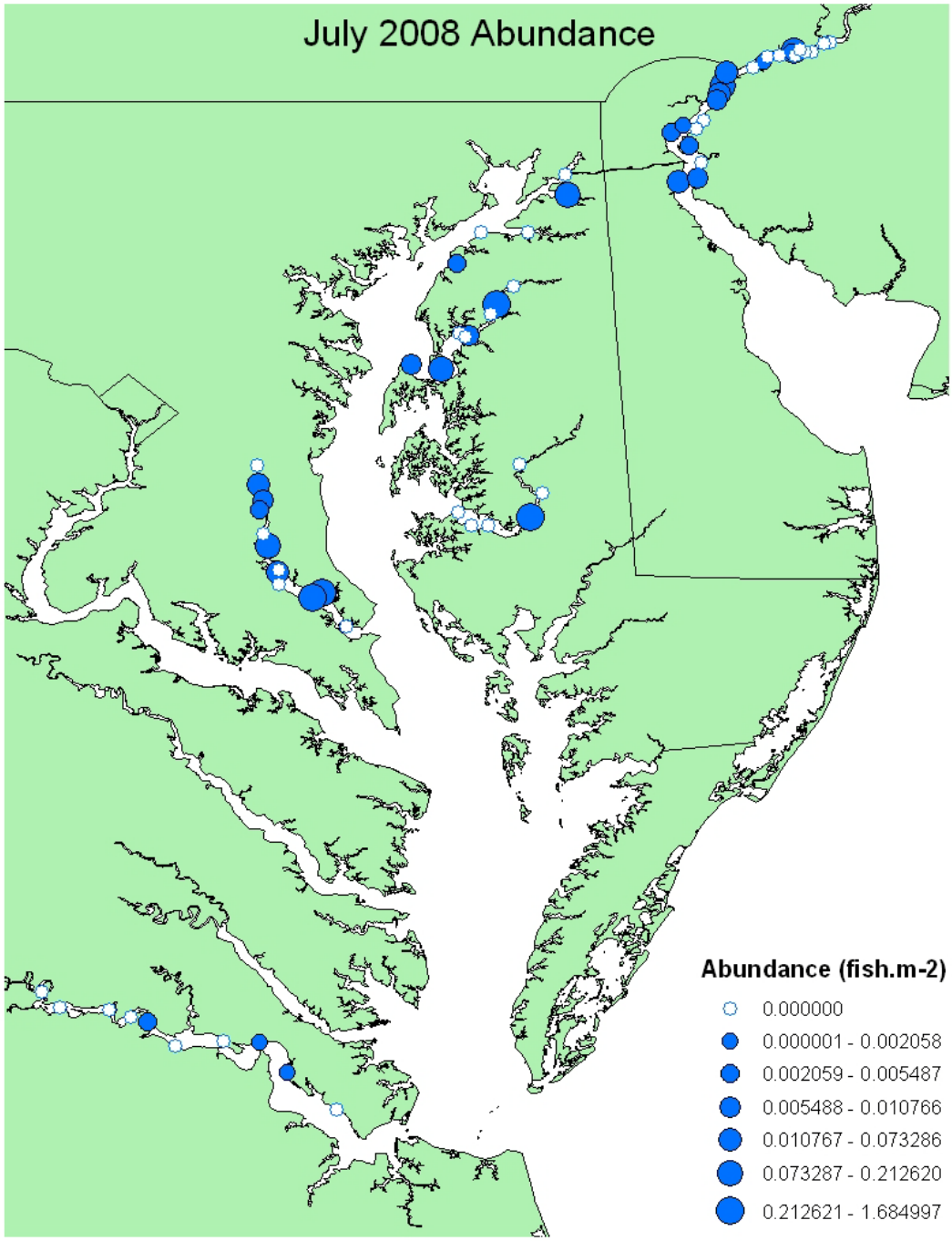

September 2008 Growth
Growth (d-1)
-0.014767 - -0.011101
-0.011100 - -0.007883
-0.007882 - -0.005207
-0.005206 - -0.003695
-0.003694 - 0.004000
0.004001 - 0.007145
0.007146 - 0.020604

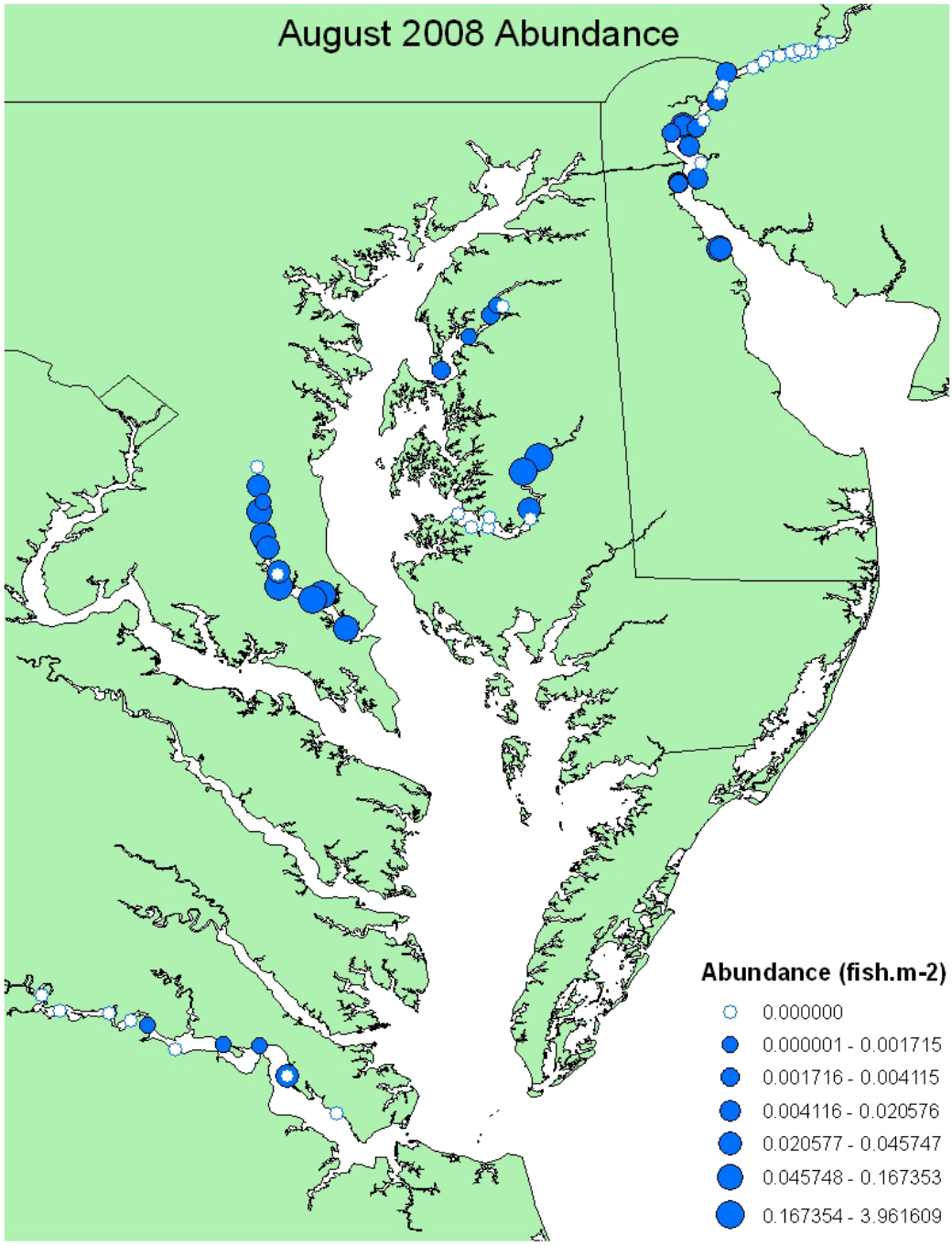

October 2008 Growth
Growth (d-1)
-0.008529
-0.008528 - -0.007893
-0.007892 - 0.009848

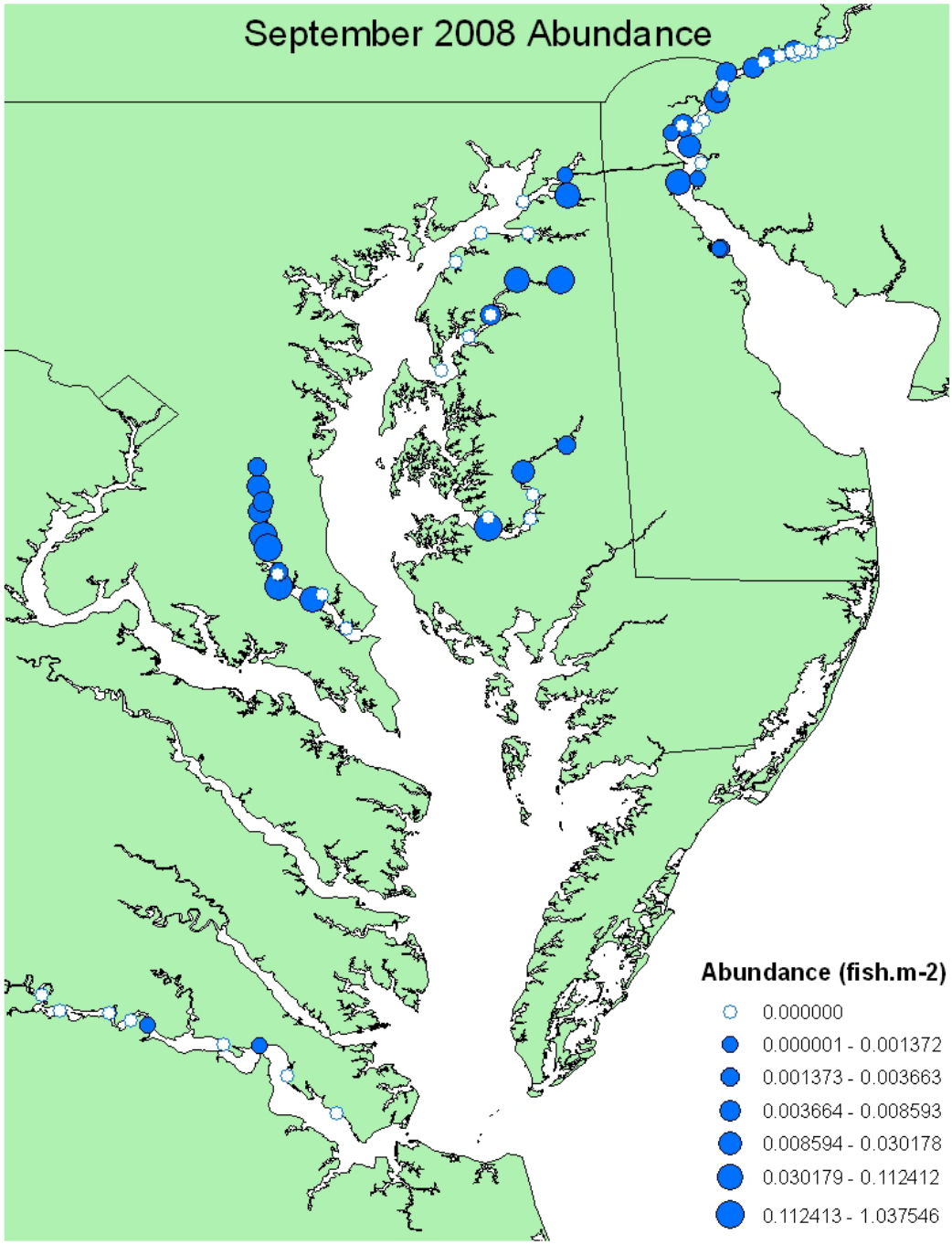
Appendix E:

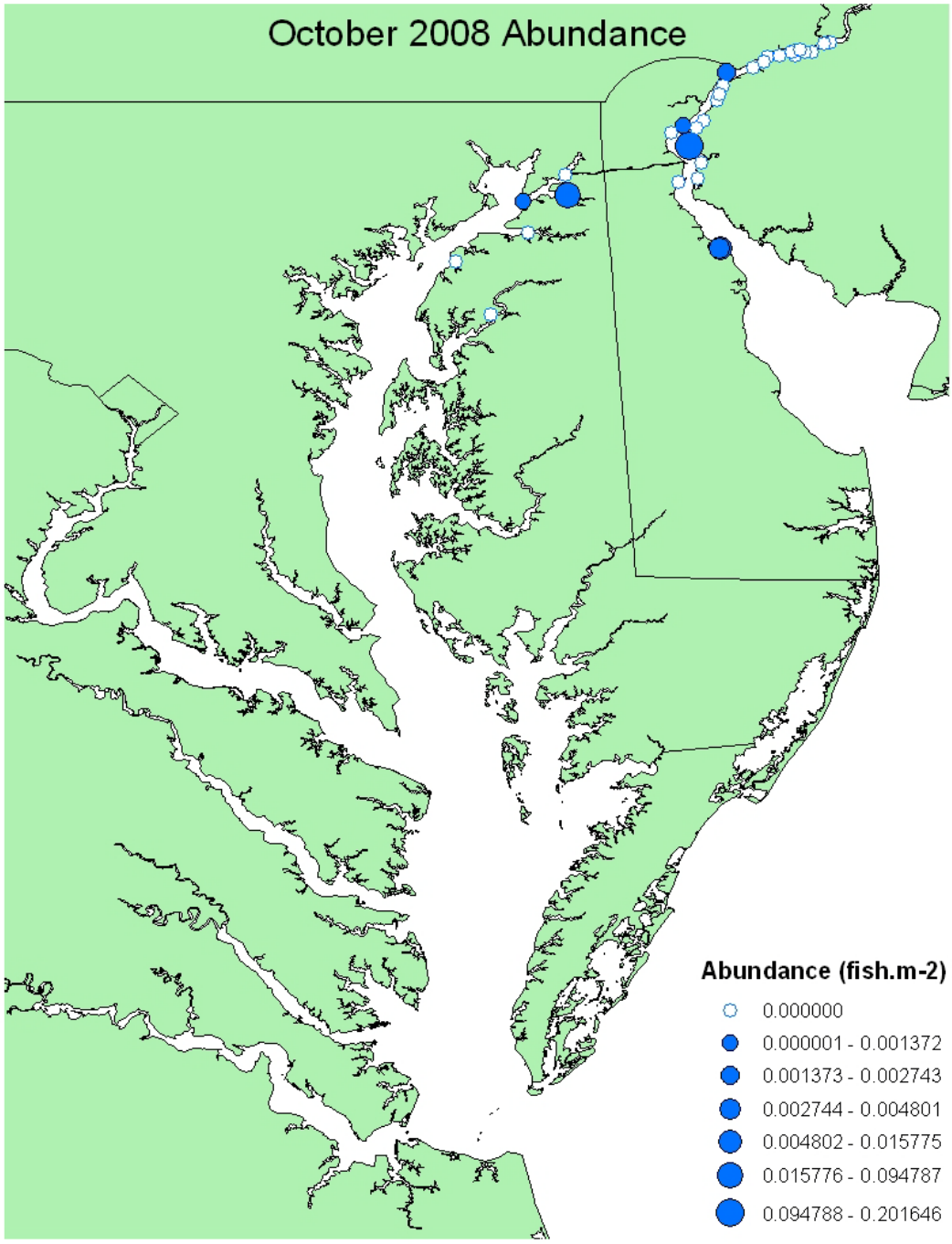
Site-specific monthly abundance for 2008

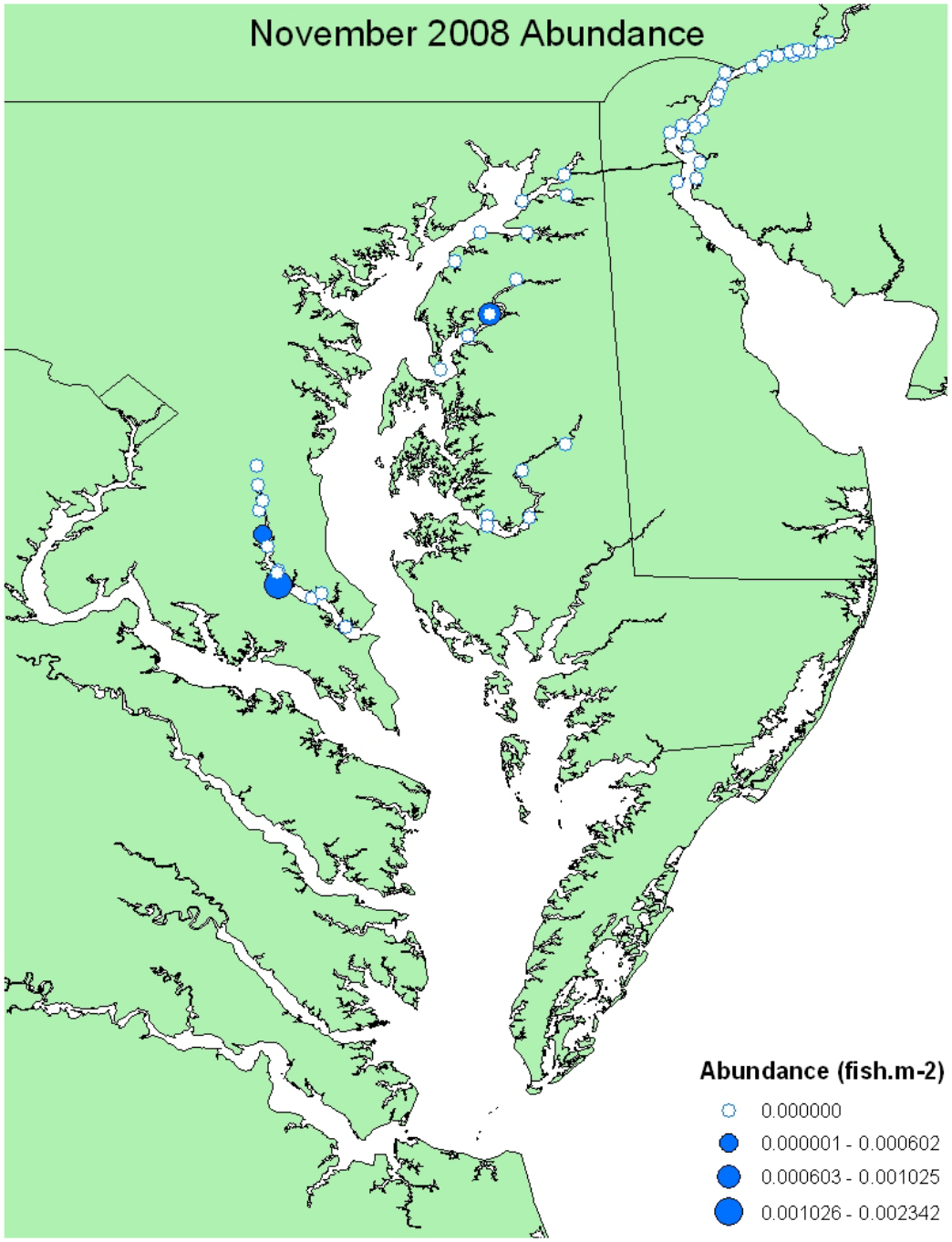

June 2008 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.001750
0.001751 - 0.005487
0.005488 - 0.009602
0.009603 - 0.079536
0.079537 - 0.928669
0.928670 - 6.927298


July 2008 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.002058
0.002059 - 0.005487
0.005488 - 0.010766
0.010767 - 0.073286
0.073287 - 0.212620
0.212621 - 1.684997


August 2008 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.001715
0.001716 - 0.004115
0.004116 - 0.020576
0.020577 - 0.045747
0.045748 - 0.167353
0.167354 - 3.961609

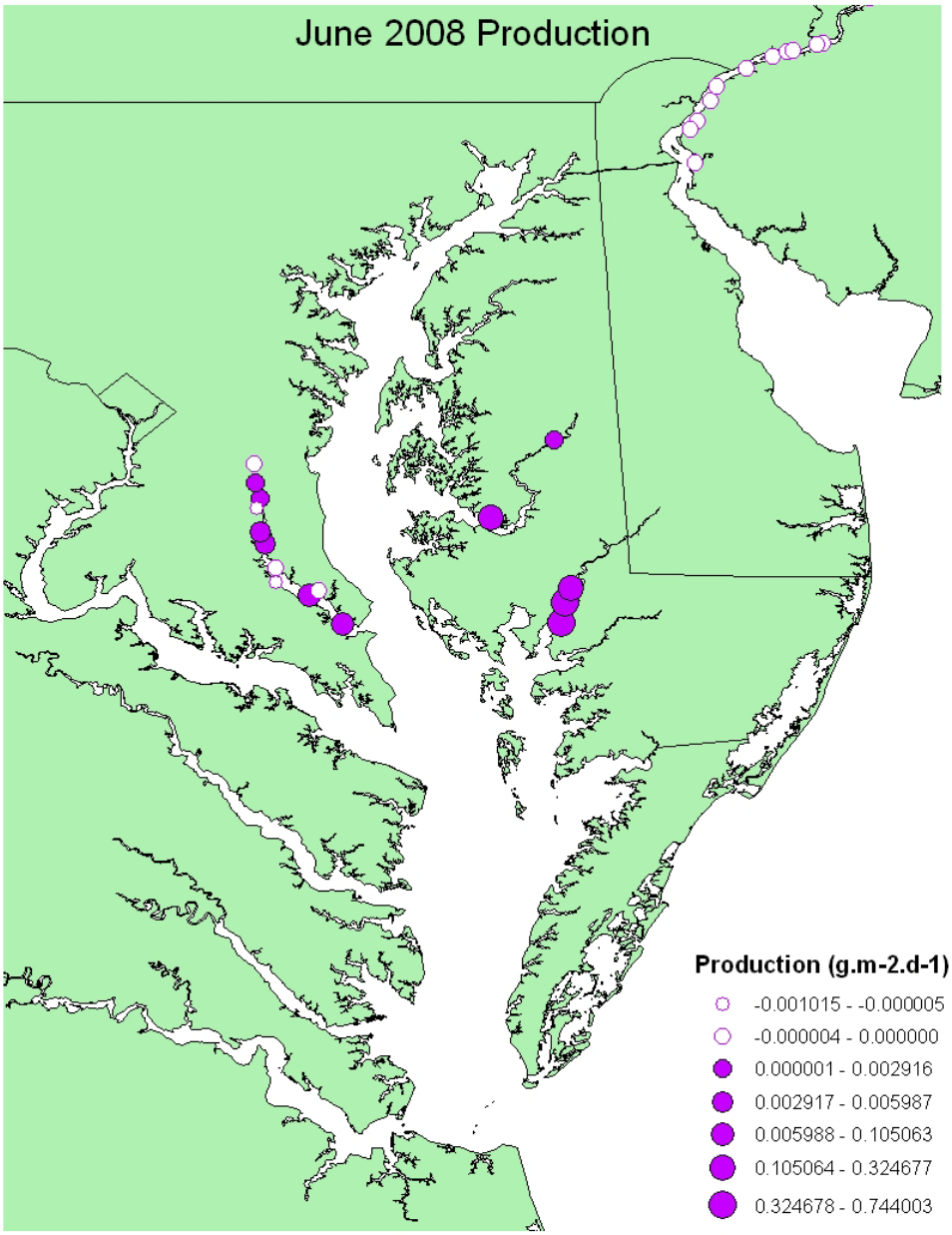

September 2008 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.001372
0.001373 - 0.003663
0.003664 - 0.008593
0.008594 - 0.030178
0.030179 - 0.112412
0.112413 - 1.037546

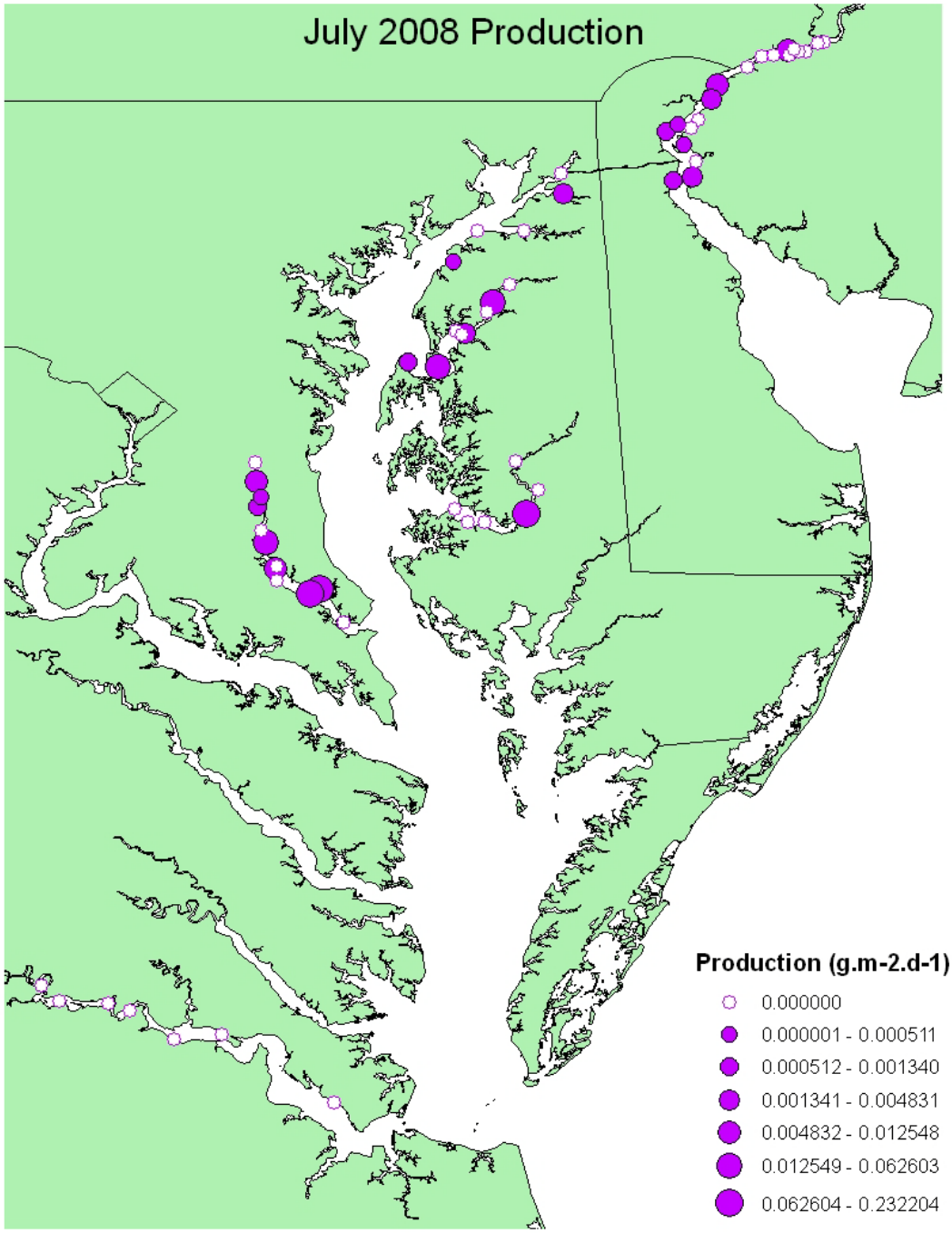

October 2008 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.001372
0.001373 - 0.002743
0.002744 - 0.004801
0.004802 - 0.015775
0.015776 - 0.094787
0.094788 - 0.201646

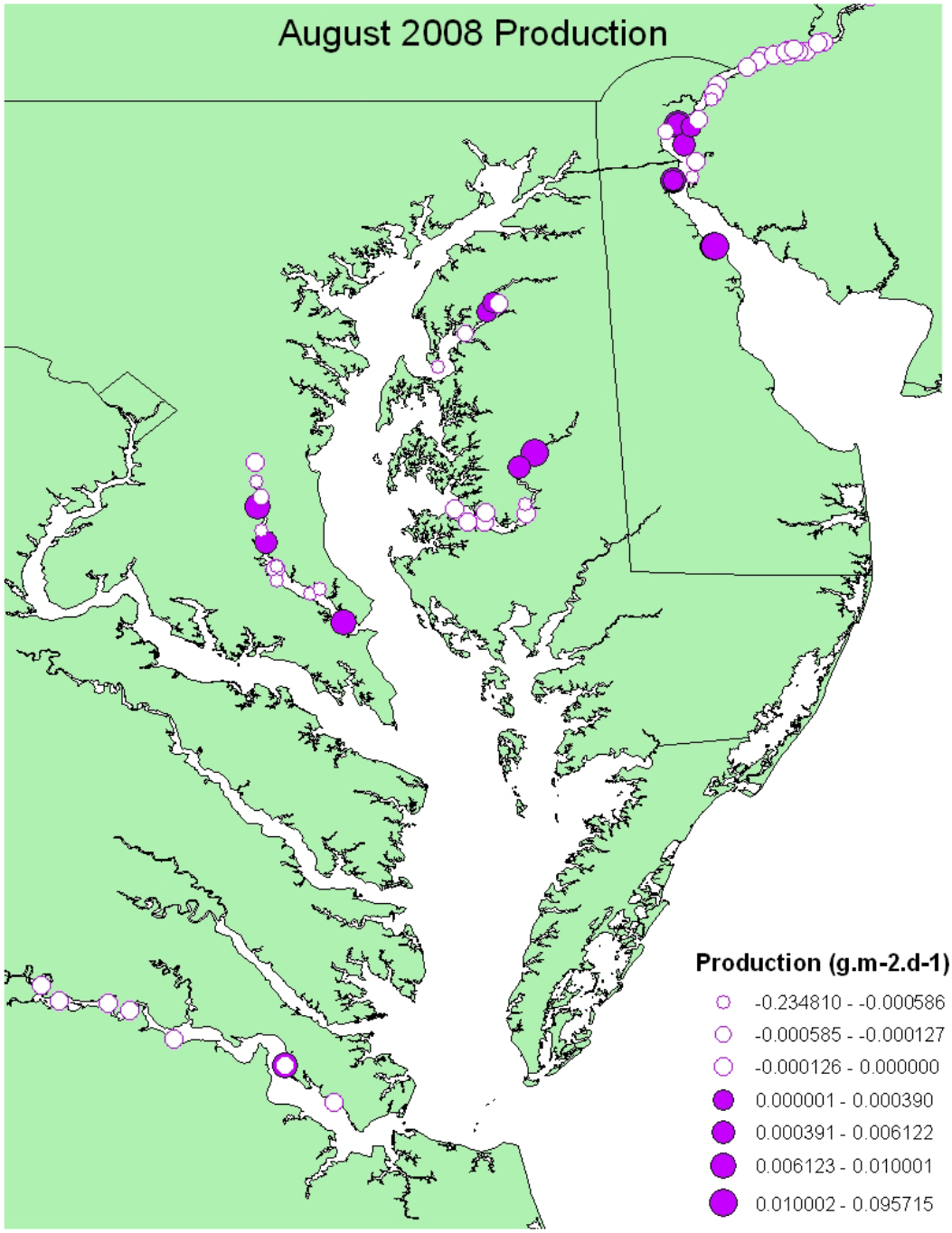

November 2008 Abundance
Abundance (fish.m-2)
0.000000
0.000001 - 0.000602
0.000603 - 0.001025
0.001026 - 0.002342

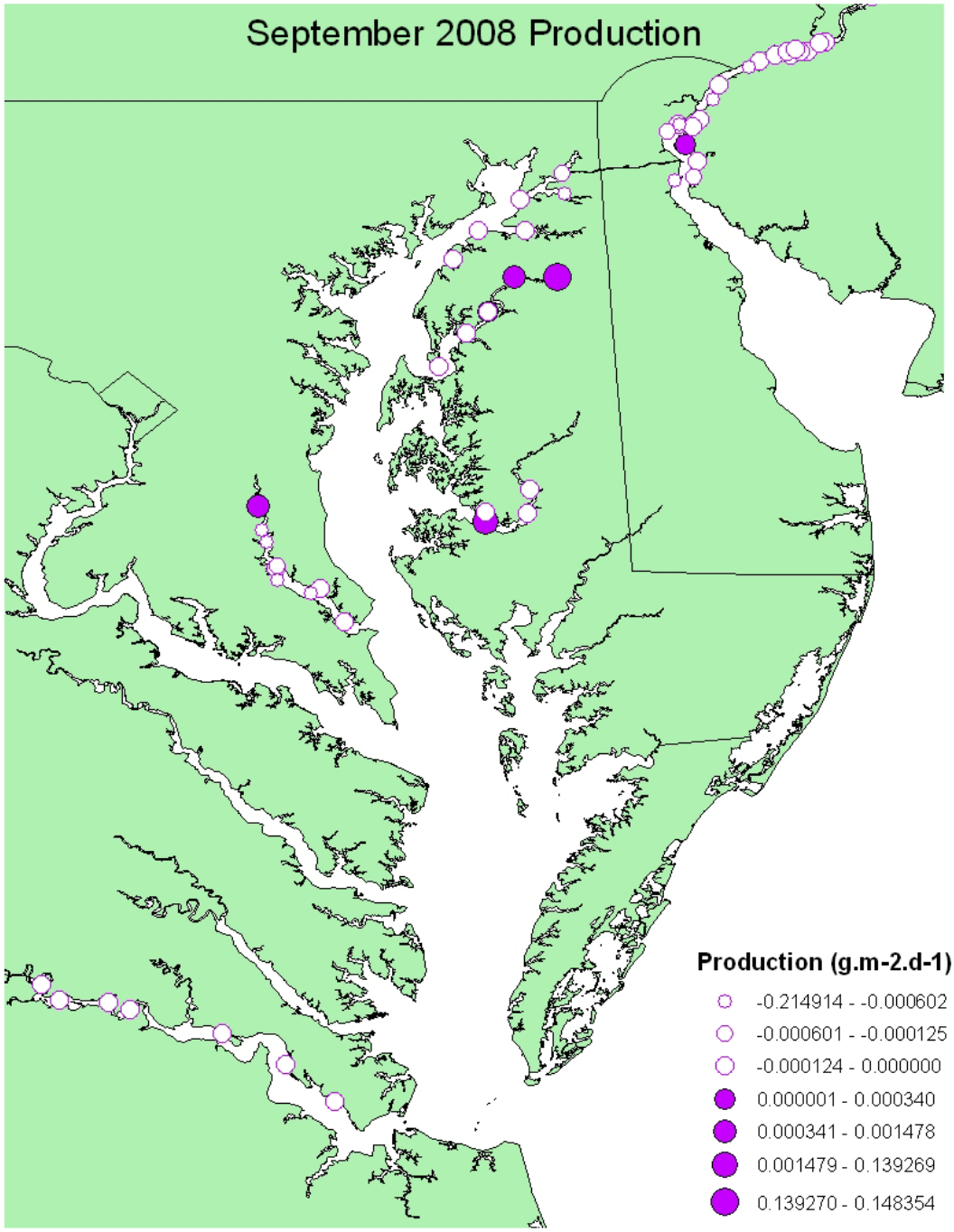
Appendix F:

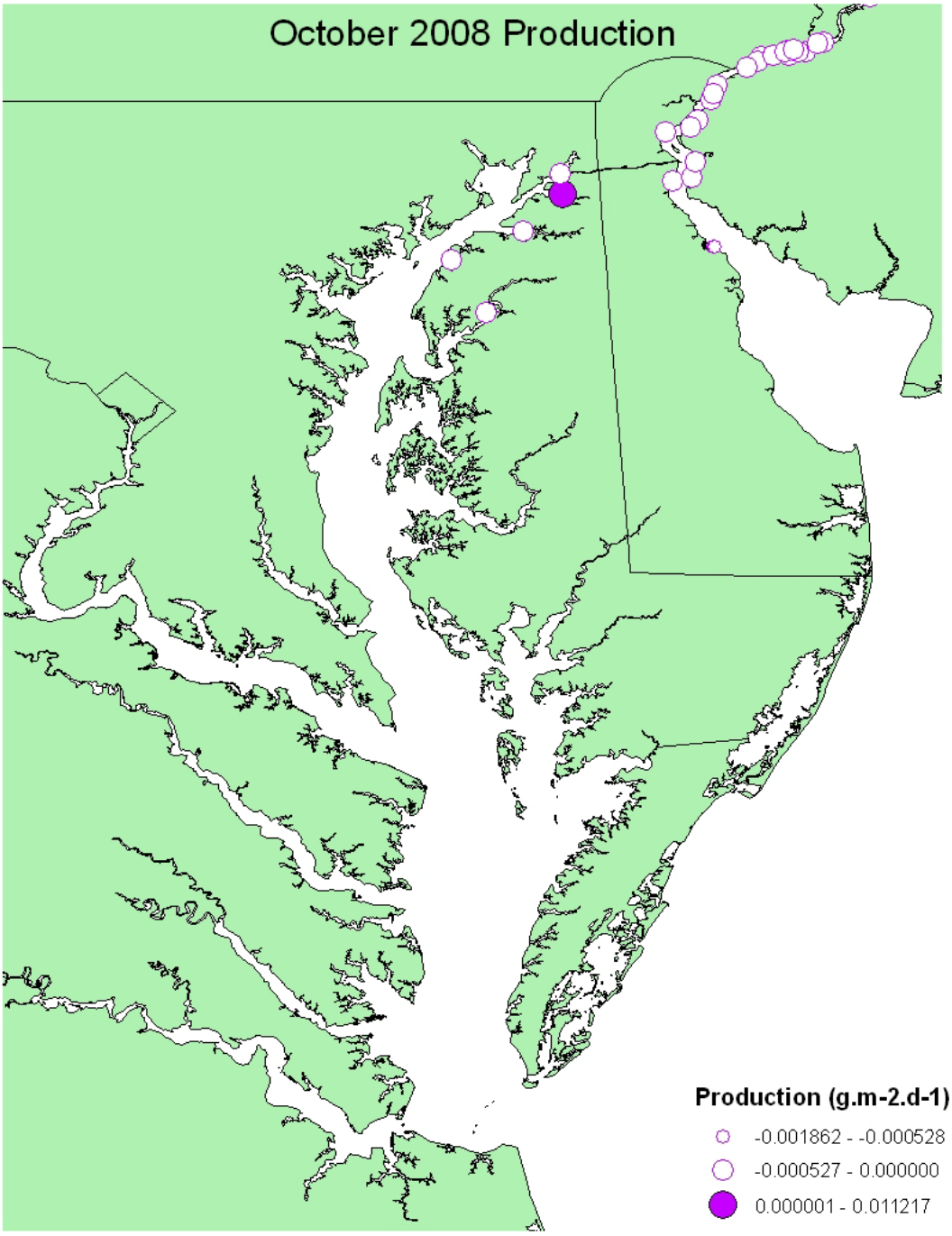
Site-specific monthly production for 2008


June 2008 Production
Production (g.m-2.d-1)
-0.001015 - -0.000005
-0.000004 - 0.000000
0.000001 - 0.002916
0.002917 - 0.005987
0.005988 - 0.105063
0.105064 - 0.324677
0.324678 - 0.744003


July 2008 Production
Production (g.m-2.d-1)
0.000000
0.000001 - 0.000511
0.000512 - 0.001340
0.001341 - 0.004831
0.004832 - 0.012548
0.012549 - 0.062603
0.062604 - 0.232204


August 2008 Production
Production (g.m-2.d-1)
-0.234810 - -0.000586
-0.000585 - -0.000127
-0.000126 - 0.000000
0.000001 - 0.000390
0.000391 - 0.006122
0.006123 - 0.010001
0.010002 - 0.095715


September 2008 Production
Production (g.m-2.d-1)
-0.214914 - -0.000602
-0.000601 - -0.000125
-0.000124 - 0.000000
0.000001 - 0.000340
0.000341 - 0.001478
0.001479 - 0.139269
0.139270 - 0.148354


October 2008 Production
Production (g.m-2.d-1)
-0.001862 - -0.000528
-0.000527 - 0.000000
0.000001 - 0.011217

Bibliography

Able KW, Fahay MP (1998) The first year in the life of estuarine fishes in the Middle Atlantic Bight, Vol. Rutgers University Press, New Brunswick, NJ

Able KW (1999) Measures of juvenile fish habitat quality: examples from a national estuarine research reserve. In: Benaka LR (ed) Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Bethesda, MD, p 134-147

Able KW, Manderson JP, Studholme AL (1999) Habitat quality for shallow water fishes in an urban estuary: the effects of man-made structures on growth. Mar Ecol Prog Ser 187:227-235

Ahrenholz DW, Nelson WR, Epperly SP (1987) Populations and fishery characteristics of Atlantic menhaden, *Brevoortia tyrannus* Fish Bull 85:569-600

Ahrenholz DW (1991) Population biology and life history of the North American menhadens, *Brevoortia* spp. Mar Fish Rev 53: 3–19

Ahrenholz DW, Fitzhugh GR, Rice JA, Nixon SW, Pritchard WC (1995) Confidence of otolith aging through the juvenile stage for Atlantic menhaden, *Brevoortia tyrannus*. Fish Bull 93:209-216

Amara R, Meziane T, Gilliers C, Hermel G, Laffargue P (2007) Growth and condition indices in juvenile sole *Solea solea* measured to assess the quality of essential fish habitat. Mar Ecol Prog Ser 351:201-208

Arndt SKA, Benfey TJ, Cunjak RA (1996) Effect of temporary reductions in feeding on protein synthesis and energy storage of juvenile Atlantic salmon. J Fish Biol 49:257-276

ASMFC (2004) Atlantic Menhaden Workshop Report and Proceedings. Atlantic States Marine Fisheries Commission, Washington, DC

ASMFC (2006) 2006 Stock Assessment for Atlantic menhaden. Atlantic States Marine Fisheries Commission, Washington, DC

Baird D, Ulanowicz RE (1989) The seasonal dynamics of the Chesapeake Bay ecosystem. Ecol Monogr 59:329-364

Bastrop R, Spangenberg R, Jurss K (1991) Biochemical adaptation of juvenile carp (*Cyprinus carpio* L.) to food deprivation. Comp Biochem Physiol A 98:143-149

Beck MW, Heck KL Jr, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern B, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein WP (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51:663-641

Brandt SB, Mason DM (2003) Effect of nutrient loading on Atlantic menhaden (*Brevoortia tyrannus*) growth rate potential in the Patuxent River. Estuaries 26:298-309

Buckley LJ (1979) Relationships between RNA-DNA ratio, prey density, and growth rate in Atlantic cod (*Gadus morhua*) larvae. J Fish Res Bd Can 36:1497-1502

Buckley LJ (1980) Changes in ribonucleic acid, deoxyribonucleic acid, and protein content during ontogenesis in winter flounder, *Pseudopleuronectes americanus*, and effect of starvation. Fish Bull 77:703-708

Buckley LJ (1982) Effects of temperature on growth and biochemical composition of larval winter flounder *Pseudopleuronectes americanus*. Mar Ecol Prog Ser 8:181-186

Buckley LJ (1984) RNA-DNA ratio: an index of larval fish growth in the sea. Mar Biol 80:291-298

Buckley LJ, Turner SI, Halavik TA, Smigielski AS, Drew SM, Laurence GC (1984) Effects of temperature and food availability on growth, survival, and RNA-DNA ratio of larval sand lance (*Ammodytes americanus*). Mar Ecol Prog Ser 15:91-97

Buckley L, Caldarone E, Ong TL (1999) RNA/DNA ratio and other nucleic acid-based indicators for growth and condition of marine fishes. Hydrobiologia 401:265-277

Bulow FJ (1970) RNA-DNA ratios as indicators of recent growth rates of a fish. J Fish Res Bd Can 27: 2343-2349

Bulow FJ (1987) RNA-DNA ratios as indicators of growth in fish: a review. In: Summerfelt RC, Hall GE (eds) The age and growth of fish. Iowa State University Press, Ames, IA, p 45-64

Caldarone EM, Wagner M, St. Onge-Burns J, Buckley LJ (2001) Protocol and guide

for estimating nucleic acids in larval fish using a fluorescence microplate reader. Report No. Northeast Fish. Sci. Cent. Ref. Doc. 01-11, National Marine Fisheries Service, Woods Hole, MA

Caldarone EM, St. Onge-Burns JM, Buckley LJ (2003) Relationship of RNA/DNA ratio and temperature to growth in larvae of Atlantic cod *Gadus morhua*. Mar Ecol Prog Ser 262:229–240

Caldarone EM (2005) Estimating growth in haddock larvae *Melanogrammus aeglefinus* from RNA:DNA ratios and water temperature. Mar Ecol Prog Ser 293: 241-252

Caldarone EM, Clemmesen CM, Berdalet E, Miller TJ, Folkvord A, Holt GJ, Olivar MP, Suthers IM (2006) Intercalibration of four spectrofluorometric protocols for measuring RNA/DNA ratios in larval and juvenile fish. Limnol Oceanogr Methods 4:153-163

Canino MF (1994) Effects of temperature and food availability on growth and RNA/DNA ratios of walleye pollock *Theragra chalcogramma* (Pallas) eggs and larvae. J Exp Mar Biol Ecol 175:1-16

Catalan IA, Berdalet E, Olivar MP, Roldan C (2007) Response of muscle-based biochemical condition indices to short-term variations in food availability in post-flexion reared sea bass *Dicentrarchus labrax* (L.) larvae. J Fish Biol 70:391-405

Checkley DM (1984) Relation of growth to ingestion for larvae of Atlantic herring *Clupea harengus* and other fish. Mar Ecol Prog Ser 18:215-224

Checkley DM Jr, Raman S, Maillet GL, Mason KM (1988) Winter storm effects on the spawning and larval drift of a pelagic fish. Nature 335:346-348

Chung KS, De B MIS, Donaldson EM (1998) RNA-DNA ratio as physiological condition of rainbow trout fry fasted and fed. Ital J Zool 65:517-519

Clemmesen CM (1987) Laboratory studies on RNA/DNA ratios of starved and fed herring (*Clupea harengus*) and turbot (*Scophthalmus maximus*) larvae. J Cons 43:122-128

Clemmesen C (1993) Improvement in the fluorimetric determination of the RNA and DNA content of individual marine fish larvae. Mar Ecol Prog Ser 100:177-183

Clemmesen C (1994) The effect of food availability, age or size on the RNA/DNA ratio of individually measured herring larvae: laboratory calibration. Mar Biol 118:377-382

Clemmesen C, Doan T (1996) Does otolith structure reflect the nutritional condition of a fish larva? Comparison of otolith structure and biochemical (RNA/DNA ratio) determined on cod larvae. Mar Ecol Prog Ser 138:33-39

Conover DO, Schultz ET (1997) Natural selection and the evolution of growth rate in the early life history: what are the trade-offs? In: Chambers RC, Trippel EA (eds) Early life history and recruitment in fish populations. Chapman & Hall, London, p 305-332

Courrat A, Lobry J, Nicolas D, Laffargue P, Amara R, Lepage M, Girardin M, Le Pape O (2009) Anthropogenic disturbance on nursery function of estuarine areas for marine species. Est Coast Shelf Sci 81:179-190

Dortch Q, Roberts TL, Clayton JR, Ahmed SI (1983) RNA:DNA ratios and DNA concentrations as indicators of growth rate and biomass in planktonic marine organisms. Mar Ecol Prog Ser 13:61-71

Duffy-Anderson JT, Able KW (1999) Effects of municipal piers on the growth of juvenile fishes in the Hudson River estuary: a study across a pier edge. Mar Biol 133:409-418

Durbin AG, Durbin EG (1975) Grazing rates of Atlantic menhaden *Brevoortia tyrannus* as a function of particle size and concentration. Mar Biol 33:265-277

Durbin EG, Durbin AG (1983) Energy and nitrogen budgets for the Atlantic menhaden, *Brevoortia tyrannus* (Pisces, Clupeidae), a filter-feeding planktivore. Fish Bull 81:177-199

Durbin AG, Durbin EG (1998) Effects of menhaden predation on plankton populations in Narragansett Bay, Rhode Island. Estuaries 21:449-465

Edgar GJ, Shaw C (1995) The production and trophic ecology of shallow-water fish assemblages in southern Australia, I: species richness, size structure and production of fishes in Western Port, Victoria. J Exp Mar Biol Ecol 194:53–81

Ferron A, Leggett WC (1994) An appraisal of condition measures for marine fish larvae. Adv Mar Biol 30:217–303

Friedland KD, Ahrenholz DW, Guthrie JF (1989) Influence of plankton on distribution patterns of the filter-feeder *Brevoortia tyrannus* (Pisces: Clupeidae). Mar Ecol Prog Ser 54:1-11

Friedland KD, Ahrenholz DW, Guthrie JF (1996) Formation and seasonal evolution

of Atlantic menhaden juvenile nurseries in coastal estuaries. Estuaries 19:105-114

Friedland KD, Ahrenholz DW, Smith JW, Manning M, Ryan J (2006) Sieving functional morphology of the gill raker feeding apparatus of Atlantic menhaden. J Exp Zool Part A-Ecol Genet Physiol 305A:974-985

Fry FEJ (1971) The effect of environmental factors on the physiology of fish. In: Hoar WS, Randall DJ (eds) Fish physiology, Vol VI. Academic Press, New York, NY, p 1-98

Fodrie FJ, Mendoza G (2006) Availability, usage and expected contribution of potential nursery habitats for the California halibut. Est Coast Shelf Sci 68:149-164

Folkvord A (2005) Comparison of size-at-age of larval Atlantic cod (*Gadus morhua*) from different populations based on size- and temperature-dependent growth models. Can J Fish Aquat Sci 62:1037-1052

Fonseca VF, Vinagre C, Cabral HN (2006) Growth variability of juvenile soles *Solea solea* and *Solea senegalensis*, and comparison with RNA:DNA ratios in the Tagus estuary, Portugal. J Fish Biol 68:1551-1562

Foster AR, Houlihan DF, Hall SJ (1993) Effects of nutritional regime on correlates of growth rate in juvenile Atlantic cod (*Gadus morhua*): comparison of morphological and biochemical measurements. Can J Fish Aquat Sci 50:502-512

Fukuda M, Sako H, Shigeta T, Shibata R (2001) Relationship between growth and biochemical indices in laboratory-reared juvenile Japanese flounder (*Paralichthys olivaceus*), and its application to wild fish. Mar Biol 138:47-55

Gillanders BM, Able KW, Brown JA, Eggleston DB, Sheridan PF (2003) Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Mar Ecol Prog Ser 247:281-295

Gilliers C, Amara R, Bergeron JP, Le Pape O (2004) Comparison of growth and condition indices of juvenile flatfish in different coastal nursery grounds. Environ Biol Fish 71:189-198

Gilliers C, Le Pape O, Desaunay Y, Morin J, Guerault D, Amara R (2006) Are growth and density quantitative indicators of essential fish habitat quality? An application to the common sole *Solea solea* nursery grounds. Est Coast Shelf Sci 69:96-106

Glass LA, Rooker JR, Kraus RT, Holt GJ (2008) Distribution, condition, and growth of newly settled southern flounder (*Paralichthys lethostigma*) in the Galveston Bay Estuary, TX. J Sea Res 59:259-268

Goolish EM, Barron MG, Adelman IR (1984) Thermoacclimatory response of nucleic acid and protein content of carp muscle tissue: influence of growth rate and relationship to glycine uptake by scales. Can J Zool 62:2164-2170

Graeb BDS, Dettmers JM, Wahl DH, Caceres CE (2004) Fish size and prey availability affect growth, survival, prey selection, and foraging behavior of larval yellow perch. Trans Am Fish Soc 133:504-514

Grant SCH, Tonn WM (2002) Effects of nutrient enrichment on recruitment of age-0 fathead minnows (*Pimephales promelas*): potential impacts of environmental change on the Boreal Plains. Can J Fish Aquat Sci 59:759-767

Gwak WS, Tanaka M (2001) Developmental change in RNA:DNA ratios of fed and starved laboratory-reared Japanese flounder larvae and juveniles, and its application to assessment of nutritional condition for wild fish. J Fish Biol 59:902-915

Hare JA, Thorrold S, Walsh H, Reiss C, Valle-Levinson A, Jones C (2005) Biophysical mechanisms of larval fish ingress into Chesapeake Bay. Mar Ecol Prog Ser 303:295:310

Hartman KJ, Brandt SB (1995) Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: applications of bioenergetics models. Can J Fish Aquat Sci 52:1667-1687

Hartman KJ (2003) Population-level consumption by Atlantic coastal striped bass and the influence of population recovery upon prey communities. Fish Manage Ecol. 10:281-288

Henshaw EC, Hirsch CA, Morton BE, Hiatt HH (1971) Control of protein synthesis in mammalian tissues through changes in ribosome activity. J Biol Chem 246:436-446

Heyer CJ, Miller TJ, Binkowski FP, Caldarone EM, Rice JA (2001) Maternal effects as a recruitment mechanism in Lake Michigan yellow perch (*Perca flavescens*). Can J Fish Aquat Sci 58:1477-1487

Hettler WF (1976) Influence of temperature and salinity on routine metabolic rate and growth of young Atlantic menhaden. J Fish Biol 8:55-65

Hettler WF (1981) Spawning and rearing Atlantic menhaden. Prog Fish-Cult 43:80-84

Hewitt AH, Machut LS, Fabrizio MC (2008) Estimation of juvenile striped bass relative abundance in the Virginia portion of Chesapeake Bay, January 2007-

December 2007. Annual Progress Report to Virginia Marine Resources Commission, 28 p

Higham JR, Nicholson WR (1964) Sexual maturation and spawning of Atlantic menhaden. Fish Bull 63:255–271

Hildebrand SF (1963) Family Clupeidae. In: Fish of the western North Atlantic. Mem Sears Found Mar Res 1:257-451, Yale Univ, New Haven, Conn

Hoss DE, Thayer GW (1993) The importance of habitat to the early life history of estuarine dependent fishes. Am Fish Soc Symp 14:147-158

Houde ED (1987) Fish early life dynamics and recruitment variability. Am Fish Soc Symp 2:17-29

Houde ED, Zastrow CE (1993) Ecosystem- and taxon-specific dynamic and energetics properties of larval fish assemblages: larval fish assemblages and oceanic boundaries. Bull Mar Sci 53:290-335.

Houlihan DF (1991) Protein turnover in ectotherms and its relationships to energetics. In: Gilles R (ed) Advances in Comparative and Environmental Physiology vol 7. Springer-Verlag, Berlin, p 1-43

Huss M, Byström P, Strand Å, Eriksson LO, Persson L (2008) Influence of growth history on the accumulation of energy reserves and winter mortality in young fish. Can J Fish Aquat Sci 65:2149-2156.

Jeffries HP (1975) Diets of juvenile Atlantic menhaden (*Brevoortia tyrannus*) in 3 estuarine habitats as determined from fatty-acid composition of gut contents. J Fish Res Board Can 32:587-592

Johnson MW, Rooker JR, Gatlin DM, Holt GJ (2002) Effects of variable ration levels on direct and indirect measures of growth in juvenile red drum (*Sciaenops ocellatus*). J Exp Mar Biol Ecol 274:141-157

Judy MH, Lewis RM (1983) Distribution of eggs and larvae of Atlantic menhaden *Brevoortia tyrannus*, along the Atlantic coast of the United States. US Dep Commer, NOAA Tech Rep NMFS SSRF 774, 23 p

June FC, Chamberlain JL (1959) The role of the estuary in the life history and biology of Atlantic menhaden. Proc Gulf Caribb Fish Inst 11th Annu Sess, p. 41-45.

June FC, Carlson FT (1971) Food of young Atlantic menhaden, *Brevoortia tyrannus*, in relation to metamorphosis. Fish Bull 68: 493–512

Jurss K, Bittorf T,Vokler T (1986) Influence of salinity and food deprivation on growth, RNA/DNA ratio and certain enzyme activities in rainbow trout (*Salmo gairdneri* Richardson). Comp Biochem Physiol B 83:425-433

Keller AA, Doering PH, Kelly SP, Sullivan BK (1990) Growth of juvenile Atlantic menhaden, *Brevoortia tyrannus* (Pisces, Clupeidae) in MERL mesocosms – effects of eutrophication. Limnol Oceanogr 35:109-122

Kellison GT, Eggleston DB, Taylor JC, Burke JS (2003) An assessment of biases associated with caging, tethering, and trawl sampling of summer flounder (*Paralichthys dentatus*). Estuaries 26:64-71

Kiørboe T, Munk P, Richardson K (1987) Respiration and growth of larval herring *Clupea harengus*: relation between specific dynamic action and growth efficiency. Mar Ecol Prog Ser 40: 1-10

Kimura R, Watanabe Y, Zenitani H (2000) Nutritional condition of first-feeding larvae of Japanese sardine in the coastal and oceanic waters along the Kuroshio Current. ICES J Mar Sci 57:240-248

Kono N, Tsukamoto Y, Zenitani H (2003) RNA:DNA ratio for diagnosis of the nutritional condition of Japanese anchovy *Engraulis japonicus* larvae during the first-feeding stage. Fish Sci 69:1096-1102

Kraus RT, Secor DH (2005) Application of the nursery-role hypothesis to an estuarine fish. Mar Ecol Prog Ser 291:301-305

Kroger RL, Guthrie JF, Judy MH (1974) Growth and first annulus formation of tagged and untagged Atlantic menhaden. Trans Am Fish Soc 103:292–296

Le Pape O, Holley J, Guérault D, Désaunay Y (2003) Quality of coastal and estuarine essential fish habitats: estimations based on the size of juvenile common sole (*Solea soloea* L). Est Coast Shelf Sci 58:793-803

Lewis RM, Hettler WF (1968) Effect of temperature and salinity on survival of young Atlantic menhaden *Brevoortia tyrannus*. Trans Am Fish Soc 97:344-349

Lewis RM, Wilkens PH, Gordy HR (1972) A description of young Atlantic menhaden, *Brevoortia tyrannus,* in the White Oak River Estuary, North Carolina. Fish Bull 70:115-118

Lewis VP, Peters DS (1984) Menhaden – a single step from vascular plant to fishery harvest. J Exp Mar Biol Ecol 84:95-100

Loughna PT, Goldspink G (1984) The effects of starvation upon protein turnover in

red and white myotomal muscle of rainbow trout, *Salmo gairdneri* Richardson. J Fish Biol 25:223:230

Love JW, Johnson AK, May EB (2006) Spatial and temporal differences of Atlantic menhaden (*Brevoortia tyrannus*) recruitment across major drainages (1966-2004) of the Chesapeake Bay watershed. Est Coast 29:794-801

Luo JG, Hartman KJ, Brandt SB, Cerco CF, Rippetoe TH (2001) A spatially-explicit approach for estimating carrying capacity: an application for the Atlantic menhaden (*Brevoortia tyrannus*) in Chesapeake Bay. Estuaries 24:545-556

Maillet GL, Checkley DM (1990) Effects of starvation on the frequency of formation and width of growth increments in sagittae of laboratory-reared Atlantic menhaden *Brevoortia-tyrannus* larvae. Fish Bull 88:155-165

Malloy KD, Targett TE (1994a) The use of RNA-DNA ratios to predict growth limitation of juvenile summer flounder (*Paralichthys dentatus*) from Delaware and North Carolina estuaries. Mar Biol 118:367-375

Malloy KD, Targett TE (1994b) Effects of ration limitation and low temperature on growth, biochemical condition, and survival of juvenile summer flounder from two Atlantic Coast nurseries. Trans Am Fish Soc 123:182-193

Malloy KD, Yamashita Y, Yamada H, Targett TE (1996) Spatial and temporal patterns of juvenile stone flounder *Kareius bicoloratus* growth rates during and after settlement. Mar Ecol Prog Ser 131:49-59

Manderson JP, Phelan BA, Meise C, Stehlik LL, Bejda AJ, Pessutti J, Arlen L, Draxler A, Stoner AW (2002) Spatial dynamics of habitat suitability for the growth of newly settled Winter Flounder *Pseudopleuronectes americanus* in an estuarine nursery. Mar Ecol Prog Ser 228:227-239

Mathers EM, Houlihan DF, Cunningham MJ (1992) Nucleic acid concentrations and enzyme activities as correlates of growth rate of the saithe *Pollachius virens*: growth-rate estimates of open-sea fish. Mar Biol 112: 363-369

Mazur MM, Wilson MT, Dougherty AB, Buchheister A, Beauchamp DA (2007) Temperature and prey quality effects on growth of juvenile walleye pollock *Theragra chalcogramma* (Pallas): a spatially explicit bioenergetics approach. J Fish Biol 70:816-836

McLaughlin RL, Ferguson MM, Noakes DLG (1995) Tissue concentrations of RNA and protein for juvenile brook trout (*Salvelinus fontinalis*): lagged responses to fluctuations in food availability. 14:459-469

McNatt RA, Rice JA (2004) Hypoxia-induced growth rate reduction in two juvenile

estuary-dependent fishes. J Exp Mar Biol Ecol 311:147-156

McMillan DN, Houlihan DF (1988) The effect of refeeding on tissue protein synthesis in rainbow trout. Physiol Zool 61:429-441

Meekan MG, Fortier L (1996) Selection for fast growth during the larval life of Atlantic cod *Gadus morhua* on the Scotian Shelf. Mar Ecol Prog Ser 137: 25-37

Meng L, Gray C, Taplin B, Kupcha E (2000) Using winter flounder growth rates to assess habitat quality in Rhode Island's coastal lagoons. Mar Ecol Prog Ser 201:287-299

Meng L, Taylor DL, Serbst J, Powell JC (2008) Assessing habitat quality of Mount Hope Bay and Narragansett Bay using growth, RNA:DNA, and feeding habits of caged juvenile Winter flounder (*Pseudopleuronectes americanus* Walbaum). Northeast Nat 15:35-56

Mercaldo-Allen R, Kuropat C, Caldarone EM (2006) A model to estimate growth in young-of-the-year tautog, *Tautoga onitis*, based on RNA/DNA ratio and seawater temperature. J Exp Mar Bio Ecol 329:187-195

Mercaldo-Allen R, Kuropat C, Caldarone EM (2008) An RNA:DNA-based growth model for young-of-the-year winter flounder *Pseudopleuronectes americanus* (Walbaum). J Fish Biol 72:1321-1331

Miglavs I, Jobling M (1989) Effects of feeding regime on food consumption, growth rates and tissue nucleic acids in juvenile Arctic charr, *Salvelinus alpinus*, with particular respect to compensatory growth. J Fish Biol 34:947-957

Miller JM, Crowder LB, Moser ML (1985) Migration and utilization of estuarine nurseries by juvenile fishes: an evolutionary perspective. In: Rankin MA, Checkley D, Cullen J, Kitting C, Thomas P (eds) Contributions in Marine Science. Marine Science Institute, Port Aransas, TX, p 338-352

Miller TJ, Crowder LB, Rice JA, Marschall EA (1988) Larval size and recruitment mechanisms in fishes: toward a conceptual framework. Can J Fish Aquat Sci 45:1657-1670.

Minello TJ, Able KW, Weinstein MP, Hays CG (2003) Salt marshes as nurseries for nekton: testing hypotheses on density, growth and survival through meta-analysis. Mar Ecol Prog Ser 246:39-59

Molony BW, Choat JH (1990) Otolith increment widths and somatic growth rate – the presence of a time-lag. J Fish Biol 37:541-551

Mugiya Y, Oka H (1991) Biochemical relationship between otolith and somatic growth in the rainbow trout *Oncorhynchus mykiss*: consequence of starvation, resumed feeding, and diel variations. Fish Bull 89:239-245

Murdy EO, Birdsong RS, Musick JA (1997) Fishes of Chesapeake Bay. Smithsonian Institution Press, Washington

Mustafa S, Mittal A (1982) Protein, RNA and DNA levels in liver and brain of starved catfish *Clarias batrachus*. Jpn J Ichthyol 28:396-400

Neilson JD, Geen GH (1985) Effects of feeding regimes and diel temperature cycles on otolith increment formation in juvenile Chinook salmon, *Oncorhynchus tshawytscha*. Fish Bull 83:91-101

Nelson WR, Ingham MC, Schaaf WE (1977) Larval transport and year-class strength of Atlantic menhaden, *Brevoortia tyrannus*. Fish Bull 75:23-41

Nicholson WR (1978) Movements and population structure of Atlantic menhaden indicated by tag returns. Estuaries 1:141–150

Nislow KH, Folt CL (2000) Spatially explicit bioenergetic analysis of habitat quality for age-0 Atlantic salmon. Trans Am Fish Soc 129:1067-1081

Nixon SW (1980) Between coastal marshes and coastal waters: a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. In: Hamilton P, MacDonald KB (eds) Estuarine and Wetland Processes. Plenum Press, New York, p 437-525

NMFS (National Marine Fisheries Service) (1997) Magnuson-Stevens Act provisions: essential fish habitat. Interim final rule and request for comments, Federal Register [Docket 961030300-7238-04; I.D. 120996A]

NMFS (National Marine Fisheries Service) (2008) Fisheries of the United States. Office of Science and Technology, Fisheries Statistics and Economics Division, Silver Spring, Maryland

NOAA (National Oceanic, and Atmospheric Administration) (2007) Magnuson-Stevens Fishery Conservation and Management Reauthorization Act amended through 12 January 2007 (P.L. 109-479), U.S. Department of Commerce, Washington, D.C.

O'Connell CP, Raymond LP (1970) The effect of food density on survival and growth of early post yolk-sac larvae of the northern anchovy (*Engraulis mordax* Girard) in the laboratory. J Exp Mar Biol Ecol 5:187-197

Overton AS, Manooch CS III, Smith JW, Brennan K (2008) Interactions between

adult migratory striped bass (*Morone saxatilis*) and their prey during winter off the Virginia and North Carolina Atlantic coast from 1994 through 2007. Fish Bull 106:174-182

Paperno R, Targett TE, Grecay PA (2000) Spatial and temporal variation in recent growth, overall growth, and mortality of juvenile weakfish (*Cynoscion regalis*) in Delaware Bay. Estuaries 23:10-20

Peck MA, Buckley LJ, Caldarone EM, Bengtson DA (2003) Effects of food consumption and temperature on growth rate and biochemical-based indicators of growth in early juvenile Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*. Mar Ecol Prog Ser 251: 233-243

Peters DS, Schaaf WE (1981) Food requirements and sources for juvenile Atlantic menhaden. Trans Am Fish Soc 10:317-324

Phelan BA, Goldberg R, Bejda AJ, Pereira J, Hagan S, Clark P, Studholme AL, Calabrese A, Able KW (2000) Estuarine and habitat-related differences in growth rates of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) and tautog (*Tautoga onitis*) in three northeastern US estuaries. J Exp Mar Biol Ecol 247:1-28

Post JR, Evans DO (1989a) Experimental evidence of size-dependent predation mortality in juvenile yellow perch. Can J Zool 67:521-523

Post, JR, Evans DO (1989b) Size-dependent overwinter mortality of young-of-the-year yellow perch (*Perca flavescens*): laboratory, in situ enclosure, and field experiments. Can J Fish Aquat Sci 46:1958-1968

Powell AB, Phonlor G (1986) Early life-history of Atlantic menhaden, *Brevoortia-tyrannus*, and Gulf menhaden, *Brevoortia-patronus*. Fish Bull 84:991-995

Quinlan JA, Blanton BO, Miller TJ, Werner FE (1999) From spawning grounds to the estuary: using linked individual-based and hydrographical models to interpret patterns and processes in the oceanic phase of Atlantic menhaden *Brevoortia tyrannus* life history. Fish Oceanogr 8:224-246

Quinlan JA, Crowder LB (1999) Searching for sensitivity in the life history of Atlantic menhaden: inferences from a matrix model. Fish Oceanogr 8(Suppl. 2):124-133

Reintjes JW (1969) Synopsis of biological data on the Atlantic menhaden, *Brevoortia tyrannus*. FAO Species Synopsis 42. 30 p

Reintjes JW, Pacheco AL (1966) The relation of menhaden to estuaries. Am Fish Soc Spec Publ 3:50-58

Rice JA, Crowder LB, Rose KA (1993a) Interactions between size-structured predator and prey populations: experimental test and model comparison. Trans Am Fish Soc 122:481-491

Rice JA, Miller TJ, Rose KA, Crowder LB, Marschall EA, Trebitz AS, DeAngelis DL (1993b) Growth rate variation and larval survival: inferences from an individual-based size-dependent predation model. Can J Fish Aquat Sci 58:133-142

Richard P, Bergeron JP, Boulhic M (1991) Effect of starvation on RNA, DNA and protein content of laboratory-reared larvae and juveniles of *Solea solea*. Mar Ecol Prog Ser 72:69-77

Robinson SMC, Ware DM (1988) Ontogenetic development of growth rates in larval Pacific herring, *Clupea harengus pallasi*, measured with RNA-DNA ratios in the Strait of Georgia, British Columbia. Can J Fish Aquat Sci 45:1422-1429

Rogers SG, Targett TE, Van Sant SB (1984) Fish-nursery use in Georgia salt-marsh estuaries: the influence of springtime fresh-water conditions. Trans Am Fish Soc 113:595–606

Rogers SG, Van Den Avyle MJ (1989) Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic): Atlantic menhaden. US Fish and Wildlife Service Biol Rep 82(11.108). US Army Corps of Engineers TR EL-82-4. 23 p

Rooker JR, Holt GJ (1996) Application of RNA:DNA ratios to evaluate the condition and growth of larval and juvenile red drum (*Sciaenops ocellatus*). Mar Freshw Res 47:283-290

Rooker JR, Holt SA (1997) Utilization of subtropical seagrass meadows by newly settled red drum *Sciaenops ocellatus*: patterns of distribution and growth. Mar Ecol Prog Ser 158:139-149

Secor DH, Dean JM (1989) Somatic growth effects on the otolith-fish size relationship in young pond-reared striped bass, *Morone saxatilis*. Can J Fish Aquat Sci 46:113-121

Smith JW (1991) The Atlantic and gulf menhaden purse seine fisheries: origins, harvesting technologies, biostatistical monitoring, recent trends in fisheries statistics, and forecasting. Mar Fish Rev 53:28–41

Smith TR, Buckley LJ (2003) RNA-DNA ratio in scales from juvenile cod provides a nonlethal measure of feeding condition. Trans Am Fish Soc 132:9-17

Sogard SM (1992) Variability in growth rates of juvenile fishes in different estuarine habitats. Mar Ecol Prog Ser 85:35-53

Sogard SM (1997) Size-selective mortality in the juvenile stage of teleost fishes: a review. Bull Mar Sci 60:1129-1157

Spitzer PR (1989) Osprey. In: Pendleton BG (ed) Proceedings northeast raptor management symposium and workshop. Natl Wildl Fed Scientific and Tech Ser, No. 13, Washington, D.C., p 22-29

Stierhoff KL, Targett TE, Power JH (2009) Hypoxia-induced growth limitation of juvenile fishes in an estuarine nursery: assessment of small-scale temporal dynamics using RNA:DNA. Can J Fish Aquat Sci 66:1033-1047

Stuck KC, Watts SA, Wang SY (1996) Biochemical responses during starvation and subsequent recovery in postlarval Pacific white shrimp, *Penaeus vannamei*. Mar Biol 125:33-45

Suneetha KB, Folkvord A, Johannessen A (1999) Reponsiveness of selected condition measures of herring, *Clupea harengus*, larvae to starvation in relation to ontogeny and temperature. Environ Biol Fish 54:191-204

Sutcliffe WH (1970) Relationship between growth rate and ribonucleic acid concentration in some invertebrates. J Fish Res Bd Can 27:606-609

Suthers IM, Cleary JJ, Battaglene C, Evans R (1996) Relative RNA content as a measure of condition on larval and juvenile fish. Mar Freshw Res 47:301-307

Sykes JE, Manooch CS (1979) Estuarine predator–prey relations. In: Clepper H (ed) Predator-prey systems in fisheries management. Sport Fishing Institute, Washington, D.C.

Szedlmayer ST (1998) Comparison of growth rate and formation of otolith increments in age-0 red snapper. J Fish Biol 53:58-65

Takahashi M, Nishida H, Yatsu A, Watanabe Y (2008) Year-class strength and growth rates after metamorphosis of Japanese sardine (*Sardinops melanostictus*) in the western North Pacific Ocean during 1996-2003. Can J Fish Aquat Sci 65: 1425-1434

Takasuka A, Aoki I, Mitani I (2004) Three synergistic growth-related mechanisms in the short-term survival of larval Japanese anchovy *Engraulis japonicus* in Sagami Bay. Mar Ecol Prog Ser 270: 217-228

Taylor DL, Nichols RS, Able KW (2007) Habitat selection and quality for multiple cohorts of young-of-the-year bluefish (*Pomatomus saltatrix*): Comparisons between estuarine and ocean beaches in southern New Jersey. Est Coast Shelf Sci 73:667-679

Theilacker GH, Shen W (2001) Evaluating growth of larval walleye pollock,

Theragra chalcogramma, using cell cycle analysis. Mar Biol 138:897-907

Uphoff JH (2003) Predator-prey analysis of striped bass and Atlantic menhaden in upper Chesapeake Bay. Fish Manage Ecol 10:313-322

Vasconcelos RP, Reis-Santos P, Fonseca V, Ruano M, Tanner S, Costa MJ, Cabral HN (2009) Juvenile fish condition in estuarine nurseries along the Portuguese coast. Est Coast Shelf Sci 82:128-138

Vidal EAG, DiMarco P, Lee P (2006) Effects of starvation and recovery on the survival, growth and RNA/DNA ratio in loliginid squid paralarvae. Aquaculture 260:94-105

Vinagre C, Fonseca V, Maia A, Amara R, Cabral H (2008) Habitat specific growth rates and condition indices for the sympatric soles *Solea solea* (Linnaeus, 1758) and *Solea senegalensis* Kaup 1858, in the Tagus estuary, Portugal, based on otolith daily increments and RNA-DNA ratio. J Appl Ichthyol 24:163-169

Walter JF III, Austin HM (2003) Diet composition of large striped bass (*Morone saxatilis*) in Chesapeake Bay. Fish Bull 101:414-423

Walter JF III, Overton AS, Ferry KH, Mather ME (2003) Atlantic coast feeding habits of striped bass: a synthesis supporting a coast-wide understanding of trophic biology. Fish Manage Ecol 10:349-360

Warlen SM (1992) Age, growth, and size distribution of larval Atlantic menhaden off North Carolina. Trans Am Fish Soc 121:588-598

Warlen SM (1994) Spawning time and recruitment dynamics of larval Atlantic menhaden *Brevoortia tyrannus* to a North Carolina estuary. Fish Bull 92:420-433

Wurtsbaugh WA, David GE (1977) Effects of temperature and ration level on the growth and food conversion efficiency of *Sulmo gairdneri*. J Fish Biol 11:87-98

Weinstein MP (1979) Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fish Bull 77:339-357

Wilkens EPH, Lewis RM (1971) Abundance and distribution of young Atlantic menhaden, *Brevoortia tyrannus*, in the White Oak River estuary, North Carolina. Fish Bull 69:783–789

Wingate RL, Secor DH (2008) Effects of winter temperature and flow on a summer-fall nursery fish assemblage in the Chesapeake Bay, Maryland. Trans Am Fish Soc 137:1147-1156

Wood RJ (2000) Synoptic scale climate forcing of multispecies fish recruitment patterns in Chesapeake Bay. PhD dissertation, College of William and Mary, Williamsburg, Virginia

Wooten RJ (1998) Ecology of teleost fishes. Kluwer Academic Publishers, Dordrecht, The Netherlands

Wright DA, Martin FD (1985) The effect of starvation on RNA:DNA ratios and growth of larval striped bass, *Morone saxatilis*. J Fish Biol 27:479-485

Yamashita Y, Tominaga O, Takami H, Yamada H (2003) Comparison of growth, feeding and cortisol level in *Platichthys bicoloratus* juveniles between estuarine and nearshore nursery grounds. J Fish Biol 63:617-630

Young VR (1970) The role of skeletal and cardiac muscle in the regulation of protein metabolism. In: Munro HH (ed) Mammalian protein metabolism. Academic Press, London, p 585–674