Summer 8-2015

Habitat Selection of Gulf-Strain Striped Bass, *Morone saxatilis*: Relationships to Dynamic Abiotic Environmental Characteristics Within the Biloxi River, Mississippi

Jennifer Lynne Green
University of Southern Mississippi

The University of Southern Mississippi

HABITAT SELECTION OF GULF-STRAIN STRIPED BASS, *MORONE SAXATILIS*: RELATIONSHIPS TO DYNAMIC ABIOTIC ENVIRONMENTAL CHARACTERISTICS WITHIN THE BILOXI RIVER, MISSISSIPPI

by

Jennifer Lynne Green

A Thesis
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Master of Science

Approved:

____
Dr. Mark S. Peterson, Committee Chair
Professor, Coastal Sciences

____
Dr. Paul F. Mickle, Committee Member
Gulf Coast Research Laboratory

____
Dr. Dewayne A. Fox, Committee Member
Associate Professor, Delaware State University

____
Dr. Karen S. Coats
Dean of the Graduate School

August 2015

ABSTRACT

HABITAT SELECTION OF GULF-STRAIN STRIPED BASS, *MORONE SAXATILIS*:

RELATIONSHIPS TO DYNAMIC ABIOTIC ENVIRONMENTAL

CHARACTERISTICS WITHIN THE BILOXI RIVER, MISSISSIPPI

by Jennifer Lynne Green

August 2015

The purpose of this project was to provide insights about the short- and long-term patterns of habitat selection of Gulf-strain Striped Bass, *Morone saxatilis*, based on spatially and seasonally variable abiotic environmental characteristics (water temperature, dissolved oxygen (DO), salinity, specific conductivity, and pH) in the Biloxi River, MS system. Juvenile hatchery-reared and feral adult Gulf-strain Striped Bass were acoustically-tagged and continuously monitored via active and passive telemetry from November 2012 – June 2014. Each month the available abiotic environmental characteristics of 40 random locations within the Biloxi River, along with sub-habitat conditions occupied by acoustically-tagged Gulf-strain Striped Bass, were sampled vertically at 1 m intervals from the surface to the bottom of the water column. Abiotic sub-habitats selected by juvenile and adult Gulf-strain Striped Bass were identified and compared to random mean abiotic conditions available in the river. During the acclimatization period to the Biloxi River, juvenile hatchery-reared Gulf-strain Striped Bass initially remained near the stocking site in sub-habitats that provided deeper depths, warmer temperatures, and higher salinity compared to other habitats within the river. Initial sub-habitat abiotic conditions may have facilitated recovery from stressors and disorientation associated with stocking. Two weeks following the stocking event, juveniles dispersed away from the release site and occupied sub-habitats with abiotic environmental characteristics that resembled background conditions of the Biloxi River. As acoustically-tagged Gulf-strain Striped Bass grew and acclimatized to the Biloxi River over the 20 month study period, seasonal patterns of habitat selection were apparent. During the fall, winter, and spring seasons, variable DO concentration and water temperatures at depth strongly influenced sub-habitat selection of both juvenile and adult Gulf-strain Striped Bass. In fall and winter, juveniles and adults were consistently located in warmer water temperatures and deeper habitats; whereas, in spring, Gulf-strain Striped Bass selected deep areas with DO > 7 mg/L. During summer, however, differences between Gulf-strain Striped Bass sub-habitats and background conditions of the Biloxi River were not clear. Although juveniles and adults were located in deep areas of the upper and lower regions of the Biloxi River, all other measured abiotic variables resembled the mean river abiotic condition characterized by DO concentrations greater than 5 mg/L and water temperatures of about 27.5°C. Ontogenetic trends in preferred habitat were evident during fall and winter when juvenile and adult sub-habitat selection was influenced by spatially-heterogeneous and vertical gradients of increased salinity at depth along the river continuum. Also, seasonal and annual variability in discharge greatly affected the decay of abiotic gradients spatially and vertically throughout the Biloxi River. Overall, the continual flux in abiotic environmental characteristics of a lotic system resulted in seasonally variable dispersal and habitat selection patterns for hatchery-reared juveniles and feral adults Gulf-strain Striped Bass in the Biloxi River.

DEDICATION

This thesis is dedicated to my husband, John, who has been a constant source of motivation and encouragement during the challenges of graduate school. I also dedicate this thesis to my dad, Joe, whose advice and optimism have always inspired me to pursue my dreams. Thank you both for your unconditional love and endless support through all my endeavors in academia and life.

ACKNOWLEDGMENTS

This research could not have been completed without support from many individuals. First, I would like to thank my major advisor, Dr. Mark Peterson, for his guidance, patience, and the opportunity to become a graduate student while working in his lab. Additionally, I appreciate the counsel from my other committee members, Drs. Paul Mickle and Dewayne Fox. Paul contributed countless hours and expertise to this project, both in and out of the field. And Dewayne, I would not be where I am in my career today had you not provided me the first opportunity to assist with fish ecology research; thank you for never having any doubts. Also, I acknowledge and thank the U.S. Fish and Wildlife Service and Mississippi Department of Marine Resources (DMR) for providing funding support, Coastal Impact Assistance Program (CIAP) and Wallop-Breaux, via the Sport Fish Restoration Program. Also, I appreciate both the Historic Ocean Springs Fly Fishing and Magnolia Fly Fishing Clubs for their donations and helpful tagging efforts. In addition, I recognize Larry Nicholson and value his dedication to the Striped Bass Restoration Project. Furthermore, I particularly would like to express my gratitude to David Rose and employees at the DMR Lyman Hatchery; their diligence in all aspects of the project, from rearing fry to stocking phase II fingerlings, made the Striped Bass Restoration Project possible. I especially would like to thank Alex Fogg, Page Vick, Paul Grammer, Jeanne-Marie Havrylkoff, Cher Griffin, Emily Satterfield, and John Green for their assistance in the field. Finally, I would like to thank the GCRL library staff for their assistance in obtaining hard to find literature and journal articles. All surgical procedures complied with protocols that were approved by The USM Institutional Animal Care and Use Committee (IACUC #10100101).

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF ILLUSTRATIONS

Figure

CHAPTER I

BACKGROUND

Striped Bass, *Morone saxatilis*, are widely distributed along the Atlantic Coast of North America ranging from the St. Lawrence River, Canada to the St. Johns River, Florida (Pearson 1938; Burgess 1980). Furthermore, the southern extreme of the species' native range is represented by a naturally disjunct population that exists along the northern Gulf of Mexico (GOM) coast from the Suwannee River, Florida westward to rivers of the Lake Pontchartrain Basin, Louisiana (McIlwain 1967; Burgess 1980; Frugé et al. 2006). In general, Striped Bass are an anadromous species; however, populations at the edge of their distribution are considered potamodromous as they remain within the confines of endemic rivers and estuaries (Hill et al. 1989; McIlwain 1980; Bjorgo et al. 2000). Striped Bass in GOM drainages (hereafter referred to as Gulf-strain Striped Bass) are genetically distinct and treated as a separate stock from Atlantic coast populations (Wirgin et al. 1991; Bulak et al. 2004; Wirgin et al. 2005).

Historically, native stocks of Gulf-strain Striped Bass inhabited rivers and estuaries of the major coastal tributaries along the GOM until the 1950s when populations severely declined (Pearson 1938; Raney and Woolcott 1955; McIlwain 1967). By the late 1960s, population declines were so extensive that they were considered to be extirpated Gulf wide, except for a remnant population in the Apalachicola-Chattahoochee-Flint (ACF) River system (Crateau et al. 1981; Wooley and Crateau 1983; Nicholson et al. 1986). It has been suggested that extensive habitat alterations to coastal river systems may have caused the decline of Gulf-strain Striped Bass populations (McIlwain 1980; Nicholson et al. 1986; Frugé et al. 2006).

As a result of declining populations, Striped Bass stock enhancement efforts across the GOM coast began in 1969 (Lukens et al. 1991) with stockings into coastal tributaries of west Florida, Alabama, Mississippi, Louisiana, and Texas (Nicholson et al. 1986; Frugé et al. 2006). During the initial phases of the program, Atlantic-strain Striped Bass fry and fingerlings were used because of their availability (Frugé et al. 2006). However, in 1980 the U.S. Fish and Wildlife Service artificially spawned Gulf-strain Striped Bass from the ACF system (Frugé et al. 2006) and by 1987 Gulf-strain Striped Bass were integrated into the Mississippi stocking program (Frugé et al. 2006). The primary goal of the GOM Striped Bass regional management plan was to reestablish and maintain self-sustaining Gulf-strain Striped Bass populations within suitable rivers throughout their historic southern range (Frugé et al. 2006). Since 1969, more than 14 million fingerling Striped Bass have been stocked in southern Mississippi coastal tributaries including the Biloxi, Jourdan, Pascagoula, Pearl, Tchoutacabouffa, and Wolf rivers, as well as Old Fort Bayou (L. C. Nicholson, The University of Southern Mississippi, personal communication). Although natural reproduction has been documented in the Chattahoochee and Flint rivers, AL-GA (Hess and Jennings 2001; Long et al. 2013), there is, however, no evidence suggesting natural recruitment of Gulf-strain Striped Bass in Mississippi's coastal tributaries (Nicholson et al. 1986). After almost half a century, the goals of the regional management plan have not been accomplished. Unfortunately, these goals may never be achieved until sufficient post-stocking research efforts can rationalize an understanding for the dearth of natural recruitment in stocked Gulf-strain Striped Bass populations.

Post-stocking success may be enhanced if suitable habitat within Mississippi's coastal tributaries can be identified and assessed for seasonal variability (see Dieterich and Fulford 2012). Since habitat use and movements of Gulf-strain Striped Bass in Mississippi tributaries are unknown beyond traditional tagging studies, the first step in enhancing survival of stocked Gulf-strain Striped Bass should be developing a better understanding about how abiotic conditions may influence their habitat use, dispersal, and movement patterns. These data may allow hatcheries to better schedule release events during the time of the year when such abiotic conditions are most appropriate. Therefore, the overall purpose of my thesis is to assess whether acoustically-tagged Gulf-strain Striped Bass select specific abiotic habitat conditions in the Biloxi River, MS system following stocking (both short- and long-term patterns). Chapter II will focus on initial short-term post-stocking movements of acoustically-tagged juvenile hatchery-reared Gulf-strain Striped Bass and abiotic sub-habitat selection during the presumed acclimatization period to the Biloxi River compared to available habitats. In Chapter III, I will examine seasonal variability in habitat selection of acoustically-tagged juvenile and feral adult Gulf-strain Striped Bass based on abiotic conditions of the Biloxi River. Finally, Chapter IV will synthesize conclusions about the findings of my research.

REFERENCES

Bjorgo, K.A., J.J. Isely, and C.S. Thomason. 2000. Seasonal movements and habitat use of Striped Bass in the Combahee River, South Carolina. Transactions of the American Fisheries Society 129:1281-1287.

Burgess, G.H. 1980. *Morone saxatillis* (Walbaum), Striped bass. Page 576 *in* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr., editors, Atlas of North American Freshwater Fishes. North Carolina Biological Survey. Raleigh, North Carolina.

Bulak, J.S., C.S. Thomason, K. Han, and B. Ely. 2004. Genetic variation and management of Striped Bass populations in the coastal rivers of South Carolina. North American Journal of Fisheries Management 24:1322-1329.

Crateau, E.J., P.A. Moon, and C.M. Wooley. 1981. Apalachicola River Striped Bass Project: Biology, Population Dynamics, and Management of Morone sp. with Emphasis on Native Gulf of Mexico Race and Introduced Atlantic Race Striped Bass, Apalachicola River, Florida. U.S. Fish and Wildlife Service, Panama City, Florida. 105p.

Dieterich, J.W., and R.S. Fulford. 2012. Habitat suitability modeling to evaluate conservation and enhancement efforts for Gulf-strain Striped Bass in Mississippi coastal rivers. Transactions of the American Fisheries Society 141:731-746.

Frugé, D.J., M. Bailey, J. Mareska, L.C. Nicholson, H. Rogillio, E. Long, J.T. Jenkins, J.M. Barkuloo, P. Cooper, Jr., I. Wirgin, and R. Weller. 2006. The Striped Bass Fishery of the Gulf of Mexico. United States: A Regional Management Plan. Gulf

States Marine Fisheries Commission No. 137, Ocean Springs, Mississippi. 363p + 14 Appendixes.

Hess, B.J., and C.A. Jennings. 2001. Reproductive success of stocked Striped Bass (*Morone saxatilis*) in the Chattahoochee River above West Point Lake: implications for the *Morone* stocking program. University of Georgia, Fisheries Stewardship Project, Final Report, Atlanta, Georgia. 20p.

Hill, J., J.W. Evans, and M.J. Van Den Avyle. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic): Striped Bass. U.S. Fish and Wildlife Service Biological Report 82 (11.118). U.S. Army Corps of Engineers TR EL-82-4. 35p.

Long, E.A., C.L. Mesing, K.J. Herrington, R.R. Weller, and I.I. Wirgin. 2013. Restoration of Gulf Striped Bass: lessons and management implications. Pages 25-64 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Lukens, R.R., L.C. Nicholson, and J.Y. Christmas, III. 1991. Success of juvenile Striped Bass in two bay systems in Mississippi 1980-1984. Gulf Research Reports 8:317-327.

McIlwain, T.D. 1967. Distribution of the Striped Bass, *Roccus saxatilis* (Walbaum), in Mississippi water. Proceeding Annual Conference Southeastern Association of Game and Fish Commissioners 21:254-257.

McIlwain, T.D. 1980. Striped bass in coastal waters, South Atlantic and Gulf of Mexico. Pages 37-44 *in* H. Clepper, editor. Proceedings of the Fifth Annual Marine Recreational Fisheries Symposium. Sport Fishing Institute, Washington, D.C.

Nicholson, L.C., I.B. Byrd, E. Crateau, J.A. Huff, V. Minton, M. Powell, G.E. Saul, F. Ware, and A. Williams. 1986. Striped Bass Fishery Management Plan. Gulf States Marine Fisheries Commission No. 16, Ocean Springs, Mississippi. 131p + 2 Appendixes.

Pearson, J.C. 1938. The life history of the Striped Bass, or rockfish, *Roccus saxatilis* (Walbaum). Fishery Bulletin 48:825-851.

Raney, E.C., and W.S. Woolcott. 1955. Races of the Striped Bass, *Roccus saxatilis* (Walbaum), in southeastern United States. Journal of Wildlife Management 19:444-450.

Wirgin, I.I., C. Grunwald, and S.J. Garte. 1991. Use of DNA fingerprinting in the identification and management of Striped Bass population in the Southeastern United States. Transactions of the American Fisheries Society 120:273-282.

Wirgin, I.I., D. Currie, N. Roy, L. Maceda, and J.R. Waldman. 2005. Introgression of nuclear DNA (nDNA) alleles of stocked Atlantic coast Striped Bass with the last remaining native Gulf of Mexico population. North American Journal of Fisheries Management 25:464-474.

Wooley, C.M., and E.J. Crateau. 1983. Biology, population estimates, and movement of native and introduced Striped Bass, Apalachicola River, Florida. North American Journal of Fisheries Management 3:383-394.

CHAPTER II

SHORT-TERM ABIOTIC HABITAT SELECTION OF STOCKED JUVENILE GULF-STRAIN STRIPED BASS

Introduction

Anadromous Striped Bass, *Morone saxatilis*, naturally range from the Labrador coast to the central Gulf of Mexico (GOM) (Burgess 1980). However, historical declines resulting from overfishing, habitat loss, and degradation created the need for extensive inputs of hatchery-reared Striped Bass to a variety of ecosystems. With advances in hatchery production since the late 19th century, fisheries managers have stocked juvenile Striped Bass into lotic systems along the Atlantic coast and northern GOM (Frugé et al. 2006; Van Horn 2013) and successfully introduced Striped Bass to lentic systems along the Pacific coast and as far inland as the central plains (Burgess 1980). Thus, stocking has played a large role in creating geographically distant populations in the United States (Russel 2005).

Since the late 1960s, fisheries managers have stocked Striped Bass in coastal drainages along the northern GOM in an effort to reestablish and maintain self-sustaining populations in their native southern range (Frugé et al. 2006). Despite almost half a century of stock enhancement activities, the majority of GOM Striped Bass populations (hereafter referred to as Gulf-strain Striped Bass) have not recovered beyond small put-grow-and-take fisheries (Frugé et al. 2006; see Callihan et al. 2015). Successful restoration of Gulf-strain Striped Bass may be inhibited because of release practices with inadequate knowledge of post-stocking fish behavior coupled with abiotic habitat limitations throughout GOM drainages (Dieterich and Fulford 2012; Long et al. 2013).

Rigorous assessments of post-stocking survival are seldom practiced among stocking programs, and success is usually measured by quantity released (Yow et al. 2013). Insufficient post-release monitoring is disconcerting because pre-stocking procedures, such as prolonged periods of confinement (Weirich et al. 1992), routine handling (Wallin and Van Den Avyle 1995), tagging, and transport activities (Mazeaud et al. 1977; Carmichael et al. 1984) induce stress which can adversely affect post-stocking survival. Furthermore, the abiotic conditions of receiving waters at stocking sites also influence post-stocking survival. For example, in freshwater reservoirs, fingerling (25 – 46 mm TL) Striped Bass survival was negatively affected by increased change in water temperature, increased conductivity, and decreased pH during stocking (Pitman and Gutreuter 1993). Furthermore, the use of sodium chloride during transportation (Mazik et al. 1991) and stocking in brackish waters has been known to enhance Striped Bass survival (Wallin and Van Den Avyle 1995). Thus, survival of hatchery-reared fish initially depends on abiotic characteristics of receiving waters along with the ability to recover from pre-stocking stress, as stress tolerance is generally inversely related to the duration of the stressor (Carmichael et al. 1984). There is a growing case to be made that post-stocking assessments may provide a better measure of success rather than quantity released (Dorazio et al. 1991; Yow et al. 2013).

The conditions in which cultured fish are reared at the hatchery may influence short-term post-stocking behavior and habitat use patterns. For example, numerous studies (mostly on salmonids) have shown that hatchery environments tend to repress basic innate survival behavior of cultured fish (Olla et al. 1998; Brown and Laland 2001). In the short-term, hatchery-reared fish do not have the ability to recognize predators, prey, and/or unfavorable abiotic conditions and consequently may lack essential behavioral responses (Olla et al. 1998) to survive new environmental conditions. Moreover, laboratory studies have shown that habitat use can differ among hatchery and wild fish species (Mesa 1991; Deverill et al. 1999) suggesting that hatchery-reared individuals may select a subset of abiotic conditions that may reduce stress (as noted above) in the short-term and then once acclimatized, stocked fish may tend to occupy a wider-range of environmental conditions. Thus, it is important to gain adequate knowledge about the post-stocking behavior of hatchery-reared fish in response to complex dynamic interactions between biotic and abiotic characteristics of receiving waters.

Understanding how different abiotic conditions of lotic systems may influence movement of juvenile hatchery-reared Gulf-strain Striped Bass could provide useful information in regards to post-stocking habitat selection. Anadromous species are able to tolerate a wide range of abiotic conditions, which generally facilitates a relatively quick acclimation period to new environments (Pottinger and Pickering 1992). However, optimal abiotic conditions typically change throughout a fish's life span. For example, Striped Bass thermal tolerance decreases with increasing age (Coutant 1980; Coutant et al. 1984), and for three size-classes (< 230 mm TL) of Striped Bass, salinity (0-7 psu) at stocking sites had a positive relationship with increased short-term survival compared to freshwater sites (Wallin and Van Den Avyle 1995). Moreover, dynamic lotic systems are unpredictable compared to highly controlled hatchery conditions. Thus, variable stream discharge, water temperature, and salinity differences can be physiologically stressful to newly stocked fish and they are most likely going to select areas that best suit their short-term physiological requirements. Fishes generally respond to large fluctuations in salinity, water temperature, and turbidity (Childs et al. 2008), suggesting abiotic conditions influence movements toward habitats with specific physiochemical conditions as a means to alleviate stress.

Poor recovery of Gulf-strain Striped Bass populations in the northern GOM may be attributed to the synergetic effects of pre-stocking stressors along with post-stocking behavioral and physiological responses to dynamic environmental conditions. The objective of this short-term (15 day) study was to use acoustic telemetry to identify initial post-stocking dispersal and habitat use patterns of juvenile hatchery-reared Gulf-strain Striped Bass in a lotic environment. I hypothesize that post-release juvenile hatchery-reared Gulf-strain Striped Bass habitat use will be influenced by spatially-variable abiotic conditions. Specifically, I predict that 1) there will be short-term (≤ 4 days post-release) use of sub-habitats with abiotic conditions that are more physiologically conducive to recovery from pre-stocking stressors than the mean abiotic condition of available habitat within the Biloxi River, MS and 2) that these abiotic habitat use patterns will change within 15 days post-release as fish acclimatize to background abiotic conditions. The results of this study should offer insights into the post-stocking behavior with regard to initial habitat selection and short-term spatial and temporal dispersal patterns based on abiotic conditions.

Study Site

The Biloxi Bay Estuary is a drowned river valley consisting of both back and outer bays adjoining the Mississippi Sound, has a mean depth of 1.3 m, and is about 21.7 km long (Eleuterius and Criss 1994). The primary sources of freshwater input in this system are the Biloxi and Tchoutacabouffa rivers which are both undammed and have drainage basin areas of 701.9 km^2 and 626.8 km^2, respectively (Figure 2.1). In a 2008

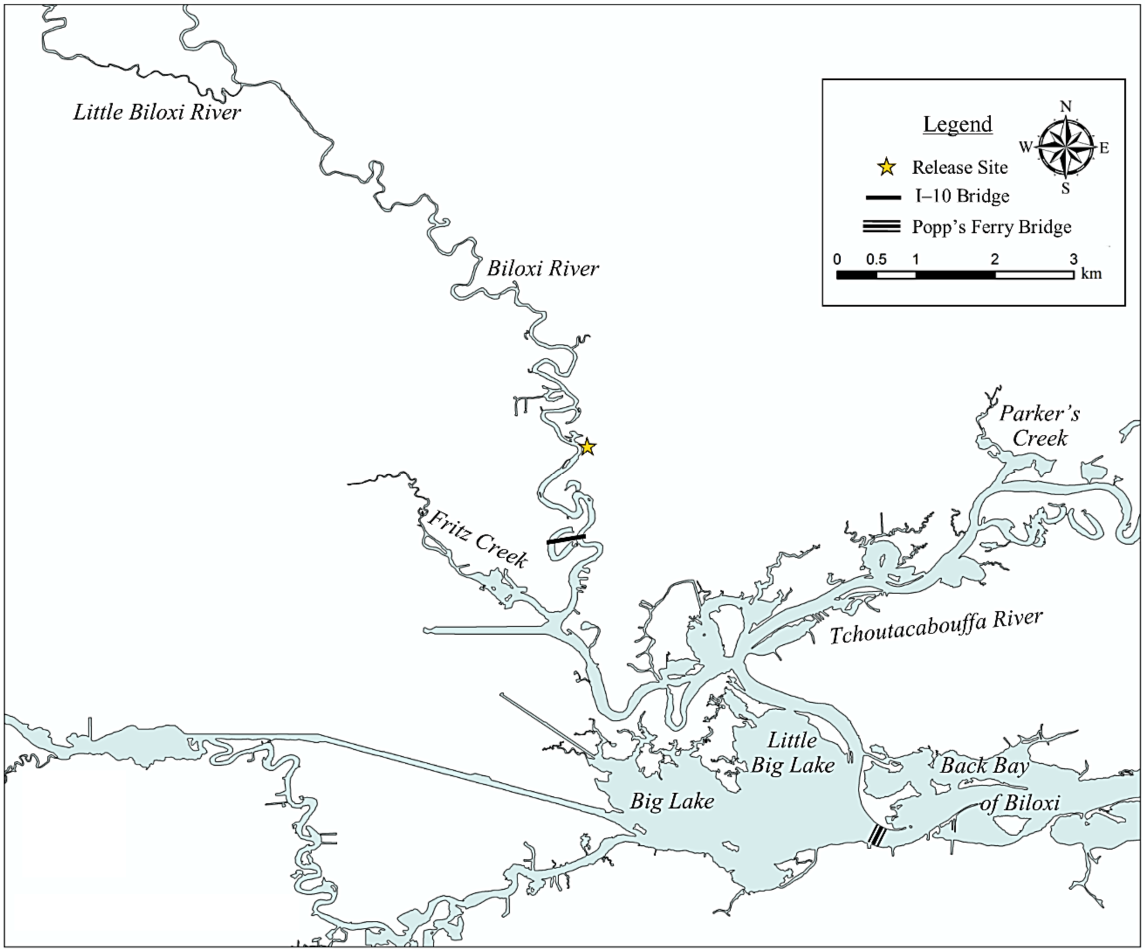


Figure 2.1. The extent of the Biloxi River, MS study area and release site (indicated by the star) of acoustically-tagged hatchery-reared juvenile Gulf-strain Striped Bass.

census, land use of the surrounding landscape was predominately categorized as 28% undeveloped or vacant lots, 25% residential areas, and 23% agriculture or forest (http://www.biloxi.ms.us/pdf/3.%20Land%20Use.pdf) which includes: 31 % evergreen forests, 18% forested wetlands, and 15% scrub/shrub mixed areas (Center for Urban Rural Interface Studies 2009). The primary study area for this project was a section of the Biloxi River that extended 13.7 river kilometer (rkm) upstream from the mouth of the river which drains at a mean annual rate of about 59.4 $m^3 s^{-1}$ (USGS webpage, waterdata.gov/nwis). Seasonal water temperature ranges from 5.9 - 36.0°C (Eleuterius and Criss 1994), and the lower portion of the study area is moderately influenced by diurnal tides (0.3-0.7 m), and salinity is largely dependent on rainfall and can range from 0.0 – 29.0 psu (Eleuterius and Criss 1994). The bathymetry of the Biloxi River has naturally-formed deep holes which mainly occur at river bends. Along the river continuum the denser, high salinity waters tend to remain in deep depressions, while less dense freshwater flows out of the system at the surface.

The Biloxi River was an ideal location to conduct this study for several biological and geographical reasons. First, environmental and prey availability data collected from the Biloxi Bay Estuary, MS suggested that this system provided suitable habitat to support the survival of juvenile Gulf-strain Striped Bass (Nicholson 1983; Lukens 1988; Lukens et al. 1991). Second, these conclusions are supported by a spatially-explicit bioenergetics model that estimated growth rate potentials of Gulf-strain Striped Bass as an indicator of suitable habitat in the Biloxi River and its tributaries (Dieterich and Fulford 2012). Their model suggested that suitable habitat was available throughout the year; however, habitat was severely limited during summer months, at which time viable habitat supporting growth was reduced by 85% (Dietrich and Fulford 2012). Also, the Biloxi River is located near areas where fingering Striped Bass were historically released at Big Lake and Parker's Creek (L.C. Nicholson, The University of Southern Mississippi, personal communication). Finally, the Biloxi River is sinuous but narrow which allowed our acoustic receiver array (see Chapter III) to monitor the entire width of the river without missing an acoustically-tagged fish.

Methods

Acoustic Tagging

Phase II (195-277 mm total length (TL)) hatchery-reared Gulf-strain Striped Bass obtained from the Mississippi Department of Marine Resources (MS-DMR) Lyman Fish Hatchery, Gulfport, MS were selected for surgical implantation with acoustic transmitters (VEMCO Ltd., Halifax, Nova Scotia, Canada). Fish were measured (mm), weighed (g), and anesthetized in a water bath containing 45 mg MS-222 (tricaine methanesulfonate; Western Chemical Inc., Ferndale, Washington) per liter of fresh water for five to seven minutes. A small incision was made along the ventral midline and an acoustic transmitter was implanted into the body cavity. In November 2012, a total of 17 individuals (Table 2.1) were implanted with V7-4L acoustic transmitters (69.0 kHz, 1.0 g in water, 22.5 x 7.0 mm, mean delay 180 s, power output 136 dB, and estimated < 345 d battery life). In December 2013, an additional 17 individuals (Table 2.1) were implanted withV9-2L acoustic transmitters (69.0 kHz, 2.9 g in water, 29.0 x 9.0 mm, mean delay 60 s, power output 146 dB, and estimated < 280 d battery life). The incision was closed with several simple interrupted sutures using polydioxanone absorbable suture material (ETHICON reverse cutting 3-0 PDS* Plus Antibacterial, Guaynabo, Puerto Rico). An external T-bar anchor tag (Hallprint Ltd., Hindmarsh Valley, South Australia) was attached at the dorsal fin base to facilitate angler reporting and identification of acoustically-tagged fish. Fish were intramuscularly injected with 2 mg/kg of Ketoprofen(Fort Dodge Animal Health Inc., Fort Dodge, Iowa), a non-steroidal anti-inflammatory agent, at the base of the dorsal fin to alleviate pain. All surgical procedures followed protocols approved by the USM Institutional Animal Care and Use Committee (USM IACUC #10100101; Appendix A).

Table 2.1

Tagging and Biological Information for Acoustically-tagged Phase II Gulf-strain Striped Bass Released in the Biloxi River, MS during November 2012 and December 2013

VEMCO Ltd. ID	External Tag ID	Date tagged	Est. battery termination date	SL (mm)	FL (mm)	TL (mm)	Weight (g)
V7-24717	SY0282	11/01/2012	10/11/2013	172	193	205	114
V7-24718	SY0064	11/01/2012	10/11/2013	215	245	260	242
V7-24719	SY0718	11/01/2012	10/11/2013	195	220	230	194
V7-24721	SY0740	11/01/2012	10/11/2013	171	195	205	111
V7-24722	SY0741	11/01/2012	10/11/2013	219	250	266	225
V7-24723	SY0742	11/01/2012	10/11/2013	168	186	198	100
V7-24724	SY0743*	11/01/2012	10/11/2013	170	185	195	96
V7-24725	SY0283	11/01/2012	10/11/2013	170	186	200	98
V7-24728	SY0747	11/01/2012	10/11/2013	184	210	215	159
V7-24729	SY0748	11/01/2012	10/11/2013	180	200	212	135
V7-24730	SY0749*	11/01/2012	10/11/2013	190	215	228	157
V7-24731	SY0276	11/01/2012	10/11/2013	185	209	220	146
V7-24732	SY0277	11/01/2012	10/11/2013	185	204	215	121
V7-24733	SY0278	11/01/2012	10/11/2013	184	209	215	138
V7-24734	SY0279	11/01/2012	10/11/2013	172	192	205	115
V7-24735	SY0280	11/01/2012	10/11/2013	172	194	206	112
V7-24736	SY0281	11/01/2012	10/11/2013	178	200	210	113
V9-30684	UB0098	12/03/2013	09/06/2014	197	226	238	170
V9-30685	UB0099	12/03/2013	09/06/2014	204	227	242	173
V9-30686	UB0100	12/03/2013	09/06/2014	190	209	226	142
V9-30687	UB0101	12/03/2013	09/06/2014	177	199	212	112
V9-30688	UB0102	12/03/2013	09/06/2014	204	229	242	158
V9-30689	UB0097	12/10/2013	09/06/2014	222	240	240	187
V9-30690	UB0095	12/10/2013	09/06/2014	223	245	251	192
V9-30691	UB0105	12/03/2013	09/06/2014	191	121	226	139
V9-30692	UB0106	12/03/2013	09/06/2014	192	214	227	137
V9-30693	UB0108	12/03/2013	09/06/2014	200	221	234	149
V9-30694	UB0109	12/03/2013	09/06/2014	207	228	242	161
V9-30695	UB0110	12/03/2013	09/06/2014	204	224	240	169
V9-30696	UB0093	12/10/2013	09/06/2014	229	253	262	213
V9-30697	UB0113	12/03/2013	09/06/2014	232	259	277	248
V9-30698	TO0122	12/10/2013	09/06/2014	223	250	261	196
V9-30699	UB0115	12/03/2013	09/06/2014	208	229	247	175
V9-30700	UB0116	12/03/2013	09/06/2014	209	238	252	177

Note. VEMCO Ltd. ID = transmitter type and unique ID; SL = standard length; FL = fork length; TL = total length. External tag IDs with a single asterisk (*) indicate loss of the external T-bar anchor tag prior to release; fish were not externally re-tagged.

Post-surgery, fish were allowed to recover for one week in a holding tank with recirculating water at the MS-DMR Lyman Fish Hatchery. After the recovery period, acoustically-tagged phase II Gulf-strain Striped Bass were placed in aerated holding tanks and transported from the MS-DMR Lyman Fish Hatchery to the Biloxi River, MS release site each year. To alleviate handling and transport stress, a mixture of Instant Ocean and potassium permanganate (5g/L) was integrated into the holding tanks and at the release site, Biloxi River water was gradually mixed into the holding tanks to acclimate the fish to river conditions. During the 1 hour transition period, water temperature (°C), salinity (psu), dissolved oxygen (DO; mg/L), and pH were continuously monitored. When water temperature of the holding tanks matched that of the Biloxi River, the Gulf-strain Striped Bass were released.

Manual Tracking Procedures

To determine post-release fine-scale abiotic habitat selection, acoustically-tagged Gulf-strain Striped Bass were manually tracked in the Biloxi River using VEMCO Ltd. omni-directional (VH165, 50-85 kHz) and directional (VH110, 50-85 kHz) hydrophones accompanied with a portable receiver (VR-100; VEMCO Ltd.). Manual tracking sessions occurred during daylight hours at one day (1 d), four days (4 d), and 15 days (15 d) post-release in November 2012, and at 1 d, three days (3 d), and 15 d post-release in December 2013. Tracking sessions were intentionally scheduled between flood events to avoid monitoring fish movements and/or habitat selection that may have been influenced by increased discharge rates and homogeneous abiotic conditions. During manual tracking sessions, acoustic monitoring occurred at ≤ 1 km intervals for ≤ 300 seconds using the omni-directional hydrophone with the VR-100 set to monitor on “Far” at the highest manual gain (a setting of 48) until an acoustically-tagged Gulf-strain Striped Bass was detected. Listening time was determined based upon the longest (230 s) nominal delay predicted between the transmitter's signals.

Once a fish was detected, the directional hydrophone was used to determine its location. In an attempt to obtain an accurate and consistent location of the fish, the VR-100 was set to monitor on "Near" and the gain was progressively decreased until the lowest gain (a setting of 6) was reached. When the transmitter's signals were ≥ 80 dB in a 360° rotation of the directional hydrophone, the location of the Gulf-strain Striped Bass was considered identified and the GPS coordinates were recorded. A vertical profile of water temperature, salinity, DO, and pH at the fish location was recorded at 1 m intervals from the surface to the bottom using a multi-parameter TROLL® 9500 (In-Situ Inc., Fort Collins, Colorado) unit and In-Situ RuggedReader™ personal digital assistant. The maximum depth (m) of each fish location was recorded by the TROLL® 9500 unit; depths were verified by hull mounted sonar. If acoustically-tagged fish appeared to be schooling, the extent of their upstream and downstream range was determined according to the strongest transmitter signal strengths while manually tracking. Then, vertical profiles of the aforementioned abiotic variables and maximum depth data were collected at three haphazard locations within the estimated range of the school.

Biloxi River Physiochemical Condition Assessment

An assessment of the study area was conducted during daylight hours to identify the abiotic conditions of the Biloxi River. During each assessment, vertical profiles of the abiotic variables and maximum depths were recorded at 40 random sites within the Biloxi River using the same equipment and techniques as the vertical profiles for fish locations (see *Manual Tracking Procedures*). The random sites were derived using the random points data management tool in ArcMap 10.0 (ArcGIS; ESRI Inc., Redlands, California). Sampling day was determined semi-randomly based on personnel availability and weather conditions. The mean river abiotic condition was sampled once on 9 November 2012 and twice during December 2013 (12th and 25th). The two December sample dates in 2013 were due to post-release severe weather events causing a peak in river discharge and gage height (see Appendix B and C), which subsequently resulted in homogeneous abiotic conditions throughout the river. These data were compared against the manual tracking data within respective month and year sampling periods to determine if Gulf-strain Striped Bass selected a subset of abiotic characteristics (i.e., sub-habitats) that were unique compared to the random mean abiotic condition of the river.

Terminology

“Fish location” was used to identify individually relocated Gulf-strain Striped Bass. “Schooling fish locations” were used to identify locations of schooling Gulf-strain Striped Bass. “Mean river abiotic condition” were used to identify the river abiotic variables recorded at the 40 random sites.

Data Analyses

Gulf-strain Striped Bass size (TL, mm) and wet weight (WW, g) were compared between November 2012 and December 2013 juvenile tagged fishes with a Student’s t-test after comparing for normality with a Kolmogorov-Smirnov one-sample test ($p < 0.05$) and Levine’s test ($p < 0.05$) (Field 2005). Mean ± 1 standard error of the mean (SEM) will be presented.

Since exact depths used by acoustically-tagged Gulf-strain Striped Bass were undeterminable, the mean (or grand mean) value of each vertical profile was calculated each sampling date for all abiotic variables collected during manual tracking events and river abiotic condition assessments. For individual fish locations, the mean abiotic data for each variable and maximum depth was used. For schooling fish locations, the grand mean (n = 3) of abiotic data for each variable and mean maximum depth were calculated; these values were repeated in the database for each acoustically-tagged Gulf-strain Striped Bass identified within the school. For the mean river abiotic condition, the mean abiotic data for each variable and maximum depth for each random site (n = 40) was used. The aforementioned abiotic and depth data that represented fish locations and schooling fish locations were then compared against the mean river abiotic conditions to identify Gulf-strain Striped Bass abiotic sub-habitats during initial acclimatization to a natural lotic system.

Abiotic sub-habitat selection by acoustically-tagged Gulf-strain Striped Bass was assessed by principle component analysis (PCA); separate PCAs were performed for: 1) November 2012, which included the mean river abiotic conditions together with 1 d, 4 d, and 15 d post-release sub-habitat data; 2) early December 2013, which included the mean river abiotic condition sampled on 12 December 2013 along with 1 d and 3 d post-release sub-habitat data; and 3) late December 2013, which included both the mean river abiotic condition and 15 d post-release sub-habitat data sampled on 25 December 2013. The fixed factor extraction method was used to extract two meaningful components for each PCA rather than Kasier's criterion, which only extracts components with eigenvalues ≥ 1.00 (Field 2005). Using Kasier's criterion with these data sometimes resulted in retaining only a single meaningful component, which often loaded all variables highly; thereby, making it difficult to tease out which variables were important for explaining the composite PCA results. However, for instances where a single component was retained using Kasier's criterion, the second component had an eigenvalue ranging from 0.75 – 0.98, and explained at least 14% of the variability. Noticing this, it was determined that Kasier's criterion may be too strict for these data, which is supported by Jolliffe (1972), who suggested retaining all factors (i.e., components) with eigenvalues > 0.70. Therefore, each PCA conducted with these data was specified to extract two meaningful components.

To examine the influence of my sample size on each PCA, I employed both the Kaiser-Meyer-Olin (KMO) measure of sampling adequacy and the Bartlett's test of sphericity (Field 2005). The KMO test represents the ratio of squared correlation between variables to the squared partial correlation between variables (Field 2005). KMO values were characterized as follows: values between 0.50 - 0.70 were considered mediocre, values between 0.70 - 0.80 were considered good, values between 0.80 - 0.90 were considered great, and values > 0.90 were considered superb (Field 2005). Bartlett's test examines whether the original correlation matrix resembled an identity matrix, where each variable correlated perfectly with itself but correlated poorly with other variables (Field 2005). Bartlett's test must be significant ($p \leq 0.05$) to conduct PCA properly (Field 2005).

The mean (or grand mean) vertical profile abiotic and depth data were orthogonally reduced with PCA being applied to the correlation matrix to establish underlying relationships among the variables (Hair et al. 1984; Mickle et al. 2010; Lopez et al. 2011). The correlation matrix represents the standardized form of the covariance matrix and thus accounts for variables measured on different scales (Field 2005). Varimax rotation was applied to minimize the number of variables with high loadings on a single factor, thereby maximizing the variance of the loadings to enhance the interpretation of the factors (Hair et al. 1984). Variables that loaded on a component with an r-value $|\geq 0.50|$ were considered significant for the interpretation of that component. If a single variable loaded with an r-value $|\geq 0.50|$ on multiple components, then only the component with the highest loadings was selected for interpretation. Factor scores were extracted from the PCA using the Anderson-Rubin (A-R) method (Field 2005) and were used for further analysis. The A-R factor scores are a composite of the *in situ* abiotic condition for each sampling period.

One-way analysis of variance (ANOVA) or a Student's *t*-test was used to test the null hypothesis that mean abiotic conditions between Gulf-strain Striped Bass sub-habitats and the mean river abiotic condition, within a month-year sampling period ($n = 3$), were not statistically different. For November 2012 and early December 2013 datasets, separate ANOVA comparisons of the A-R factor scores among a month-year sampling period were made for each meaningful component of the PCA. However, both datasets violated the assumption of homogeneity of variance and had unequal sample sizes; thus, I used the robust test of equality of means, the Brown-Forsythe *F*-ratio (Field 2005), and these values are reported. Pairwise comparisons were made using Games-Howell (GH; heterogeneous variance) post hoc procedures (Field 2005) to separate significant main effects among 1, 3 or 4, 15 d, and mean river abiotic conditions ($n = 4$ for November 2012; $n = 3$ for early December 2013). A Student's *t*-test was performed on the A-R factor scores extracted from late December 2013 PCA to compare 15 d post-release sub-habitat conditions with the mean river abiotic condition collected on that day. Based on the results of the PCA composite A-R factor scores, I then used summary *in situ* abiotic data to interpret any differences or similarities. All statistics were conducted with SPSS Statistics for Windows (Version 22.0; IBM Corp., Armonk, New York), and mean differences were significant when $p \leq 0.05$ (Field 2005).

Results

Manual Tracking Relocations

During November 2012, manual tracking of acoustically-tagged hatchery reared juvenile Gulf-strain Striped Bass occurred at 1 d, 4 d, and 15 d post-release in the Biloxi River. At 1 d post-release, 16 Gulf-strain Striped Bass were detected (94% of all tagged fish). Of these, the vast majority (81%) of individuals were found schooling near the release site (Figure 2.2), with the remaining found in separate locations (19%) ranging from 343 m upstream to 1,144 m downstream from the release site (Figure 2.3).

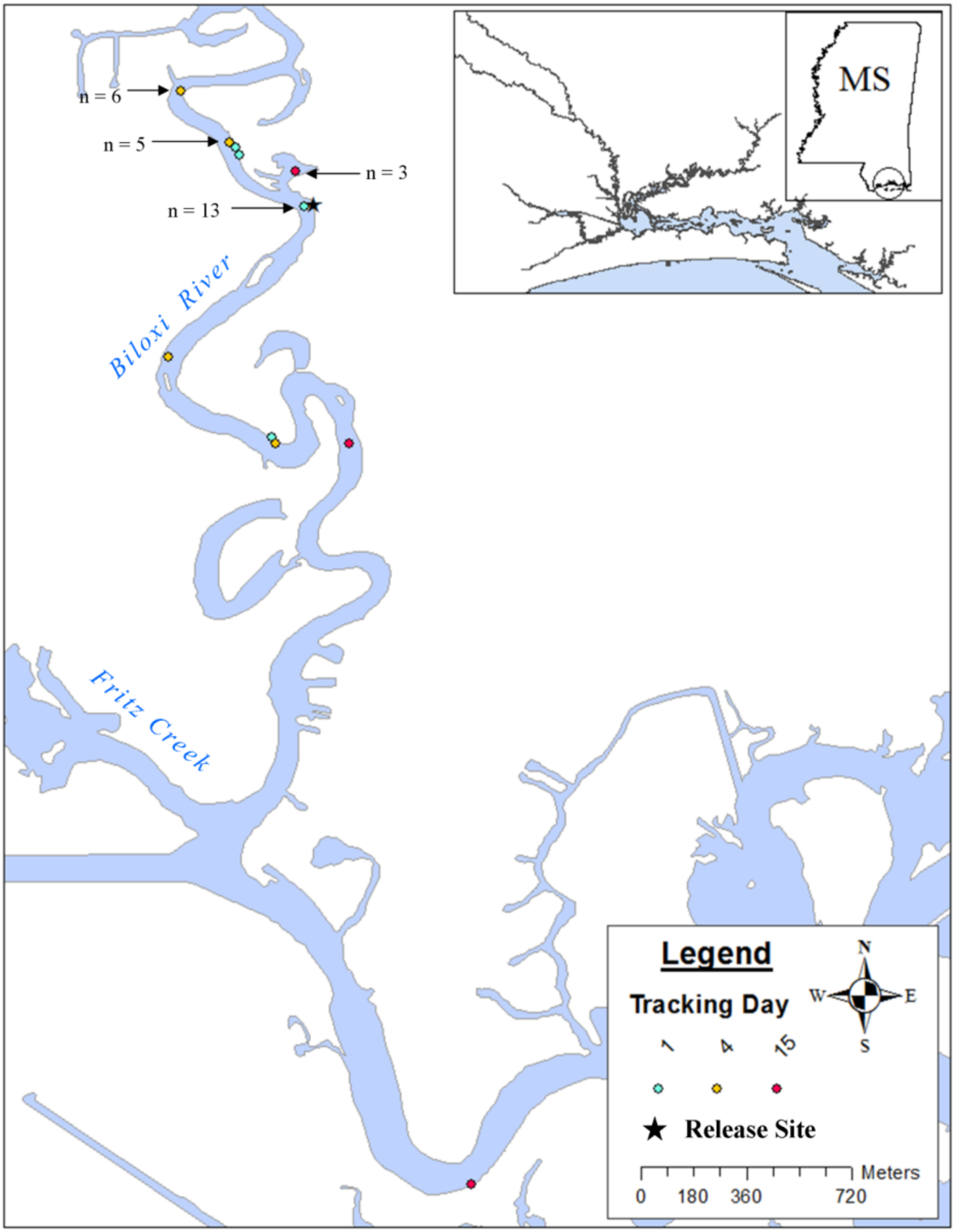


Figure 2.2. Locations of acoustically-tagged hatchery-reared juvenile Gulf-strain Striped Bass sub-habitat in November 2012 during manual tracking events at 1, 4, and 15 days (d) post-release in the Biloxi River, MS. Sub-habitat locations occupied by more than one Gulf-strain Striped Bass are indicated by an arrow with the exact number of fish detected represented by n. Inset depicts the location of the study area in Mississippi.

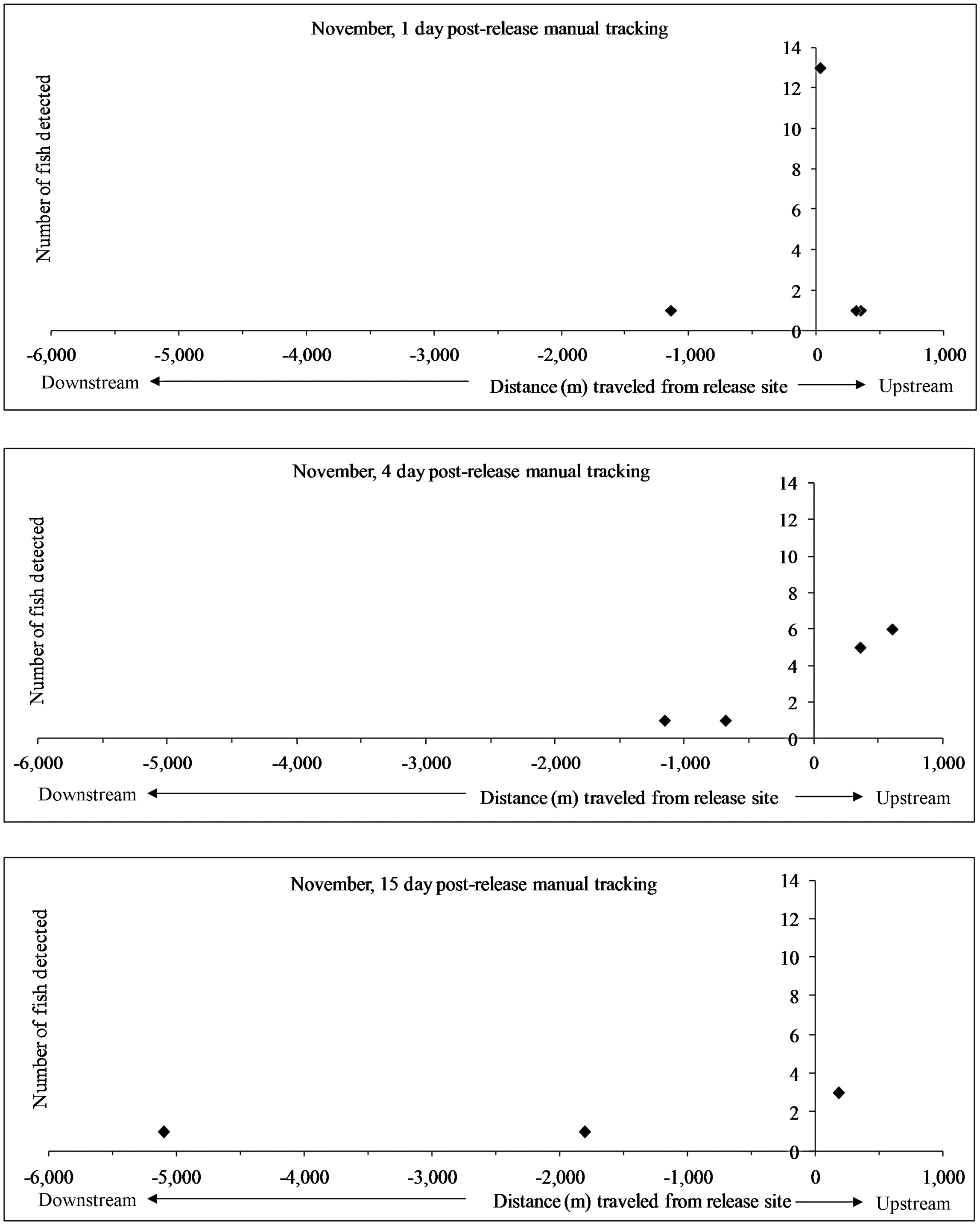


Figure 2.3. Upstream (+) and downstream (-) distances (m) traveled from release site (x-axis) by acoustically-tagged juvenile Gulf-strain Striped Bass in the Biloxi River, MS during manual tracking events in November 2012 at 1, 4, and 15 days (d) post-release. The number of fish detected at each sub-habitat location is indicated on the y-axis.

At 4 d post-release, 13 Gulf-strain Striped Bass were detected (77% of all tagged fish). Fish started to disperse from the release site (Figure 2.2), but the majority were found in two separate schools (85% combined) upstream from the release site (Figure 2.3). By 15 d post-release, only five Gulf-strain Striped Bass were detected (29% of all tagged fish), the majority of these fish were schooling (60%) in a small, shallow (< 3 m) backwater area just upstream from the release site (Figure 2.2); however, remaining individuals were located as far as 5,101 m downstream from the release site (Figure 2.3).

In December 2013, manual tracking of acoustically-tagged hatchery reared juvenile Gulf-strain Striped Bass at 1 d, 3 d, and 15 d post-release revealed more extensive upstream and downstream dispersal from the release site than fish stocked in November 2012 (Figure 2.4). At 1 d post-release, all acoustically-tagged fish (n = 17; 100% of all tagged fish) were detected. Most of fish were found in three separate schools located as far as 560 m downstream from the release site; however, two individuals traveled over 600 m upstream from the release site. By 3 d post-release, 16 Gulf-strain Striped Bass were detected (94% of all tagged fish). Of these, individuals were widely dispersed both upstream and downstream from the release site (Figure 2.4), but the majority of fish were found in two separate schools (63% combined) below the release site (Figure 2.5). At 15 d post-release, 10 Gulf -strain Striped Bass were detected (59% of all tagged fish); fish were found in individual locations (n = 5) and two separate schools (n = 5). Similar to the November 2012 manual tracking event, 15 d post-release fish and schooling fish locations were again widely dispersed from the release site (Figure 2.4). However, individuals released in December 2013 occupied areas ranging from 4.1 rkm downstream to 5.7 rkm upstream from the release site (Figures 2.4 and 2.5).

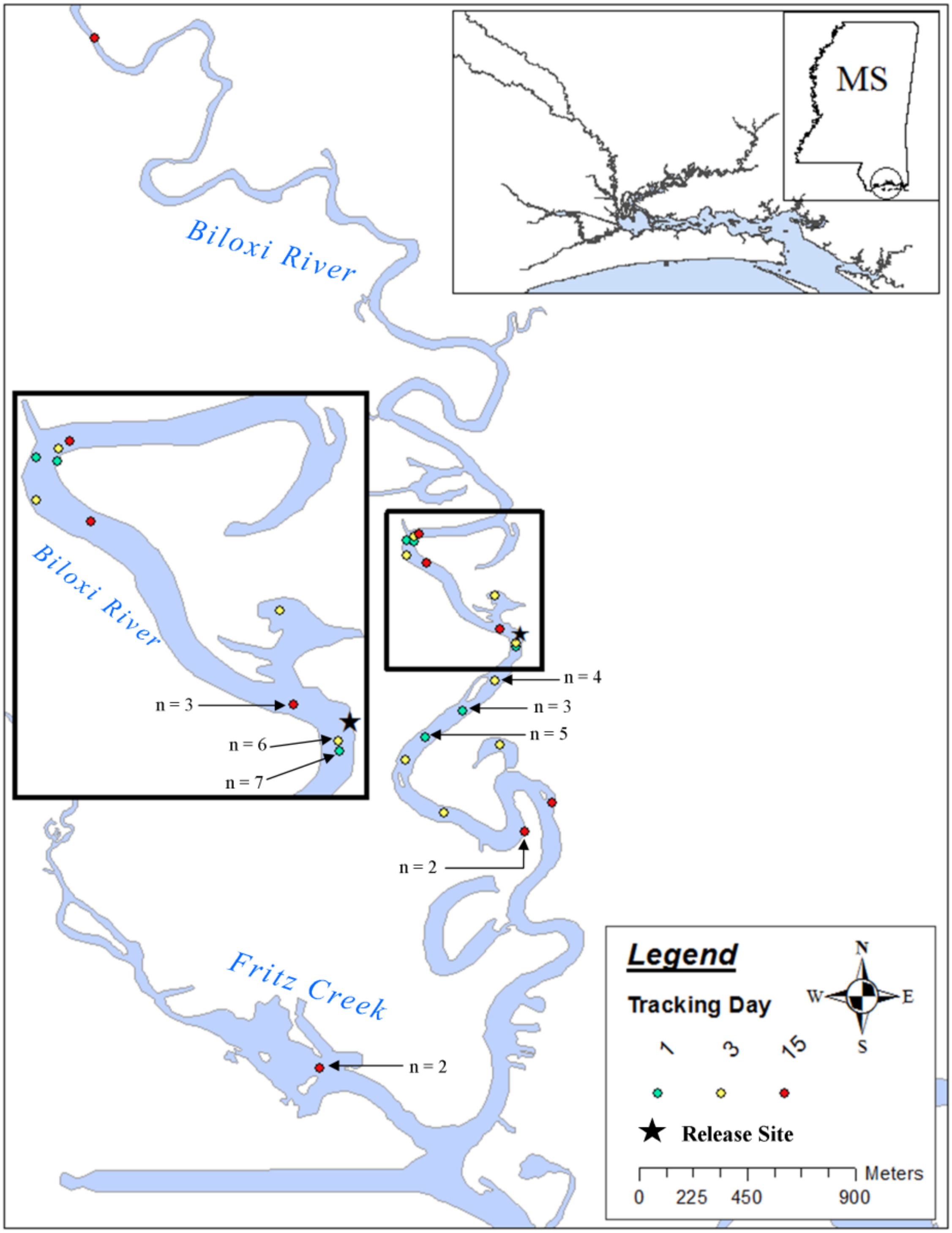


Figure 2.4. Locations of acoustically-tagged juvenile Gulf-strain Striped Bass sub-habitats in December 2013 during manual tracking events at 1, 3, and 15 days (d) post-release in the Biloxi River, MS. Sub-habitat locations occupied by more than one Gulf-strain Striped Bass are indicated by an arrow with the exact number of fish detected represented by n. Top right inset depicts the location of the study area in Mississippi. The bold inset depicts the area around the release site.

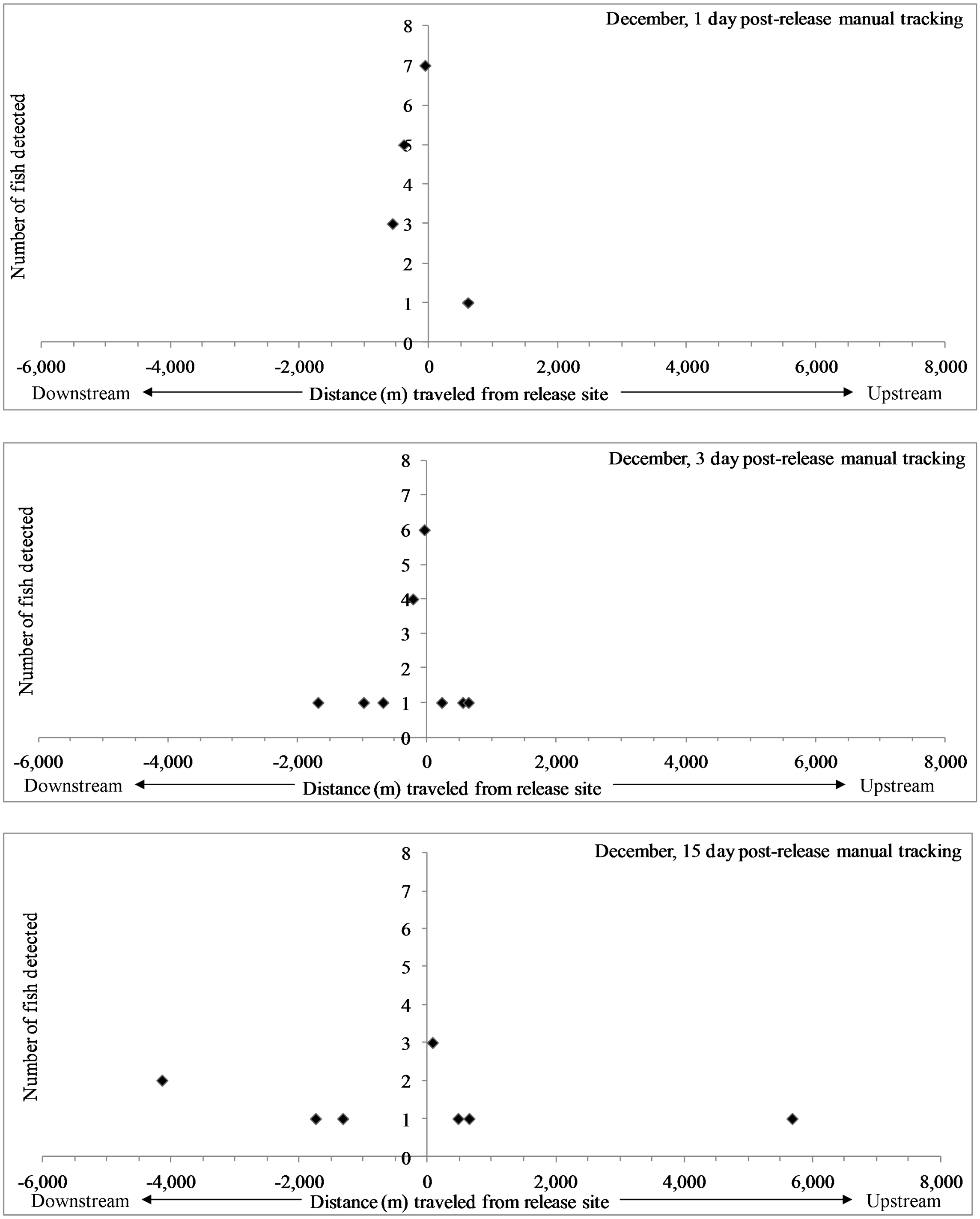


Figure 2.5. Upstream (+) and downstream (-) distances (m) traveled from release site (x-axis) by acoustically-tagged juvenile Gulf-strain Striped Bass in the Biloxi River, MS during manual tracking events in December 2013 at 1, 3, and 15 days (d) post-release. The number of fish detected at each sub-habitat location is indicated on the y-axis.

Quantitative Comparisons

Gulf-strain Striped Bass TL and WW of juveniles were normally distributed and homogeneous within each year (all $p > 0.28$) with fish in 2012 being smaller in TL (216.76 ± 4.82) than those in 2013 (242.29 ± 3.79; $p < 0.01$) and in WW 139.76 ± 10.60 and 170.47 ± 7.75 ($p = 0.03$).

For the November 2012 data set, the KMO was 0.56 and Bartlett's test was significant ($p < 0.01$), which indicated PCA was appropriate. The PCA reduced the five original variables into two meaningful components that explained 88.76% of the variation (Table 2.2 A). Component I explained 54.22% of the total variance and consisted of positive correlations with mean water temperature and mean maximum depth and negative correlations with mean DO (Table 2.2 A, Figure 2.6). Component II explained another 34.54% of the total variance and was composed of positive correlations with mean pH and mean salinity (Table 2.2 A, Figure 2.6).

Table 2.2

Results of Three Principal Component Analyses. A) November 2012, B) Early December 2013, and C) Late December 2013.

A) November 2012 Components (% explained = 88.76)

Variables	I (54.22%)	II (34.54%)
Maximum Depth	**0.760**	0.391
Mean Water Temperature	**0.949**	-0.005
Mean Dissolved Oxygen	**-0.946**	0.110
Mean Salinity	0.542	**0.806**
Mean pH	-0.213	**0.955**

B) Early December 2013 Components (% explained = 81.09)

Variables	I (56.19%)	II (24.91%)
Maximum Depth	**0.840**	-0.079
Mean Water Temperature	**0.920**	-0.036
Mean Dissolved Oxygen	-0.362	**0.868**
Mean Salinity	**0.861**	-0.103
Mean pH	0.620	**-0.688**

C) Late December 2013 Component (% explained = 85.66)

Variables	I (58.01%)	II (27.65%)
Maximum Depth	0.168	**0.933**
Mean Water Temperature	**0.955**	0.250
Mean Dissolved Oxygen	**-0.913**	-0.388
Mean Salinity	**0.932**	0.163
Mean pH	0.509	**0.522**

Note. Bold = variables loaded ≥ |0.50| and were used to interpret the axes.

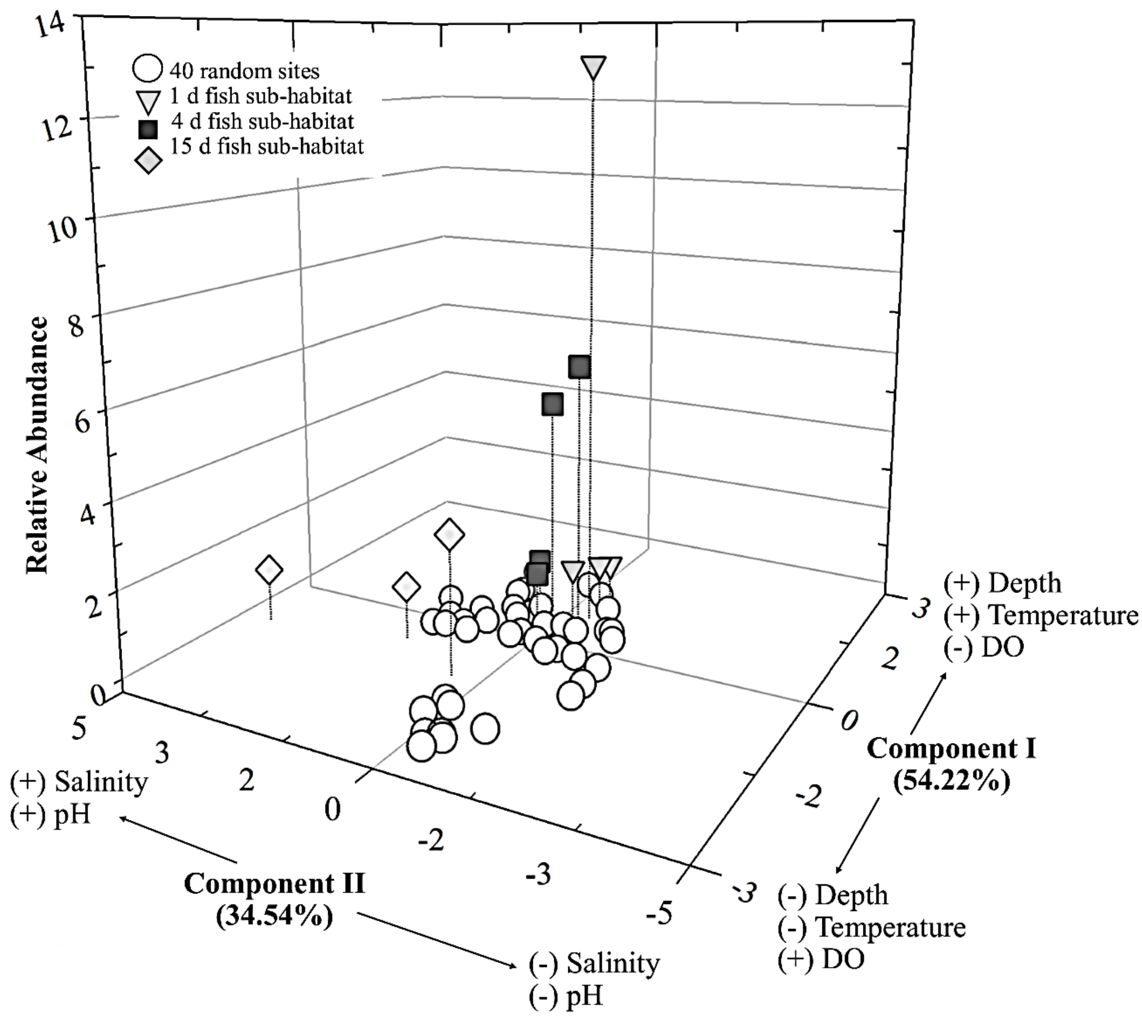


Figure 2.6. Principle component analysis for November 2012. Axes are labeled with principle components (% variance explained) and relative abundance of acoustically-tagged Gulf-strain Striped Bass found at 1 (triangles), 4 (squares), and 15 (diamonds) days (d) post-release sub-habitats. The composite Anderson-Rubin factor scores for the mean river abiotic conditions are represented by open circles. Arrows on component axes indicate how variables with r-values |≥ 0.50| loaded (i.e., positive (+) versus negative (-) correlations) on respective components.

November 2012 composite A-R factor scores from Component I were significantly different among sub-habitat abiotic conditions (n = 3) and between mean river abiotic conditions (Brown-Forsythe $F_{3, 44.80} =$ 43.23, $p < 0.01$). Composite abiotic conditions selected by tagged Gulf-strain Striped Bass were different between 1 d (GH, $p < 0.01$), 4 d (GH, $p < 0.01$), and 15 d (GH, $p = 0.02$) compared to the mean river conditions (Appendix D). Fish in these abiotic sub-habitat conditions on 1 d and 4 d typically occupied deeper and warmer waters than those available, but with slightly lower DO concentrations (Table 2.3). In contrast, mean water temperature for 15 d fish sub-habitat was, on average, lower than the mean river abiotic condition but was deeper and had higher DO concentrations (Table 2.3). Fish locations at 15 d post-release sites were, on average, shallower areas with lower water temperature and higher DO than fish detected in either 1 d or 4 d post-release sub-habitats (GH, all $p < 0.01$). A comparison of composite A-R factor scores for November 2012 Component II indicated minimal differences among all sub-habitats and mean river abiotic conditions (Brown-Forsythe $F_{3,5.65} = 4.91$, $p = 0.05$). However, Gulf-strain Striped Bass appeared to be located in areas with, on average, both higher salinity and pH conditions as post-release time increased and the fish acclimatized to overall abiotic river conditions.

Table 2.3

Mean Abiotic Variables and Depth (± Standard Error of the Mean (SEM)) of the Vertical Profiles Recorded in the Biloxi River, MS for the Mean River Abiotic Condition and Acoustically-Tagged Gulf-strain Striped Bass Post-release Sub-habitats During November 2012 and December 2013.

Date	Event	N	Depth (m)	Temperature (°C)	DO (mg/L)	Salinity (psu)	pH
11/9/2012	40 Random Sites	40	2.85 ± 0.30	17.60 ± 0.25	6.30 ± 0.21	7.39 ± 0.69	6.82 ± 0.04
11/7/2012	Fish sub-habitat 1 d post-release	16	4.22 ± 0.08	19.38 ± 0.03	5.08 ± 0.05	8.12 ± 0.14	6.66 ± 0.01
11/10/2012	Fish sub-habitat 4 d post-release	13	3.63 ± 0.21	19.02 ± 0.04	4.48 ± 0.01	9.61 ± 0.11	6.83 ± 0.03
11/21/2012	Fish sub-habitat 15 d post-release	5	3.29 ± 1.08	16.32 ± 0.16	7.23 ± 0.25	11.48 ± 2.60	7.18 ± 0.13
12/12/2013	40 Random Sites	40	3.05 ± 0.22	12.87 ± 0.17	7.29 ± 0.13	3.83 ± 0.53	14.09 ± 0.05
12/11/2013	Fish sub-habitat 1 d post-release	17	4.27 ± 0.23	14.14 ± 0.14	7.46 ± 0.04	3.79 ± 0.36	14.34 ± 0.04
12/13/2013	Fish sub-habitat 3 d post-release	16	3.77 ± 0.27	13.52 ± 0.16	6.58 ± 0.26	5.69 ± 0.41	13.88 ± 0.01
12/25/2013	40 Random Sites	40	3.26 ± 0.18	10.64 ± 0.10	8.73 ± 0.07	0.14 ± 0.08	13.65 ± 0.04
12/25/2013	Fish sub-habitat 15 d post-release	10	4.37 ± 0.76	11.13 ± 0.52	8.07 ± 0.60	1.43 ± 0.94	13.62 ± 0.08

Note. Fish sub-habitat conditions were measured during manual tracking events that occurred at 1, 4, and 15 days after stocking in November, and at 1, 3, and 15 days after stocking in December. 40 Random Sites = mean river abiotic conditions; d = days post released; DO = dissolved oxygen.

Early December 2013 data were appropriate for PCA (KMO = 0.68; Bartlett's test, $p < 0.01$). The PCA reduced the five original variables into two meaningful components that explained 81.09% of the variation (Table 2.2B; Figure 2.7). Component

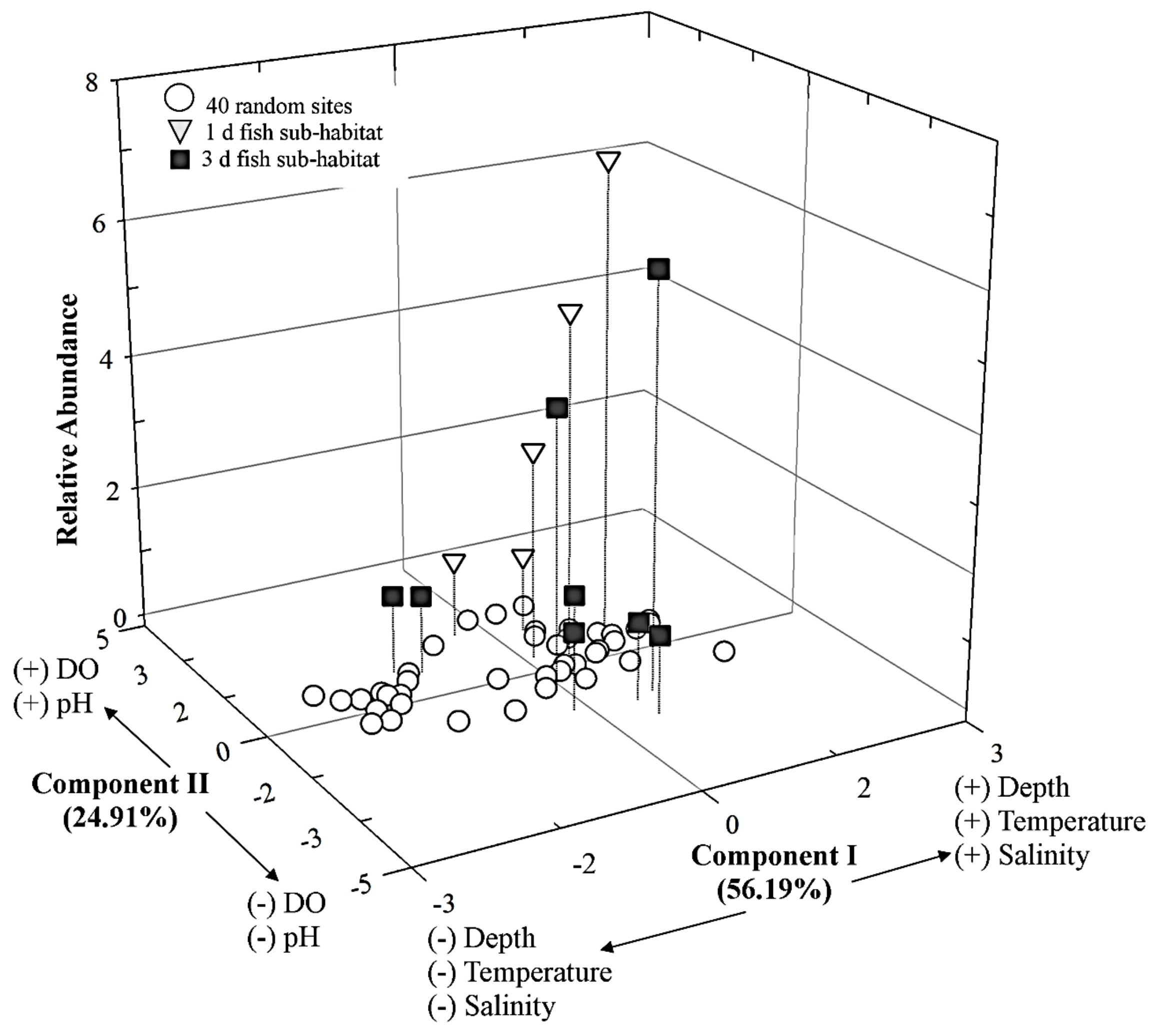


Figure 2.7. Principle component analysis for Early December 2013. Axes are labeled with principle components (% variance explained) and relative abundance of acoustically-tagged Gulf-strain Striped Bass found at 1 (triangles) and 3 (squares) days (d) post-release sub-habitats. The composite Anderson-Rubin factor scores for the mean river abiotic conditions are represented by open circles. Arrows on component axes indicate how variables with r-values |≥ 0.50| loaded (i.e., positive (+) versus negative (-) correlations) on respective components.

I loaded with 56.19% of the total variance and consisted of positive correlations with mean water temperature, mean salinity, and mean maximum depth (Figure 2.7).

Component II explained another 24.91% of the total variance and loaded positively with mean DO and mean pH (Figure 2.7).

Early December 2013 composite A-R factor scores for Component I indicated significant differences among sub-habitats (n = 2) and between mean river abiotic conditions (Brown-Forsythe $F_{2,\,64.98} = 8.76$, $p < 0.01$). Composite abiotic conditions selected by tagged Gulf-strain Striped Bass were different between 1 d post release sub-habitat conditions and the mean river abiotic condition ($p < 0.01$). Fish were located in areas that were, on average, deeper and warmer than the mean river abiotic condition; however, salinity conditions were comparable. In contrast, there were no differences between 3 d sub-habitat conditions and mean river abiotic condition ($p = 0.12$) nor between 1 d and 3 d sub-habitat conditions ($p = 0.14$) (Appendix D). A comparison of A-R factor scores for Component II indicated significant differences between sub-habitat conditions (n = 2) and the mean river abiotic condition (Brown-Forsythe $F_{2,\,37.92} = 19.95$, $p < 0.01$). Composite abiotic conditions selected by tagged fish differed between 1 d ($p < 0.01$), and 3 d ($p < 0.01$) sub-habitat conditions compared to mean river conditions, as well as between 1 d and 3 d sub-habitat conditions ($p < 0.01$; Appendix D). The sub-habitats selected by acoustically-tagged juvenile Gulf-strain Striped Bass were, on average, higher pH and DO values than available river conditions (Table 2.3) and 1d sub-habitats had, on average, higher pH and DO values than 3 d sub-habitats (Table 2.3).

Late December 2013 data were appropriate for PCA (KMO = 0.59; Bartlett's test, $p < 0.01$) and the PCA reduced the five original variables into two meaningful component that explained 85.66% of the variation (Table 2.2C). Component I explained 58.01% of the total variance and consisted of positive correlations with mean water temperature, mean salinity and mean pH, and negative correlations with mean DO (Figure 2.8).

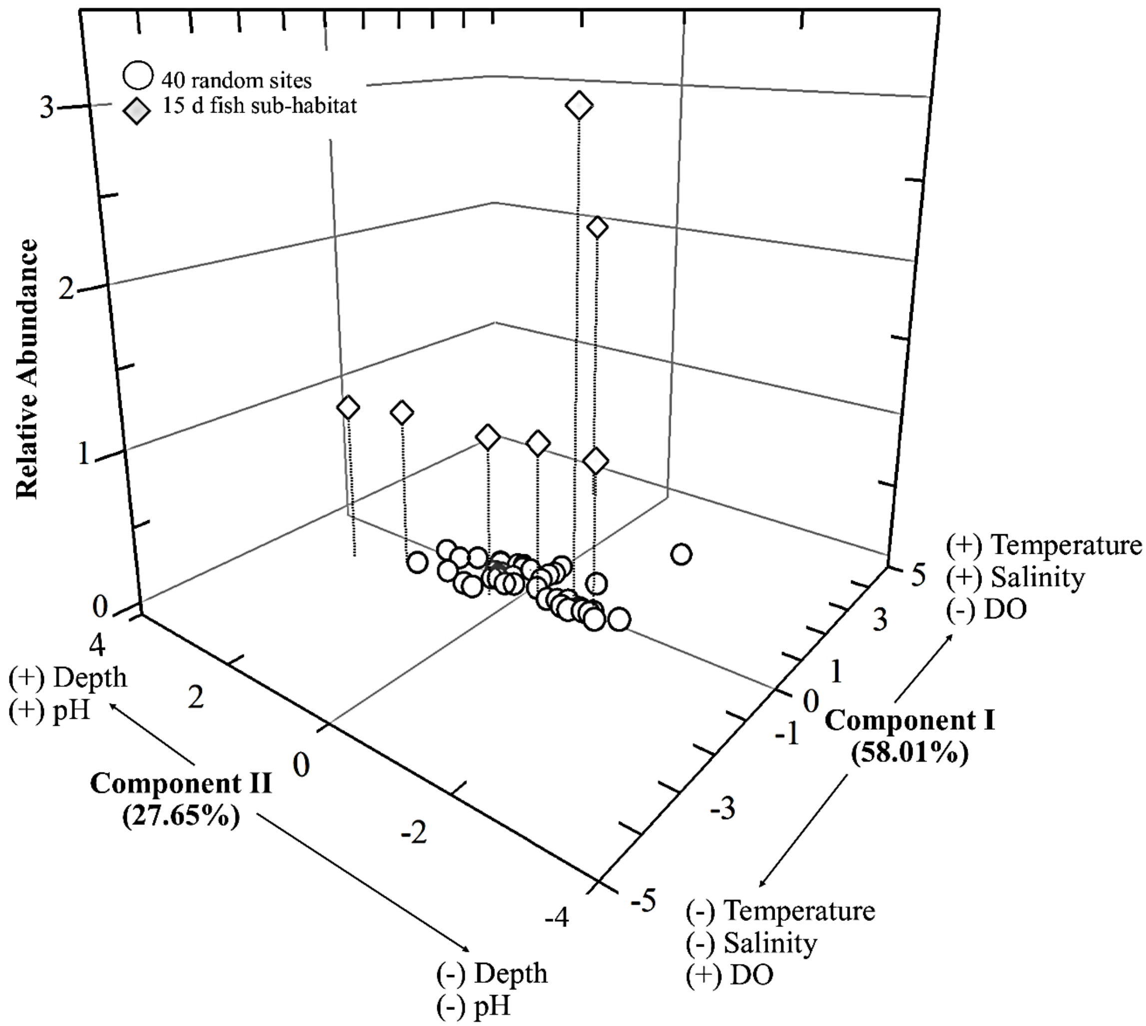


Figure 2.8. Principle component analysis for Late December 2013. Axes are labeled with principle components (% variance explained) and relative abundance of acoustically-tagged Gulf-strain Striped Bass found at 15 (diamonds) days (d) post-release sub-habitats. The composite Anderson-Rubin factor scores for the mean river abiotic conditions are represented by open circles. Arrows indicate how variables with r-values |≥ 0.50| loaded (i.e., positive (+) versus negative (-) correlations) on respective components.

Component II explained another 27.65% of the total variance and consisted of positive correlations with mean maximum depth and mean pH (Figure 2.8). The assumption of homogeneity of variance was violated for Component I (Levene's test $p < 0.01$) and

Component II (Levene's test $p = 0.02$); therefore, the two tailed Student's t-test was reported for equal variances not assumed. The Student's t-test indicated 15 d post-release sub-habitat conditions were not significantly different than the re-sampled mean river abiotic condition for Component I ($t_{9.39} = 0.39$, $p > 0.05$; see Table 2.3), nor were they significantly different for Component II ($t_{10.80} = 0.44$, $p > 0.05$; see Table 2.3).

Discussion

Acoustically-tagged juvenile hatchery-reared Gulf-strain Striped Bass appeared to select a sub-set of abiotic conditions within 1-4 day post-stocking in the Biloxi River drainage compared to available river abiotic conditions. Although sub-habitat location conditions varied annually, trends appeared to be similar among years. These sub-habitat conditions were characterized as deeper, warmer, and with slightly higher salinity compared to other areas within the river. The conditions where I re-located tagged fish were consistent with data on other populations of Striped Bass of various size classes. Several studies have suggested Striped Bass, in general, avoid cold temperatures in freshwater systems during late fall and winter months. For example, in freshwater lakes, reservoirs and rivers sub-adult and adult Striped Bass (430-1,130 mm TL) have been shown to occupy warmer water temperatures at depth (Coutant and Carroll 1980; Van Den Avyle and Evans 1990; Schaffler et al. 2002) to avoid cooler and more variable surface water temperatures. Also, in mid-Atlantic estuarine systems, deep waters served as important over-wintering habitat for juvenile (280-320 mm TL) Striped Bass in Chesapeake Bay (Moore and Burton 1975), whereas adult (483-953 mm fork length) Striped Bass in a New Jersey estuary showed year round preference for channelized areas that were up to 4 m deeper than the average depth of the estuary (Ng et al. 2007). Adult

(490-876 mm TL) Striped Bass in North Carolina also selected the deepest (5.4-7.2 m) estuarine habitat available, albeit only during summer months (Haeseker et al. 1996). In general, shallow water habitats are more susceptible to rapid water temperature and salinity fluctuations; deep water habitats, however, likely provide more consistent conditions in dynamic lotic and estuarine systems. For instance, during the transition between fall and winter in north-central GOM systems, the ambient air temperatures can remain cool, but deep water habitats are typically characterized with warmer water temperatures and higher salinity compared to surface waters (Jackson et al. 2002). Similar temperature and salinity conditions were associated with the deep sub-habitats initially selected by juvenile hatchery-reared Gulf-Strain Striped Bass during this study. Thus, juvenile hatchery-reared Gulf-strain Striped Bass may initially seek deeper water habitats that provide warmer temperature and higher salinity as refuge from stress associated with stocking procedures and being placed into a dynamic novel lotic environment.

Furthermore, water temperature and salinity interactions at depth are important for maintaining physiological homeostasis. The combination of stress, low water temperatures and altered salinities can jeopardize osmoregulatory ability. For example in laboratory settings, young-of-the-year (YOY; 67-160 mm TL) Atlantic-strain Striped Bass were intolerant of low water temperatures as salinities approached freshwater and full seawater (Hurst and Conover 2002). Intermediate salinities (5-15 psu), however, facilitates osmotic balance by decreasing the osmotic gradient between the water and the fish’s blood, which helps alleviate osmoregulatory dysfunction (Mazik et al. 1991) and may influence survival of stocked juvenile Striped Bass (Wallin and Van Den Avyle

1995). Thus, possible avoidance of cooler water temperatures and preference for deep sub-habitats with higher than average salinity may be driven by the fish's physiological need to maintain osmotic homeostasis following standard handling, transport, and stocking procedures in Mississippi lotic systems during November and December.

In contrast, as the number of days post-release increased, juvenile hatchery-reared Gulf-strain Striped Bass appeared more acclimatized to the lotic system because not only did tagged fish occupy abiotic conditions that more closely resembled the mean abiotic condition available within the Biloxi River, but also tagged fish dispersed greater distances from the stocking site. Additionally, post-release sub-habitat locations varied spatially and temporally. For both years, the largest groups of schooling acoustically-tagged Gulf-strain Striped Bass occupied sub-habitats near the stocking site during the initial 3 to 4 d post-stocking. This initial lingering in close proximity to the release site may have been attributed to elevated blood cortisol and glucose levels from increased handling and stocking stress (Carmichael et al. 1984; Wallin and Van Den Avyle 1995), since recovery time for common indicators of stress (e.g., plasma concentrations of corticosteroid, glucose, and chloride) is directly proportional to the duration of the stressful event (Carmichael et al. 1984). Furthermore, initial sub-habitats provided deeper, warmer, and more saline abiotic conditions that were in close proximity to the release site which may have facilitated recovery from physiological stress as well as short-term acclimatization. Delayed dispersal of hatchery-reared fish may be caused by their initial disorientation associated with stocking stressors and time required to adapt to a natural environment (Wells et al. 1991). Other studies have suggested that dispersal of hatchery-reared Striped Bass may simply be a slow process. For example, in the Hudson

River, the majority of stocked YOY (72-86 mm TL) Atlantic-strain Striped Bass were recaptured within 20 river km (rkm) of release sites up to 100 d post-stocking, which was interpreted as slow dispersal considering the study covered 246 rkm (Wells et al. 1991). Similarly, a two year mark-recapture study in the Patuxent River, Maryland, recovered 93% of all tagged hatchery-reared YOY and juvenile (35-200 mm TL) Striped Bass within 16 rkm of the release site the first year, and 94% within 8 rkm of the release site the following year when sampling occurred within 80 d post-stocking for both years (Dorazio et al. 1991). However, juvenile Gulf-strain Striped Bass occupied sub-habitats located up to 5.1-5.6 rkm away from the release site 15 d after being stocked in the much smaller Biloxi River system, which is only about 75.2 rkm long (determined using Google Earth path measure tool). Considering the size of the Biloxi River, dispersal in excess of 5.1 rkm within 15 d by juvenile hatchery-reared fish that were introduced to a lotic system seems plausible. Furthermore, 15 d fish sub-habitat appeared to provide abiotic conditions quite similar to those of the mean river abiotic conditions. This may indicate that juvenile hatchery-reared Gulf-strain Striped Bass became acclimatized to mean abiotic conditions associated with the Biloxi River within two weeks after being released and thus did not select abiotic conditions characteristic of 1 to 4 d post-release sub-habitats.

Despite large differences in river flow, displacement of acoustically-tagged juvenile hatchery-reared Gulf-strain Striped Bass in the Biloxi River were comparable for both years. This is in contrast to the general idea that increased discharge may promote non-migratory fish movements (Taylor and Cooke 2012). Surprisingly, tagged juveniles traveled greater distances upstream in December 2013 when periods of high flow

(Appendix C) and low salinity conditions prevailed compared to low flow (Appendix B) and high salinity conditions in November 2012. This supports the idea that Striped Bass are attracted to river flow (Crance 1984; Young and Isely 2007), and is in agreement with the reaction to move greater distances upstream towards higher turbulence (Lamprecht and Shelton 1986). According to the manual tracking sub-habitat locations, tagged juveniles appeared to favor downstream movements in November 2012 during decreased flows (Appendix B) and increased salinity conditions. However, concurrent detection data collected by fixed receivers in the Biloxi River passive acoustic array (see Chapter III for details) revealed that the majority of juveniles not only preferred areas upstream from the release site, but also remained in these areas within the initial 15 d post-release. Likewise, manual tracking data of December 2013 sub-habitat locations suggested tagged juveniles favored sub-habitats downstream from the release site; yet, the passive acoustic telemetry data from the Biloxi River receiver array showed that the majority of tagged juveniles moved into areas upstream from the release site. Moreover, of the individuals (n = 15) detected on receivers within 1 to 15 d post-release during December 2013, 39% of the time fish made upstream movements, with downstream movements only 15% of the time, and remained in that area 46% of the time following a movement in either direction. This suggests that prolonged periods of intense stream discharge did not result in downstream displacement of these young and naive juvenile fish in the Biloxi River. This is in contrast to the effect of flow on Striped bass in the Sacramento-San Joaquin Estuary, California, where juveniles were more abundant downstream during years of high outflow and low salinity as opposed to years of low outflow and high salinity, when juveniles were located farther upstream (Turner and Chadwick 1972).

There are several caveats associated with the implications about post-stocking movements and habitat selection of juvenile hatchery-reared Gulf-strain Striped Bass in the Biloxi River. First, the sub-habitat abiotic conditions were usually represented by a small sample size because not all tagged fish were located during every manual tracking session each year. While these data may only represent a limited subset of abiotic conditions occupied by juveniles, Striped Bass are generally considered to be schooling fish (Hill et al. 1989); therefore, it is assumed that stocked but non-tagged juvenile Gulf-strain Striped Bass potentially occupied the same or similar abiotic conditions. Second, for situations were tagged fish appeared to be schooling, the abiotic conditions were represented by a grand mean of the vertical profiles at three haphazard locations within the school's range. Although less than ideal, it still provided a conservative representation of preferred abiotic conditions considering tag collisions inhibited pinpointing exact fish locations when tagged fish were in close proximity to each other. Third, the depth of the fish could not be precisely determined with acoustic tags used resulting in the use of mean values based on the abiotic vertical profiles. Since vertical distributions of Striped Bass is influenced mainly by water temperature and DO requirements (Coutant 1985; Matthews et al. 1985) these values appear reasonable and would differ if there is a clear vertical gradient in abiotic conditions at these sites compared to mean river conditions. Finally, differences between occupied sub-habitat conditions and the mean river abiotic condition might have been indistinguishable during inclement weather events that increased discharge and consequently homogenized physiochemical conditions throughout the river. We focused our tracking events to minimize these weather events but there may have been residual influences on vertical abiotic values.

Recent advances in acoustic telemetry, such as modern portable equipment and smaller transmitters, facilitate tracking studies on young or juvenile fishes (Heupel et al. 2006; Able and Grothues 2006). Unlike typical mark-recapture techniques, acoustic telemetry provides the ability to actively track tagged individuals to identify dynamic behavior associated with movement patterns and habitat selection. The use of acoustic telemetry can be an invaluable tool for fisheries managers to enhance success of stocking programs because post-stocking survival of hatchery-reared fish is ultimately linked with behavioral and physiological responses to dynamic environmental conditions (see Callihan et al. 2015). Short-term post-stocking telemetry studies can allow fisheries managers to elucidate potential drivers of initial spatial and temporal dispersal patterns observed within the receiving waters. Fisheries managers could use information from post-stocking telemetry studies to conduct stocking events near sub-habitats that present abiotic conditions resembling those that previously stocked fish initially sought after. For juvenile hatchery-reared Gulf-strain Striped Bass stocked in the Biloxi River, initial post-stocking habitat selection indicated an affinity for a subset of abiotic conditions that potentially facilitated recovery from stocking stressors and disorientation following release in a new lotic environment. Within two weeks after stocking, acoustically-tagged fish dispersed farther away from the release site and fish sub-habitat conditions resembled the mean abiotic conditions available, suggesting that juvenile hatchery-reared Gulf-strain Striped Bass became acclimatized to the Biloxi River system.

REFERENCES

Able, K.W., and T.M. Grothues. 2006. Diversity of estuarine movements of Striped Bass (*Morone saxatilis*): a synoptic examination of an estuarine system in southern New Jersey. Fishery Bulletin 105:426-435.

Brown, C., and K. Laland. 2001. Social learning and life skills training for hatchery reared fish. Journal of Fish Biology 59:471-493.

Burgess, G. H. 1980. *Morone saxatilis* (Walbaum), Striped bass. Page 576 *in* D. S. Lee, C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, editors. Atlas of North American Freshwater Fishes. North Carolina Biological Survey, Raleigh, NC.

Callihan, J.L., C.H. Godwin, K.J. Dockendorf, and K.A. Buckel. 2015. Growth and mortality of hatchery-reared Striped Bass stocked into nonnatal systems. North American Journal of Fisheries Management 34:1131-1139.

Carmichael, G.J., J.R. Tomasso, B.A. Simco, and K.B. Davis. 1984. Characterization and alleviation of stress associated with hauling Largemouth Bass. Transactions of the American Fisheries Society 113:778-785.

Center for Urban Rural Interface Studies. 2009. Harrison County, Mississippi: Land Cover Analysis. Mississippi State University Coastal Research and Extension Center. 12p.

Childs, A-R., P.D. Cowley, T.F. Næsje, A.J. Booth, W.M. Potts, E.B. Thorstad, and F. Økland. 2008. Do environmental factors influence the movement of estuarine fish? A case study using acoustic telemetry. Estuarine, Coastal and Shelf Science 78:227-236.

Coutant, C.C. 1980. Environmental quality for Striped Bass. Pages 179-187 *in* H. Clepper, editor. Marine Recreational Fisheries, volume 5. Sport Fishing Institute, Washington, D.C.

Coutant, C.C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Transactions of the American Fisheries Society 114:31-61.

Coutant, C.C., and D.S. Carroll. 1980. Temperatures occupied by ten ultrasonic-tagged Striped Bass in freshwater lakes. Transactions of the American Fisheries Society 113:666-671.

Coutant, C.C., K.L. Zachmann, D.K. Cox, and B.L. Pearman. 1984. Temperature selection by juvenile Striped Bass in laboratory and field. Transactions of the American Fisheries Society 113:666-671.

Crance, J.H. 1984. Habitat Suitability Index Models and In-Stream Flow Suitability Curves: Inland Stocks of Striped Bass. U.S. Fish and Wildlife Service OBS-82/10.85. 63p.

Deverill, J.I., C.E. Adams, and C.W. Bean. 1999. Prior resistance, aggression, and territory acquisition in hatchery-reared and wild brown trout. Journal of Fish Biology 55:868-875.

Dieterich, J.W., and R.S. Fulford. 2012. Habitat suitability modeling to evaluate conservation and enhancement efforts for Gulf-strain Striped Bass in Mississippi coastal rivers. Transactions of the American Fisheries Society 141:731-746.

Dorazio, R.M., B.M. Florence, and C.M. Wooley. 1991. Stocking of hatchery-reared Striped Bass in the Patuxent River, Maryland: survival, relative abundance, and cost-effectiveness. North American Journal of Fisheries Management 11:435-442.

Eleuterius, C.K., and G.A. Criss. 1994. Biloxi Bay Hydrology and Selected Chemistry with Data Appendix. Final Report, Vol. 2. Minerals Management Service, U.S. Department of the Interior. Submitted by Gulf Coast Research Laboratory, Ocean Springs, MS. 15p + 2 Appendixes.

Field, A. 2005. *Discovering Statistics Using SPSS*, 2nd ed. Sage Publications, London. 771p.

Frugé, D.J., M. Bailey, J. Mareska, L.C. Nicholson, H. Rogillio, E. Long, J.T. Jenkins, J.M. Barkuloo, P. Cooper, Jr., I. Wirgin, and R. Weller. 2006. The Striped Bass Fishery of the Gulf of Mexico. United States: A Regional Management Plan. Gulf States Marine Fisheries Commission No. 137, Ocean Springs, Mississippi. 363p + 14 Appendixes.

Haeseker, S.L., J.T. Carmichael, and J.E. Hightower. 1996. Summer distribution and condition of Striped Bass within Albemarle Sound, North Carolina. Transactions of the American Fisheries Society 125:690-704.

Hair, J.F. Jr., R.E. Anderson, R.L. Tatham, and B.J. Grablowsky. 1984. *Multivariate Data Analysis with Readings*. Macmillan Publishing Co., New York. 360p.

Hill, J., J.W. Evans, and M.J. Van Den Avyle. 1989. Species Profiles: Life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic): Striped Bass. U.S. Fish and Wildlife Service Biological Report 82 (11.118). U.S. Army Corps of Engineers TR EL-82-4. 35p.

Hurst, T.P., and D.O. Conover. 2002. Effects of temperature and salinity on survival of young-of-the-year Hudson River Striped Bass (*Morone saxatilis*): implications for optimal overwintering habitats. Canadian Journal of Fisheries and Aquatic Sciences 59:787-795.

Heupel, M.R., J.M. Semmens, and A.J. Hobday. 2006. Automated acoustic tracking of aquatic animals: scales, design, and deployment of listening station arrays. Marine and Freshwater Research 57:1-13.

Jackson, D.C., E.D. Dibble, and J.F. Mareska. 2002. Location of thermal refuge for Striped Bass in the Pascagoula River. Journal of the Mississippi Academy of Sciences 47(2):106-113.

Jolliffe, I.T. 1972. Discarding variables in a principal component analysis, I: Artificial data. Journal of the Royal Statistical Society: Applied Statistics 21:160-173.

Lamprecht, S.D., and W.L. Shelton. 1986. Spatial and temporal movements of Striped Bass in the upper Alabama River. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 40:266-274.

Long, E.A., C.L. Messing, K.J. Herrington, R.R. Weller, and I.I. Wirgin. 2013. Restoration of Gulf Striped Bass: lessons and management implications. Pages 25-63 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium, 80, Bethesda, Maryland.

Lopez, J.D., M.S. Peterson, J. Walker, G.L. Grammer, and M.S. Woodrey. 2011. Distribution, abundance, and habitat characterization of the Saltmarsh Topminnow, *Fundulus jenkinsi* (Everman 1892). Estuaries and Coasts 34:148-158.

Matthews, W.J., L.G. Hill, and S.M. Schellhaass. 1985. Depth distribution of Striped Bass and other fish in Lake Texoma (Oklahoma-Texas) during summer stratification. Transactions of the American Fisheries Society 114:84-91.

Mazeaud, M.M., F. Mazeaud, and E.M. Donaldson. 1977. Primary and secondary effects of stress in fish: some new data with a general review. Transactions of the American Fisheries Society 106:201-212.

Mazik, P.M., B.A. Simco, and N.C. Parker. 1991. Influence of water hardness and salts on survival and physiological characteristics of Striped Bass during and after transport. Transactions of the American Fisheries Society 120:121-126.

Mesa, M.G. 1991. Variation in feeding, aggression, and position choice between hatchery and wild Cutthroat Trout in an artificial stream. Transactions of the American Fisheries Society 120:723-727.

Mickle, P.F., S.F. Schaefer, S.B. Adams, and B.R. Kreiser. 2010. Habitat use of age 0 Alabama Shad in the Pascagoula River drainage, USA. Ecology of Freshwater Fish 19:107-115.

Moore, C.J., and D.T. Burton. 1975. Movements of Striped Bass, *Morone saxatilis*, tagged in Maryland waters of Chesapeake Bay. Transactions of the American Fisheries Society 104:703-709.

Ng, C.L, K.W. Able, and T.M. Grothues. 2007. Habitat use, site fidelity, and movement of adult Striped Bass in a southern New Jersey estuary based on mobile acoustic telemetry. Transactions of the American Fisheries Society 136:1344-1355.

Olla, B.L., M.W. Davis, and C.H. Ryer. 1998. Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. Bulletin of Marine Science 62:531-550.

Pitman, V.M., and S. Gutreuter. 1993. Initial poststocking survival of hatchery-reared fishes. North American Journal of Fisheries Management 13:151-159.

Pottinger, T.G., and A.D. Pickering. 1992. The influence of social interaction on the acclimation of Rainbow Trout, *Oncorhynchus mykiss* (Walbaum) to chronic stress. Journal of Fish Biology 41: 435-447.

Russel, D. 2005. Striper Wars. Island Press, Washington, D.C.

Schaffler, J.J., J.J. Isely, and W.E. Hayes. 2002. Habitat use by Striped Bass in relation to seasonal changes in water quality in a southern reservoir. Transactions of the American Fisheries Society 131:817-827.

Taylor, M.K., and S.J. Cooke. 2012. Meta-analyses of the effects of river flow in fish movement and activity. Environmental Reviews 20:211-219.

Turner, J.L., and H.K. Chadwick. 1972. Distribution and abundance of young-of-the-year Striped Bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 101:442-452.

Van Den Avyle, M.J., and J.W. Evans. 1990. Temperature selection by Striped Bass in a Gulf of Mexico coastal river system. North American Journal of Fisheries Management 10:58-66.

Van Horn, S.L. 2013. A brief history of inland Striped Bass management. Pages 1-13 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium, 80, Bethesda, Maryland.

Wallin, J.E., and M.J. Van Den Avyle. 1995. Interactive effects of stocking site salinity and handling stress on survival of Striped Bass fingerlings. Transactions of the American Fisheries Society 124:736-745.

Weirich, C.R., J.R. Tomasso, and T.I.J. Smith. 1992. Confinement and transport-induced stress in White Bass *Morone chrysops* X Striped Bass *M. saxatilis* hybrids: effect of calcium and salinity. Journal of the World Aquaculture Society 23:49-57.

Wells, A.W., D.M. Randall, D.J. Dunning, and J.R. Young. 1991. Dispersal of young-of-the-year hatchery Striped Bass in the Hudson River. North American Journal of Fisheries Management 11:381-392.

Young, S.P., and J.J. Isely. 2007. Diel behavior of adult Striped Bass using tailwater habitat as summer refuge. Transactions of the American Fisheries Society 136:1104-1112.

Yow, D.L., B.J. McRae, D.A. Besler, and W.E. Taylor. 2013. Survey of transportation practices for Striped Bass and Striped Bass hybrids. Pages 383-393 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium, 80, Bethesda, Maryland.

CHAPTER III

SEASONAL VARIABILITY IN HABITAT SELECTION OF ADULT AND STOCKED JUVENILE GULF-STRAIN STRIPED BASS

Introduction

Acoustic telemetry research can provide an understanding of seasonal movement patterns and habitat selection of acoustically-tagged animals. Other telemetry studies have documented that habitat selection, movement and distribution patterns of Striped Bass are influenced by flow (Lamprecht and Shelton 1986) and water quality (Cheek et al. 1985; Matthews et al. 1989; Schaffler et al. 2002). Since anadromous species generally have a broad tolerance for salinities ranging from freshwater (0 psu) to full seawater (35 psu), suitable habitat for Striped Bass is mostly defined by dissolved oxygen (DO) concentration and water temperature (Coutant 1985; Coutant 2013). In general, the concentration of DO is inversely related to water temperature, and low DO levels are more tolerable in cooler temperatures. For Striped Bass, optimal DO concentrations are considered ≥ 5 mg/L (Coutant 1985) while DO < 2 mg/L is considered uninhabitable (Crance 1984). Although Striped Bass can tolerate DO conditions from 2-5 mg/L, they become physiologically stressed when DO is below 3 mg/L (Coutant 1985). Water temperature also influences habitat selection because Striped bass have ontogenetic shifts in thermal requirements. Juveniles (80-300 mm total length, TL) have a greater tolerance of warm waters and generally prefer water temperatures in the range of 24-27°C (Coutant et al. 1984). Conversely, sub-adults and adults require cooler water temperatures for physiological requirements (Bettoli 2005; Coutant 2013). Although adults can tolerate water temperatures ranging from 6-27°C (Merriman 1941), the thermal niche for sub-adults (430-630 mm TL) is considered to be in the range of 20-24°C (Coutant and Carroll 1980), while it tends to be centered around 20°C (range 18-25°C) for adults (> 631 mm TL; Coutant 1985).

Acoustic telemetry studies in southeastern United States rivers and reservoirs suggest Striped Bass exhibit seasonal thermally-mediated habitat use and movement patterns. For example, in the Apalachicola-Chattahoochee-Flint (ACF) River system seasonal distribution patterns of adult Gulf-strain Striped Bass were dependent on water temperature. During the summer season while river temperatures were 23-31°C, adult Gulf-strain Striped Bass exclusively inhabited spring-fed areas with much cooler water temperatures (mean of 21.6°C; Wooley and Crateau 1983; Van Den Avyle and Evans 1990). During the fall, winter, and spring seasons ACF Gulf-strain Striped Bass distribution was not restricted as water temperatures throughout the river cooled to 17-23°C (Van Den Avyle and Evans 1990). Similar seasonal habitat selection patterns were also demonstrated by Striped Bass populations in southern reservoirs (Cheek et al. 1985; Moss 1985; Schaffler et al. 2002; Young and Isley 2002). Seasonally limited suitable water temperature and DO conditions have been attributed to the decline of potamodromous Gulf-strain Striped Bass within their native southern range (Coutant 1985; Matthews et al. 1989).

Coastal rivers, estuaries, and inland waters throughout southeastern United States experience adverse water quality conditions during summer months when increased water temperatures and deoxygenation progressively spread throughout the water column. According to the temperature-oxygen squeeze hypothesis (Coutant 1985; Coutant 2013), summer stratification greatly reduces the volume of suitable adult Striped Bass habitat because epilimnetic surface waters heat to suboptimal water temperatures (> 25°C) concurrently while deep, hypoxic (DO < 2 mg/L) hypolimnetic waters expand vertically towards the surface. These conditions essentially force Striped Bass into less favorable habitat. Consequently, prolonged exposure to inadequate water quality increases physiological and thermal stress, which can ultimately result in mortality due to secondary mechanisms related to overcrowding in marginally suitable habitat, poor growth, disease, and/or starvation (Coutant 1985; Matthews 1985; Zale et al. 1990; Rice et al. 2013).

Striped Bass are able to overcome seasonal water quality habitat limitations by seeking thermal refuges, which are isolated areas with cool, well oxygenated waters (Coutant 1985). Many studies emphasize the importance of thermal refuges for summer survival of adult Striped Bass (Cheek et al. 1985; Coutant 1985; Frugé 2006; Long et al. 2013); however, not all systems have cool water refuges available for relief from poor summer conditions or they appear limited (Jackson et al. 2002). The presence or absence of thermal refuges is known to influence adult Striped Bass habitat selection behavior. In systems with thermal refuges available during summer, adult Striped Bass avoid water temperatures of 23-25°C by moving into refuge habitats with ambient water temperatures ranging from 18-21°C and DO above 4 mg/L (Coutant 1985; Van Den Avyle and Evans 1990; Young and Isely 2002). In systems without thermal refuges, Striped Bass are forced to tolerate warm temperatures (27-30°C) for extended periods to avoid hypoxic DO levels (> 2.5 mg/L) (Matthews et al. 1985; Farquhar and Gutreuter 1989; Zale et al. 1990; Thompson et al. 2010). Studies have shown that Striped Bass preferred to reside in areas with the highest DO concentrations (4-8 mg/L) and moved extensive horizontal distances within the epilimnion to limit exposure to warm temperatures without compromising access to the highest DO concentrations (Farquhar and Gutreuter 1989; Thompson et al. 2010) when thermal refuges were not available. Seasonal habitat selection behavior is important because suitable habitat becomes greatly reduced during summer and thermal refuges are limited within coastal rivers along the northern GOM (Jackson et al. 2002).

Although literature regarding seasonal habitat selection, distribution and movement patterns of adult Striped Bass is indeed extensive, there is however a dearth of information addressing similar seasonal patterns for juvenile Gulf-strain Striped Bass in reservoir (Combs and Peltz 1982; Jackson and Hightower 2001) and coastal river systems (Van Den Avyle and Evans 1990). Several studies acknowledge that Striped Bass have size-specific habitat preferences and requirements; however, juvenile and sub-adult sized Striped Bass are seldom incorporated in telemetry field studies (Coutant et al. 1984; Matthews et al. 1989). Hatchery-reared fingerling and juvenile Gulf-strain Striped Bass have been released in Mississippi tributaries for over 40 years, yet information regarding habitat selection and movement patterns of these stocks is deficient (Phalen et al. 1988; Jackson et al. 2002; Dieterich and Fulford 2012). The objective of this portion of the study was to identify seasonal variability in habitat selection of acoustically-tagged juvenile hatchery-reared and feral adult Gulf-strain Striped Bass based on abiotic conditions of the Biloxi River using passive and active telemetry methods. In addition, abiotic conditions selected by juvenile were compared with those of adult Gulf-strain Striped Bass by season to evaluate potential size effects on habitat selection.

Methods

To provide clarification, this portion of my thesis was a continuation of the short-term (15 d) study (see Chapter II); therefore, the same acoustically-tagged juvenile hatchery-reared Gulf-strain Striped Bass detailed in Chapter II were tracked during this portion of the study. To gain an understanding about seasonal habitat use and movement patterns in the Biloxi River, MS (see Chapter II for Study Area description), these fish were continuously tracked via an array of passive hydroacoustic receivers, as well as manually tracked on a monthly basis. Accurately interpreting movement patterns and behaviors of acoustically-tagged animals based on passive telemetry data can be challenging (Payne et al. 2010; Kessel et al. 2013). For example, increased detection frequency may not be associated with increased activity (Payne et al. 2010); rather, this could indicate the tagged animal remained within the detection radius of one receiver without entering the detection range of another receiver (Kessel et al. 2013). Likewise, decreased detection frequency may not always be associated with less activity; conversely, that could suggest fish were mobile throughout the expanse of the array while being detected few times on multiple receivers, or occupied areas outside of a receiver's detection radius, or may even indicate emigration from the system. Also, various external factors (e.g., biological noise, sea state, wind, tides, and substrate type to list a few) can influence detection efficiency of acoustic receivers, which may affect interpretations of animal movement and activity patterns (Payne et al. 2010). Acknowledging the limitations associated with interpreting acoustic telemetry data, my inferences about seasonal movement patterns in the Biloxi River system were based on the presence of acoustically-tagged Gulf-strain Striped Bass within the study area, along with fine-scale habitat selection as indicated by manual tracking events.

Acoustic-tagging of juvenile hatchery-reared Gulf-strain Striped Bass

Phase II (195 - 277 mm TL) Gulf-strain Striped Bass from the MS-DMR Lyman Fish Hatchery, Gulfport, MS were acoustically-tagged following the same surgical procedures described in Chapter II (see *Acoustic Tagging Methods*). All surgical procedures complied with protocols approved by the USM Institutional Animal Care and Use Committee (USM IACUC #10100101; Appendix A). Two telemetry trials were conducted on juvenile hatchery-reared Gulf-strain Striped Bass. For the Telemetry Trial I, 17 Phase II (195 – 266 mm TL) Gulf-strain Striped Bass were surgically implanted with VEMCO Ltd. V7 acoustic transmitters on 1 November 2012 (see Table 2.1 in Chapter II) and were released in the Biloxi River on 6 November 2012 (see Figure 2.1 in Chapter II). For Telemetry Trail II, an additional 17 began, Phase II (212 – 277 mm TL) Gulf-strain Striped Bass acoustically-tagged with VEMCO Ltd. V9 acoustic transmitters on 3 December 2013 (see Table 2.1 in Chapter II) and were released in the Biloxi River (see Figure 2.1 in Chapter II) on 10 December 2013. Also, an additional 2,923 Phase II Gulf-strain Striped Bass were externally tagged with T-bar anchor tags and stocked in Biloxi River.

Sampling and acoustic-tagging of feral adult Gulf-strain Striped Bass

In addition to monitoring juvenile hatchery-reared Gulf-strain Striped Bass, I also acoustically-tagging feral adult Gulf-strain Striped Bass from the Biloxi River to compare seasonal movement patterns and habitat selection based on abiotic conditions with hatchery-reared juveniles. Collection efforts began in November 2012 via hook-and-line fishing using a variety of artificial top-water lures and fly fishing techniques. Following the same surgical procedures as the Phase II hatchery-reared juveniles (USM IACUC #10100101; Appendix A), adult Gulf-strain Striped Bass were acoustically-tagged with VEMCO Ltd. acoustic transmitters with varying power outputs (V16-1L (n = 3), 69.0 kHz, 19.0 g in air, 54 mm length, mean delay 30 s, power output 150 dB, estimated < 455 d battery life; or V13-1L (n = 5), 69.0 kHz, 16.0 g in water, 36 mm length, mean delay 90 sec., power output 147 dB, estimated < 372 day battery life; or V7-4L (n =2), 69.0 kHz, 1.0 g in water, 22.5 mm length, mean delay 180 sec., power output 136 dB, estimated < 345 day battery life). After surgery, each adult fish was allowed to recover from anesthesia in ambient Biloxi or Tchoutacabouffa river water and was released at the capture location upon regaining equilibrium.

Telemetry trial time periods

Two telemetry trials were conducted on acoustically-tagged juvenile (n = 34) and adult (n = 10) Gulf-strain Striped Bass in the Biloxi River, MS from November 2012 through June 2014. The telemetry trials were considered separate because two different groups of Phase II hatchery-reared juvenile Gulf-strain Striped Bass were acoustically-tagged. Transmitters implanted in juveniles released in November 2012 stopped transmitting during October 2013 and the following group of acoustically-tagged juveniles was not released in the Biloxi River until December 2013.

All juvenile and adult data collected was parceled and analyzed based on annual seasons during the 20 consecutive months of the project (Table 3.1), which agrees with those in Dieterich and Fulford (2012). The duration of each season was determined by plotting mean daily water temperatures for Back Bay of Biloxi (via U.S.G.S. monitoring station 02481270; http://waterdata.usgs.gov) and identifying rising and falling water temperature flux patterns that reoccurred from January 2011 through December 2014.

Table 3.1

Monthly Duration for Each Season

Telemetry Trial	Season (Year)	Months
I	Fall (2012)	November
	Winter (2012 - 2013)	December, January, February
	Spring (2013)	March, April, May
	Summer (2013)	June, July, August
	Fall (2013)	September, October[1], November
II	Winter (2013 - 2014)	December, January, February
	Spring (2014)	March, April[2], May[3]
	Summer (2014)	June[4]

Note. [1] = Telemetry Trial I V7 transmitter batteries expired in telemetered juveniles (n = 17); [2] = last month of manual tracking data; [3] = receivers in the Biloxi River, Tchoutacabouffa River, and Little Big Lake were removed from the system on 19 May 2014; [4] = receiver in the Little Biloxi River was removed from the system on 17 June 2014.

Acoustic receiver array

A network of passive acoustic hydrophone receivers was used to continuously monitor seasonal movement patterns and habitat selection of acoustically-tagged Gulf-strain Striped Bass within the study area. All receivers were secured to a conduit pipe with a buoy at the surface with the hydrophone in a downward direction about 1 m below the surface of the water. Stainless steel cable (6.35 mm) and shackles were used to attach the conduit pipe to a concrete block (22-34 kg). Each receiver recorded the date, time, and unique transmitter ID when acoustically-tagged fish were within the detection radius (≤ 250 m) of the receiver. The receiver array was downloaded and maintained on at least a monthly basis. From November 2012 to September 2013, I deployed 14 acoustic receivers split equally between Sonotronics submersible underwater receivers (SUR) and VEMCO Ltd. VR2W receivers (VEMCO Ltd., Halifax, Nova Scotia, Canada) strategically positioned in the Biloxi River, one positioned at the confluence of the Little Biloxi River, and one positioned in the lower Tchoutacabouffa River. In September 2013, four additional VEMCO Ltd. VR2W receivers were deployed within the array to enhance detection coverage and the entire array was converted to VEMCO Ltd. VR2W receivers, with the exception of the Little Biloxi River SUR (Figure 3.1).

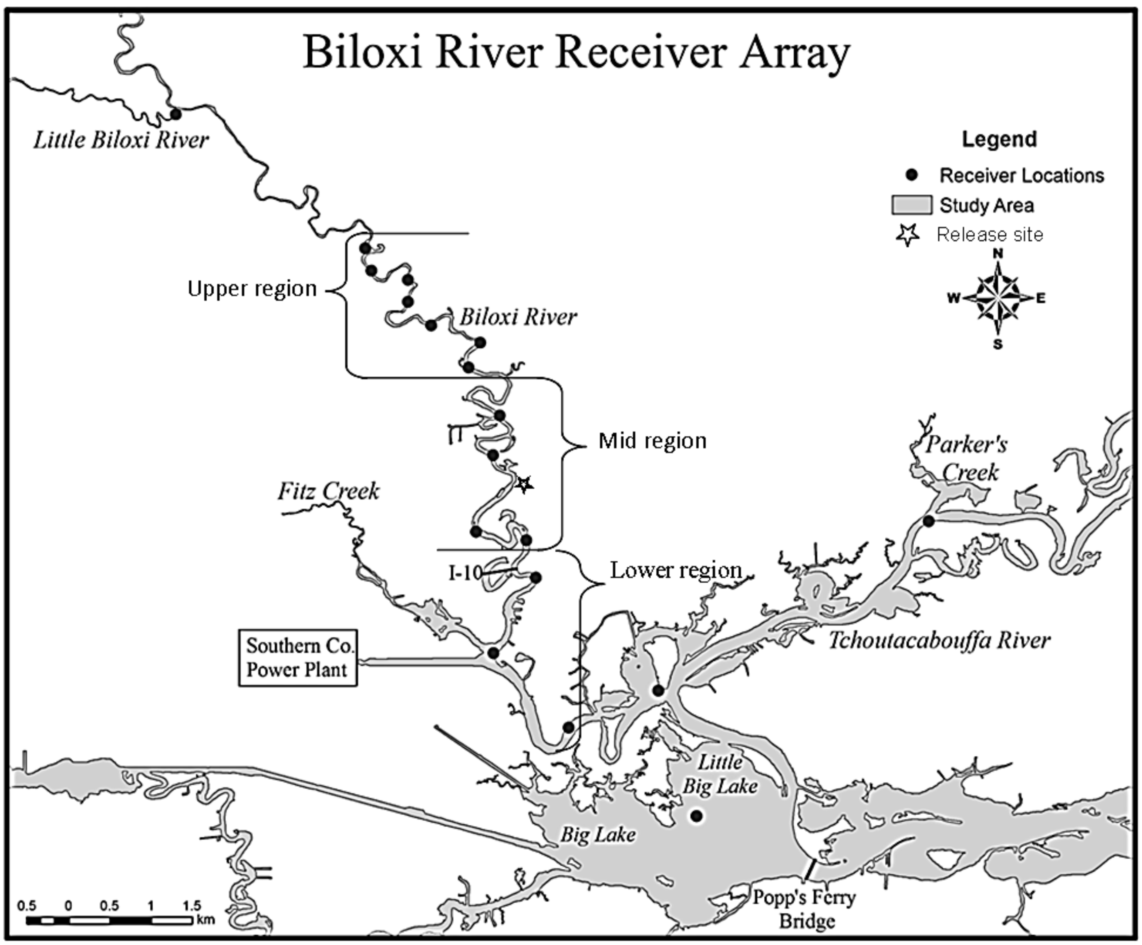


Figure 3.1. The location of the passive acoustic receiver array used to monitor telemetered juvenile and adult Gulf-strain Striped Bass from November 2012 through June 2014. Filled circles represent the locations of VEMCO Ltd. VR2W receivers (n = 17) as well as the Sonotronics SUR receiver in the Little Biloxi River (n = 1). The open star represents the release location of all juveniles. The brackets indicate the upper, mid-, and lower regions of the Biloxi River.

I conducted two range tests in the Biloxi River to compare transmitter detection probabilities between Sonotronics and VEMCO Ltd. receivers in both fresh and brackish water environments using multiple transmitters with varying power outputs matching those implanted in Gulf-strain Striped Bass. At each range test site, SUR and VR2W receivers were attached to the same line and were placed at six distances (50, 100, 150, 200, 225, 250 m) upstream and downstream from the transmitter. Each transmitter type (VEMCO Ltd. V7, V9, and V13) was tested individually for 30 minutes while receivers were orientated upstream, and 30 minutes while receivers were orientated downstream from the transmitter. Also, V16 transmitters were tested following the same methods, but due to incompatibility with SUR code map they were only detected on VR2W receivers. For each receiver model, I totaled the upstream and downstream detections for each distance based on transmitter and environment type. A full factorial model analysis of covariance (ANCOVA) was used to compare detection efficiencies of SUR and VR2W receivers by transmitter type with distance (m) as the covariate in both fresh and brackish water environments. Datasets that did not meet the homogeneity of variance assumption were arcsine square root-transformed prior to analysis to stabilize the variance; thus, only V7 in brackish water, V9 in freshwater, and V13 in freshwater datasets were transformed. Then, receiver detections were adjusted using the significant mean differences based on ANCOVA results.

Furthermore, detection records were thoroughly reviewed and all duplicate and simultaneous detections were omitted from further analysis because there was no way of knowing which detection provided an accurate description of the fish location. Duplicate detections were considered to be multiple detections from a single fish with the exact same time and date information on a single receiver. Simultaneous detections were defined as detections of an individual transmitter detected on two or more receivers at the exact same time and date. The total number of detections was partitioned by life stage for each receiver by season. For descriptive purposes, the Biloxi River was divided into upper, mid-, and lower regions based on visual appearance (Figure 3.1) and detailed descriptions of the system provided by Dieterich and Fulford (2012).

Manual tracking

Acoustically-tagged juvenile and adult Gulf-strain Striped Bass were manually tracked within the Biloxi River system at least once a month following the same procedures described in Chapter II (see *Manual tracking methods*). Also, vertical profiles of water temperature (°C), salinity (psu), specific conductivity (µS), dissolved oxygen concentration (DO; mg/L), and pH at fish sub-habitat locations were recorded following the same methods described in Chapter II.

Biloxi River Physiochemical Condition Assessment

Vertical profiles for the aforementioned abiotic variables at 40 random sites were located using the Random Points Data Management Tool in ArcGIS 10.0 (ESRI Inc. ArcMap, Redlands, California). The mean river abiotic condition within these sites were sampled once a month using the same equipment and procedures described in Chapter II. Also, hydrographs were created for data collected from the U.S. Geological Survey Biloxi River monitoring station at Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov), located about 12 river km (rkm) above the study area. The hydrographs illustrated the daily trends in mean gage height (ft) and mean discharge (ft sec^{-3}) for each season.

Terminology

The definitions for “fish location”, “schooling fish locations”, and “mean river abiotic conditions” are described in Chapter II.

Analysis

The mean (or grand mean) of each vertical profile collected during mean river abiotic condition sampling and manual tracking events was calculated for each variable following the same methods detailed in Chapter II (see *Data Analysis*). Then, the mean (or grand mean) values of the vertical profiles were pooled by season and used for further analysis. All analyses were conducted with SPSS Statistics for Windows (Version 22; IBM Corp., Armonk, New York).

Mean abiotic and maximum depth data of fish and schooling fish locations were compared against mean river abiotic conditions to identify seasonally unique subsets of abiotic habitats (i.e., sub-habitats) utilized by telemetered juvenile and adult Gulf-strain Striped Bass during each trial. Principle component analysis (PCA) was used to determine seasonal variation of abiotic sub-habitat selection following the same methods detailed in Chapter II (see *Data Analysis*). However, seasonal PCAs included depth (m) and all abiotic variables, including specific conductivity (µS) despite being highly correlated with salinity (psu), to obtain acceptable KMO values that satisfied the appropriateness and parsimony requirements of this analysis. Anderson-Rubin (A-R) factor scores (Field 2005), which represented a composite of the seasonal *in situ* abiotic condition, were used for further analyses.

To evaluate differences between sub-habitat conditions occupied by Gulf-strain Striped Bass and the mean river abiotic condition, I compared the composite A-R factor scores extracted from seasonal PCAs using Mann-Whitney U-tests (two-tailed test values; p-value ≤ 0.05). The original *in situ* abiotic values were summarized $(\bar{x} \pm \text{standard error of the mean } (SEM))$ by seasonal sub-habitat and mean river abiotic condition for ease of interpretation. The group (i.e., fish sub-habitat or mean river abiotic condition) with the highest mean rank value was identified and the variables that loaded highest on the rotated component matrix were considered to be the driving forces leading to statistical significance. Significant Mann-Whitney U-test results were interpreted based on the aforementioned summarized seasonal *in situ* data. Also, Student t-tests were used to compare the mean *in situ* abiotic conditions of fish sub-habitats based on life history stage and season. I employed a Levene's test to examine the homogeneity of equal variance with a two-tailed p-value ($p \leq 0.05$).

Results

Fishing effort

Through directed angling and cooperative anglers we captured a total of ten feral adult Gulf-strain Striped Bass ranging in size from 345 – 660 mm TL and weights ranged from 0.50 – 3.50 kg during November - December 2012 and October - November 2013 (Table 3.2). All adults were captured and released in the lower region of the Biloxi River.

Table 3.2

Biological Information for Acoustically-tagged Feral Adult Gulf-strain Striped Bass Captured and Released in the Biloxi River, MS During 2012 and 2013

VEMCO Ltd. ID	External Tag ID	Capture Date	Est. Battery Termination Date	SL (mm)	FL (mm)	TL (mm)	Weight (kg)
V16-39584	SB0012	11/06/2012	02/03/2014	451	541	574	2.04
V16-39585	SB0013	11/09/2012	02/06/2014	530	624	660	3.00
V16-39586	SB0015	12/18/2012	04/17/2014	360	429	455	1.50

Table 3.2 (continued).

VEMCO Ltd. ID	External Tag ID	Capture Date	Est. Battery Termination Date	SL (mm)	FL (mm)	TL (mm)	Weight (kg)
V13-40714	SB0014	12/18/2012	12/24/2013	360	426	451	1.00
V13-11387	No. 0016	10/25/2013	10/31/2014	504	566	601	2.00
V13-11388	No. 0017	10/29/2013	11/04/2014	397	452	493	1.00
V13-11389	No. 0018	10/29/2013	11/04/2014	441	502	533	1.60
V7-24720	No. 0019	10/29/2013	10/11/2014	284	325	345	0.50
V13-11390	No. 0020	10/31/2013	11/06/2014	474	545	579	3.50
V7-24727	No. 0021	11/22/2013	11/04/2014	479	547	573	3.00

Note. VEMCO Ltd. ID = transmitter type and unique ID; SL = standard length; FL = fork length; TL = total length. The fish with VEMCO Ltd. ID V16-39585 was captured and released in the Tchoutacabouffa River, MS. Also included are the estimated dates that the transmitter batteries terminated; notice, adults acoustically-tagged in 2012 were still detected through mid-February (n = 2) and mid-March 2014 (n = 1).

Range tests

Transmitter detection efficiency significantly differed by manufacturers, environmental conditions, and transmitter configuration. Differences in transmitter detection efficiency between VR2W and SUR receivers in brackish conditions ranged from 4.3% to 13.0% based on transmitter type, but these differences were not significant ($p > 0.05$). In freshwater, detection efficiency varied by transmitter type and was statistically different for V9 ($p < 0.01$) and V13 ($p < 0.01$) transmitters, with VR2W receivers recording on average 16.7% and 12.6% more detections, respectively, than SUR receivers. Therefore, the total number of SUR detections for fish in freshwater locations was adjusted as follows: V9 detections were increased by 16.7% and V13 detections were increased by 12.6%.

Receiver array

Telemetry Trial I

From November 2012 – November 2013, there were a total of 421,424 detection records from acoustically-tagged juvenile (n = 17) and adult (n = 4; fall 2013 n = 10) Gulf-strain Striped Bass (Table 3.3). The large variation between juvenile and adult detections was likely a result of transmitter nominal delay times, which were programed for about 180 seconds juvenile transmitters and about 60 seconds average for adult transmitters. Also, the higher power output of adult transmitters probably facilitated a greater detection distance than juvenile transmitters in the lower, more open regions of the study area. The battery life for juvenile transmitters was estimated to expire during fall 2013.

Table 3.3

Total Number of Acoustic Transmitter Detections from Telemetered Gulf-strain Striped Bass in the Biloxi River, MS Study Area during Telemetry Trial I

	Juvenile Detections		Adult Detections		Total Detections	
Season (Year)	n	%	n	%	n	%
Fall (2012)	7,992	15.1	5,787	1.6	13,779	3.3
Winter (2012 - 2013)	26,073	49.4	62,621	17.0	88,694	21.1
Summer (2013)	1,352	2.6	64,810	17.6	66,162	15.7
Fall (2013)	1,007	1.9	140,685	38.2	141,692	33.6
Total Detections	52,816		368,608		421,424	

Note. The number of detections (n) and percent detection (%) are separated by season for acoustically-tagged juvenile hatchery-reared (n = 17) and feral adult (n = 4; fall 2013 n = 10) Gulf-strain Striped Bass.

Fall 2012. During the 2012 fall season, all telemetered juveniles (n = 17) were detected and widely dispersed within the study area (Figure 3.2). Less than one month after being released, two juveniles were detected in the confluence area of the Biloxi and

Tchoutacabouffa rivers (Table 3.4). Only two adults were detected in the mid- to lower regions of the Biloxi River during fall 2012 (Figure 3.2; Table 3.4).

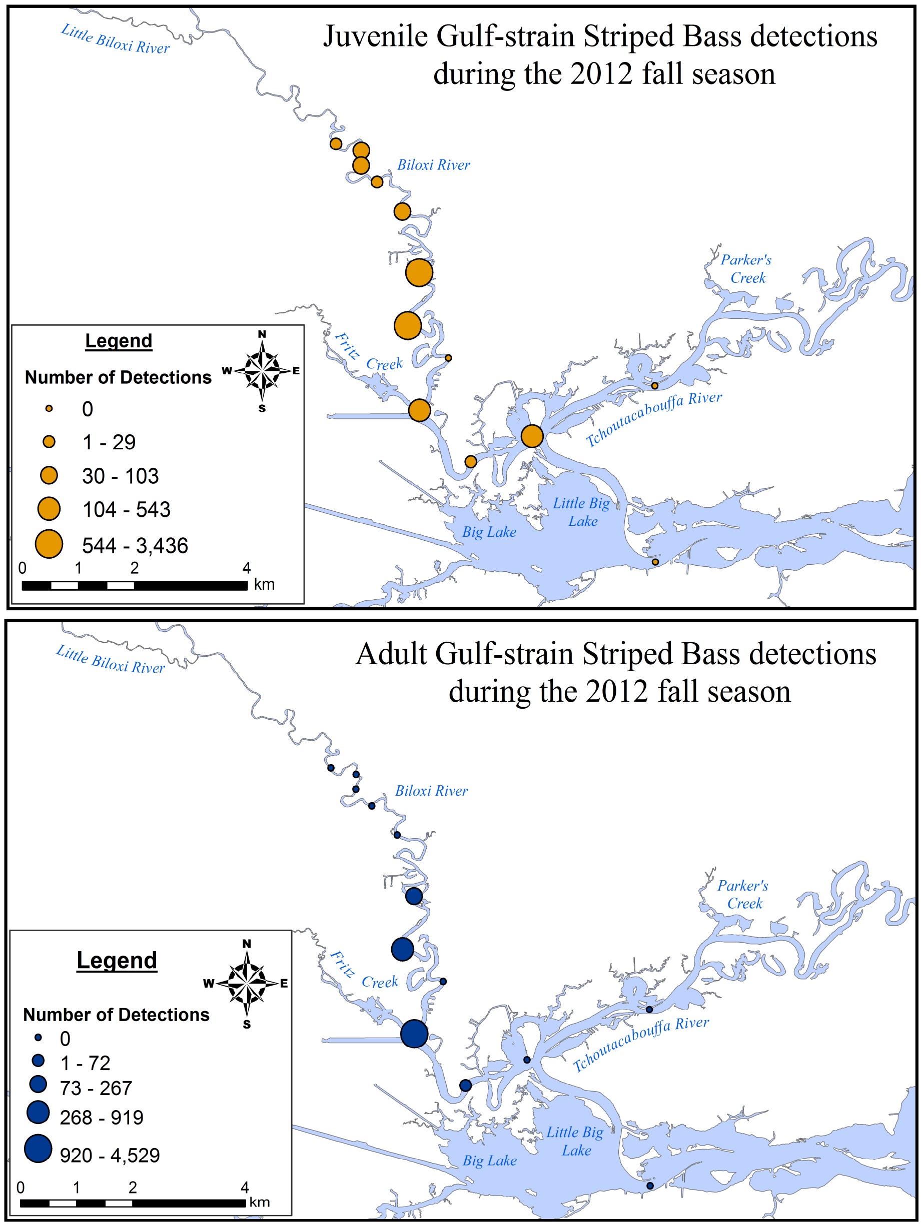


Figure 3.2. The number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2012 fall season (November).

Table 3.4

Passive Acoustic Receiver Array Detection Summaries of Juvenile and Adult Gulf-strain Striped Bass in the Biloxi River, MS during Telemetry Trial I

				Number of fish detected on receivers in each river region						
Season (Year)	Size class	n	Total Detected	Little Biloxi	Upper Biloxi	Mid-Biloxi	Lower Biloxi	Confluence	Tchoutacabouffa	Little Big Lake
Fall (2012)	Juvenile	17	17		8	17	3	2		
	Adult	4	1			1	1			
Winter (2012 - 2013)	Juvenile	17	16		6	12	10	4		
	Adult	4	3		3	3	3	1	1	
Spring (2013)	Juvenile	17	11		6	6	9	2	1	
	Adult	4	4		4	4	4	2	2	
Summer (2013)	Juvenile	17	3		1	2	3	3		
	Adult	4	4	1	4	4	4	1	1	
Fall (2013)	Juvenile	17	3		2		1			
	Adult	10	10	1	6	7	9	6	2	2

Note. n = total number of acoustically-tagged Gulf-strain Striped Bass for each size class. The number of fish detected in each river region of the study area was separated by season and life stage.

Winter 2012 – 2013. A total of 16/17 juveniles and 3/4 adults were detected during the winter season (Figure 3.3, Table 3.4). Gulf-strain Striped Bass were widely dispersed throughout the entire study area (Figure 3.3). Both juveniles and adults were frequently detected in the mid- and lower regions of the Biloxi River (Figure 3.3).

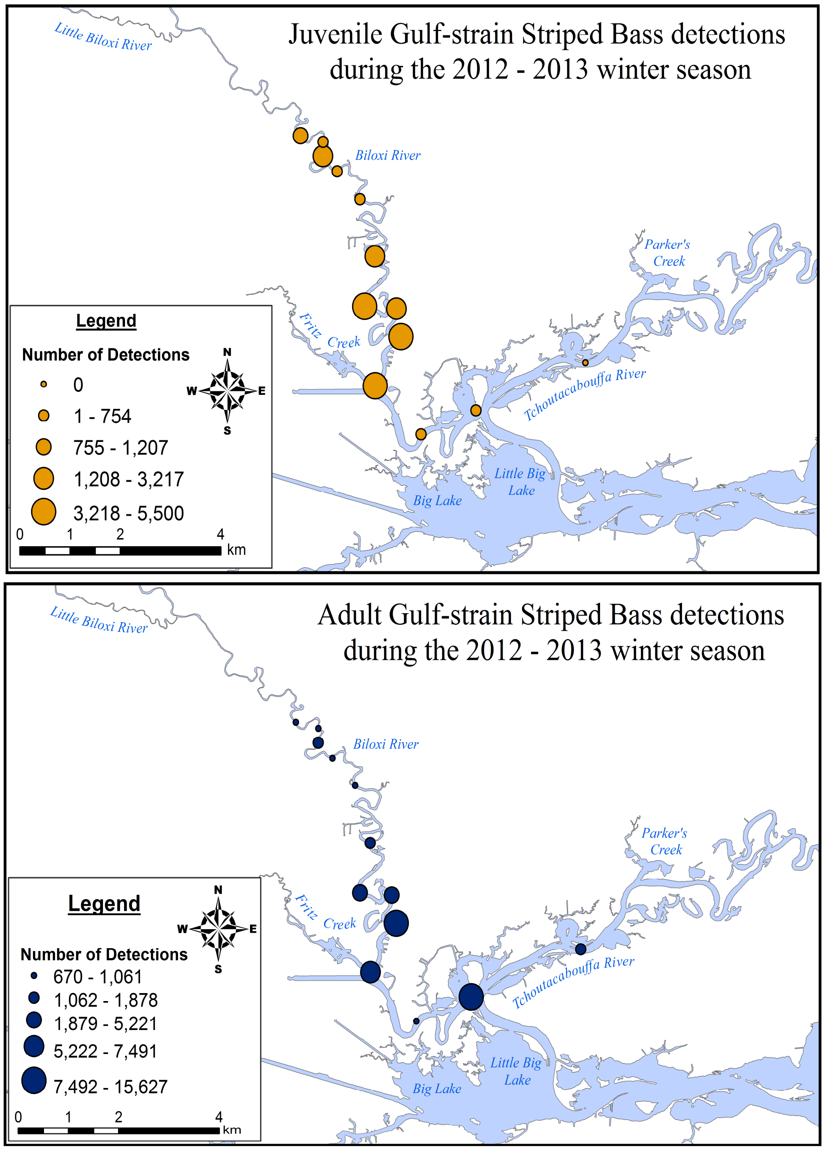


Figure 3.3. The number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2012 - 2013 winter season (December through February).

Spring 2013. During the 2013 spring season, 11/17 juveniles and all adults (n = 4) were detected on the receiver array and appeared widely dispersed in the study area (Figure 3.4, Table 3.4). Juveniles were frequently detected in the lower region (Table 3.4), while greatest numbers of adult detections were split between the confluence area and the upper region of the Biloxi River (Table 3.4). Interestingly, a single juvenile was detected in the Tchoutacabouffa River (Figure 3.4), which was my first record of a hatchery-reared juvenile in a different river than which it was stocked.

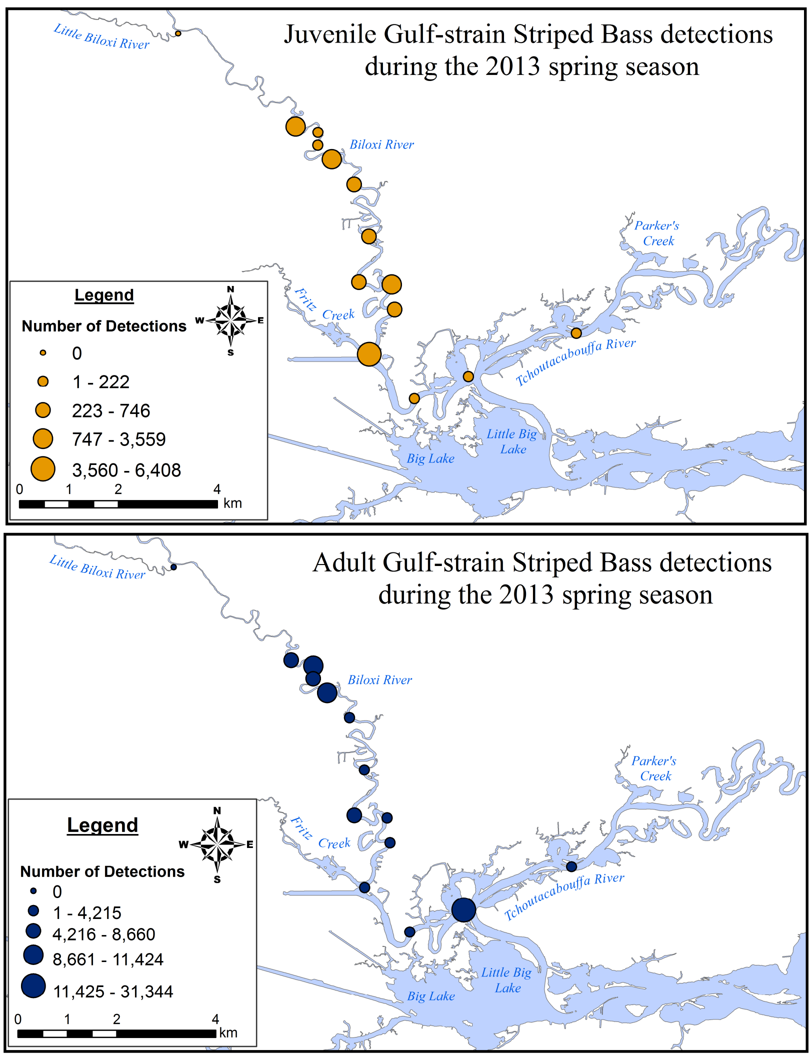


Figure 3.4. The number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2013 spring season (March through May).

Summer 2013. During the 2013 summer season, juvenile Gulf-strain Striped Bass were not frequently detected. Only three juveniles were detected; however, they were widely dispersed from the confluence area to the upper region of the Biloxi River (Figure 3.5, Table 3.5). Conversely, all adults (n = 4) were detected and appeared prevalent from the Little Biloxi River to the Tchoutacabouffa River during the summer season (Figure 3.5; Table 3.4).

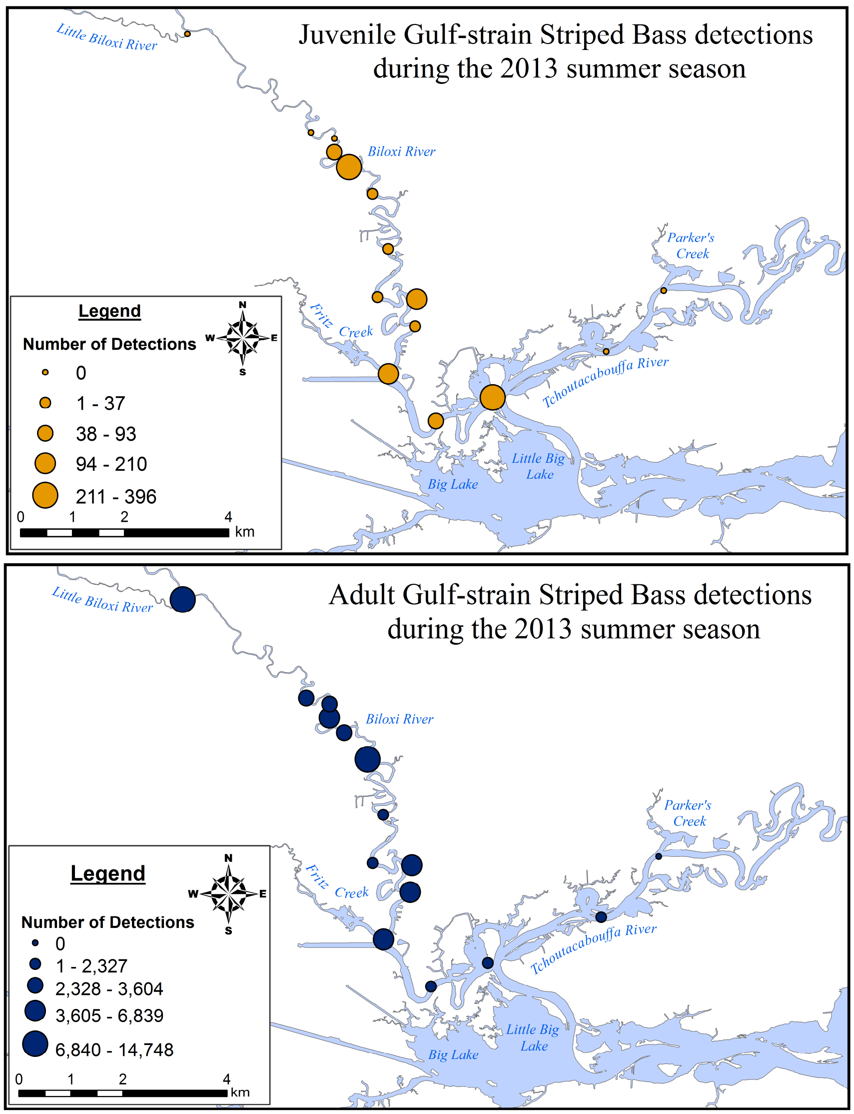


*Figure 3.5. T*he number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2013 summer season (June through August).

Fall 2013. The receiver array consisted entirely of VEMCO Ltd. VR2W receivers after 9 September 2013. During the 2013 fall season, three juveniles were detected from September to early October (Figure 3.6, Table 3.4). The observed detection results were expected because the battery life of juvenile acoustic-transmitters was estimated to terminate early October. On the other hand, all adults (n = 10) were detected and appeared wide spread throughout the study area, from the Little Biloxi River to the Tchoutacabouffa River (Figure 3.6). Two adults were even detected in Little Big Lake (Table 3.4).

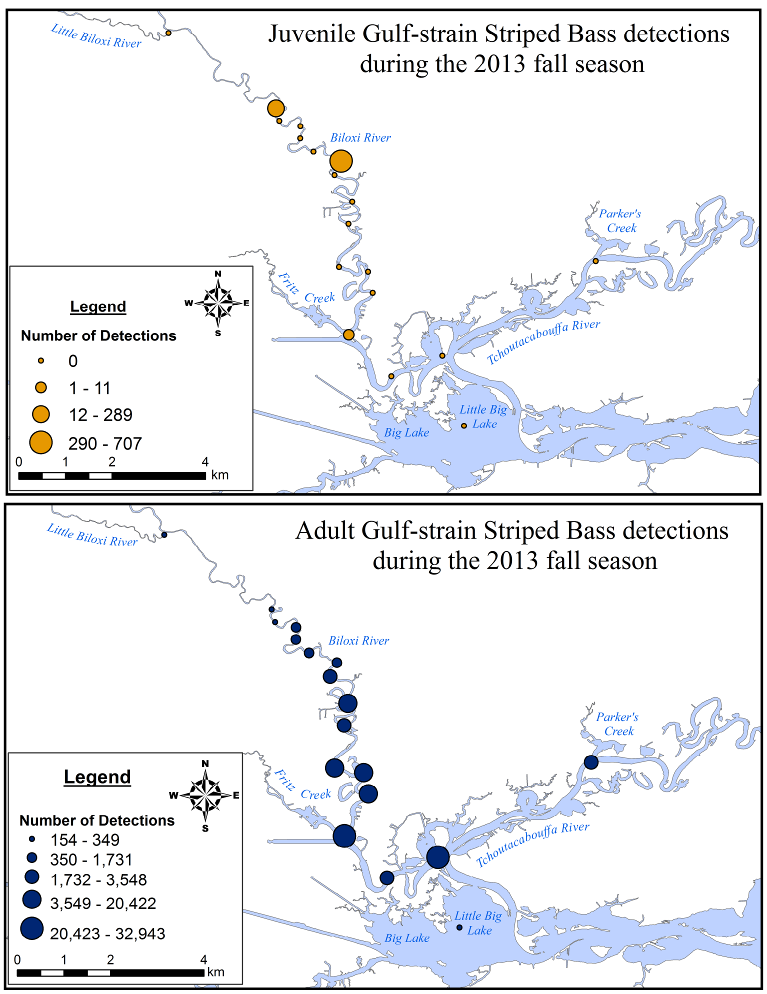


Figure 3.6. The number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2013 fall season (September through November).

Telemetry Trial II

During the second telemetry trial period (December 2013 – June 2014), there were nearly 725,000 detection records from juvenile (n = 17) and adult (winter n = 10; spring-summer n = 7) Gulf-strain Striped Bass (Table 3.5). The battery life of three adult transmitters were estimated to expire by February (Table 3.3). Juveniles were only detected during the winter and spring seasons because the passive receiver array was pulled in May, with the exception of the Little Biloxi River receiver which remained deployed until early June. Removing the receivers in this manner may have impinged on the following seasonal distribution interpretations of Gulf-strain Striped Bass for the 2014 spring and summer seasons.

Table 3.5

Total Number of Acoustic Transmitter Detections from Telemetered Gulf-strain Striped Bass in the Biloxi River, MS Study Area during Telemetry Trial II

	Juvenile Detections		Adult Detections		Total Detections	
Season (Year)	n	%	n	%	n	%
Winter (2013-2014)	447,793	69.9	66,222	79.0	514,015	70.9
Spring (2014)	193,260	30.1	17,034	20.3	210,294	29.0
Summer (2014)			532	0.6	532	0.1
Total Detections	641,053		83,788		724,841	

Note. The number of detections (n) and percent detection (%) are separated by season for acoustically-tagged juvenile hatchery-reared (n = 17) and feral adult (winter n = 10; spring – summer n = 7) Gulf-strain Striped Bass.

Winter 2013 – 2014. A total of 16/17 juveniles and 8/10 adults were detected during the winter months (Table 3.6). Juveniles were frequently detected in the mid-region, near the release site, as well as in the upper and lower regions of the Biloxi River (Figure 3.7). Adults appeared to have a broad distribution range because all receivers had detections; even receivers located at the northern (Little Biloxi River), southern (Little

Table 3.6

Passive Acoustic Receiver Array Detection Summaries of Juvenile and Adult Gulf-strain Striped Bass Detected in the Biloxi River, MS Study Area during Telemetry Trial II

				Number of fish detected on receivers in each river region						
Season (Year)	Size class	n	Total detected	Little Biloxi	Upper Biloxi	Mid-Biloxi	Lower Biloxi	Confluence	Tchoutacabouffa	Little Big Lake
Winter	Juvenile	17	16		8	16	9	2	2	
(2013 - 2014)	Adult	10	8	2	5	6	7	4	3	2
Spring (2014)	Juvenile	17	13			9	7		1	
	Adult	7	7	3	3	5	7	6	5	2
	Juvenile	17	0							
Summer (2014)	Adult	7	1	1						

Note. n = total number of acoustically-tagged Gulf-strain Striped Bass by size class. The number of fish detected in each river region of the study area was separated by season and life stage. All receivers were pulled 19 May 2014, except the Little Biloxi receiver, which remained deployed and active until 17 June 2014.

Big Lake), and eastern (Tchoutacabouffa River) extremes of the array detected several adults throughout the winter season (Figure 3.7).

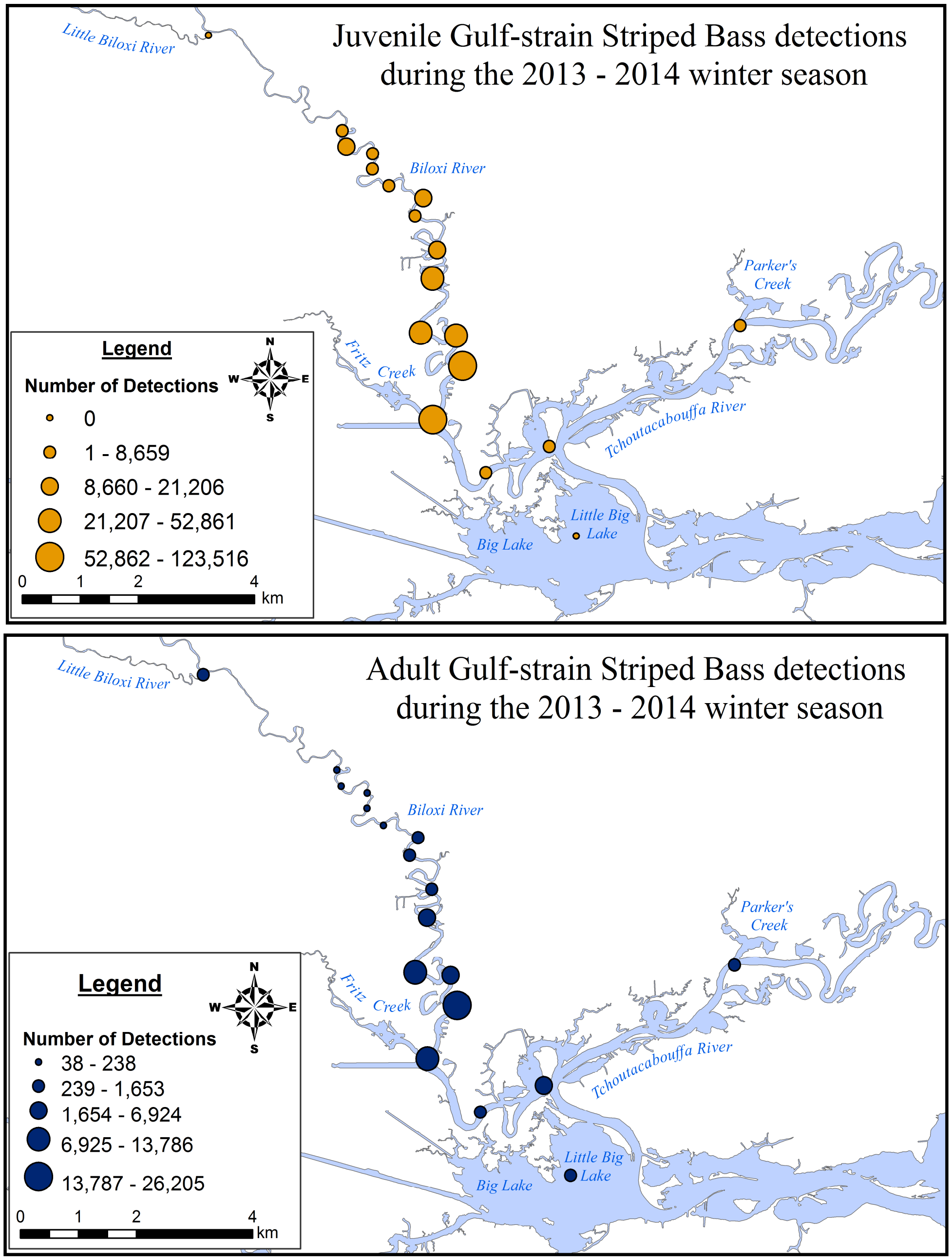


Figure 3.7. The number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2013 - 2014 winter season (December through February).

Spring 2014. A total of 13/17 juveniles were detected mostly in the mid- to lower regions and all detections occurred during March (Table 3.6, Figure 3.8). Conversely, all adults were detected during spring months and were widely dispersed throughout the study area until mid-May when all but the Little Biloxi receiver was removed (Figure 3.8). Receivers in the Biloxi River, confluence area, Tchoutacabouffa River, and Little Big Lake were pulled on 19 May 2014.

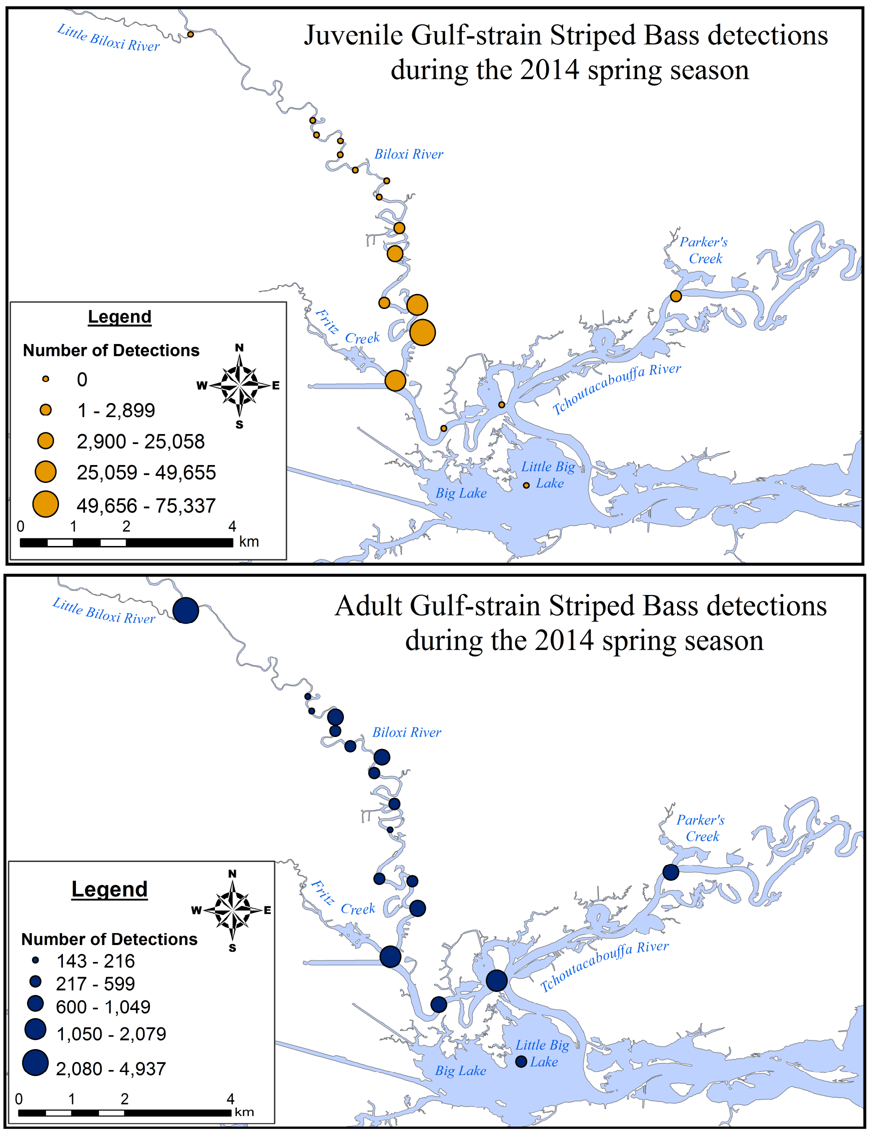


Figure 3.8. The number of transmitter detections of telemetered juvenile and adult Gulf-strain Striped Bass on passive acoustic receivers in the Biloxi River, MS study area during the 2014 spring season (March through May).

Manual tracking: Fish sub-habitat vs. mean river abiotic conditions

Telemetry Trial I

Fall 2012. In November, acoustically-tagged juvenile Gulf-strain Striped Bass were manually tracked in the Biloxi River during one, four, and 15 days (d) post-release (Figure 3.9),

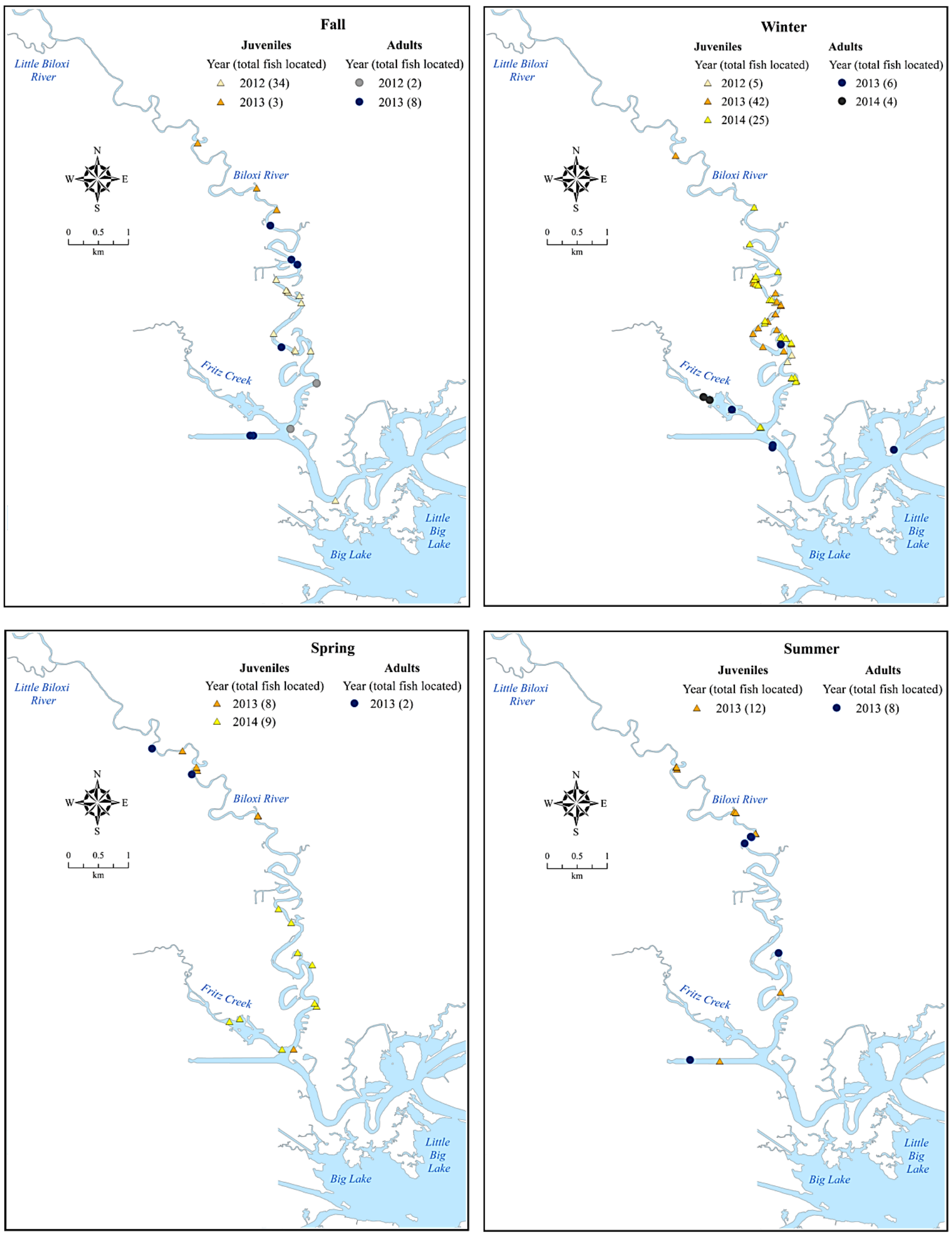


Figure 3.9. Seasonal sub-habitat locations of telemetered juvenile and adult Gulf-strain Striped Bass during manual tracking events from fall 2012 through spring 2014 in the Biloxi River, MS. Triangles represent juvenile sub-habitat locations and circles represent adult sub-habitat locations. Symbols are colored by year.

while the river was at base flow conditions (Figure 3.10). A total of 16 juveniles were located 1 d post-release, 13 juveniles were located 4 d post-release, and five juveniles were located 15 d post-release. Also, a single adult was located during the manual tracking events. The mean river abiotic condition was sampled on 9 November.

The sample size was considered mediocre (KMO = 0.66) and Bartlett's test was significant ($p < 0.01$); thus, PCA was appropriate. PCA reduced the six original variables into two meaningful components that explained 90.19 % of the variability (Table 3.7). Component I loaded with 46.29% of the total variance and consisted of positive correlations for mean salinity, mean specific conductivity, and mean pH (Table 3.7). Component II explained 43.90% of the total variance and was composed of positive correlations for mean maximum depth and mean temperature and was negatively correlated with mean DO (Table 3.7). Component II composite A-R factor scores for fish sub-habitat locations had a significantly different conditions (*Mean rank* = 49.50, $U = 324.00$, $p < 0.01$) than that of the mean river abiotic condition (*Mean rank* = 28.6; Figure 3.11). Thus, Gulf-strain Striped Bass abiotic sub-habitat conditions were interpreted as areas that had, on average, deeper depths, warmer water temperatures, and slightly lower DO than the mean abiotic river condition (Table 3.8). Although mean salinity and specific conductivity of Gulf-strain Striped Bass sub-habitats were higher than that of the mean river abiotic condition (Table 3.8), they were interpreted as being comparable since the mean rank values of the A-R factor scores for Component I were not significant ($U = 600.00$, $p = 0.21$; Figure 3.11).

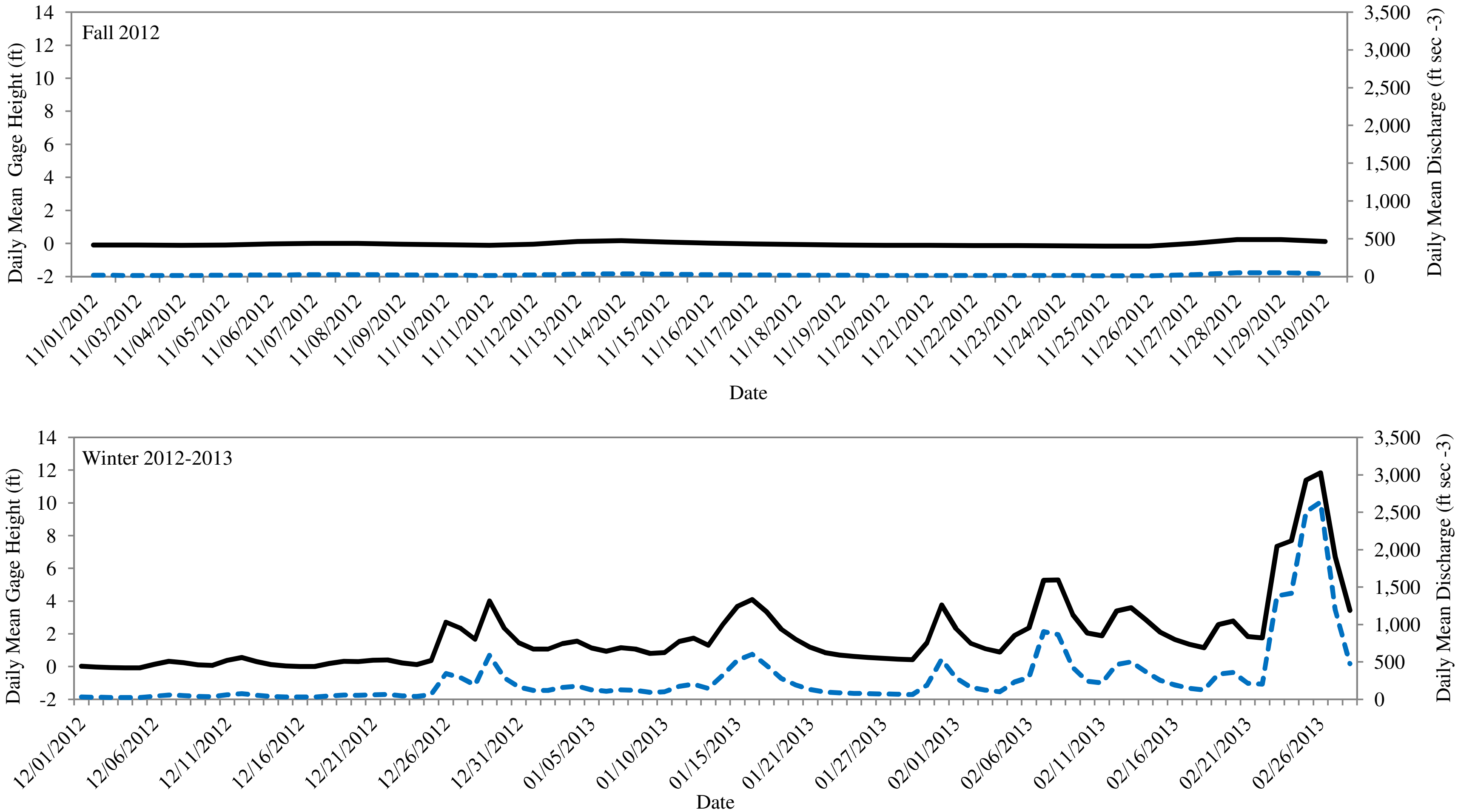


Figure 3.10. Daily mean gage height (ft; solid line) on the primary y-axis and daily mean discharge (ft sec $^{-3}$; dashed line) on the secondary y-axis for the Biloxi River at the Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov), which is located approximated 12 river km above the study area.

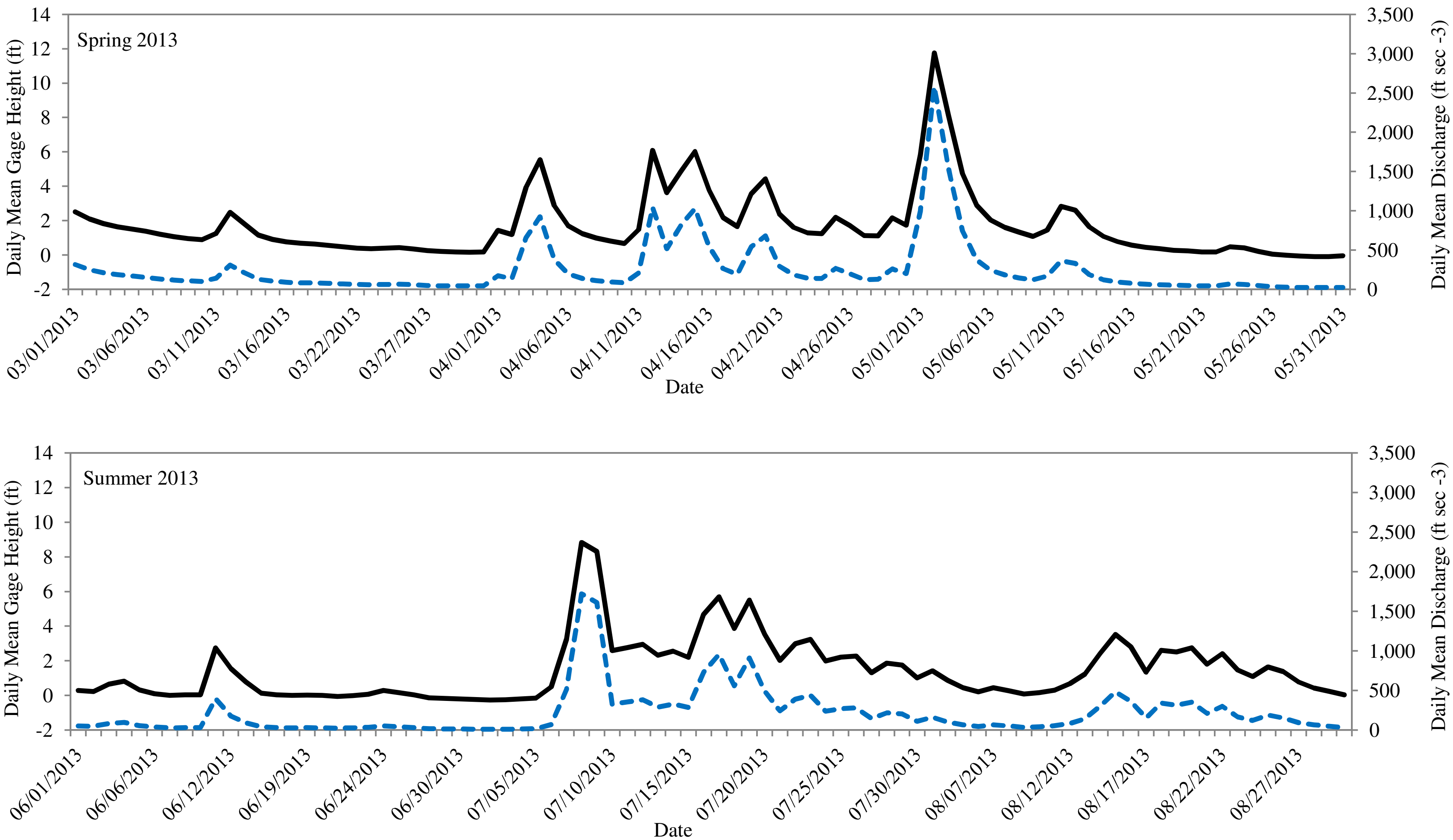
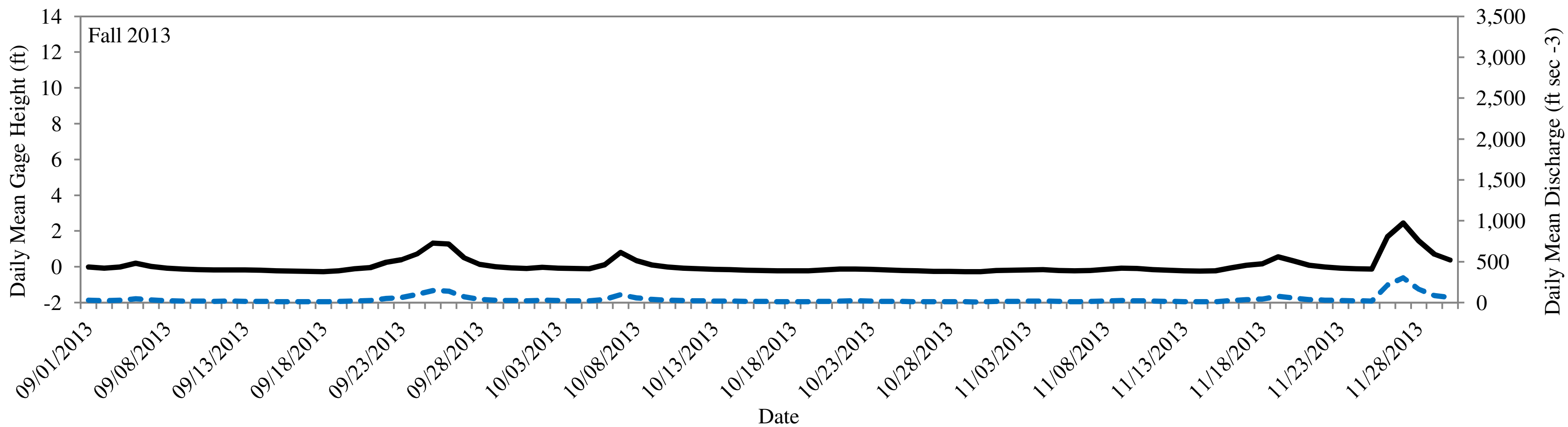


Figure 3.10 (continued). Daily mean gage height (ft; solid line) on the primary y-axis and daily mean discharge (ft sec $^{-3}$; dashed line) on the secondary y-axis for the Biloxi River at the Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov), which is located approximated 12 river km above the study area.



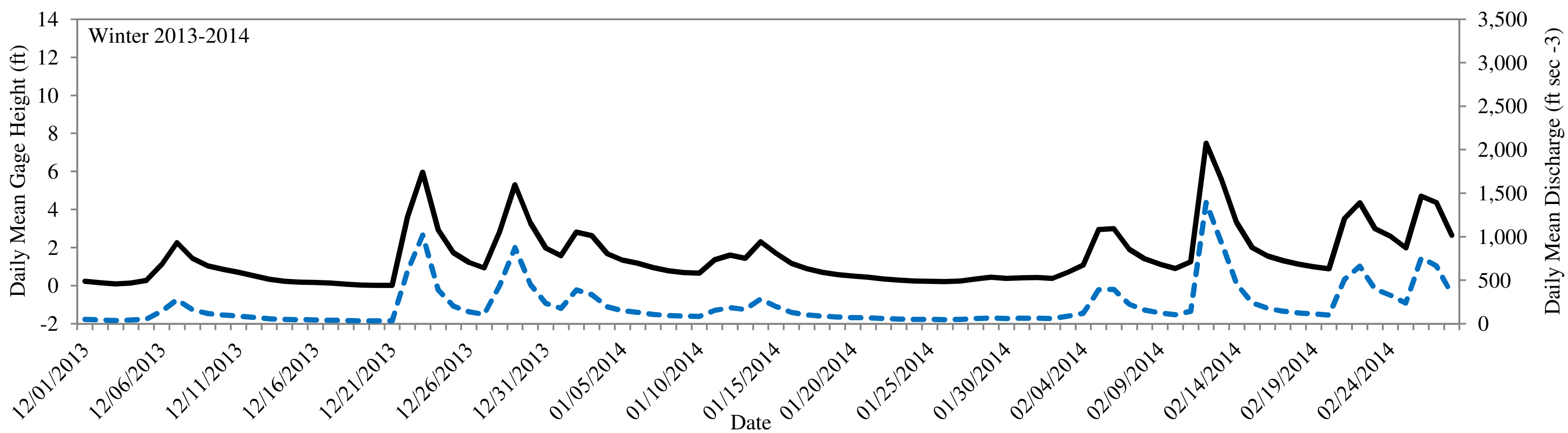


Figure 3.10 (continued). Daily mean gage height (ft; solid line) on the primary y-axis and daily mean discharge (ft sec $^{-3}$; dashed line) on the secondary y-axis for the Biloxi River at the Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov) which is located approximated 12 river km above the study area.

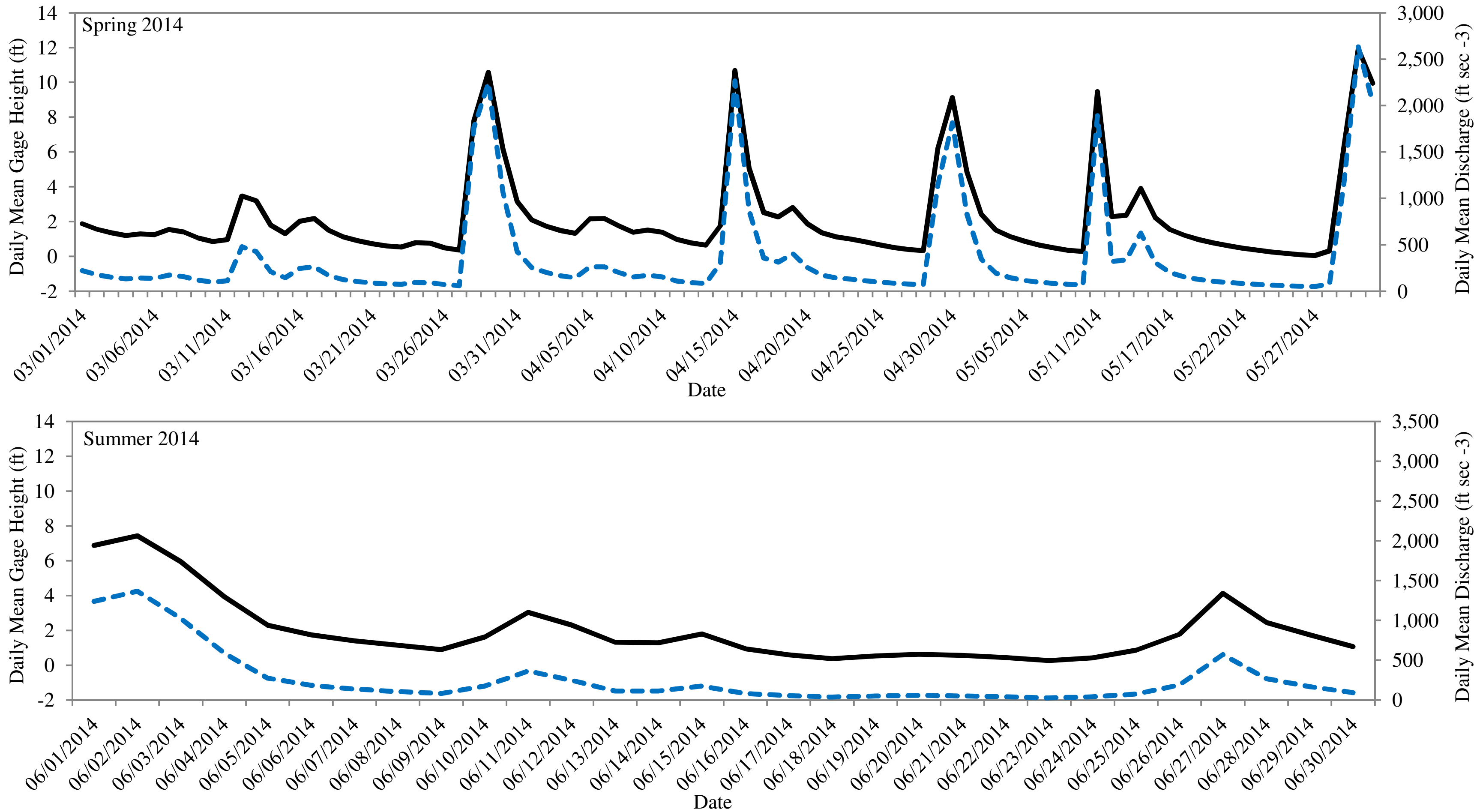


Figure 3.10 (continued). Daily mean gage height (ft; solid line) on the primary y-axis and daily mean discharge (ft sec $^{-3}$; dashed line) on the secondary y-axis for the Biloxi River at the Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov), which is located approximated 12 river km above the study area.

Table 3.7

Seasonal Summaries of the Principle Component Analysis and Mann-Whitney U-Test Results from Comparisons of Gulf-strain Striped Bass Sub-habitats and the Mean River Abiotic Condition in the Biloxi River, MS

Season (year)	Fall (2012)		Winter (2012-2013)		Spring (2013)		Summer (2013)		Fall (2013)		Winter (2013-2014)		Spring (2014)	
KMO	0.66		0.73		0.56		0.70		0.45		0.77		0.63	
PCA Results														
Total Variance	90.19%		90.87%		74.66%		69.22%		75.38%		81.58%		74.77%	
Component	I	II	I	II	I	II	I	II	I	II	I	II	I	II
% Variance	46.29	43.90	55.12	35.77	38.67	36.00	47.32	21.90	39.41	35.98	62.53	19.05	54.02	20.75
Variable Loadings (│r│≥ 0.05)														
Mean Max. Depth (m)	0.527	0.653		0.846				0.832	0.715			0.980	0.610	
Mean Temperature (°C)		0.945	0.805	0.513		0.921	0.777			-0.952	0.895			-0.747
Mean DO (mg/L)		-0.955		-0.855		-0.917		-0.560		0.717	-0.884		-0.957	
Mean Salinity (psu)	0.920		0.879		0.932		0.890		0.941		0.908		0.970	
Mean Specific Cond. (µS)	0.910		0.882		0.932		0.891		0.929		0.911		0.970	
Mean pH	0.899		0.973		0.714	-0.537	0.640			0.721	0.698			0.801
Mann-Whitney U Test														
Mean River Condition MR	35.50	28.60	22.38	21.43	46.09	**48.46**	73.10	70.51	46.36	46.81	107.59	103.79	21.50	25.68
Fish Sub-habitat MR	41.83	**49.50**	28.00	**35.60**	40.80	21.80	54.90	70.45	43.36	40.09	**142.70**	**150.60**	**40.56**	22.00
Mann-Whitney *U*	600.00	324.00	74.00	37.00	353.00	163.00	888.00	1,199.00	411.00	375.00	4,335.00	3727.00	40.00	153.00
p value	0.21	**< 0.01**	0.37	**0.02**	0.55	**< 0.01**	0.06	0.10	0.74	0.43	**< 0.01**	**< 0.01**	**< 0.01**	0.49

Note. KMO = Kaiser-Meyer-Olkin measure of sampling adequacy; PCA = Principal component Analysis; DO = Dissolved oxygen; Cond. = Conductivity; MR= Mean Rank. Variables that loaded │r│≥ 0.05 are shown for each component extracted for seasonal PCAs. Mann-Whitney U mean rank and *p* values in bold represent significant results.

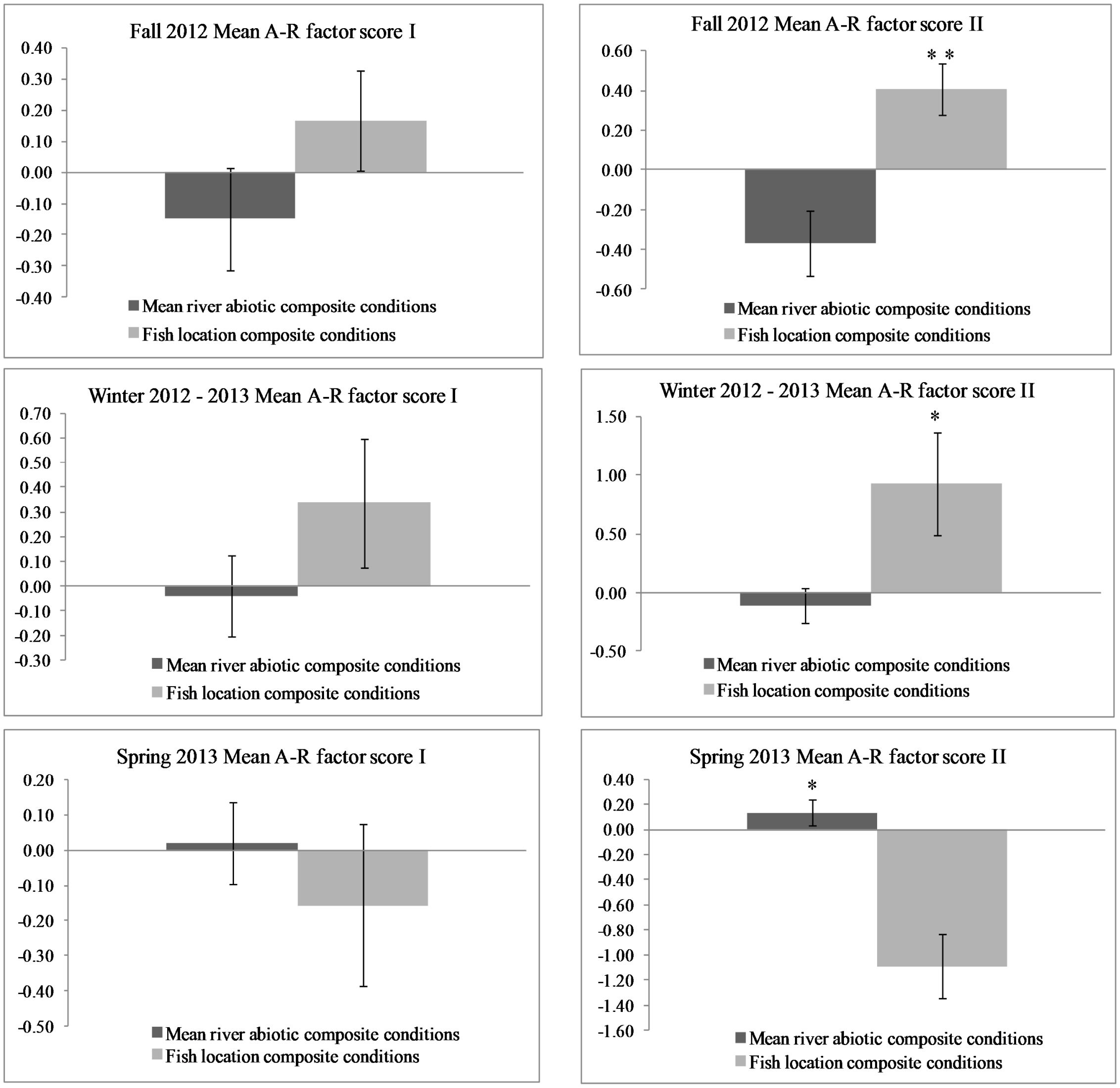


Figure 3.11. Seasonal mean Anderson-Rubin (A-R) factors scores extracted from principle component analysis (PCA) for the mean river abiotic condition (i.e., 40 random sites) and Gulf-strain Striped Bass sub-habitat locations during manual tracking events from fall 2012 through spring 2014. Plots were made for each meaningful component of the PCA. Asterisk symbols represent the significance level based on Mann-Whitney U-test comparing the mean rank values of the A-R factor scores; * $p < 0.05$, ** $p \leq 0.01$.

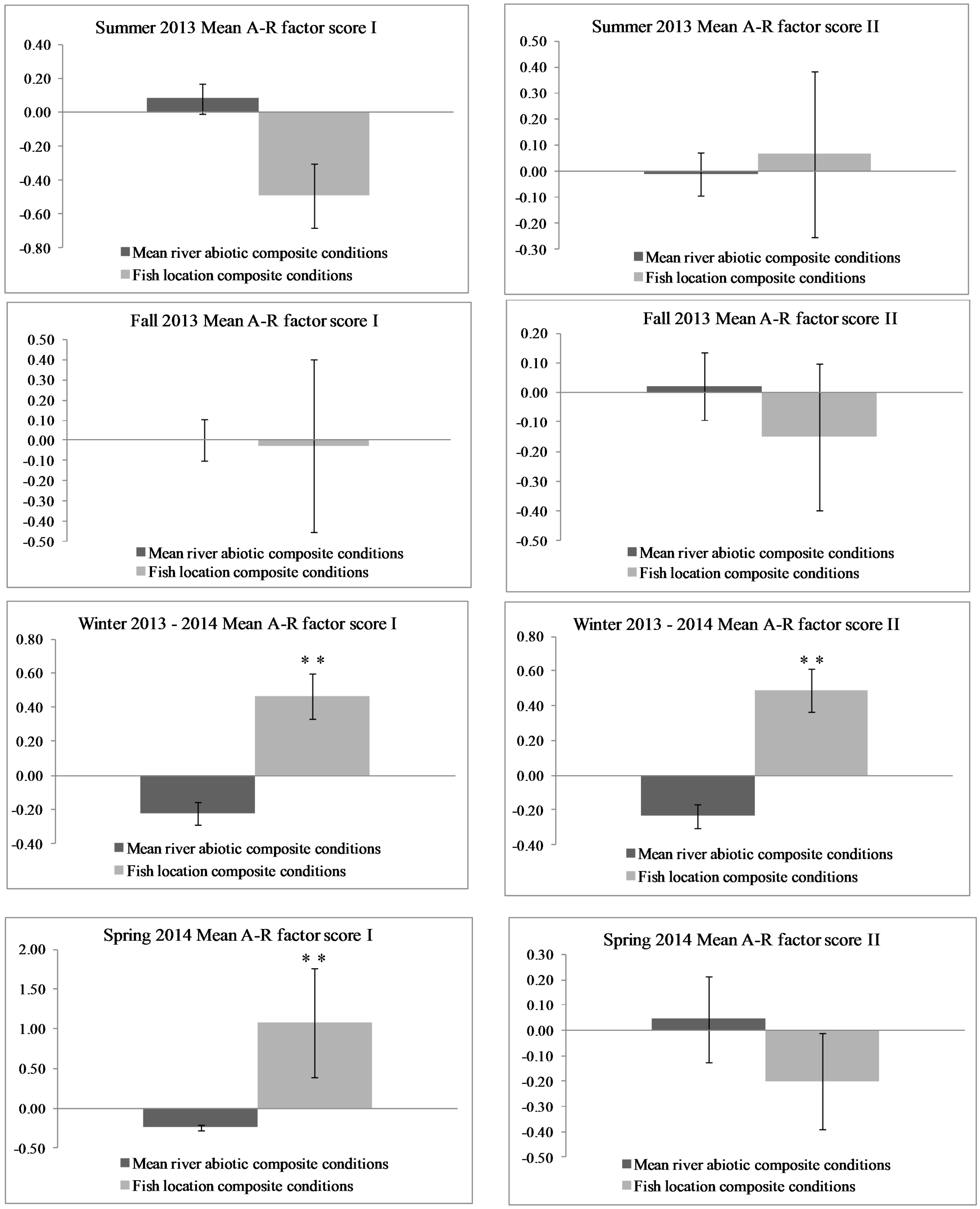


Figure 3.11 (continued). Seasonal mean Anderson-Rubin (A-R) factors scores extracted from principle component analysis (PCA) for the mean river abiotic condition (i.e., 40 random sites) and Gulf-strain Striped Bass sub-habitat locations during manual tracking events from fall 2012 through spring 2014. Plots were made for each meaningful component of the PCA. Asterisk symbols represent the significance level based on Mann-Whitney U-test comparing the mean rank values of the A-R factor scores; * $p < 0.05$, ** $p \leq 0.01$.

Winter 2012 – 2013. Manual tracking only occurred during December because inclement weather events from January through February 2013 resulted in variable gage height and discharge conditions of the Biloxi River (Figure 3.10), which subsequently homogenized abiotic variables throughout the system. Gulf-strain Striped Bass sub-habitat conditions were represented by five juveniles (Figure 3.9). No adults were found during the manual tracking event this season. The mean river abiotic condition was sampled on 19 December.

The sample size was considered good (KMO = 0.73), and Bartlett's test was significant ($p < 0.01$). PCA reduced the six original variables into two meaningful components that explained 90.9% of the variability (Table 3.7). Component I loaded with 55.1% of the total variance and consisted of positive correlations with mean water temperature, mean salinity, mean specific conductivity, and mean pH (Table 3.7). Component II loaded with 35.8% of the total variance and was positively correlated with mean maximum depth and negatively correlated with mean DO (Table 3.7). Component II composite A-R factor scores for fish sub-habitat locations had significantly different conditions (*Mean rank* = 35.06, $U = 37.00$, $p = 0.02$) than the mean river abiotic condition (*Mean rank* = 21.4; Figure 3.11). Based on these results, Gulf-strain Striped Bass abiotic sub-habitat conditions were interpreted as areas that were, on average, deeper with less DO than the mean river abiotic condition (Table 3.8). Abiotic variables that loaded on Component I were not statistically significantly ($p = 0.37$).

Spring 2013. Manual tracking did not occur during March 2013 due to inclement weather and limited personnel availability. Gulf-strain Striped Bass sub-habitat conditions were represented by juveniles (n = 8) and adults (n = 2) manually tracked during April and May (Figure 3.9). The mean river abiotic condition was sampled on 26 April and 31 May. The Biloxi River stage conditions were variable throughout spring months, with peaks in gage height and discharge occurring mid-April (Figure 3. 10).

The spring sampling size was considered mediocre (KMO = 0.56) and Bartlett's test was significant ($p < 0.01$). PCA reduced the six original variables into two meaningful components explaining 74.66% of the variability (Table 3.7). Component I loaded with 38.67% of the total variance and consisted of positive correlations for mean salinity, mean specific conductivity, and mean pH (Table 3.7). Component II explained another 36.00% of the total variance and loaded positively with mean temperature and negatively with mean DO (Table 3.7). Mean maximum depth did not load on either principle component. Component II composite A-R factor scores for the mean river abiotic condition (*Mean rank* = 48.46) were significantly greater ($U = 136.00$, $p < 0.01$) than the abiotic conditions at fish sub-habitat locations (*Mean rank* = 21.80). Gulf-strain Striped Bass sub-habitat locations were interpreted as areas that had, on average, cooler water temperatures and greater DO available than that of the mean river condition (Table 3.8). Component I composite A-R factor scores for the mean river abiotic condition (*Mean rank* = 46.09) and fish sub-habitats (*Mean rank* = 40.80) did not differ significantly ($U = 353.00$, $p = 0.55$; Table 3.7, Figure 3.11); thus, mean salinity, mean specific conductivity, and mean pH conditions were interpreted as comparable (Table 3.8).

Summer 2013. Manual tracking events occurred once in June, three times in July, and once in August. Gulf-strain Striped Bass sub-habitats were represented by juveniles (n = 12) and adults (n = 8) that were identified individually and in schools (Figure 3.9).

Mean river abiotic conditions were sampled on 21 June, 16 July, and 7 August. Biloxi River stage conditions were moderately variable throughout the season, with increased frequency of flashy discharge and gage heights occurring during July (Figure 3.10).

Table 3.8

Seasonal Summaries of the In-Situ Mean Abiotic Variables for Juvenile and Adult Gulf-strain Striped Bass Sub-habitats and the Mean River Abiotic Condition in the Biloxi River, MS for Telemetry Trials I and II

	Season (Year)	Fall 2012		Winter 2012 - 2013		Spring 2013		Summer 2013	
Variables	Condition Location	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM
Depth (m)	Mean River	40	2.85 ± 0.30	40	2.41 ± 0.24	80	2.52 ± 0.15	120	2.97 ± 0.15
	Fish Sub-habitat	36	3.94 ± 0.18	5	4.13 ± 0.67	10	3.36 ± 0.53	20	3.46 ± 0.30
Water Temperature (°C)	Mean River	40	17.60 ± 0.25	40	14.75 ± 0.12	80	22.48 ± 0.45	120	27.72 ± 0.23
	Fish Sub-habitat	36	18.70 ± 0.19	5	15.50 ± 0.12	10	17.81 ± 0.37	20	27.50 ± 0.30
DO (mg/L)	Mean River	40	6.30 ± 0.21	40	7.19 ± 0.16	80	6.82 ± 0.14	120	5.12 ± 0.07
	Fish Sub-habitat	36	5.23 ± 0.17	5	6.47 ± 0.29	10	8.75 ± 0.32	20	5.48 ± 0.18
Salinity (psu)	Mean River	40	7.39 ± 0.69	40	7.12 ± 0.77	80	0.16 ± 0.04	120	0.97 ± 0.12
	Fish Sub-habitat	36	9.51 ± 0.46	5	11.55 ± 0.78	10	0.01 ± 0.01	20	0.13 ± 0.10
Specific Conductivity (µS)	Mean River	40	12,489.68 ± 1,132.39	40	1,9945.30 ± 1,274.52	80	325.91 ± 70.67	120	1,785.24 ± 220.74
	Fish Sub-habitat	36	15,979.53 ± 700.71	5	19,212.58 ± 1,238.17	10	44.42 ± 5.60	20	268.01 ± 188.18
pH	Mean River	40	6.82 ± 0.04	40	6.65 ± 0.06	80	6.11 ± 0.05	120	5.81 ± 0.06
	Fish Sub-habitat	36	6.83 ± 0.04	5	6.73 ± 0.06	10	6.27 ± 0.31	20	5.61 ± 0.59

Table 3.8 (continued).

	Season (Year)	Fall 2013		Winter 2013 - 2014		Spring 2014	
Variables	Condition Location	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM
Depth (m)	Mean River	80	2.80 ± 0.19	160	3.03 ± 0.11	40	3.19 ± 0.21
	Fish Sub-habitat	11	3.30 ± 0.53	77	4.41 ± 0.19	9	5.67 ± 0.82
Water Temperature (°C)	Mean River	80	22.86 ± 0.67	160	11.18 ± 0.11	40	17.41 ± 0.16
	Fish Sub-habitat	11	23.10 ± 1.59	77	12.48 ± 0.21	9	17.92 ± 0.24
DO (mg/L)	Mean River	80	5.85 ± 0.18	160	8.84 ± 0.09	40	8.27 ± 0.03
	Fish Sub-habitat	11	7.51 ± 0.68	77	7.69 ± 0.21	9	7.11 ± 0.54
Salinity (psu)	Mean River	80	3.96 ± 0.34	160	1.03 ± 0.18	40	0.01 ± 0.001
	Fish Sub-habitat	11	4.28 ± 1.48	77	3.41 ± 0.39	9	1.21 ± 0.85
Specific Conductivity (µS)	Mean River	80	7,120.49 ± 593.45	160	1,803.49 ± 312.43	40	49.03 ± 3.41
	Fish Sub-habitat	11	7,275.32 ± 2,504.23	77	5,828.17 ± 661.78	9	2,052.06 ± 1,404.28
pH	Mean River	80	10.68 ± 0.16	160	13.18 ± 0.07	40	12.37 ± 0.12
	Fish Sub-habitat	11	8.48 ± 0.71	77	13.52 ± 0.08	9	12.33 ± 0.05

Note. Mean River = the mean river abiotic condition; Fish Sub-habitat = abiotic conditions at manually tracked locations of acoustically-tagged Gulf-strain Striped Bass; n = number of random sites sampled that season for Mean River condition, or number of Gulf-strain Striped Bass located during manually tracking events that season. Abiotic data are presented as mean ± standard error of the mean (SEM) of the vertical profiles for each variable.

The summer sampling size was considered good (KMO = 0.70) and Bartlett's test was significant ($p < 0.01$). PCA reduced the six original variables into two meaningful components explaining 69.22% of the variability (Table 3.7). Component I explained 47.32% of the total variance and consisted of positive correlations with mean water temperature, mean salinity, mean specific conductivity, and mean pH (Table 3.7). Component II explained another 21.90% of the total variance and loaded positively with mean maximum depth and negatively with mean DO (Table 3.7). Component I composite A-R factor scores for the mean river abiotic condition (*Mean rank* = 73.10) and fish sub-habitats (*Mean rank* = 54.90) were not significantly different (U = 888.00, p = 0.06) (Table 3.7). Also, Component II composite A-R factor scores for the mean river abiotic condition (*Mean rank* = 70.51) and fish sub-habitats (*Mean rank* = 70.45) were not significantly different (U = 1,199.00, p = 0.10; Table 8). Based on these results, Gulf-strain Striped Bass sub-habitat conditions in the Biloxi River were considered to be comparable to that of the mean river abiotic condition during the summer season (Figure 3.11; Table 3.8).

Fall 2013. Gulf-strain Striped Bass sub-habitat conditions were represented by juveniles (n = 3) and adults (n = 8) located during manual tracking events in September and November (Figure 3.9). The batteries in juvenile transmitters expired between late September and early October; thus, juveniles located this season only represented sub-habitat conditions selected in September. Also, manual tracking did not occur in October. Mean river abiotic condition were sampled on 17 September and 20 November.

The sample size was considered just less than mediocre (KMO = 0.45), but Bartlett's test was significant ($p < 0.01$) so PCA was continued. PCA reduced the six original variables into two meaningful components explained 75.38% of the variability (Table 3.7). Component I explained 39.41% of the total variance and consisted of positive correlations with mean maximum depth, mean salinity, and mean specific conductivity (Table 3.7). Component II explained another 35.98% of the total variance and loaded negatively with mean water temperature and positively with mean DO and mean pH (Table 3.7). Component I composite A-R factor scores for the mean river abiotic condition (*Mean rank* = 46.36) and fish sub-habitats (*Mean rank* = 43.36) were not significantly different (U = 411.00, p = 0.74; Table 3.7). Also, Component II composite A-R factor scores for the mean river abiotic condition (*Mean rank* = 46.81) and fish sub-habitats (*Mean rank* = 40.09) were not significantly different (U = 375.00, p = 0.43; Table 3.7). Based on these results, Gulf-strain Striped Bass sub-habitat conditions in the Biloxi River were considered to be comparable to that of the mean river abiotic condition during the fall season (Table 3.8, Figure 3.11).

Telemetry Trial II

Winter 2013 – 2014. In December, juvenile Gulf-strain Striped Bass (n = 17) were manual tracked at one, three, and 15 days (d) post-release. All juveniles were located 1 d post-release, 16 were located 3 d post-release, and 10 juveniles were located 15 d post-release. The mean river abiotic condition was sampled on 12 December; however, before the 15 d manual tracking event, intense precipitation caused flood conditions (Figure 3.10), which subsequently resulted in homogenized abiotic conditions throughout the Biloxi River system. Because of this, the mean river abiotic condition was re-sampled during the 15 d manual tracking event on 25 December 2014. Both sets of December mean river abiotic condition samples were included in winter analysis. In January, 12 juveniles and three adult Gulf-strain Striped Bass were manually tracked in schools and individual areas within the Biloxi River. The mean river abiotic condition was also sampled on 17 January. In February, 12 juveniles and one adult Gulf-strain Striped Bass were found in separate locations during the manual tracking event. The mean river abiotic condition was also sampled on 17 February.

The sample size was considered good (KMO = 0.77) and Bartlett's test was significant. PCA reduced the six original variables into two meaningful components that explained 81.58% of the variability (Table 3.7). Component I explained 62.53% of the total variation and consisted of positive correlations with mean water temperature, mean salinity, mean specific conductivity, and mean pH and negative correlations with mean DO (Table 3.7). Component II explained another 19.05% of the total variance and was positively correlated with mean maximum depth (Table 3.7). Component I composite A-R factor scores for fish sub-habitat conditions (*Mean rank* = 142.70) conditions were significantly different (U = 4,335.00, $p < 0.01$) than the mean river abiotic condition (*Mean rank* = 107.60; Table 3.7, Figure 3.11). Also, Component II composite A-R factor scores for fish sub-habitat conditions (*Mean rank* = 150.60) were significantly greater (U = 3,727.00, $p < 0.01$) than the mean river abiotic condition (*Mean rank* = 103.79; Table 3.7, Figure 3.11).Thus, winter sub-habitats occupied by Gulf-strain Striped Bass were interpreted as, on average, warmer with higher salinity and specific conductivity, more basic pH conditions, less DO and deeper than the mean river abiotic condition (Table 3.8).

Spring 2014. In March 2014, neither manual tracking nor sampling of the mean river abiotic condition occurred due to inclement weather. Gulf-strain Striped Bass sub-habitat conditions were only represented by juveniles (n = 9) located during the final manual tracking event for this project that occurred on 11 April (Figure 3.9). The mean river abiotic condition was also sampled on 11 April. Biloxi River gage height and discharge conditions were flashy and highly variable (Figure 3.10).

The sampling size was considered mediocre (KMO = 0.63) and Bartlett's test was significant ($p < 0.01$). PCA reduced the six original variables to two meaningful components that explained 74.77% of the variability (Table 3.7). Component I accounted for 54.02% of the total variation and consisted of positive correlations with mean maximum depth, mean salinity, and mean specific conductivity, as well as negative correlations with mean DO (Table 3.7). Component II explained another 20.75% of the total variation and consisted of positive correlations with mean pH and negative correlations with mean water temperature (Table 3.7). Component I composite A-R factor scores for Gulf-strain Striped Bass sub-habitat conditions (*Mean rank* = 40.56) were significantly greater ($U = 40.00$, $p < 0.01$) than the mean river abiotic condition (*Mean rank* = 21.50; Figure 3.11). Thus, fish locations were interpreted as areas that had, on average, deeper depths with higher salinity and specific conductivity conditions and less DO available than locations that represented the mean river abiotic condition (Table 3.8). The Mann-Whitney U analysis for Component II was not statistically significant ($U = 153.00$, $p = 0.49$) when composite A-R factor scores for fish sub-habitat conditions (*Mean rank* = 22.00) were compared against the mean river abiotic condition (*Mean rank* = 25.68; Figure 3.11). Therefore, the mean river abiotic condition and Gulf-strain Striped Bass sub-habitats had comparable average water temperature and nearly the same average pH conditions during the spring (Table 3.8).

Juvenile vs. adult Gulf-strain Striped Bass sub-habitat condition comparisons

Gulf-strain Striped Bass were manually tracked occupying different sub-habitat conditions based on life stage (i.e., juvenile or adult) and season. During fall 2012, juvenile and adult Gulf-strain Striped Bass were detected in sub-habitats that had significantly different mean maximum depth, mean salinity, mean specific conductivity, and mean pH (Table 3.9). Based on the mean abiotic conditions, juveniles occupied sub-

Table 3.9

Results from Independent Student's t-test Comparisons of Juvenile and Adult Gulf-strain Striped Bass Sub-habitat Conditions in the Biloxi River, MS by Season

Season	Variables	Levene's test p-values	*t* statistic	df	2-tailed *p*
Fall 2012	Mean Max. Depth (m)	0.61	-2.04	34.00	**0.05**
	Mean Water Temperature (°C)	0.25	1.70	34.00	0.10
	Mean DO (mg/l)	0.08	-1.59	34.00	0.12
	Mean Salinity (psu)	0.58	-3.34	34.00	**< 0.01**
	Mean Specific Conductivity (µS)	0.61	-3.40	34.00	**< 0.01**
	Mean pH	0.97	-3.10	34.00	**< 0.01**
Spring 2013	Mean Max. Depth (m)	0.09	0.02	8.00	0.98
	Mean Water Temperature (°C)	0.96	-0.07	8.00	0.94
	Mean DO (mg/l)	0.99	-0.34	8.00	0.75
	Mean Salinity (psu)	0.83	0.45	8.00	0.67
	Mean Specific Conductivity (µS)	0.93	0.36	8.00	0.73
	Mean pH	**0.02**	-1.00	1.06	0.49
Summer 2013	Mean Max. Depth (m)	**< 0.01**	0.83	14.53	0.42
	Mean Water Temperature (°C)	0.25	0.05	18.00	0.96
	Mean DO (mg/l)	0.53	0.32	18.00	0.75
	Mean Salinity (psu)	0.06	0.93	18.00	0.37
	Mean Specific Conductivity (µS)	0.06	0.94	18.00	0.36
	Mean pH	0.58	-1.40	18.00	0.18
Fall 2013	Mean Max. Depth (m)	0.47	-0.29	9.00	0.78
	Mean Water Temperature (°C)	**< 0.01**	2.72	7.17	**0.03**
	Mean DO (mg/l)	0.09	-1.10	9.00	0.30
	Mean Salinity (psu)	**< 0.01**	-3.41	7.00	**0.01**
	Mean Specific Conductivity (µS)	**< 0.01**	-3.42	7.00	**0.01**
	Mean pH	**0.02**	-1.12	8.85	0.29

Table 3.9 (continued).

Season	Variables	Levene's test p-values	*t* statistic	df	2-tailed *p*
Winter 2013-2014	Mean Max. Depth (m)	0.30	-3.29	75.00	**< 0.01**
	Mean Water Temperature (°C)	**< 0.01**	-6.56	64.32	**< 0.01**
	Mean DO (mg/l)	0.15	6.38	75.00	**< 0.01**
	Mean Salinity (psu)	**< 0.01**	-10.66	17.76	**< 0.01**
	Mean Specific Conductivity (µS)	**< 0.01**	-10.55	18.43	**< 0.01**
	Mean pH	**0.01**	-0.58	19.68	0.57

Note. Winter 2012-2013 not included because no adults were located. Max. = maximum; DO = dissolved oxygen concentration; df = degrees of freedom. Bold text indicates a significant result. For Levene's test, a significant result means homogeneity of equal variance was not assumed.

habitats that were on average, shallower with lower salinity and specific conductivity, and slightly more acidic conditions than adult sub-habitats (Table 3.10). Life stage sub-habitat comparisons could not be made for winter 2012-2013 because only juveniles were located. Juveniles and adults did not occupy significantly different sub-habitat conditions during spring 2013 and summer 2013 (Tables 3.9 and 3.10). However during fall 2013, juvenile and adult sub-habitats had significantly different mean temperature, mean salinity and mean specific conductivity conditions (Table 3.9). Juveniles were detected in sub-habitats with warmer, lower salinity and specific conductivity conditions than adult sub-habitat locations. Juveniles were found in similar sub-habitat conditions the previous fall season. During winter 2013-2014, the second group of acoustically-tagged juveniles was released and manually tracked in the Biloxi River. Mean maximum depth, mean temperature, mean DO, mean salinity, and mean specific conductivity conditions of juvenile and adult sub-habitats were significantly different during the winter 2013-2014 season (Table 3.9). Juveniles were located in shallower sub-habitats that were cooler, well oxygenated, and had less salinity and specific conductivity conditions than the sub-habitats where adult Gulf-strain Striped Bass were located (Table 3.10). Size comparisons could not be made for spring 2014 because only juveniles were located.

Table 3.10

Summaries of Juvenile and Adult Gulf-strain Striped Bass Sub-habitat Conditions in the Biloxi River, MS by Season

Season	Size	n	Mean Max. Depth (m)	Mean Water Temperature (°C)	Mean DO (mg/l)	Mean Salinity (psu)	Mean Specific Conductivity (µS)	Mean pH
Fall 2012	Juv.	34	**3.86 ± 0.18**	18.78 ± 0.18	5.17 ± 0.16	**9.18 ± 0.41**	**15,472.60 ± 629.93**	**6.80 ± 0.04**
	Adult	2	**5.39 ± 0.52**	17.42 ± 1.37	6.33 ± 1.51	**15.05 ± 2.13**	**24,597.43 ± 3,192.57**	**7.28 ± 0.16**
Winter 2012-2013	Juv.	5	4.13 ± 0.67	15.50 ± 0.12	6.47 ± 0.29	11.55 ± 0.78	19,212.58 ± 1,238.17	6.73 ± 0.06
Spring 2013	Juv.	8	3.37 ± 0.67	17.80 ± 0.42	8.70 ± 0.36	0.01 ± 0.03	45.46 ± 0.46	6.01 ± 0.22
	Adult	2	3.33 ± 0.33	17.87 ± 1.06	8.98 ± 0.91	0.01 ± 0.01	40.23 ± 14.88	7.32 ± 1.29
Summer 2013	Juv.	12	3.64 ± 0.49	27.51 ± 0.45	5.53 ± 0.26	0.21 ± 0.17	412.43 ± 311.71	4.95 ± 0.81
	Adult	8	3.20 ± 0.21	27.48 ± 0.38	5.41 ± 0.23	0.01 ± 0.01	51.37 ± 9.98	6.59 ± 0.73
Fall 2013	Juv.	3	3.04 ± 0.89	**27.00 ± 0.22**	6.29 ± 0.36	**0.01 ± 0.01**	**42.50 ± 0.59**	7.62 ± 0.43
	Adult	8	3.40 ± 0.67	**21.64 ± 1.96**	7.96 ± 0.89	**5.88 ± 1.72**	**9,987.63 ± 2,909.46**	8.80 ± 0.96
Winter 2013-2014	Juv.	57	**4.18 ± 0.20**	**12.25 ± 0.23**	**8.10 ± 0.18**	**2.55 ± 0.34**	**44,13.40 ± 5,75.42**	13.51 ± 0.09
	Adult	10	**5.95 ± 0.40**	**14.03 ± 0.14**	**4.93 ± 0.38**	**9.14 ± 0.52**	**15,307.13 ± 857.19**	13.60 ± 0.13
Spring 2014	Juv.	9	5.67 ± 0.82	17.92 ± 0.24	7.11 ± 0.54	1.21 ± 0.85	2,052.06 ± 1,404.28	12.33 ± 0.05

Note. n = number of fish manually tracked for each size class; SEM = standard error of the mean; DO = dissolved oxygen concentration; Juv. = juveniles. Bold text indicates significantly different (t-test, $p < 0.05$) abiotic sub-habitat conditions were occupied by juvenile hatchery-reared and adult Gulf-strain Striped Bass in the Biloxi River, MS.

Discussion

Restoration of the Gulf-strain Striped Bass population to a sustainable fishery throughout its range in the Gulf of Mexico is a complex issue (Long et al. 2013) which requires, in particular, knowledge of vital life history traits and ontogenetic abiotic habitat requirements that may vary based on the river-system examined. Historically, most restoration efforts have focused on brood stock development and stock-enhancement activities (reviewed in Frugé et al. 2006; Long et al. 2013), with little information on the ecology of stocked fishes. In fact, most data on these vital metrics and basic ecology stem directly from research on Atlantic Striped Bass populations from stocked reservoirs or in tidal-river estuarine basins and are assumed appropriate requirements and capabilities for Gulf-strain populations as these data are often used in predictive modeling exercises (e.g., Dieterich and Fulford 2012). Habitat loss or modification act as limiting factors in species recovery (Kerr and Deguise 2004; Ahrens and Pine 2014) and thus any interpretation of recovery success of Gulf-strain Striped Bass must recognize that the lack and/or loss of temporally and spatially appropriate abiotic habitat conditions (Jackson et al. 2002; Coutant 2013) may be a major limiting factor in successful recovery and the development of a sustainable fishery. My study provides important insights on the habitat preferences for two key life stages of Gulf-strain Striped Bass and how those preferences vary by season. This information is a nice addition to the body of Gulf-strain Striped Bass knowledge and will help inform recovery efforts.

Fall patterns

During this study, there was almost no variability in river discharge and gage height during the fall season for both years as the Biloxi River was nearly at base flow conditions. The lack of variability in discharge appears to facilitate spatially heterogeneous and vertical abiotic gradients in deeper areas of the Biloxi River. Initially both juvenile and adult Gulf-strain Striped Bass remained near the release points; however, fish distribution range increased over the course of 20 month following the initial fall 2012 tagging event. However, in fall 2013 juveniles were only located in the upper region during early September prior to the expiration of the transmitters in Gulf-strain Striped Bass released in the fall of 2012. As a result our fall findings on selected habitats may be limited. In contrast, adults were detected throughout the study area, suggesting that a wide range of suitable, or at least tolerable, habitat conditions were available during the fall 2013 season. Conversely, juveniles and adults tagged in fall 2012 selected habitats with, on average, greater depths, warmer water temperatures, and slightly lower DO concentrations than the mean river abiotic conditions, suggesting Gulf-strain Striped Bass actively select these transitional conditions as has been noted by Jackson et al. (2002) in the Pascagoula River system as well as in reservoirs and tidal-river estuaries (Coutant 2013; Long et al. 2013). Therefore, suitable habitats appeared less limiting with the breakup of stratified summer conditions before the onset of cooler winter months.

Juveniles selected habitats that were significantly different than adults during fall for both years with typically warmer, lower salinity and higher pH. These differences were likely attributed to spatial segregation and river region characteristics; juveniles were mostly located in the shallower mid- to upper freshwater reaches of the Biloxi River, whereas the majority of adults were located within the salt wedge in the deeper mid- to lower regions of the study area.

Winter patterns

Winter abiotic conditions are conducive to all size classes of Striped Bass throughout its geographic range (Coutant 2013; Long et al. 2013). The Biloxi River appears to have suitable habitats for juvenile and adult Gulf-strain Striped Bass throughout its length during winter months, so they remained resident for both years of this study. This broad distribution pattern suggests fish were not limited by abiotic conditions of the Biloxi River which has been reported for Striped Bass in a Tennessee reservoir in cooler seasonal periods (Cheek et al.1985). The majority of juvenile and adult winter detections for this study, however, occurred in the mid- and lower regions of the receiver array; these areas offered deep habitats, which potentially functioned as over wintering sites (Lamprecht and Shelton 1986; Jackson and Hightower 2001; Jackson et al. 2002; Young and Isely 2002) because they likely provide warmer water temperatures preferred during this time of the year. For example, adult Striped Bass in Lake Whitney, Texas occupied areas with water temperatures warmer (mean range 7.4-11.2°C) than mean surface temperatures (4.0 - 9.5°C) during winter months (Farquhar and Gutreuter1989). Also, Gulf-strain Striped Bass in the Apalachicola River system avoided cold waters during winter by occupying spring-fed areas with mean temperatures ranging from 14.6-16.2°C while mean ambient water temperatures were 5-8°C (Van Den Avyle and Evans 1990).

Across both years of this study juvenile and adult Gulf-strain Striped Bass consistently selected habitat that was usually deeper with significantly lower DO concentrations than the overall mean river condition. Although DO levels at fish sub-habitats were lower than the mean river conditions, concentrations were always greater than 5.12 mg/L. During the 2013-2014 winter season, other significant differences between habitat types indicated Gulf-strain Striped Bass consistently selected habitats that were, on average, warmer with higher salinity, specific conductivity, and pH. These preferred abiotic conditions may be attributed to the region of the river fish were found or annual variability in river discharge and gage height. The majority of Gulf-strain Striped Bass, regardless of size, occupied sub-habitats in the mid- to lower regions of the Biloxi River. Juvenile sub-habitats were mostly located in the mid-region of the Biloxi River, which ranged about ± 2.50 rkm above and below the release site. Striped Bass stocked at different stages have shown similar behavior; for example, fingerling Atlantic Striped Bass stocked in Tennessee's Watts Bar reservoir remained within the area in which they were released (Van Den Avyle and Higginbotham1980), which supports the general patterns noted in the Biloxi River. However, roughly half of the juveniles in my study moved downstream following the release. Post-stocking downstream flight response upon release has also been observed in other southern rivers (Carmichael et al.1998) and reservoirs (Jackson and Hightower 2001).

Winter manual tracking events only located individuals from both life stage during Telemetry Trial II; thus, size effects for winter sub-habitat conditions was only evaluated for the 2013-2014 winter season. All abiotic conditions measured, except pH, at juvenile and adult Gulf-strain Striped Bass habitats were significantly different. Adults were more abundant in the lower region of the Biloxi River which may be attributed to wintering in deep, warm habitats; similar Striped Bass wintering habitats have been reported for southern rivers Van Den Avyle and Evans 1990; Bjorgo et al. 2000) and lakes (Farquhar and Gutreuter 1989).

Spring patterns

During spring, juvenile and adult Gulf-strain Striped Bass were widely distributed throughout my study area, with the exception of the Little Biloxi River. It was interesting that a juvenile was detected in the Tchoutacabouffa River since others have reported that stocked Striped Bass usually remain in the system in which they were released (Frugé et al. 2006). This wide distribution may have been attributed to increased movement rates that corresponded with periods of changing limnological conditions (Cheek et al. 1985; Farquhar and Gutreuter 1989; Wilkerson and Fisher 1997; Young and Isely 2002) driven, in part, by annual discharge differences. Others have attributed higher movement rates and large horizontal movements of adult Striped Bass to spawning migratory behavior during spring (Braschler et al. 1988, Henley 1998; Schaffler et al. 2002). Gulf-strain Striped Bass have been documented making spawning migrations in southeastern rivers from early April to late May (Dudley et al. 1977). While low levels of successful natural reproduction have been documented in the Apalachicola-Chattahoochee-Flint River system in Florida, Georgia, and Alabama (Long et al. 2013), natural reproduction has not been reported for Gulf-strain Striped Bass in Mississippi waters (Frugé et al. 2006). Thus, it is more likely that the Biloxi River population of Striped Bass had a wide range due limnological conditions and/or varying discharge conditions.

Annual comparisons of Gulf-strain Striped Bass sub-habitat types for spring seasons indicated significant difference for both years. Manual tracking occurred during flashy river conditions experienced mid-season, as well as after discharge and gage height peaked in early May. Variable river conditions would have likely caused spatially homogeneous and vertical abiotic gradient conditions; however, fish sub-habitats had significantly different limnological conditions than the rest of the river. During spring 2013, juvenile and adult Gulf-strain Striped Bass were concentrated in the upper Biloxi River region in similar sub-habitat conditions that consisted of the highest mean DO concentrations and coolest water temperatures available. These habitats were similar to those documented for Striped Bass in southern reservoirs and coastal river systems (Schaffler et al. 2002; Van Den Avyle and Evans 1990; Bjorgo et al. 2000). Conversely, however, sub-adults in freshwater quarry lakes occupied the warmest waters available during spring and fall (Coutant and Carroll 1980). Similarly, juvenile Striped Bass (80-300 mm TL) in a laboratory study preferred warmer temperatures (above 26°C) during spring and summer (Coutant et al. 1984). Likewise, during spring 2014, juvenile Gulf-strain Striped Bass sub-habitat conditions in the Biloxi River were primarily associated with deep areas in the mid- and lower regions characterized by warmer water temperatures, lower DO (although above 5 mg/L), and higher salinity.

Summer patterns

Juvenile and adult Gulf-strain Striped Bass were widely disbursed throughout my study area. This observation was not in agreement with predictions from a biogenetics model that proposed lower regions of Biloxi Back Bay estuary (i.e., areas east of Big Lake and Little Big Lake that were not monitored for this study) were the primary areas able to support positive growth rate potential for juveniles and adults during the summer (Dieterich and Fulford 2012). Moreover, receiver detections from my study showed juveniles and adults frequented habitats in the upper and lower regions of the Biloxi River. Although abiotic conditions in these regions were sub-optimal, mean temperature and DO concentrations remained within tolerable limits and were closer to the preferred range than the mean river conditions. This observed preference towards opposite regions of the Biloxi River suggest Gulf-strain Striped Bass were actively searching for tolerable conditions, potentially as a means to limit exposure in warm temperatures while accessing areas with the highest DO concentrations available (Thompson et al. 2010). The geomorphology and general openness of the lower region of the Biloxi River study area may have had high DO concentrations due to through mixing of surface waters via wind-driven circulation (Dieterich and Fulford 2012). Also, lower regions of the Biloxi River were associated with deep habitats, which potentially provided assess to cooler water temperatures. Likewise, in the upper region, the Little Biloxi River may have been a cool water refuge for adult Gulf-strain Striped Bass during the summer (sensu Jackson et al. 2002). Other telemetry studies in southeastern reservoirs reported that Striped Bass moved downstream to selected habitats in lower embayment areas during mid-summer (Matthews et al. 1989; Farquhar and Gutreuter 1989; Schaffler et al. 2002). Other riverine and reservoir populations of Striped Bass have been documented making upstream migrations during summer in an effort to occupy coolest water temperatures available (Wilkerson and Fisher 1977; Dudely et al. 1977; Cheek et al. 1985; Bjorgo et al. 2000). However, Striped Bass have frequently been reported occupying summer habitats with above optimal temperatures and adequate DO concentrations for extended durations sometimes lasting up to one month (Combs and Peltz 1982; Matthews et al. 1985; Zale 1985; Farquhar and Gutreuter 1989; Young and Isely 2002). It has also been hypothesized that Gulf-strain Striped Bass inherently have increased tolerance for higher water temperatures than their Atlantic Striped Bass counterparts (Wirgin et al. 1991) due to extended isolation in southeastern riverine habitats with higher temperatures than the

Mid-Atlantic (Coutant 2013). However, there is concern with the decadal mixed-genetic strain stocking of GOM coastal drainages and the potential role it may play in thermal ecology (Long et al. 2013) and thus movement patterns. Furthermore, periods of increased flow due to episodic rain events in July and August may have also influenced Gulf-strain Striped Bass movements in the Biloxi River as the upper region and the Little Biloxi River were frequented by adults during summer. The presence of the adult Gulf-strain Striped Bass in the Little Biloxi River occurred when river gage height and discharge peaked for the summer season in the Biloxi River. Similarly, adults in the upper Alabama River moved upstream, towards higher turbulence during intense flow conditions (Lamprechet and Shelton 1986). Additionally, increased gage height and associated greater depths could have made shallow portions in the upper region of the Biloxi River passable and accessible to adults. For example, Striped Bass movements in the Ohio River were oriented upstream and associated with higher water periods during summer (Henley 1991).

Juvenile and adult summer sub-habitat conditions were similar despite having known ontogenetic shifts in thermal requirements. Typically, juveniles have a higher tolerance of warm waters (Matthews et al. 1989), and adults tend to select cooler temperatures than juveniles (Coutant 2013). Differences in selected habitats were minimal because the Biloxi River had similar mean conditions throughout the study area during summer.

Summary

Gulf-strain Striped Bass sub-habitats were significantly different than mean river abiotic conditions during fall 2012, as well as both winter and springs seasons for this telemetry study. Results suggested that DO concentrations, depth and water temperature conditions in the Biloxi River strongly influenced Gulf-strain Striped Bass habitat selection during fall, winter and spring seasons. During the cooler seasons (i.e., fall and winter), deeper areas with warmer temperatures had a greater influence on habitat selection than DO concentration, which were consistently lower than the mean river DO concentration but were always greater than 5 mg/L at fish sub-habitats. During the spring season, mean DO concentrations were greater than 7 mg/L at fish sub-habitats; these concentrations were lower than the mean river DO concentration during spring 2014 due to extreme flashy discharge conditions that likely facilitated increased mixing and high DO concentrations throughout the Biloxi River. Depth at selected fish sub-habitats were deeper in both spring seasons; water temperature in spring 2014 may have been nearly the same as the mean river water temperature condition due to intense flashy discharge episodes that likely caused homogeneous abiotic conditions throughout the river. Summer sub-habitats of Gulf-strain Striped Bass were not significantly different than the mean river abiotic condition nor by size. Juvenile and adults occupied sub-habitats characterized by abiotic conditions that were nearly the same as other habitats throughout the Biloxi River during the summer. Sub-habitat locations of Gulf-strain Striped Bass mainly occurred in deep areas within the upper and lower regions of the Biloxi River that were characterized by average DO concentrations greater than 5 mg/L and water temperature of about 27.5°C. Moderately variable discharge occurred mid-summer, which may have been severe enough to breakup vertically and spatially stratified abiotic environmental conditions typically characteristic of the summer season.

Juvenile and adult Gulf-strain Striped Bass sub-habitats also varied by season. During fall and winter, juvenile and adult Gulf-strain Striped Bass sub-habitat selection was likely influenced by salinity, specific conductivity, depth, and water temperature conditions as these variables were frequently associated with size-class sub-habitat differences. For fall (both telemetry trials) and winter 2013-2014, adult Gulf-strain Striped Bass were consistently located in deeper habitats with higher salinity and specific conductivity conditions than juveniles. Moreover, adults occupied cooler water temperatures in the fall and warmer temperatures in winter; whereas, juveniles were located in warmer waters in fall and cooler areas in winter. Of course water temperature and salinity are largely influenced by depth; however, differences between water temperature and depth at juvenile and adult sub-habitats were not always significant. Therefore, habitat selection in fall and winter was strongly influenced by salinity and specific conductivity as these variables were consistently significantly different for juvenile and adult sub-habitats.

REFERENCES

Ahrens, R.N.M., and W.E. Pine. 2014. Informing recovery goals based on historical population size and extant habitat: A case study of the Gulf Sturgeon. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science [online serial] 6(1):274-286.

Bettoli, P.W. 2005. The fundamental thermal niche of adult landlocked Striped Bass. Transactions of the American Fisheries Society 134:305-314.

Bjorgo, K.A, J.J. Isely, and C.S. Thomason. 2000. Seasonal movements and habitat use of Striped Bass in the Combahee River, South Carolina. Transactions of the American Fisheries Society 129:1281-1287.

Braschler, D.W., M.G. White, and J.W. Foltz. 1989. Movements and habitat selection of Striped Bass in the Santee-Cooper reservoirs. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 42:27-34.

Carmichael, J.T., S.L. Haeseker, and J.E. Hightower. 1998. Spawning migration of telemetered Striped Bass in the Roanoke River, North Carolina. Transactions of the American Fisheries Society 127:286-297.

Cheek, T.E., M.J. Van Den Avyle, and C.C. Coutant. 1985. Influences of water quality on distribution of Striped Bass in a Tennessee River impoundment. Transactions of the American Fisheries Society 114:67-76.

Combs, D.L., and L.R. Peltz. 1982. Seasonal distribution of Striped Bass in Keystone Reservoir, Oklahoma. North American Journal of Fisheries Management 2:66-73.

Coutant, C.C. 1985. Striped bass, temperature, and dissolved oxygen: A speculative hypothesis on environmental risk. Transactions of the American Fisheries Society 114:31-61.

Coutant, C.C. 2013. When is habitat limiting for Striped Bass? Three decades of testing the temperature-oxygen squeeze hypothesis. Pages 65-91 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Coutant, C.C., and D.S. Carroll. 1980. Temperatures occupied by ten ultrasonic-tagged Striped Bass in freshwater lakes. Transactions of the American Fisheries Society 113:666-671.

Coutant, C.C., K.L. Zachmann, D.K. Cox, and B.L. Pearman. 1984. Temperature selection by juvenile Striped Bass in laboratory and field. Transactions of the American Fisheries Society 113:666-671.

Crance, J.H. 1984. Habitat Suitability Index Models and In-Stream Flow Suitability Curves: Inland Stocks of Striped Bass. U.S. Fish and Wildlife Service OBS-82/10.85. 63p.

Dieterich, J.W., and R.S. Fulford. 2012. Habitat suitability modeling to evaluate conservation and enhancement efforts for Gulf-strain Striped Bass in Mississippi coastal rivers. Transactions of the American Fisheries Society 141:731-746.

Dudley, R.G., A.W. Mullins, and J.W. Terrell. 1977. Movements of adult Striped Bass *Morone saxatilis* into the Savannah River, Georgia. Transactions of the American Fisheries Society 106:314-322.

Farquhar, B.W., and S. Gutreuter. 1989. Distribution and migration of adult Striped Bass in Lake Whitney, Texas. Transactions of the American Fisheries Society 118:523-532.

Field, A. 2005. *Discovering Statistics Using SPSS*, 2nd ed. Sage Publications, London. 771p.

Frugé, D.J., M. Bailey, J. Mareska, L.C. Nicholson, H. Rogillio, E. Long, J.T. Jenkins, J.M. Barkuloo, P. Cooper, Jr., I. Wirgin, and R. Weller. 2006. The Striped Bass Fishery of the Gulf of Mexico, United States: A Regional Management Plan. Gulf States Marine Fisheries Commission No. 137, Ocean Springs, Mississippi. 363p + 14 Appendixes.

Hair, J.F. Jr., R.E. Anderson, R.L. Tatham, and B.J. Grablowsky. 1984. *Multivariate Data Analysis with Readings*. Macmillan Publishing Co., New York. 360p.

Henley, D.T. 1991. Seasonal movements and distribution of Striped Bass in the Ohio River. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 45:370-384.

Jackson, J.R., and J.E. Hightower. 2001. Reservoir Striped Bass movements and site fidelity in relation to seasonal patterns in habitat quality. North American Journal of Fisheries Management 21:34-45.

Jackson, D.C., E.D. Dibble, and J.F. Mareska. 2002. Location of thermal refuge for Striped Bass in the Pascagoula River. Journal of Mississippi Academy of Sciences 2:106-114.

Kerr, J.T., and I. Deguise. 2004. Habitat loss and the limits to endangered species recovery. Ecology Letters 7:1163-1169.

Kessel, S.T., S.J. Cooke, M.R. Heupel, N.E. Hussey, C.A. Simpfendorfer, S. Vagle, and A.T. Fisk. 2014. A review of detection range testing in aquatic passive acoustic telemetry studies. Reviews in Fish Biology and Fisheries 24:199-218.

Lamprecht, S.D., and W.L. Shelton. 1988. Spatial and temporal movements of Striped Bass in the upper Alabama River. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 40:266-274.

Long, E.A., C.L. Mesing, K.J. Herrington, R.R. Weller, and I.I. Wirgin. 2013. Restoration of Gulf Striped Bass: lessons and management implications. Pages 25-63 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Lopez, J.D., M.S. Peterson, J. Walker, G.L. Grammer, and M.S. Woodrey. 2011. Distribution, abundance, and habitat characterization of the Saltmarsh Topminnow, *Fundulus jenkinsi* (Everman 1892). Estuaries and Coasts 34:148-158.

Matthews, W.J. 1985. Summer mortality of Striped Bass in reservoirs of the United States. Transactions of the American Fisheries Society 114:62-66.

Matthews, W.J., L.G. Hill, D.R. Edds, and F.P. Gelwick. 1989. Influence of water quality and season on habitat use by Striped Bass in a large southwestern reservoir. Transactions of the American Fisheries Society 118:243-250.

Merriman, D. 1941. Studies on the Striped Bass (*Roccus saxatilis*) of the Atlantic Coast. U.S. Fish and Wildlife Service Fishery Bulletin 50:1-77.

Mickle, P.F., S.F. Schaefer, S.B. Adams, and B.R. Kreiser. 2010. Habitat use of age 0 Alabama Shad in the Pascagoula River drainage, USA. Ecology of Freshwater Fish 19:107-115.

Moss, J.L. 1985. Summer selection of thermal refuges by Striped Bass in Alabama reservoirs and tailwaters. Transactions of the American Fisheries Society 114:77-83.

Payne, N.L., B.M Gillanders, D.M. Webber, and J.M. Semmens. 2010. Interpreting diel activity patterns from acoustic telemetry: the need for controls. Marine Ecology Progress Series 419:295-301.

Phalen, P.S., R.J. Muncy, and T.K. Cross. 1988. Hybrid Striped Bass movements and habitat in Ross Barnett Reservoir, Mississippi. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 42:35-43.

Rice, J.A., J.S. Thompson, J.A. Skyes, and C.T. Waters. 2013. The role of metalimnetic hypoxia in Striped Bass summer kills: consequences and management implications. Pages 121-145 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Schaffler, J.A., J.J. Isely, and W.E. Hayes. 2002. Habitat use by Striped Bass in relation to seasonal changes in water quality in a southeastern reservoir. Transaction of the American Fisheries Society 131:817-827.

Thompson, J.S., J.A. Rice, and D.S. Waters. 2010. Striped bass habitat selection rules in reservoirs without suitable summer habitat offer insight into consequences for growth. Transactions of the American Fisheries Society 139:1450-1464.

Van Den Avyle, M.J., and B.J. Higginbotham. 1980. Growth, survival and distribution of Striped Bass stocked into Watts Bar Reservoir, Tennessee. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 33:361-370.

Van Den Avyle, M.J., and J.W. Evans. 1990. Temperature selection by Striped Bass in a Gulf of Mexico coastal river system. North American Journal of Fisheries Management 10:58-66.

Wilkerson, M.L., and W.L. Fisher. 1997. Striped bass distribution, movements, and site fidelity in Robert S. Kerr Reservoir, Oklahoma. North American Journal of Fisheries Management 17:677-686.

Wirgin, I.I., C. Grunwald, S.J. Garte, and C. Messing. 1991. Use of DNA fingerprinting in the identification and management of a Striped Bass population in the southeastern United States. Transactions of the American Fisheries Society 120:273-282.

Wooley, C.M., and E.J. Crateau. 1983. Biology, population estimates, and movement of native and introduced Striped Bass, Apalachicola River, Florida. North American Journal of Fisheries Management 3:383-394.

Young, S.P., and J.J. Isely. 2002. Striped bass annual site fidelity and habitat utilization in J. Strom Thurmond Reservoir, South Carolina-Georgia. Transactions of the American Fisheries Society 131:828-837.

Zale, A.V., J.D. Wiechman, R.L. Lochmiller, and J. Burroughs. 1990. Limnological conditions associated with summer mortality of Striped Bass in Keystone Reservoir, Oklahoma. Transactions of the American Fisheries Society 119:72-76.

CHAPTER IV

CONCLUSIONS

Striped Bass have been stocked in coastal drainages along the northern Gulf of Mexico (GOM) since the late 1960s in an effort to reestablish and maintain self-sustaining populations in their native southern range (Frugé et al. 2006). However, despite nearly half a century of stock enhancement activities, the majority of GOM Striped Bass populations have not recovered beyond small put-grow-and-take fisheries (Frugé et al. 2006; Callihan et al. 2015). Early stocking efforts potentially facilitated thermal ecology issues because mixed genetic-strains of Striped Bass were stocked in coastal rivers of the GOM for over a decade (Long et al. 2013). Moreover, successful restoration of Gulf-strain Striped Bass may be inhibited because of release practices with inadequate knowledge of post-stocking fish behavior coupled with seasonally-marginal habitats in GOM drainages (Dieterich and Fulford 2012; Long et al. 2013).

Advances in acoustic telemetry have facilitated research that focuses on habitat use and movement patterns of tagged animals. By implementing telemetry equipment accompanied with passive and active manual tracking techniques for this study, I was able to gain insight about seasonal habitat selection and distribution patterns of both feral adults and hatchery-reared juveniles immediately post-stocking and over a 20 month period under different flow regimes. Acoustically-tagged juvenile hatchery-reared Gulf-strain Striped Bass initially selected sub-habitats that were deeper areas with warmer temperatures, and slightly higher salinity compared to randomly-sampled areas within the Biloxi River, suggesting juveniles used these areas as refuge from stress associated with stocking procedures and unpredictable abiotic variation in a lotic environment. In the long term, acoustically-tagged juvenile hatchery-reared and feral adult Gulf-strain Striped Bass showed seasonal and annual variability in habitat selection which was strongly influenced by seasonally variable DO concentrations and water temperature conditions at depth in the Biloxi River and these variables were consistently delineated as significant over the 20 month period, except during summer. However, within a season, and, in particular, within the summer/fall transitional period, juvenile and adult sub-habitat selection was influenced by spatially-heterogeneous and vertical gradients of increased salinity at depth along the river continuum which I interpreted as being attributed to the lack or reduction of appropriate deep, saline thermal habitat in all regions of the Biloxi River. Dispersal patterns of Gulf-strain Striped Bass varied by life stage with adults generally dispersed over a much wider range throughout the study area from the narrow upper reaches of the Little Biloxi River to the open areas of Big Lake. Juveniles initially remained concentrated near the stocking site; however, as fish grew and became acclimatized to the lotic environment over the 20 month study period they dispersed into other regions of the Biloxi River. My findings suggest that both hatchery-reared juvenile and feral adult Gulf-strain Striped Bass were able to overcome seasonal habitat limitations in the Biloxi River by seeking refugia needed for their physiological requirements.

REFERENCES

Callihan, J.L., C.H. Godwin, K.J. Dockendorf, and K.A. Buckel. 2015. Growth and mortality of hatchery-reared Striped Bass stocked into nonnatal systems. North American Journal of Fisheries Management 34:1131-1139.

Dieterich, J.W., and R.S. Fulford. 2012. Habitat suitability modeling to evaluate conservation and enhancement efforts for Gulf-strain Striped Bass in Mississippi coastal rivers. Transactions of the American Fisheries Society 141:731-746.

Frugé, D.J., M. Bailey, J. Mareska, L.C. Nicholson, H. Rogillio, E. Long, J.T. Jenkins, J.M. Barkuloo, P. Cooper, Jr., I. Wirgin, and R. Weller. 2006. The Striped Bass Fishery of the Gulf of Mexico, United States: A Regional Management Plan. Gulf States Marine Fisheries Commission No. 137, Ocean Springs, Mississippi. 363p + 14 Appendixes.

Long, E.A., C.L. Mesing, K.J. Herrington, R.R. Weller, and I.I. Wirgin. 2013. Restoration of Gulf Striped Bass: lessons and management implications. Pages 25-63 *in* J.S. Bulak, C.C. Coutant, and J.A. Rice, editors. Biology and management of inland Striped Bass and hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

APPENDIX A

INSTITUTIONAL AMIMAL CARE AND USE COMMITTEE NOTICE OF COMMITTEE ACTION

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

Institutional Animal Care and Use Committee

118 College Drive #5147
Hattiesburg, MS 39406-0001
Phone: 601.266.4063
Fax: 601.266.4377

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE NOTICE OF COMMITTEE ACTION

AMENDMENT NOTIFICATION

The *proposal amendment* noted below was reviewed and approved by The University of Southern Mississippi Institutional Animal Care and Use Committee (IACUC) in accordance with regulations by the United States Department of Agriculture and the Public Health Service Office of Laboratory Animal Welfare. The project expiration date is noted below. If for some reason the project is not completed by the end of the three year approval period, your protocol must be reactivated (a new protocol must be submitted and approved) before further work involving the use of animals can be done.

Any significant changes (see attached) should be brought to the attention of the committee at the earliest possible time. If you should have any questions, please contact me.

PROTOCOL NUMBER:	**10100101**
PROJECT TITLE:	**Striped Bass Restoration for the MS Gulf**
PROPOSED PROJECT DATES:	**9/2010 – 9/2013**
AMENDMENT NUMBER:	**2**
PRINCIPAL INVESTIGATOR(S):	**Mark Peterson**
DEPARTMENT:	**Coastal Sciences/COST**
FUNDING AGENCY/SPONSOR:	
IACUC COMMITTEE ACTION:	**Designated Member Review (Jodie Jawor)**
PROTOCOL EXPIRATON DATE:	**9/30/2013**

Frank Moore, Ph.D.
IACUC Chair

THE UNIVERSITY OF
SOUTHERN MISSISSIPPI

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE
118 College Drive #5116 | Hattiesburg, MS 39406-0001
Phone: 601.266.4063 | Fax: 601.266.4377 | iacuc@usm.edu | www.usm.edu/iacuc

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE NOTICE OF COMMITTEE ACTION

The proposal noted below was reviewed and approved by The University of Southern Mississippi Institutional Animal Care and Use Committee (IACUC) in accordance with regulations by the United States Department of Agriculture and the Public Health Service Office of Laboratory Animal Welfare. The project expiration date is noted below. If for some reason the project is not completed by the end of the three year approval period, your protocol must be reactivated (a new protocol must be submitted and approved) before further work involving the use of animals can be done.

Any significant changes (see attached) should be brought to the attention of the committee at the earliest possible time. If you should have any questions, please contact me.

PROTOCOL NUMBER:	**10100101**
PROJECT TITLE:	**Striped Bass Restoration for the Mississippi Gulf Coast**
PROPOSED PROJECT DATES:	**9/2013 – 9/ 2015**
PROJECT TYPE:	**Renewal**
PRINCIPAL INVESTIGATOR(S):	**Mark Peterson**
DEPARTMENT:	**Coastal Sciences**
FUNDING AGENCY/SPONSOR:	**CIAP, Wallop-Breaux USFWS**
IACUC COMMITTEE ACTION:	**Full Committee Approval**
PROTOCOL EXPIRATON DATE:	**September 30, 2015**

F. R. Moore

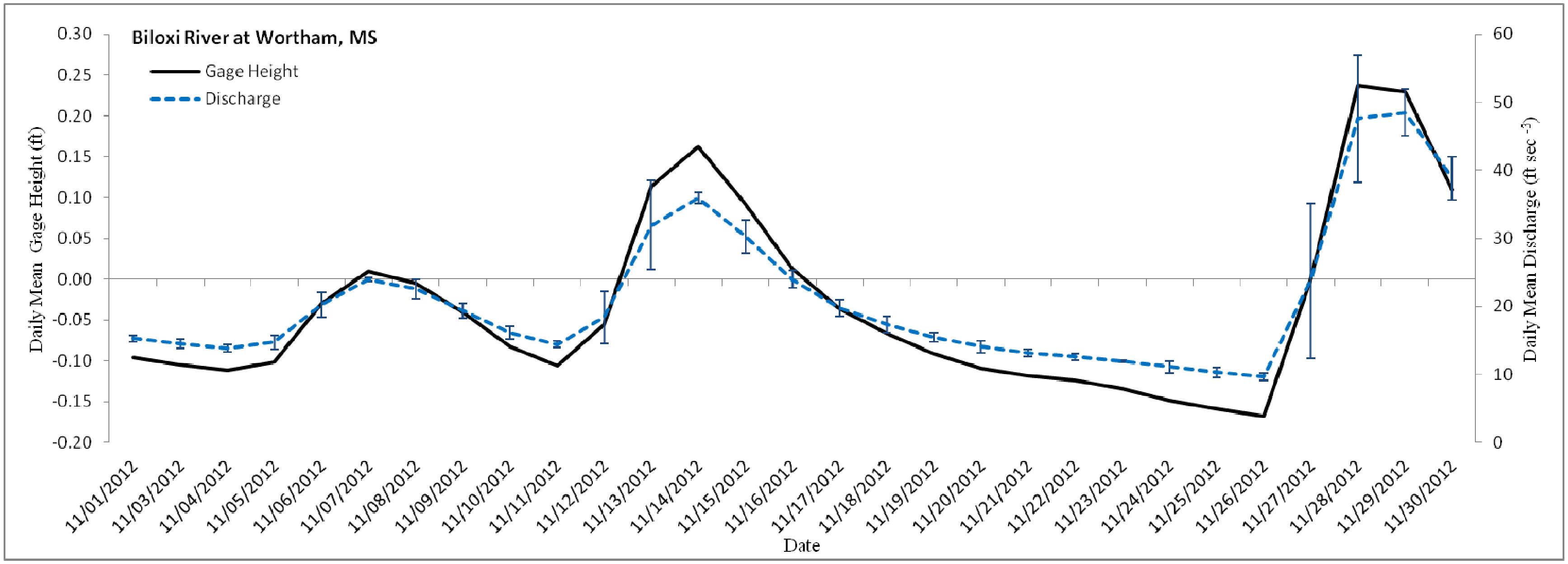
Frank Moore, Ph.D.
IACUC Chair

Date 10-21-2013

APPENDIX B

NOVEMBER 2012 DISCHARGE AND GAGE HEIGHT IN BILOXI RIVER AT WORTHAM, MS

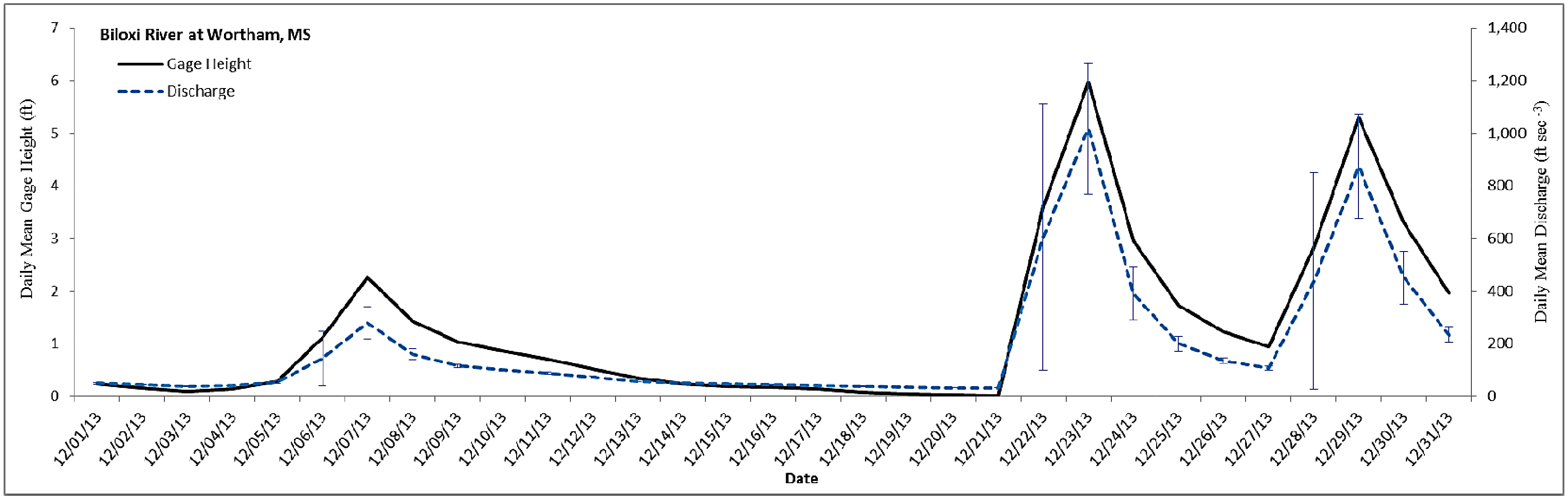
Daily mean gage height (ft; solid line) on the primary y-axis and daily mean discharge (ft sec $^{-3}$; dashed line) on the secondary y-axis for the Biloxi River at the Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov) located approximated 12 river km above the study area. During November 2012, telemetered juvenile Gulf-strain Striped Bass were released in the Biloxi River, MS on 11/6/12. Manual tracking occurred on 11/7/12, 11/10/12, and 11/21/12, and the mean river abiotic condition was sampled on 11/9/12. In general, the gage height and discharge levels were variable throughout November, with peaks in gage height and discharge reached during the middle and end of the month.



APPENDIX C

DECEMBER 2013 DISCHARGE AND GAGE HEIGHT IN BILOXI RIVER AT WORTHAM, MS

Daily mean gage height (ft; solid line) on the primary y-axis and daily mean discharge (ft sec $^{-3}$; dashed line) on the secondary y-axis for the Biloxi River at the Wortham, MS (U.S.G.S monitoring station 02481000; http://waterdata.usgs.gov) located approximated 12 river km above the study area. During December 2013, telemetered juvenile Gulf-strain Striped Bass were released in the Biloxi River, MS on 12/10/13. Manual tracking occurred on 12/11/13, 12/13/13, and 12/25/13. The mean river abiotic condition was sampled on 12/12/13 and again on 12/25/13. Increased precipitation and runoff due to severe local weather events at the end of the month caused river discharge and gage height to peak, which subsequently resulted in homogeneous abiotic conditions within the water column and throughout the river that lasted until the end of December.



APPENDIX D

ANOVA SUMMARY TABLE FOR NOVEMBER 2012 AND DECEMBER 2013

Summary table of ANOVA results for November 2012 and early December 2013 datasets. Games-Howell pairwise comparisons identified significant responses (in bold) between sub-habitat conditions and the mean river abiotic condition, as well as significant differences (in bold) among sub-habitat conditions for each tracking day (d). Interpretation of post hoc comparisons is based on grand mean values recorded during each sampling event. Rdm = random. DO = dissolved oxygen concentration.

Month	Principal component (% variance explained)	Brown-Forsythe *F*-ratio	Games-Howell post hoc comparisons	Significance level	Interpretation* (*reference Table 2.2 for mean ± SEM)
November	I (54.22%)	**$F_{3, 44.80} = 43.23$, $p < 0.01$**	40 Rdm vs. 1 d	**$p < 0.01$**	1 d > 40 Rdm depth and temperature; 1 d < 40 Rdm DO
			40 Rdm vs. 4 d	**$p < 0.01$**	4 d > 40 Rdm depth and temperature; 4 d < 40 Rdm DO
			40 Rdm vs. 15 d	**$p = 0.02$**	15 d > 40 Rdm depth and DO; 15 d < 40 Rdm temperature
			1 d vs. 4 d	$p = 0.16$	1 d > 4 d depth, temperature and DO
			1 d vs. 15 d	**$p < 0.01$**	1 d > 15 d depth and temperature; 1 d < 15 d DO
			4 d vs. 15 d	**$p < 0.01$**	4 d > 15 d depth and temperature; 4 d < 15 d DO
	II (34.54%)	$F_{3,5.65} = 4.91$, $p = 0.05$			

Appendix D (continued).

Month	Principal component (% variance explained)	Brown-Forsythe *F*-ratio	Games-Howell post hoc comparisons	Significance level	Interpretation* (*reference Table 2.2 for mean ± SEM)
December	I (56.19%)	$\boldsymbol{F_{2, 64.97} = 8.76, p < 0.01}$	40 Rdm vs. 1 d	$\boldsymbol{p < 0.01}$	1 d > 40 Rdm depth and temperature, but salinity values were comparable
			40 Rdm vs. 3 d	$p = 0.12$	Although not significant 3 d > 40 Rdm salinity, and depth and temperature values were comparable
			1 d vs. 3 d	$p = 0.14$	Although not significant 3 d > 1 d salinity, and depth and temperature values were comparable
	II (24.91%)	$\boldsymbol{F_{2, 37.92} = 19.95, p < 0.01}$	40 Rdm vs. 1 d	$\boldsymbol{p < 0.01}$	1 d > 40 Rdm DO and pH
			40 Rdm vs. 3 d	$\boldsymbol{p < 0.01}$	3 d < 40 Rdm DO and pH
			1 d vs. 3 d	$\boldsymbol{p < 0.01}$	3 d < 1 d DO and pH