ABSTRACT

OAKLEY, NATHANIEL COREY. Status of shortnose sturgeon, *Acipenser brevirostrum*, in the Neuse River, North Carolina. (Under the direction of Joseph E. Hightower)

The purpose of the research was to determine if shortnose sturgeon, *Acipenser brevirostrum*, occur within the Neuse River, North Carolina. Shortnose sturgeon historically occurred in most major Atlantic Coast rivers from Saint Johns River, New Brunswick, Canada to St. Johns River, Florida. Anecdotal evidence suggests that a population of shortnose sturgeon once occurred in the Neuse River, North Carolina, but their current status was unknown. In compliance with the National Marine Fisheries Service shortnose sturgeon sampling protocol, a two-year intensive gillnet survey was conducted in order to determine the population status of shortnose sturgeon within the Neuse River. Habitat surveys showed that the lower Neuse River, where shortnose sturgeon would be expected to occur during summer, was severely hypoxic in June - September of 2001 - 2002. No shortnose sturgeon were observed during the two-year survey (> 200 h of netting effort) although four juvenile Atlantic sturgeon were encountered. These two species occupy similar habitats in other river systems. A juvenile Atlantic sturgeon tagged with a transmitter moved upstream of the unsuitable habitat and remained in a restricted area until late fall, when water quality improved due to increased flows and lower temperatures.

The probability of detection for varying population sizes of shortnose sturgeon was calculated in order to determine if adequate sampling had been completed to conclude an absence of shortnose sturgeon in the Neuse River. The detection analysis stated that a population size of 50 or more individuals should be detected in 200 h of netting effort. Therefore, based on our sampling efforts, we hypothesize that shortnose sturgeon are

extirpated from the Neuse River. We believe that poor water quality is a key factor in the extirpation of shortnose sturgeon in the Neuse River. Population recovery may be impossible until habitat quality can be improved.

Finally, we observed that shortnose sturgeon have a disjunct distribution with an absence spanning from Chesapeake Bay to Pamlico Sound tributaries. Logistic regression models based on river characteristics were developed to help predict presence of shortnose sturgeon within a river system. River characteristics included in the models: total length, estimated watershed area above the fall line, and distance to the first dam. These characteristics described size of the river system, available spawning habitat, and blockage to spawning migration. Current models suggested that large river systems with sufficient spawning habitat and no blockages to migration are more likely to contain a population of shortnose sturgeon. The models predict that the Neuse River should contain a population of shortnose sturgeon; therefore, leading to further evidence that poor water quality within the Neuse River may be the key factor to the recovery of the species.

STATUS OF SHORTNOSE STURGEON, *ACIPENSER BREVIROSTRUM*, IN THE NEUSE RIVER, NORTH CAROLINA

by
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-Dedicated to my parents, Richard and Janice-

Thank you for raising me in the admonition of our Lord Jesus Christ, giving me a loving home, teaching me how to be a man, and instilling my deep love for nature.

Biography

I was born on September 15, 1979 in the small coastal town of New Bern, North Carolina. My parents taught me to work hard, love my family, and most importantly honor the Lord in everything. I am thankful for the time I spent in New Bern. It was there that I fell in love with the water and the natural world. I remember as a young boy, my father taking me to Lawson's Creek to go fishing on sunny Saturday afternoons. As I matured, my father and I became best friends and spent many days fishing along the Neuse River. My love for fishing grew into a passion for conserving our natural resources.

After graduating from West Craven High School in the spring of 1997, I looked forward to attending North Carolina State University. I soon learned of the fisheries and wildlife program at NCSU. Dr. Richard Noble was the first person I met in fisheries. I remember leaving the meeting inspired to become a fisheries biologist. Rich and I have spent many hours discussing fisheries and why fishing can be so difficult at times. Rich soon became a mentor, advisor, and a good friend. In December 2000, I graduated from NCSU with a bachelor's degree in Fisheries and Wildlife Science.

I entered the fisheries and wildlife graduate program at NCSU in January 2001. Dr. Joseph Hightower invited me to work on endangered species conservation in the Neuse River. I could not pass on the opportunity to work on the river where I grew up fishing, and the opportunity to make a difference in the resource that I fell in love with as a child. Joe has been a great mentor and has taught me valuable lessons over the past two years. Completion of this project has allowed me to grow as a biologist. As I seek employment, I know the lessons that I have learned here at NCSU will benefit me as an individual.

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I thank E. Lin Peterson, III, Jennifer Scott, and Roy Coggin for their work as field technicians, without their arduous work completion of the project would have been impossible. I would also like to thank Donald Heath, Dave Hewitt, Ed Malindzak, Bill Pine, Rob Aguilar, Bob Barwick, Steve West, and Richard Oakley for volunteering when I needed them the most. We thank commercial fishermen Ed McGovern, Jr. and Richard Lamb for capturing and reporting sturgeon through our sturgeon reward program. I would personally like to recognize my committee for all their hard work and patience throughout the project. Finally, I thank the U.S. Fish and Wildlife Service and NC Beautiful for funding this project.

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CHAPTER ONE

GENERAL INTRODUCTION

The anadromous shortnose sturgeon (*Acipenser brevirostrum*) occupies coastal rivers and estuaries along the Atlantic Coast (Gilbert 1989). Because of declines in abundance and extirpation from some river systems, the U.S. Fish and Wildlife Service listed the shortnose sturgeon as an endangered species in 1967 (National Marine Fisheries Service 1998). Presently, shortnose sturgeon are known to occur in the following northern rivers: Saint John, Penobscot, Kennebec system, Merrimack, Connecticut, Hudson, and Delaware (Dadswell 1979; Hastings et al 1987; Kieffer and Kynard 1996; Bain 1997; National Marine Fisheries Service 1998). Southern populations are known to occur in the following rivers: Cape Fear, Winyah Bay system, Santee-Cooper, Ashepoo-Combahee-Edisto (ACE) system, Savannah, Ogeechee, and Altamaha (Moser and Ross 1995; Rogers and Weber 1995; Collins and Smith 1997; National Marine Fisheries Service 1998).

Shortnose sturgeon vary greatly in abundance in northern rivers, from estimated population sizes of less than 100 (Merrimack River) to greater than 38,000 (Hudson River) individuals (Kynard 1997). Southern populations are relatively small with estimated adult population sizes ranging from less than 100 (Cape Fear River) to greater than 1,600 (Savannah River) individuals (Kynard 1997). Southern rivers north of the Cape Fear to the Delaware have no known populations of shortnose sturgeon.

Historical fishery

Sturgeon were once common in coastal rivers of North Carolina. John Lawson, in 1709, wrote, "Of the sturgeon we have plenty, all the fresh parts of our rivers being well stored therewith" (Lawson 1709; Smith 1907). During the mid- to late- 1800s, the haul seine fishery for shad and herring (*Alosa* spp.) in western Albemarle Sound commonly reported bycatch of sturgeon (Zarzecki and Hightower 1997). Increased demand for sturgeon roe led to the development of an Albemarle Sound fishery for sturgeon in 1889 (North Carolina State Board of Agriculture 1896; Leary 1905; Smith 1907). The Cape Fear River, during the late 1800s, recorded the largest landings of sturgeon in the southeastern United States (McDonald 1887). In 1880, statewide landings of sturgeon were reported at 198,174 kg, but declined to 60,838 kg by 1902 (Bowers 1905; Smith 1907). Intensive harvest of sturgeon in North Carolina resulted in "the species being almost wiped out in a short time and has never been able to reestablish itself" (Smith 1907).

Historical occurrence

Historical records of sturgeon harvest were not species-specific (National Marine Fisheries Service 1998). Large individuals would have been Atlantic sturgeon (*Acipenser oxyrinchus*), but smaller individuals could have been shortnose sturgeon. Referring to shortnose sturgeon, Smith (1907) stated that, "While it doubtless ascends all suitable streams in North Carolina, actual records of its occurrence are rare." The lack of information about shortnose sturgeon is due in part to the difficulty of distinguishing between species. Adult shortnose sturgeon resemble juvenile Atlantic sturgeon, and both historically co-occurred in the lower reaches of major Atlantic coast rivers (Kynard 1997). Therefore, historical accounts of shortnose sturgeon are likely of limited value due to the similarities in appearance between species.

Few shortnose sturgeon have been collected in North Carolina waters. In 1881, a single shortnose sturgeon was collected from Salmon Creek, a tributary of the Chowan River in the Albemarle Sound system (National Marine Fisheries Service 1998). In the late 1800s, a shortnose sturgeon capture was reported in coastal waters near Beaufort, NC (Jordan 1886). More recently shortnose sturgeon were considered to be extirpated from North Carolina waters, until an individual was found in the Brunswick River in 1987 (Ross et al. 1988). Recent intensive gill-net studies establish the presence, though rare, of shortnose sturgeon in the lower Cape Fear River (Moser and Ross 1995). Despite intensive gill-net sampling (893 net-days), Moser and Ross (1995) only obtained five shortnose sturgeon in the lower Cape Fear River between 1989 and 1993. In 1998, the North Carolina Division of Marine Fisheries reported a capture of a shortnose sturgeon in western Albemarle Sound (Armstrong and Hightower 1999).

Life history

Growth Shortnose sturgeon begin life in deep scoured channels with substrates consisting of gravel, cobble, and logs in upper reaches of rivers (Dadswell et al. 1984; Kynard 1997). After hatching, juvenile shortnose sturgeon have rapid growth of 14-30 cm during the first year. Fish in northern populations attain a greater size than southern populations, but southern shortnose sturgeon grow at faster rates (Kynard 1997). Age at sexual maturity differs among populations and between sexes. In southern populations, males mature at 2 - 5 years and females mature at 4 - 5 years. In contrast, males in northern population mature at 6 - 11 years and females mature at 7 - 18 years, depending on the river system (Kynard 1997). Northern adults typically live 30 - 67 years, while southern adults only live 10 - 25 years (Dadswell 1979; Kynard 1997).

Spawning Adult shortnose sturgeon vary in spawning migration patterns. Variation may be due to energetic adaptations to river discharge and temperature, migration distance, or physiological conditions of the individual fish (Kieffer and Kynard 1993). Adults overwintering a short distance (<25 km) from spawning areas may migrate for only a two-week period (Buckley and Kynard 1985a). An extended migration (>80 km), during winter and spring before spawning, has been observed in southern populations. A third, two-phase pattern, fish undergo an extended fall migration to an overwintering area close to spawning grounds, then undergo a shorter migration in spring to the spawning grounds (Kynard 1997). Northern populations exhibit both the two-week and two-phase migration patterns (Dadswell 1979; Kieffer and Kynard 1993). Adults in southern rivers (Savannah, Altamaha, and Pee Dee rivers) display the extended migration in late winter and spring. Southern fish migrate to spawning locations near rkm 200 or farther depending on dam locations (Hall et al. 1991; Rogers and Weber 1995; Kynard 1997).

Spawning reportedly occurs during a short period of time when environmental parameters such as river discharge are within suitable limits (Crance 1986). Spawning activity typically lasts from 2 - 3 days to nearly 2 weeks, suggesting that suitable spawning conditions are only briefly present (Kieffer and Kynard 1996). Typical spawning sites are channel habitats that have substrates containing rocks, rubble, sand, or woody debris (Crance 1986; Hall et al. 1991; Rogers and Weber 1995; Kieffer and Kynard 1996). The habitat suitability index model indicates that cobble and gravel substrates provide optimal habitat for spawning shortnose sturgeon (Crance 1986). Spawning sites typically have a moderate river discharge (0.4 - 1.8 m sec^{-1}) and water temperatures ranging from 9 - 12°C (Dadswell et al. 1984; Kieffer and Kynard 1996). High river discharge is reported to inhibit females from releasing eggs (Buckley and Kynard 1985b).

Habitat selectivity Habitat selectivity of the species varies latitudinally. Adults in the Saint John and Kennebec river systems primarily utilize saline waters for much of the year with brief migrations to freshwater habitats seen during warmer water temperatures that occur from June – August (Dadswell 1979; Kynard 1997). Shortnose sturgeon in central rivers (Merrimack – Delaware) typically do not utilize saline waters. Adults in these systems both forage and spawn in freshwater reaches of the river and rarely enter saline habitats (Kieffer and Kynard 1993; O'Herron et al. 1993; Kynard 1997). Southern populations utilize both fresh and saltwater habitats. Adults are known to forage in and around the saltwater-freshwater interface. During periods of high water temperatures (28 – 30° C), both adults and juveniles utilize deep cool refuges found within the interface area (Rogers and Weber 1995; Kynard 1997). Higher salinity habitats are utilized during the fall and winter as water temperatures cool (Hall et al. 1991; Moser and Ross 1994; Rogers and Weber 1995; Kynard 1997). Spawning migration to upstream freshwater habitat occurs in late winter to early spring (Kynard 1997).

Factors affecting decline

Major factors influencing a decline in southern populations of shortnose sturgeon are harvest (bycatch and poaching), pollution (e.g., paper mill effluent), dams (inhibiting spawning migration), river flow regulation, and dredging of saltwater-freshwater interface (Kynard 1997; Collins et al. 2000). Severe degradation of water quality in southern rivers has led to diminished or extirpated populations of shortnose sturgeon (Kynard 1997; Collins et. al 2000). Poor water quality has also affected migration and abundance of other anadromous species such as American shad in the Delaware River (Chittenden 1974).

Recovery of shortnose populations in North Carolina may depend heavily upon improvements in water quality.

Shortnose sturgeon recovery plan

To promote restoration of shortnose sturgeon populations, the National Marine Fisheries Service created a recovery plan in 1998 (National Marine Fisheries Service 1998). The ultimate goal of the recovery plan is to increase population sizes to a level at which the species no longer requires protection under the Endangered Species Act (National Marine Fisheries Service 1998).

One observation in the recovery plan was that shortnose sturgeon have often been undetected in general fish surveys, and only located when a directed survey was done. Also, previous studies of shortnose sturgeon have used varying levels of sampling effort, so survey results were not definitive in some cases. For that reason, the recovery plan includes a standardized sampling protocol to assess the status of shortnose sturgeon within a river system. The protocol establishes the level of effort required to reach a conclusion about the presence or absence of shortnose sturgeon. If the protocol is followed and shortnose sturgeon are not encountered, then the National Marine Fisheries Service will consider restoration of the species by restocking.

Objectives

We wanted to determine if shortnose sturgeon occur within the Neuse River and evaluate the habitat quality for shortnose sturgeon, possibly for reintroduction. We also wanted to estimate the detection probability of shortnose sturgeon for different population sizes. Finally, we wished to develop models to predict shortnose sturgeon presence based on physical characteristics of a river system.

Our approach to achieving these objectives was to conduct a two-year sampling survey in order to verify presence/absence of shortnose sturgeon and to obtain fish for telemetry studies. This two-year survey included two summers, a spring, and a fall sampling period. The original Neuse River project design was to follow protocol guidelines until sufficient numbers of shortnose sturgeon had been captured to initiate telemetry studies.

After completion of the two-year sampling survey, research has been focused on determining a minimal effort level for detecting shortnose sturgeon. We have also focused on habitat characteristics of river systems to predict the presence/absence of shortnose sturgeon in rivers that lack information about shortnose sturgeon.

CHAPTER TWO

NEUSE RIVER SURVEY

Introduction

The absence of shortnose sturgeon in mid-Atlantic rivers has drawn the attention of fisheries biologists (Figure 2.1). A few shortnose sturgeon have been encountered recently in Chesapeake Bay through a reward program, although those fish may be transients from the Delaware River (Welsh et al. 2002). Albemarle Sound tributary rivers have no known populations of shortnose sturgeon. Armstrong and Hightower (1999) documented an occurrence of a single shortnose sturgeon in western Albemarle Sound, but further work has not detected a population. Pamlico Sound tributaries may have populations of shortnose sturgeon but no surveys targeting the species had been conducted prior to this study.

Anecdotal evidence suggested that shortnose sturgeon might occur in the Neuse River. Moser et al. (1998) interviewed two shad fishermen who stated they had captured a shortnose sturgeon about 3 km downstream of New Bern near channel marker 22. Identification of populations of shortnose sturgeon in this region is important to management and recovery of the species.

Shortnose sturgeon often are undetected until a directed survey for the species is conducted (National Marine Fisheries Service 1998). Therefore, the goal of this project was to conduct a survey using the National Marine Fisheries Service shortnose sturgeon sampling protocol (Moser et al. 2000) to determine the status of shortnose sturgeon within the Neuse River. When the status has been determined, appropriate steps can be taken to restore or reintroduce the species.

Methods

Shortnose sturgeon sampling protocol

The Shortnose Sturgeon Recovery Plan (National Marine Fisheries Service 1998) specified the need for a sampling and handling protocol because of: 1) expected increases in research on shortnose sturgeon in future years by a broader group of scientists and the concomitant need for standardization of methods; 2) the need for guidance in permitting research activities that may harm shortnose sturgeon; and 3) the need for minimum sampling requirements to determine that shortnose sturgeon are extant in a given system. To address these needs, a protocol was developed by fisheries biologists who had conducted previous research on shortnose sturgeon (Moser et al. 2000).

Shortnose sturgeon typically aggregate in deep areas (> 10 m) within the freshwater-saltwater interface during summer (Rogers and Weber 1995; Moser and Ross 1995). Because of that restricted distribution during summer, the protocol mandates that initial sampling be done within the freshwater-saltwater interface. If shortnose sturgeon are not encountered in the first summer season, then a spring netting season should be conducted at the base of the first dam or falls during January – April (Moser et al. 2000).

The protocol requires the use of either standard sinking gill nets 100 m long, with 13 – 14 cm stretched mesh (5 – 5.5 in) or trammel nets of the same length with 5 – 8 cm (2 – 3 in) stretched inner mesh panels and 35 cm (14 in) stretched outer mesh panels. Net sets should not exceed 2 h during the summer and 24 h during the spring. The protocol requires a minimum sampling effort of 288 100-m net hours during summer and 144 100-m net days during spring in order to determine the presence/absence of shortnose sturgeon within a given river system.

To insure that shortnose sturgeon are sampled when restricted to deep sites within the freshwater-saltwater interface, netting during summer occurs when water temperatures exceed 27°C (Moser et al. 2000). For that reason, we conducted summer netting during late June – August and limited net sets to 1 – 1.5 h in areas identified by bathymetry mapping. Spring netting was done from mid-February through early April. Additional fall netting was conducted from September – December in order to capture sturgeon for telemetry studies. All fish captured were measured (TL mm) and weighed (g).

Study Area

The Neuse River drains approximately 14,500 km^2 of the piedmont and coastal plain of North Carolina. The river begins at the confluence of the Eno and Flat rivers in the piedmont of North Carolina. The Neuse flows southeasterly for 430 km through eastern North Carolina where it eventually discharges into Pamlico Sound (Hawkins 1980; USGS 1995). As of 1995, land surrounding the river was composed of 48% forest, 30% agriculture, 9% wetlands, 6% developed lands and 5% water (USGS 1995). The Neuse begins with relatively high gradients and rocky substrates, but widens and slows with substrates of sand and silt throughout the coastal plain (USGS 1995). The freshwater-saltwater interface of the Neuse is located near New Bern (rkm 61) (NCDENR 2001).

Neuse River flow regimes are regulated by Falls Lake Dam (rkm 370), which was built by U.S. Army Corps of Engineers in 1983. The dam impounds water for water supply, water quality, flood control and recreation.

Bathymetry

Shortnose sturgeon are typically found in the deepest water available within the general area occupied (Hall et al. 1991; Moser and Ross 1995; Collins et al. 2000). Therefore, to focus netting efforts effectively, we began by mapping the location of deep holes within the freshwater-saltwater interface. During the summer of 2001, an intensive depth mapping survey was conducted along the Neuse River from channel marker 22 (rkm 58) to Spring Garden (rkm 82). Historically, this has been the location of the freshwater-saltwater interface (Lebo et al. 2002). Along transects perpendicular to the shoreline and separated by 5 m intervals we recorded depth and geographic location. Because spawning sites were not known, the main channel depth was also surveyed between the freshwater-saltwater interface and the first blockage to migration (Milburnie dam rkm 328) to identify potential spring netting sites.

Water quality assessment

To determine the amount of suitable shortnose sturgeon habitat within the freshwater-saltwater interface, water quality measurements were taken weekly at each sampling location during both summer field seasons. Dissolved oxygen (mg/L), salinity (ppt), and water temperature (°C) were measured for both surface and bottom waters using a YSI Model 55 dissolved oxygen-temperature meter and a YSI Model 30 salinity-conductivity-temperature meter. The measurements allowed for location of the freshwater-saltwater interface and determining suitable sampling locations during the summer season (no netting in areas lacking dissolved oxygen). Dissolved oxygen levels were classified as well oxygenated (> 4 mg/L), hypoxic (2 – 4 mg/L), and severely hypoxic (< 2 mg/L). Secor and Gunderson (1998) stated that an oxygen level of < 2 mg/L is too stringent for sturgeon because oxygen concentrations at that level are often lethal.

Sturgeon captures

The original design of this project was to focus on the presence/absence of shortnose sturgeon in the Neuse River. During field sampling it became apparent that shortnose sturgeon captures were either extremely rare or nonexistent within the river. Therefore, we attempted to tag juvenile Atlantic sturgeon to gain an understanding of movements of a related species during periods of increased water temperatures. We also hypothesized that information about the distribution of juvenile Atlantic sturgeon would aid in locating shortnose sturgeon. Juvenile Atlantic sturgeon and adult shortnose sturgeon utilize similar habitats during periods of increased water temperatures (Rogers and Weber 1995; Bain 1997; Kynard 1997).

In April 2002, we established a cooperative reward program with Neuse River commercial fisherman and the North Carolina Division of Marine Fisheries to increase captures of sturgeon. Commercial fishermen would receive a $100 reward for every sturgeon captured and reported.

For each captured sturgeon, we recorded date, location in zone 18 Universal Transverse Mercator (UTM) coordinates, mesh size of net (cm) and length of net (m). Approximate water depth (m) at the capture site was recorded, as was surface and bottom water temperature (°C), dissolved oxygen (mg/L), conductivity (µS), and salinity (ppt).

For each captured sturgeon, we recorded fork length (mm), weight (g), and external condition (presence of lesions or injuries). We also measured interorbital width (mm), inner mouth width (mm), outer mouth width (mm), and snout length (mm), which are useful in distinguishing between Atlantic and shortnose sturgeon (Jenkins and Burkhead 1994; Moser et al. 1998). Shortnose sturgeon snout length (distance from anterior edge of the lips to the tip of snout) is typically equal to or less than the outer mouth width (outer edge of lips), whereas snout length of Atlantic sturgeon is greater than mouth width (Jenkins and Burkhead 1994). Outer mouth width of shortnose sturgeon is greater than 1.7 times the interorbital distance (Menhinick 1991). The ratio of inner mouth width to interorbital width is usually greater than 62% for shortnose sturgeon and less than 55% for Atlantic sturgeon (Dadswell et al. 1984). A 1 cm^2 pectoral fin tissue sample was taken for DNA analysis. Fin clips were stored in a tissue buffer solution provided by the NOAA Sturgeon DNA Bank at NOS-Charleston. Photographs were taken of each captured sturgeon to document the species identification.

Tagging

A passive integrate transponder (PIT) tag was injected directly under the skin posterior to and to the left of the fourth dorsal scute. Because this tagging site has been commonly used by previous sturgeon researchers it should make identification by other researchers more likely. A nylon dart tag, provided by the U.S. Fish and Wildlife Service was applied to one juvenile Atlantic sturgeon greater than 600 cm. The tag was placed subcutaneously, parallel to the dorsal fin.

The tagged Atlantic sturgeon was fitted with an ultrasonic transmitter (Sonotronics model CHP-87-S) which was 67 mm in length, 8 g (in-air) in weight, and operated at a frequency of 40 kHz with 7-month battery life. Because water temperature was between 7 –

27 °C (~20 °C) (Moser et al. 2000) at the time of capture, we surgically implanted the transmitter following the methods used by Fox et al. (2000). The fish was anesthetized using tricaine methane sulfonate (MS-222) at a concentration of about 50 mg/L. The fish was on its dorsum in a surgical trough, with a constant water flow maintained over the gills throughout the surgery. A small ventral incision approximately 25 – 30 mm in length was made 4 – 6 cm anterior to the pelvic fin. The transmitter and surgical instruments were sterilized using quaternary ammonium disinfectant (Nolvasan). The transmitter was placed into the body cavity, and the incision was closed using 2-0 Dermalon©, a non-absorbable suture material. The incision was dressed with a triple antibiotic ointment, and the fish was injected with oxytetracycline at the rate of 10 mg/kg body weight.

Telemetry

Telemetry is an effective tool for monitoring the movement and habitat selectivity of sturgeon over an extended period of time (Kieffer and Kynard 1993; Moser and Ross 1995; Armstrong and Hightower 1999). Tracking of the telemetered Atlantic sturgeon was conducted using a Sonotronics USR-5B receiver and directional hydrophone. An attempt was made to relocate the telemetered fish twice each day during May through mid-August and occasionally in September - October. Water quality measurements, identical to measurements taken at time of capture, were taken at relocation sites. Depth was recorded using a depth finder.

Detection probability

Catch-per-unit-effort (CPUE) data can be difficult to interpret because of the unknown relationship between CPUE and population size. Using data from our study and other intensive studies of shortnose sturgeon, we examined this relationship for selected river systems in order to estimate the probability of detecting shortnose sturgeon, if present. This probability, which depends on the catchability and amount of effort, is termed the detection probability. The five river systems used in this analysis were selected based on data availability, size of river system, and estimated size of shortnose sturgeon populations.

The netting surveys in various rivers were conducted independently; therefore netting methods were not consistent among studies. To compare survey methods among the rivers, we standardized netting effort based on net requirements of the shortnose sturgeon sampling protocol (1 protocol hour = 100 m net length with required mesh sizes set for one hour) (Table 2.1). Surveys were conducted either year-round (e.g., Cape Fear, Altamaha) or during summer (e.g., Merrimack, Neuse, Ogeechee). Surveys focused on small segments of the river that contained known shortnose sturgeon habitat.

After standardizing effort, we then determined detection probabilities of a single individual. First, we determined the catchability rate (q*) for shortnose sturgeon by plotting CPUE against estimated population size. Once catchability is calculated, then we determined the probability of detection. The probability of an individual not being caught is:

$$\exp(-q * E)$$

where q* is the catchability rate and E is amount of netting effort. For a population of size N, the probability that none of the N individuals would be caught is:

$$[\exp(-q * E)]^{N} \approx \exp(-q * EN)$$

Therefore, the probability that at least one individual would be caught is:

$$P = 1 - \exp(-q * EN)$$

Detection probabilities were plotted against hours of netting effort for different population sizes, in order to help determine the minimum amount of sampling needed to establish presence or absence of a small population of shortnose sturgeon.

Model Development The equation relating survey effort to detection probability is based on a catch-effort method described by Seber (1982). Model assumptions are as follows:

1. The catchability coefficient is constant across surveys and is the same for all individuals.
2. Units of survey effort are independent.
3. Sampling is a Poisson process with regard to effort.

The relationship between catch (C), population size (N), survey effort (E), and survey catchability (q*) is as follows:

$$E(C) \approx Nq^* E$$

$$\frac{C}{E} \approx CPUE \approx Nq^*$$

$$\hat{q}^* \approx \frac{CPUE}{\hat{N}}$$

Thus, we can estimate q* as the slope of a linear equation (with no intercept) relating estimates of CPUE and N.

Study rivers The Merrimack River begins in the mountains of New Hampshire and flows through Massachussetts emptying into the Atlantic Ocean. A Shortnose sturgeon survey was conducted in a section of the river, between rkm 13 and 24 (Kieffer and Kynard 1993). The Merrimack has an estimated population of 50 individuals, based on a sampling period of 11,396 protocol hours (Kynard 1997, Kieffer and Kynard 1993).

The Neuse River drains approximately 14,500 km^2 of the piedmont and coastal plain of North Carolina. The river begins at the confluence of the Eno and Flat rivers in the piedmont of North Carolina. The Neuse then flows southeasterly for 430 km through eastern North Carolina where it eventually discharges into the Pamlico Sound (Hawkins 1980; USGS 1995). The study was focused in the freshwater-saltwater interface between rkm 58 and 82. The Neuse River is estimated to have a shortnose sturgeon population size of 0, based on 217 summer protocol hours (current research).

The Cape Fear River drains 23,695 km^2 of the piedmont and coastal plain of North Carolina. The mainstem river begins at the confluence of the Deep and Haw rivers. The drainage contains approximately 15,799 km of river and streams including several major tributaries: Little, South, Black and Northeast Cape Fear rivers. Moser and Ross (1995) focused on Wilmington Harbor (confluence of Cape Fear and Brunswick rivers) (rkm 37 – 46) from December to May and in the Cape Fear (rkm 46 – 66) from April to November. The Cape Fear population of shortnose sturgeon is estimated at approximately 10 individuals, based on year-round sampling effort of 10,716 protocol hours (Kynard 1997, Moser et al. 1998)

The Ogeechee River spans approximately 375 km through the lower piedmont and drains 14,300 km^2 before entering the Atlantic Ocean. The survey is focused on 12 kilometer stretch just upstream of the confluence of the Canoochee River (rkm 55). The Ogeechee population is estimated at 216 individuals, based on a summer sampling effort of 415 protocol hours (Kynard 1997, Rogers and Weber 1994).

The Altamaha, the largest river east of the Mississippi River, drains 48,200 km^2 of piedmont and coastal plain in Georgia. The Altamaha is formed by the confluence of the

Ocmulgee and Oconee rivers at rkm 212 (Rogers and Weber 1995). The survey focused on the Altamaha River delta, a span of approximately 22 rkm. The Altamaha has an estimated shortnose sturgeon population of 650 individuals, based on a year-round sampling effort of 354 protocol hours (Kynard 1997; Rogers and Weber 1995).

Results

Bathymetry

The summer mapping survey showed that the freshwater-saltwater interface was located between rkm 58 and 82 and included both riverine and lacustrine sections. This part of the river contained 14 potential sampling locations, two of which met the protocol standard (>10 m in depth), 11 locations ranged from 6 – 10 m, and one location was less than 6 m in depth (Figure 2.2). The deeper sites were located in the riverine section, typically in the outer edges of curves. Below rkm 70, the river widens substantially and was generally shallow with very few areas deeper than 6 m.

Searches were done by boat to identify potential spring netting sites between freshwater-saltwater interface and the first blockage to migration (Milburnie Dam, rkm 328). Sampling locations were identified as deep water areas, typically greater than 3m in depth. Twenty sampling sites qualified in this 246 km section of the river. Downstream locations between Goldsboro and Kinston ranged from 6 – 10 m in depth, whereas the more upstream locations near Milburnie Dam were shallower (≥ 3 m in depth) (Figure 2.3).

Gill net survey

No shortnose sturgeon were encountered in 64.5 h of gill-net sampling in the freshwater-saltwater interface during summer 2001 and 150.8 h of sampling during summer 2002. One juvenile Atlantic sturgeon was captured at the confluence of Swift Creek and the Neuse River (rkm 75) on June 24, 2000 (Figure 2.4). A total of 13 fish species was encountered during summer sampling, with highest catches of Atlantic menhaden, flathead catfish, and channel catfish (Appendix Table 1). Flathead catfish, longnose gar, and blue catfish were the dominant species captured in fall netting.

No shortnose sturgeon were encountered during 50 overnight sets during the 2002 spring field season although other anadromous species (American shad, striped bass) were collected (Appendix Table 2). Highest catches were of gizzard shad, Atlantic menhaden, and flathead catfish.

We obtained two juvenile Atlantic sturgeon from commercial gill-net fishermen (Figure 2.4). The first was encountered in Banner Bay (rkm 55) just upstream of the confluence of Northwest Creek and the Neuse River on April 30, 2002. The second juvenile Atlantic sturgeon was captured at rkm 58 on February 6, 2003.

Water quality assessment

Water quality measurements were taken weekly during both summer field seasons. During 2001, observations were made only at netting sites used during that week. During 2002, all sites between rkm 58 and 82 were sampled weekly. Results were generally consistent between years in that severe hypoxic conditions (< 2 mg/L dissolved oxygen) were prevalent in bottom waters from June – August (Appendix Figure 1). The hypoxic zone was generally limited to brackish waters, as the more upstream areas of the interface had adequate oxygen levels. One difference between years was that salinity levels increased and the "salt-wedge" pushed further upstream in 2002.

Bottom water temperatures ranged from 25 – 30°C in both years (Appendix Figure 2). Due to stratification, there was typically about a 1 - 2°C difference between surface and bottom temperature. Temperatures increased gradually from upstream to downstream stations during most weeks.

Tagging

The juvenile Atlantic sturgeon captured on April 30, 2002 measured 992 mm fork length (FL) and weighed 6,500 g (Table 2.2). It was tagged with PIT tag # 4163256D1B and a CHP-87-S transmitter. The juvenile Atlantic sturgeon captured on June 24, 2002, 639 mm (FL) and 1,800 g in weight, died upon release. The juvenile Atlantic sturgeon captured on February 6, 2003, 561 mm (FL) and 1,250 g in weight, was tagged with PIT tag # 41633F7800 and released. A juvenile Atlantic sturgeon captured on March 27, 2003, 740 mm (FL) and 3,050 g in weight, was tagged with PIT tag # 4163487E4B (Table 2.2).

Telemetry

The juvenile Atlantic sturgeon tagged with a surgically implanted sonic transmitter was tracked for a period of six months (May – October 2002). During May, the fish migrated upstream from its release location to a distributary (locally named "The Gut"), a distance of approximately 10 rkm (Figure 2.5). According to water quality assessment at relocations, both the main river channel and "The Gut" were oxygenated during May (> 4 mg/L) (Figure 2.6). The fish moved within "The Gut" during June, but remained upstream of severe hypoxic bottom waters that had entered the lower reaches of the distributary and extended to rkm 70 in the main river channel (Figure 2.7). By July, severe hypoxic conditions had developed up the main river channel to rkm 75 (confluence of Swift Creek) (Figure 2.8). The tagged fish remained within the distributary and was relocated in a two-curve area (<1 rkm in distance) for the entire month of July (Figure 2.8). During August, severe hypoxic conditions in the main channel remained near rkm 75, and the juvenile Atlantic sturgeon utilized the same two-curve area as the previous month (Figure 2.9). In September, the telemetered fish was relocated in hypoxic conditions (2 – 4 mg/L) (Figure 2.6) in the main channel of the Neuse River near rkm 73 (Figure 2.10). The fish was relocated twice in October with the final relocation near rkm 80 (Figure 2.11).

The tagged Atlantic sturgeon was rarely relocated at sites with severe hypoxic bottom waters (4.5 % of relocations). Severe hypoxic events were seen in mid June, July, and early August (Figure 2.6). During this period, 26.1 % of relocations had evidence of hypoxic conditions (2 – 4 mg/L) in bottom waters. The fish was relocated in salinity levels ranging from 0 – 11 ppt with most relocations between 0 – 3 ppt (Figure 2.12). Severe hypoxic bottom waters at relocation sites typically corresponded to a high bottom salinity level (Appendix Table 3). Bottom water temperatures for May and October relocations ranged between 20 – 25 °C. Summer relocations had increased water temperatures ranging from 26 – 30 °C (Figure 2.13).

Detection Probability

Estimated CPUE was substantially higher for the Altamaha River than for the remaining river systems. To obtain a range of catchability (q*) estimates, the regression equation was fitted both with and without the Altamaha River being included in the analysis. The estimated catchability rate ranged from 0.0004 to 0.0008, depending on whether the Altamaha river was included (Figure 2.14). We also included a q* level of 0.0002 in order to examine a wider range of values.

Detection probabilities for each q* illustrated similar patterns. Detection probabilities were higher as both survey effort and assumed population sizes increased (Figures 2.15 – 2.17). Given a catchability of 0.0008, the estimated detection probability was approximately 1 for a population of 50 individuals and only 200 h of sampling effort (Figure 2.15). For populations of 1000 or more individuals, only 10 hours of netting effort was required to have a detection probability of approximately one. Therefore, larger populations such as the Hudson River (>38,000 individuals; Kynard 1997) would be detected with minimal sampling effort. Low population sizes such as the estimate for the Cape Fear River (~10) would require approximately 1,000 hours of netting effort in order to have a detectability of nearly one.

For a catchability of 0.0004, population sizes of 50 or more individuals had a detection probability of about one at 200 h of netting effort (Figure 2.16). Detectability of a population size of 10 was estimated to be 0.982 for 1000 h of netting effort. At an assumed catchability of 0.0002, a population of 50 or more individuals should be detected by 500 hours of netting effort (Figure 2.17).

Discussion

Identifying factors affecting the decline of shortnose sturgeon within the Neuse River is critical to the recovery of the species. Factors thought to be responsible for declines of shortnose sturgeon populations within other southern rivers may be similarly important in the Neuse River. Collins et al. (2000) classified six major categories leading to the decline of shortnose sturgeon populations: harvest (bycatch and poaching), pollution (paper mill effluent), dams (inhibiting spawning migration), river flow regulation, dredging of saltwater-freshwater interface, and poor water quality. The Neuse River has several of these factors affecting shortnose sturgeon habitat.

Eutrophication due to point and nonpoint source pollution are becoming is an increasing concern in southern rivers (Collins et al. 2000). Industrial effluents, municipal wastewater discharges, and use of fertilizer are sources of nutrient loading within the Neuse Basin (NCEMC 1998). The Albemarle-Pamlico National Estuary Program; Neuse River Estuarine Modeling and Monitoring Program; and U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) agree that very low dissolved oxygen and high contaminant levels are producing poor water quality in the Neuse estuary during warmer months (NCDENR 2001).

The poor summer water quality that was observed in this study has also been documented through other monitoring programs. NCDENR (2001) reported sporadic violations of state standards for dissolved oxygen level and fecal coliform counts in the Neuse River near the freshwater-saltwater interface. During the 1970s and 1980s, this area experienced massive algal blooms (rkm 80). The ban of phosphorus detergents in the 1980s decreased algal blooms but events still occur (NCDENR 2001). In July 1997 and June 1998, diatom and chrysophyte blooms were reported at the confluence of Swift Creek (rkm 75). These blooms, which may be correlated with phosphorus and nitrogen concentrations, can result in oxygen depletion. The highest concentrations of phosphorus and nitrate+nitrite were reported at rkm 61 (freshwater-saltwater interface) near New Bern (NCDENR 2001). Another concern for a benthic feeder like shortnose sturgeon is the high level, of contaminants found in benthic habitats of the Neuse estuary including DDT, PCBs, arsenic, nickel, and chromium (Hackney et al. 1998).

Poor water quality conditions have been linked to numerous fish kills within the Neuse estuary. Since monitoring began in 1996, fish kill sites typically undergo eutrophication, stratification, and low dissolved oxygen levels during the warmer months (NCDENR 2001). These conditions could certainly impact shortnose sturgeon, given their benthic life history. It seems clear that recovery of dissolved oxygen levels and decreased nutrient loading must to be rectified before shortnose sturgeon can be restored to the Neuse River.

The North Carolina Environmental Management Commission has implemented legislation that should lead to improvements in the Neuse Basin water quality. In 1998, the commission began requiring decreased nitrogen inputs from several point and non-point pollution sources (NCEMC 1998). A 30% reduction of annual nitrogen loading is required from all wastewater facilities. There is also a maximum of 2.8 million lbs of total nitrogen which can be released into the river by wastewater facilities. Agricultural operations must also decrease their nitrogen inputs by a combined 30%. Agricultural, recreational, and commercial operations that apply large amounts of fertilizer are required to undergo training in proper application techniques. Several rules regarding urban stormwater runoff and fertilizer application have been established to decrease nutrient loading within the Neuse Basin. Furthermore, the state is establishing 15.2 m buffer zones that should protect all surface waters (intermittent and perennial streams, lakes, ponds, and estuaries) within the Neuse Basin. In combination, these steps in reducing nutrient loading should aid in the improvement of water quality within the saltwater-freshwater interface and promote recovery of shortnose and Atlantic sturgeon populations within the river basin.

Dams can have substantiated impacts because they eliminate historical spawning areas for anadromous species. The Neuse River basin currently has two dams located on the main river channel. Falls Lake Dam (rkm 370) is a flood control system established by the U.S. Army Corps of Engineers in 1983. Purposes of the dam include water supply, water quality, flood control and recreation. Milburnie Dam (rkm 328), the current lowermost obstruction, is a hydroelectric facility. Prior to 1999, Quaker Neck Dam (rkm 225) was the lowermost obstruction to migration. The migration of both American shad and striped bass was limited by the dam, and both species migrated farther upstream after the dam's removal (Beasley and Hightower 2000; Bowman and Hightower 2001). We currently have no information about spawning areas for either Atlantic or shortnose sturgeon, but removal of Quaker Neck Dam may aid both species in reaching historic spawning areas.

There is some evidence for a current spawning population of Atlantic sturgeon within the Neuse River. Early-intermediate juveniles are generally found within their natal river system (age 6 and younger; Bain 1997).   Hassler (1974) captured a few Atlantic sturgeon in the 1970s near Weyerhauser Paper Mill Facility (rkm 80) during annual trawl surveys. Based on museum records from the NCSU fish collection, three early juveniles captured on September 10, 1974 were about 40 mm in length. One juvenile captured on October 18, 1974 was 100 mm total length. Two of the juvenile Atlantic sturgeon captured during our survey demonstrated the observed lengths (44 – 63 cm fork length) for intermediate juvenile life stage (3 – 6 years of age; Bain 1997). In the Hudson River, intermediate juvenile Atlantic sturgeon remain in riverine habitat (Bain 1997). These findings suggest that spawning may be occurring and that suitable spawning habitat exists within the Neuse River. Atlantic and shortnose sturgeon utilize similar but not identical spawning habitats (Bain 1997); therefore, we do not know if the Neuse River contains suitable shortnose sturgeon spawning habitat.

Improvements in riverine and estuarine habitat quality should also benefit the Neuse River population of Atlantic sturgeon. Netting effort from both our survey and commercial fishermen suggest that the Atlantic sturgeon population is at a low level. In comparison, survey catch rates and commercial gill-net bycatch rates are relatively high within Albemarle Sound (Armstrong and Hightower 2002). This suggests that the Neuse River population may be small in comparison. Management implications of these findings include maintaining the ban on commercial harvest of adult and juvenile Atlantic sturgeon within the river and continuing efforts to improve water quality in the lower river.

Determining the absence of rare or endangered species is difficult (Venette et al. 2002). Determining detectability of a rare species often depends on knowing its geographic range and habitat use within the range (Reed 1996). Three components are critical to species detectability: (1) density of the individuals, (2) sampling effort, and (3) probability of detecting an individual at a particular point with a unit of sampling effort (Reed 1996). Complete observation or capture of species is usually impossible for mobile, aquatic organisms such as fish (Bayley and Peterson 2001). In planning our survey, we expected that the density of individuals would be low, given that there were no prior records of shortnose sturgeon within the Neuse River. Therefore, we needed to estimate the probability of detecting an individual shortnose sturgeon for different assumed population sizes and the amount of sampling done during the survey.

Our summer sampling conducted to date (217 h) represents about 75% of the level required by the protocol. The 50 overnight sets during spring represent about 35% of the level required for spring sampling. There is a much greater uncertainty about the adequacy of spring sampling because of the 246 rkm between the freshwater-saltwater interface and the first dam. If only the summer sampling is considered, the netting carried out thus far should be adequate to detect a population of 50 or more. Additional survey effort would be needed to detect a population of only 10 individuals, or if q* is lower than the range estimated in this study (0.0004 – 0.0008). From our lack of catch, in combination with the lack of reported captures by commercial fishermen, the population of shortnose sturgeon within the Neuse River is either extremely low or extirpated.

One potential source of error in estimating detection probability is whether all surveys are generating comparable CPUE data. It is well documented that shortnose sturgeon aggregate in deep holes during summer, and often are not detected unless sampling occurs at those sites (Rogers and Weber 1995; National Marine Fisheries Service 1998). This strong habitat preference of shortnose sturgeon allows survey effort to be highly focused, and can result in relatively high CPUE values even though population size may be small. The surveys used in this analysis to estimate q* were conducted not at random locations but in river reaches thought (or known) to contain shortnose sturgeon. Our summer netting was carried out within the freshwater-saltwater interface, so the q* that we obtained should be appropriate. Therefore, the current sampling protocol may be inappropriate for detecting a shortnose sturgeon population. The detection probability analysis shows that a minimal sampling effort of 200 h is adequate to detect a population size of 50 or more individuals. Therefore, the current protocol standard of 288 minimum summer net hours may exceed the necessary effort required to detect a population of shortnose sturgeon. If the population is less than 50 individuals, then adequate sampling standards may be unattainable due to low probability of detection.

Based on netting and detection probability data, we conclude that the species is absent from the river believing that stocking of cultured shortnose sturgeon would not be appropriate until habitat quality improves within the freshwater-saltwater interface. The regulations initiated by the North Carolina Environmental Management Commission appear to be a major step in alleviating water quality problems within the basin, and may eventually allow a hatchery-based shortnose stocking program to be implemented.

Table 2.1 Gill-net survey effort and catch-per-unit-effort of shortnose sturgeon from river systems for which an estimate of population size was available. Effort in hours fished was adjusted to an estimate of protocol effort, based on the standard netting protocol defined by Moser et al. (2000).

River System	State	Net Length (m)	Gill net (cm)	Trammel net (cm)	Time (hrs)	Actual captures	CPUE (fish/net hr)	Protocol effort (hrs)	Population size	Source
Merrimack	MA	100	15.4		11,396	25	0.00219	11,396	50	Kieffer & Kynard (1996)
Neuse	NC	100	14		767	0	0.00000	767	0	Personal study
Cape Fear	NC	50	14		21,432	3	0.00028	10,716	10	Moser & Ross (1995)
Ogeechee	GA	100		7.6 (35.6)	415	34	0.08193	415	216	Rogers & Weber (1994)
Altamaha	GA	100		7.6 (35.6)	354	196	0.55367	354	650	Rogers & Weber (1995)

Table 2.2 Identification and measurements of 2001 – 2003 captured juvenile Atlantic sturgeon. The ratio of inner mouth width to interorbital width is typically greater than 62% for shortnose sturgeon and less than 55% for Atlantic sturgeon (Dadswell et al. 1984).

Date of capture	**UTM 1**	**UTM 2**	**Capture Type**	**PIT tag #**	**Fork length (mm)**	**Weight (g)**	**Interorbital width (mm)**	**Inner mouth width (mm)**	**Outer mouth width (mm)**	**Snout length (mm)**	**Interorbital Inner mouth ratio**
4/30/2002	318832	3881880	Commercial bycatch	4163256D1B	639	1800	54.6	23.2	27.2	79.4	42.5 %
6/24/2002	308807	3896152	Gill-net survey	416345282D	992	6500	75.7	44.0	48.2	104.3	58.1 %
2/06/2003	317068	3883543	Commercial bycatch	41633F7800	561	1250	41.6	20.0	31.9	78.0	48.1 %
3/27/2003	320350	3881100	Commercial bycatch	4163487E4B	740	3050	54.1	31.8	41.8	90.0	58.8 %

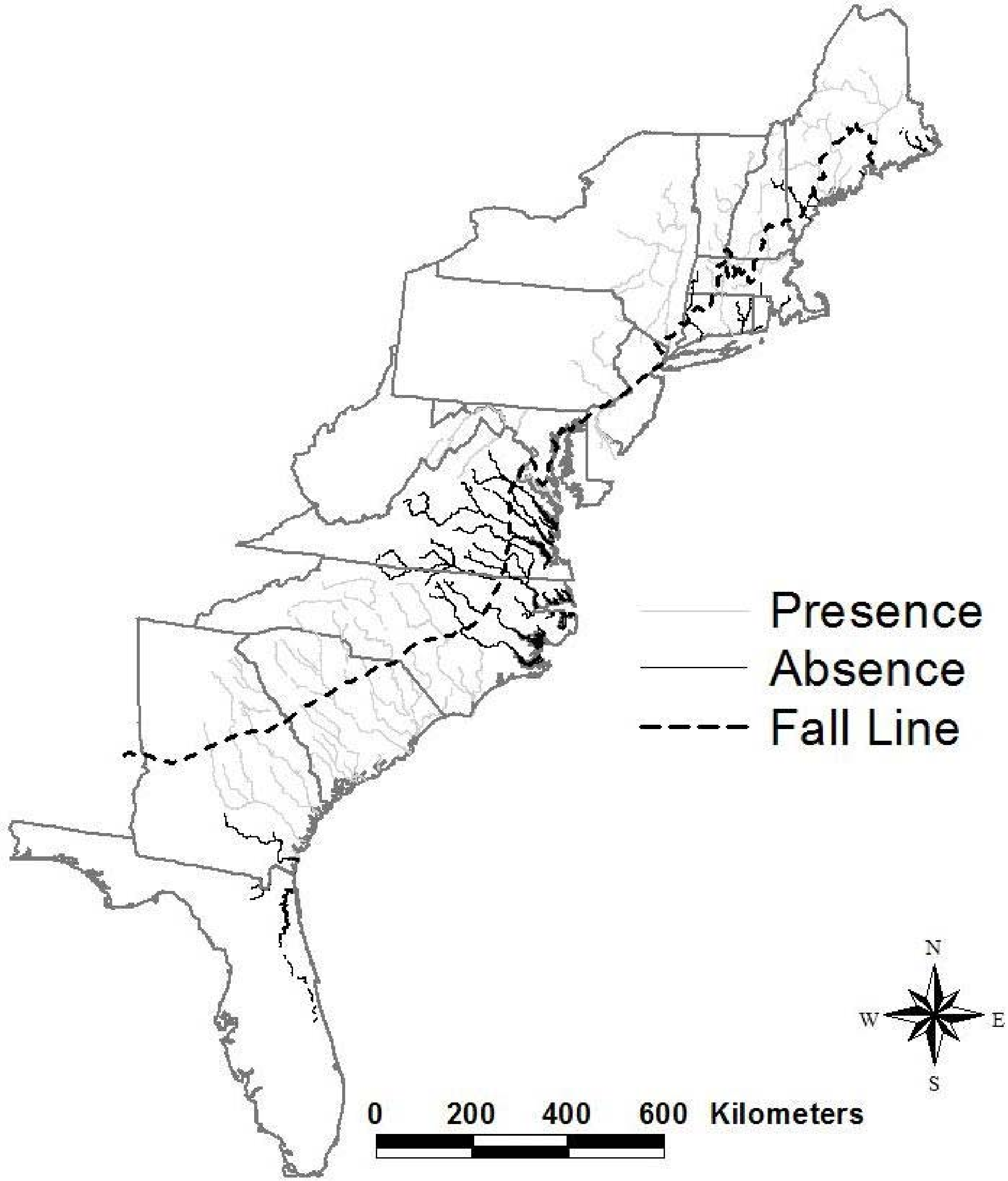


Figure 2.1 Atlantic Coast rivers that currently contain or lack a population of shortnose sturgeon.

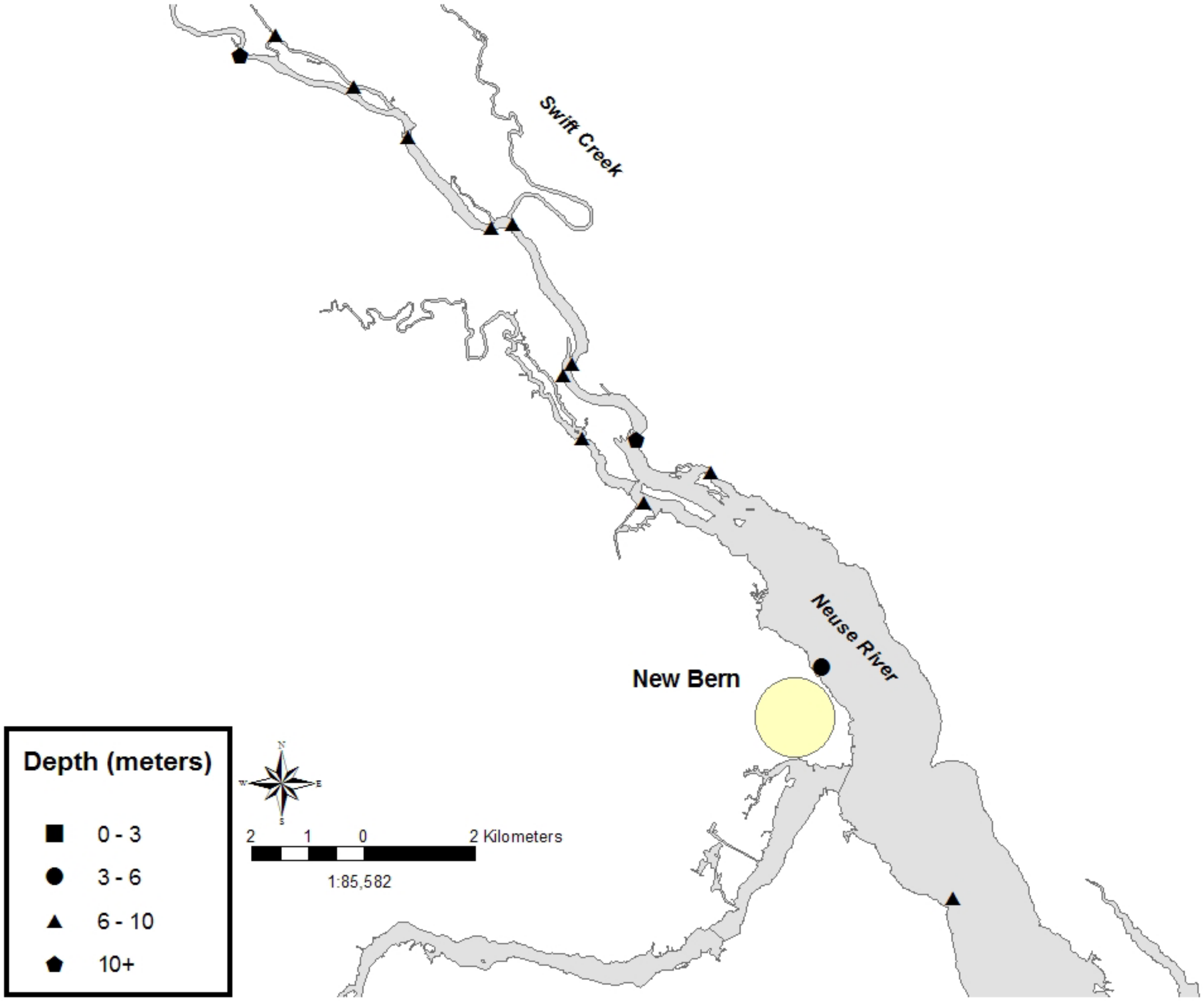


Figure 2.2 Summer netting locations within the saltwater-freshwater interface near New Bern, NC. Depths ranged from less than 6 m to greater than 10 m.

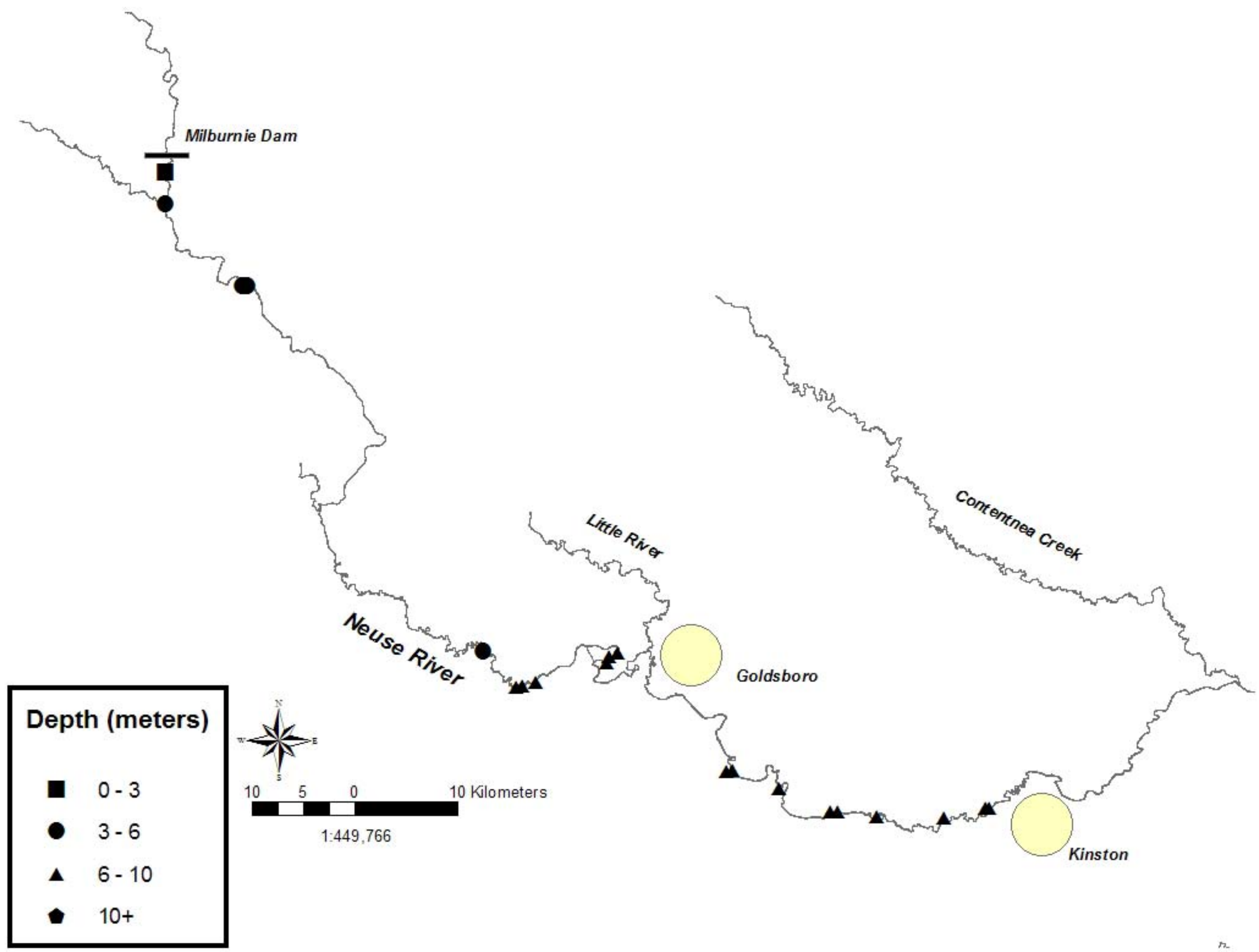


Figure 2.3 Spring netting locations in the upstream areas of the Neuse River. Depths ranged from less than 3 m to greater than 6 m.

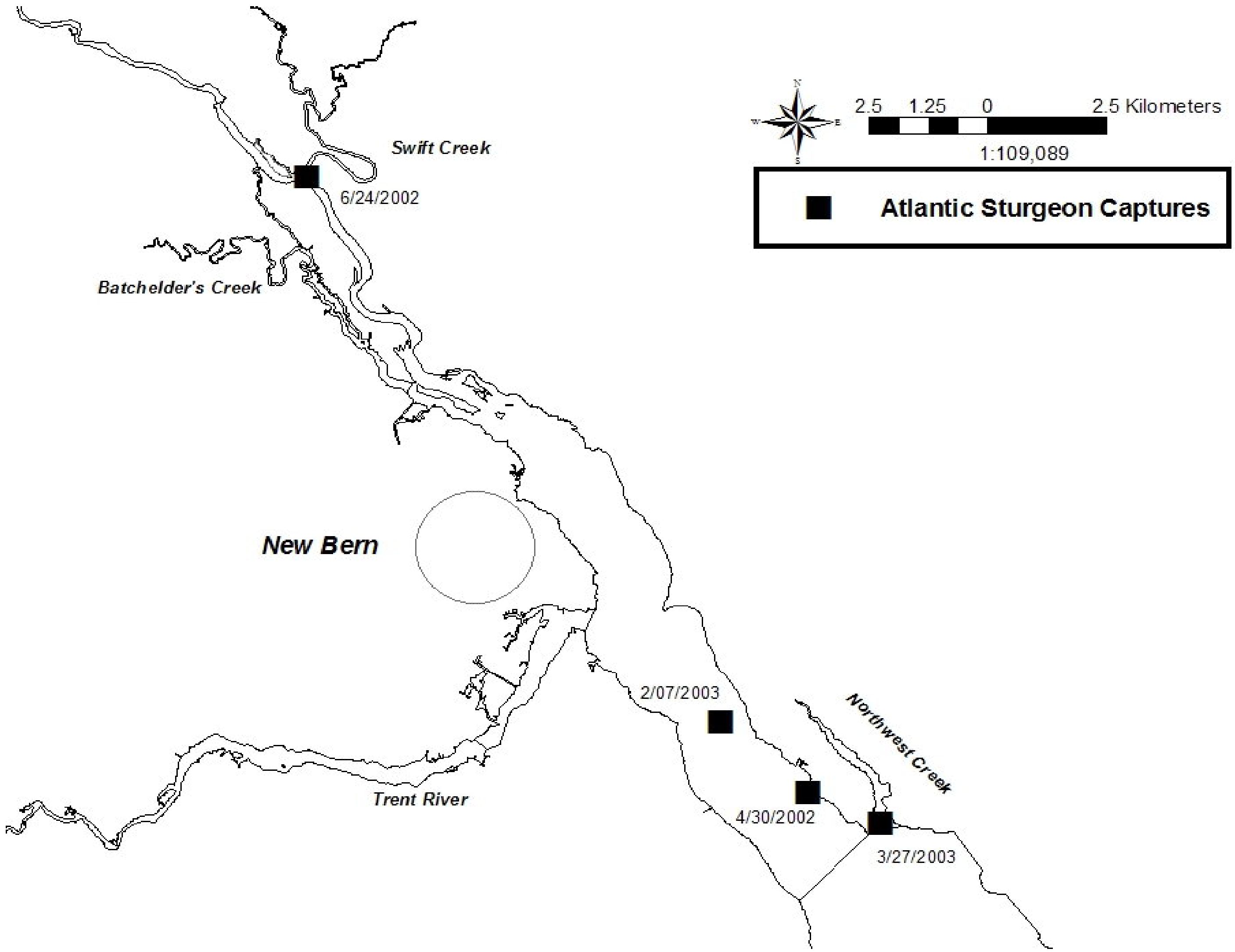


Figure 2.4 Juvenile Atlantic sturgeon captures in the Neuse River during 2001 - 2003.

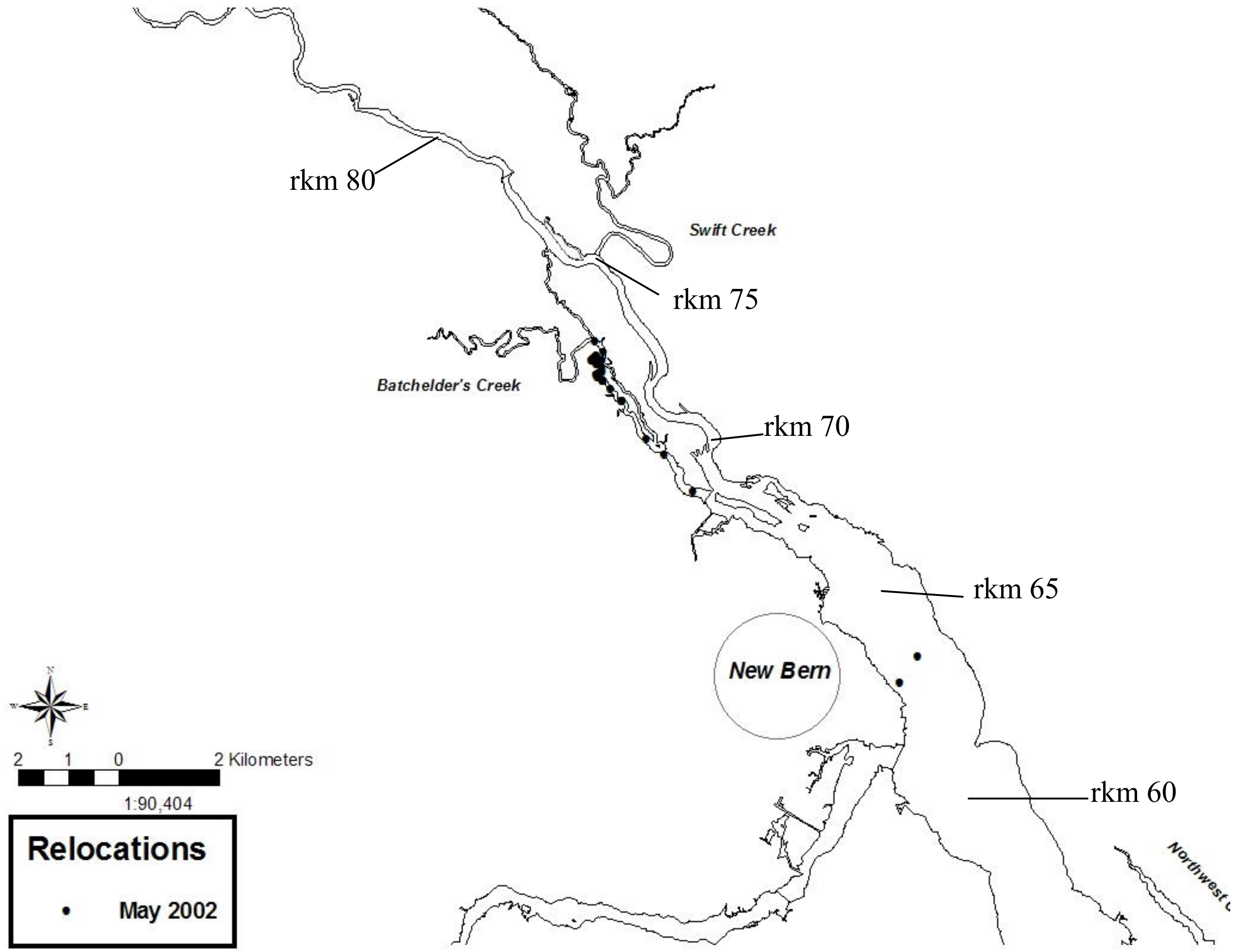


Figure 2.5 May 2002 telemetry relocations for juvenile Atlantic sturgeon (PIT #4163256D1B).

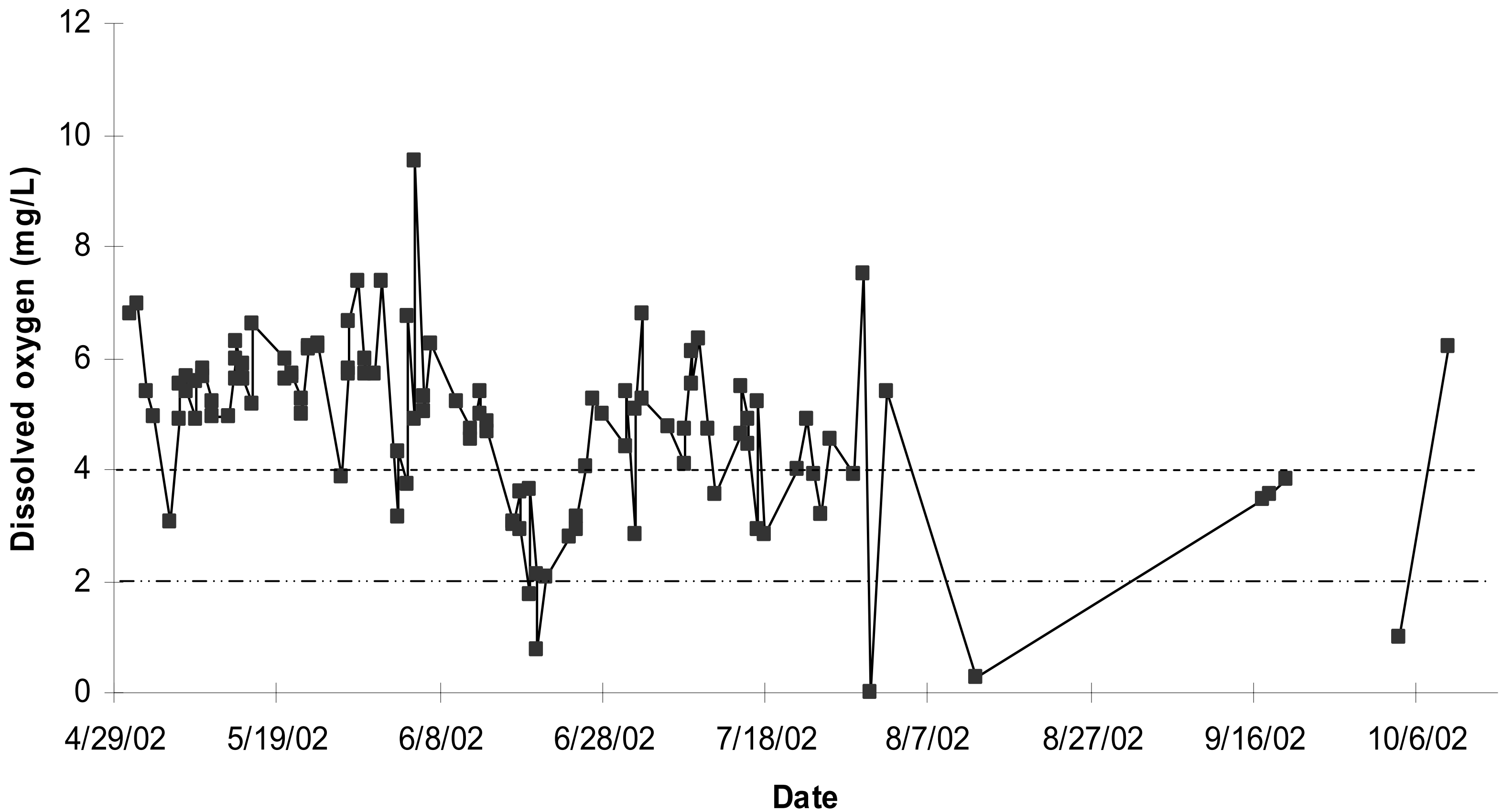


Figure 2.6 Bottom dissolved oxygen levels (mg/L) for relocations of telemetered juvenile Atlantic sturgeon (PIT tag # 4163256D1B). Severe hypoxic (< 2 mg/L) events were seen in mid June, late July, and early August (4.5 %). Hypoxic conditions (2 – 4 mg/L) were seen in 26.1 % of relocations.

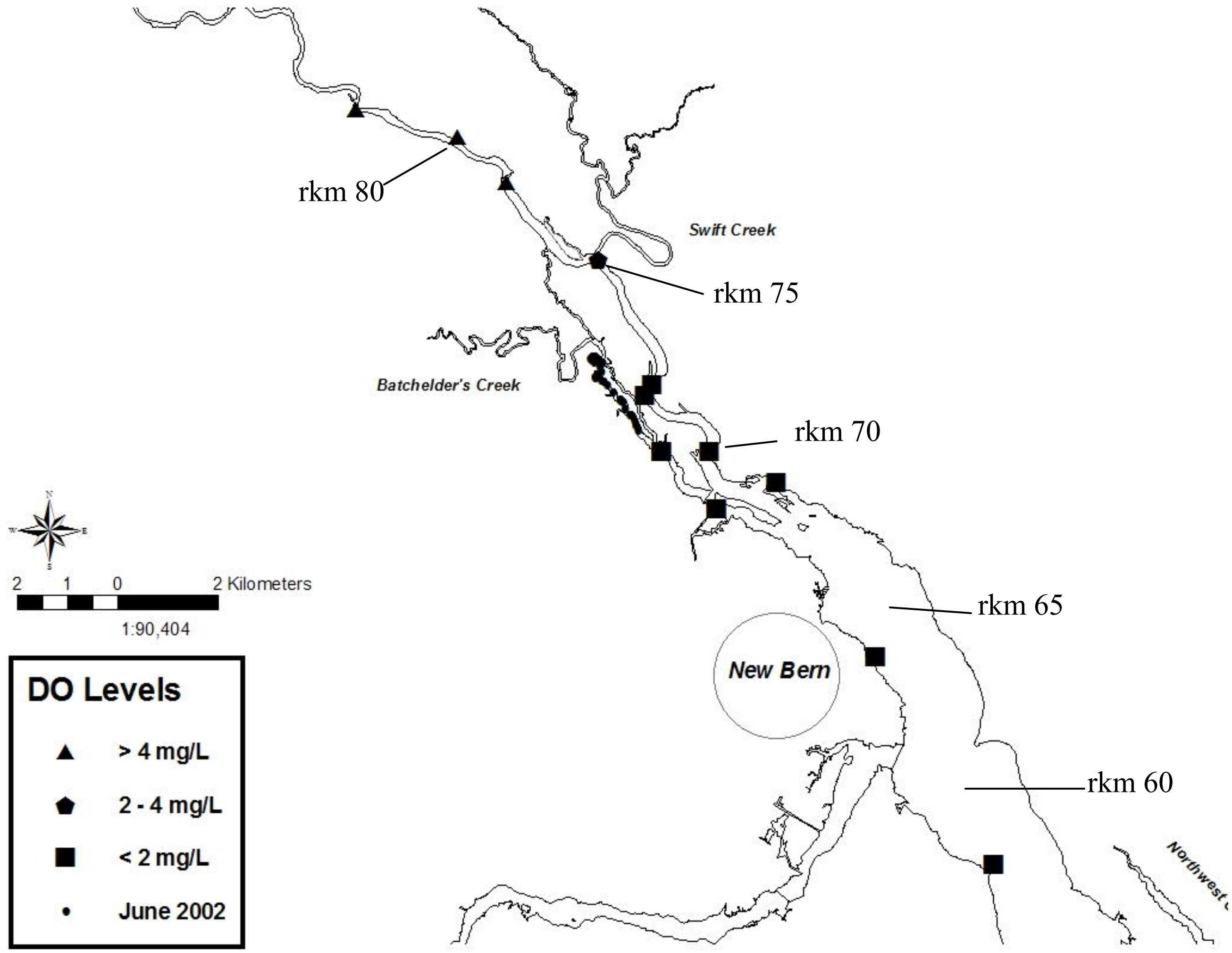


Figure 2.7 June 2002 telemetry relocations for juvenile Atlantic sturgeon (PIT #4163256D1B). Oxygen levels (minimum monthly value) in upstream locations were > 4 mg/L. Hypoxic (2 – 4 mg/L) conditions were seen at rkm 75, with severe hypoxia (< 2 mg/L) prevalent in downstream locations.

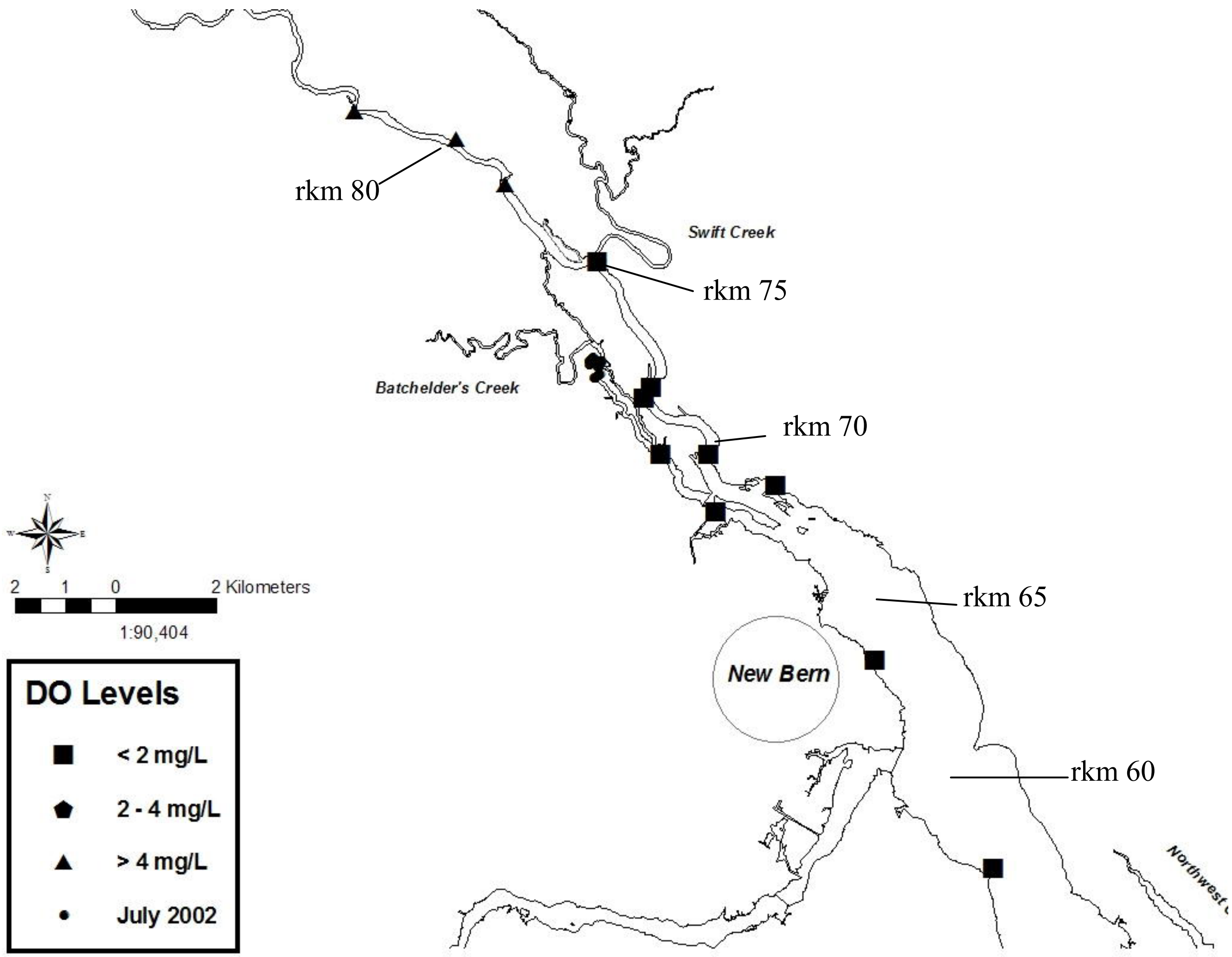


Figure 2.8 July 2002 telemetry relocations for juvenile Atlantic sturgeon (PIT #4163256D1B). Oxygen levels (minimum monthly value) in upstream locations were > 4 mg/L. Severe hypoxic conditions (< 2 mg/L) were seen downstream from rkm 75.

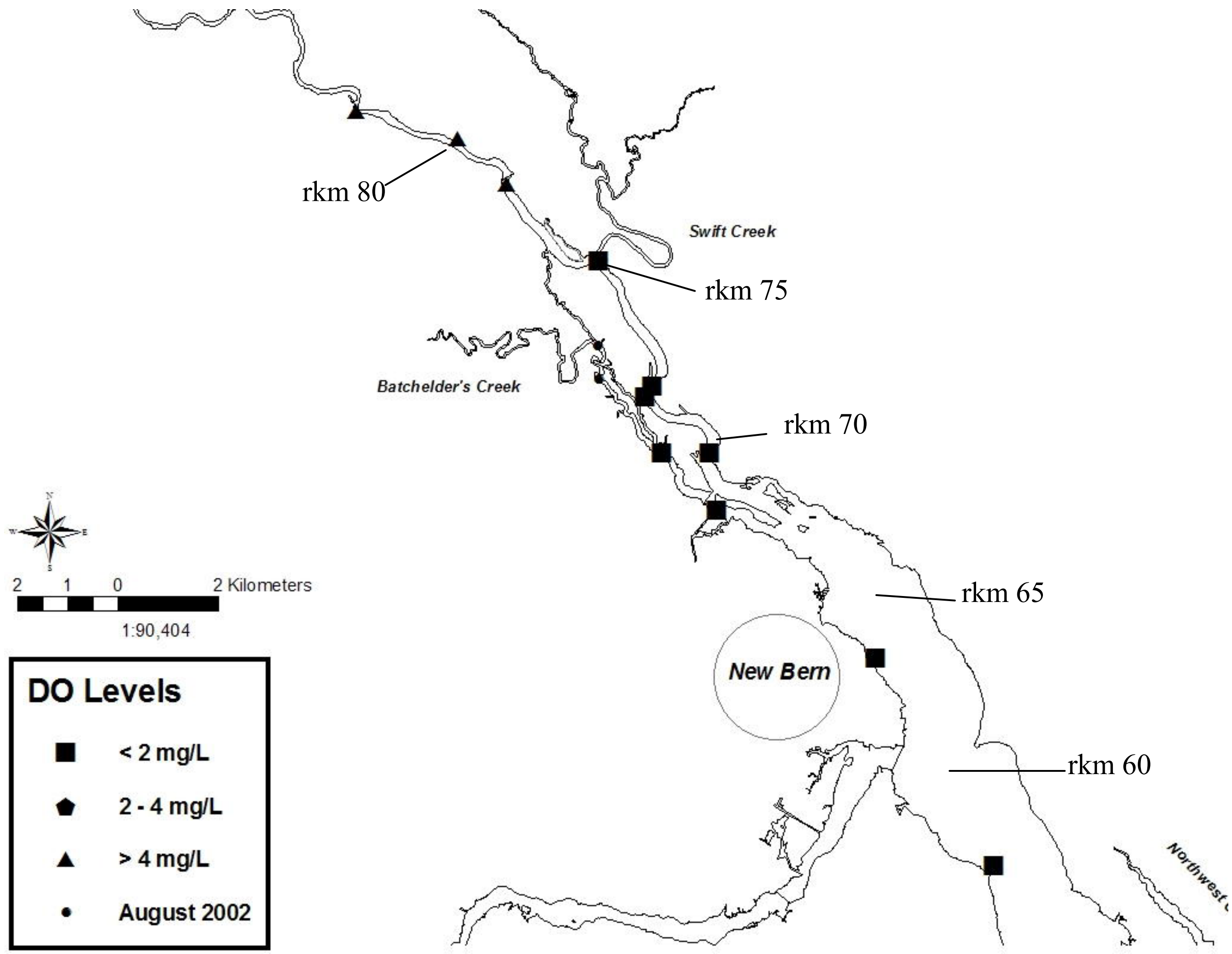


Figure 2.9 August 2002 telemetry relocations for juvenile Atlantic sturgeon (PIT #4163256D1B). Oxygen levels (minimum monthly value) in upstream locations were > 4 mg/L. Severe hypoxic conditions (< 2 mg/L) were seen downstream from rkm 75.

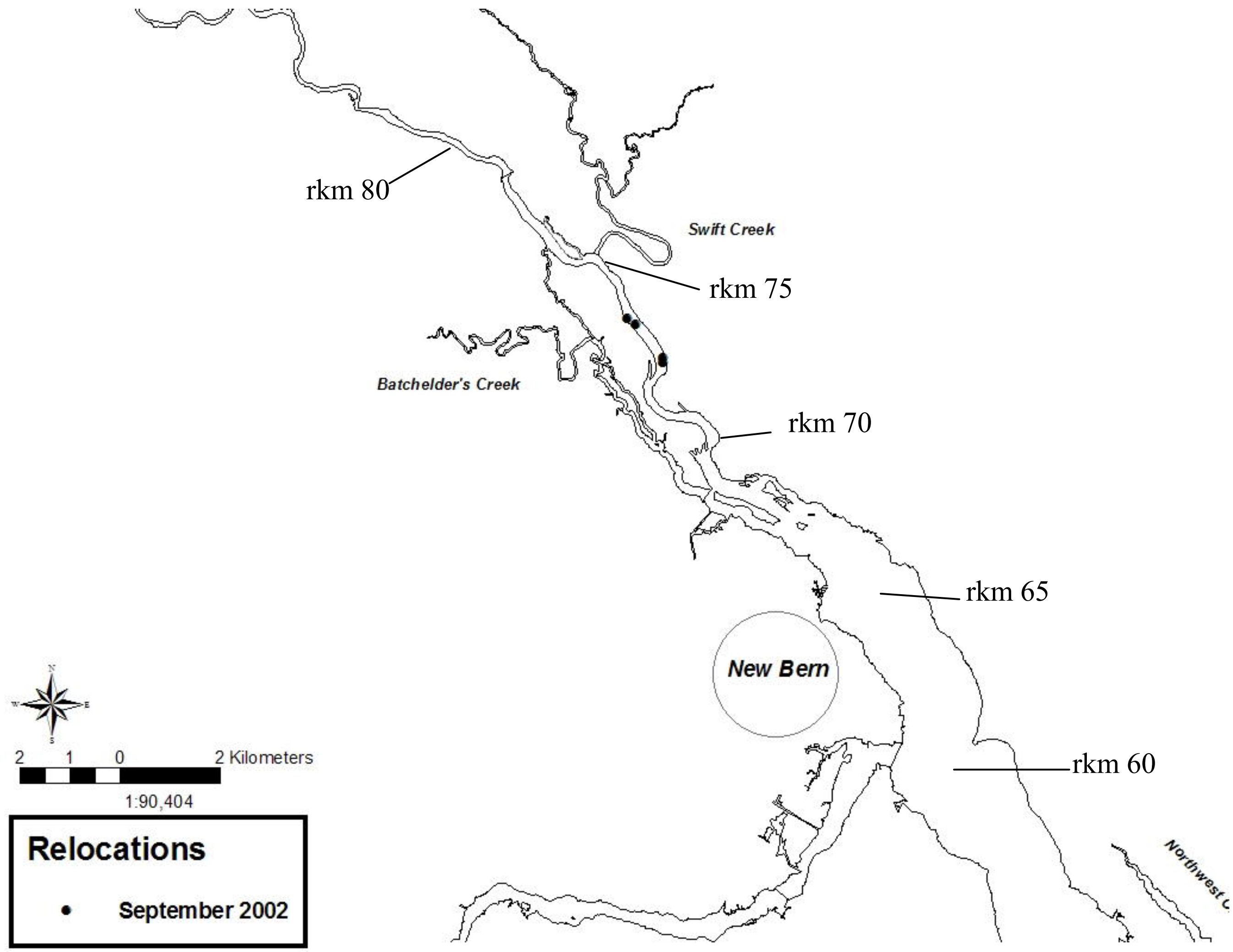


Figure 2.10 September 2002 telemetry relocations for juvenile Atlantic sturgeon (PIT #4163256D1B).

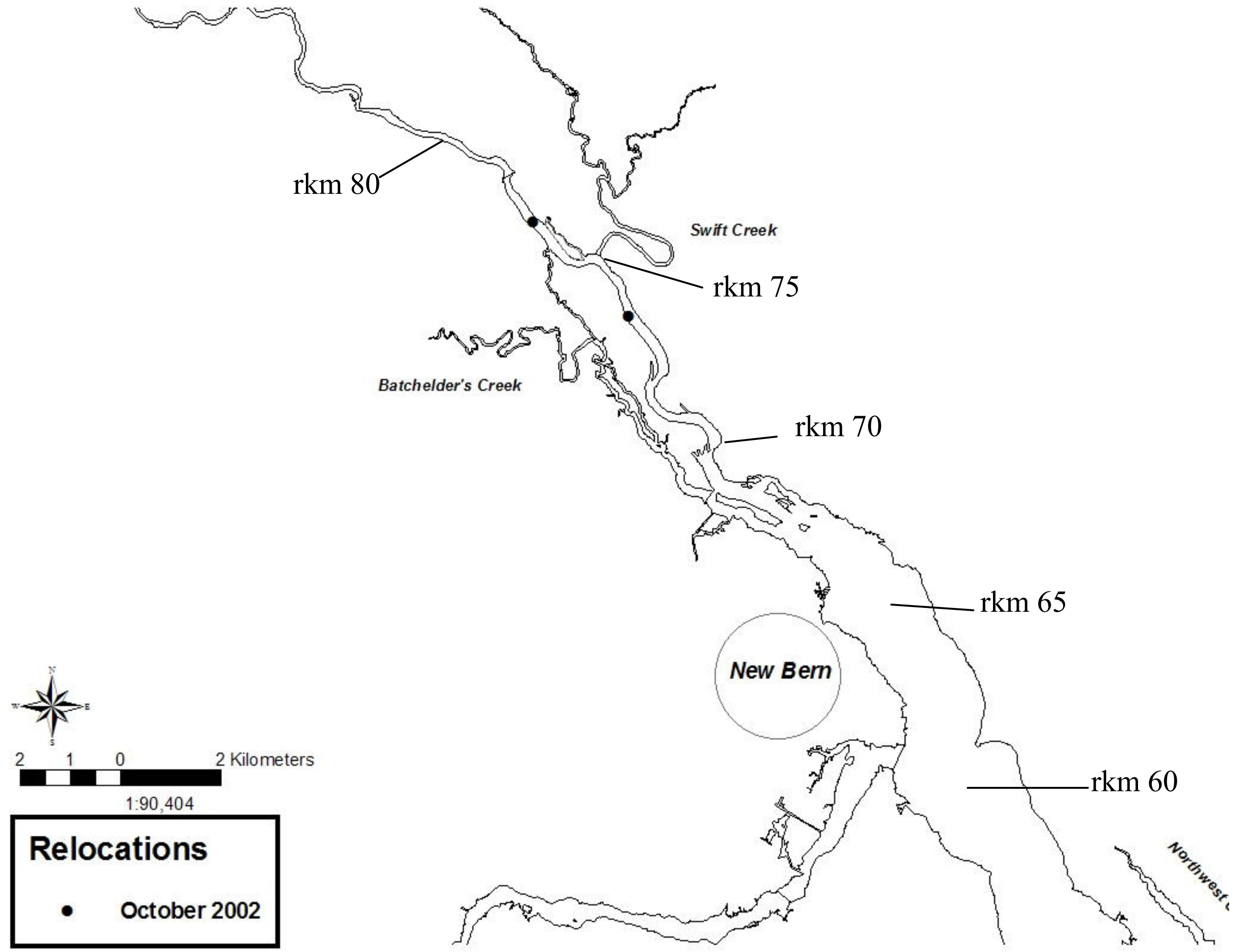


Figure 2.11 October 2002 telemetry relocations for juvenile Atlantic sturgeon (PIT #4163256D1B).

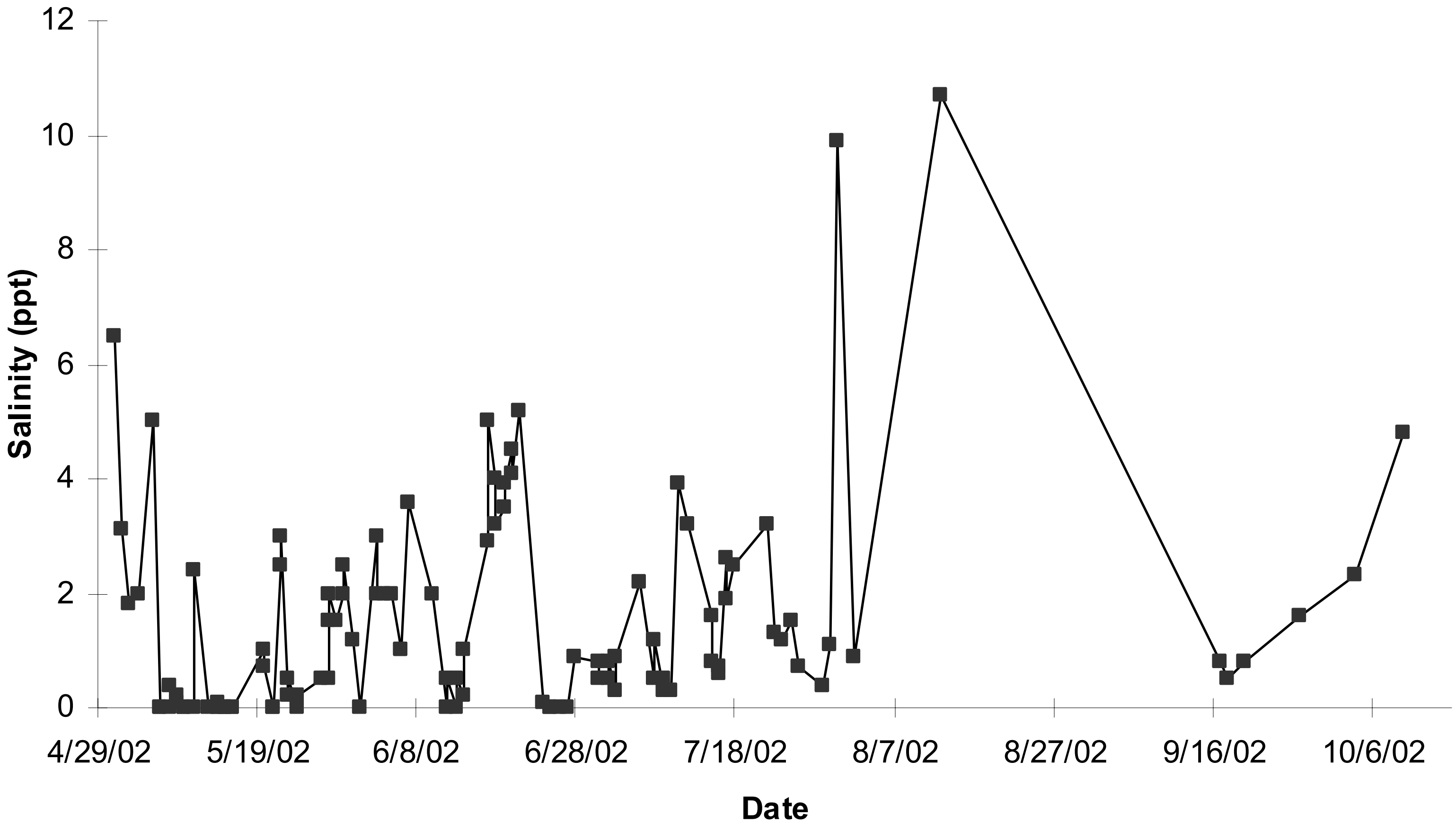


Figure 2.12 Bottom salinity levels (ppt) for relocations of telemetered juvenile Atlantic sturgeon (PIT tag # 4163256D1B). Typical relocation salinity levels ranged from 0 – 3 ppt

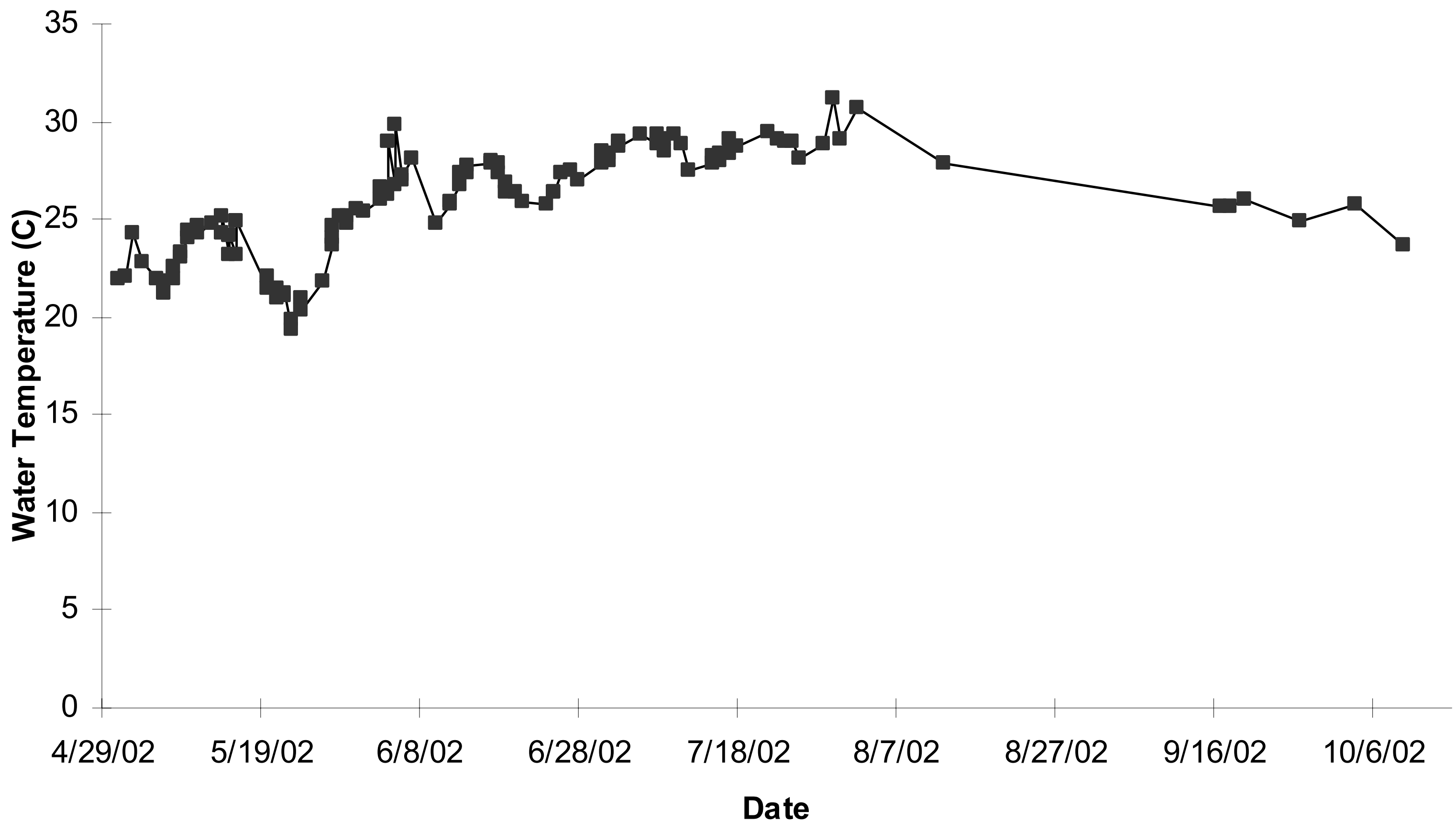


Figure 2.13 Bottom water temperatures (°C) for relocations of telemetered juvenile Atlantic sturgeon (PIT tag # 4163256D1B). May and October had lower temperatures, while summer months had increased water temperatures

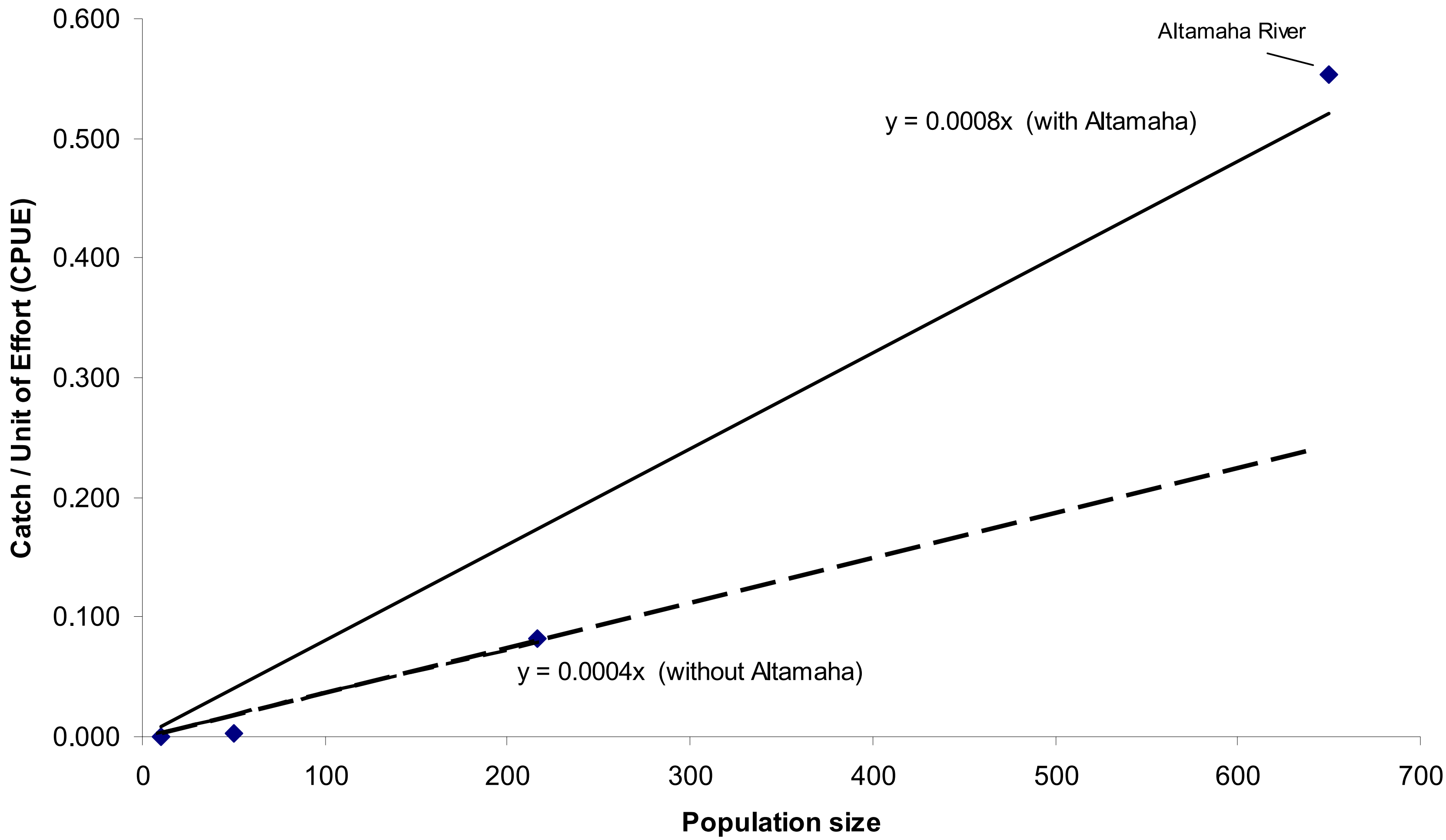


Figure 2.14 Linear relationship between CPUE and population size, when the Altamaha River system is included (solid line) or excluded (dashed line). The slope of the linear relationship is an estimate of catchability (q*).

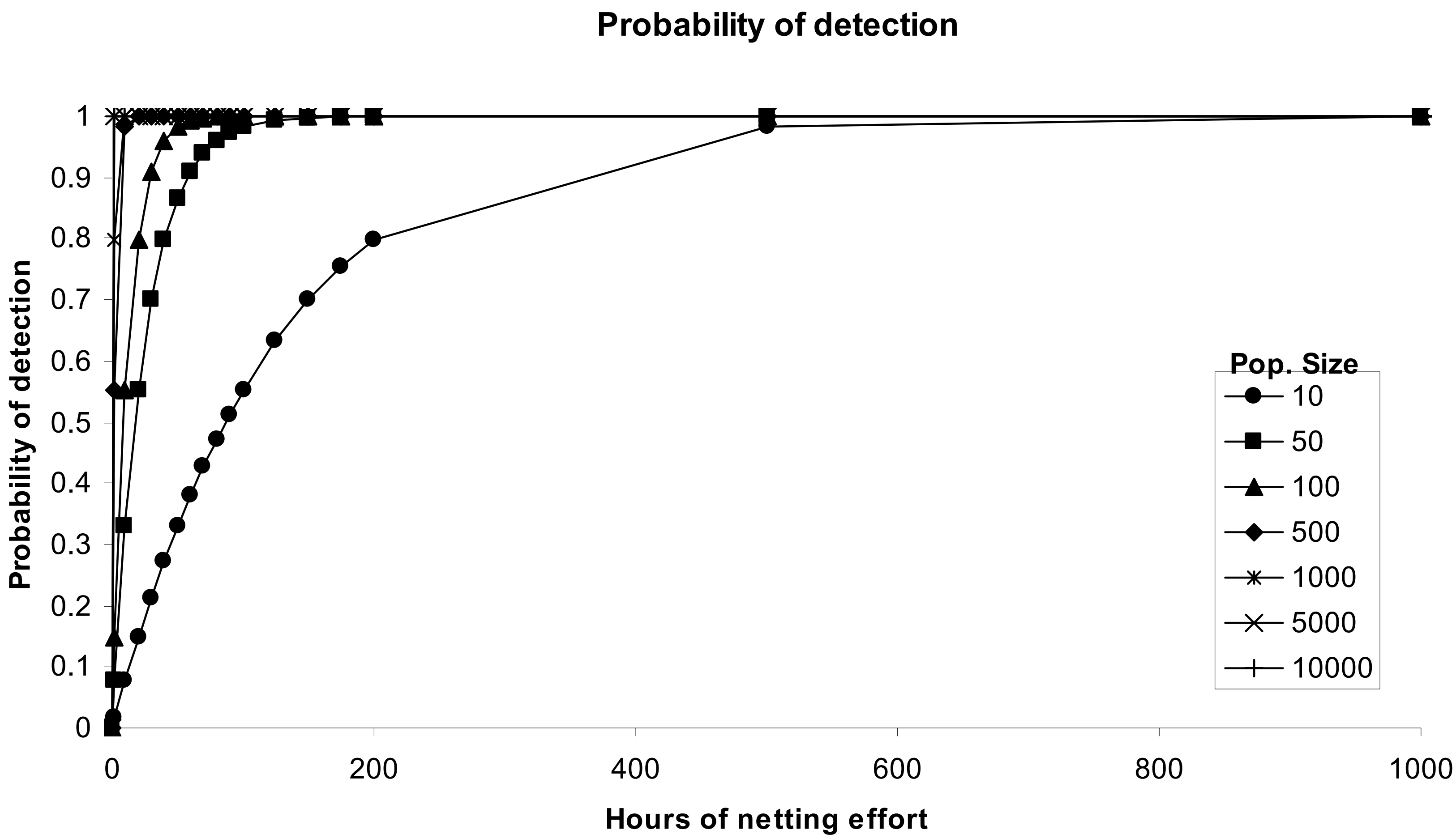


Figure 2.15 Detection probabilities for varying population levels when the catchability rate (q*) equals 0.0008. Population sizes above 10 have a probability of detection approximately one at 200 hours of effort.

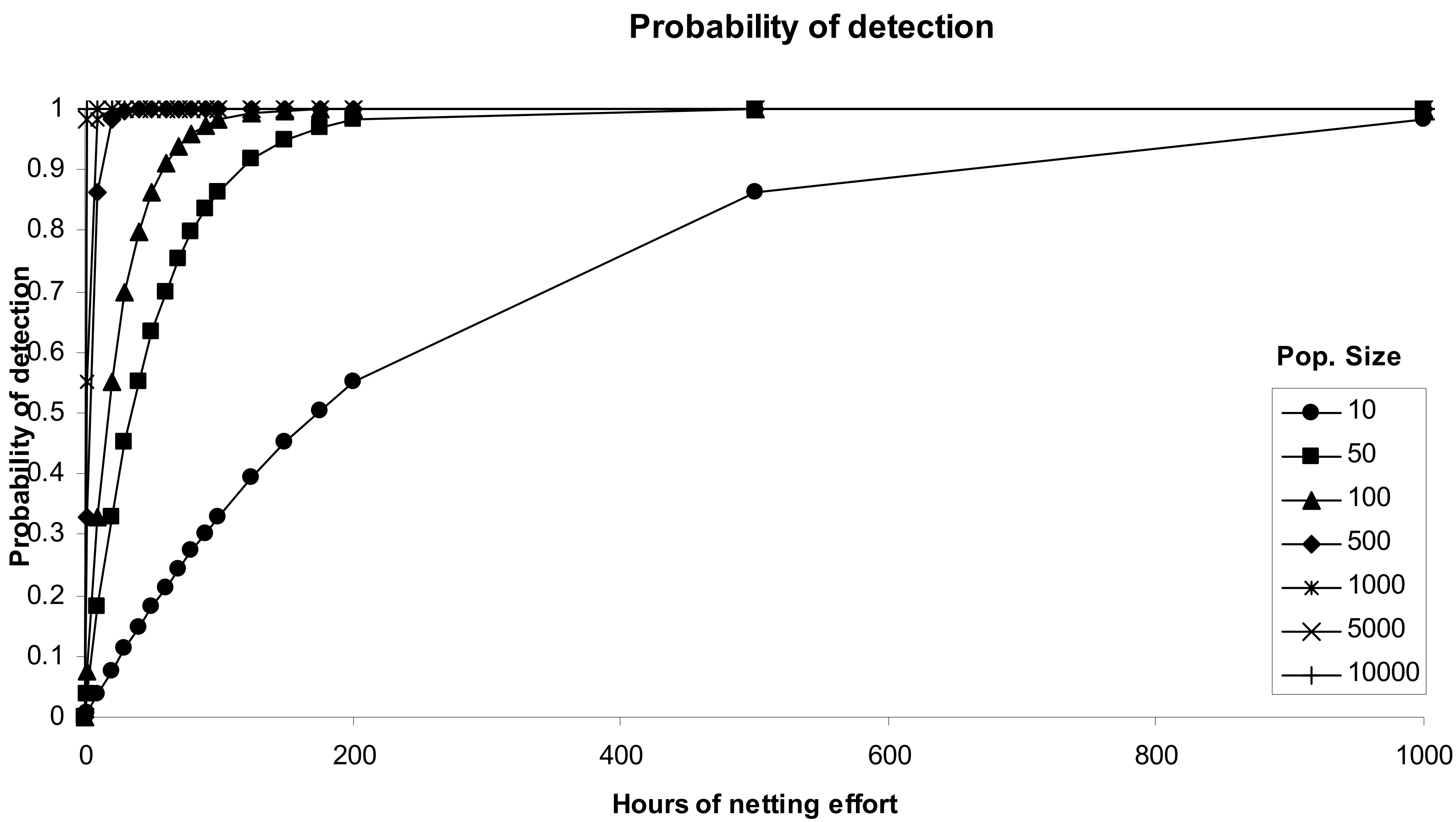


Figure 2.16 Detection probabilities for varying population levels when the catchability rate (q*) equals 0.0004. Population sizes greater than 10 have a detection probability approximately one at 500 hours of netting effort.

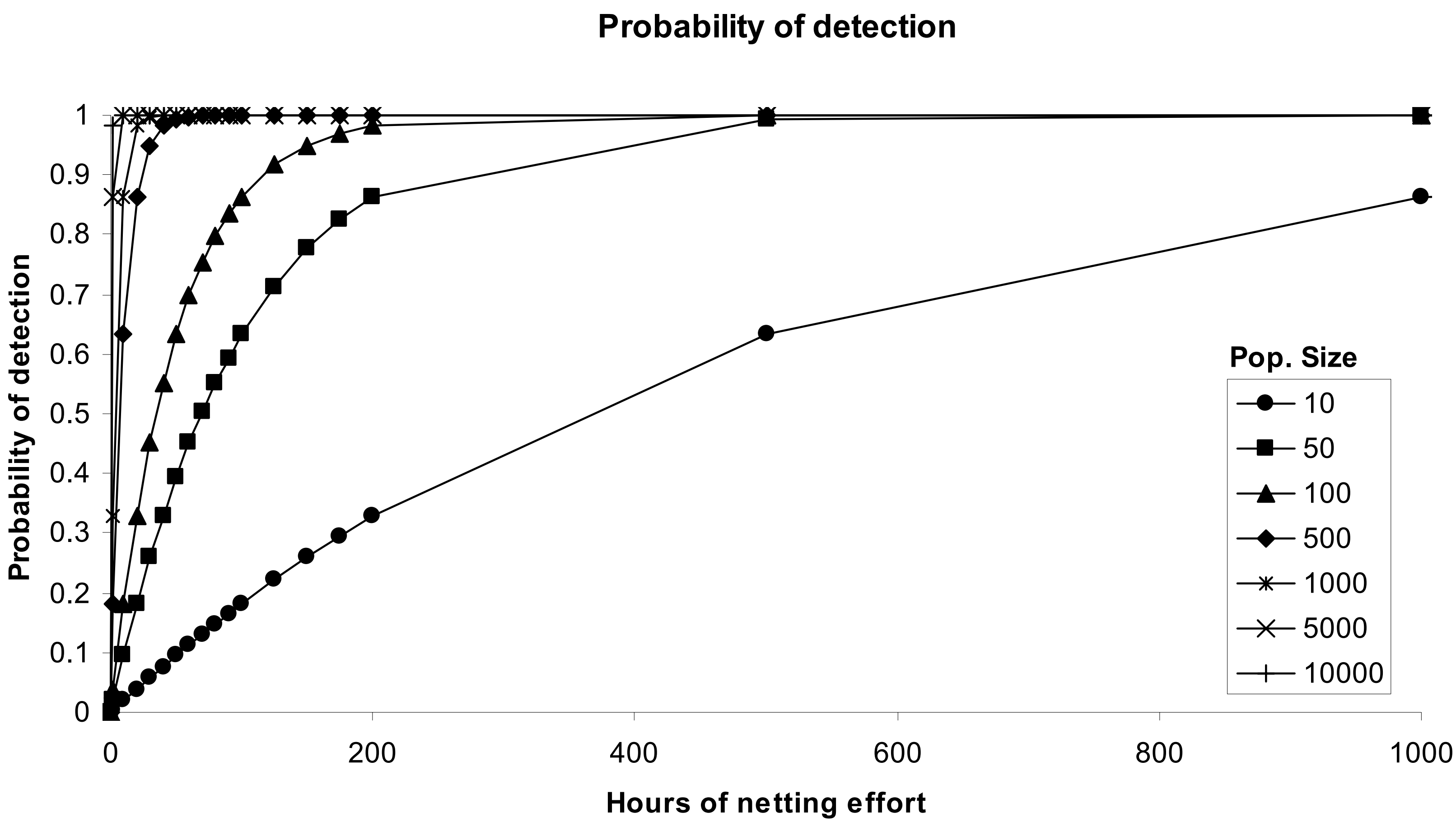


Figure 2.17 Detection probabilities for varying population levels when the catchability rate (q*) equals 0.0002. Population sizes greater than 10 have a detection probability approximately one at 500 hours of netting effort.

CHAPTER THREE

LOGISTIC REGRESSION MODELS

Introduction

Shortnose sturgeon historically occurred in Atlantic Coast rivers from Saint John River, New Brunswick, Canada to St. John's River, Florida (Kynard 1997). However, combinations of habitat loss and overfishing resulted in the populations in most rivers being extirpated or substantially reduced in abundance (National Marine Fisheries Service 1998). The species was listed by the U.S. Fish and Wildlife Service as endangered in 1967 (NMFS 1998). Presently, shortnose sturgeon are known to occur in the following northern rivers: Saint John, Penobscot, Kennebec system, Merrimack, Connecticut, Hudson, and Delaware (Dadswell 1979; Hastings et al 1987; Kieffer and Kynard 1996; Bain 1997; NMFS 1998). Southern populations are present in the following rivers: Cape Fear, Winyah Bay system, Santee-Cooper, Ashepoo-Combahee-Edisto (ACE) system, Savannah, Ogeechee, and Altamaha (Moser and Ross 1995; Rogers and Weber 1995; Collins and Smith 1997; NMFS 1998).

A few shortnose sturgeon have been collected within Chesapeake Bay, and the shortnose sturgeon recovery plan considers Chesapeake Bay to have a distinct population segment (NMFS 1998). However, genetic analyses, captures during a reward program, and telemetry results suggest that shortnose sturgeon in Chesapeake Bay may be transients from the Delaware River population (Welsh et al. 2002). There are no known populations of shortnose sturgeon within the tributary rivers of Chesapeake Bay, or the tributary rivers of the Albemarle and Pamlico Sounds of North Carolina (Figure 3.1). This gap in distribution could be due to several factors, including harvest bycatch, pollution, dams (inhibiting spawning migration), river flow regulation, poor water quality, and dredging of the saltwater-freshwater interface (Collins et al. 2000).

One factor that could account for the disjunct distribution is that, due to patchy distribution within a river and typically low population level, shortnose sturgeon are often undetected until direct surveys are conducted (NMFS 1998). No known surveys have been conducted for shortnose sturgeon in the tributaries of Chesapeake Bay. The NC Division of Marine Fisheries collected a single shortnose sturgeon in Albemarle Sound in 1998, but further work has not detected other individuals (Armstrong and Hightower 1999). Our current study has shown that shortnose sturgeon are either rare or extirpated from the Neuse River.

Two modeling approaches have been used to examine how habitat quantity or quality might affect shortnose sturgeon abundance. Kynard (1997) noted that the maximum upstream spawning location for shortnose sturgeon in unobstructed rivers was typically greater than 200 rkm. In river systems with dams, the maximum upstream spawning location was usually the lowermost dam unless the first dam was greater than 300 rkm upstream. Kynard also developed a nonlinear model relating population size to the maximum upstream spawning location. The model indicated that population size increased with increasing river length. Possible advantages of spawning far upstream include a lower risk of young contacting saltwater before salinity tolerance develops and a reduced risk of predation (Kynard 1997).

A second approach for examining habitat effects on shortnose sturgeon is through development of a habitat suitability model (Crance 1986). The model for shortnose sturgeon included components for adult summer feeding habitat and spring spawning habitat. The summer foraging component included variables for temperature, velocity and predominant substrate. Optimal habitat was defined as a mean water temperature of 11 – 22°C, a water column velocity of 15 – 45 cm/s, and predominate substrates of macrophytes, mud/clay, silt or sand. The spring spawning component also included variables for temperature, velocity and predominant substrate. Optimal habitat for spawning was defined as a mean water temperature of 10 – 16°C, a water column velocity of 30 – 76 cm/s and a substrate consisting of gravel, cobble or rubble.

Models that use large-scale physical characteristics to predict shortnose sturgeon presence or absence have not been developed. Our objective for this project was to determine if suitable habitat was available for shortnose sturgeon in the Neuse River, based on a model incorporating physical characteristics such as total length of river (km), distance to first dam or blockage (km), estimated annual mean flow (cfs), total watershed area (km^2), and total watershed area above fall line (km^2). If the Neuse River contains suitable habitat based on physical characteristics, the observed poor water quality during summer may be the primary habitat factor accounting for the apparent absence of shortnose sturgeon.

Methods

Presence/Absence

Model development required the identification of rivers that did or did not contain populations of shortnose sturgeon. The Shortnose Sturgeon Final Recovery Plan lists river systems along the Atlantic seaboard that currently contain populations of shortnose sturgeon (NMFS 1998). For our study, only those rivers that have a current population of shortnose sturgeon were included in the "presence" category. Rivers classified as having an "absence" of shortnose sturgeon were: rivers having no recent captures (St. Mary's and St. John's River, FL); rivers for which records occur only in the estuaries (Taunton, Blackstone, Pawcatuck, and Thames); and rivers where sampling for shortnose sturgeon has not detected their presence (Housatonic, Neuse, and Roanoke) (NMFS 1998). We did not include other river systems that appear to lack populations of shortnose sturgeon if directed surveys for shortnose sturgeon had not been conducted.

Determining physical characteristics

The following physical characteristics were examined as candidate variables in predictive models: total watershed area (km^2), total watershed area above fall line (km^2), total length (km), distance to first dam (km) or total length if undammed, and estimated mean annual flow (cfs). The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS 3.0; www.epa.gov/OST/BASINS) program was used to estimate these physical characteristics for each river. BASINS is a GIS-based program developed by the U.S. Environmental Protection Agency (EPA) for use by regional, state, and local agencies in performing watershed and water quality based studies. Data for river systems included in the analysis were downloaded from BASINS. Total length and distance to first dam were determined for each river using the attributes contained in the river reach file (coverage describing the stream network). Total watershed area was calculated using attributes associated with watershed polygons (Figure 3.2). EPA Level III ecoregion polygons within BASINS were used to establish location of the fall line using the boundary between coastal and piedmont regions. Total watershed area above the fall line was estimated by clipping ecoregion and total watershed polygons. Mean flow rates were estimated by BASINS using U.S. Geological Survey (USGS) gaging stations data. Habitat accessibility was not accounted for in calculating characteristics; therefore, in some systems, a portion of the total potential habitat (watershed area, watershed area above the fall line, total length) may be upstream of an impassible dam.

After calculating the five physical characteristics for each river system, a correlation matrix was developed to determine if any characteristics showed strong correlations. A reduced set of characteristics with correlations less than 0.90 were retained as candidate variables.

Model Development

Models to predict presence or absence of a shortnose sturgeon population were developed using logistic regression. Logistic regression models are nonlinear equations that relate one or more independent variables to a binary response variable. In this case, the binary response was presence or absence of a shortnose sturgeon population. The standard logistic regression function (Ramsey and Schafer 1997) describes the population proportion or probability (π) as

$$\pi = \frac{e^{\eta}}{1 + e^{\eta}} \qquad (1)$$

where

$$\eta = \beta_0 + \beta_1 X_1 + ... + \beta_p X_p$$

based on intercept (β_0), slopes (β_p), and independent variables (X_p). Parameter estimates were obtained with SAS® using the PROC LOGISTIC procedure. Overall model significance was determined through a standard chi-squared test (likelihood ratio test). Model selection was based on Akaike's Information Criterion (AIC):

$$\text{AIC} = -2 \log \text{likelihood} + 2\ (k + s)$$

where k is the number of ordered values for the response, and s is the number of explanatory variables (SAS 1990). The first term of the AIC tends to decrease as parameters are added to the model while the second term penalizes for each additional parameter (Burnham and Anderson 1998). Therefore, the model with the lowest calculated AIC value is considered the best approximation for information within the data. A useful approach for comparing alternative models is to calculate ΔAIC values:

$$\Delta\text{AIC}_i = \text{AIC}_i - \min(\text{AIC})$$

where min(AIC) is the lowest AIC values among the candidate models. Models with a ΔAIC of less than 2 are generally considered acceptable and should be used in inferences about the data, ΔAIC values between 4 and 7 have some support, and models with ΔAIC greater than 10 have virtually no support (Burnham and Anderson 1998).

Results

Thirty-seven rivers were selected for logistic regression analysis, 20 of which had a current population of shortnose sturgeon and the remaining 17 were reported to lack shortnose sturgeon (Table 3.1). Included river systems ranged latitudinally from Dennys River, ME to St. John's River, FL and in size from Ducktrap River, ME to Hudson River, NY.

A preliminary examination of all five characteristics suggested that large river systems typically have a higher probability of shortnose sturgeon presence (Figure 3.3). Rivers with a greater total length, watershed area, or mean annual flow more often contained a population of shortnose sturgeon. Rivers with greater distances to the first dam were also more likely to contain a population of shortnose sturgeon.

Correlations were relatively high and positive among the five physical characteristics (Table 3.2). Of the three variables that describe overall size of the river system (total watershed area, total length, and mean annual flow), we chose total length because correlations with the two remaining variables were less than 0.90. These remaining three physical characteristics (estimated watershed area above the fall line, total length, and distance to first dam) were used to fit all possible 1 – 3 variables models.

Based on a likelihood ratio test, overall model significance was less than 0.05 for all seven candidate models, indicating a significant effect of the 1 – 3 independent variables (Table 3.3). Five models had substantial support, based on ΔAIC values less than 2 (Table 3.3).

The three highest ranking candidate models based on ΔAIC values were estimated watershed area above the fall line combined with distance to first dam; estimated watershed area above the fall line; and total length. The models performed well in predicting absence of a shortnose sturgeon population ($\hat{\pi} < 0.5$) but were less effective in predicting presence (Tables 3.4 – 3.5). Errors in predicting presence or absence in a river system occurred for all three models (e.g. Waccamaw, Roanoke). The Neuse River had a high probability of shortnose sturgeon presence in the models for estimated watershed area above the fall line combined with distance to first dam ($\hat{\pi} = 0.729$) and total length ($\hat{\pi} = 0.747$) but would be predicted not to contain shortnose sturgeon in the model for estimated watershed area above the fall line ($\hat{\pi} = 0.489$). The Roanoke River had high probabilities for all three models: $\hat{\pi} = 0.915$ (estimated watershed area above the fall line combined with distance to first dam), $\hat{\pi} = 0.918$ (estimated watershed area above the fall line), and $\hat{\pi} = 0.862$ (total length).

Discussion

Current modeling efforts demonstrate that five models (based on AIC) may be useful in predicting the probability of shortnose sturgeon presence in river systems. However, the similarity among AIC values may be due in part to low sample size and the correlations among variables (Burnham and Anderson 1998). Increasing the sample size substantially is unlikely because shortnose sturgeon only inhabit Atlantic Coast drainages where there is a continued lack of information on the status of shortnose sturgeon. Some progress might be made by adding variables that are uncorrelated to the existing physical characteristics (e.g. measures of estuaries habitat quality).

According to the three highest ranked models we considered, the Neuse and Roanoke rivers would be expected to contain a population of shortnose sturgeon. Both rivers are predicted to have adequate estimated watershed area above the fall line when combined with distance to the first dam and river size (total length). The Neuse River differs from the Roanoke River by having a lower predicted probability of presence when considering estimated watershed area above the fall line.

Large estuaries may be a key factor affecting recovery of shortnose sturgeon in mid-Atlantic drainages. These estuaries may inhibit proper flushing of critical summer habitat, resulting in poor water quality conditions. For example, the Neuse River flows into Pamlico Sound and has negligible flow within the freshwater-saltwater interface during summer. Summer temperatures in the freshwater-saltwater interface typically exceed 27 °C; thus, predicted habitat suitability during summer would be essentially zero based on the current HSI model. Poor flushing of summer habitat might account for the apparent lack of shortnose sturgeon in tributaries of Chesapeake Bay, Albemarle Sound, and Pamlico Sound.

Higher flushing rates may account for the presence of shortnose sturgeon in some southern rivers further south (e.g. Cape Fear, Savannah). The higher flushing rates in rivers flowing directly into the ocean could result in higher dissolved oxygen levels and lower temperatures. For example, summer habitat within the Savannah River (Collins et al. 2002) was well oxygenated (mean dissolved oxygen = 6.85 mg/L), in comparison to severe hypoxic conditions encountered in the Neuse River.

Another physical characteristic that could be important is the presence of freshwater springs. Small rivers that have low summer flows may still maintain a population of shortnose sturgeon if springs provide a refuge (Collins et al. 2000). There is some evidence that springs are important in summer habitat locations of Gulf of Mexico sturgeon (Chapman and Carr 1995; Clugston et al. 1995; Carr et al. 1996; Foster and Clugston 1997; Hightower et al. 2002).

The current suite of models is a first step in determining overall characteristics of river systems that would be expected to contain shortnose sturgeon. The models should be useful for identifying mid-Atlantic rivers that should (but do not) contain shortnose sturgeon. Such rivers might be suitable candidates for restoration programs if habitat quality is adequate or can be improved.

Further modeling efforts might include the addition of variables that characterize the degree of eutrophication within estuarine summer habitats (National Oceanic and Atmospheric Administration 1997). It would also be useful to test whether large estuaries (Chesapeake Bay; Albemarle and Pamlico Sounds) have an effect on presence of shortnose sturgeon. If sufficient data are available regarding springs, future models could include whether southern rivers that retain shortnose sturgeon populations have freshwater springs that provide a physiochemical refugia during summer (Collins et al. 2000). Modeling efforts would also be aided by field surveys to confirm the presence or absence of shortnose sturgeon in tributaries of Chesapeake Bay. If improved models can be developed, they should be helpful for prioritizing shortnose sturgeon restoration efforts among river systems.

The primary goal of the Shortnose Sturgeon Recovery Plan is to remove the species from the endangered species list by 2024 (NMFS 1998). Current information about the status of populations indicates that many are small in size and have habitat quality problems that may hamper recovery efforts (Kynard 1997). Steps to improve water quality in coastal rivers and estuaries will aid in the recovery of southern shortnose sturgeon populations (Collins et al. 2000).

Table 3.1 Physical characteristics for each river system. Distance to first dam is assumed to be equivalent to total river length in undammed rivers.

State	River System	SNS Presence	Estimated Watershed Area (km^2)	Estimated Watershed Area above Fall Line (km^2)	Distance to first dam (rkm)	Estimated Mean Annual Flow (cfs)	Total Length (rkm)
ME	Penobscot	YES	25580	23800	50	14554	401
ME	Sheepscot	YES	3620	0	8	381	63
ME	Kennebec	YES	17530	12323	42	9652	237
ME	Androscoggin	YES	10330	9457	14	6489	378
NH/MA	Merrimack	YES	14420	7775	49	7894	301
MA/CT	Connecticut	YES	32070	26930	143	18970	660
NY	Hudson	YES	46540	42897	280	20328	547
NJ/DE/PA	Delaware	YES	37550	27662	579	22111	682
MD	Potomac	YES	39590	32146	698	14747	698
NC	Cape Fear	YES	25110	10413	95	11215	476
SC	Waccamaw	YES	4170	0	214	1865	214
SC	Pee Dee	YES	38030	21311	276	17517	666
SC	Black	YES	5170	0	216	1367	224
SC	Santee	YES	39240	31865	119	18751	684
SC	Edisto	YES	7750	227	280	2299	280
SC	Ashepoo	YES	1262	0	78	538	78
SC	Combahee	YES	3195	0	163	1282	163
SC/GA	Savannah	YES	26410	18886	317	12555	591
GA	Ogeechee	YES	14440	1207	375	4193	375
GA	Altamaha	YES	35590	15509	400	15419	613

Table 3.1 Continued

State	River System	SNS Presence	Estimated Watershed Area (km^2)	Estimated Watershed Area above Fall Line (km^2)	Distance to first dam (rkm)	Estimated Mean Annual Flow (cfs)	Total Length (rkm)
ME	Dennys	NO	1277	0	29	279	29
ME	East Machias	NO	740	0	53	545	69
ME	Machias	NO	1326	0	125	1540	125
ME	Ducktrap	NO	117	0	16	57	16
ME	Royal	NO	430	60	1	281	45
ME	Saco	NO	4940	4736	8	3455	206
ME	Presumpscot	NO	2932	2105	2	1188	127
MA	Taunton	NO	1485	0	66	489	66
RI	Blackstone	NO	3625	0	8	949	79
RI	Pawcatuck	NO	1080	0	11	609	60
CT	Thames	NO	14310	0	31	2580	113
CT	Housatonic	NO	5430	3625	23	3296	229
NC	Roanoke	NO	25560	22399	151	8119	568
NC	Neuse	NO	14430	4814	328	5896	443
GA	Satilla	NO	10300	0	314	2637	314
GA/FL	St. Marys	NO	3860	0	196	1740	196
FL	St. Johns	NO	22160	0	184	8673	451

Table 3.2 Correlation matrix for five physical characteristics. Highly correlated variables (>0.9) are not included in logistic regression models.

	Estimated Watershed Area	**Estimated Watershed Area above the Fall Line**	**Distance to First Dam**	**Estimated Mean Annual Flow**	**Total Length**
Estimated Watershed Area	1.000	0.915	0.599	0.964	0.931
Estimated Watershed Area above the Fall Line	0.915	1.000	0.465	0.924	0.830
Distance to First Dam	0.599	0.465	1.000	0.524	0.677
Estimated Mean Annual Flow	0.964	0.924	0.524	1.000	0.911
Total Length	0.931	0.830	0.677	0.911	1.000

Table 3.3 Parameter estimates, standard errors, model significance, and AIC model selection for all models used to predict presence of shortnose sturgeon for river systems.

# of X parameters	*Intercept*	*SE*	**Estimated Watershed Area above the Fall Line**		**Distance to First Dam**		**Total Length**		*Likelihood Ratio Test*	*AIC*	*ΔAIC*
			β_1	*SE*	*β_1*	*SE*	*β_1*	*SE*			
3	1.1487	0.7491	-0.00016	0.00012	-0.0067	0.0055	0.0021	0.0055	0.0026	44.81	1.85
2	1.3097	0.6249	-0.00013	0.00006	-0.0051	0.0034			0.0009	42.96	0.00
2	1.2405	0.7290	-0.00008	0.00008			-0.0031	0.0033	0.0019	44.50	1.54
2	1.5976	0.0037			-0.0018	0.0037	-0.0052	0.0026	0.0032	45.54	2.58
1	0.7775	0.5203			-0.0065	0.0030			0.0100	48.42	5.46
1	1.5634	0.6784					-0.0060	0.0021	0.0008	43.78	0.82
1	0.7191	0.4465	-0.00014	0.00006					0.0006	43.40	0.44

Table 3.4 Probability of shortnose sturgeon presence based on model estimation.

State	River System	SNS Presence	Est. Water Area above the FL & Dist. to Dam *Predicted Presence*	Estimated Watershed Area above the Fall Line *Predicted Presence*	Total Length *Predicted Presence*
SC/GA	Savannah	YES	0.941	0.873	0.878
SC	Ashepoo	YES	0.213	0.328	0.251
SC	Great PeeDee	YES	0.946	0.906	0.918
SC	Waccamaw	YES	0.213	0.328	0.430
SC	Combahee	YES	0.213	0.328	0.356
SC	Edisto	YES	0.218	0.335	0.528
SC	Santee	YES	0.969	0.977	0.926
SC	Black	YES	0.448	0.328	0.444
NY	Hudson	YES	0.997	0.995	0.847
NJ/DE/PA	Delaware	YES	0.995	0.959	0.925
NH/MA	Merrimack	YES	0.487	0.591	0.559
NC	Cape Fear	YES	0.629	0.677	0.783
ME	Kennebec	YES	0.624	0.732	0.463
ME	Penobscot	YES	0.885	0.932	0.697
ME	Androscoggin	YES	0.497	0.647	0.668
ME	Sheepscot	YES	0.219	0.328	0.234
MD	Potomac	YES	0.946	0.978	0.932
MA/CT	Connecticut	YES	0.949	0.955	0.915
GA	Altamaha	YES	0.940	0.810	0.891
GA	Ogeechee	YES	0.240	0.366	0.664
FL	St. Johns	NO	0.408	0.328	0.756
ME	East Machias	NO	0.261	0.328	0.241
GA/FL	St. Marys	NO	0.213	0.328	0.403
GA	Satilla	NO	0.213	0.328	0.578
RI	Blackstone	NO	0.219	0.328	0.251
RI	Pawcatuck	NO	0.222	0.328	0.231
NC	Neuse	NO	0.729	0.489	0.747
NC	Roanoke	NO	0.915	0.918	0.862
ME	Presumpscot	NO	0.264	0.395	0.309
ME	Royal	NO	0.215	0.329	0.215
ME	Saco	NO	0.342	0.486	0.418
ME	Dennys	NO	0.213	0.328	0.199
ME	Ducktrap	NO	0.213	0.328	0.187
ME	Machias	NO	0.213	0.328	0.307
MA	Taunton	NO	0.213	0.328	0.237
CT	Housatonic	NO	0.327	0.447	0.451
CT	Thames	NO	0.240	0.328	0.291

Table 3.5 Efficiency of the three best models based on AIC values.

Model	**Presence**		**Absence**	
	Correct	*Misclassified*	*Correct*	*Misclassified*
Estimated Watershed Area above the Fall Line & Distance to First Dam	55.0 %	45.0 %	88.2 %	11.8 %
Estimated Watershed Area above the Fall Line	65.0 %	35.0 %	94. 1 %	5.9 %
Total Length	70.0 %	30.0 %	76.5 %	23.5 %

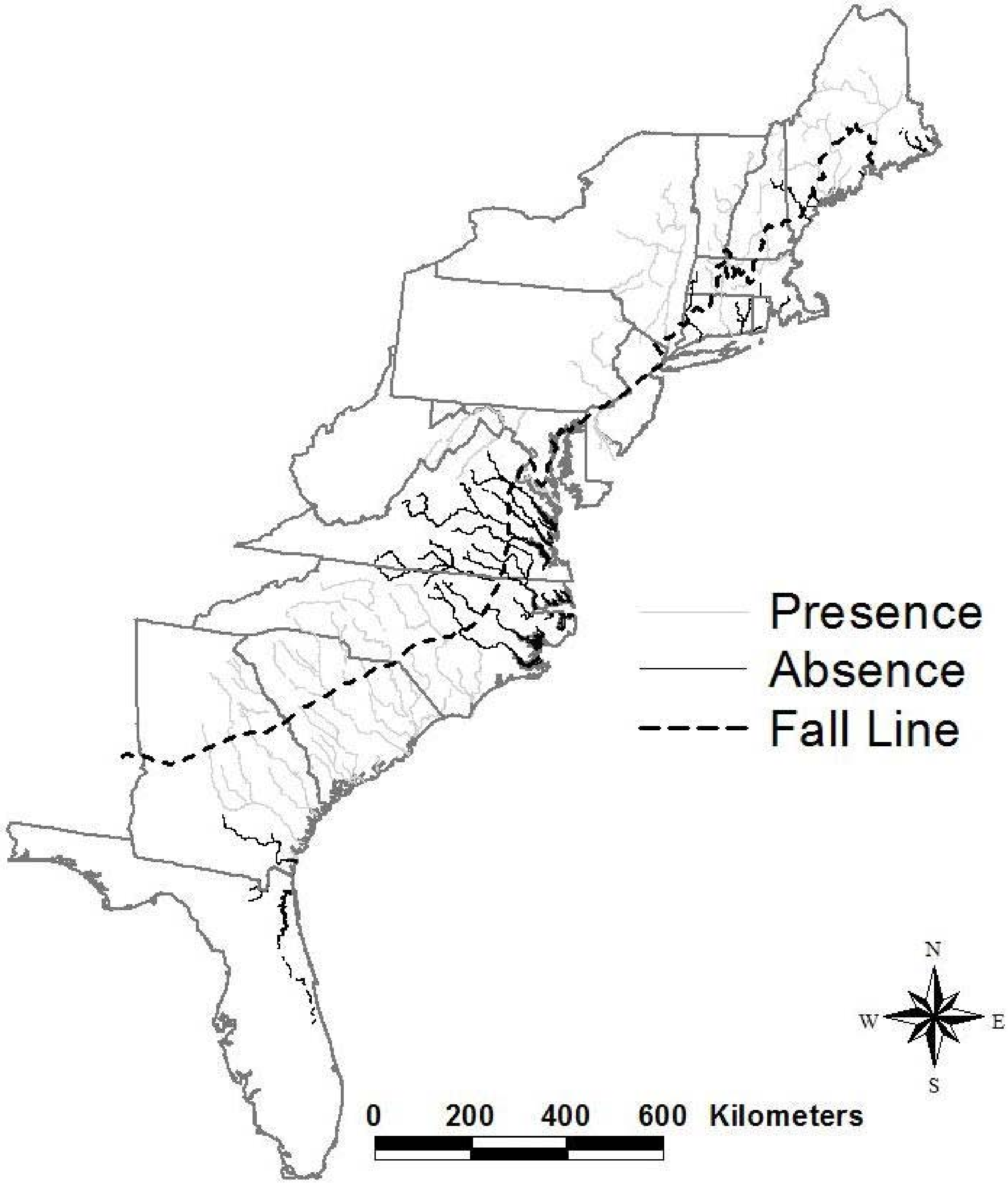


Figure 3.1 Atlantic Coast rivers that currently contain or lack a population of shortnose sturgeon.

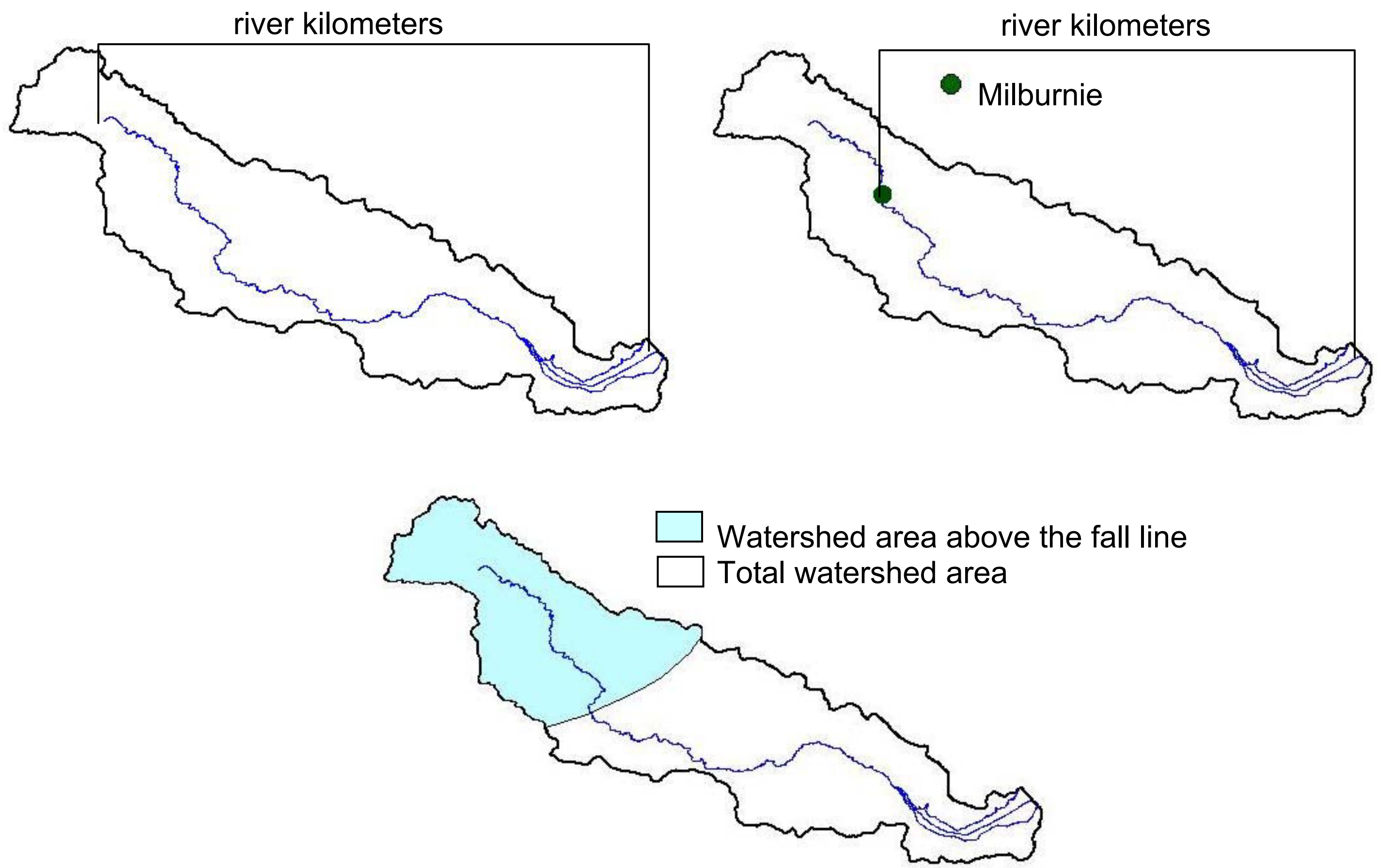


Figure 3.2 Example (Neuse River) of some physical characteristics used in logistic regression models, based on GIS coverage from BASINS.

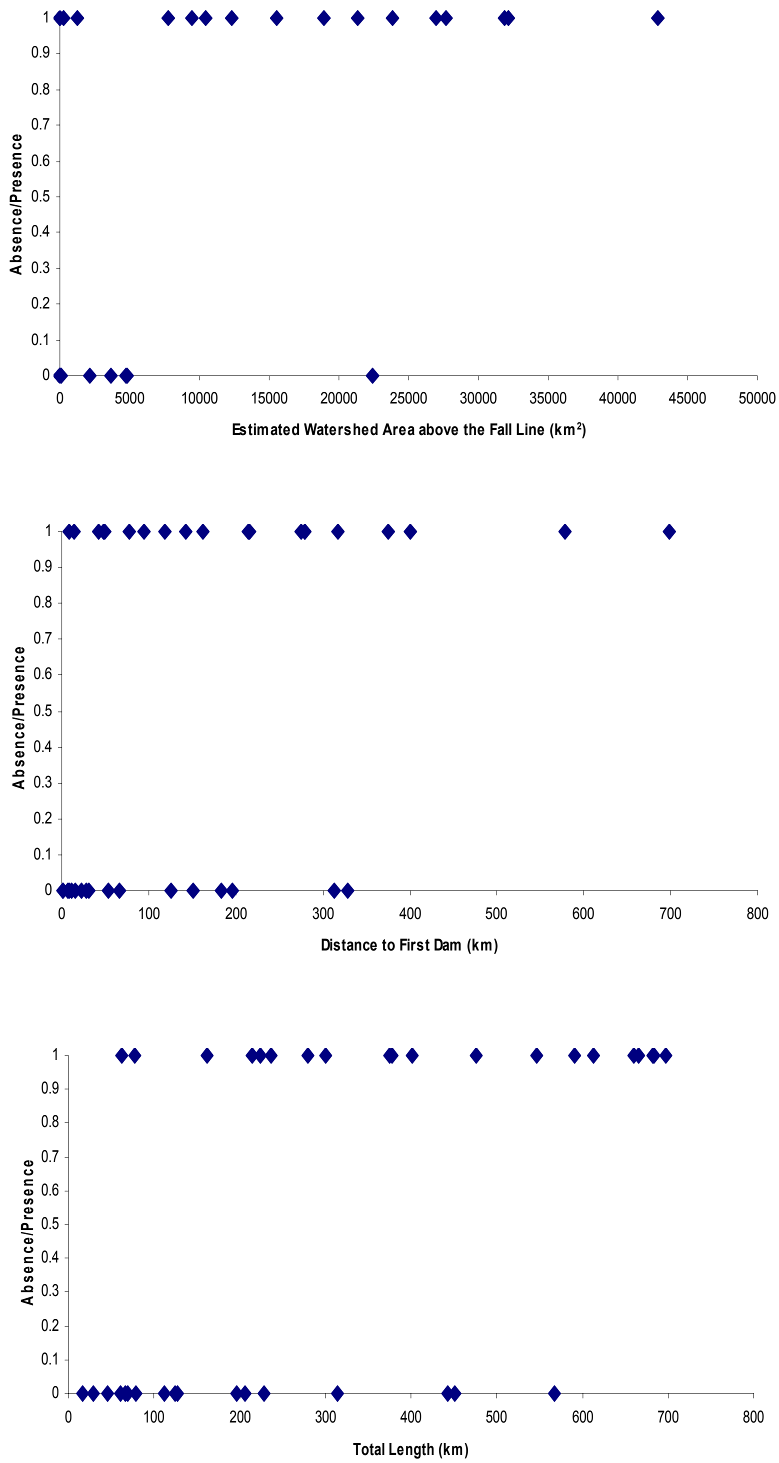
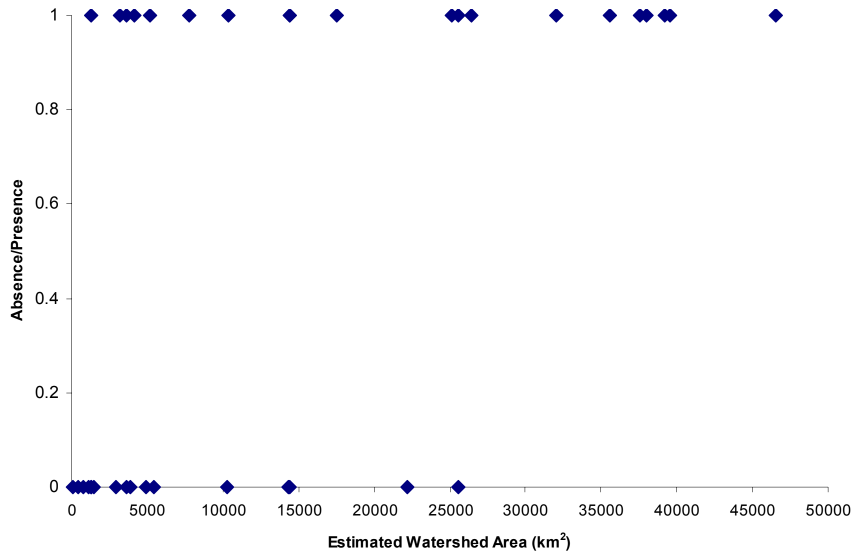


Figure 3.3 Presence/absence based on physical characteristics. Y value of 1 equals presence of shortnose sturgeon. Y value of 0 equals absence of shortnose sturgeon.



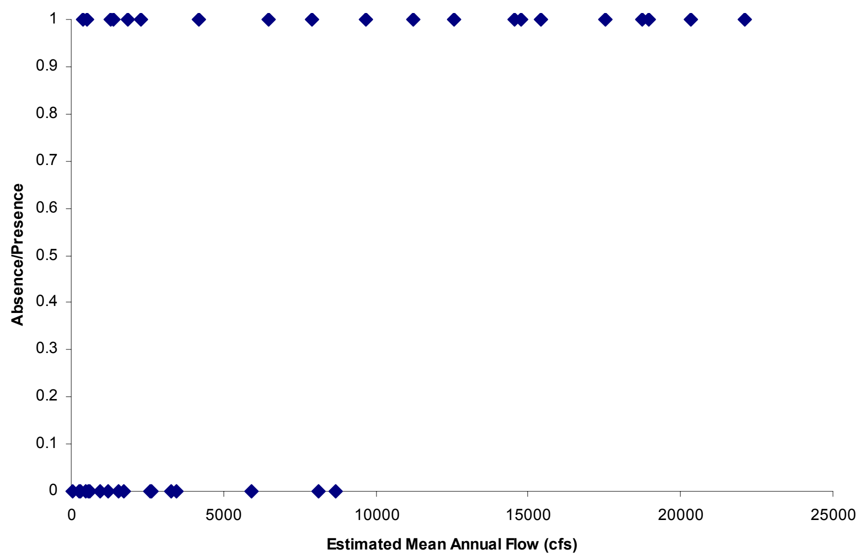


Figure 3.3 continued

CHAPTER FOUR

CONCLUSIONS

There had been no known surveys conducted for shortnose sturgeon in the Neuse River. Current research suggests that shortnose sturgeon are extirpated from the river. Our study illustrated that poor water quality within the freshwater-saltwater interface may be the leading factor in the species decline. Enhanced water quality within the interface is vital to the recovery of a shortnose sturgeon population within the Neuse River. Detection probability analysis illustrated that sufficient sampling has been completed to determine the status of shortnose sturgeon in the Neuse River; therefore, revising the shortnose sturgeon sampling protocol should be considered before being implemented in future research. Finally, the logistic regression modeling effort suggests that large river systems with sufficient spawning habitat with few blockages should provide habitat to sustain a population of shortnose sturgeon; therefore, most tributary rivers of Chesapeake Bay - Pamlico Sound should contain shortnose sturgeon.

Future plans should include implementing more water quality regulations to aid in alleviating poor water quality conditions in the Neuse River. If water quality improves, then stocking of hatchery-raised shortnose sturgeon may be an option in restoring a population. Telemetry of hatchery-raised shortnose sturgeon within the river may help identify habitats utilized by shortnose sturgeon that have not been sampled. Also, revision of the NMFS shortnose sturgeon sampling protocol should be completed to allow for more efficient sampling in order to determine a population. Finally, we hope to add more river characteristics to the logistic regression models in order to develop a model that best predicts presence of shortnose sturgeon. Estuarine flushing rates, estuarine water quality, and the presence of freshwater springs are characteristics that are vitally important in predicting presence within a river system. Our final goal is to see the restoration of shortnose sturgeon throughout its historic range and removal of the species from the endangered species list.

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APPENDIX

Appendix Table 1. Monthly summary of catch for summer 2001 and 2002.

Species	May		June		July		August	
	2001	*2002*	*2001*	*2002*	*2001*	*2002*	*2001*	*2002*
American shad				2		1		
Atlantic menhaden		143		12		22		
Atlantic sturgeon				1				
Blue catfish				1	2	8		
Bluegill								
Bowfin								
Channel catfish		2		2	3	38		
Common carp				1	2	2		
Flathead catfish				6	36	1		
Gizzard shad		5		9		20		
Grass carp								
Largemouth bass		1						
Longnose gar		1		3	1	6	1	
Notch-lipped redhorse sucker								
Redear sunfish								
Shorthead redhorse sucker								
Southern flounder		1		1	1	3		
Striped bass		1		1		1		
White catfish		1		1	2	2		
White perch								

Appendix Table 2. Monthly summary of catch from Fall 2001 – Spring 2002

Species	September	October	November	December	February	March
American shad					3	5
Atlantic menhaden			5		36	60
Atlantic sturgeon						
Blue catfish	3	2	7	23	11	14
Bluegill		1				
Bowfin					4	1
Channel catfish		1	3		14	
Common carp				1		4
Flathead catfish	23	39	22	10	48	14
Gizzard shad	1		1		190	36
Grass carp						2
Largemouth bass						
Longnose gar	3	23	67	1	19	8
Notch-lipped redhorse sucker						19
Redear sunfish				1		
Shorthead redhorse sucker						1
Southern flounder			1	1		2
Striped bass					16	
White catfish	2	1		1	4	1
White perch					1	

Appendix Table 3 Telemetry relocations for Atlantic sturgeon (PIT #4163256D1B). Water quality parameters measured at each location included dissolved oxygen (mg/L), salinity (ppt), temperature (°C), and conductivity (µS). See Appendix Table 4 for locations.

	Dissolved Oxygen (mg/L)		Temperature (°C)		Salinity (ppt)		Conductivity (µS)	
ID #	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*
1	6.6	6.8	21.0	21.9	2.4	6.5		
2	7.1	7.0	22.2	22.0	2.9	3.1		
3	5.3	5.4	24.3	24.3	1.5	1.8		
4	4.3	4.9	22.6	22.8	2.2	2.0		
5	3.5	3.1	19.8	21.9	0.9	5.0		
6	5.1	4.9	21.2	21.2	0.0	0.0		
7	6.6	5.6	23.9	21.8	0.0	0.0	275.0	250.0
8	5.9	5.7	22.1	21.9	0.0	0.0	290.0	250.0
9	6.5	5.4	24.8	22.5	0.5	0.4	500.0	700.0
10	5.4	4.9	23.1	23.0	0.0	0.1	500.0	780.0
11	6.5	5.6	26.5	23.3	0.0	0.2	350.0	300.0
12	5.5	5.7	24.1	24.0	0.0	0.0	450.0	500.0
13	6.6	5.8	27.1	24.4	0.0	0.0	410.0	510.0
14	5.6	5.2	24.8	24.7	0.2	0.0	380.0	320.0
15	5.0	4.9	24.3	24.3	2.3	2.4	4000.0	4000.0
16	5.1	4.9	25.0	24.8	0.0	0.0	290.0	300.0
17	6.1	6.0	24.3	24.3	0.0	0.1	600.0	610.0
18	6.1	5.6	24.5	24.3	0.0	0.0	810.0	900.0
19	6.5	6.3	25.0	25.1	0.0	0.0	400.0	400.0
20	6.1	5.6	23.2	23.2	0.0	0.0	1000.0	1100.0
21	6.0	5.9	24.3	24.2	0.0	0.0	400.0	400.0
22	6.0	5.6	24.8	24.1	0.0	0.0	370.0	410.0
23	5.7	5.2	23.3	23.2	0.0	0.0	300.0	300.0
24	6.7	6.6	26.6	24.9	0.0	0.0	300.0	200.0
25	6.1	6.0	21.4	21.5	1.0	1.0	1200.0	1400.0
26	6.5	5.6	22.5	22.1	0.2	0.7	800.0	880.0
27	5.9	5.7	20.5	21.0	0.0	0.0	550.0	500.0
28	5.7	5.7	22.0	21.4	0.0	0.0	400.0	500.0
29	5.9	5.2	20.5	21.1	2.0	2.5	3000.0	3000.0
30	5.8	5.0	20.9	21.2	2.0	3.0	3000.0	4000.0
31	6.5	6.2	19.5	19.4	0.2	0.2	500.0	500.0
32	6.8	6.2	22.0	19.9	0.0	0.5	250.0	600.0
33	6.7	6.3	23.2	21.0	0.0	0.0	600.0	700.0
34	6.5	6.2	20.3	20.3	0.1	0.2	390.0	400.0

Appendix Table 3 (continued)

ID #	Dissolved Oxygen (mg/L)		Temperature (°C)		Salinity (ppt)		Conductivity (µS)	
	Surface	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*
35	6.8	3.9	25.1	21.8	0.0	0.5	450.0	900.0
36	6.1	5.8	24.0	23.7	0.5	0.5	720.0	800.0
37	7.4	5.7	26.2	24.0	1.0	1.5	1750.0	2000.0
38	9.5	6.7	26.7	24.6	1.5	2.0	2550.0	3100.0
39	7.2	7.4	24.9	25.1	1.5	1.5	2400.0	2600.0
40	5.8	5.7	24.7	24.8	1.2	2.0	2000.0	3100.0
41	6.6	6.0	26.7	25.1	1.5	2.5	2150.0	2500.0
42	7.0	5.7	28.3	25.5	0.9	1.2	1200.0	2100.0
43	14.7	7.4	25.5	25.4	0.0	0.0	700.0	700.0
44	3.7	3.1	26.1	26.0	2.5	3.0	4300.0	6000.0
45	4.9	4.3	27.2	26.6	1.2	2.0	2190.0	3050.0
46	3.8	3.7	26.4	26.2	2.0	2.0	2900.0	3100.0
47	6.7	6.7	29.0	28.9	2.0	2.0	3200.0	3200.0
48	4.9	4.9	26.9	26.8	1.0	2.0	1900.0	3900.0
49	10.4	9.6	30.3	29.8	2.0	2.0	3100.0	3900.0
50	5.3	5.3	27.1	27.0	1.0	1.0	1600.0	2300.0
51	6.1	5.0	29.3	27.2	1.0	1.0	1300.0	1900.0
52	8.0	6.3	28.1	28.1	2.1	3.6	3100.0	4800.0
53	5.1	5.2	25.0	24.8	1.2	2.0	2500.0	3200.0
54	5.1	4.7	26.2	25.7	0.0	0.0	600.0	600.0
55	7.0	4.5	27.9	25.9	0.5	0.5	600.0	650.0
56	5.6	5.4	27.1	26.8	0.0	0.0	600.0	600.0
57	7.0	5.0	29.5	27.3	0.5	0.5	850.0	1000.0
58	5.5	4.9	27.3	27.3	0.2	0.2	900.0	900.0
59	6.0	4.7	29.0	27.7	0.9	1.0	1280.0	1390.0
60	4.0	3.1	27.5	27.9	1.5	2.9	2600.0	4800.0
61	4.3	3.0	28.8	28.0	4.1	5.0	8000.0	9000.0
62	3.7	3.6	27.2	27.4	4.0	4.0	7000.0	7000.0
63	3.0	2.9	27.8	27.8	3.1	3.2	5500.0	5800.0
64	2.3	1.8	26.2	26.4	3.0	3.5	5000.0	6000.0
65	3.7	3.7	26.9	26.9	3.9	3.9	6500.0	6500.0
66	2.7	2.1	26.3	26.4	4.0	4.5	7000.0	8000.0
67	2.3	0.8	26.7	26.4	3.2	4.1	5900.0	7100.0
68	2.2	2.1	26.0	25.9	5.0	5.2	9000.0	9000.0
69	3.3	2.8	26.2	25.8	0.1	0.1	800.0	900.0
70	4.9	2.9	27.5	26.4	0.0	0.0	600.0	800.0

Appendix Table 3 (continued)

	Dissolved Oxygen (mg/L)		Temperature (°C)		Salinity (ppt)		Conductivity (µS)	
ID #	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*
71	6.8	3.2	28.2	26.4	0.0	0.0	600.0	700.0
72	5.1	4.1	28.3	27.3	0.0	0.0	750.0	850.0
73	5.4	5.3	27.8	27.5	0.0	0.0	600.0	600.0
74	5.2	5.0	27.0	27.0	0.9	0.9	1600.0	1600.0
75	4.5	4.4	27.9	27.9	0.6	0.8	1347.0	1689.0
76	9.4	5.4	31.3	28.5	0.3	0.5	625.0	920.0
77	6.2	2.8	28.1	28.0	0.4	0.5	781.0	1034.0
78	10.4	5.1	30.7	28.3	0.2	0.8	549.0	1702.0
79	7.5	6.8	28.8	29.0	0.2	0.3	405.0	612.0
80	8.1	5.3	30.1	28.7	0.4	0.9	994.0	1895.0
81	4.9	4.8	29.2	29.3	1.5	2.2	3162.0	4550.0
82	6.1	4.1	29.0	28.8	0.3	0.5	743.0	985.0
83	9.2	4.7	31.7	29.3	0.7	1.2	1609.0	2410.0
84	7.2	6.1	28.9	28.5	0.3	0.3	562.0	644.0
85	9.4	5.6	30.6	29.1	0.3	0.5	594.0	1055.0
86	7.0	6.3	29.0	29.3	0.2	0.3	523.0	596.0
87	4.9	4.7	28.8	28.8	3.9	3.9	7650.0	7650.0
88	6.9	3.6	28.3	27.5	2.6	3.2	5240.0	6250.0
89	5.5	4.6	28.0	27.8	1.4	1.6	2920.0	3450.0
90	7.3	5.5	29.4	28.2	0.7	0.8	1510.0	1720.0
91	5.9	4.9	28.9	28.0	0.5	0.7	1025.0	1523.0
92	9.1	4.4	32.4	28.3	0.2	0.6	462.0	1318.0
93	5.0	2.9	28.5	28.3	1.7	2.6	3360.0	4285.0
94	7.4	5.2	30.6	29.1	0.2	1.9	527.0	3700.0
95	8.2	2.9	30.7	28.7	0.4	2.5	945.0	5000.0
96	7.6	4.0	29.6	29.4	1.9	3.2	3920.0	6000.0
97	5.4	4.9	29.3	29.1	1.2	1.3	2500.0	2580.0
98	5.9	3.9	29.5	29.0	1.0	1.2	2250.0	2600.0
99	8.7	3.2	30.3	28.9	1.1	1.5	2475.0	3070.0
100	4.6	4.5	28.1	28.1	0.7	0.7	1430.0	1415.0
101	6.7	3.9	30.9	28.8	0.3	0.4	680.0	780.0
102	8.8	7.5	32.5	31.2	0.1	1.1	310.0	499.0
103	5.9	0.0	30.7	29.1	0.3	9.9	637.0	18450.0
104	5.3	5.4	31.0	30.7	0.9	0.9	1420.0	1686.0

Appendix Table 3 (continued)

ID #	Dissolved Oxygen (mg/L)		Temperature (°C)		Salinity (ppt)		Conductivity (µS)	
	Surface	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*	*Surface*	*Bottom*
105	13.3	0.3	30.3	27.9	4.7	10.7	8900.0	19150.0
106	5.2	3.5	26.2	25.6	0.4	0.8	865.0	1713.0
107	5.6	3.5	25.7	25.6	0.3	0.5	675.0	981.0
108	5.1	3.8	25.9	26.0	0.5	0.8	1032.0	1382.0
109			24.8	24.9	0.6	1.6	176.0	3116.0
110	5.3	1.0	25.4	25.7	0.4	2.3	832.0	4268.0
111	5.2	6.2	23.3	23.7	0.7	4.8	1180.0	8580.0

Appendix Table 4 Telemetry relocations of Atlantic Sturgeon (PIT #4163256D1B). Depth, time, zone 18 UTM coordinates, and substrate type were measured at each location.

ID #	Date	Time	UTM_1	UTM_2	Depth_m	Substrate
1	5/1/02	950	314459	3887437	2.9	
2	5/2/02	845	314845	3887961	2.7	
3	5/3/02	1927	310483	3891425	5.6	Silt
4	5/4/02	1008	309940	3892205	8.5	Silt
5	5/6/02	555	309587	3892527	4.7	Sand
6	5/7/02	610	308757	3893736	2.3	Sand/Silt
7	5/7/02	1805	308685	3893863	2.5	Sand
8	5/8/02	930	308761	3893734	2.3	Sand
9	5/8/02	1554	308677	3893805	3.2	Sand/Silt
10	5/9/02	555	308635	3893857	5.5	Sand
11	5/9/02	1759	308691	3893870	6.7	Sand
12	5/10/02	545	309111	3893302	2.7	Silt
13	5/10/02	1429	308709	3893880	2.6	Sand
14	5/11/02	800	308694	3893869	6.8	Sand
15	5/11/02	1707	308635	3894209	2.8	Sand
16	5/13/02	554	308569	3894151	5.2	Sand
17	5/14/02	903	308793	3894313	3.5	Sand
18	5/14/02	1133	308758	3893907	3.5	Sand
19	5/14/02	1735	308730	3894012	3.8	Sand
20	5/15/02	839	308642	3894213	2.9	Sand
21	5/15/02	1251	308664	3894180	2.9	Sand
22	5/15/02	1518	308570	3894182	3.5	Sand
23	5/16/02	913	308673	3894180	2.6	Sand/Silt
24	5/16/02	1345	308695	3894150	2.7	Sand
25	5/20/02	846	308666	3893813	7.3	Sand
26	5/20/02	1457	308645	3893843	7.0	Sand
27	5/21/02	910	308677	3893870	3.5	Sand
28	5/21/02	1640	308604	3894198	2.5	Sand
29	5/22/02	849	308640	3894236	3.0	Sand
30	5/22/02	1053	308631	3894083	3.6	Sand
31	5/23/02	912	308772	3894139	3.1	Sand
32	5/23/02	1536	308642	3894538	2.0	Sand
33	5/24/02	315	308684	3894158	2.2	Sand
34	5/24/02	854	308570	3894156	6.5	Sand
35	5/27/02	1028	308557	3894150	6.8	Sand
36	5/28/02	935	308709	3894132	6.5	Sand
37	5/28/02	1356	308580	3894137	2.9	Sand
38	5/28/02	1552	308754	3893958	3.3	Sand

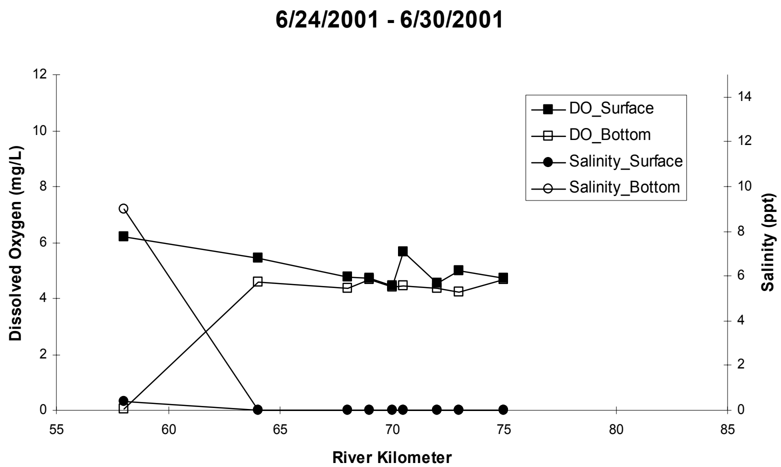
Appendix Table 4 (continued)

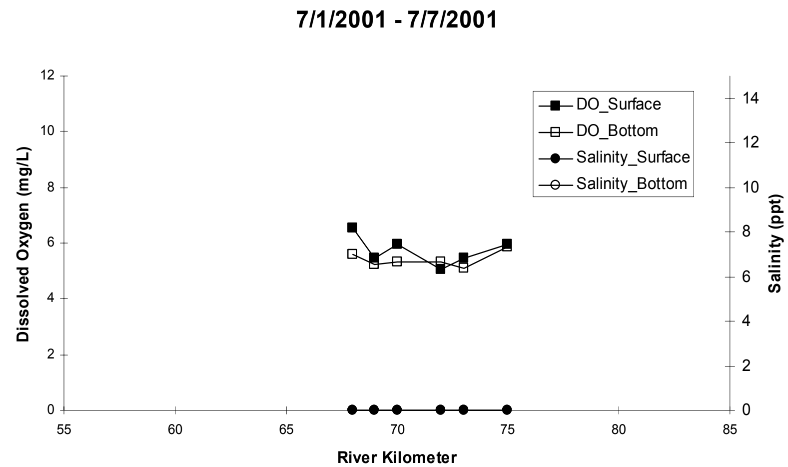
ID #	Date	Time	UTM_1	UTM_2	Depth_m	Substrate
39	5/29/02	911	308686	3893869	2.6	Sand
40	5/30/02	925	308767	3893731	2.8	Silt
41	5/30/02	1521	308908	3893569	3.4	Silt
42	5/31/02	1353	309136	3893315	2.6	Sand
43	6/1/02	735	308636	3893786	3.6	Sand
44	6/3/02	920	308643	3894191	2.8	Sand/Silt
45	6/3/02	1225	308650	3894228	3.3	Sand/Silt
46	6/4/02	9	308804	3893715	3.0	Silt
47	6/4/02	1625	308751	3893723	3.0	Sand/Silt
48	6/5/02	925	309166	3893292	1.4	Mud
49	6/5/02	1602	309160	3893277	2.2	Mud
50	6/6/02	845	309117	3893328	2.0	Sand
51	6/6/02	1210	309142	3893298	1.6	Sand
52	6/7/02	1651	309402	3892793	3.1	Sand/Silt
53	6/10/02	936	309451	3892702	3.1	Sand
54	6/12/02	954	308683	3894162	2.3	Sand
55	6/12/02	1459	308578	3894147	3.1	Sand
56	6/13/02	920	308736	3894000	2.9	Sand
57	6/13/02	1610	308708	3894131	7.2	Mud
58	6/14/02	950	308558	3894166	5.5	Sand
59	6/14/02	1355	308756	3893897	3.7	Sand
60	6/17/02	1000	308860	3893628	2.0	Sand/Silt
61	6/17/02	1530	309112	3893317	3.4	Sand
62	6/18/02	945	309389	3892884	3.8	Sand/Silt
63	6/18/02	1713	309289	3893018	3.1	Mud
64	6/19/02	1020	309345	3892990	3.7	Mud/Sand
65	6/19/02	1510	308685	3893856	3.0	Sand
66	6/20/02	1010	308626	3893814	7.3	Sand
67	6/20/02	1425	308735	3894077	3.7	Sand
68	6/21/02	1020	309199	3893145	7.5	Mud
69	6/24/02	915	308577	3894205	4.9	Sand/Silt
70	6/25/02	1100	308607	3894221	5.0	Sand
71	6/25/02	1500	308782	3894092	6.6	Gravel
72	6/26/02	1050	308621	3894093	5.0	Sand
73	6/27/02	1600	308602	3894221	4.3	Mud
74	6/28/02	608	308980	3893474	3.7	Sand/Silt
75	7/1/02	1005	308633	3894242	3.2	Mud
76	7/1/02	1610	308683	3894162	2.6	Sand
77	7/2/02	945	308555	3894174	4.0	Sand

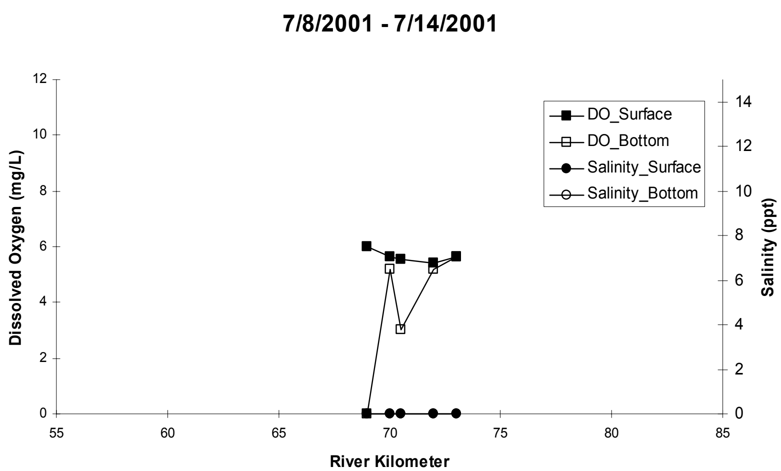
Appendix Table 4 (continued)

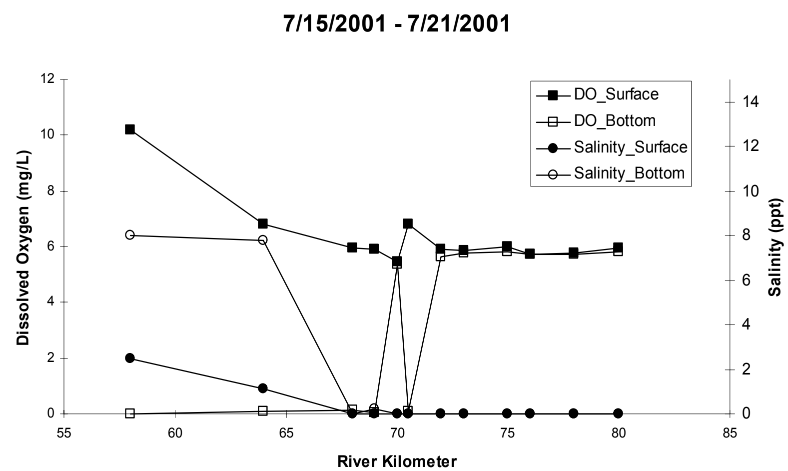
ID #	Date	Time	UTM_1	UTM_2	Depth_m	Substrate
78	7/2/02	1545	308657	3894158	3.0	Sand
79	7/3/02	925	308674	3894165	2.6	Sand
80	7/3/02	1325	308602	3894206	2.6	Mud
81	7/6/02	855	308760	3893895	7.1	Sand
82	7/8/02	1020	308633	3894190	2.4	Sand
83	7/8/02	1622	308665	3894179	3.0	Sand
84	7/9/02	1023	308621	3894207	2.7	Mud
85	7/9/02	1530	308663	3894180	2.5	Sand
86	7/10/02	1137	308608	3894199	2.5	Sand
87	7/11/02	1610	308684	3893861	3.4	Sand
88	7/12/02	1352	308578	3894192	7.7	Sand
89	7/15/02	1235	308642	3893835	5.3	Sand
90	7/15/02	1710	308689	3894154	4.1	Sand
91	7/16/02	1045	308570	3894124	2.8	Sand
92	7/16/02	1614	308701	3894153	3.5	Silt
93	7/17/02	945	308699	3894140	5.9	Silt
94	7/17/02	1340	308781	3894173	3.4	Sand
95	7/18/02	1257	308793	3894167	2.1	Sand
96	7/22/02	1550	308785	3894149	1.9	Sand
97	7/23/02	1102	308598	3894228	3.0	Mud
98	7/24/02	1235	308546	3894094	3.4	Sand
99	7/25/02	1459	308705	3894043	4.6	Sand
100	7/26/02	1301	308572	3894131	5.5	Sand
101	7/29/02	1242	308709	3893874	4.9	Mud
102	7/30/02	1333	308649	3894179	5.4	Sand
103	7/31/02	711	308552	3894163	6.7	Mud
104	8/2/02	1421	308712	3894447	2.0	Sand
105	8/13/02	1752	308689	3893773	4.1	Sand
106	9/17/02	1155	309998	3894018	4.3	Mud
107	9/18/02	743	310008	3894117	3.2	Sand
108	9/20/02	916	309311	3894927	3.5	Sand
109	9/27/02	847	309474	3894802	3.5	Sand
110	10/4/02	924	309320	3894994	4.7	Mud
111	10/10/02	820	307482	3896968	2.4	Sand

Appendix Figure 1 Summer 2001 – 2002 surface and bottom dissolved oxygen (mg/L) and salinity (ppt) measurements within the saltwater-freshwater interface.

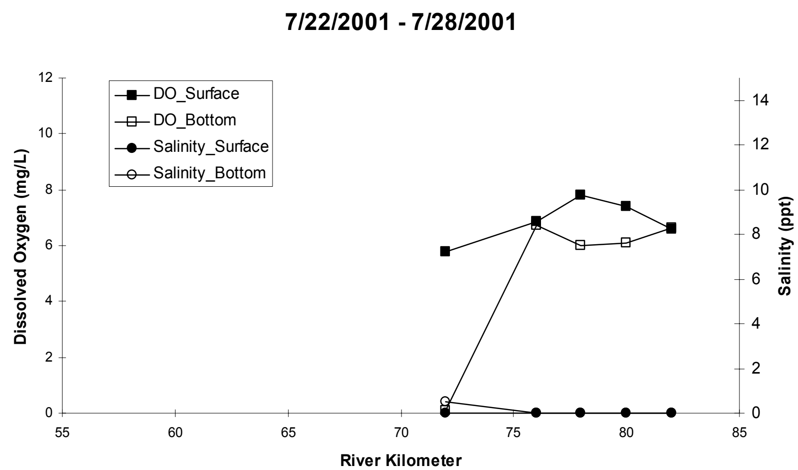


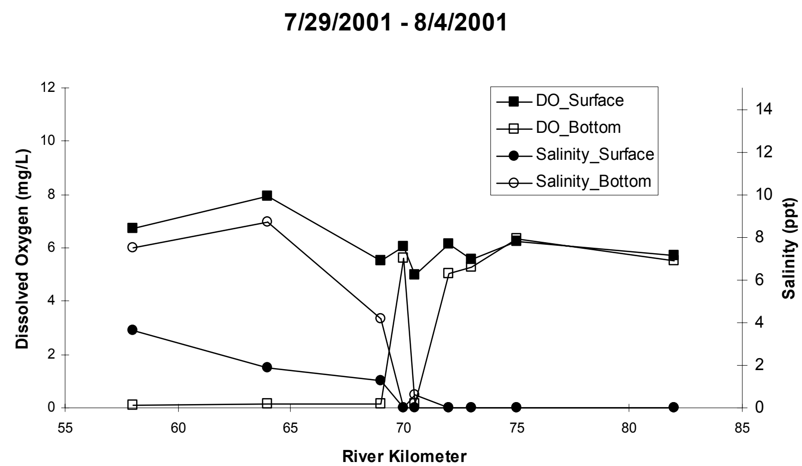


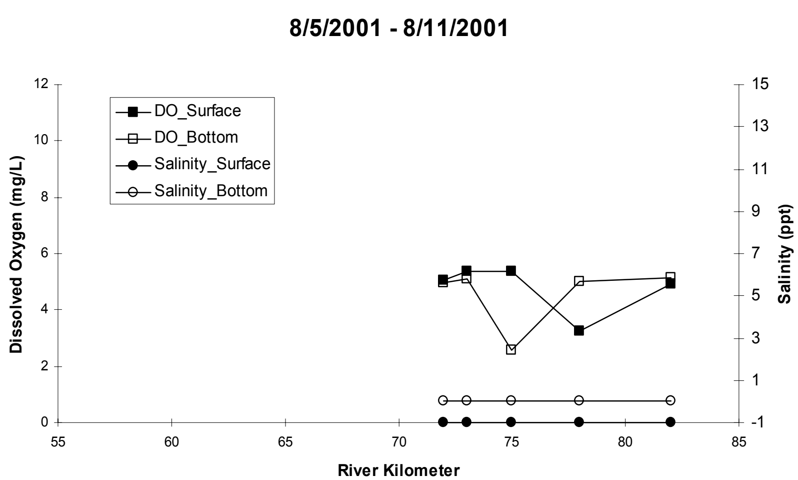


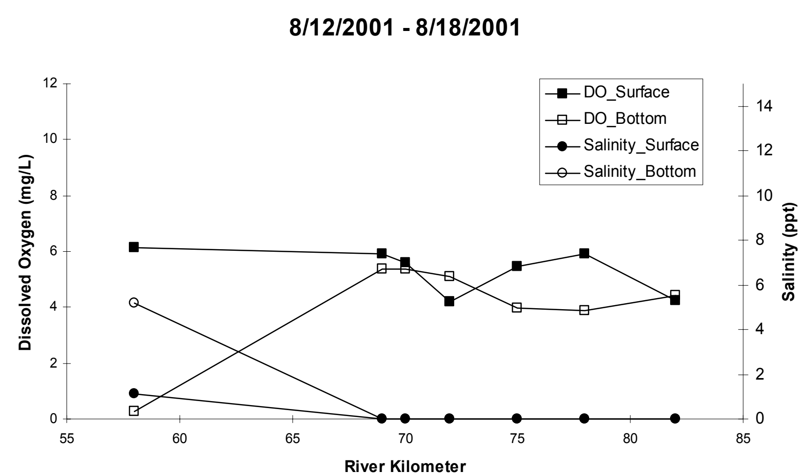


Appendix Figure 1. (continued)

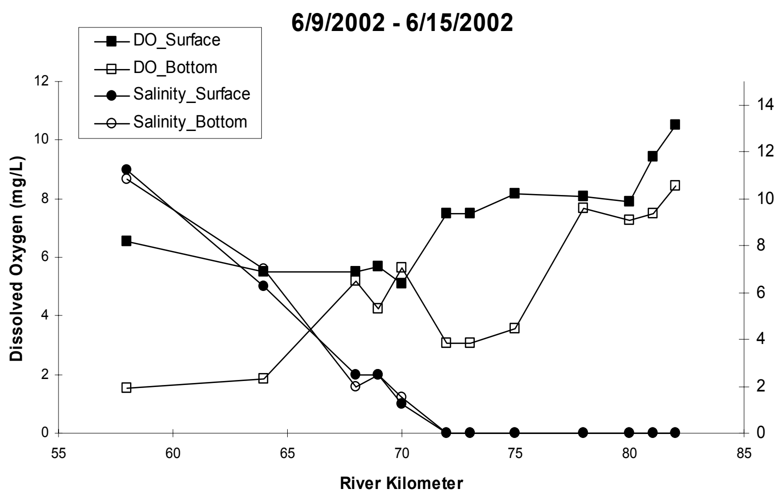


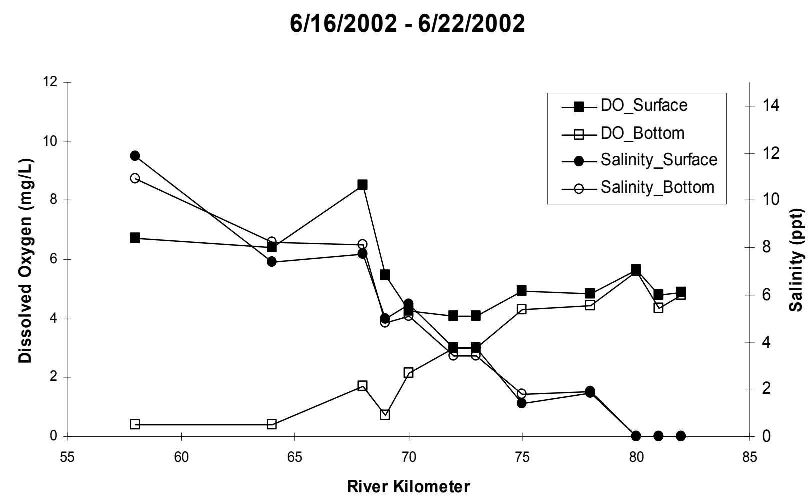


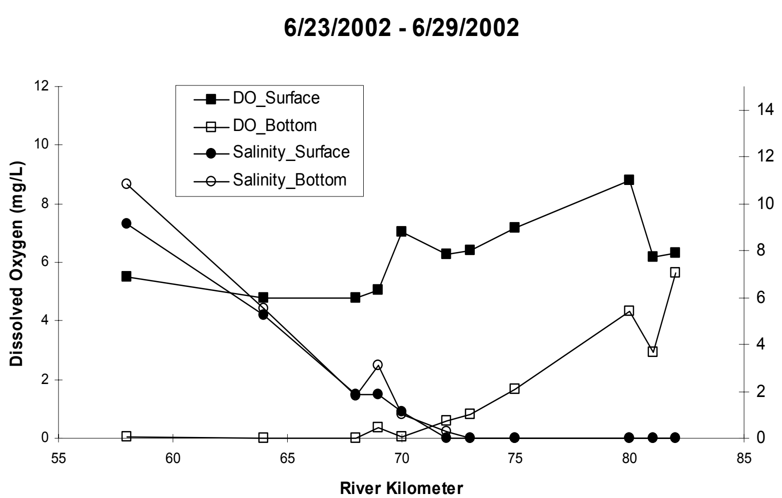


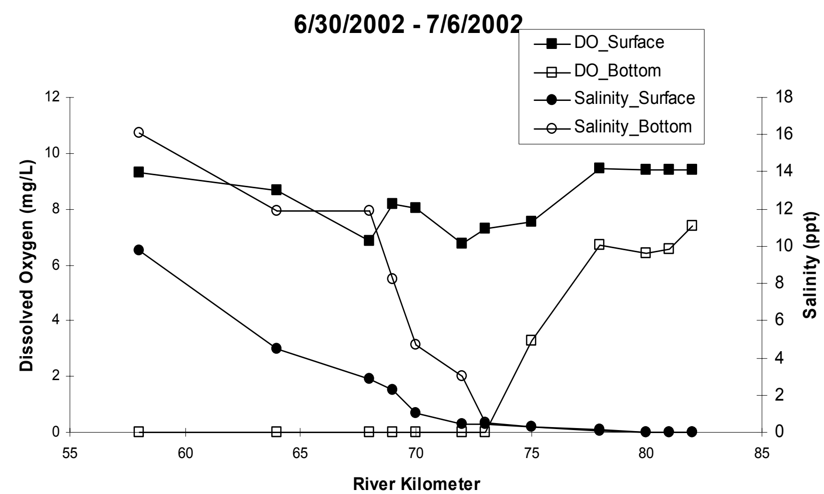


Appendix Figure 1. (continued)

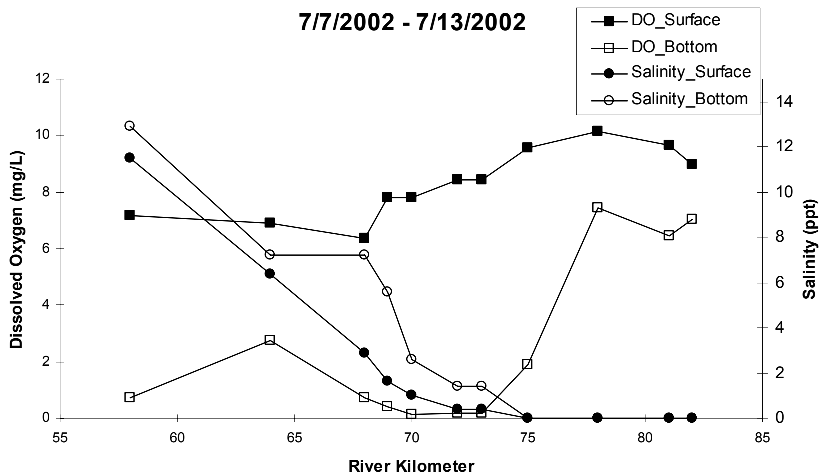


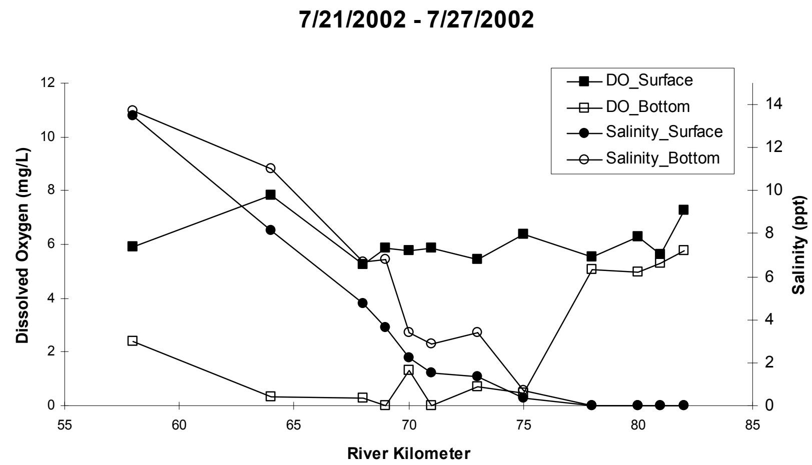


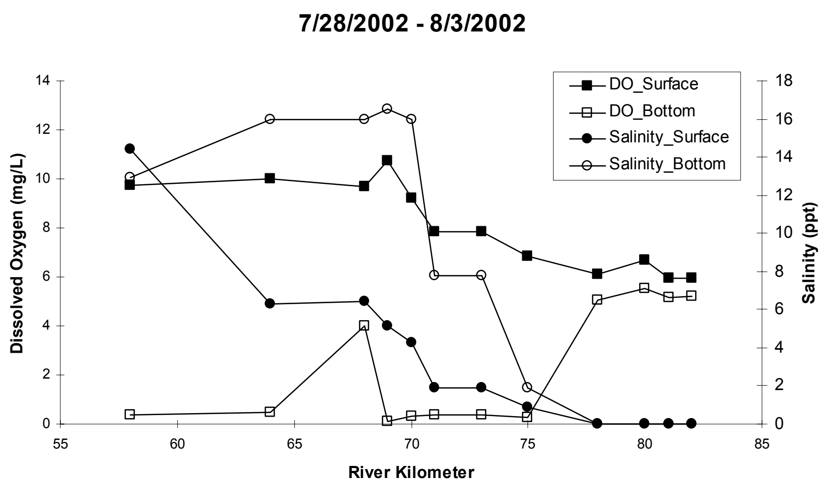




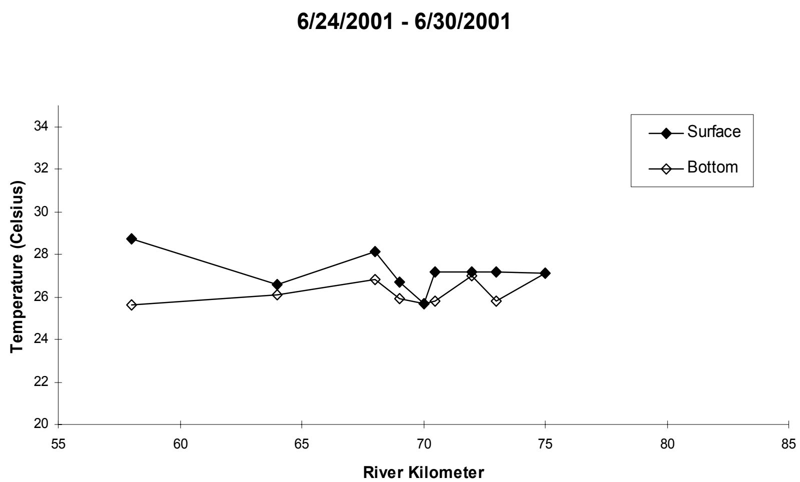
Appendix Figure 1. (continued)

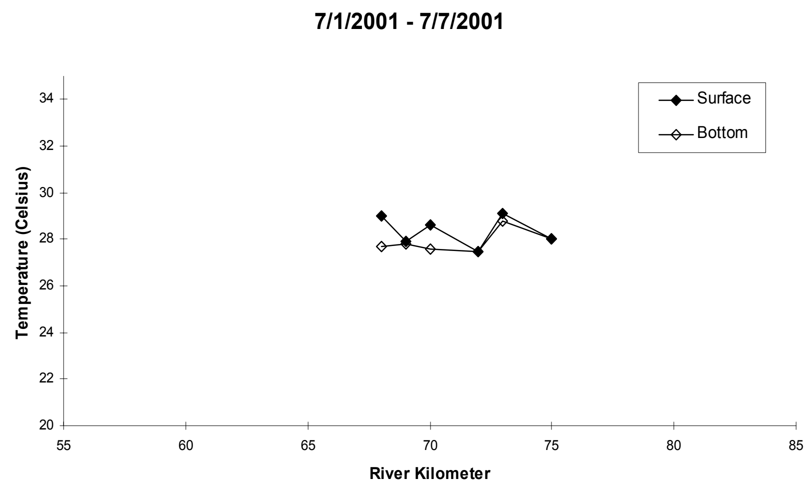


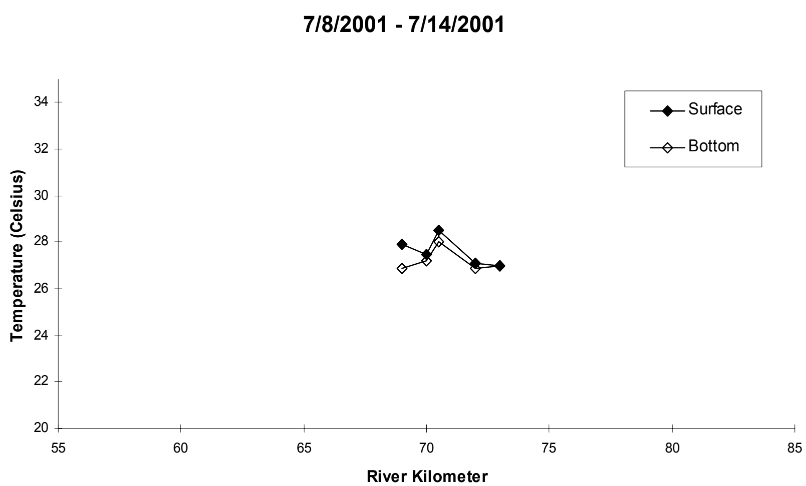


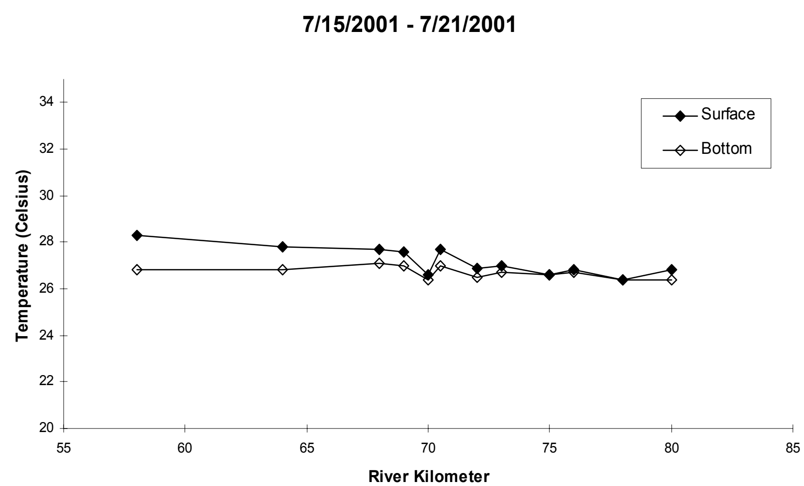


Appendix Figure 2. Summer 2001 – 2002 surface and bottom water temperatures (°C) within the saltwater-freshwater interface.

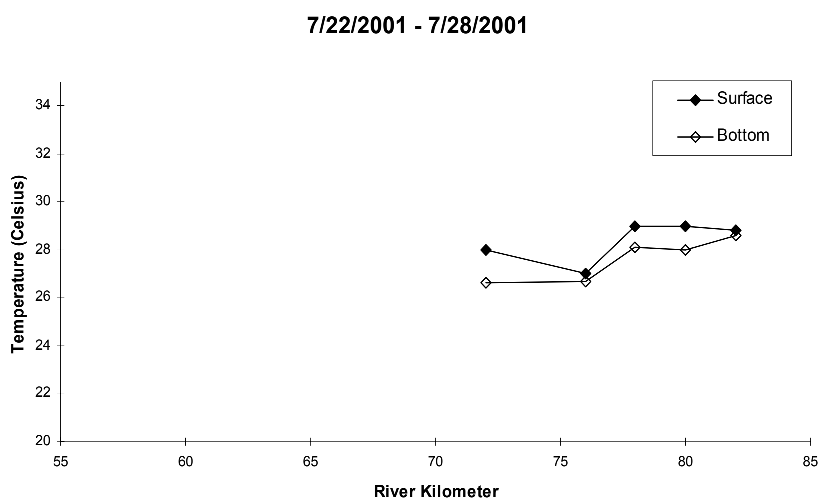


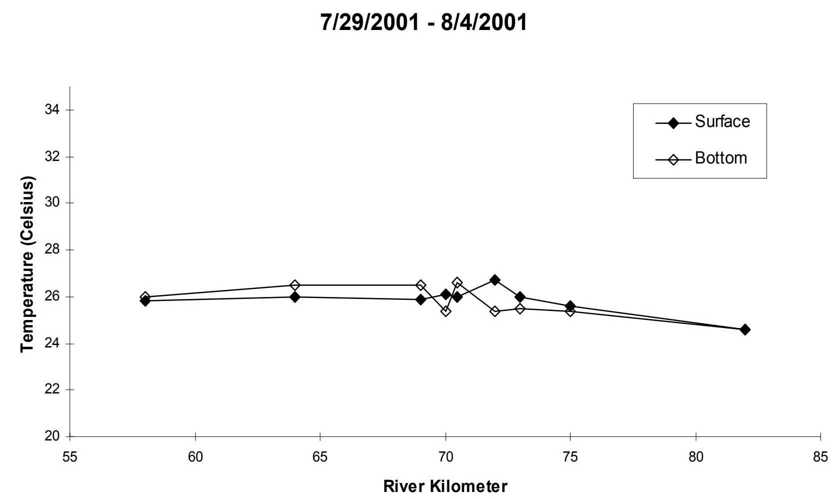


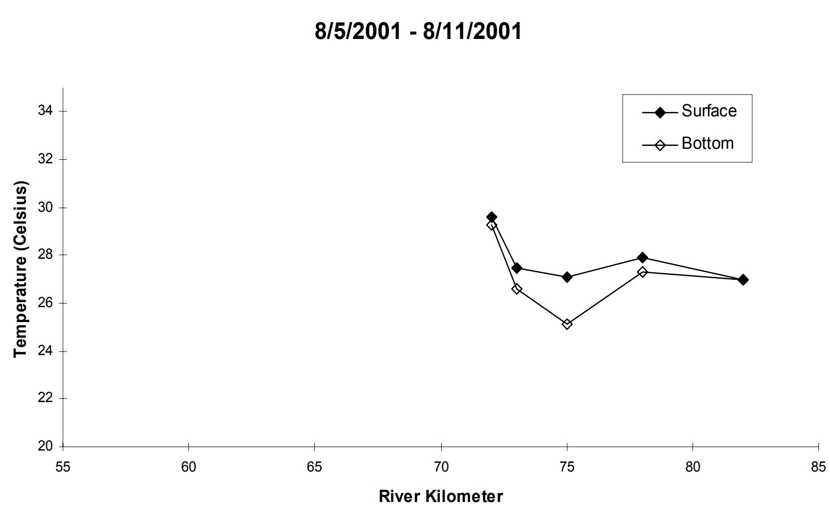


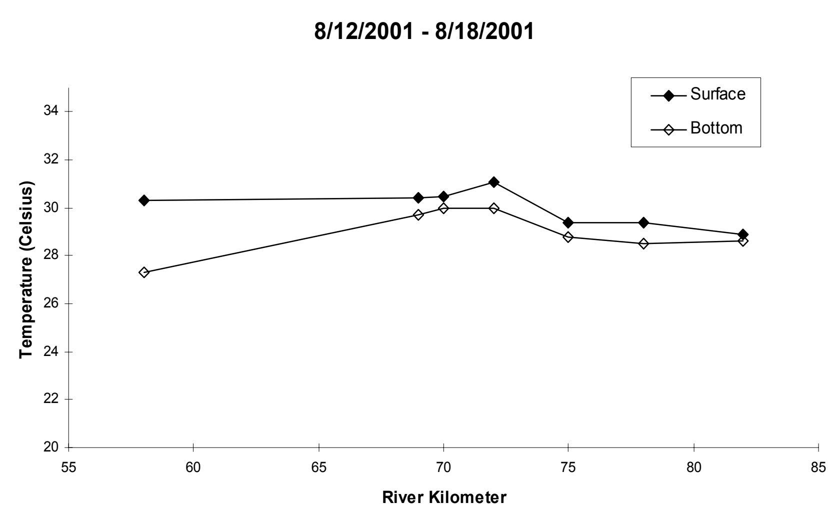


Appendix Figure 2. (continued)



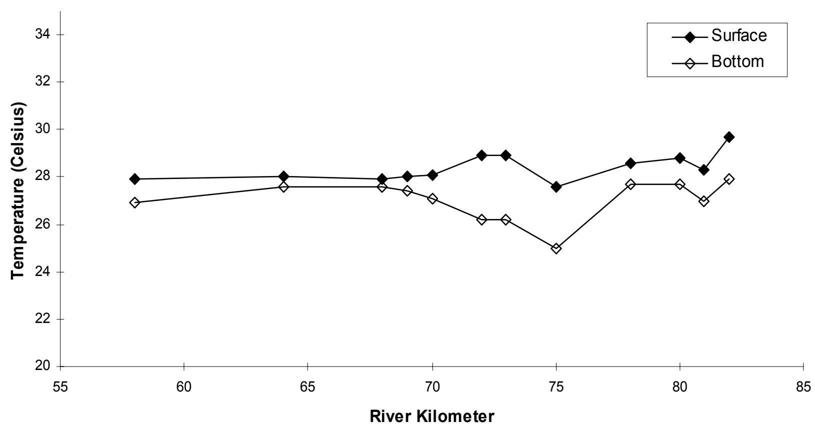




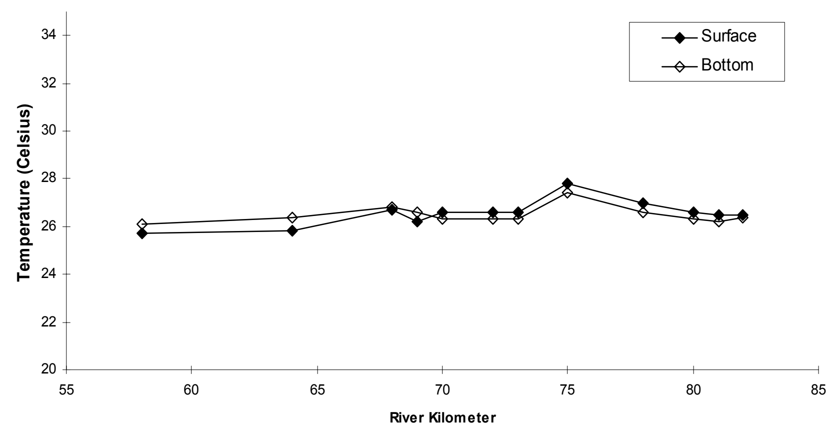


Appendix Figure 2. (continued)

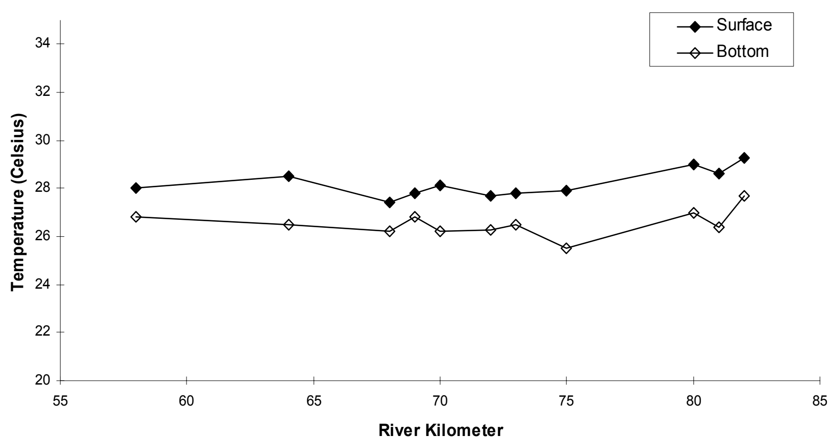
6/9/2002 - 6/15/2002



6/16/2002 - 6/22/2002



6/23/2002 - 6/29/2002



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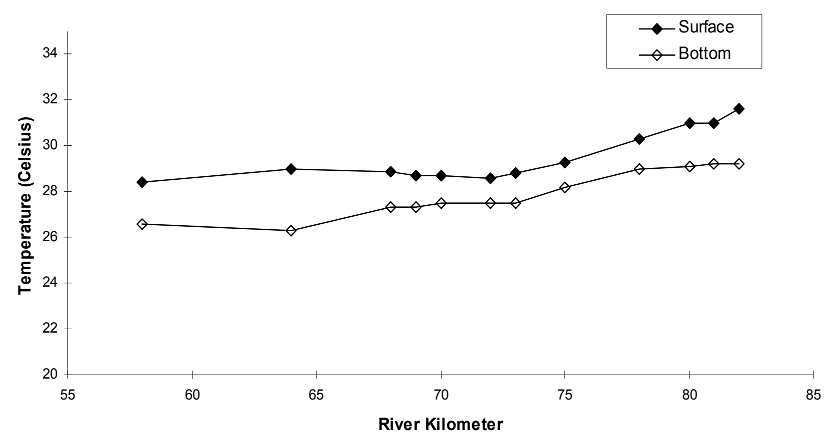

Appendix Figure 2 (continued)