To: Dr. Saundra F. DeLauder, Dean, School of Graduate Studies and Research

The members of the Committee approved the Thesis of Marissa Brady
Candidate's Name

as presented on 5/12/11
Date

We recommend that it be accepted in partial fulfillment of the requirements for the degree

Master of Science in Natural Resources
Degree Name | Major/Program Name

[signature] Department AgNR Date 5-2-16
Advisor

[signature] Department Ag-NR Date 5-3-16
Member

[signature] Department AGNR Date 5-3-16
Member

[signature] Affiliation Colorado State University Date May 3, 2016
External Member

Approved

[signature] Department Ag-NR Date 5-3-16
Department Chairperson or Designee

[signature] College CARS Date 5-3-16
Academic Dean or Designee

[signature] Date 5/4/16
Dean, School of Graduate Studies and Research

Environmental Drivers of American Eel (*Anguilla rostrata*) Behavior and Habitat Use in the St. Jones River, DE

by

MARISSA GISSELLE BRADY

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in the
Natural Resources Graduate Program
of Delaware State University

DOVER, DELAWARE
May 2016

ACKNOWLEDGEMENTS

I would like to begin by recognizing Dr. Leonard Davis, I still remember the day he walked me over to the Department of Agriculture and Natural Resources. I was excited and scared all at once; he mentioned he knew a professor that I would be able to gain research experience with over the summer. Little did I know that I would be receiving a Master's degree from the aforementioned Department. That morning, I met my advisor Dewayne Fox, aka "Daddy". All jokes aside, I would not be the scientist I am today if it was not for Dr. Fox, or just "Dewayne" as he prefers to be called. His unwavering encouragement, experience, guidance, and assistance have left a mark which I hope to pass on one day.

Many thanks go to Dr. Paul Conn, for guiding me through the modeling process with patience and firm direction. Before this endeavor, I had zero experience in the world of programming and modeling. When I was at the point where I could not figure out coding in R, or why the models were not running, I would go to Paul with countless questions hoping for a quick answer to continue on to my next stumble. Fortunately, with every question came another question on Paul's part, forcing me to think for myself. I also thank Dr. Larissa Bailey for spending time with me in the field and giving me guidance when I needed it most. A special thanks to Dr. Richard Barczewski for serving on my committee and for always listening to the many complaints, as graduate students continuously have.

Thank you to Dr. Kevina Vulinec for her service on my committee and for always finding a different way to analyze a problem.

In addition to a new appreciation for coffee in my life, I gained many friends in pursuit for this degree. If it was not for Lori and Jimmy Kroon I would be lost in the GIS world, and many other worlds for that matter. Lori is a rare gem in this fast paced country we call America, she is the type of person that always lends a helping hand when needed. She knows how to listen and give advice even when you are not asking for it. Jen Hampton-Green is the most precise and thorough assistant I have ever met. Having her by my side during my graduate studies was comforting. In addition to having fun at work we became very good friends along with Johnny Moore, a fellow graduate student who was there from the beginning; Big Cat as we called him was very dependable and always said yes to coming out in the field. I am really thankful for all the graduate and undergraduate students that helped me throughout my years in the Natural Resources Department, including Matthew Breece who helped out whenever he could and did an amazing job maintaining the boats and field gear. Thank you to Don Wujtewicz and Grant Blank from the ponds for always giving a helping hand and providing us extra storage and work space when things were cold. Besides friends, I also gained a husband. Aaron Zelinskas supported me in every way throughout this process, from bringing lunch to the landing for Jennifer and me, to pulling pots, and pushing me to keep working through the analysis.

I would like to give special thanks to Ed and Sharon Farrall for being so patient with me and letting me come to their home at all hours to scan their catch. We spent many mornings and evenings talking about eels and life in general. Thanks to Mike Stansky for always having a funny story about eels and allowing me to scan his catch as well.

Lastly, I would like to thank the National Science Foundation Bridge to the Doctorate Program for providing funds for tuition and travel, the NOAA Living Marine Resources Cooperative Science Center, and Dr. Mazen Shahin for helping me along the way.

ABSTRACT

Environmental drivers of American Eel (Anguilla rostrata) behavior and habitat use in the St. Jones River, DE

Marissa G. Brady

Faculty Advisor: Dr. Dewayne Fox

American Eels (*Anguilla rostrata*) serve key roles in the ecological and economic health of the mid-Atlantic region. Resource managers facing a combination of declining landings and changing environmental regimes are in need of information on the factors influencing American Eel behavior. In the spring of 2009, a combined mark-recapture and biotelemetry study was initiated in the St. Jones River, Delaware. Monthly mark-recapture events took place using fixed locations (n = 40) stratified by commercial fishing practices (i.e. intense, occasional, and rarely harvested). Acoustic transmitters were implanted in a random sample of eels (>305 mm) in each strata. Telemetered individuals were allowed to recover before released at initial site of capture, and were monitored using a combination of active and passive telemetry. Using data from telemetered eels, we conducted home range analysis and used general linear mixed models (GLMMs) to assess the importance of covariates in determining eel movement rates. The vast majority (98/102) of telemetered individuals were detected at least once over the course of the study (May 2009 through January 2011). During the summer months, site fidelity was very high for the majority of American Eels which primarily remained at the initial tagging locations. In the late fall, when water temperatures began to decline, detected American Eels moved to higher saline waters of the Delaware Bay, possibly for thermal refugia or migration. Despite increased movement in the fall, average home range estimates remained low (8.30 ha) over all seasons. In addition to season, modeling efforts indicated that eel movements were also dependent on water temperature, tide, turbidity, diel periods, and size of the animal; there was also evidence for considerable heterogeneity of movement rates between eels of similar size class. Insights from this study have improved our understanding of movement ecology of American Eels in the mid-Atlantic region, and should allow for better management and conservation decisions.

TABLE OF CONTENTS

LIST OF TABLES

Page

TABLE

LIST OF FIGURES

CHAPTER I

Biology, Population Dynamics, and Ecology of the American Eel (Anguilla rostrata); A Literature Review

For more than two centuries American Eels (*Anguilla rostrata*) have sustained large profitable fisheries and were once a significant source of protein for numerous Native American tribes (Casselman 2003). It is thought that the Pilgrims of Plymouth Colony feasted on American Eels thanks to Squanto, a Patuxet Indian who had learned English (Prosek 2010). That first harsh winter Squanto taught them how to catch a fatty, nutritious fish that would sustain them in the worst of times. Today, the advent of new technology has facilitated the transport of eels around the world, so much so that live American Eels are carried from their native waters to global markets. American Eels still support large and diverse fisheries targeting many life stages (Casselman 2003). However, recent declines have caused concerns regarding their population status.

Distribution and Life History

American Eels range from Greenland to northern Brazil, inhabiting freshwater, estuarine and marine environments. The life history of American Eels has undergone some revision and today they are commonly considered a facultative catadromous species, exhibiting far more flexibility in habitat use (Daverat et al. 2006; Jessop et al. 2008) than previously thought. Prior to reaching sexual maturity, American Eels spend their life growing in freshwater, estuarine, and marine environments. At maturation, they migrate to the Sargasso Sea to spawn and die.

Spawning is thought to occur from February through April (or later) in a region of the Sargasso Sea located in the southwestern North Atlantic Ocean (Tesch and Wegner 1990). Leptocephalus American Eels passively drift to the coast (Fahay 1978) moving into estuaries, they undergo metamorphosis first into glass eels, then elvers, before eventually becoming yellow eels. Elvers and glass eels are caught with fine mesh fyke and dip nets in their respective fisheries (Bohun and Winn 1966). American Eels remain in this stage for an extensive period ranging from approximately 7-19 years (Able and Fahay 1998). Maturation is accompanied by changes in morphology and coloration which occur in the fall prior to seaward migration. At this point, American Eels are referred to as "silver eels" and begin migrating down river to the ocean where maturation continues as they move towards the spawning grounds (Facey and Van Den Avyle 1987). During their silver phase, American Eels are believed to cease feeding as a result they are primarily caught intercepted in weirs as they begin their spawning migration.

Further complicating their life history, American Eels exhibit sex-specific strategies with males maturing at a younger age and smaller size in comparison to slower maturing larger (>400 mm) females (Helfman et al. 1987; Oliveira 1999; Barber 2004). It is generally believed that males are encountered in the southern portion of their range and closer to the mouth of estuaries; while females are found in more northerly habitats and inland freshwater portions of rivers and streams (Oliveira 1999). These latitudinal differences have been hypothesized as a mechanism to reduce the likelihood of intersex competition allowing resource competition (Oliveira 1999). Furthermore, the productive brackish water habitats utilized by males likely contributes to the decreased age at maturity while the freshwater areas occupied by females are believed to maximize size and fecundity (Helfman et al. 1987). It appears that sex specific reproductive strategies are adopted by American Eels with females maximizing growth at smaller sizes while males tend to maintain sub-maximum growth rates to help achieve smaller sizes for maturity (Oliveira and McCleave 2002). In Delaware, a study conducted in two tributaries determined that out-migrating silver American Eels differed by sex with proportionally more males reaching maturity at smaller sizes/ages than females (Barber 2004).

Behavior

American Eels are commonly believed to be more active at night seeking cover during daylight hours (Baras et al. 1998; Thomas 2006), foraging mainly on crustaceans, bivalves, polychaetes and fish (Wenner and Musick 1975; Daniels 1999) although levels of piscivory increase with size (Daniels 1999). The feeding periodicity of American Eels make them a significant predator on commercially important invertebrates (Wenner and Musick 1975) including blue crabs (*Callinectes sapidus*), and the soft clam (*Mya arenaria*). The use of olfactory cue seems a likely mechanism of foraging given the increased activity of American Eels during evening and low light hours. It has been hypothesized that American Eels primarily utilize olfaction in choosing the appropriate tide for transport and location of a home site (Barbin et al. 1998). Additionally, American Eels are believed to use olfaction for migration to the Sargasso Sea (Barbin et al. 1998).

Ecologically, American Eels are generalists capable of tolerating large changes in environmental conditions and occupying broad habitats, as such they likely play an important role in structuring aquatic communities (Helfman et al. 1987). To understand a species' population dynamics, a better understanding of its home range is necessary as it provides insight on space utilization, habitat selection and behavior when coupled with ecological information (Bolden 2002). Here I define home range as the area in which an animal normally lives, exclusive of migrations, emigrations, dispersal movements or unusual wanderings (Brown 1975). Through numerous mark-recapture and biotelemetry studies it is known that American Eels display strong site fidelity with most individuals occupying habitats or being recaptured within 1km of their released location (Oliveira et al. 1997; Lamothe et al. 2000; Morrison and Secor 2003; Cairns 2009).

Although American Eels display high site fidelity, there seems to be an increase in movement seasonally related to environmental drivers, such as temperature, diel period, and tide among others. Studies conducted in the Maritime Provinces of Canada (Smith and Saunders 1955) and the Delaware River Basin (Compton 1968) indicate that eels are generally not found in freshwater during the winter suggesting that American

Eels may be hibernating in unconsolidated substrates. In Delaware waters it is believed that although some American Eels hibernate in mud bottoms during the winter prior to this hibernation large numbers migrate into the bay and remain there until the following spring (Brady, unpublished data). These generalized movements towards higher saline waters may be related to thermal refugia and underlying physiological requirements in American Eels (Thibault et al. 2007).

Management

In Delaware, American Eels occupy a key role in dictating community structure as a result of their abundance, longevity, and year round residence. Commercially, American Eels support fisheries throughout much of their range although the largest landings are centered in the mid-Atlantic with Delaware consistently among the top states in eel landings (Clark 2009). However, the continued stability of these fisheries has been brought into question with increased uncertainty regarding the range-wide population status of American Eels (Casselman 2003). The causes of the purported declines in American Eels are unknown due to variations associated with abundance data and an incomplete understanding of life history, ecology, and population dynamics (Haro et al. 2000). Potential causes for the declines in American Eel abundance include overfishing, pollution, habitat loss, climate change, and mortality from hydroelectric turbines (Castonguay et al. 1994; Haro et al. 2000; Anonymous 2003). In the last couple of decades there is a growing body of work suggesting that the appearance of a non-native swim bladder parasite (*Anguillicola crassus*) may be an additional source of mortality in American Eels (Barse and Secor 1999; Moser et al. 2001; Fenske et al. 2010).

The Atlantic States Marine Fisheries Commission (ASMFC) is tasked with the interstate management of American Eels (ASMFC 2007). In 2000, a fishery management plan (FMP) was drafted by the ASMFC to address recent declines in both commercial and recreational landings of American Eels (ASMFC 2000). In 2004, the federal government was petitioned to include the American Eel under the provisions of the Endangered Species Act (USOFR 2004) and a status review determined that the listing was not warranted (USOFR 2007). Actions on management measures were delayed to incorporate the results of a future stock assessment (ASMFC 2008). Although concerns for decreases in commercial and recreational landings worldwide appear valid, it is important to note that these changes can have numerous causes other than those previously mentioned (e.g. overfishing). In Delaware, increase in bait prices and changes in market conditions have been proposed as likely underlying causes for decreases in landings (Clark 2009). In 2011, a status review was initiated to determine if American Eel warranted to be under the Endangered Species Act (ESA). The 2012 stock assessment gave way for the approval of Addendum III in August 2013 and Addendum IV in October 2014. On October 7, 2015 USFWS announced that the American Eel is stable and does not need protection under the ESA.

Resource managers require data to effectively manage fisheries including reliable estimates of population structure, impacts of harvest on mortality, and emigration rates. Mark-recapture studies have historically been the primary method of quantifying the abundance and survival of animal populations although newer techniques combining tag return and telemetry methods are providing more precise and unbiased estimates of population parameters including harvest mortality (Hightower et al. 2001; Pine et al. 2003; Bacheler et al. 2008). These methods are an active field of research in wildlife ecology (Lebreton et al. 1995; Lebreton et al. 1999; Barker 1997) and show much promise to the application of fisheries issues. The integration of both telemetry and mark-recapture in models is being utilized more frequently in fisheries as it allows for the full usage of all possible data types in a single analysis (mark-recapture and telemetry data); as well as, more precise and unbiased estimates of natural and harvest related mortality.

As with many managed species, limited information is available on the influence of harvest on the population dynamics and behavior of American Eels. As such, any spatial and temporal closures or development of special management areas should proceed with caution while taking into consideration the flexible nature of habitat use in American Eels as they may provide benefits for both the target species and the surrounding community as well (Airame´et al. 2003, Gerber et al. 2003).

Objectives

My thesis is focused on attaining relevant information for fisheries managers regarding American Eel population dynamics in the St. Jones River, Delaware. Cairns (2009) utilized statistical models to develop estimations of abundance, survival, growth, movement, dispersal, mortality, and the impact of commercial harvest on American Eels for my system of interest. By adding the telemetry component to the mark-recapture framework I hope to shed light on the role of environmental drivers (e.g. season, temperature, lunar illumination, tide, turbidity and diel periods), the role of harvest pressure and size of American Eels influencing American Eel movements and home range in the St. Jones River, DE. Through model development I will provide fisheries professionals a more precise understanding of American Eel population dynamics; thereby, allowing for better management decisions regarding the conservation of this economically and ecologically important species.

CHAPTER II

Combining manual and passive telemetry to determine home range for American Eels (Anguilla rostrata) in the St. Jones River, DE

2.1 Introduction

The American Eel (*Anguilla rostrata*) provides both important ecological and commercial benefits throughout most of their range including Delaware. Recent declines in the commercial harvests of American Eels in the northern part of their range highlighted the need for an improved understanding of the population dynamics of this important species (Casselman 2003). Potential causes of the decline in American Eel abundance include: overfishing, pollution, habitat loss, barriers to migration, parasites, and mortality from hydroelectric turbines (Castonguay et al. 1994; Haro et al. 2000; Anonymous 2003). In light of perceived declines, the Atlantic States Marine Fisheries Commission (ASMFC) cited a need for tagging programs to address survival, mortality, and habitat use (ASMFC 2007).

In the majority of mark-recapture and biotelemetry studies, yellow-phase American Eels were caught at their initial site of tagging or within 1 km of where they were released; providing evidence of high site fidelity for the majority of tagged individuals (Oliveira et al. 1997; Lamothe et al. 2000; Morrison and Secor 2004; Cairns

2009). Although, dispersion of American Eels among estuarine environments is known to occur; in the Hudson River microchemistry studies suggest that the vast majority will spend 2-19 years in fresh water before moving to and residing in, brackish water habitats (Morrison et al. 2003). Some individuals moved great distances (>50km) downstream in an exhibition of high movement rates which is counter to most findings whereby American Eels exhibit limited home ranges during periods of freshwater residency. Otolith microchemistry established that there was limited evidence of regular seasonal movement among salinity gradients in the Hudson River and the increase in movement observed was essentially the migration from freshwater to brackish water.

Although the majority of published studies suggest limited dispersal rates for most yellow-phase American Eels, individual behavioral differences exist. A telemetry study conducted in Silver Lake, DE, showed evidence of behavioral differences among telemetered American Eels, and overall very large home ranges were exhibited in comparison to the overall limited home range (Thomas 2006). In addition, other studies suggested that American Eel behavior is at least partially mediated by environmental cues including water temperature (McGrath et al. 2003; Hammond and Welsh 2009), lunar phase (Lowe 1952; Winn et al. 1975; Cairns and Hooley 2003), diel periodicity (Wenner and Musick 1975), and precipitation (Tesch 1977; Winn et al. 1975; Hammond and Welsh 2009). A study conducted in the Shenandoah River, WV noted that the highest rates of upstream movement occurred in the spring while downstream movements occurred in the fall suggesting that individuals were actively searching for overwintering areas (Hammond and Welsh 2009).

Traditional home range studies have focused on mark-recapture and manual telemetry to estimate movement patterns (Brown 1975). In this study, I utilized a combination of passive and manual telemetry and mark-recapture data to provide improved insights into American Eel home range, as well as an understanding of residency in a tidal tributary. My primary goals of this study were to examine the seasonal patterns of home range and occupancy of American Eels in a tidal salt marsh creek. My findings on the factors mediating the behavior of American Eels will provide managers with a better understanding of the spatial and temporal aspects of habitat utilization to assist in designing conservation measures for American Eels.

2.2 Methods

Study Site and water quality measurements

The St. Jones River, DE (Figure 2-1) is tidally influenced and encompasses a watershed of 8,262 ha which exhibits marked seasonal variability in its physical parameters (DNERR 1999).There are three stations along the St. Jones River and one at the mouth of the neighboring river (Murderkill River) that continuously record water parameters including temperature (°C), salinity (ppt), dissolved oxygen (mg/L), conductivity (mS/cm) and tides. Retrieved data are made available through the Delaware National Estuarine Research Reserve (DNERR) and U.S. Geological Survey (USGS).

See Cairns (2009) for a detailed description of the study site and water quality measurements.

Sampling

In June 2009, I utilized 40 fixed sampling locations in the St. Jones River designated in a previous mark-recapture study (Cairns 2009) to collect American Eels needed for this telemetry study. The St. Jones River was divided into three strata based on the activities of commercial harvesters (Figure 2-1); intensely harvested (Sites 1-14), occasionally harvested (Sites 15-25) and rarely harvested (Sites 26-40). American Eels were captured using commercial traps, identical to the ones used by commercial harvesters. The traps are rectangular in shape (76 x 30 x 30cm) constructed of iron rebar and surrounded by 1.2cm mesh. Traps were baited with half a gravid female horseshoe crab (*Limulus polyphemus*), the preferred bait and quantity used by commercial harvesters (Clark 2009) and allowed to fish overnight. Upon capture, American Eels were placed in an induction tank following previously established protocols (Thomas 2006) until loss of equilibrium. Following induction, all captured eels were tagged in the dorsal musculature with a Passive Integrated Transponder (PIT tag) (12mm Biomark TX1411l). Additionally, one yellow-phase American Eel (≥400 mm) at each fixed sampling location was implanted with an acoustic transmitter (VEMCO Ltd. V9-2L) (29 mm, 142 dB, 2.9 g in water, 537 days battery life) following previously developed protocols (Thomas 2006).

During May and June 2010, an additional 60 American Eels were implanted with acoustic transmitters. A stratified random design was employed for transmitter deployment among harvest strata (Figure 2-1) (30 VEMCO Ltd. V9-2L: 29 mm, 142 dB, 2.9 g in water, 405 days of battery life and 30 VEMCO Ltd. V8-4L: 20.5 mm, 144 dB, 0.9 g in water, 194 days battery life). Equal numbers of small and large (n=10) transmitters were deployed in randomly selected captured eels in each strata. The smaller transmitters utilized during 2010 allowed for the tagging of smaller American Eels (350-450mm). Transmitters were surgically implanted in American Eels between 350-450 mm (VEMCO Ltd. V8-4L) and ≥450 mm (VEMCO Ltd. V9-2L) in length to minimize transmitter induced behavioral changes. To maximize tag longevity, the smaller V8-4L transmitters were programmed to allow a 21 day delay before transmitting, allowing eels to heal and re-establish home-range areas (Thomas 2006). During both field seasons, traps were moved slightly (≤50 m) from the initial sampling location if untagged American Eels were not caught after several attempts (Figure 2-1). I applied transmitters to untagged American Eels (without PIT tags) exclusively, as these animals had no previous capture histories and would not be influenced by multiple handling events. Captured eels were placed in an induction tank until loss of equilibrium when they were removed and scanned for the presence of a PIT tag, measured (mm), and weighed (g). Previously unmarked American Eels which met the size criteria received both a PIT tag and an acoustic transmitter. They were then placed in a tank to regain equilibrium and released back into the river at the site of capture.

Tag Recoveries

Over the course of this project I worked collaboratively with two commercial harvesters (Mr. Ed Farrall, Harrington, Delaware and Mr. Mike Stansky, Smyrna, Delaware). In addition, two unknown harvesters fished in my study area for brief periods (2-4 days total) although I was not able to scan their catches. Cooperating harvesters separated their St. Jones River landings from their overall catch and allowed me to scan their landings to recover the majority of commercially harvested American Eels. Commercial harvesters maintained their normal fishing schedules and practices over the course of the study. Through regular conversations with the harvesters, I was kept abreast of their fishing schedules and was notified of the general area of harvest efforts, including soak times and number of traps fished. If a previously marked American Eel was encountered while scanning the commercial harvest, it was removed from their catch and placed in a bath with a lethal dose of anesthetic. Length and weight were collected for all recovered eels. Additionally, a random sub-sample of 50 un-marked eels was collected each time a catch was scanned, measured and weighed (Cairns 2009). The total catch (kg) information was provided by the harvesters prior to the sale of unmarked individuals. In the event that American Eels implanted with acoustic transmitters were recovered through the commercial harvest the transmitters were removed and if sufficient battery life was remaining ($\geq$ 50%) the transmitters were redeployed using the previously described methods at a later date.

Biotelemetry

Both manual and passive acoustic (VEMCO Ltd.) methodologies were used to monitor the behaviors of telemetered American Eels. Weekly searches for telemetered individuals took place during ice-free months in all navigable portions of the St. Jones River. In 2009, manual tracking was conducted using an omni-directional (VEMCO Ltd. VH165) hydrophone; if a telemetered American Eel was detected, a directional (VEMCO Ltd. VH110) hydrophone was utilized to establish its location (estimated ± 10m). Once the location was established, physical parameters (i.e. temperature (°C), salinity (ppt), dissolved oxygen (mg/l), and conductivity (mS/cm)) were recorded using a YSI Model 85. In May 2010, the addition of 60 acoustic transmitters made manual tracking logistically impossible due to increased time demands and code collision issues. To facilitate manual searches I positioned the omni-directional hydrophone a depth of 1m holding it in place with a PVC bracket. Tracking was conducted in a manner so as to minimize the relative flow of water (i.e. tracking with tidal flow) across the hydrophone surface in an attempt to minimize flow associated noise. The acoustic receiver (VEMCO Ltd. VR100) was programmed to log detections along with corresponding geolocation information. I estimated the location of American Eels based on maximal signal strength of the recorded detections. In the event that equal signal strengths were recorded, the first recording was utilized. In 2010, environmental parameters were recorded using an environmental data logger (YSI Model 85) which allowed for the continuous logging of data. To facilitate the merger of telemetry and environmental data sets, both the manual tracking receiver and environmental logger were synched at the start and end of every tracking event.

Passive Telemetry

In the first year of the study I utilized an array of seven passive acoustic receivers (VEMCO Ltd. VR2 and VR2-W) arranged to account for the immigration and emigration of telemetered American Eels in the St. Jones River as well as movement between strata. Three additional receivers were placed in Delaware Bay near the mouth of the St. Jones River, DE in an attempt to document estuarine residency (Figure 2-2). Acoustic receivers were downloaded monthly to minimize data loss and to conduct maintenance. In addition to the acoustic receivers allocated for this project there were a large number of fully compatible passive acoustic receivers placed throughout the Delaware Estuary and near shore marine waters (Delaware River and Bay) (Figure 2-3) many of which were seasonally deployed from March through November in both years of my study.

Range Testing

To assess the detection efficiency of my array in July 2010, a series of tests were conducted utilizing two range testing tags similar in power to the transmitters (VEMCO Ltd. V8-4L, VEMCO Ltd. V9-2L) employed in this study although pulse times were fixed at 10s intervals to allow a known number of transmissions during the study period. The range test transmitters were deployed for a period of one week at the boundary between each harvest strata (Figure 2-1) in an attempt to better understand the varying dynamics in the river (e.g. night/day, tides, etc). I deployed a range testing transmitter 100 meters from both sides (i.e. upstream/downstream) of a receiver location.

Data generated from the passive acoustic receivers, as well as estimates of stream flow and American Eel swimming speed were utilized to determine detection probability in the system. Stream flow and estimates of swimming speed for American Eels (Tytell 2004; Palstra et al. 2008) were used to generate an estimate of the maximum velocity an eel can pass a receiver with normal swimming speed. Delaware's Department of Natural Resources and Environmental Control (DNREC) provided data on stream flow in the St. Jones River, DE (Bob Scarborough, DNREC, personal communication).

Statistical and GIS Analyses

Although there are other methods including minimum convex polygons (MCP's), kernels are believed to more accurately estimate (Hooge and Eichenlaub 1997; Hooge et al. 1999) home range than other techniques. Kernel home range (95% and 50%) estimates were calculated in ArcGIS® (ESRI). The 95% kernel represents the entire area used by the animal while the 50% kernel represents the core area of activity. A previous behavioral study focused on American Eel in Silver Lake, DE determined that kernel estimators provided better estimates of home ranges compared to minimum convex polygons (Thomas 2006). There is much disagreement in the literature regarding the minimum sample size requirements for estimation of home range. Silverman (1986) suggested that 19 points were necessary to estimate home range utilizing kernel estimators. Another study proposed that 50 points produced unbiased estimates of home range (Seaman et al. 1999). For my analyses, I censored telemetered American Eels with less than 10 relocation events due to the lack of manual relocation points obtained in this study and the availability of passive telemetry data.

Behavioral studies reporting home range estimates typically only utilize manual relocation points since passive acoustic arrays can generate an overwhelming amount of data skewing the derived estimates. In addition, accurate location of telemetered individuals is difficult in most passive arrays compared to manual relocations. As a result of the relatively sinuous nature of the St. Jones River coupled with the fact that eels were often in complex habitats (e.g. roots and undercut banks) which limited detection ranges (<100m in vast majority of instances) I felt relatively confident in the location estimates provided through my passive acoustic receivers. In an attempt to generate robust estimates of home range and increase sample sizes, I utilized all available (manual relocations, passive relocations and mark-recapture events) data. To minimize possible biases associated with the passive telemetry data, I limited my utilization of passive data to one detection per individual per week to match the frequency of the manual tracking data. If a telemetered American eel was detected on multiple receivers in a given week, one data point from each receiver was utilized. In an attempt to understand the impact of using all data sources (manual relocations(man), passive relocations($pass$) and mark-recapture events(mr)) on home range estimates, I utilized a regression analysis to explore the relationship between the proportion of manual to combined ($\frac{man}{man+pass+mr}$)

relocation points by the % change in the home range area (home range estimated from manual relocations only (mhr)– home range estimated from the combined data set(chr).

$$\text{x-axis} = \frac{man}{man + pass + mr} \text{ by y-axis} = mhr - chr$$

Dependent variable: $mhr - chr$

Independent variable: $\frac{man}{man+pass+mr}$

I censored telemetered individuals that did not meet the threshold (less than 10 relocations) to run home range analysis utilizing manual relocations or combined relocations. If the regression analysis suggest that there is no correlation between the proportions of manual to combined relocation points by the % change in individual home range area I will proceed to combine the data sets to perform home range estimates and seasonal home range estimates.

2.3 Results

Collection, biotelemetry and tag recoveries

A total of 102 American Eels were implanted with transmitters throughout the course of my study. Seventy one large (≥450 mm) American Eels were implanted with VEMCO Ltd. V9-2L transmitters while thirty one smaller individuals (≥350-450 mm) were implanted with VEMCO Ltd. V8-4L transmitters. Recaptures (n= 43) and recoveries from the commercial harvest (n= 12) of telemetered American Eels suggested it took approximately 35 days for the incision site to fully close (Figure 2-4). A total of

969 manual relocations were made over the course of 72 tracking events and 454,992 detections were recorded on the passive acoustic receivers. Telemetered American Eels were manually relocated an average of 9 times (range 0-31) with a mean detection rate of 4,460 times (range 0-79,943) on the passive receivers. In addition to detections in the river, American Eels were detected in the Delaware Bay (Figure 2-3). The majority of these detections occurred in the fall of each year (Table 2-3).

During both years of the study water quality parameters (temperature (°C), salinity (ppt), dissolved oxygen (mg/L), and conductivity (mS/cm)) were collected during the manual tracking events. Mean temperature was 20.7°C (range 0.3-32.9 °C); dissolved oxygen 8.1 mg/L (range 0.2-36.4 mg/L), salinity 10.5 (ppt) (range 0.1-31.5 ppt) and conductivity 16.8 mS/cm (range 0.1-46.5 mS/cm). Temperature, dissolved oxygen, salinity and conductivity varied with the seasons (Table 2-4). Moreover, salinity varied spatially with highest values near the mouth and the lowest in upper portion of the river.

In June 2009, transmitters were implanted into 40 yellow-phase American Eels with an average lenght of 520 mm (range 405-724 mm) and weight of 295 g (range 175-815 g) (Table 2-1a, b, and c). In the fall a total of two of my telemetered American Eels were caught in the commercial harvest and redeployed, bringing the total number of implanted American Eels to 41. In the spring of 2010, an additional six telemetered American Eels that were implanted in 2009 were harvested in the commercial fishery. In May 2010, 60 transmitters were implanted into yellow-phase American Eels (range 370-655 mm; 115-615 g), 30 medium (mean 420 mm, 175 g) and 31 large (mean 530 mm, 318 g) (Table 2-2a, b, and c). Shortly thereafter a telemetered American Eel was harvested in the commercial fishery; the transmitter was retrieved and quickly implanted into another American Eel. Additionally, in the fall two telemetered American Eels were harvested by the fishery although the transmitters were not redeployed. In the second field season, I experienced a high incidence (n=9) of apparent transmitter failure with the V8 transmitters, the majority of which had been deployed in the rarely harvested strata. Nonfunctional transmitters were removed from recaptures and recoveries of telemetered individuals and sent to the vendor for examination. The transmitter failure was due to an apparent programming error.

Range Testing

The frequency of detections in the St. Jones River, DE varied by strata (Table 2-5), with the highest levels occurring in the rarely harvested stratum while the intensely harvest stratum provided the lowest detection frequency. Although the exact cause for this discrepancy is not known, I hypothesize that this difference was likely the result of a physical barrier between the transmitter and receiver during the range test. I had the opportunity to examine the area with a side-scan sonar (Humminbird 1198c-455/800 kHz dual frequency) after the study was completed and noticed a submerged tree between the receiver location and the transmitter. Unfortunately, I was not able to do this before the study was conducted; however, it paints a realistic picture of the obstacles influencing transmitter detections in the system. Additionally, based on the frequency of detections by strata, I estimated the number of detections that would occur for different swimming speeds of American Eel and the speed of the current of the St. Jones River, DE. My transmitters pulsed approximately 3 times for a fast eel with max current before it was out of detection range which based on my range tests and experiences manual tracking was assumed to be ≈100m in my system.

Home Range Assessment

Home range estimates for large yellow-phase telemetered American Eels averaged 25.0 ha (8.0-67.5 ha) for the 95% kernel estimator while the 50% kernel provided a mean estimate of 5.0 ha (1.9-15.9 ha) (Table 2-7). For medium yellow-phase telemetered American Eels, the mean home range was 28.0 ha (8.6-43.0 ha) for the 95% kernel estimator and 5.2 ha (2.2-12.3 ha) for the 50% kernel estimator (Table 2-7). Home range varied by strata, with the lowest home range estimates in the rarely harvested strata for both medium (mean 6.0 ha) and large (mean 6.2 ha) telemetered American Eel (Table 2-8). A few American Eels displayed large home ranges (Figure 2-5a and 2-5b) although overall home range estimates were generally low (Figure 2-5c and 2-5d). For instance, American eel 11559 (471 mm; 250 g) moved between all strata's and over all seasons (Figure 6). Seasonal home range estimates varied, with a 47.1 ha (95%) home range in the summer and 25.1 ha (95%) home range in the fall. When observing the seasonal core area of activity for American eel 11559, in the summer and fall it utilized 11.0 ha.

When only the core area of activity (50% kernel) was examined seasonal home range for large (Figure 2-7) and medium (Figure 2-8) yellow-phase American Eels do not vary. Seasonal home range estimates for large American Eels were highly variable with the spring and the fall generating the largest estimates when you consider the entire area used (95% kernel) (Figure 2-9). Medium yellow-phase American Eels showed similar results with larger home range estimates in the fall (Figure 2-10). It is important to note that the battery life of the medium American Eel transmitters prevented analysis of home range for the spring. Additionally, regardless of season, the home range estimates for telemetered American eel in the rarely harvested strata where very low for large (Figure 2-9) and medium (Figure 2-10) individuals.

Through the coupling of all multiple data sources, I was able to expand the sample size for home range estimates up to 71 American eels. An examination of the regression analysis suggested that there was no correlation (R^2=0.09) between the proportions of manual to combined relocation points by the % change in individual home range area (Figure 2-11). Therefore, I combined the data sets to perform the home range estimates for each telemetered individual as well as generating seasonal home range estimates. Furthermore, home range estimates utilizing only manual relocations were lower (17.0 ha) in comparison to the combined data set (25.0 ha) specifically for the entire area occupied (95% kernel) (Table 2-7).

2.4 Discussion

The use of the combined data sets (passive and manual relocation points, as well as recapture events) proved very beneficial for this study. The sole use of manual relocation points for assessment of home range in the St. Jones River produced low estimates (17.0 ha (95%), 3.7 ha (50%)) of home range when compared to the combined data set (25.0 ha (95%), 4.9 ha (50%)). Suggesting that home range estimates from the combined data better reflected the actual space American Eels were utilizing in the St. Jones River, DE. Passive relocations provided key insights into the timing and frequency of movements between strata allowing for a better understanding of the movements and home range of American Eels.

The inclusion of passive relocations sheds extensive light on seasonal home range estimates. In the fall and spring American Eel home ranges generally increased, although this is partially due to seasonal movements between the river and the bay. Previous studies have shown that yellow-phase American Eels display seasonal movements that are in response to changes in water temperatures among other parameters (Jessop 1987; Hammond and Welsh 2009; Thibault et al. 2007). The passive array detected several individuals moving between the river and the bay seasonally, possibly in search for overwintering grounds. The increase in home range is possibly a reflection of the distance that was traversed from one habitat to the other and not necessarily its seasonal home range. In the St. Jones River distances traversed by telemetered individuals in some instances were from the rarely harvested strata to the Delaware Bay (approximately 25 km). Average home range for American Eels varied between strata as well, with the lowest home range estimates in the rarely harvested strata for all size classes.

American Eels in the St. Jones River primarily exhibit high site fidelity. When 95% of their movement was captured I estimate a home range of 25.0 ha. Additionally, when only 50% of their movement is considered the home range is even less (4.9 ha).

My findings are comparable to results from other mark-recapture and biotelemetry studies for American eel (Oliveira 1997; Morrison and Secor 2003; Thomas 2006) which exhibit high site fidelity in other systems. Similar to previously documented findings, my results suggest the presence of occasionally high levels of variability between individual behaviors in my telemetered American Eels (Morrison and Secor 2003; Thomas 2006; Hammond and Welsh 2009). In my study several American eels exhibited extensive movements when compared to other individuals. However, manual relocations on their own did not display this increase in movement (less than ten relocations). For telemetered American eel 11559, movement between strata occurred consistently in the summer and the fall. Overall, this individual utilized an extensive area (46.3 ha) compared to the average home range estimate (25 ha (95%)); emphasizing the variability between individual behavior.

Addendum II was added to the American eel FMP to propose measures that would facilitate escapement of silver eels during or just prior to their spawning migration as a means to improve recruitment and abundance (ASMFC 2008). Restricting harvest to higher saline areas of estuaries has been proposed as a way to protect American eel stocks (Morrison and Secor 2003; Cucherousset et al. 2007) as females are more abundant in freshwater portions of rivers (Barber 2004). Previous works on habitat use of American eels suggest that they are a facultative catadromous species, giving them far more flexibility in habitat use (Daverat et al. 2006; Jessop et al. 2008). Future management measures should allow for the seasonal transitions between habitats and protect areas that include the full suite of habitat occupied by American Eels, Additionally, home range estimates for some American Eels in the St. Jones River were relatively expansive, with individuals moving between strata consistently in the summer and fall. My results support a buffer zone of at least 4km between fishing areas and freshwater protected areas which would help minimize the effect of American Eels moving from an un-harvested area into a fishing area previously suggested by Cairns (2009).

My findings bolster previous findings that home range size of yellow-phase American Eels is at least partially dependent on seasonality (Bozeman et al. 1985; LaBar and Facey 1983; Morrison and Secor 2004) although individual behaviors play an important role in developing management strategies for this species. Movements for American Eels in the St. Jones River increased in the fall and spring, while home range estimates varied between individuals. As such, spatial and temporal closures or development of special management areas (SMA's) should proceed with caution while taking into consideration the flexibility of habitat use by American Eels since a SMA may provide benefits for both the target species and the surrounding community as well (Airame´et al. 2003, Gerber et al. 2003).

Collection Date	Strata	Transmitter #	Length (mm)	Weight (g)	# Manual Relocations	# Passive Relocations	# Mark Recapture	95% Kernel (ha)	50% Kernel (ha)	Notes
6/22/2009	Intense	11529	493	235	3	0	0			*
6/23/2009	Intense	11534	533	320	1	13	0			*
6/23/2009	Intense	11535	474	175	0	120	0			*
6/23/2009	Intense	11536	491	245	1	0	1			*
10/30/2009	Intense	11536r	519		8	960	1	37.53	7.34	TR
6/23/2009	Intense	11537	536	305	6	0	0			*
6/23/2009	Intense	11538	468	205	3	3	3			*
6/23/2009	Intense	11539	505	225	23	1	0	10.51	2.70	
6/23/2009	Intense	11540	600	445	2	57	1			*
6/23/2009	Intense	11541	546	285	0	0	0			*
6/23/2009	Intense	11546	545	310	1	826	1	21.74	3.10	
6/23/2009	Intense	11547	561	270	0	1	0			*
6/26/2009	Intense	11549	546	345	0	312	0	33.67	7.32	
7/1/2009	Intense	11556	532	300	1	144	0			*
7/3/2009	Intense	11557	487	205	4	989	0	21.94	3.73	

Table 2-1a: Date of capture, transmitter number, length (mm), weight (gm), manual relocations, passive relocations, mark-recapture and commercial catch information for all American Eel tagged in the St. Jones River, DE intense harvest strata. Home ranges were not calculated for animals with less than 10 relocation points. Abbreviations: * = not enough manual tracking data to estimate home range; TR=Tag return through commercial harvest and re-used.

Collection Date	Strata	Transmitter #	Length (mm)	Weight (g)	# Manual Relocations	# Passive Relocations	# Mark Recapture	95% Kernel (ha)	50% Kernel (ha)	Notes
6/22/2009	Occasional	11533	461	210	4	7713	1	13.88	3.34	
6/23/2009	Occasional	11542	633	580	2	1989	2	27.82	3.24	
6/23/2009	Occasional	11545	466	210	8	285	0	42.48	8.51	
6/26/2009	Occasional	11550	438	175	10	106	1	23.11	5.96	
6/26/2009	Occasional	11552	535	305	4	1212	3	30.22	6.80	
6/26/2009	Occasional	11553	459	240	5	391	0	14.74	3.47	
7/1/2009	Occasional	11555	461	215	7	1361	0	50.10	8.02	
7/7/2009	Occasional	11559	471	250	2	2213	0	46.30	11.03	
7/7/2009	Occasional	11560	443	180	8	1450	0	64.02	15.96	
7/7/2009	Occasional	11562	567	325	12	49172	0	30.21	4.17	
8/20/2009	Occasional	11567	533	320	3	733	0	42.77	9.60	

Table 2-1b: Date of capture, transmitter number, length (mm), weight (gm), manual relocations, passive relocations, mark-recapture and commercial catch information for all American Eel tagged in the St. Jones River, DE occasional harvest strata. Home ranges were not calculated for animals with less than 10 relocation points. Abbreviations: * = not enough manual tracking data to estimate home range; TR=Tag return through commercial harvest and re-used.

Collection Date	Strata	Transmitter #	Length (mm)	Weight (g)	# Manual Relocations	# Passive Relocations	# Mark Recapture	95% Kernel (ha)	50% Kernel (ha)	Notes
6/22/2009	Rarely	11530	440	180	11	0	4	34.30	6.72	
6/22/2009	Rarely	11531	580	360	14	0	3	25.00	5.60	
6/22/2009	Rarely	11532	405	200	0	1	0			*
6/23/2009	Rarely	11543	695	595	12	9	0	22.96	3.63	
6/23/2009	Rarely	11544	490	260	6	45495	0	11.72	1.90	
6/28/2009	Rarely	11548	577	315	7	1	5	8.71	3.24	
10/23/2009	Rarely	11551	514	270	28	0	4	20.90	3.40	
6/26/2009	Rarely	11554	478	235	5	0	0			*
7/3/2009	Rarely	11558	475	230	6	14316	2	31.10	2.63	
10/30/2009	Rarely	11561	559	300	31	0	1	15.61	2.72	
7/7/2009	Rarely	11563	484	225	8	11	2	34.93	4.20	
7/7/2009	Rarely	11564	466	190	12	0	4	9.89	2.70	
7/18/2009	Rarely	11565	550	315	22	0	2	20.54	4.68	
7/19/2009	Rarely	11566	724	815	0	5	0			*
8/28/2009	Rarely	11568	550	325	23	0	5	8.05	2.23	

Table 2-1c: Date of capture, transmitter number, length (mm), weight (gm), manual relocations, passive relocations, mark-recapture and commercial catch information for all American Eel tagged in the St. Jones River, DE rarely harvest strata. Home ranges were not calculated for animals with less than 10 relocation points. * = not enough manual tracking data to estimate home range.

Collection Date	Strata	Transmitter #	Transmitter Type	Length (mm)	Weight (g)	# Manual Relocations	# Passive Relocations	# Mark Recapture	95% Kernel (ha)	50% Kernel (ha)	Notes
5/27/2010	Intense	37559	V9	535	275	19	0	0	9.48	2.41	
5/27/2010	Intense	37560	V9	566	365	1	0	0			*
5/28/2010	Intense	37561	V9	491	245	24	61605	0	48.41	5.05	
6/3/2010	Intense	37562	V9	578	405	15	35	0	24.76	3.85	
6/3/2010	Intense	37563	V9	486	255	3	0	0			*
6/4/2010	Intense	37565	V9	509	325	19	19887	0	58.46	11.90	
6/4/2010	Intense	37566	V9	570	425	16	79943	0	10.62	2.43	
6/4/2010	Intense	37567	V9	556	425	3	875	0	67.46	12.36	
6/8/2010	Intense	37568	V9	579	515	11	198	0	29.22	5.8	
6/10/2010	Intense	37575	V9	515	280	6	9877	0	12.70	4.20	
5/27/2010	Intense	37537	V8	429	180	5	0	0			*
5/27/2010	Intense	37538	V8	426	145	17	188	0	42.96	7.91	
5/28/2010	Intense	37539	V8	421	185	0	0	0			*
5/28/2010	Intense	37540	V8	427	160	18	0	0	12.93	3.11	
5/28/2010	Intense	37541	V8	400	125	8	8	1	34.72	6.44	
5/28/2010	Intense	37542	V8	430	180	17	98	0	29.11	4.12	
6/4/2010	Intense	37543	V8	425		3	13406	0	8.60	2.22	
6/7/2010	Intense	37544	V8	435	145	5	116	0	20.24	3.12	
6/8/2010	Intense	37545	V8	449	185	11	348	2	52.73	10.48	
6/10/2010	Intense	37546	V8	413	135	6	4	0			*
7/22/2010	Intense	37539r	V8	424		10	0	0	23.17	5.60	TR

Table 2-2a: Date of capture, transmitter number, length (mm), weight (gm), manual relocations, passive relocations, mark-recapture and commercial catch information for all American Eel tagged in the St. Jones River, DE intense harvest strata. Home ranges were not calculated for animals with less than 10 relocation points. * = not enough manual tracking data to estimate home range; TR=Tag return through commercial harvest and re-used.

Collection Date	Strata	Transmitter #	Transmitter Type	Length (mm)	Weight (g)	# Manual Relocations	# Passive Relocations	# Mark Recapture	95% Kernel (ha)	50% Kernel (ha)	Notes
6/4/2010	Occasional	37564	V9	526	305	16	135	2	41.60	6.30	
5/28/2010	Occasional	37569	V9	487	230	7	0	0			*
5/28/2010	Occasional	37570	V9	460	180	17	0	0	16.99	4.61	
5/28/2010	Occasional	37571	V9	505	250	23	0	0	16.76	3.35	
5/28/2010	Occasional	37572	V9	545	355	23	0	0	16.22	2.94	
5/28/2010	Occasional	37573	V9	475	255	17	12472	2	26.74	5.9	
6/4/2010	Occasional	37574	V9	576	395	17	7383	1	13.70	3.63	
6/7/2010	Occasional	37576	V9	489	215	21	0	0	10.96	2.53	
6/8/2010	Occasional	37577	V9	515	280	19	0	0	20.91	4.96	
6/8/2010	Occasional	37578	V9	505	265	19	23702	1	34.78	7.69	
5/27/2010	Occasional	37547	V8	405	115	17	0	1	12.25	2.67	
5/28/2010	Occasional	37549	V8	390	135	15	310	3	41.65	5.21	
5/28/2010	Occasional	37550	V8	402	150	9	0	1	13.61	3.42	
5/28/2010	Occasional	37551	V8	400	135	11	25775	2	17.24	3.27	
6/7/2010	Occasional	37553	V8	370	115	8	50855	2	40.26	4.90	
6/7/2010	Occasional	37554	V8	445	175	8	24	0	59.26	12.25	
6/7/2010	Occasional	37555	V8	415	150	5	1	0			*
6/8/2010	Occasional	37557	V8	448	175	5	65	4	19.67	4.80	
7/5/2010	Occasional	37587	V8	417	457	0	0	2			**
7/5/2010	Occasional	37588	V8	421	453	0	1	5			**

Table 2-2b: Date of capture, transmitter number, length (mm), weight (gm), manual relocations, passive relocations, mark-recapture and commercial catch information for all American Eel tagged in the St. Jones River, DE occasional harvest strata. Home ranges were not calculated for animals with less than 10 relocation points. * = not enough manual tracking data to estimate home range and ** = battery malfunction.

Collection Date	Strata	Transmitter #	Transmitter Type	Length (mm)	Weight (g)	# Manual Relocations	# Passive Relocations	# Mark Recapture	95% Kernel (ha)	50% Kernel (ha)	Notes
6/3/2010	Rarely	37579	V9	535	225	15	0	1	12.25	2.88	
6/3/2010	Rarely	37589	V9	521	260	8	0	2	9.85	2.29	
6/7/2010	Rarely	37590	V9	585	435	22	0	0	17.64	2.88	
6/8/2010	Rarely	37591	V9	561	380	9	0	0			*
6/8/2010	Rarely	37592	V9	655	615	15	0	0	11.31	2.60	
6/10/2010	Rarely	37593	V9	491	235	12	0	1	14.02	3.18	
6/11/2010	Rarely	37594	V9	457	240	18	0	0	9.56	2.31	
6/11/2010	Rarely	37595	V9	479	215	17	0	0	10.52	2.43	
6/14/2010	Rarely	37596	V9	530	370	14	11	2	28.10	6.31	
7/3/2010	Rarely	37597	V9	495		8	0	0			*
6/4/2010	Rarely	37552	V8	417	160	19	17750	2	15.60	4.60	
6/8/2010	Rarely	37556	V8	417	165	9	0	2	17.90	3.10	
5/27/2010	Rarely	37558	V8	445	185	16	18	0	39.98	7.27	
5/27/2010	Rarely	37580	V8	435	165	0	6	1			**
6/4/2010	Rarely	37581	V8	400	150	0	7	0			**
6/4/2010	Rarely	37582	V8	415	130	0	0	5			**
6/8/2010	Rarely	37583	V8	395	140	0	0	0			**
6/10/2010	Rarely	37584	V8	449	170	0	0	0			**
6/11/2010	Rarely	37585	V8	401	135	0	0	2			**
6/14/2010	Rarely	37586	V8	429	175	0	0	0			**

Table 2-2c: Date of capture, transmitter number, length (mm), weight (gm), manual relocations, passive relocations, mark-recapture and commercial catch information for all American eel tagged in the St. Jones River, DE rarely harvest strata. Home ranges were not calculated for animals with less than 10 relocation points. * = not enough manual tracking data to estimate home range and ** = battery malfunction.

Season	# of Relocations	# of Transmitters
Summer	69	2
Fall	289	12
Winter	7	1

Table 2-3: Seasonal detections of telemetered American Eels tagged in the St. Jones River, DE that were recorded in the Delaware Bay.

Harvest Strata	Season	Temp (°C)	DO (mg/L)	Salinity	Conductivity
Intense	Spring	19.54	5.61	11.52	18.96
	Summer	26.16	3.62	19.13	30.85
	Fall	12.51	16.26	14.00	24.42
	Winter	5.28	17.34	7.50	17.52
Occasional	Spring	22.70	4.10	9.70	16.44
	Summer	26.80	3.30	15.73	25.80
	Fall	12.08	14.15	11.68	18.20
	Winter	3.84	20.71	8.60	20.60
Rarely	Spring	20.12	10.21	7.37	3.52
	Summer	27.60	7.10	6.01	10.73
	Fall	11.73	10.92	6.43	7.13
	Winter	7.30	10.21	5.23	4.30

Table 2-4: Average water quality parameters in the St. Jones River, DE by season for each stratum recorded during all tracking events.

Harvest Strata	Actual # of detections	Predicted # of detections	Frequency
Rarely	21,020	43,470	0.48
Occasional	14,462	42,840	0.34
Intense	779	45,864	0.02

Table 2-5: Frequency of detections for transmitters during the range test in the St. Jones River, DE.

Events by strata			
Rarely	**Speed (m/s)**	**Time (s) to traverse 100 (m)**	**Estimated # of detections**
Fast River/Fast Fish	1.54	64.77	3.13
Fast River/Slow Fish	0.76	131.41	6.35
Slow River/Fast Fish	1.04	95.79	4.63
Slow River/Slow Fish	0.26	383.14	18.53
Occasional			
Fast River/Fast Fish	1.54	64.77	2.19
Fast River/Slow Fish	0.76	131.41	4.44
Slow River/Fast Fish	1.04	95.79	3.23
Slow River/Slow Fish	0.26	383.14	12.93
Intense			
Fast River/Fast Fish	1.54	64.77	0.11
Fast River/Slow Fish	0.76	131.41	0.22
Slow River/Fast Fish	1.04	95.79	0.16
Slow River/Slow Fish	0.26	383.14	0.65

Table 2-6: : Estimated number of detections a passive receiver will detect a telemetered American Eel over a 100m distance (+/- 50m of a passive receiver) under four scenerios involving combinations of river and fish speed (e.g. fast river/fast fish, fast river/slow fish, slow river/fast fish, and slow river/slow fish) in the St. Jones River, DE.

Data	Large		Medium	
	95 % Kernel(V9)	50% Kernel (V9)	95 % Kernel (V8)	50 % Kernel (V8)
Manual Relocation Points	17.22	3.68	19.50	3.90
Combined Relocation Points	24.71	4.86	27.88	5.24

Table 2-7: Average home range estimates by of telemetered American Eel in the St. Jones River, DE by size (large (≥ 400 mm) and medium (≤ 350-400 mm) based on both manual relocation and combined data sets (manual relocations, passive relocations and mark-recapture).

Strata	Large		Medium	
	95 % Kernel (ha)	50 % Kernel (ha)	95 % Kernel (ha)	50 % Kernel (ha)
Rarely	17.84	3.43	24.50	5.00
Occasional	28.50	5.92	29.13	5.22
Intense	29.73	5.55	28.05	5.40

Table 2-8: Average home range estimates by strata for both large and medium American Eels in the St. Jones River, DE. American Eel in the intense and occasional strata had larger home range compared to the rarely strata.

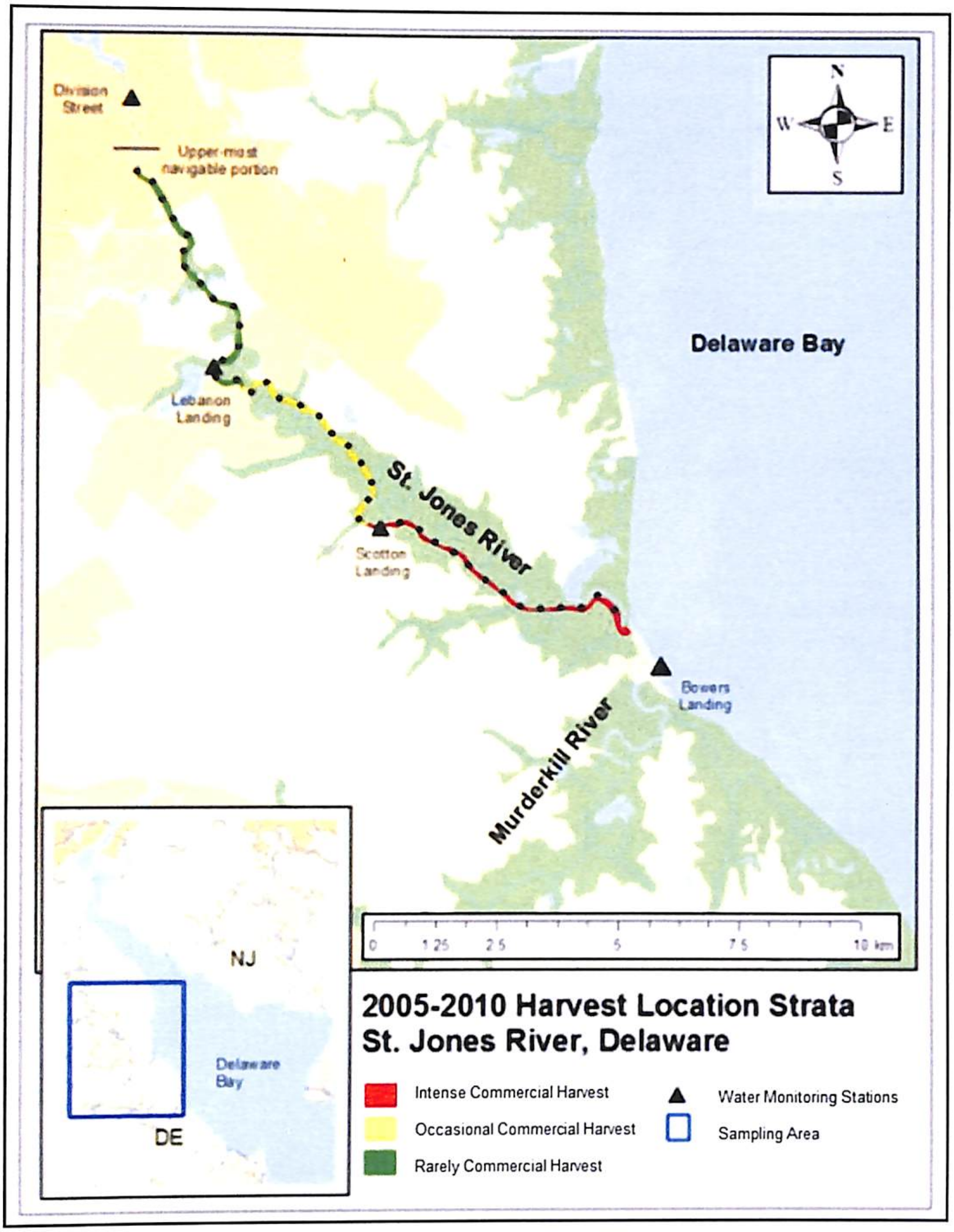

Figure 2-1: Location of the St. Jones River, DE, with sampling sites (black circles), American Eel harvest location strata (intense (red), occasional (yellow) and rarely (green)), and water quality stations (triangles).

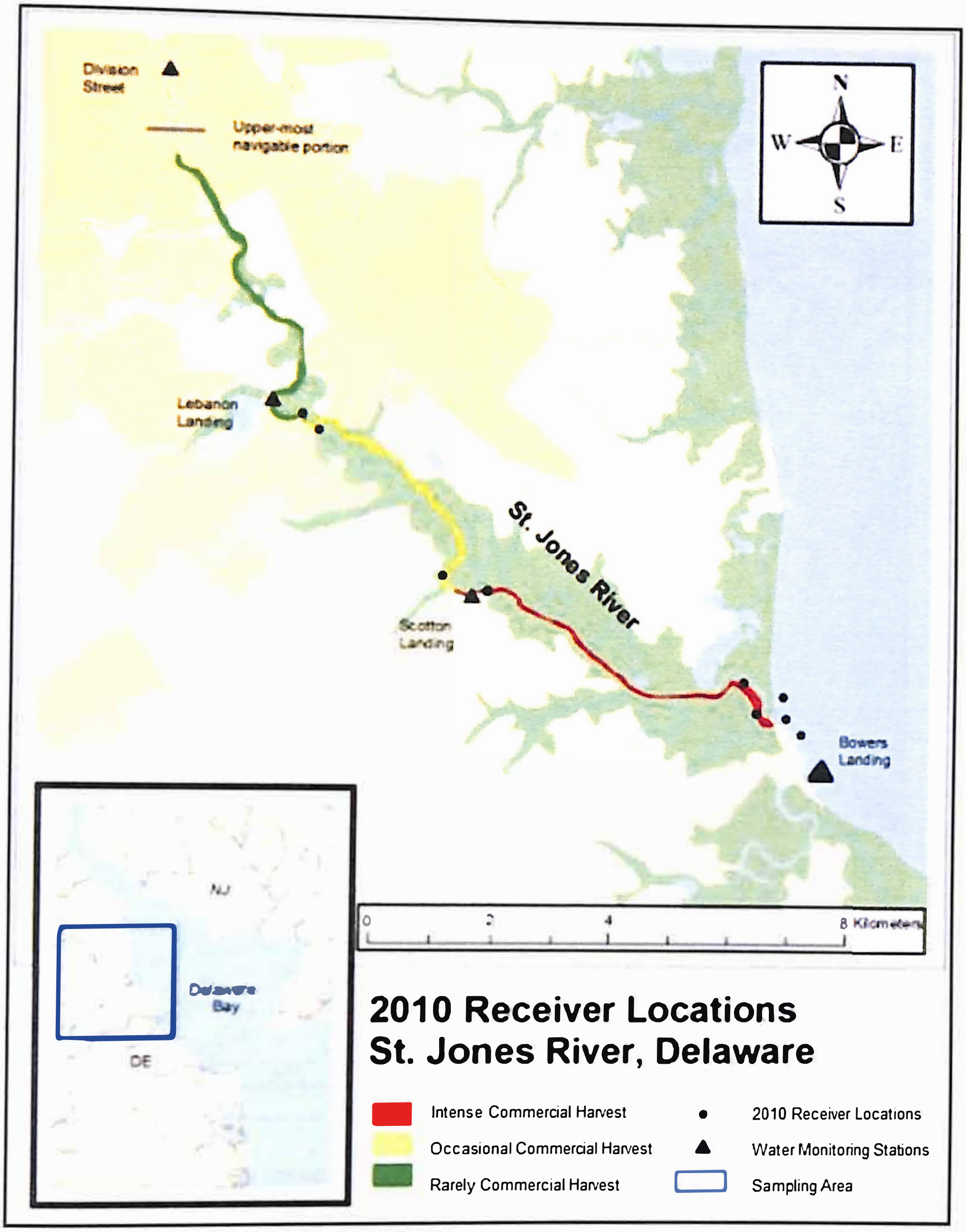

Figure 2-2: Locations of passive acoustic receivers (black circles), water quality monitoring sites (triangles) and American Eel harvest location strata (intense (red), occasional (yellow) and rarely (green)) in the St. Jones River, DE.

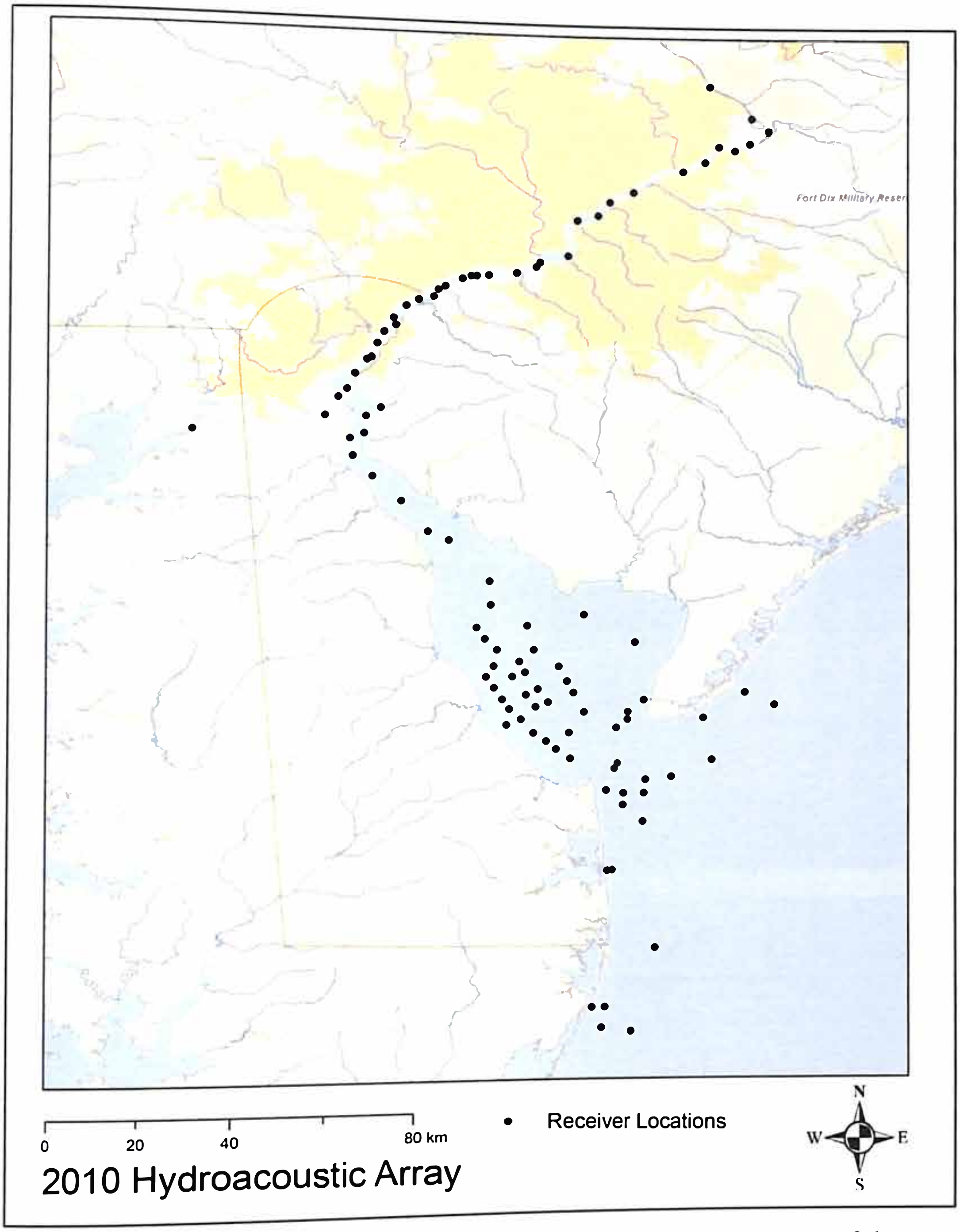

Figure 2-3: Locations of passive acoustic receivers in the waters of the Delaware River Estuary and near shore marine waters.

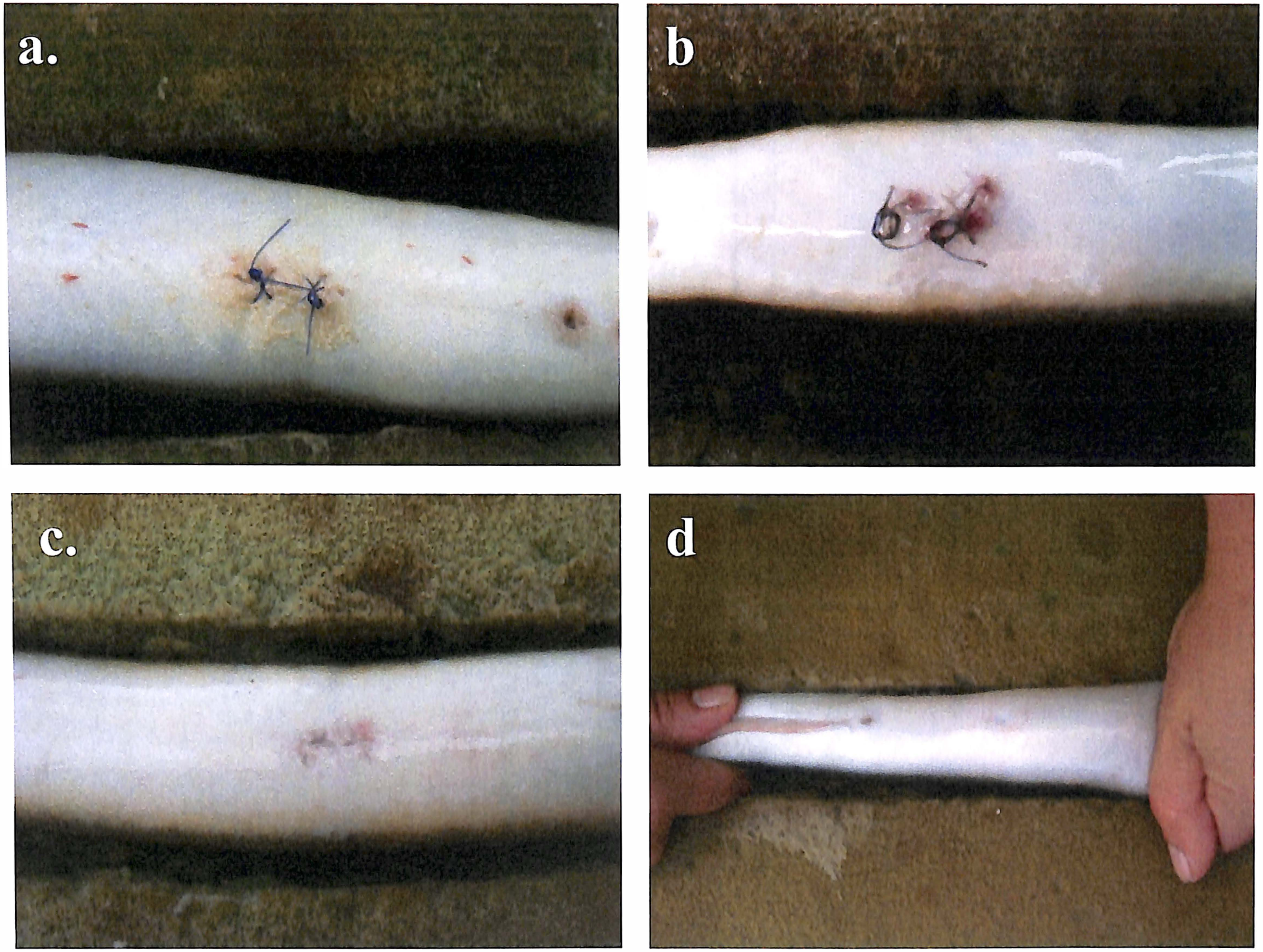

Figure 2-4: Healing times of sutures in American Eel 11552 (535 mm TL, 305 g) tagged in occasional strata: a. transmitter implanted 6/26/2009; b. recaptured 7/16/2009 (20 days after suture); c. recaptured 8/14/2009 (35 days after suture); and d. recaptured 9/11/2009 (63 days after suture).

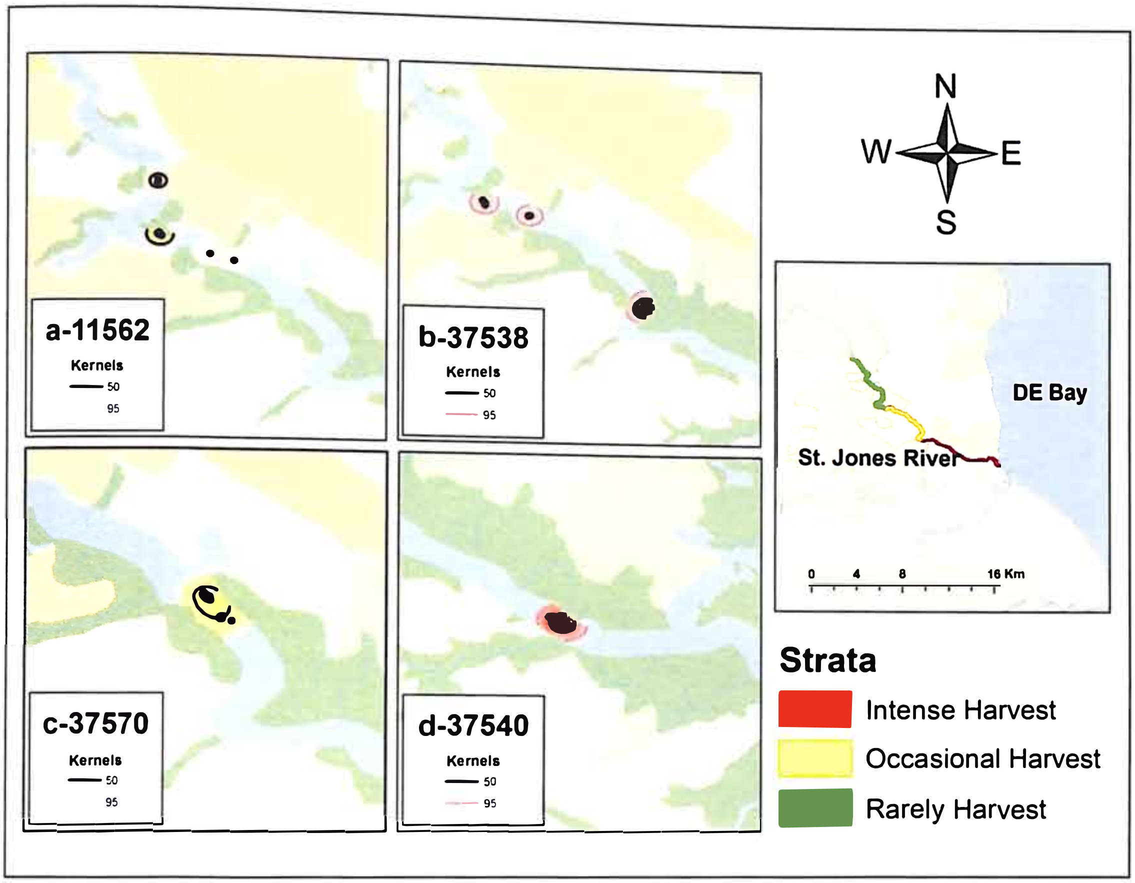

Figure 2-5: Representative home range estimates for yellow-phase American Eels in the St. Jones River, DE in both the intense (red) and occasional (yellow) harvest strata: a. a large home range for a large American Eel (#11562 (567 mm, 325 g)); b. a large home range for a medium American Eel (#37538 (426 mm, 145 g)); c. a limited home range for a large American Eel (#37570 (460 mm, 180 g)); and d. a limited home range for a medium American Eel (#37540 (427 mm, 160 g). Both 50% and 95 % kernels are shown for each example.

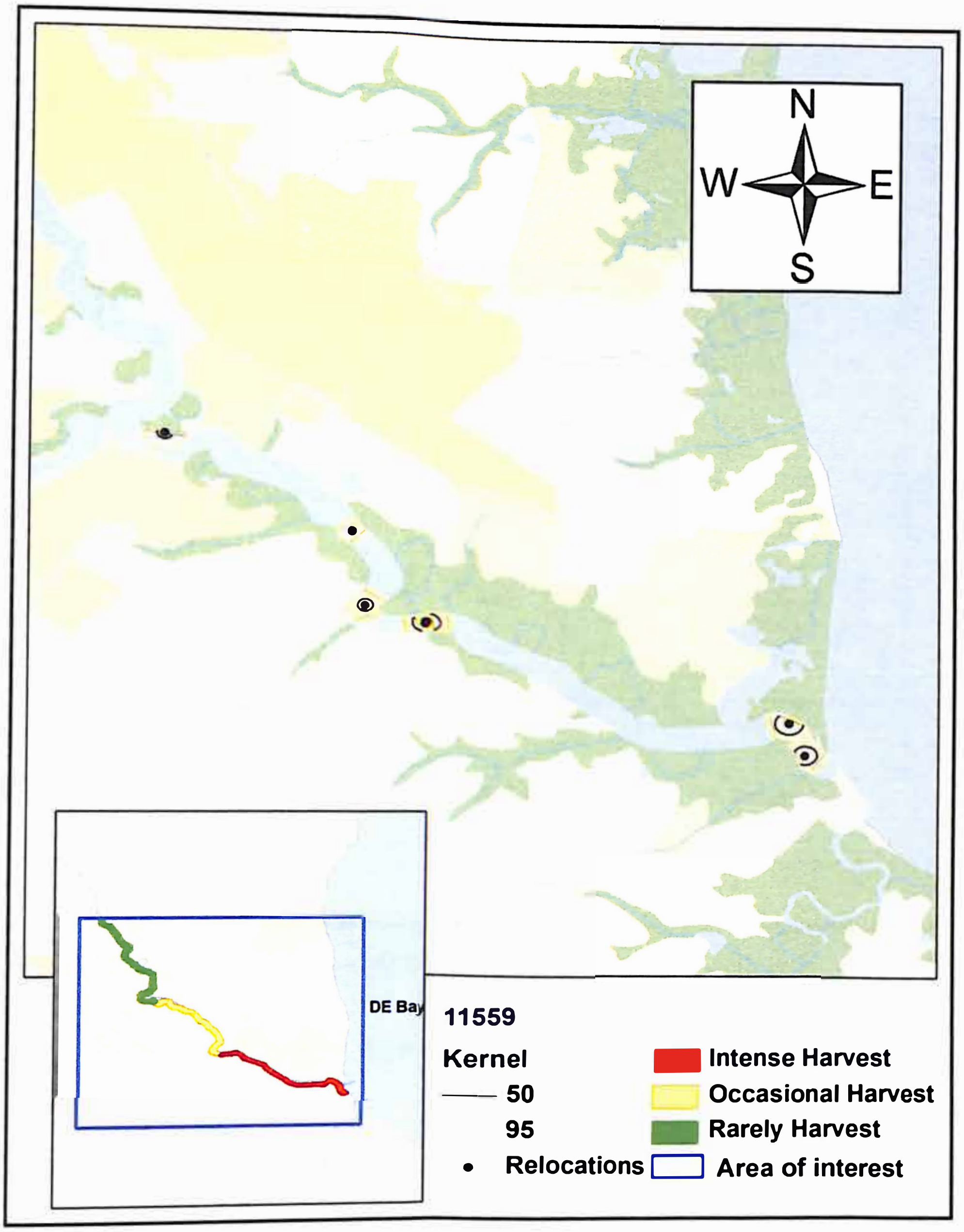

Figure 2-6: American Eel 11559, tagged in the occasional strata (471 mm, 250 g). Home range estimates were high for both the 95% (21.4 ha) and 50% (18.0 ha) kernels. Inset showing the entire St. Jones River, DE by harvest strata.

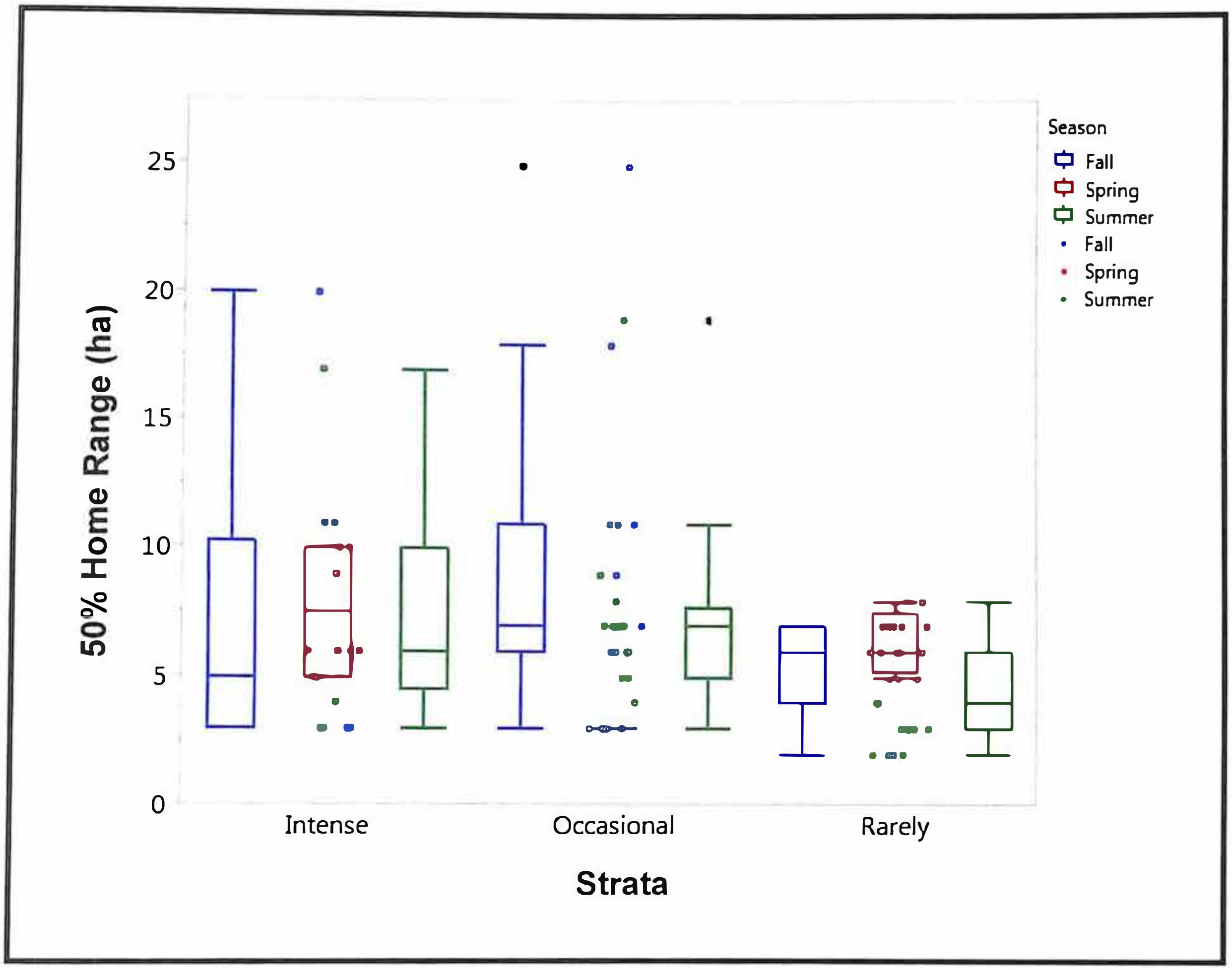

Figure 2-7: Seasonal home range (50% kernel) for large (≥400 mm) yellow-phase American Eels by harvest strata (intense, occasional and rarely) in the St. Jones River, DE by season (fall (blue), spring (red), summer (green)).

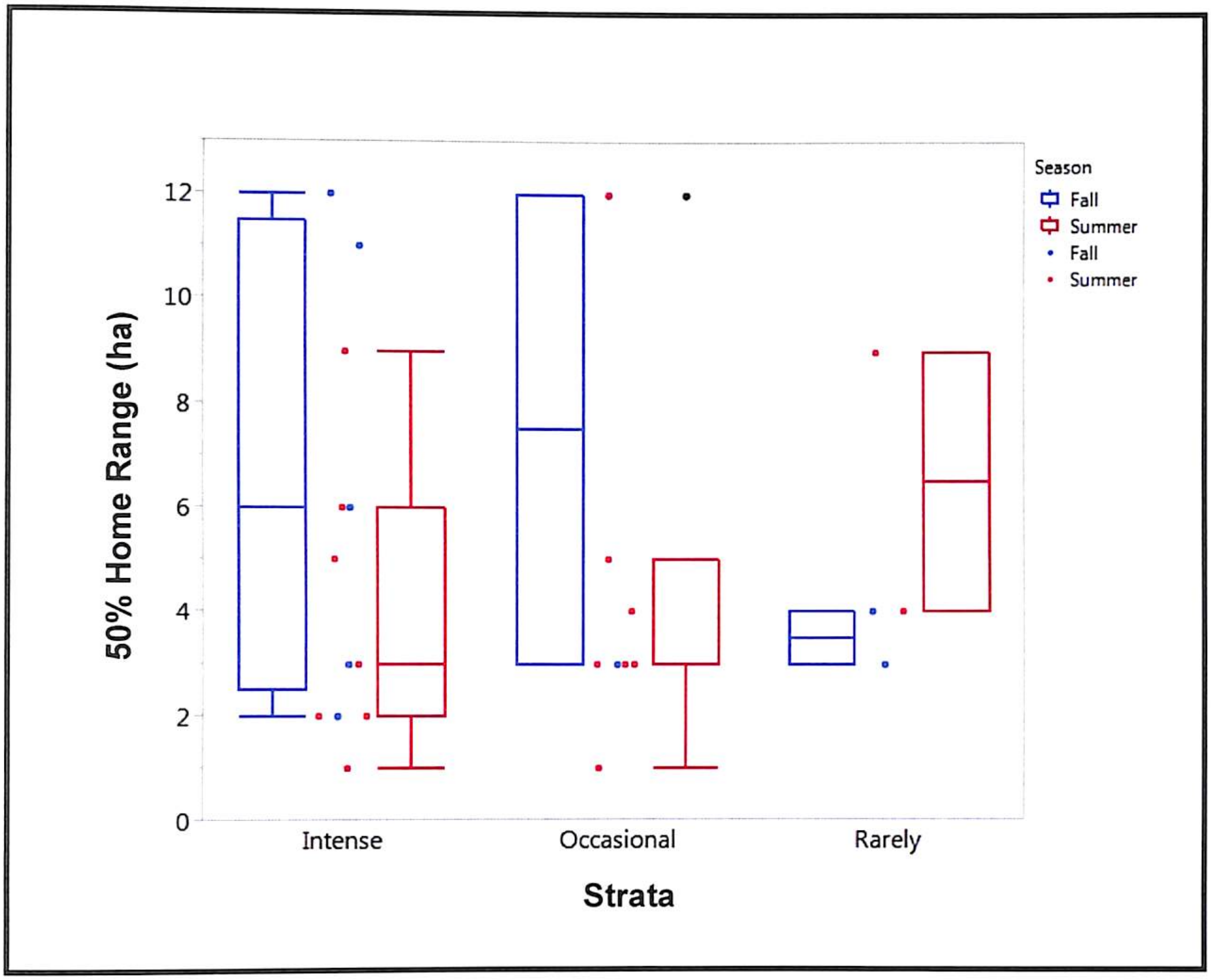

Figure 2-8: Seasonal home range (50% kernel) for medium (≥350-450 mm) yellow-phase American Eels by harvest strata (intense, occasional and rarely) in the St. Jones River, DE by season (fall (blue), spring (red), summer (green)).

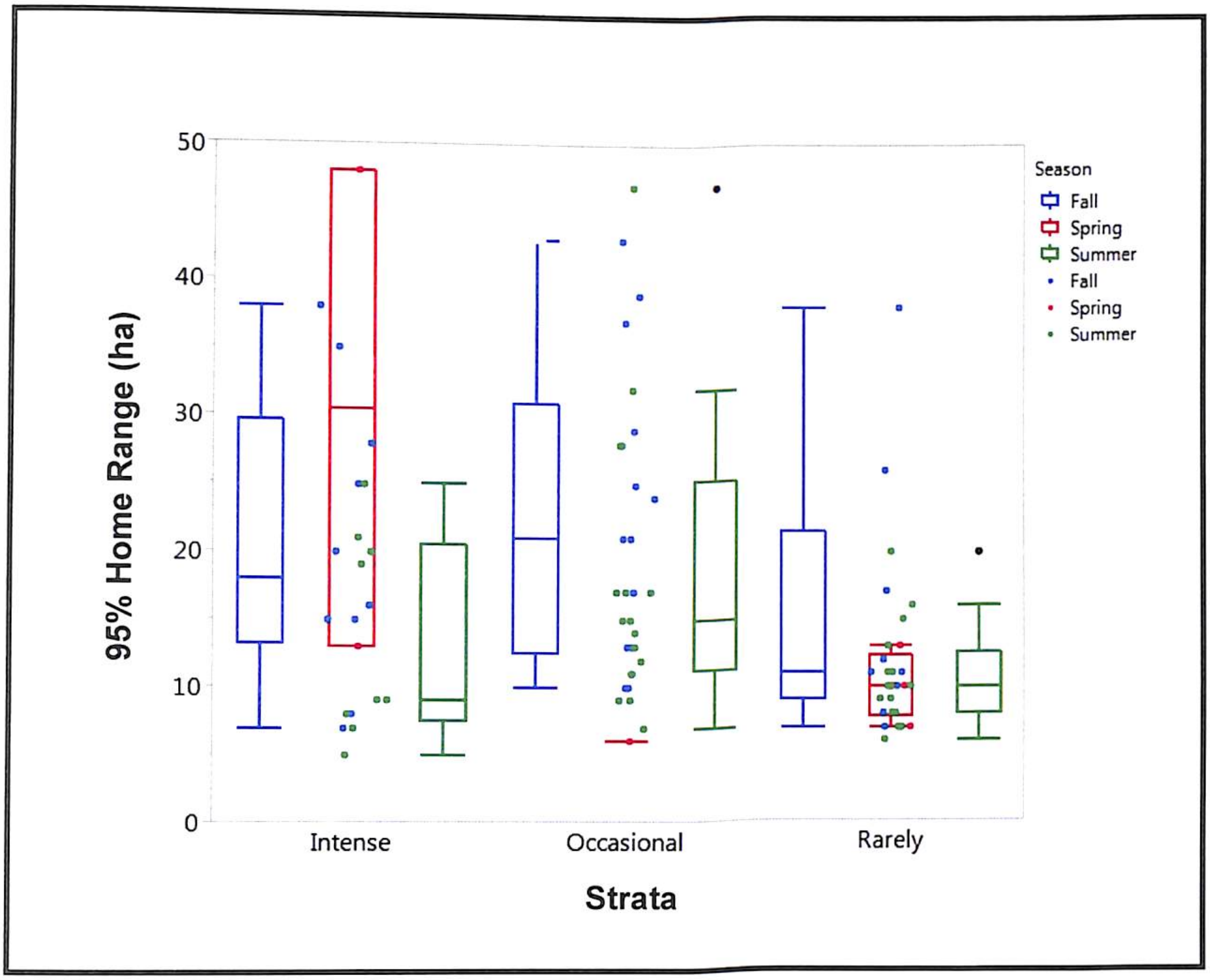

Figure 2-9: Seasonal home range (95% kernel) for large (≥400 mm) yellow-phase American Eels by harvest strata (intense, occasional and rarely) in the St. Jones River, DE by season (fall (blue), spring (red), summer (green)).

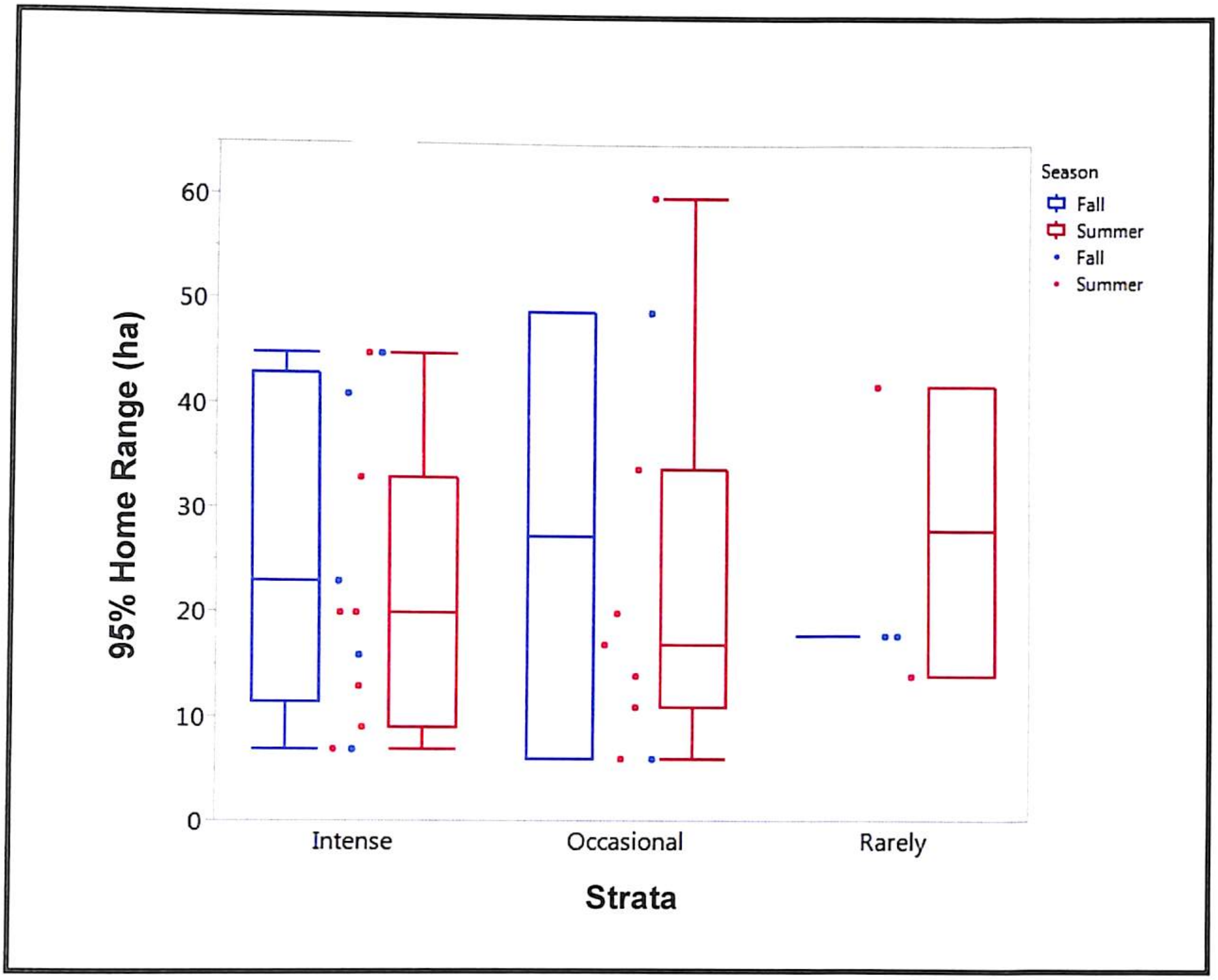

Figure 2-10: Seasonal home range (95% kernel) for medium (≥350-450 mm) yellow-phase American Eels by harvest strata (intense, occasional and rarely) in the St. Jones River, DE by season (fall (blue), spring (red), summer (green)).

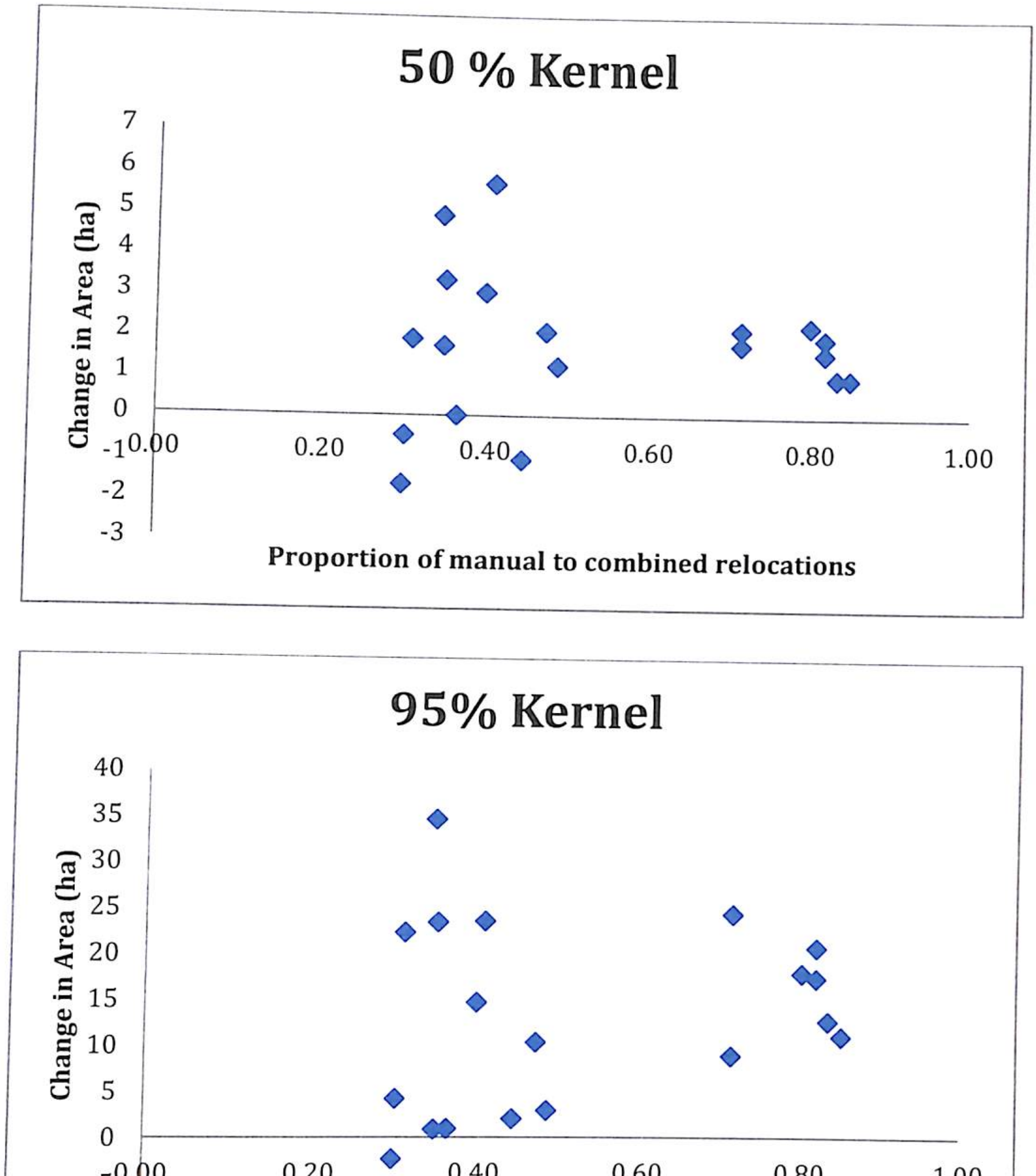

Figure 2-11: Plot of regression analysis for coupling manual relocations, passive relocations and mark-recapture events for telemetered American Eels in the St. Jones River, DE. R-square =0.09 and P-value=0.92.

CHAPTER III

Modeling environmental and spatial parameters that may influence movement behaviors of American eel (Anguilla rostrata) using passive telemetry data in the St. Jones River, DE

3.1 Introduction

The conservation and successful management of aquatic resources has become increasingly difficult for resource managers who often struggle with declining populations, increased demand, and anthropogenic changes in habitat. Some fisheries with long histories have recently begun to show signs of strain. The American Eel (*Anguilla rostrata*) fishery is one such example: landing data suggest declining catches, and resource agencies have noted a need for more detailed studies that address issues of survival, mortality, and habitat use (Casselman 2003, ASMFC 2007). American Eels undergo a complex life history (Daverat et al. 2006; Jessop et al. 2008) which is linked to a range of diverse habitats stretching from the open ocean to small freshwater systems; consequently a successful management plan must consider all of these attributes. The Atlantic States Marine Fisheries Commission (ASMFC) is tasked with protecting and enhancing American Eel abundance which requires an understanding of movement behavior as it is closely linked to habitat use. Specifically, a more complete understanding of the environmental drivers of American Eel movement behavior is needed if resource managers are to effectively oversee the fishery.

The behavior of American Eels has been examined in a wide range of habitats including estuaries (Helfman et al. 1983; Bozeman et al. 1985; Ford and Mercer 1986; Barbin et al. 1998; Dutil et al. 1989; Cairns 2009), tidal and non-tidal streams (Gunning and Shoop 1962), lakes and reservoirs (LaBar and Facey 1983; Lamothe et al. 2000; Thomas 2006), and large rivers (Oliveira 1997; McGrath et al. 2003; Hammond and Welsh 2009). A general model of American Eel behavior has emerged where seasonality plays a key role in mediating movements; with downstream movements in the fall, upstream movement in the spring, and reduced movement during the summer months with little or no information on behaviors during the winter months (Jessop 1987; Richkus and Dixon 2003; Thomas 2006; Thibault et al. 2007; Hammond and Welsh 2009; Cairns 2009). A number of environmental cues have been linked to eel movements, including water temperature (McGrath et al. 2003; Hammond and Welsh 2009), turbidity (Dutil et al. 1988; Hildebrand 2005), salinity (Winn et al. 1975; Tesch 1977; Daverat et al. 2006; Thibault et al. 2007; Jessop et al.2002) tides (Parker and McCleave 1997) and lunar illumination (Cairns and Hooley 2003; Hildebrand 2005; Hammond and Welsh 2009). American Eels are thought to maximize upstream movements in the spring during temperatures above 15 °C, downstream movements in the fall occur below 15° C, and typically temperatures below 10° C are a deterrent of movement (Walsh et al. 1983; McGrath et al. 2003; Verdon et al. 2003; Thibault et al. 2007; Hammond and Welsh 2009). Low light availability coincide with increased turbidity and river flow, and low levels of lunar illumination have been proposed as collective cues stimulating upstream American Eel movement (Dutil et al. 1988; Hildebrand 2005). Downstream movements are thought to primarily occur during darker nights in the fall (Cairns and Hooley 2003; Hildebrand 2005; Hammond and Welsh 2009) although rapid changes in water temperature or stream flow may stimulate movements. As a facultative catadromous species, American Eels are not restricted to freshwater environments and often occupy habitats that experience large tidally influenced salinity gradients in addition to their directed movements between habitats (Tesch 1977; Daverat et al. 2006; Thidbault et al. 2007; Jessop et al.2002). Furthermore, American Eels are thought to be more active at night (Helfman et al. 1983; LaBar et al.1987; Dutil et al. 1988; Dutilet al. 1989; Thidbault et al. 2007; Hedger et al. 2010). Like numerous other diadromous fishes, American Eels use tidal currents as a transport mechanism and possibly as a means of orientation with upstream movements typically occurring during ebbing tides with downstream movement taking place on flooding tides (Parker and McCleave 1997). Yellow-phase American Eels used selective tidal stream transport to make long, round trip excursions and to move about their home range (Parker and McCleave 1997).

Most studies addressing American Eel behavior in the mid-Atlantic have been descriptive in nature; those studies that include quantitative modeling usually have made use of mark-recapture data (e.g., Cairns 2009 and Fenske et al. 2010), which permit inferences about movement probabilities but are often restricted to coarse temporal scales. In this study, I will utilize passive acoustic telemetry to model movements of

American Eel. These data are gathered at a much finer temporal scale, permitting one to investigate the role of environmental covariates on eel behavior on a much finer temporal scale. Using these data, I will examine a number of environmental cues (i.e. water temperature (C°), salinity (ppt), turbidity (NTU), tides, lunar illumination, diel periods and season) that have been hypothesized to mediate American Eel behavior. In addition, I plan to investigate the interactions of individual size and commercial harvest pressures on eel behavior. Given the economic and ecological importance of American Eels, coupled with the concerns in population declines an improved understanding of the factors affecting behavior is central to successful conservation and management of this species.

3.2 Methods

Sampling

In 2009, a combined mark-recapture and telemetry study was initiated in the St. Jones River, DE (Figure 2-1). This watershed is 8,262 ha, is tidally influenced and exhibits seasonal variability in its physical parameters (DNERR 1999). There are three stations in the St. Jones River that record water parameters (temperature (°C), salinity (ppt), dissolved oxygen (mg/L), conductivity (mS/cm) and tides) continuously and one at the mouth of the neighboring river (Murderkill River). Retrieved data are available through the Delaware National Estuarine Research Reserve (DNERR) and U.S. Geological Survey (USGS). American Eels were implanted with transmitters and monitored over two field seasons (2009-2010). For more details on standardized sampling and handling protocols see Chapter 2 (methods). I tagged two size classes (350-449 mm (medium) and ≥450 mm (large)) in the study.

Telemetry

A total of 10 VEMCO Ltd VR-2 and VR-2W passive acoustic receivers were utilized in this study to of American Eel movements. Seven passive acoustic receivers where arranged in the St. Jones River to account for the immigration and emigration of telemetered American Eels, as well as movements between strata. Three passive acoustic receivers were placed near the mouth of the St. Jones River, in the Delaware Bay (Figure 2-2). Furthermore, there were a large number of fully compatible passive acoustic receivers placed throughout the Delaware Estuary and near shore marine waters (Figure 2-3). In addition to the passive array, I conducted weekly searches for telemetered individuals during ice-free months in all navigable portions of the St. Jones River using an omni-directional (VEMCO Ltd. VH165) hydrophone.

If a telemetered individual was detected on a receiver the direction of movement was inferred by the location of subsequent detections through a combination of manual and passive acoustic tracking. Hence if the telemetered individual was manually tracked above the location of the receiver, we know that the individual was moving upriver and vice versa. I censored the first 21 day(s) for individuals implanted with V9-2L transmitters (large (≥450 mm) yellow-phase American Eel). However, V8-4L (medium (350-450 mm) yellow-phase American Eel) transmitters were programmed to start transmitting after 21d post implantation to allow healing (Figure 2-4) and to increase tag longevity. In instances where telemetered individuals were recorded skipping a stratum (e.g. movement from the rarely harvested to intensely harvested stratum without being detected by receivers in the occasionally harvested stratum) the data were censored. The manual tracking data, recovery data (i.e. harvest), mark-recapture data, estimated battery life of the transmitter, as well as the passive data in some instances were used to determine the final hour that an individual was available to have moved between strata.

Data Formatting

To gain inference on the interplay between environmental drivers and spatial parameters on the fine scale movements of telemetered American Eels, I tabulated hourly response variables utilizing the passive and manual telemetry data and hourly covariates from a variety of sources. Continuous water quality data were obtained from stations along the St. Jones River, DE (http://cdmo.baruch.sc.edu) and the Murderkill River, DE (http://waterdata.usgs.gov/usa/nwis/uv?01484085) (Figure 2-1). Data were obtained from the Murderkill River, DE station due to a lack of environmental data for the mouth of the St. Jones River. The US Geological Survey (USGS) gauging station on the Murderkill River is <1km from the mouth of the St. Jones River, DE and it drains an area of similar size. Temperature, salinity, turbidity and water level were recorded every 15 minutes at these stations. The water level data were utilized to estimate tidal period (i.e. ebb, flood, high and low)(Bartholomew Wilson, DNREC, personal communication). Unfortunately, the Murderkill River station does not record salinity; however, a conversion equation developed by the USGS was utilized to estimate salinity for that site (Miller et al. 1988). The visible fraction of the moon's surface was utilized to quantify lunar illumination (http://aa.usno.navy.mil/data/docs/MoonFraction.html) while sunrise and sunset times were estimated through the use of an online calculator (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). Seasons were partitioned into spring (March 20-June 20), summer (June 21-September 21), fall (September 22-December 20), and winter (December 21-March 19). I developed two covariates from the temperature data. First, since previous studies suggested that upstream movements typically occur at temperatures≥ 15° C and downstream movements occur below < 15°C (Hammond and Welsh 2009), I developed a binary predictor variable which received a value of 1 if the temperature was greater than 15°C and 0 otherwise. However, I also hypothesized that 10°C might also be appropriate so I developed an analogous binary covariate based on a 10°C temperature threshold. Estimates of harvest pressure were provided through a combination of volunteer reporting from cooperating commercial harvesters (Mr. Ed Farrall, Harrington, Delaware and Mr. Mike Stansky, Smyrna, Delaware) as well as fishery independent surveys conducted during manual tracking events that consisted of recording the number and location of pots. Given that the vast majority of harvesters in the St. Jones River, DE reported effort which included number of traps and soak times time. I utilized the number of traps to determine harvest pressure for each stratum. Therefore, in a given day if there were traps in the strata I noted for how long they remained there. Previous work on American Eels in the St Jones River suggests that downstream movements were common for all size classes (Cairns 2009).

Model Development

Once the data were formatted I partitioned them into downstream, upstream, intense-bay and bay-intense transitions to model the following movement probabilities in four separate analyses: downstream (Ψ_{12} and Ψ_{23}), upstream (Ψ_{32} and Ψ_{21}), intense-bay (Ψ_{34}) and bay-intense (Ψ_{43}) (Figure 3-1). Movements were modeled with ten covariates derived from water temperature (°C) , lunar illumination, tidal stage, salinity (ppt), turbidity (NTU), diel period, season, size, initial strata (Figure 2-1) and harvest pressure (Table 3-1).

I used general linear mixed models (GLMMs) within an information-theoretic modeling framework (Burnham and Anderson 2003) to assess the importance of covariates in determining telemetered American Eel movement rates in the St. Jones River. In each case, the realized movement (moved=1, did not move=0) was treated as a Bernoulli response variable with a logit link function. In a GLMM, both fixed and random effects are incorporated in the linear predictor. A preliminary examination of data indicated considerable heterogeneity in movement among telemetered individuals, suggesting that it was important to account for individuals when modeling movement probabilities. When included, the other 10 covariates were treated as fixed effects (Table 3-1).

Model Selection

A number of models were fit to the data from each type of movement (upstream, downstream, intense-bay, bay-intense). To reduce the number of models, I included random effects for individuals in all models, as well as additive effects for "season", "diel period", and "initial strata" (site of initial capture). Based on previous American Eel research in the St. Jones River (e.g., Cairns 2009); and results from additional eel movement studies (Hammond and Welsh 2009), all of these play a role in eel movement behavior, and there seemed little reason to "test" whether these variables were of importance. However, I attempted to fit models incorporating all possible combinations of the remaining covariates; when the additive effects of comprising variables were also included, I also considered models that did or did not include several interactions (e.g. turbidity * diel period, turbidity * diel period * lunar, and season * size). A combination of increased turbidity and low levels of lunar illumination has been hypothesized to play a role in mediating the movement of American Eels (Dutil et al. 1988; Hildebrand 2005). Additionally, I hypothesized that individual size may play a role in the seasonal movements of American Eels as females mature at larger sizes (Oliveira 1997; Barber 2004). Models were fitted utilizing the R software package lme4 (http://lme4.r-forge.r-project.org/). Quasi-likelihood AIC (QAIC) was computed for all models to account for over-dispersion in count data (Burnham and Anderson 2003).

$$QAIC = -[\frac{2\log\left(\mathcal{L}(\hat{\theta})\right)}{\hat{c}}] + 2K$$

Models were ranked based on relative QAIC and model weights, which selects parsimonious models (or suite of competing models) (Burnham and Anderson 2002).

$$\Delta_i = QAIC_i - QAICmin$$

$$w_i = \exp\left(-\frac{1}{2}\Delta_i\right) / \sum_{r=1}^{R} \exp(-\frac{1}{2}\Delta_r)$$

Variable relative importance weights (sum of the Akaike weights for predictor variable i over all models in which i occurs) were determined for all modeled parameters (Burnham and Anderson 2002).

3.3 Results

A total of 58 telemetered individuals were utilized in this analysis out of the 102 American Eels that were implanted with transmitters. A total of 454,992 detections were recorded on the passive acoustic receivers, 969 manual relocations (72 tracking events), 43 recaptures, and 12 recoveries from the commercial catch. Telemetered American Eels were detected at a mean rate of 4,460 times (range 0-79,943) with an average of 9 (range 0-31) relocations on an omni-directional (VEMCO Ltd. VH165) hydrophone.

A total of 1,372 models were fit for the four possible American Eel movements between harvest strata transition types (downstream (R=504 models), upstream (R=504 models), intense-bay (R=332 models) and bay-intense (R=32 models) movements). All 504 possible models were successfully fit for both downstream and upstream transitions although only a limited number of models were successfully fit for the intense-bay and bay-intense transitions; only models that converged were utilized in the analysis.

Downstream movements

An examination of the QAIC on the analysis of downstream movements, indicated that 'Move~ Individual + Season +Diel period + Initial strata + Temperature ≤10 °C + Turbidity + Size + Tide + Season * Size + Turbidity *Diel period' was the most parsimonious model (Table 3-2). Diel periods and turbidity were associated with downstream movement, with the majority of American Eels moving downriver at night during periods of high turbidity (Figure 3-2). Downstream movements of American Eels occurred seasonally (Figure 3-3) and during temperatures above 10°C (Figure 3-4); in the summer (range 23.9-30.6 °C) and fall (range 9-25 °C) both large and medium individuals moved downstream although in the spring (range 12-29°C) the movement probability of medium sized individuals declined. However, movement probability of large individuals was highest in the spring. Telemetered American Eels exhibited increased probability of movement during periods of high turbidity at night although the majority of downstream movements occurred during the night for both size classes. Size appears to play some role in mediating the behavior of American Eels as large individuals moved downstream more often than medium American Eels, generally from the rarely harvest stratum to the occasional harvest stratum (Figure 3-5). Additionally, tidal stage likely plays a role in the behavior of American Eels as downstream movement probabilities were increased during the low and ebb-tide periods (Figure 3-6).

Upstream movements

An examination of the QAIC for upstream movements, indicated that 'Move~ Individual + Season +Diel period + Initial strata + Temperature ≤10 °C + Size + Salinity + Tide + Season * Size' was the most parsimonious model (Table 3-2). Increases in salinity were indicative of movement upriver (Figure 3-7), with the majority of movements occurring during high tide (Figure 3-8). Upstream movement probabilities were maximized during the summer although the movements of medium individuals tended to maximize in the spring and fall (Figure 3-9). Temperature and diel period appear to at least partially mediate American Eel upstream movement which were highest at temperatures greater than 10°C (range 9.3-27.0 °C) and during periods of daylight (Figure 3-10). Additionally, American Eels tended to move from the intense to the occasional harvest strata more often than from the occasional to the rarely harvest strata (Figure 3-11).

Bay movements

Intense Strata-Bay

The highest-ranked model for movement from the intense harvest strata into the bay was 'Move~ Individual+ Season +Diel period + Temperature ≤10 °C + Turbidity + Turbidity *Diel period'. Movements of telemetered American Eels increased more often from the intense strata to the bay during nights in the fall generally characterized by low turbidity (Figure 3-12) and temperatures above 10°C (range 9.3-22.3 °C (Figure 3-13).

Bay-Intense Strata

A lack of data prevented convergence for the majority of the bay-intense models which likely played a role in the fact that the highest ranked model for these transitions was the most simple (Table 3-2); suggesting that only season and diel periods play a role in movements into the river. Specifically, only data for summer and fall were available since we did not have receivers located in the bay during the spring and summer of the first year of the study due to funding restrictions.

3.4 Discussion

The behavior of American Eels is complex and appears to be controlled by a number of factors as highlighted through my modeling efforts. The movements of American Eels in the St. Jones River appear to be heavily influenced by seasonality as well as water temperature, tide, turbidity, salinity, diel periodicity, and individual size although I also documented considerable heterogeneity of individual movement rates for eels of the same size class. There was less support for models that used fishing effort or lunar illumination to explain movements (Table 3.2), suggesting that the behavior of eels in the St. Jones River is not influenced by harvest strategies, or that they key in on lunar cycles as has previously been reported in the literature (Hildebrand 2005; Hammond and Welsh 2009) (however, the lunar illumination covariate did not factor in cloud cover). Additionally, American Eels may not be moving into areas that are being harvested to take advantage of underutilized resources that have become available as previously been reported (Barber 2004; Cairns 2009) (Figure 3-5 and 3-11). Furthermore, temperatures ≥10 °C did a better job of predicting movements in our system, I included temperature

≥15 °C as a covariate as it has been reported that upstream movements typically occurred above this temperature threshold (Hammond and Welsh 2009).

Downstream movements of American Eel appear to be most influenced by temperatures ≥10°C although my results suggest that movements differed seasonally between size classes as well. Large American Eels moved downstream in the spring across a broad range of temperatures (12-29 °C). Movement downriver in fall (9-25 °C) was limited possibly as individuals were transitioning from the river into the bay, perhaps in search of overwintering areas (Hammond and Welsh 2009). Both size classes displayed downstream movements in the summer, which may be an indication of American Eel foraging behavior. As outlined in Chapter 2, the estimated home ranges for telemetered American Eels showed a high degree of seasonality and were very limited in the summer over all strata and size classes with a generalized pattern of increases in home range for both the fall and spring which may be coincident with a shift in habitat occupancy (i.e. American Eels in search of overwintering areas (bay/upper reaches of the river) in the fall and returning to their home (river/stream) in the spring). However, there is some individuality in home range size emphasizing that these movements in the summer may be an indication of foraging and utilization of available habitat. The increase in movements of American Eels at night are well documented (Lowe 1952; Wenner and Musick 1975), similarly in the St. Jones River movement increased at night during periods of high turbidity although, the majority of downstream movement occurred during the day. My findings suggest that American Eels primarily utilized both low and ebb tide for downstream movements which helps refine our understanding of this species. Previous work on tidally mediated movements suggests that American Eels generally lack precision in timing their movements to maximize transport on each tide; however, it was demonstrated that both yellow and silver phase American Eels utilized selective tidal stream transport during movements in tidal habitats (Parker and McCleave 1997). My findings also suggest that downstream movements occurred during high and flood tide; emphasizing the lack of timing to maximize transport. However, it is possible that eels are moving along the edges of the river utilizing the counter current flow.

Upstream movements of telemetered American Eels appear primarily dependent on season, diel periodicity, temperature, size, salinity, and tides. Similar to downstream movements, temperatures ≥10°C may have served as an environmental cue for the upstream movements of American Eels. Large American Eels upriver movements increased in the summer. Medium American Eels moved upriver in the spring over broad temperatures (range 11.8-27.0°C), possibly migrating (Jessop 2003; Hammond and Welsh 2009) to freshwater areas where productivity is generally lower although individuals may be balancing this with decreased predation risk (Oliveira and McCleave 2002). Additionally, telemetered American Eels may be returning to areas previously occupied after moving downstream during the winter. In Delaware, it is thought that there may be a generalized shift in habitat use, with American Eels moving to the bay in the fall and then back to the rivers/creeks in the spring (John Clark, Delaware Division of Fish and Wildlife, personal communication) although quantifiable data are lacking.

Moreover, it is hypothesized that female American eels move upstream where predation risk is low, maximizing size for their eventual migration to spawn (Oliveira 1997; Barber 2004). Ichthyofaunal surveys (DNERR) conducted in the St. Jones River, DE suggest that White Perch (*Morone americana*) along with some Striped Bass (*Morone saxatilis*) are present in the system during their juvenile phase. Considering the size of American Eels studied, more than likely they move upriver were they prey on these fish (e.g. white perch and striped bass). In the fall (range 9.1-25.3°C), large and medium American Eels displayed upriver movements perhaps maybe in search for areas to hibernate in mud bottoms (Smith and Saunders 1955; Compton 1968). Studies in Canada suggest a different approach, with American Eels moving towards the estuaries in the fall where they burrow in the mud to avoid freezing (Jessop 1987). American Eels in the mid-Atlantic may utilize a different strategy considering the risk of freezing throughout the water column is not very high in most tidal creeks. Additionally, it is important to note that the initial capture location of individuals may play a role in determining movement upstream/downstream in search for overwintering areas as American Eels in the St. Jones River also move downstream towards the estuary and bay in the fall. Salinity also likely played a role in upstream movements; during high tide when salinity was maximized American Eels in the St. Jones River, DE migrated upstream. Physiological requirements in the American Eel possibly trigger movement upriver at high tide when salinity is maximized; because they are moving from an area of high salinity into an area of relatively low salinity.

The movements from the St. Jones River to the Delaware Bay were likely influenced by seasonality as well as temperature. During the fall in low turbidity conditions and temperatures ≥10°C (range 9.3-22.3 °C), American Eels were more likely to move from riverine to bay habitats suggesting that a search for overwintering areas or the initiation of the spawning migration to the Sargasso Sea. A study conducted in two freshwater tributaries in the mid-Atlantic indicated that silver-phase American Eel migrate in the fall (Barber 2004), the last major pulse of maturing individuals in this study occurred in early October when temperatures approached 10.2 °C. In addition, Barber (2004) reported that yellow-phase American Eels move towards the bay possibly because of high densities of eels in estuarine environments. The majority of American Eels that moved from the lower portion of the St. Jones River into the bay were large in size (519-580mm). In the mid-Atlantic it is generally believed that American Eel's ≥450mm are females while smaller individuals are comprised of immature females and mature/maturing males (Barber 2004). In my study the emigration from riverine to bay waters may have been due to the start of maturation and spawning for large females. Conversely, it is possible that these telemetered individuals moved into the bay in the fall and the following spring moved into other tidal rivers along the coast. Although, I did not scan commercial harvest for the presence of PIT tags in other nearby systems, I had the opportunity to scan the commercial harvest from other nearby rivers for transmitters and did not recover any telemetered individuals from these systems.

Movement towards higher saline waters may also be related to thermal refugia and the physiological requirements in the American Eel (Thibault et al. 2007). One American Eel that moved from the river into the bay in the fall was encountered in the commercial fishery the following spring. Additionally, this same individual was detected in the river prior to harvesting in early March, emphasizing the existence of a general shift in habitat occupancy by American Eels (i.e. eels moving into the bay in the fall and back into the river in the spring) which has been suggested for the mid-Atlantic (John Clark, Delaware Division of Fish and Wildlife, personal communication). Based on range testing estimates, the frequency of detection at my study site were generally low, likely due to a variety of reasons including the transmitter power output, ambient noise, and physical obstructions to signal reception (e.g. snags, sandbars, and stream sinuosity) (Chapter 2). In addition, receivers in the nearby bay (i.e. 500 meters from the mouth of the St. Jones River, DE) were not available until the second field season. However, I documented 16 telemetered individuals near the mouth of the river in the fall of 2009 (not included in the model) of which only one was detected the following spring in the river highlighting the possible migration of American Eel in the fall for spawning, as well as the general shift in habitat between the river and the bay.

Summer movements of American Eel from the river to the bay occurred consistently for some individuals with correspondingly low overall home range estimates for the majority of telemetered individuals (See Chapter 2). Additionally, overall movements in the winter were very low with one individual moving from the river to the bay at 7°C. Similarly, in the Shenandoah River, WV, most individuals moved less than 5 m between relocations during winter (Hammond and Welsh 2009). Additionally, another study reported downstream movements of silver-phase American Eels at water temperatures as low as 6°C (Euston et al. 1998). Moreover, an increase in movement downstream in the fall may be an indication that more American Eels are moving towards the bay seasonally.

Water temperatures appear to be a particularly important cue in mediating seasonal movements of American Eels. In my study, temperatures ≥10°C triggered both upstream/downstream movement and migrations. Size also played an important role in movements for American Eel; large and medium individuals displayed different strategies for moving upstream, downstream and between the river and the bay. Additionally, the location before movement is important in determining what direction to move in.

My findings support the premise that environmental factors influenced the probability of movement for American Eels more than harvest in the St. Jones River as originally proposed by Cairns (2009). Since decreases in American Eel densities in estuaries impact movement probabilities from one area to another (Barber 2004; Cairns 2009), this hypothesis may hold true. Harvesters in the mid-Atlantic region will fish an area for relatively short periods of time (<2 weeks), until catches decrease and then return after an extended period of time (>2 months) (Barber 2004; Cairns 2009); suggesting that American Eels will occupy regions that have been previously harvested as resources in these areas have become available. Cairns (2009) reported that 15% of recovered American Eels came from areas that were not harvested undermining the effectiveness of the proposed reserves (Morrison and Secor 2003; Cucherousset 2007) to protect American Eel populations as exploited areas were re-occupied by individuals moving from other habitats. Twelve percent of the telemetered individuals in my study were caught in the commercial fishery; however all of them were released in the intense and occasional strata. Although, none of the telemetered individuals that were caught in the fishery came from the rarely harvested strata, it is important to note that home range estimates for American Eels were generally low, but increased seasonally (Chapter 2). Therefore, the creation of a "buffer zone" between marine reserves and fishing areas as suggested by Cairns (2009) may prove an effective management tool for the conservation of this important resource. Insights from my study have improved our understanding of movement ecology of large and medium yellow-phase American Eels in the mid-Atlantic region, and should allow for better management and conservation.

Variable name	Variable type	Definition	Levels
Individual	Continuous	Telemetered individuals utilized in this study	
Initial strata	Categorical	Strata from where movement occurred	Intense, Occasional, Rarely
Diel period	Categorical	Day and night hourly	Day, Night
Temperature ≥ 15°C	Categorical	Hourly temperatures ≥ 15°C	Above, Below
Temperature ≥10°C	Categorical	Hourly temperatures≥10°C	Above, Below
Salinity	Continuous	Dissolved salt content in a body of water (PPT) in the river hourly	
Turbidity	Continuous	Suspended solids (NTU) in the river hourly	
Lunar illumination	Continuous	Percent of the moon illuminated hourly	
Size	Categorical	350-400 mm (medium) and ≥450 mm (large)	Medium, Large
Harvest	Continuous	Number of pots utilized by the commercial harvester in each stratum hourly	
Season	Categorical	Seasons hourly	Winter, Spring, Summer, Fall
Tide	Categorical	Rise and fall of sea level hourly	High, Low, Ebb, Flood

Table 3-1: Parameters definitions, utilized to model American Eel movement in the St. Jones River, DE.

Variable	**Downstream**	**Upstream**	**Intense-Bay**
Temp10	0.99	0.85	0.62
Temp15	$9.74e^{-05}$	0.06	0.13
Turbidity	0.96	0.37	0.92
Salinity	0.31	0.99	0.34
Lunar illumination	0.32	0.34	0.34
Size	0.84	0.99	0.39
Harvest	0.27	0.23	0.48

Table 3-2: Variable importance weights for downstream, upstream and Intense-Bay movements of American Eels in the St. Jones River, DE; all parsimonious models for each movement type included highly weighted variables.

Model	Movement	QAIC	Aw_i
Move ~ Individual + Season +Diel period + Initial strata + Temperature ≥10 °C + Turbidity + Size + Tide + Season * Size + Turbidity *Diel period	Downstream	2646	0.21204
Move ~ Individual + Season +Diel period + Initial strata + Temperature ≥10 °C + Size + Salinity + Tide + Season *Size	Upstream	2520	0.24734
Move~ Individual + Season +Diel period + Temperature ≥10 °C + Turbidity + Turbidity *Diel period	Intense-Bay	243	0.04752
Move ~ Individual + Season +Diel period	Bay-Intense	8	0.27209

Table 3-3: Highest ranked QAIC models for movement probabilities of American Eel from the set of four movement analyses for the St. Jones River, DE. Lack of data prevented convergence for all but the simplest of models fpr Bay-Intense transition.

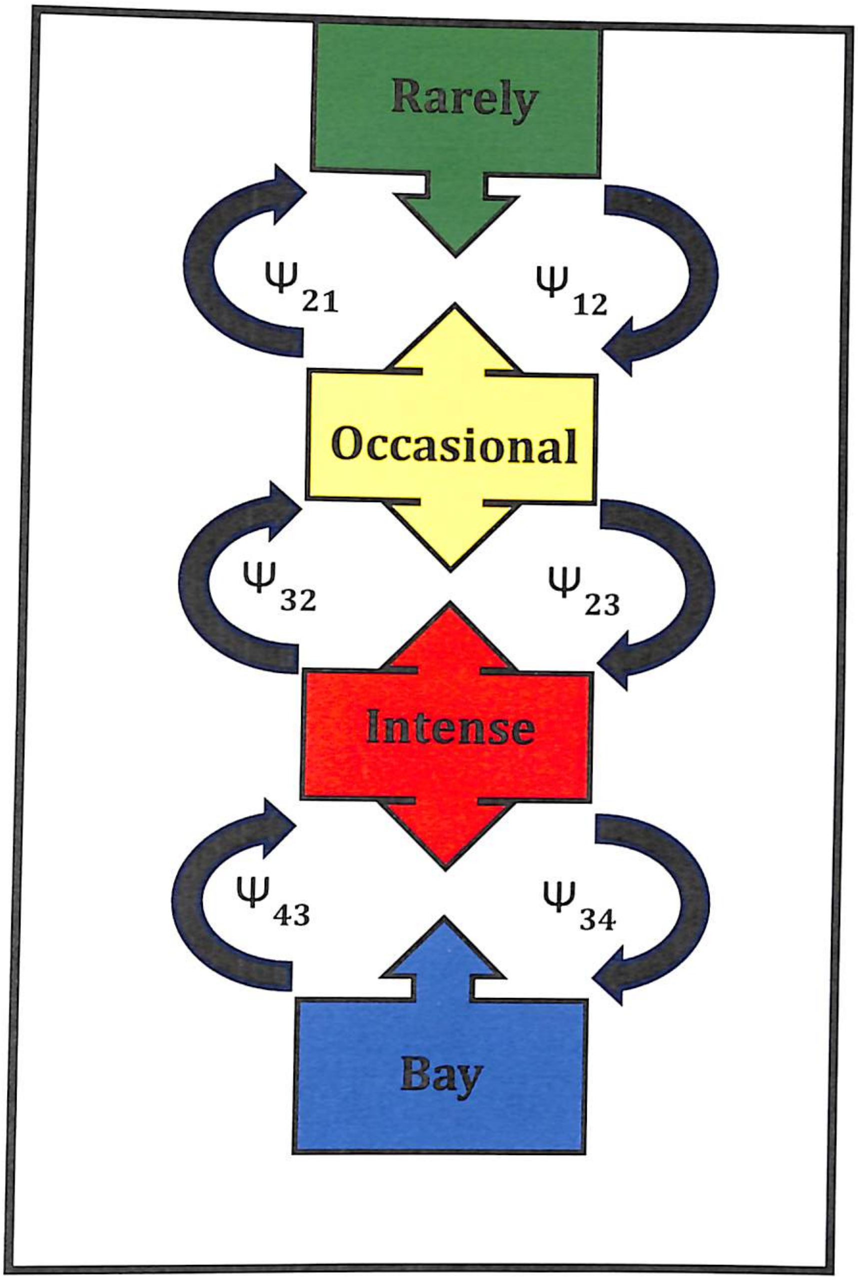

Figure 3-1: Schematic of modeled movements of American Eel in the St. Jones River, DE by strata (rarely, occasional, intense and bay); downstream (Ψ_{12} and Ψ_{23}), upstream (Ψ_{32} and Ψ_{21}), intense-bay (Ψ_{34}) and bay-intense (Ψ_{43}).

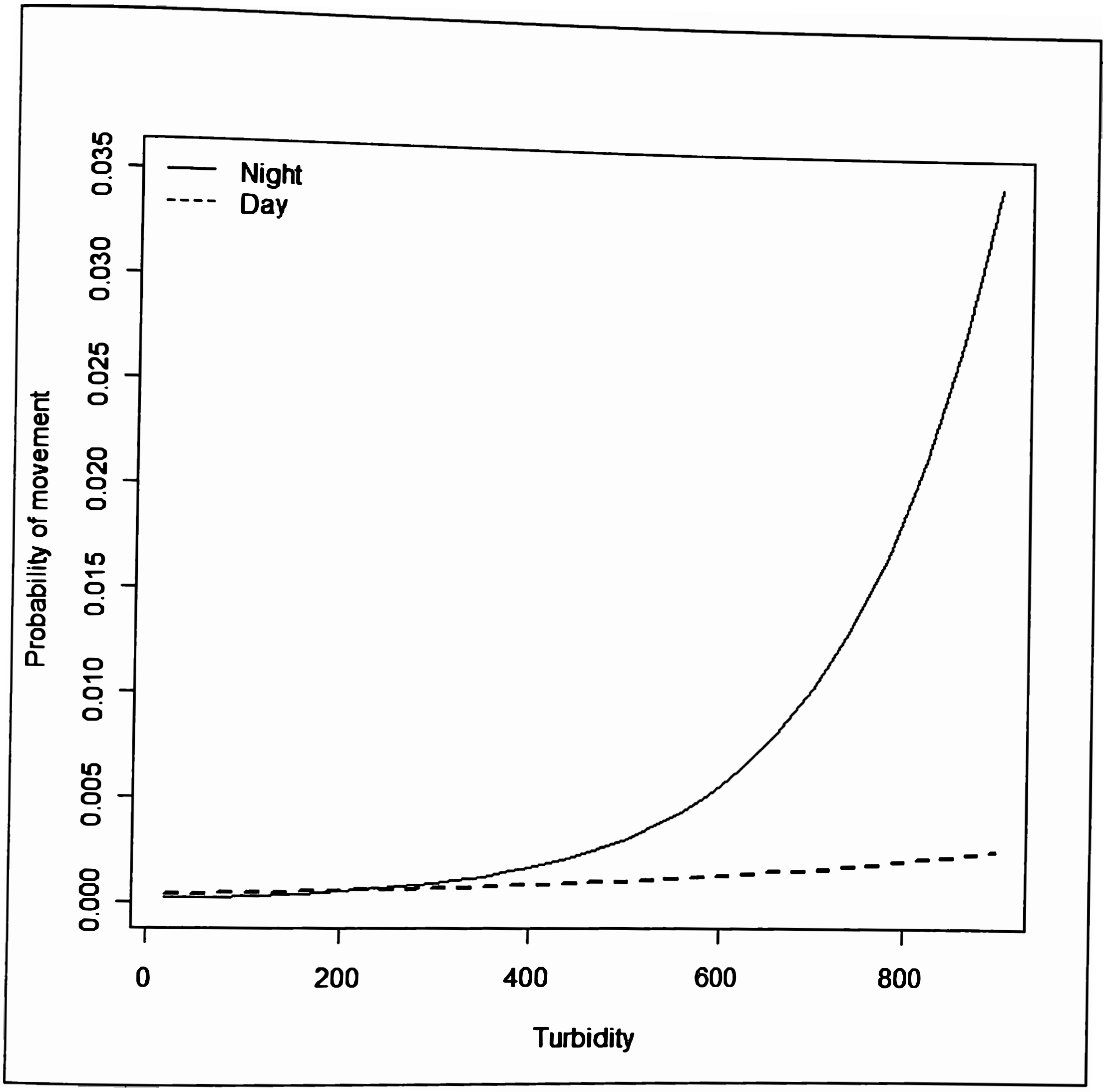

Figure 3-2: Effect of turbidity on hourly downstream movement probabilities for yellow-phase American Eel in the St. Jones River, DE as estimated by the highest-ranked QAIC mixed model.

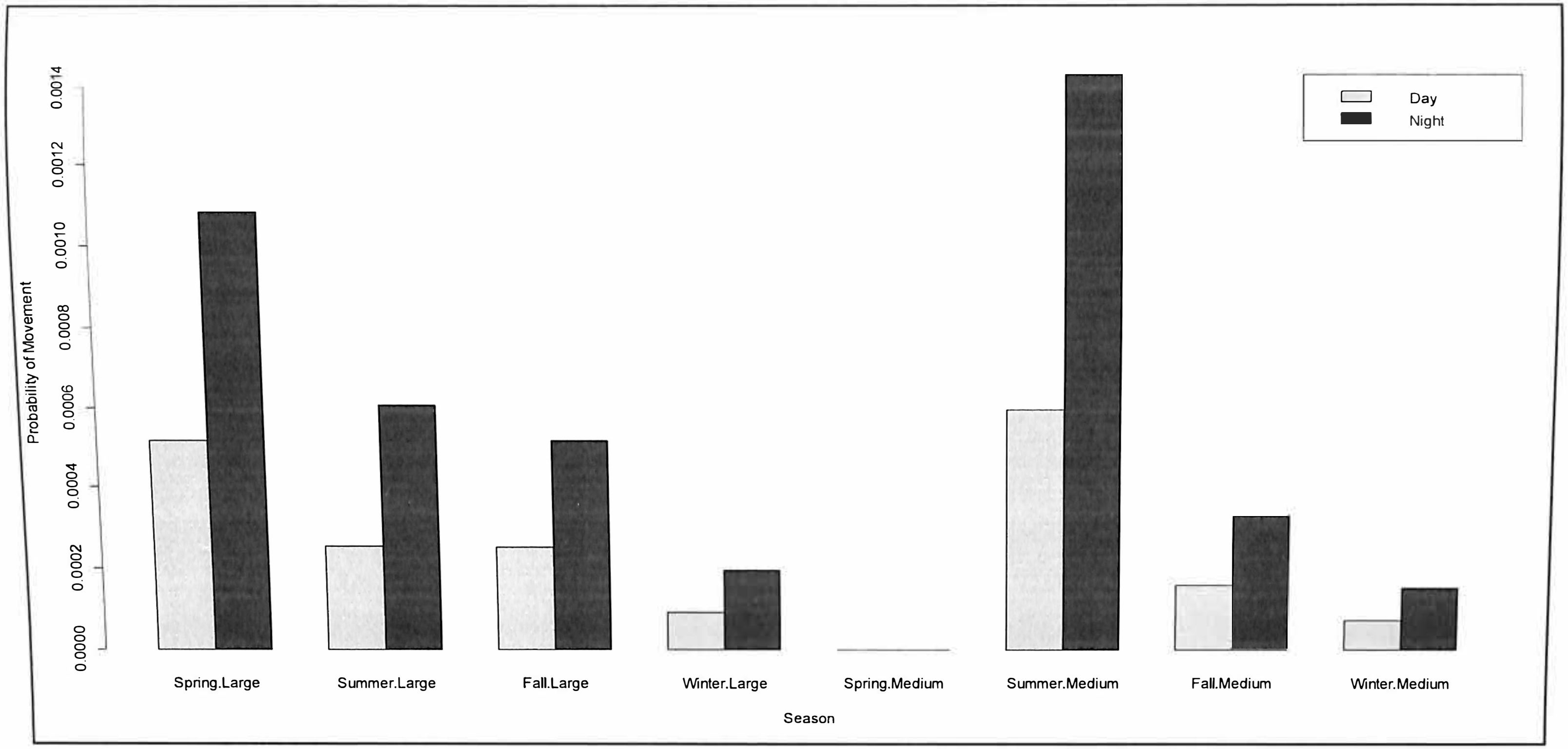

Figure 3-3: Hourly downstream movement probabilities by American Eel by size (large and medium) and season by diel periods as estimated by the highest-ranked QAIC mixed model. Due to transmitter battery life limitations the tags did not last until the spring season.

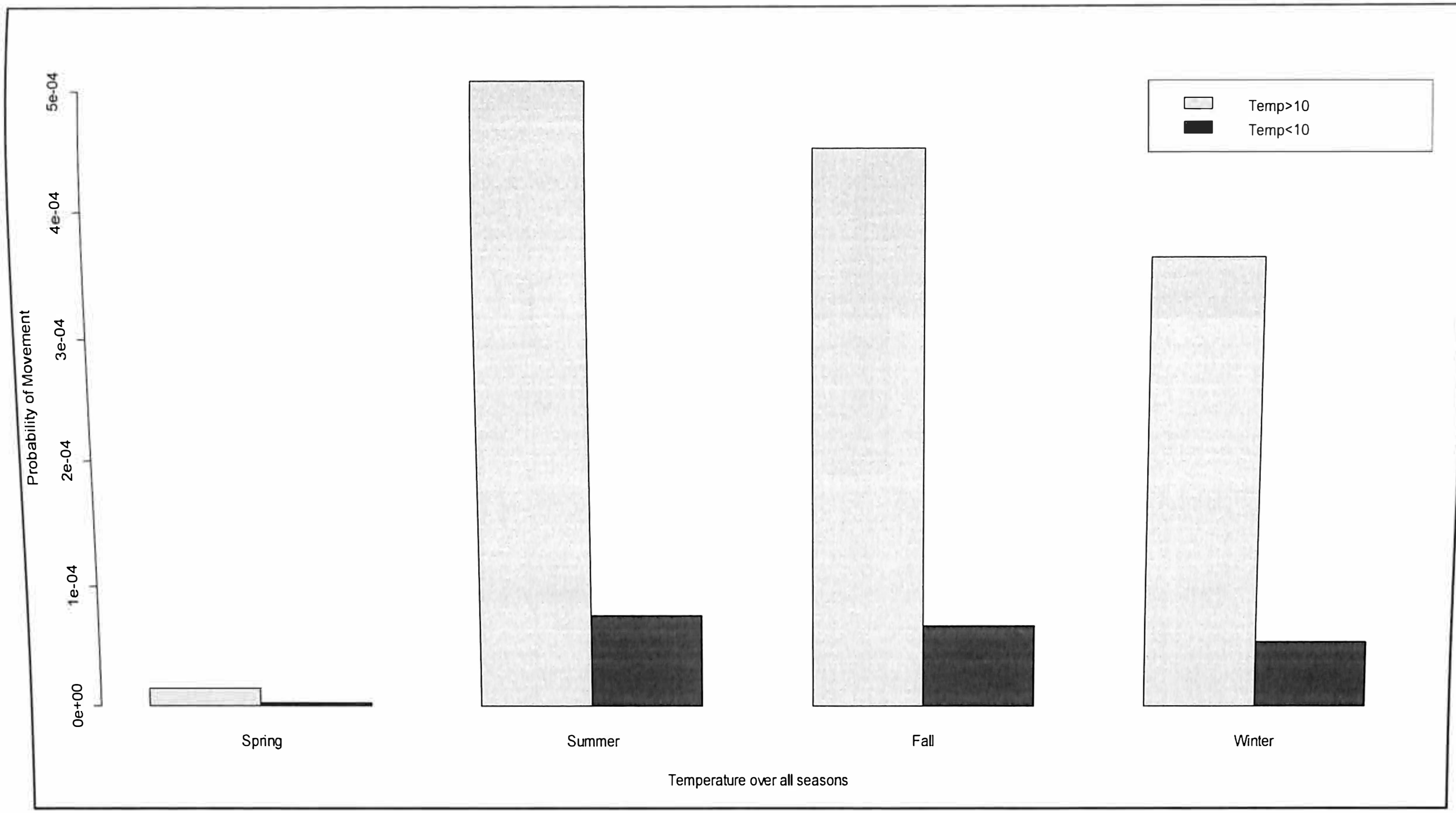

Figure 3-4: Hourly downstream movement probabilities of American Eels by season and temperature relative to 10 °C in the St. Jones River, DE as estimated by the highest-ranked QAIC mixed model.

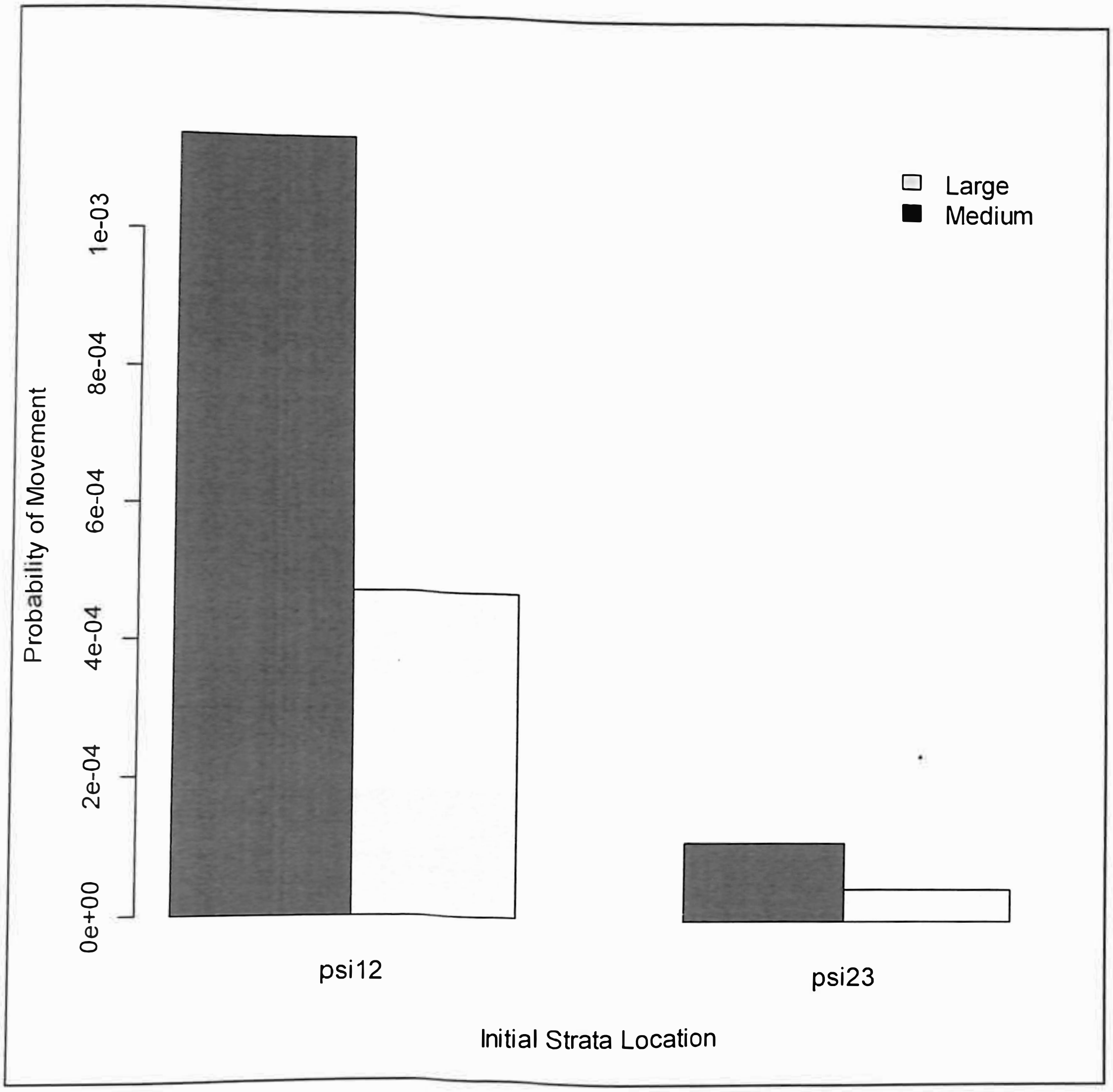

Figure 3-5: Hourly downstream movement probabilities of American Eel in the St. Jones River, DE by initial tagging location and size.

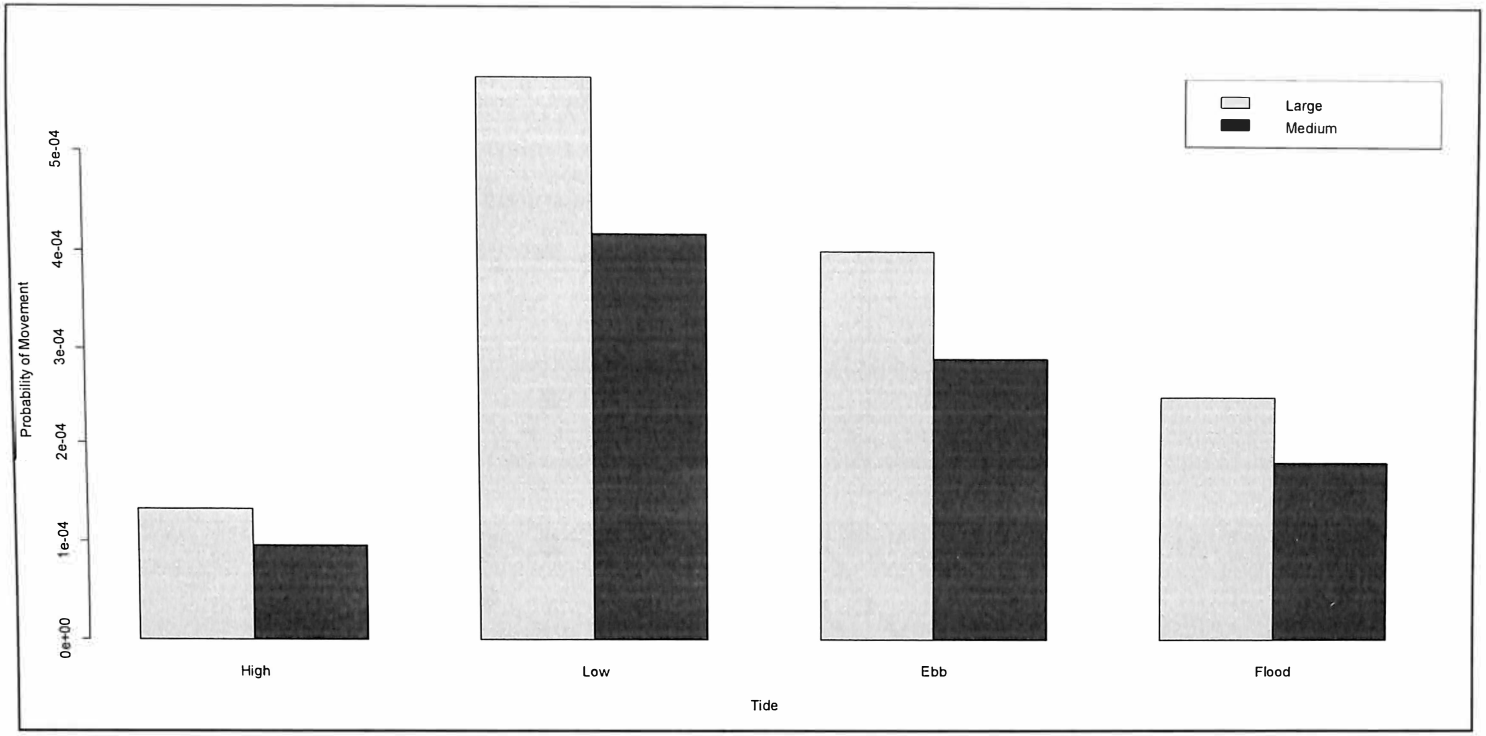

Figure 3-6: Hourly downstream movement probabilities for yellow-phase American Eels in the St. Jones River by size and tidal stage as estimated by the highest-ranked QAIC mixed model.

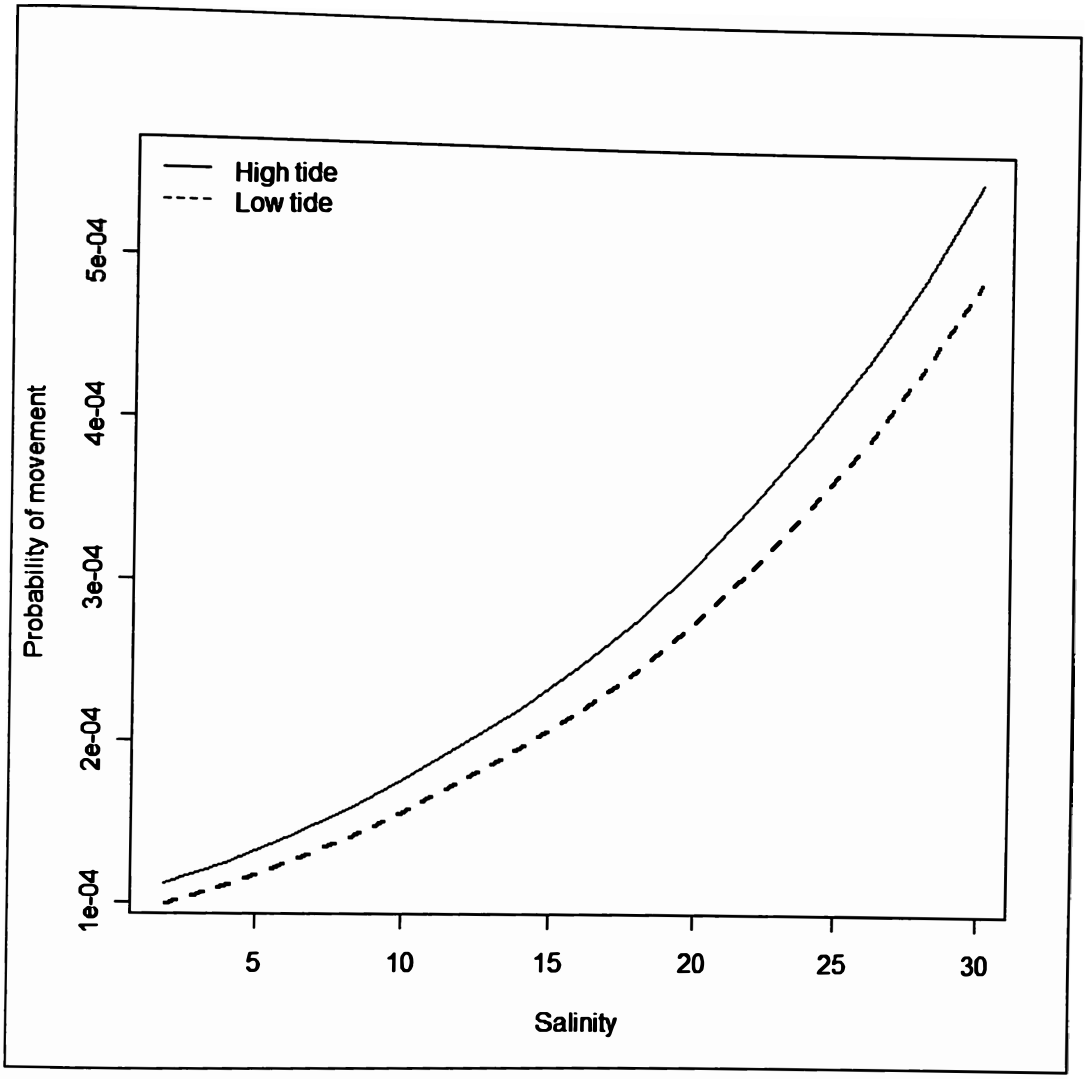

Figure 3-7: Hourly upstream movement probabilities of telemetered American Eels for the St. Jones River, DE by salinity (ppt) and tidal stage.

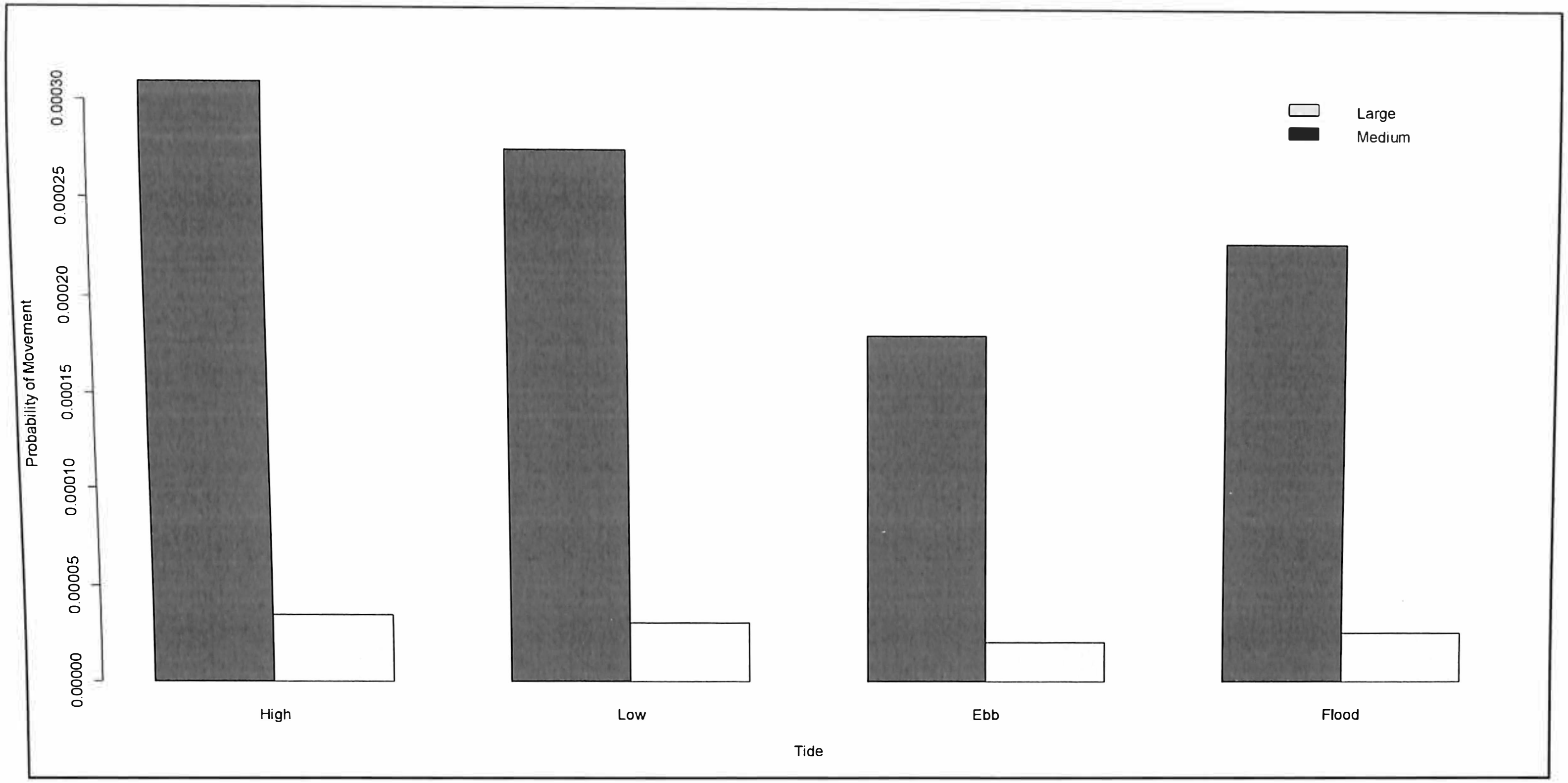

Figure 3-8: Hourly upstream movement probabilities of telemetered American Eels by size and tidal cycle for the St. Jones River, DE.

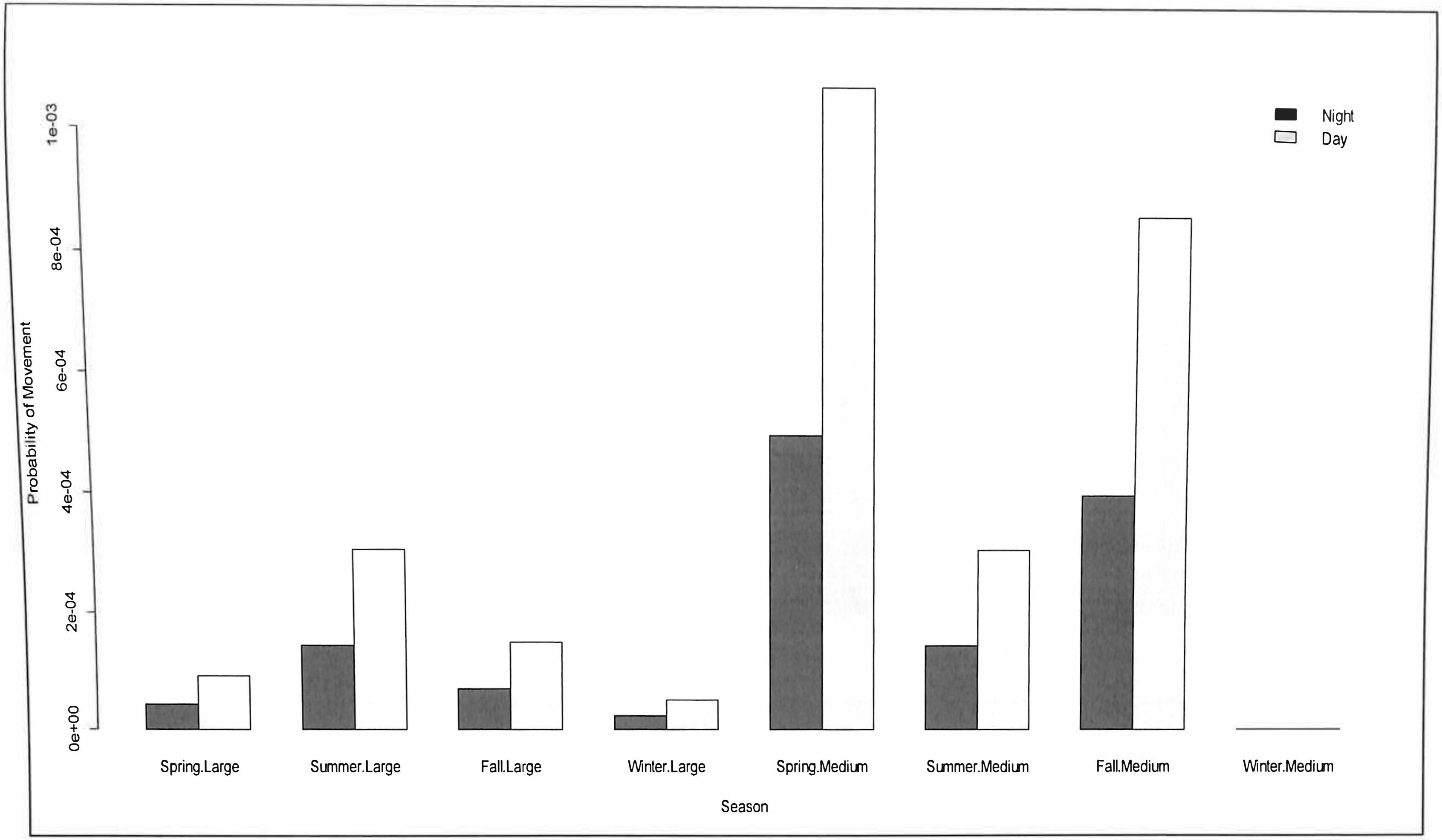

Figure 3-9: Hourly upstream movement probabilities of telemetered American Eel by season, diel period, and size for the St. Jones River, DE.

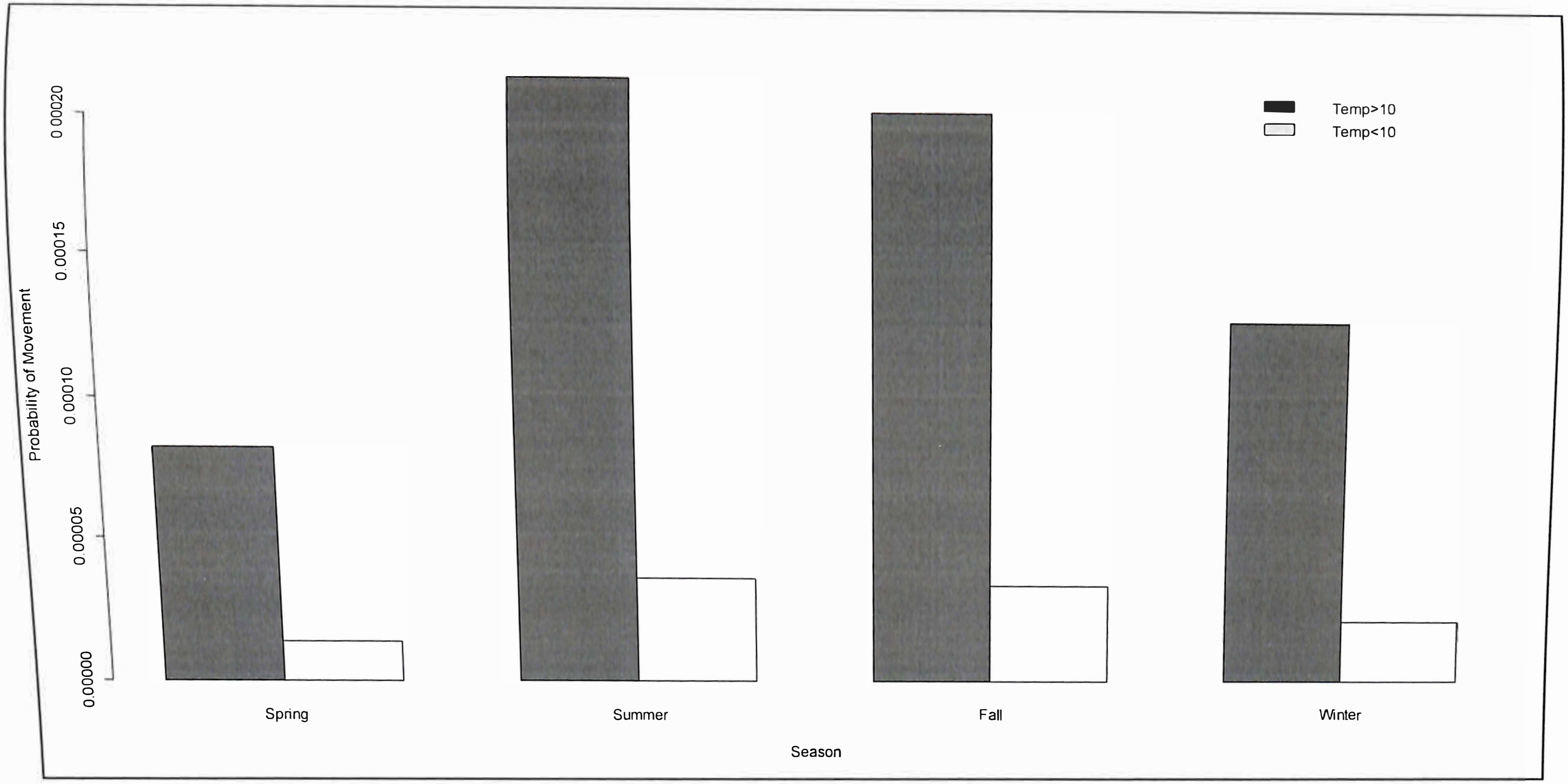

Figure 3-10: Hourly upstream movement probability for telemetered American Eels by season and relative temperature in the St. Jones River, DE.

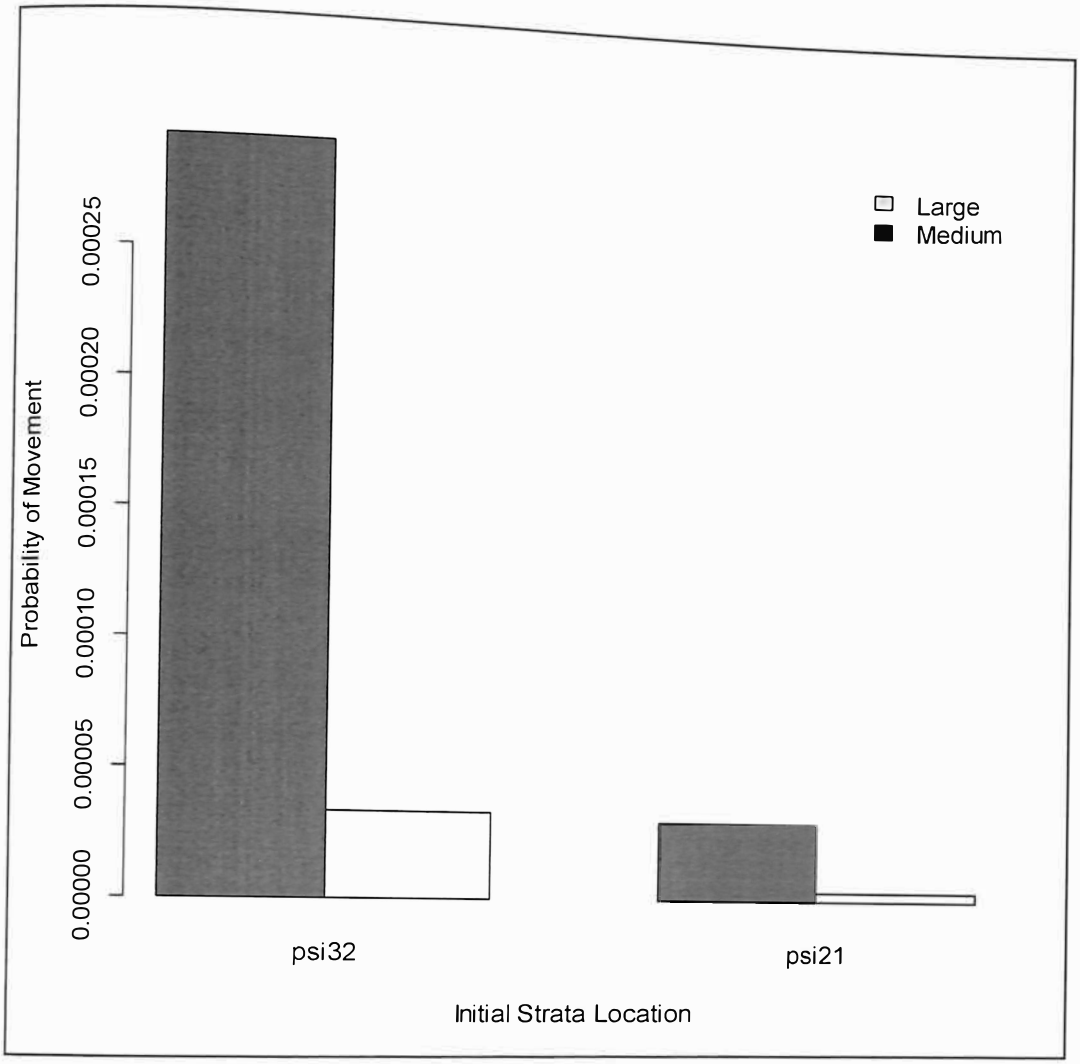

Figure 3-11: Hourly upstream movement probabilities by initial tagging strata for telemetered American Eels in the St. Jones River, DE by size.

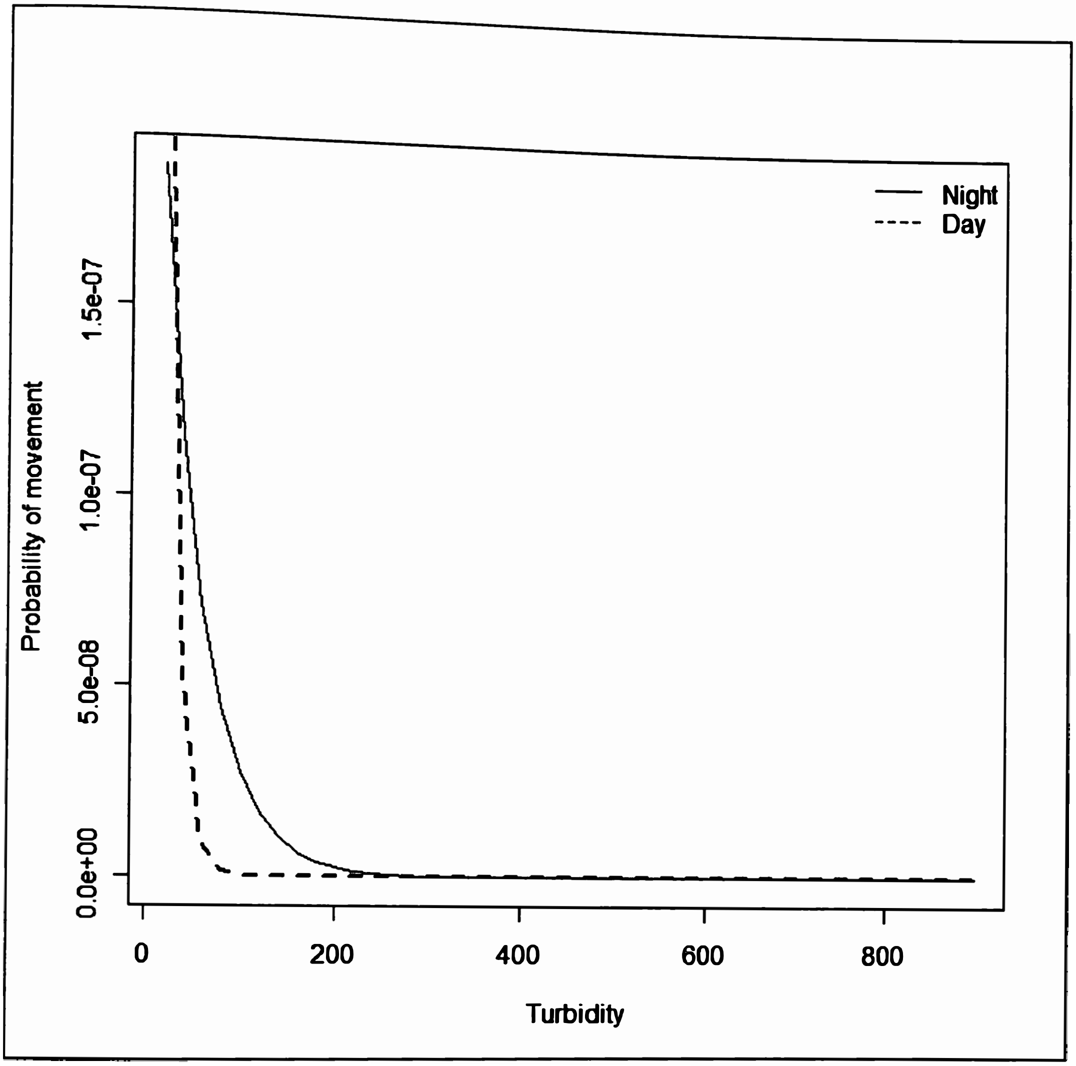

Figure 3-12: Hourly movement probabilities from the lower St. Jones River (intense strata) to the Delaware Bay for telemetered American eels by turbidity (NTU).

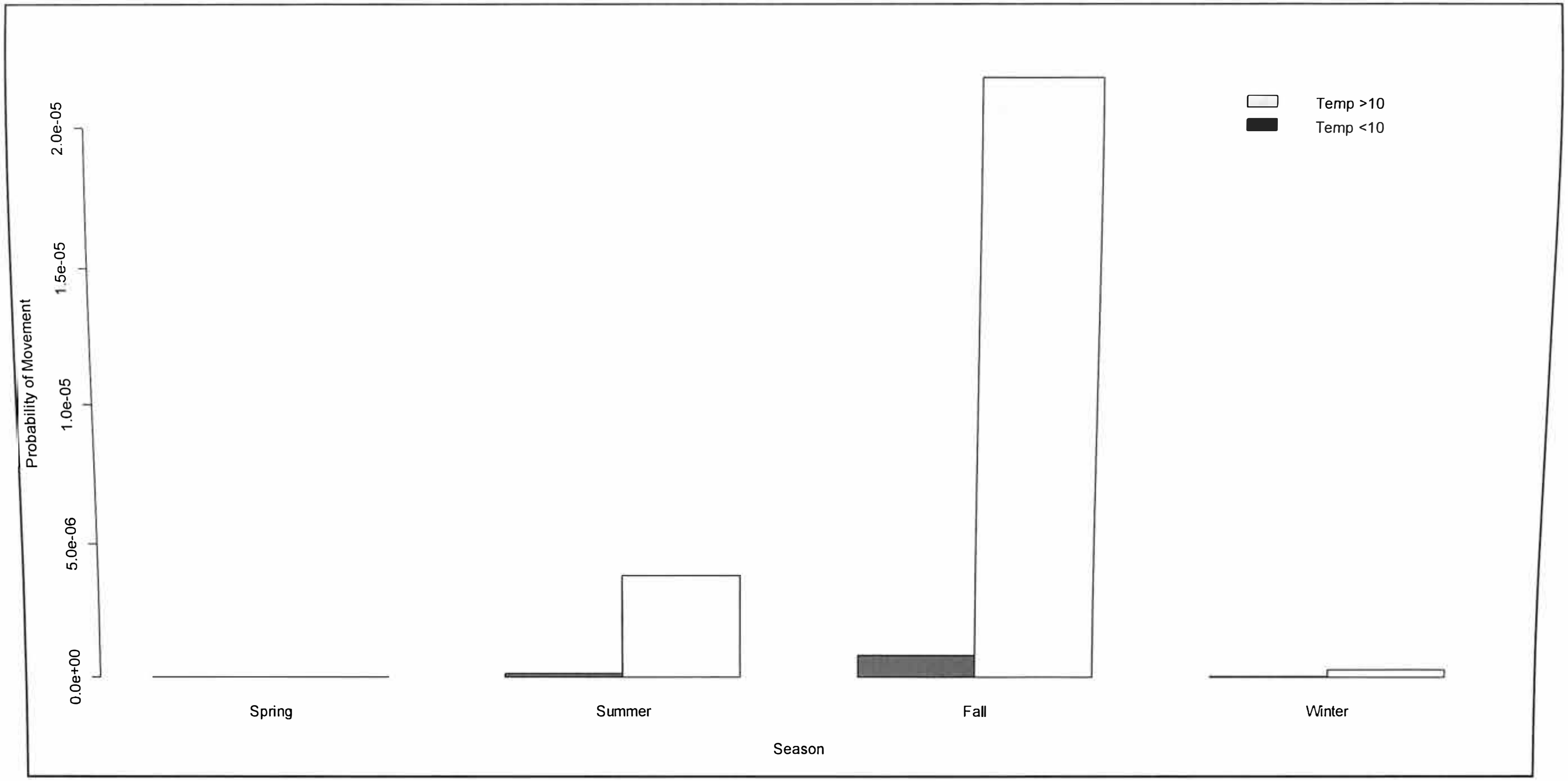

Figure 3-13: Hourly movement probabilities of telemetered American Eels from the lower St. Jones River (intense strata) to the Delaware Bay by season and temperature.

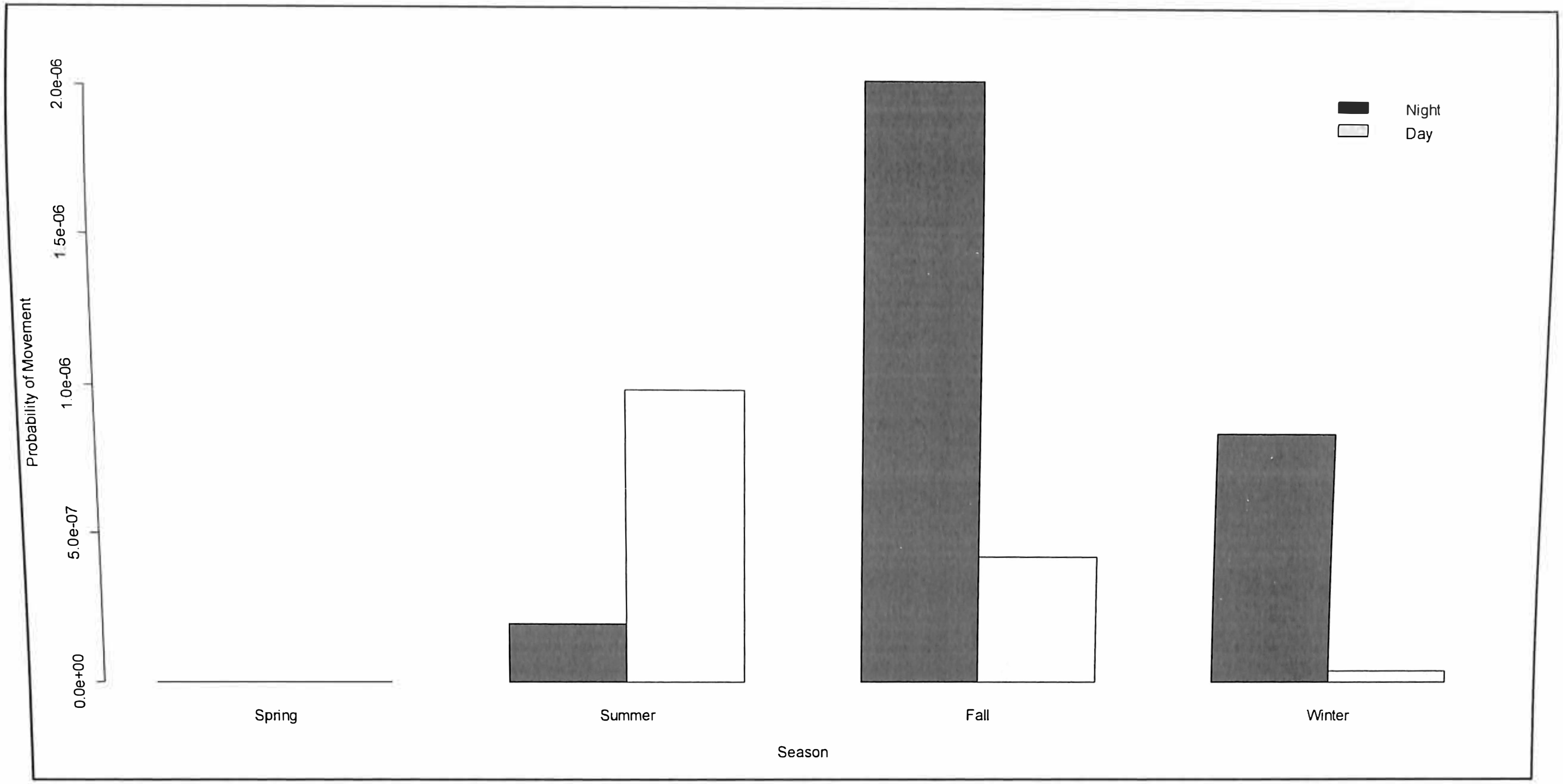

Figure 3-14: Hourly movement probabilities from the lower portion of the St. Jones River (intense harvest strata) to the Delaware Bay by season and diel period.

REFERENCES

Able, K. W. and M. P.Fahay. 1998. The first year in the life of estuarine fishes in the Middle Atlantic Bight. Rutgers University Press, New Brunswick, New Jersey.

Airamé, S., J.E. Dugan, K.D. Lafferty, H. Leslie, D. A. McArdle, and R.R. Warner. 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. Ecological Applications 13:S170-S184.

Anonymous. 2003. Worldwide decline of eel resources necessitates immediate action: Québec declaration of concern. Fisheries 28 (12):28-30.

ASMFC (Atlantic States Marine Fisheries Commission). 2000. Interstate fishery management plan for American eel. ASMFC Fishery Management Report No. 36, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 2007. Review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for American eel (*Anguilla rostrata*).

ASMFC (Atlantic States Marine Fisheries Commission). 2008. Addendum to the fishery management plan for the American eel for public comment.

Bacheler, N. M., J. E. Hightower, L. M. Paramore, J. A.Buckel, and K. H. Pollock. 2008. An age-dependent tag return model for estimating mortality and selectivity of an estuarine-dependent fish with high rates of catch and release. Transactions of the American Fisheries Society 137:1422–1432.

Baras, E., D. Jeandrain, B. Serouge, and J. C. Philippart. 1998. Seasonal variations intime and space utilization by radio-tagged yellow eels *Anguilla anguilla* (L.) in a small stream. Hydrobiologia 371-372(1-3):187-198.

Barber, R. 2004. Sex ratio of silver American eels (*Anguilla rostrata*) migrating out of two southern Delaware streams. Master's Thesis. University of Delaware, Newark, Delaware.

Barbin, G. P., S. J. Parker, J. D. McCleave. 1998. Olfactory clues play a critical role in the estuarine migration of silver-phase American eels. Environmental Biology of Fishes 53:283-291.

Barbin, G. P., and J. D. McCleave. 1997. Fecundity of the American eel *Anguilla rostrata* at 45°N in Maine, U.S.A. Journal Fish Biology 51:840-847.

Barker, R. J. 1997. Joint modeling of live recapture, tag-resight, and tag-recovery data. Biometrics 53: 666-677.

Barse, A. M. and D.H. Secor. 1999. An exotic parasite of the American eel. Fisheries 24 (2):6-10.

Bohun, S., and H.W. Winn. 1966. Locomotor activity of the American eel (*Anguilla rostrata*). Chesapeake Science 7:137-147.

Bolden, S.K. 2002. Using ultrasonic telemetry to determine home range of a coral-reef fish. Pages 167-188 in J. Silbert and J.L. Nielsen, editors. Proceedings of the symposium on tagging and tracking marine fish with electronic devices. Kluwer Academic Publishers, Netherlands.

Bolker, B. M. 2008. Ecological Models and Data in R. Princeton University Press: Princeton, NJ.

Bozeman, E. L., G. S. Helfman, and T. Richardson. 1985. Population size and home range of American eels in a Georgia tidal creek. Transactions of American Fisheries Society 114: 821-825.

Brown, J. L. 1975. The Evolution of Behavior. Norton, New York, 761 p.

Burnham, K. P. and D. R. Anderson. 2003. Model selection and multimodel inference: a practical information-theoretic approach, Second Edition. Springer, New York, New York.

Cairns, C. M. 2009. Population ecology of yellow-phase American eels (*Anguilla rostrata*) in the St. Jones River, Delaware. Master's Thesis. Delaware State University, Dover, Delaware.

Cairns, D. K. and P. J. D. Hooley. 2003. Lunar cycles of American eels in tidal waters of the southern Gulf of the St. Lawrence, Canada. Pages 265-274 in D.A. Dixon, editor. Biology, Management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland.

Casselman, J. M. 2003. Dynamics of resources of the American eel, *Anguilla rostrata*: declining abundance in the 1990s. Pages 255-274 in K. Aida, K. Tsukamoto, and K. Yamauchi, editors. Eel Biology. Springer-Verlag. Tokyo, Japan.

Castonguay, M., P.V. Hodson, C.M. Couillard, M.J. Eckersley, J. D. Dutil, and G. Verreault. 1994. Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St. Lawrence River and Gulf? Canadian Journal of Fisheries and Aquatic Sciences 51:479-488.

Clark, J. 2009. The American eel fishery in Delaware: recent landings trends and characteristics of the exploited eel population. Pages 229-240 in J. M. Casselman and D. K. Cairns, editors. Eels at the edge: science, status, and conservation concerns. American Fisheries Society Symposium 58, Québec Canada.

Compton, R. C. 1968. Some observations of the feeding of *Anguilla rostrata* (Lesueur) in two tributaries of the Delaware River. Master's Thesis, Rutgers Univ., New Brunswick, New Jersey.

Cucherousset, J., J. –M. Paillisson, A. Carpentier, V. Thoby, J. –P. Damien, M. –C. Eybert, E. Feunteun, and T. Robinet. 2007. Freshwater protected areas: an effective measure to reconcile conservation and exploitation of the threatened European eels (*Anguilla anguilla*)? Ecology of Freshwater Fish 16: 528-538.

Daniels, L. R. 1999. Diet of American eels, *Anguilla rostrata,* (LeSueur) in five freshwater lakes, Maine, U.S.A.Master's Science Thesis, University of Maine, Orono.

Daverat F, K. E. Limberg, I. Thibault, J. C. Shiao, J. J. Dodson, F. Caron, W. N. Tzeng, Y. Iizuka, H. Wickström. 2006. Phenotypic plasticity of habitat use by three temperate eel species, *Anguilla anguilla*, *A. japonica* and *A. rostrata*. Marine Ecology Progress Series 308:231–241.

Delaware Division of Fish and Wildlife (DDFW). 2006. American eel fishery annual compliance report to ASMFC. Delaware Division of Fish and Wildlife, Dover, DE 19901.

Delaware Department of Natural Resources and Environmental Control. 1999. Delaware National Estuarine Research Reserve: Estuarine Profiles. Dover, DE 164pp.

Dutil, J.-D., M. Michaud, and A. Giroux. 1989. Seasonal and diel patterns of stream invasion by American eels (*Anguilla rostrata*) in the northern Gulf of St. Lawrence. Canadian Journal of Zoology 67:182-188.

Dutil, J.-D., A. Giroux, A. Kemp, G. LaVoie, and J.-P. Dallaire. 1988. Tidal influence on movements and on daily cycle of activity of American eels. Transactions of the American Fisheries Society 117:488-494.

Euston, E.T., D.D. Royer, and C.L. Simons. 1998. American eels and hydro plants: clues to eel passage. Hydro Review 17 (4): 94-103.

Facey, D. E. and M. J. Van Den Avyle. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)- American eel. U. S. Fish and Wildlife Service Biological Report. 82(11.74) U.S. Army Corps of Engineers, TR EL 82-4.

Fahay, M. P. 1978. Biological and fisheries data on American eel, *Anguilla rostrata* (LeSeur) .U.S. Department Commerce National Marine Fisheries Service Report No.17, Northeast Fisheries Center Highlands, N.J. 82 pp.

Fenske, K. H., M. J. Wilberg, D. H. Secor and M. C. Fabrizio. 2011. An age- and sex-structured assessment model for American eels (*Anguilla rostrata*) in the Potomac River, Maryland. Canadian Journal of Fisheries and Aquatic Sciences 68: 1024-1037.

Ford, T. E. and E. Mercer. 1986. Density, size distribution and home range of American eels, *Anguilla rostrata*, in a Massachusetts salt marsh. Environmental Biology of Fishes 17:309-314.

Gerber L. R., L. W. Botsford, A. Hastings, H. P. Possingham, S. D. Gaines, S. R. Palumbi, S. J. Andelman. 2003. Population models for reserve design: A retrospective and prospective synthesis. Ecological Applications 13: S47–S64.

Gunning, G.E. and C.R. Shoop. 1962. Restricted movements of the American eel, *Anguilla rostrata* (LeSueur), in freshwater streams, with comments on growth rate. Tulane Studies in Zoology 9:265-272.

Hammond, S. D. and S. A. Welsh. 2009. Seasonal movements of large yellow American Eels downstream of a hydroelectric dam, Shenandoah River, West Virginia. Pages 309-323, in J. M. Casselman and D. K. Cairns, editors. Eels at the edge: science, status, and conservation concerns. American Fisheries Society, Symposium 58, Bethesda, Maryland.

Haro, A., W. Richkus, K. Whalen, A. Hoar, W. Busch, W. Dieter, S. Lary, T. Brush, and Dixon, D. 2000. Population Decline of the American eel: implications for research and management. Fisheries 25(9):7-16.

Hedger R. D., J. J. Dodson, D. Hatin, F. Caron, D. Fournier. 2010. River and estuary movements of yellow-stage American eels *Anguilla rostrata*, using a hydrophone array. Journal of Fish Biology 76 (6): 1294-3110.

Helfman, G. S., D. E. Facey, L. S. Hales, Jr., and E. L. Bozeman, Jr. 1987. Reproductive Ecology of the American eel. American Fisheries Society Symposium 1:42-56.

Helfman, G. S., D. L. Stoneburner, E. L. Bozeman, P. A. Christian, and R. Whalen. 1984. Ultrasonic telemetry of American eel movements in a tidal creek. Transactions of the American Fisheries Society 112:105-110.

Hightower, J. E., J. R. Jackson, K. H. Pollock. 2001. Use of telemetry methods toestimate natural and fishing mortality of striped bass in Lake Gaston, North Carolina. Transactions of the American Fisheries Society, 557-567.

Hildebrand, H. 2005. Size, age composition, and upstream migration of American eels at the Millville Dam eel ladder, Shenandoah River, West Virginia. Master's Thesis. West Virginia University, Morgantown.

Hooge, P. N., W. M. Eichenlaub, and E. K. Solomon. 1999. Using GIS to analyze animal movements in the marine environment. United States Geological Survey. Available: http//www.absc.usgs.gov/glba/gistools/anim_mov_useme.pdf.

Hooge P. N. and B. Eichlaub. 1997. Animal movement extension to Arcview v.1.1. Alaska Biological Science Center, United States Geological Survey, Anchorage, Alaska.

Jessop, B. M., D. K. Cairns, I. Thibault, W. N. Tzeng. 2008. Life history of American eel *Anguilla rostrata*: new insights fromotolith microchemistry.Aquatic Biology 1:205–216.

Jessop, B.M. 2003. The run size and biological characteristics of American eel elvers in the East River, Chester, Nova Scotia, 2000. Canada Technical Report of Fisheries and Aquatic Sciences: 2444.

Jessop, B. M., J. C. Shiao, Y. Iizuka, W. N.Tzeng. 2002. Migratory behaviour and habitat use by American eels *Anguilla rostrata* as revealed by otolith microchemistry. Marine Ecology Progress Series 233:217–229.

Jessop, B.M. 1987. Migrating American eels in Nova Scotia. Transactions of the American Fisheries Society 116:161-170.

LaBar, G. W. and D. E. Facey. 1983. Local movements and inshore population sizes of American eels in Lake Champlain, Vermont. Transactions of the American Fisheries Society 112:111-116.

Lamothe, P.J, M. Gallagher, D. P. Chivers, and J. R. Moring. 2000. Homing and movement of Yellow-phase American eels in freshwater ponds. Environmental Biology of Fishes 58:393-399.

Lebreton J. D., T. Almeras and R. Pradel. 1999. Competing events, mixtures of information and multi-stratum recapture models. Bird Study 46: S39-46.

Lebreton, J. D., M. J. T. Morgan, R. Pradel, and S. N. Freeman. 1995. A simultaneous analysis of dead recover and live recapture data. Biometrics 51:1418-1428.

Lowe, R. H. 1952. The influence of light and other factors on the seaward migration of the silver eel, *Anguilla anguilla*. Journal of Animal Ecology 21:275-309.

Miller, R. L., W. L. Bradford and N. E. Peters. 1988. Specific conductance: Theoretical considerations and application to analytical quality control, U.S. Geological Survey Water-Supply Paper 2311, 16p.

McGrath, K. J., D. Desrochers, C. Fleury and J.W. Dembeck, IV. 2003. Studies of upstream migrant American eels at the Moses-Saunders Power Dam on the St. Lawrence River near Massena, New York. Pages 153-166 in D.A. Dixon, editor. Biology, Management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland.

Morisson, W. E. and D. H. Secor. 2004. Local abundance of yellow-phase American eels in the Hudson River estuary. Transactions of American Fisheries Society 133: 894-908.

Morrison, W. E. and D. H. Secor. 2003. Demographic attributes of yellow-phase American eels (*Anguilla rostrata*) in the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Science 60:1487-1501.

Morrison, W. E., D. H. Secor, and P. M. Piccolo. 2003. Estuarine habitat use by Hudson River American eels as determined by otolith strontium: calcium ratios. In Biology, management and protection of catadromous eels. American Fisheries Society Symposium 33: 87-100.

Moser, M. L., W. S. Patrick, and J. U. Crutchfield, Jr. 2001. Infection of American eels, *Anguilla rostrata*, by an introduced nematode parasite, *Anguillicola crassus*, in North Carolina. Copeia 3:848-853.

National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, National Estuarine Research Reserve System-wide Monitoring Program. 2004. Centralized Data Management Office, Baruch Marine Field Lab, University of South Carolina http://cdmo.baruch.sc.edu

Oliveira, K. and McCleave, J. D. 2002. Sexually different growth histories of the American eel in four rivers in Maine. Transactions of the American Fisheries Society 131: 203-211.

Oliveira, K. 1999. Life history characteristics and strategies of the American eel, *Anguilla rostrata*. Canadian Journal of Fisheries and Aquatic Science 56:795-802.

Oliveira, K. 1997. Movements and growth rates of yellow phase American eels, *Anguilla rostrata*, in the Annaquatucket River, Rhode Island. Transactions American Fisheries Society 126:638-646.

Palstra, A., V. Ginneken, G. Thillart G. 2008. Cost of transport and optimal swimming speeds in farmed and wild European silver eels (*Anguilla anguilla*). Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology151:37–44.

Parker, S.J., and J.D. McCleave. 1997. Selective tidal stream transport by American eels during homing movements and estuarine migration. Journal of the Marine Biological Association of the United Kingdom 77:871-889.

Pine, W.E., K. H. Pollock, J. E. Hightower, T. J. Kwak, and J. A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28(10): 10–23.

Prosek, J.Give Thanks for ... Eel? New York Times. November 24, 2010.

Richkus, W.A. and D.A. Dixon. 2003. Review of research and technologies on passage and protection of downstream migrating catadromous eels at hydroelectric facilities. Pages 377-388 in D.A. Dixon, editor. Biology, Management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C.Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739–747.Silverman, B. W. 1986. Density estimation for statistics and data analysis. Chapman and Hall, London.

Smith, H. W., and J.W. Saunders. 1955. The American eel in certain freshwater of the Maritime Provinces of Canada. Journal of the Fisheries Research Board of Canada 12:238-269.

Tesch, E. W. 1977. The eel: biology and management of anguillids eels. Chapman and Hall, London. 437 p.

Tesch, F-W. and G. Wegner. 1990. The distribution of small larvae of Anguilla sp. Related to hydrographic conditions in 1981 between Bermuda and Puerto Rico. Internationale Revue der Gesamten Hydrobiologie 75: 845-858.

Thibault I., J. J. Dodson, F. Caron, W. N. Tzeng, Y. Iizuka and J. C. Shiao. 2007. Facultative catadromy in the American eel: testing the conditional strategy hypothesis. Marine Ecology Progress Series 344: 219–229.

Thomas, J. C. 2006. American eel behavioral patterns in Silver Lake, Dover, Delaware. Master's Thesis. Delaware State University, Dover, Delaware.

Tytell E. D. 2004. Kinematics and hydrodynamics of linear acceleration in eels, *Anguilla rostrata*. Proceedings of the Royal Society B 271, 2535–2540.

USOFR (United States Office of the Federal Register). 2007. Endangered and threatened wildlife and plants; 12 month finding on a petition to list the American eel as threatened or endangered. 50 CRF Part 17. Federal Register 70:22 (2 February 2007):4967-4997.

USOFR (United States Office of the Federal Register). 2005. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the American eel as threatened or endangered. 50 CRF Part 17. Federal Register 70:28 (6 July 2005): 38849-38861.

USOFR (United States Office of the Federal Register). 2004. ESA petition for the American eel *Anguilla rostrata*. 5 U.S.C. § 553(3) and 50 C.F.R. part 424.14.

Verdon, R. and D. Desrochers. 2003. Upstream migratory movements of American eel *Anguilla rostrata* between the Beauharnois and Moses-Saunders power dams on the St. Lawrence River. Pages 139-152 in D.A. Dixon, editor. Biology, Management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland.

Walsh, P.J., G.D. Foster, and T.W. Moon. 1983. The effects of temperature on metabolism of the American eel *Anguilla rostrata* (LeSueur): compensation in the summer and torpor in the winter. Physiological Zoology 56:532-540.

Wenner, C.A. and J. A. Musick. 1975. Food Habits and Seasonal Abundance of the American eel, *Anguilla rostrata*, from the lower Chesapeake Bay. Virginia Institute of Marine Science. Chesapeake Science 16 (1):62-66.

Winn, H. E., W. A. Richkus, and L. K. Winn. 1975. Sexual dimorphism and natural movements of the American eel (*Anguilla rostrata*) in Rhode Island streams and estuaries. HelgoländerWissenschaftlicheMeeresuntersuchungen 27: 156-166.

CURRICULUM VITAE

Marrisa Gisselle Brady
Sandy Bay, Roatán, Honduras
Phone: 2445-3117/ 9460-4483
E-mail: marissagbrady@yahoo.com

Education:

M.S. Natural Resources...May 2016
Concentration in Fisheries.................................Delaware State University
GPA: 3.84

B.S. Biology...May 2008
Biotechnology......................................Delaware State University
GPA: 3.11

Minors...Chemistry & Environmental Science

Work/Research Experience:

January 2016-Present Assistant Director
Bay Islands Conservation Association (BICA), Roatan, Honduras, Central America

January 2012 – Present Coordinator of Research and Monitoring
Bay Islands Conservation Association (BICA) Roatan, Honduras, Central America

The Bay Islands Conservation Association is an environmental non-profit organization that promotes the conservation of marine and terrestrial ecosystems, the defense of wildlife (flora and fauna) in danger of extinction and awareness of the ecological and environmental topics through outreach and education.

As Coordinator of Research and Monitoring it is my primary responsibility to conduct monitoring programs which contribute to the effective management of the marine and terrestrial protected areas and those that are not currently protected under the law. In facilitating this I develop monitoring and research programs for the organization, find financial backing to support and continue new and current research and monitoring, and utilize collected data to better manage protected areas as well as other ecosystems in the Bay Island National Marine Park (BINMP).

- Build financial and technical monthly, quarterly and annual reports for current grants
- Hire and train technical staff on varying grants, data collection, analysis and reporting
- Coordinate development of programs (environmental education, research and monitoring, community development, reforestation and others) with staff
- Continually search for new funding to assist in management of natural resources and sustainability of the NGO
- Represent the NGO in protected areas management committee and provide information to the legislature

2013-Present
Monthly marine water quality monitoring in the Sandy Bay - West End Special Marine Protection Zone and Cordelia Banks

- Assisted in identification of sampling locations
- Conducted monthly field sampling including organization of field crews
- Monitored water quality parameter at sampling locations
- Analyze data and provide written and oral reports of results

2013-Present
Monthly reef fish larvae monitoring in the Sandy Bay - West End Special Marine Protection Zone

- Assisted in identification of sampling locations
- Conducted monthly field sampling including organization of field crews
- Deployed sampling gear and monitored water quality parameters at sampling locations
- Analyze data and provide written and oral reports of results

2012-Present
Atlantic Gulf Rapid Reef Assessment (AGRRA) Monitoring in the Bay Islands National Marine Park

- Receive training in the AGRRA methodology
- Conducted field monitoring
- Enter data in database

September 2014-February 2015
Sewage Effect on Sea-grass beds, Sandy Bay West End Special Marine Protection Zone

- Assisted in identification of sampling locations

August 2008-May 2011
Graduate Research Assistant
Delaware State University, Dover, DE
Defended Thesis May 2011

- Biotelemetry and Mark-recapture study on American eel
- Developed population models of American eels using R to assist resource managers with conservation measures
- Conducted home range analysis utilizing Arc GIS
- Conducted monthly tagging events (August-November 2008, April-November 2009, April-November 2010)
- Conducted weekly tracking for telemetered American eels
- Worked collaboratively with local commercial harvesters to recover tagged eels
- Analyzed and presented study result via oral and poster presentations

May 2006-August 2008
Research Intern NSF-HBCU-UP, and NSF-EPsCOR
Delaware State University, Dover DE

- The impact of non-native parasite infestation on the health of American eels

September 2007-August 2008

- Developed a protocol for extraction, reconstitution and analysis of lipids
- Processed samples to asses parasite infestation rates and lipid levels between infested and non-infested eels
- Analyzed data and provided written and oral reports of results

May 2007-August 2008

- Testing of a synthetic Atlantic horseshoe crab bait for the American eel fishery
- Assisted in the development of a statistically sound sampling scheme
- Conducted monthly field sampling including organization of field crews
- Analyzed and presented study result via oral and poster presentations

May 2006-May 2008

- Assessment of non-native parasitism rates in American eel
- Assisted in a concurrent research project (mark-recapture of American eel) and dissected recovered eel to determine infestation rates
- Deployed sampling gear and monitored water quality parameters at sampling locations
- Analyzed and presented study result via oral and poster presentations

May 2006-November 2006

- Residency patterns of American eels in Delaware tidal creeks
- Assisted in identification of sampling locations using ESRI ArcMap
- Deployed sampling gear and monitored water quality parameters
- Conducted field mark-recapture sampling to assess large-scale movement and residency patterns in American eel
- Analyzed and presented study result via oral and poster presentations

May 2006-August 2008
Research Assistant

- Assisted Graduate Students with research projects:
- American Eel Research
- Atlantic Sturgeon Research
- Aquaculture Research (Catfish, Shrimp, and Trout)
- Sand Tiger Shark Research

January 2008 Research Assistant (Volunteer), NOAA Research Cruise
Woods Hole, MA

- Collected, identified, weighed and measured catch from trawls and plankton nets beam
- Stood regular watch hours as part of the scientific crew
- Data Entry

March 2007
Research Assistant (Volunteer), Bay Islands Conservation Association
Sandy Bay-West End Marine Park Roatan, Honduras, Central America

- Collected, identified and analyzed sea grasses

June 2004-December 2004
Research Assistant (Volunteer) Honduras Institute of Tourism
Roatan, Honduras, Central America

- Assisted in collection of the endangered coral (*Acropora cerviconis*)
- Assisted in determining sampling location, replanting and monitory of survival
- Built and deployed concrete base to attach coral

Presentations:

2014 Brady, M. G., Ramos, N., Vazquez, L. and Malca, E. Reef Fish Larvae Monitoring in the Sandy Bay - West End Marine Protection Zone. XVIII SMBC Congress Copan Ruins, Honduras 2014. (Poster)

2011 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox Environmental parameters affecting American eel (*Anguilla rostrata*) behavior and habitat use in the St. Jones River, DE (Presentation of Thesis)

2010 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox. Combining mark-recapture and telemetry methods to understand American eel population dynamics. American Fisheries Society Tidewater Chapter Meeting. Annapolis, MD. (Poster)

2009 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox. Combining Telemetry and Mark-Recapture Methods to Study the Population Dynamics of American Eels in Delaware. NOAA EPP Forum 2009, Hampton University, Washington, DC. (Oral Presentation)

2009 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox. Combining Telemetry and Mark-Recapture Methods to Study the Population Dynamics of American Eels in Delaware. 12th Annual Philadelphia AMP Res. Symposium and Mentoring Conf. Philadelphia, PA. (Oral Presentation)

2009 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox. Combining Telemetry and Mark-Recapture Methods to Study the Population Dynamics of American Eels in Delaware. American Fisheries Society Mid-Atlantic Chapter Meeting. Galloway, NJ. (Oral Presentation)

2009 Brady, M. G., D. A. Fox, W. Quijang, and C. M. Cairns. Impact of non-native parasitic nematode on American eels (*Anguilla rostrata*) in Delaware waters. American Society of Ichthyology and Herpetology Meeting. Portland, OR. (Oral Presentation)

2009 Brady, M. G., D. A. Fox, W. Quijang, and C. M. Cairns. Impact of *Anguillicola crassus* on American eel in Delaware waters. The 15th Biennial Research Symposium of ARD. Atlanta, GA. (Oral Presentation)

2009 Brady, M. G., D. A. Fox, W. Quijang, and C. M. Cairns. The invasive swim bladder nematode strikes back in Delaware waters. American Fisheries Society Tidewater Chapter Meeting. Wilmington, NC. (Oral Presentation)

2008 Brady, M. G., C. M. Cairns, and D. A. Fox. Prevalence of Parasitism by a Non-Native Nematode in the Delaware American eel. Honors Day, Delaware State University, Dover, DE. (Oral Presentation)

2008 Brady, M. G., C. M. Cairns, and D. A. Fox. Prevalence of Parasitism by a Non-Native Nematode in the Delaware American eel. American Fisheries Society Tidewater Chapter Meeting. Gloucester Point, VA. (Poster)

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. Development of artificial Atlantic horseshoe crab bait for the American eel fishery: results from recent field trials. HBCU-UP National Research Conference. Washington, DC. (Poster)

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. Development of artificial Atlantic horseshoe crab bait for the American eel fishery: result in recent field trials. EPsCOR Summer Undergraduate Research Symposium at the University of Delaware. Newark, DE. (Poster)

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. Non-native parasitic nematode infection rates of American eel in Delaware waters: A cause for concern? American Fisheries Society 137th Annual Meeting. San Francisco, CA. (Oral Presentation)

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. Non-native parasitic nematode infection rates of American eel in Delaware waters: a cause for concern? International Conference on the Biology and Management of Diadromous Fishes. Halifax, NS. (Oral Presentation)

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. Non-native parasitic nematode infection rates of American eel in Delaware waters: a cause for concern? Honors Day, Delaware State University, Dover, DE. (Oral Presentation)

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. An assessment of American eel (Anguilla rostrata) dispersal and prevalence of parasitism by *Anguillicola crassus* in the waters surrounding the St. Jones River, DE. American Fisheries Society Mid-Atlantic and Tidewater Chapter Joint Meeting. Lewes, DE. (Poster)

2006 Brady, M. G., C. M. Cairns, and D. A. Fox. An assessment of American eel (Anguilla rostrata) dispersal and prevalence of parasitism by *Anguillicola crassus* in the waters surrounding the St. Jones River, DE. NOAA EPP Forum at Florida A & M University. Tallahassee, FL. (Poster)

2006 Brady, M. G., C. M. Cairns, and D. A. Fox. An assessment of American eel (*Anguilla rostrata*) dispersal and prevalence of parasitism by *Anguillicola crassus* in the waters surrounding the St. Jones River, DE. HBCU-UP Undergraduate Summer Research Poster Presentation. Dover, DE. (Poster)

2006 Brady, M. G., C. M. Cairns, and D. A. Fox. An assessment of American eel (*Anguilla rostrata*) dispersal and prevalence of parasitism by *Anguillicola crassus* in the waters surrounding the St. Jones River, DE. EPsCOR Summer Undergraduate Research Symposium at the University of Delaware. Newark, DE. (Poster)

Awards:

2010 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox. Combining mark-recapture and telemetry methods to understand American eel population dynamics. American Fisheries Society Tidewater Chapter Meeting. Annapolis, MD. (Poster)
3rd Place Poster Presentation

2009 Brady, M. G., P. B. Conn, L. L. Bailey, K. W. Shertzer and D. A. Fox. Combining Telemetry and Mark-Recapture Methods to Study the Population Dynamics of American Eels in Delaware. 12th Annual Philadelphia AMP Res. Symposium and Mentoring Conf. Philadelphia, PA. (Oral Presentation) 2nd Place Oral Presentation for Graduate Student Presentations

2008 Minorities in Natural Resources Committee Student Stipend. Corpus Christi, TX. Recipient of student stipend to participate in the 62nd Annual Conference of the 2008 Southeastern Association of Fish and Wildlife Agencies (SEAFWA)

2008 National Science Foundation Bridge to the Doctorate Fellowship Award. Philadelphia, PA. Recipient of the Greater Philadelphia Region Bridge to the Doctorate Fellowship Award for two years

2007 Commissioner's All Academic Award. Hampton, VA. Achieved 3.0 or higher GPA

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. Development of artificial Atlantic horseshoe crab bait for the American eel fishery: results from recent field trials. HBCU-UP National Research Conference. Washington, DC. (Poster) 2nd Place Poster Presentation for Ecology, Environmental and Earth Science

2007 Brady, M. G., C. M. Cairns, and D. A. Fox. An assessment of American eel (*Anguilla rostrata*) dispersal and prevalence of parasitism by *Anguillicola crassus* in the waters surrounding the St. Jones River, DE. American Fisheries Society Mid-Atlantic and Tidewater Chapter Joint Meeting. Lewes, DE. (Poster) 3rd Place Poster Presentation

2006 Commissioner's All Academic Award. Hampton, VA. Achieved 3.0 or higher GPA

2006 Brady, M. G., C. M. Cairns, and D. A. Fox. An assessment of American eel (*Anguilla rostrata*) dispersal and prevalence of parasitism by *Anguillicola crassus* in the waters surrounding the St. Jones River, DE. HBCU-UP Undergraduate Summer Research Poster Presentation. Dover, DE. (Poster) 1st Place Poster Presentation

2005 Kingwood College Student Ambassadors. Kingwood, TX. Outstanding Student Award

2005 Kingwood College. Kingwood, TX. Who's who among students in American Junior Colleges

2005 Kingwood College Rider Volleyball. Kingwood, TX. Outstanding Student Award

Workshops:

2016 Coral Restoration Workshop. Coral Reef Alliance and Healthy Reef Initiative, Roatan, Bay Islands, Honduras.

2014 The Environment as a Mechanism for Sustainable Development. Coral Reef Alliance. El Cangrejal, Honduras, C.A.

2014 Healthy Reef Initiative Partners Workshop. Healthy Reef Initiative. Tela, Honduras, C.A.

2014 Elaboration of the Research and Monitoring Plan for the Bay Islands National Marine Park and the Establishment of the Ecological Integrated Baseline. USAID-PROPARQUE. Roatan, Honduras, C.A.

2013 Consultation and Revision of the Tool: Technical Guide of Regulations and Guidelines for the Integrated Management of Marine and Freshwater Ecosystems. USAID-PROPARQUE. La Ceiba, Honduras, C.A.

2013 Validation of the Tool Evaluation of the Effective Management of Protected Areas through a hands on methodology. USAID-PROPARQUE. La Ceiba, Honduras, C.A.

2013 Consultation for the Formulation of the National Strategy for Marine Turtles. USAID-Management of Natural Resources. La Ceiba, Honduras, C.A.

2013 Validation of the Climate Change Adaptation Plan for the Caribbean Honduras. USAID. La Ceiba, Honduras, C.A.

2013 Coastal Marine Workshop. PNUD, DIBIO and SERNA. Tegucigalpa, Honduras, C.A.

2013 Global Socioeconomic Monitoring Initiative for Coastal Management (SocMon). Center for Marine Studies. Roatan, Bay Islands, Honduras, C.A.

2012 Practical Methods for Conducting Threat Assessments for Reef Managers. The Coral Disease and Health Consortium (CDHC) St.

Thomas, U.S. Virgin Islands.

Certifications:

US Coast Guard Auxiliary

- America's Boating Course – Boating Safety June 2006
- State of Delaware Boating certification June 2006

PADI Certification

- Scuba Open Water Diver 2002
- Advanced Open Water Diver 2012

Software:

Program Mark

- Basic knowledge
- Program Mark 2009 Workshop,
  Dr Gary C. White, Colorado State University

Program R

- Basic Knowledge
- Introduction to R for Fisheries Scientists 2010 Workshop
  Annual Conference of the American Fisheries Society

Arc GIS

- Basic Knowledge
- Introduction to Arc GIS through a GIS class in 2010

Quantum GIS

- Basic Knowledge
- Introduction to QGIS 2014 Workshop for technicians in working in multiple disciplines including environmental science, CREDIA, La Ceiba, Honduras, C.A.

Extra-Curricular Activities:

January 2013-Present, Roatan Geotourism Council, Board member

January 2012-Present, Bay Islands Volleyball League

- Secretary
- Coordinator of Beach Volleyball
- Coach

April 2014-January 2015, Beach Volleyball Honduran National Selection Team

- Player

June 2011, Star High School Students Summer Program, Speaker

June 2010, ExxonMobil Bernard Harris Summer Science Camp, Speaker

July 2009, Girls Explorations in Mathematics and Science, Speaker

June 2009, ExxonMobil Bernard Harris Summer Science Camp, Speaker

August 2008, Minorities in Agriculture, Natural Resources and Related Sciences
- Participated in the annual AIDs walk

August 2005-November 2008, Delaware State Women's Volleyball Team
- Team captain
- 3-year full athletic scholarship

August 2007-May 2008, Delaware State University Latin Student Association
- Assisted in organizing the Latin Association at Delaware State University

January 2006-May 2008, Delaware State University Caribbean Student Association
- Participated in the annual AIDs walk
- Organized informative presentations on various Caribbean countries

August 2004-May 2005, Kingwood College Student Government Association
- Scholarship and Student Body Treasurer
- Organized informative seminars on governmental issues

August 2003-May 2005, Kingwood College Student Ambassador
- Earned a 2-year Academic Scholarship
- Participated and organized school events

August 2003-May 2005, Kingwood College Volleyball Team
- Team captain: organized practices and games

August 2004-May 2005, Kingwood College Hispanic Organization
- Organize events for students to introduce the Hispanic culture

Course Work:

▪ Advanced Cell Biology ▪ Biochemistry ▪ Bioinformatics ▪ Biometrics ▪ Biotechnology Lab I & II ▪ Calculus I & II ▪ Comparative Vertebrae Anatomy ▪ Conservation & Restoration ecology	▪ Experimental design ▪ Environmental & Resource Economics ▪ Fisheries Policy ▪ Fisheries Science ▪ Genetics ▪ GIS ▪ Habitat Restoration	▪ Ichthyology ▪ Marine Biology ▪ Marine Population Dynamics ▪ Microbiology ▪ Molecular Biology ▪ Organic Chemistry I & II

Lab-Techniques:

▪ Biological Assays ▪ Cell and bacterial culture ▪ Chromatography ▪ Dissections	▪ Gel Electrophoresis ▪ *Drosophila* sp. Culture ▪ Extraction of Lipids	▪ PCR ▪ Titration ▪ Reef fish larvae identification

Field Techniques:

▪ Downloading hydro acoustic receivers ▪ Gill netting ▪ GPS ▪ Long lining ▪ Potting	▪ Manual tracking of telemetered fish using acoustic hydrophones ▪ Small craft boating ▪ Suturing	▪ Coral Reef Restoration (Acropora spp.) ▪ Mangrove monitoring ▪ AGRRA reef monitoring

Professional References:

- Davis, Leonard; Chairperson of Dept. of Biology, Delaware State University, Dover, DE, 19901 (302) 857-7370 ledavis@desu.edu
- Fox, Dewayne; Assistant Professor Fisheries, Delaware State University, Dover, DE, 19901 (302) 857-6436 dfox@desu.edu
- Myton, Jenny; Honduras Rep of Coral Reef Alliance, West End, Honduras, C.A.
- Solorzano, Kennedy; President of Bay Islands Conservation Association, Sandy Bay, Honduras, C.A. 504-2445-3214 bicaroatan@gmail.com