Abstract

AGUILAR, ROBERT. Short-term hooking mortality and movement of adult red drum (*Sciaenops ocellatus*) in the Neuse River, North Carolina. (Under the direction of Peter S. Rand).

Despite the increasing importance of the red drum *Sciaenops ocellatus* recreational fishery, little is known about mortality rates of caught and released adult red drum. In this study, short-term hooking mortality rates (3-d) of adult red drum caught on 7/0 j-style hooks and 16/0 circle ("tuna") hooks from the Neuse River, North Carolina were determined via ultrasonic telemetry (2000) and confinement in field enclosures (2001). From June to September 2000, 22 red drum (928-1180 mm fork length; FL) were angled, tagged with ultrasonic transmitters, and released. An overall short-term mortality rate of 5.7% was determined for 17 fish. Due to the limited sample size, no attempt was made to model the factors associated with mortality. From June to September 2001, 112 red drum (880-1250 mm FL) were angled and held in net pens for 3 d to assess short-term mortality. An overall mortality rate of 6.7% was determined for 104 fish. Logistic regression analysis indicated that hook position (P = 0.012) and surface salinity (P = 0.002) were significantly related to mortality However, fish size (FL), sex, surface water temperature, depth, landing time, handling time, transport time, and hook type were not significantly related to mortality. Logistic regression analysis also indicated that hook position was dependent on hook type (P = 0.002) and sex (P = 0.015), but not fork length, surface water temperature, and depth. Approximately 52% percent of fish caught with j-style hooks were deep hooked, compared with 4.2% of those caught with circle hooks. A larger percentage of fish deep hooked with j-style hooks died compared to those deep hooked with circle hooks (15.9% vs. 0%, respectively). Necropsy analysis of five mortalities (all deep hooked) indicated extensive

internal hemorrhaging and damage to tissues and organs. These data suggest the conservation goal of reducing post-release mortality on these fish can be achieved through directed efforts at either promoting or requiring certain terminal gear (particularly through the use of circle hooks) to reduce incidence of deep hooking.

Movement information was collected for 18 of the 22 (81.8%) red drum angled and tagged with ultrasonic transmitters in 2000. Biotelemetry proved to be an effective method for examining adult red drum movement. Red drum appeared to exhibit seasonal fidelity to the lower Neuse River during the summer and fall months, but not to specific locations within this system. Most adult red exhibited a noticeable upriver-downriver ("longshore") pattern of movement, which was supported by Rayleigh's tests of individual fish movement. There was no significant difference between the mean angles (Watson's two-sample U^2 test: $0.2 < P < 0.5$) and movement rates (Wilcoxon rank sum test; $P = 0.4068$) of male (3.25±0.62 km $d^{-1)}$ and female (5.50±2.08 km d^{-1}) tagged and released red drum. Furthermore, the difference between day and night relocation depths for male and female red drum was not significantly different (Wilcoxon rank sum test: $P = 0.5610$). On 14 separate occasions, two red drum were located in close proximity to each other (~5 m to 300m), which was defined as a co-occurrence. Given the high number of co-occurrences, mobile nature of fish movement, seasonal residency, and apparent longshore movement pattern, adult red drum appear to form short-term loose aggregations within the Neuse River during the summer and early fall months. These data also indicate the lower Neuse River and similar areas of the western Pamlico Sound are important habitat for red drum in North Carolina.

SHORT-TERM HOOKING MORTALITY AND MOVEMENT OF ADULT RED DRUM (*SCIAENOPS OCELLATUS*) IN THE NEUSE RIVER, NORTH CAROLINA

by
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A thesis submitted to the Graduate Faculty
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ZOOLOGY

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Dedication

To my grandfather

Samuel M. Fraser

To my grandmother

Dorothy B. Fraser

And to the remainder of my family
I am who I am because of you.

Biography

I, Robert Aguilar, along with my sister, Michelle, was unexpectedly born on a chilly 5th day of October 1976 in the great state of New Jersey. My formative years were spent living in the sister cities of Scotch Plains and Fanwood before completing high school in [south-central] Edison.

In 1994, with a bad haircut and teenage mustache I entered the marine science program of the Richard Stockton College of New Jersey. A small school nestled in the pines, in the pines where the sun don't ever shine. Under the direction of Dr. Rudy Ardent I soon discovered the joys of fish biology, field research, and the enchanting bouquet of formalin. It still brings tears to my eyes, literally.

After graduation, I worked as a field technician for the Rutgers University Marine Field Station (RUMFS) in Tuckerton, NJ assisting in several projects examining the early life history of fishes of the Mid-Atlantic Bight, putting the fun in *Fundulus*, as the kid say. This only further solidified my love of all things muddy and desire to conduct my own research and to never work in a cubicle (silly cubies).

Therefore, in the summer of 1999, I entered the Master's program in the Department of Zoology at North Carolina State University. My main research, as you will soon read for yourself, concerned catching big fish and quantifying the wiliness of red drum via ultrasonic telemetry and voodoo math. My research did not focus on determining why so many people like NASCAR, though it is a question that needs to be answered.

I am presently employed as a biologist at the Smithsonian Environmental Research Center in Edgewater, Maryland

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First, I would like to thank my advisor, Dr. Peter Rand for his invaluable support, guidance, faith in my abilities, and patience with respect to this project and my personal "scientific" evolution. I am also grateful to the remainder of my committee, Dr. Joseph Hightower and Dr. Kenneth Pollock for their scientific input and great care in editing this manuscript.

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I owe a great debt of thanks to the North Carolina Division of Marine Fisheries, principally Lee Paramore and Louis Daniel for providing insight, guidance, dock space, a pump to fix downed net pens and boat use (R/V Red Menace). I am also immensely grateful for the statistical assistance provided by Dr. Kenneth Pollock (NCSU), Dr. Marcia Gumpertz (NCSU), Dr. Roger L. Berger, (NCSU), Dr. Larisa Avens (NOAA), and Dr. Jana Davis (SERC). Without their input I would have resorted to chicken bones and hat pins.

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Lucakovic (MD DNR), Dr. R. Glenn Thomas (LA DFG), Dr. Ronald Taylor (FMRI), Dr. Michael D. Murphy (FMRI), Dr. Eric Prince (NMFS), Dr. Joe Hightower (NCSU), Karen Burns (MML), Dr. "Spud" Woodward (GDNR), Lee Paramore (NCDMF), Dr. Joan Holt (UToA), and Scott Holt (UToA). Their patience with my many questions and unsolicited phone calls is greatly appreciated.

Not to be a copy cat, but I would also like to thank the DCL basement crew, especially J-Rob, Regan, Rich, Laura-lee, and Jess. You kids made life locked in the dungeon like Sloth bearable. I would also like to thank the couch in my office, for always being there when I needed you and never judging, no matter the time of the afternoon, thank you.

Individual thanks go to Chris Taylor for putting up with me and being one fine lab mate and role model; Geoff Bell for living with me even after we worked together at RUMFS and providing the program JACKEM; J-Rob for hours of commiseration and for always being a fine southern gentleman, even when you beat me to the couch; Regan for her sense of humor, camaraderie, and the good times. Beaufort wouldn't have been Beaufort without you (that's a good thing); Jake for being a top-notch drum tracking partner and keeping the whimpering to a minimum during the many lightning storms and waterspouts; Tim Wynne for always waiting exactly 8 hours before complaining; Holly for providing well needed alternatives to drum tracking; John Bichy for being a thesis writing role model; Josh and Amanda for their hard work and effort during their many rob-less drum fishing expeditions; Dr. Tuck Hines and SERC for my present position and the time required to finish this thesis. And to anyone I forgot, thanks for everything, I appreciate it.

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CHAPTER ONE

OVERVIEW OF RED DRUM LIFE HISTORY AND MANAGEMENT

Red Drum Life History

The red drum *Sciaenops ocellatus* is a large estuary-dependant sciaenid that occurs from Massachusetts to Northern Mexico (Lux and Mahoney 1969), but appears to be most common south of the Chesapeake Bay. In the late summer and early fall, adult red drum move from nearshore overwintering areas and typically spawn in the vicinity of tidal passes and inlets (Pearson 1929; Simmons and Breuer 1962; Yokel 1966), near bay mouths (Peters and McMichael 1987) and along the continental shelf (Peters and McMichael 1987; Comyns et al. 1991). However, recent evidence indicates that spawning also occurs inside estuaries. Spawning has been documented within Mosquito Lagoon, a high salinity estuary along the Atlantic coast of Florida (Murphy and Taylor 1990; Johnson and Funicelli 1991). Ripe adults have also been collected within the mouths of several estuaries along the Atlantic and Gulf Coast during the spawning period (Carr and Smith 1977; Murphy and Taylor 1990; Johnson and Funicelli 1991; Ross et al. 1995). Furthermore, Luczkovich et al. (1999) documented spawning vocalizations and collected eggs inside of Hatteras and Oracoke Inlets and in a lower salinity portion of the western Pamlico Sound near the mouth of the Bay River, North Carolina. Spawning vocalizations and the presence of eggs have also been documented in the Neuse River, North Carolina (P. S. Rand, North Carolina State University, unpublished data). Red drum eggs typically hatch in 18-29 hours, depending on water temperature (Arnold et al. 1977; Holt et al. 1981; Vetter et al. 1983; Holt et al. 1985). Spawning events have been documented from August to January (Matlock 1990); with peaks typically reported in September and October (Shaw et al. 1988; Matlock 1990; Ross et al 1995). Spawning peaks have also been documented to coincide with new and full moon phases (Peters and McMichael 1987; Coymns et al. 1991). Holt et al. (1985) estimated that red drum spawn predominantly from near sunset to approximately 3 hours post sunset. Prior to spawning, male red drum produce vocalizations ("drumming") and exhibit attending and nudging behaviors (Arnold et al. 1977; Guest 1978). Fitzhugh et al. (1988) reported that red drum are group synchronous, batch spawners (Wallace and Selman 1981) with an estimated mean batch fecundity of 1.7 x 10^6 hydrated eggs. Furthermore, individual adult females may have the ability to spawn every 2 - 4 d (Wilson and Nieland 1994). Red drum produce spherical eggs, approximately 0.86-0.98mm in diameter with a clear unsculptured chlorion, a small privetilline space, which is often less than 2 percent of the egg diameter and typically contain one large oil globule (Holt et al. 1981). Sciaenid eggs can be extremely difficult to identify to the species level (Holt et al. 1988); therefore, collected eggs must either be genetically analyzed (see Luczkovich et al. 1999) or allowed to hatch and the larvae identified (Holt et al. 1988; Johnson and Funicelli 1991). Tides and currents carry red drum eggs and larvae into estuarine nursery grounds (Mansueti 1960; Simmons and Breuer 1962; Holt et al. 1989). Following a short pelagic stage, larvae (6-8 mm TL; Rooker et al. 1997) settle into seagrass and marsh-edge habitats (Holt et al. 1983; Peters and McMichael 1987; Rooker et al 1998; Geary et al. 2001; Stunz et al. 2001) and can remain in these habitats as juveniles (up to 3 to 5 years) before joining the migratory adult population (Pearson 1929; Miles 1950; Overstreet 1983). Movements of both juveniles and sub-adults appear to be limited and typically restricted to within nursery estuaries (Osburn 1982; Pafford et al.1990; Ross and Stevens 1992; Marks and DiDomenico 1996; Adams and Tremain 2000). However, some sub-adults may leave the estuary for areas along ocean beachfronts, especially during the fall and winter months (Ross et al. 1995). Once red drum leave nursery estuaries, their movements are far less restricted, principally comprised of extensive annual seasonal migrations.

Red drum growth is rapid through age 4 or 5, but then slows distinctly as fish approach maturity (Beckman et al. 1989; Murphy and Taylor 1990; Ross et al. 1995). Red drum are a long-lived species, with the oldest individual (62 years) reported from North Carolina waters (Ross et al. 1995). Ross et al. (1995) did not report a significant difference in growth rates between the sexes. However, males typically attain sexual maturity at a smaller size and younger age than females (Murphy and Taylor 1990; Wilson and Nieland 1994; Marks and DiDomenico 1996; Ross et al. 1995). In North Carolina, more than 50 % of males were sexually mature by age 2 and 100 % were mature by age 3 whereas, 57 % of females were mature by age 2 and 100 % were mature by age 4 (Ross et al 1995). Moreover, Marks and DiDomenico (1996) reported that sizes at 50 % maturity for males and females were 650-700 and 800-850 mm, respectively. The estimated ages at maturity reported by Marks and DiDoemico (1996) were consistent with those published by Ross et al. (1995).

In North Carolina, adult red drum typically appear along the Outer Banks in late March (Mercer 1984). Most fish will soon enter the Pamlico Sound, while others remain in the vicinity or move north towards the Chesapeake Bay and the Virginia barrier islands (Mercer 1984). Adult red drum usually arrive in the western portions of the Pamlico Sound in late June and may remain in these areas into early October. In September, as the number of adult red drum in western Pamlico Sound decrease, numbers of fish near Hatteras and Ocracoke Inlets and adjacent beachfronts increase (Ross et al. 1995). Adult fish may be found in nearshore waters through December after which fish return to overwintering grounds. Little is known of red drum movement during the overwintering period; however, commercial fishing vessels occasionally capture large schools of red drum several km offshore of North Carolina during this period.

Within the Pamlico Sound Estuary System, red drum spawning occurs in the vicinity of tidal inlets, along the outer bars in nearshore ocean waters and along shoal and channel sites in the inner side of the barrier islands, and around the mouths of bays and rivers in the western portion of the Pamlico Sound (Ross et al. 1995). However, specific spawning locations within the western Pamlico Sound have yet to be identified. Peak spawning occurs in August and September as determined by maturity stages and gonadosomatic indices (GSI) of captured adults and the subsequent appearance of newly settled juveniles in nursery habitats (Ross et al. 1995).

Red Drum Management History

Red drum are one of the most highly sought sport fishes along the southeastern United States (Schmied and Burgess 1991; Pattillo et al. 1997; National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). In 2000 alone, roughly 1.6 million red drum were recreationally angled along the Atlantic Coast and over 250,000 were landed in North Carolina (National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication.). Red drum are consistently reported as one of the primary target species by North Carolina shore-based recreational anglers and in recent years the number of in-shore charter boats targeting red drum have increased (NC DMF 2001). According to the latest figures, the estimated expenditure of anglers targeting red drum in North Carolina in 1997 was nearly 13.2 million dollars (NC

DMF 2001). In addition to being an important sport fish, red drum are also a highly prized food fish and have historically supported an intense commercial fishery throughout most of its range (Wilson and Nieland 1994; National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). In the early 1900s, red drum once supported commercial fisheries as far north as New Jersey (Mercer 1984). However, landings north of Virginia since the 1950s have been predominantly less than 1 metric ton (Mercer 1984; National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). The historic nucleus of the commercial red drum fishery existed in the northern Gulf of Mexico; however, most likely due to fishing pressure and habitat degradation, catches of red drum from the Gulf of Mexico decreased in the 1970s and 1980s (Pattilo et al. 1987; National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). Coinciding with the recognized decline in overall catches was a tremendous increase in commercial demand for red drum in the mid 1980s, owing primarily to the dramatic popularity of "blackened redfish." As a result, the United States red drum commercial catch more than doubled from nearly 3,000 to a record high of 6,500 metric tons from 1985 to 1986 (Figure 1.1). In response to these factors, regulations limiting both commercial and recreational harvest were enacted to prevent the overfishing of Gulf and Atlantic red drum stocks.

In the early 1980s, strict regulations were enacted upon the red drum fishery beginning in the Gulf of Mexico. In 1981, Texas and Alabama closed their targeted commercial fishery and Louisiana, Mississippi and Florida placed restrictions on harvest (Pattillo et al. 1987). A federal Fishery Management Plan (FMP) was implemented in 1986, which prohibited the harvest of red drum in federal waters off the coast of Florida and Texas

(NMFS 1986). In 1990, this ban was extended to the entire Gulf of Mexico. The Atlantic States Marine Fisheries Commission (ASMFC) adopted a red drum FMP for the Atlantic Coast from Maryland to Florida in 1984; this plan was later revised in 1988 to include all Atlantic Coast states (NC DMF 2001). In 1990, the South Atlantic Fishery Management Council (SAFMC) ratified a red drum FMP, which was subsequently adopted as Amendment 1 to the ASMFC Red Drum FMP (NC DMF 2001). Both the ASMFC and SAFMC FMP indicated that red drum were overfished due to low juvenile escapement and extremely low Spawner Recruit Ratios (SPR, or spawner biomass, expressed as a percentage of expected spawner biomass at equilibrium in the absence of fishing mortality). The SPR was reported to be 2-3% in the 1990 red drum stock assessment (Vaughn and Hessler 1990). The overfishing level was described as a mortality rate that, if continued, would yield SPR values less than 30%. In order to rebuild red drum stocks and curb overfishing, Amendment 1 recommended prohibiting the harvest and possession of red drum within the EEZ. This plan also proposed management options designed to rebuild stocks to 40% SPR, beginning with an initial goal of 10% SPR. States were required to adopt one of two options. The first option was a slot limit of 18-27 in. TL and a 5 fish minimum with an option of one fish exceeding the 27 in. TL maximum. The second option was a 14-27 in. TL slot limit and a 5 fish bag limit with no retained fish exceeding 27 in. TL. North Carolina, Maryland and Virginia adopted option 1 and South Carolina and Georgia adopted option 2. At that time, Florida had already enacted more restrictive regulations. Furthermore, South Carolina, Florida, and Georgia, in addition to Texas, Louisiana, and Alabama, granted red drum gamefish status and prohibited commercial sale of red drum. According to the latest Atlantic Coast stock assessment SPR has surpassed the initial goal of 10% and increased to 18% for 1992-1997

(Vaughn and Carmichael 2000). Currently, North Carolina imposes a recreational slot limit of one fish 18-27 in. TL and a commercial trip limit of 7 fish (18-27 in. TL) per commercial operation with a 250,000 lb. annual cap.

Most likely in response to length restrictions, bag limits, and a heightened social consciousness, a large recreational catch-and-release fishery for red drum has developed over most of its range. In recent years the ratio of recreational to commercial catch has increased tremendously. In 2000, the United States commercial catch was only 146.7 metric tons, whereas the recreational catch was estimated to be approximately 7015 metric tons (National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). Along the Atlantic coast, the recreational catch represents over 90% of total red drum catch by number (Vaughn and Carmichael 2000) and over 95% by weight (Figure 1.2). Furthermore, the overwhelming majority of the recreational catch is now being released alive by anglers. Over the last decade the percentage of total US recreational catch released alive has reached approximately 75% (Figure 1.3). In North Carolina, the percentage of red drum released alive is slightly larger, approximately 80% (National Marine Fisheries Service, Fisheries Statistics and Economics Division, personal communication). Furthermore, the recreational fishery for adult red drum in North Carolina is almost entirely catch-and-release, as adult red drum typically exceed the 27 in. TL upper slot limit.

With increases in the number of red drum released by recreational anglers (identified as catch category "B2" fish in stock assessments), an accurate estimate of the percentage of fish that suffer post-release mortality becomes increasingly important, particularly the older age classes that represent the spawning members of the population. The proper application of length and bag limits depends on sufficiently low hooking mortality rates within mandated size ranges (Waters and Huntsman 1986; Muoneke and Childress 1994). Furthermore, hooking mortality estimations are critical components in stock assessments, which are often used as a baseline for management strategies. The latest Atlantic Coast red drum stock assessment and North Carolina red drum FMP have both identified the mortality rate of caught-and-released red drum as a research need for future management strategies (Vaughn and Carmichael 2000; NC DMF 2001). Despite this, little is known about the mortality rates of caught and released adult red drum, as the majority of literature concerning red drum hooking mortality has focused primarily on juvenile and sub-adult fish (Table 2.1).

CHAPTER TWO

SHORT-TERM HOOKING MORTALITY OF ADULT RED DRUM CAUGHT IN THE NEUSE RIVER, NORTH CAROLINA

Introduction

Catch and release mortality for some species has been shown to be relatively high (Muoneke and Childress 1994), and has raised concerns about how some fishing practices may be at odds with conservation goals established to rebuild exploited stocks of fish. Recognition of this has led to focused research on gear impacts. Circle hooks, in particular, have shown a great deal of promise in reducing the incidence of gut or deep hooking (Caruso 2000; Hand 2001; Prince et al. 2002; Skomal 2002). The hooking of critical areas has been shown to elevate mortality risk in many fishes (Muoneke and Childress 1994). As a result, circle hooks have garnered much attention by management and funding agencies (e.g. Massachusetts Division of Marine Fisheries, New Hampshire Division of Fish and Game, North Carolina Sea Grant, Florida Sea Grant, Louisiana Sea Grant) and gained in popularity among recreational anglers, including those targeting adult red drum.

The main objective of this study is to determine the mortality rate of caught and released adult red drum in the Neuse River, North Carolina. An additional objective is to determine whether mortality rates of red drum can be reduced by the use of circle hooks, as opposed to the more commonly used j-style hooks. The hypothesis is that the use of circle hooks would result in a significantly lower deep hooking probability and a significantly higher likelihood of survival following release. Furthermore, the effects of several variables (including physical variables, landing times, and handling times) on mortality is explored. Recognition of particular terminal gear and conditions that significantly affect post-release mortality could aid management agencies in promoting responsible fishing techniques. This work could also provide a firm empirical base from which regulations could be developed to help achieve certain conservation goals for the fishery.

Recreational Fishery Characteristics

In North Carolina, adult red drum become available to the recreational fishery as they move inshore for spawning from offshore overwintering grounds. In the spring and during the late fall and early winter months, adult red drum are most prevalent along beachfronts of the Outer Banks. At this time, many adult red drum are landed from the surf zone by shore-based anglers; however, they may also been taken by boat in nearshore waters. During the summer and early fall, red drum are primarily caught in western Pamlico Sound and inside the mouths of the Bay, Neuse and Pamlico rivers. Catches of adult red drum from the western Pamlico Sound recreational fishery usually begin in July and remain relatively high through Setember. Catch rates diminish markedly in October. Within western Pamlico Sound and its adjoining rivers, red drum are almost exclusively taken by boat. Anglers typically fish multiple unattended rods employing bottom rigs and cut bait. However, anglers may also fish live bait, jigs, spoons and flies. At the beginning of this project, the 7/0 j-style hook was recognized as the most commonly used hook in the western Pamlico Sound red drum recreational fishery. However, it appears that circle hooks are gaining popularity with anglers. In a recent survey of North Carolina red drum anglers, 13/0 circle hooks were listed as the most common hook used (Lee Paramore, NC DMF, personal communication). In

2001, North Carolina Sea Grant published literature that supported the use of circle hooks in the red drum recreational fishery. Other species caught while targeting adult red drum in the western Pamlico Sound include cownose rays *Rhinoptera bonasus*, bluefish *Pomatomus saltatrix*, tarpon *Megalops atlanticus*, stingray *Dasyatis sp*., and there are anecdotal reports of catches of bull shark *Carcharhinus leucas*.

Methods

Study Area

The study area is the lower Neuse River located in east-central North Carolina, USA (Figure 2.1). The estuarine portion of the Neuse River is a shallow drowned river valley with a mean depth of 3.6 meters, mean width of 6.5 km and length of 70 km (Luettich et al. in press). The Neuse River Estuary is part of the larger Pamlico Sound Estuary System, which also includes the Pamlico and Bay river systems. The Pamlico Sound Estuary System (along with the Albemarle and Croatan Sounds) is part of the largest lagoonal system and after the Chesapeake Bay is the second largest estuary system in the United States (Xie and Eggleston 1999). The average depth of Pamlico Sound is about 4-5 m; however, the depth may vary from 2 to 3 m on shoals and bars to 7-8 m in the deeper portions (Xie and Eggleston 1999). It is separated from the Atlantic Ocean by a chain of barrier islands, commonly referred to as the “Outer Banks.” Inlets between these barrier islands (e.g. Hatteras, Ocracoke, and Oregon Inlets) provide a tidal flux of seawater. Due to the narrow widths of these inlets and the wide and shallow nature the Pamlico Sound System, it is considered principally wind driven (Pietrafesa et al. 1986; Xie and Eggleston 1999; Luettich et al. in press) with a negligible tidal signature at the mouths of connecting rivers (Luettich et al. in press).

Hooking Mortality Estimation

In this study, two methods were employed to determine the post-hooking mortality of adult red drum. In 2000, ultrasonic telemetry was used to track fish for 72 hours to determine mortality. However, this method achieved a sample size that was too low to accurately estimate release mortality and reliably model causative factors. Therefore, in 2001, all caught red drum were confined in net pens for 3-d to determine short-term mortality.

All red drum were captured using recreational angling techniques by project personnel and numerous volunteers of varying experience levels from the lower Neuse River, North Carolina (Figure 2.1). Multiple (4-7) unattended rods were fished simultaneously from research vessels. Terminal tackle (Figure 2.2) included Gamakatsu 7/0 octopus hooks (Style: 02417) and Mustad 16/0 circle hooks (Style: 39960D) baited with similar sized pieces of cut striped mullet, *Mugil cephalus*. Both hook types were used in conjunction with a conventional bottom rig consisting of a 15 in. (3.8 cm) 80lb. (36.3 kg) test monofilament leader and a 2 oz (56.7 g) egg weight connected to 20-30 lb. (9.1-13.6 kg) test line by a 100 lb. (45.4 kg) barrel swivel. Fish were landed with no extraneous "playing" and either netted with a soft nylon net or gently lifted from the water by hand. Hooks were removed by hand on all fish hooked above the pharyngeal teeth while the leaders were cut on all gut hooked fish. Red drum possess large pharyngeal teeth and this procedure most likely represents typical angler behavior. The following parameters were recorded for each fish landed in this study: fish size (total length, fork length, standard length and girth), hook type, anatomical location of hook, wound severity, surface and bottom water temperature, salinity, dissolved oxygen, air temperature, depth of capture, geographic location (GPS coordinates), landing time (time from hook set to landing), handling time (time from landing to placement in on-board tank), and in 2001, transport time (time in on-board tank until placement in net pen). Drumming fish were assumed to be male, and all others were identified as female. Identification of males was also confirmed in some cases by release of milt from the urogenital pore. Four categories of wound severity were defined in this study. A categorical ranking of volume of blood present was used as the criterion, resulting in the following four categories: 1) no bleeding, 2) mild bleeding, 3) moderate bleeding, and 4) severe bleeding. Fish that required resuscitation were submersed, cradled upright, and held by the caudal peduncle, which was moved back and forth until the fish regained equilibrium.

In 2000, following landing, fish were tagged with a transmitter and float assembly modified from Bettoli and Osbourne (1998). The transmitter (Sonotronics Model CHP-87-S) was attached to a PVC closed cell foam float. The tag-float assembly was connected to a stainless steel dart via dissolvable polyglactin suture (Vicryl, Ethicon) which was inserted in the dorsal musculature. The suture dissolved in approximately one month and the tag-float assembly was then free to float to the surface for recovery and refurbishment. The tag-float assembly (excluding the stainless steel dart) weighed 26 g in air and exerted 8 g of positive buoyancy. Transmitters had a guaranteed life of 7 months and were coded with unique frequencies and pulse intervals for individual identification. After transmitter attachment, fish were immediately released.

Transmitters had a published range of 3 km. However, wave action, boat activity (running motors and depth finders), and stratification can severely reduce the likelihood of detection and position accuracy. To determine the maximum detection distance, transmitters were submerged at fixed points on several occasions under differing conditions. The boat was driven away from the tag in several directions and the maximum distance at which the tag could still be detected was recorded. Under most conditions in the lower Neuse River, detection levels of transmitters averaged approximately 2 km. The position accuracy was also determined for transmitters. On several occasions, transmitters were submerged at locations unknown to both the boat and hydrophone/transceiver operator. The distance between the true location and the location determined by the hydrophone/transceiver operator of the submerged transmitter was calculated. Under most conditions, the positional error was 4 m.

Two tracking techniques were employed in the 2000 field season. Attempts were made to track two released fish for 72 consecutive hours post release (hereafter referred to as intensive tracking). However, this method was exceedingly time intensive and would have yielded an extremely low sample size. Furthermore, the high frequency of thunderstorms and strong wind events made it difficult to track fish continuously for extended periods of time. Therefore, the remaining fish were tracked by a series of waypoints spaced approximately 2 km apart over most of the lower Neuse River, from Minnesott Beach to approximately 6 km east of Cedar Island (hereafter referred to as non-intensive tracking; Figure 2.3). At each waypoint, a unidirectional hydrophone was used to scan the range of possible frequencies to detect tagged fish. Non-waypoint positions within the lower Neuse River were also occasionally surveyed for the presence of tagged red drum. Attempts were made to locate tagged fish on three consecutive days (72 hours) post release. Searches typically began in the vicinity of the last recorded location and moved progressively further from that location. Upon detecting a fish, the boat was positioned so the transmitter ping strength was equal in all directions (i.e. 360°). If more than one fish was detected at a given waypoint, attempts were made to relocate the fish closest to the tracking vessel first. After all relocations were recorded, hydrophone monitoring began again, generally at the nearest waypoint. For each relocation, transmitter frequency and pulse interval, time, date, location (GPS coordinates), depth, air temperature, surface and bottom water temperature, salinity, and dissolved oxygen were recorded. To better gauge ambient conditions of the lower Neuse River, physical variables were generally recorded at every other waypoint where no red drum were detected. Relocated fish were presumed dead when no net movement was evident. Relocations of fish with that previously categorized as survivors (i.e. > 72 hours post-release) were also recorded for movement analysis (see chapter 3).

In 2001, following landing, fish were tagged in the dorsal musculature with an individually numbered dart tag (provided by North Carolina Division of Marine Fisheries), immediately placed in an on-board circulating tank (550 l or 950 l capacity, depending on boat in use) and transported to a net pen. Due to the schooling behavior of red drum, additional fish occasionally struck a bait while landed fish were being processed on board. In these instances, angling continued until all fish were landed. If no additional fish struck a rod before the last landed fish was placed in the holding tank, fishing ceased and the boat was used to transport fish to the net pen. Holding capacity for each net pen was limited to 13 individual fish. Individual holding trials lasted approximately 72 hours, which commenced when individual fish were placed into the net pen. Individuals in the net pen typically represented catches over one fishing interval. However, three trials (trials 15, 20 and 21; Table 2.2) included cumulative catches over a period of 2 nights of fishing, which increased the holding period by 22.5 to 27.8 h.. A 3-d holding period was chosen based on previous studies of red drum and other fish species, in which most mortality occurred during this interval (Marnell and Hunsaker 1970; Warner 1978; Warner and Johnson 1978; Warner 1979; R. G. Thomas, Louisiana Department of Fish and Game, personal communication)

Fishing sites were located in the vicinity of net pens to minimize transport stress. Net pens (8.5 m x 8.5m x 3 m) were constructed of 2” latex-dipped nylon mesh. Two net pens were used in the study, each placed in water about 2.4 m within the lower Neuse River (Figure 2.4). Net pens were checked daily for mortalities and the following parameters were recorded: air temperature, surface and bottom temperature, salinity and dissolved oxygen concentration. Mortalities, if present, were removed from net pens, identified by tag number and retained for necropsy analysis. If hypoxic conditions were detected, the position of the pycnocline from the bottom was determined.

Furthermore, in order to better gauge water quality at net pens during trials, Hydrolab minisondes (Hydrolab Corp. Austin, Texas) were deployed during eight trials (trials 7, 8, 9, 10, 12, 17, 19, and 22). The datasondes recorded bottom temperature, salinity, pH, and dissolved oxygen concentration continuously at 15-20 minute intervals during the holding period.

At the end of the holding period, each fish was checked for dart tag retention and identified by tag number. Gut hooked fish were checked for presence of retained hooks. All surviving fish were released. In instances where nets pens contained fish caught over successive fishing periods, fish in the trial were released only after all had been held for at least 72 hrs in the net.

Fish that died during the course of this study were necropsied to determine probable causes of mortality. Fish were examined for placement of hook within the body cavity (if deep hooked), occurrence of hemorrhaging, maceration of esophagus and internal organs, integrity of pericardium, others signs of direct internal damage, presence of lesions or signs of infection, and any indicators of indirect causes of mortality. In all necropsies, sex was determined based on gonad examination. This provided a check on the field approach for sex determination based on the presence or absence of drumming.

Statistical analyses

In 2001, logistic regression analysis (PROC LOGISTIC) was used to test whether hook type, hook position, fish size, sex, landing time, handling time, transport time, water temperature at capture, surface salinity at capture, and depth of capture significantly affected mortality (SAS Institute 1990). Due to the low number fish that exhibited bleeding at the time of capture and the results of necropsy analysis, the wound severity classification was determined to be a poor indicator of injury. Thus, it was not included as a variable in the model. The logistic model describes the probability of mortality for individual fish as:

$$P(M) = e^{u} / (1 + e^{u})$$

where *u* is the linear function of the independent variables and *e* is the base of the natural logarithm. A stepwise selection technique (selection=stepwise; SAS 1990) was originally utilized. However, the quasi-complete separation of data points was detected because for both categorical variables all mortalities occurred within only one of the classifications. Therefore, the maximum likelihood estimation may not have existed, invalidating the model output. As a result, a manual stepwise technique was employed using *p*-values obtained from conditional exact tests. An acceptance level of 0.01 for incorporating a variable into the model and an acceptance level of 0.05 for retaining a variable was used. Nearly all of the trials contained less than 10 red drum; therefore, the data were pooled so the logistic model had sufficient observations for each independent variable (Taylor et al. 2001; Table 2.2).

In 2000 and 2001, stepwise logistic regression analysis was also used to test whether hook type, fish sex, fish size (FL), surface water temperature, surface salinity, and depth significantly affected hook position.

Similar to linear regression, multicolinearity among independent variables can negatively affect the validity of a logistic regression model. However, several of the more advanced techniques (e.g. assessment of multicolinearity) are not well developed for exact logistic regression as they are for standard linear regression (R. Berger, North Carolina State University, personal communication). Therefore, multicolinearity among the continuous independent variables was assessed by first computing a correlation matrix employing Pearson's correlation coefficients in SAS (SAS 1990). Significant correlations and all pairwise associations of a continuous independent variable and a categorical independent variable were examined using simple linear regression. If an r^2 value was > 0.25 then the residuals computed in the linear regression model were used in place of the raw data for one of the variables. This method allows a variable to be retained in a full model even if there is significant correlation between two independent variables because it effectively removes the correlation of one independent variable upon another (Graham 1997).

In 2001, significant positive correlations were noted between fork length and landing time ($P = 0.0003$), fork length and handling time ($P = 0.0222$), transport time and depth ($P =$ < 0.0001), and surface temperature and depth ($P = 0.0001$) and significant negative correlations were noted between landing time and surface temperature ($P = 0.0427$), transport time and surface temperature ($P = 0.0039$), handing time and surface salinity (P = 0.0153), and surface salinity and surface temperature ($P = < 0.0001$). The residuals calculated for temperature when temperature was regressed against salinity was $r^2 = 0.2587$. Prior research indicated that salinity was an important factor of red drum hooking mortality in the Pamlico Sound (Gearhart 2002). Therefore, the residuals calculated for temperature were included in the logistic regression model examining post-hooking mortality. However, because temperature may play a more import role than salinity in the determining hook position due to increased activity rates, the residuals calculated for salinity when salinity was regressed against temperature were incorporated in the logistic regression model examining hook position. All the remaining r^2 values were <0.25; thus, the original untransformed data for these continuous variables were incorporated into the models.

In 2000, a significant negative correlation was noted between surface salinity and depth ($P = 0.0051$). The residuals calculated for depth when salinity was regressed against depth was 0.3304. Therefore, the residuals calculated for depth when salinity was regressed against depth were incorporated in the logistic regression model examining hook position. All the remaining r^2 values were <0.25; thus, the original untransformed data for these continuous variables were incorporated into the models.

Pairwise associations among the categorical variables were examined using logistic regression. The aforementioned procedure could not be performed with logistic regression because there is no direct analog to the r^2 computed in ordinary least squares regression. Nevertheless, in 2001,logistic regression indicated significant ($P = <0.05$) relationships between hook type and hook position and hook position and sex. These relationships did not appear to confound the mortality analysis; thus they were not removed from the multiple logistic regression models examining post-hooking mortality (see discussion).

Chi-square analysis was used in both years to determine if hook type was dependent on sex. A Wilcoxon rank-sum test (PROC NPAR1WAY, option = WILCOXON; SAS 1990) was used in 2000 and 2001 to test the null hypothesis that fish size did not significantly differ between hook types. In 2001, general linear modeling (PROC GLM; SAS 1990) with analysis of variance (ANOVA) was used to determine if fork length was associated with landing times and if fork length, hook type, and hook position were associated with handling times. All summary statistics were calculated using SAS (SAS 1990). Normality was assessed with normal-quantile plots generated using SAS (SAS 1990). All variables that did not meet assumptions regarding univariate normality were log transformed. A significance level of 0.05 was chosen for statistical analyses unless otherwise stated.

Results

2000 – Ultrasonic Telemetry

Twenty-two adult red drum were caught, tagged with ultrasonic transmitters and released from 11 July to 25 September 2000. Fork lengths ranged from 928-1180 mm (mean±SE 1052±13.25 mm; Figure 2.5). There was no significant difference between the fork lengths of fish caught with j-style and circle hooks (Wilcoxon rank sum test: P = 0.0816). Fourteen red drum were caught using j-style hooks and eight red drum were caught using 16/0 circle hooks. Equal number of circle hooks and j-style hooks were fished at all times. Assuming equal effort, there was no significant difference in the number of fish caught with j-style hooks and circle hooks (Yates corrected χ^2 goodness-of-fit test: $0.05 < P < 0.1$). All fish were caught either in the corner of the maxilla (shallow) or the gut region (deep); no other hooking locations occurred. Fish caught with circle hooks were far more likely to be hooked in the maxilla than the gut region (Table 2.3). However, the hooking percentages for fish caught on j-style hooks were similar for the maxilla and gut region (Table 2.3). Hook type, sex, fork length, depth, and surface temperature were independent of hook position (Table 2.4). Thirteen females and eight males were tagged and released in the 2000 field season. Water temperatures averaged 27.1°C and ranged from 25.4°C to 29°C during the 2000 field season; capture depths averaged 3.4 m and ranged from 1.6 m to 5.8 m; landing times averaged 3.7 min and ranged from 1.8 min to 10.0 min; handling times averaged 3.6 min and ranged from 2.1 min to 7.0 min.

Of the 22 adult red drum tagged and released in 2000, final fates (survival or mortality after 72h) were not determined for five fish. Three fish were not detected by hydrophone surveys after release. Relocations were recorded for the remaining two fish; however, all were less than 3 d post release. One fish was relocated at 2.3 d after release and the other fish was relocated twice up to 1.2 days after release. There is no compelling evidence to assume that the five fish without final fates scored died as a result of angling. However, all five fish were removed from mortality analysis, leaving 17 fish for evaluation.

A single mortality was recorded in the 2000 field season (5.88%; 95% CL = 0% - 17.07%; Table 2.5). This fish was caught with a 7/0 regular hook, which was lodged in the gut region at the time of landing. There was no noticeable bleeding or distended stomach at landing; however, it appeared noticeably lethargic in comparison to other fish landed. Upon release, this fish was held by the caudal peduncle and moved back and forth in a swimming motion. The fish momentarily swam off, floated at the water's surface for approximately six minutes, and then sank. On three successive days post-release this fish exhibited no movement from the tagging location. Given only a single morality was observed in 2000, no attempt was made to model factors associated with mortality.

2001 - Confinement

One hundred-twelve adult red drum were caught from 24 June to 23 September 2001 with hook and line gear. Fork lengths ranged from 880 to 1250 (mean1069±7.6 mm; Figure 2.6). There was no significant difference between the fork lengths of fish caught with circle and j-style hooks (Wilcoxon rank sum test; *P* = 0.1383; Figure 2.7). In all, 63 females and 49 males were caught with hook-and-line gear. There was no significant difference between the sizes of male (mean±SE 1058±10 mm) and female (mean±SE 1077±11 mm) red drum (Wilcoxon rank sum test: *P* =0.1708). Chi-square analysis indicated hook type was independent of fish sex ($\chi 2$ = 0.4828; df = 1; *P* = 0.4871). Eighty-eight red drum were caught with j-style hooks and 24 red drum were caught with circle hooks. Although far more fish were caught with j-style hooks than circle hooks, these numbers do not directly reflect hooking effectiveness (defined here as a joint probability of bait ingestion, initial hook set, and hook retention during the landing period). Circle and j-style hooks were always fished simultaneously; however, on average 2.9 times as many j-style hooks were fished than circle hooks. A Yates corrected x^2 goodness of fit test was used to test the null hypothesis that circle hooks and j-style hooks caught fish in a 1:2.9 ratio (Zar 1991). A significant difference in number of fish caught between hook types was noted (number landed with j-style hooks > number landed with circle hooks, *P* = < 0.005). The mechanism responsible for this apparent difference is not clear. Although characteristics of the hooks themselves are important in determining performance (e.g. size, gauge, and shape), other factors thought to be important in hook performance include rod attendance, line tension resulting from prevailing wind conditions and sea state, and ability of fish to detect the hook type prior to ingestion. The present study was not designed to evaluate hooking effectiveness; thus, drawing any conclusions about hook performance is beyond the scope of this study.

For red drum caught with j-style hooks the hooking position percentages for the maxilla, tongue, throat and gut region were 45.46%, 2.27%, 3.41%, and 48.86 %, respectively (Figure 2.8). Conversely, the majority of red drum (95.8%) caught with circle hooks were hooked in the maxilla, while 4.2% were hooked in the gut region (Figure 2.8). Given the low probability of hooking in the tongue and throat region, the gut and throat hooking classifications were pooled into a single category (deep) and the tongue and maxilla classification were pooled into a separate category (shallow). J-style hooks were far more likely to hook deep than circle hooks (Table 2.5). Similarly, females were more likely to be hooked deep than males (52.38% vs. 28.57%, respectively). Logistic regression analysis indicated that hook position (shallow vs. deep) was dependent on hook type and sex; but independent of fork length, capture depth and surface salinity (Table 2.6).

Landing times ranged from 0.5 to 10.3 min (mean±SE 3.8±0.17 min). Larger fish had significantly greater landing times ($P = 0.001$). Handling times varied from 0.9 to 7.1 min (mean±SE 3.1± 0.12 min). Larger fish also had significantly greater handling times ($P = 0.027$). However, hook type ($P = 0.516$) and hook position ($P = 0.944$) were not significantly related to handling time. Transport times ranged from 0 – 32 min (mean±SE 7.5 ±0.55 min). Fish with transport times of 0 minutes were caught beside and placed directly in holding pens following handling procedures.

Seven red drum (6.73 %; 95% CI = 1.92 % - 11.55 %) died during the 3-d holding period. Mean water temperatures in the net pens were 24.2 – 29.2 °C. Two fish died immediately after angling and the remaining fish died at some point within the 3-d holding period. Two dead individuals were observed during the first 24 hours of containment, one was observed between 24-48 hours, and two others were noted during the final 24-h period.

Hook position and surface salinity were the only independent variables found to significantly affect red drum post-hooking mortality (Table 2.8). Fish size (FL) and depth of capture were also incorporated in the logistic regression model, but were subsequently dropped because they did not meet the 0.05 significance level for retaining an independent variable (Table 2.8). A higher percentage of deep hooked fish suffered mortality compared to shallow hooked fish (Table 2.9). Furthermore, among fish caught with j-style hooks, a much larger proportion of deep hooked fish died than shallow hooked fish (Table 2.9). The mean (±SE) surface salinity at capture was less for mortalities (15.8±0.6 psu) than survivors (17.3±0.15 psu).

Eight captured fish were removed from the mortality analysis because final fates (survival or mortality) were not determined. On two occasions, net pens (trial 18 and 19; Table 2.2) were damaged by strong winds and wave action. During these instances, at least one side of the net pen was at or below the surface of the water. As a result, seven fish (two on the first occasion, five on the second occasion) were allowed to escape the confinement of the net pen. In another instance, a net pen was damaged by a project vessel and a single fish was observed swimming from the enclosure. Complete data (landing time, handling time, and transport time) were not recorded for eight surviving fish due to the technical malfunction of a chronometer. Therefore, a total of 8 fish were removed from the mortality rate determination (total N = 104) and 16 fish were removed from the logistic regression model (total N = 87).

Hypoxic or near hypoxic (<2.5 mg/l O_2) conditions were noted by project personnel during daily recordings in trials 7 and 22 (Table 2.2). Hypoxic conditions spanned two consecutive readings during trial 7 and was recorded once in trial 22. On each of these occasions, the pycnocline was 0.5-1.5 meters from the bottom of the net pen. The deployed minisondes also recorded hypoxic or near hypoxic conditions during trial 7 and in trials 10, 12, 17, and 19 (Table 2.2). A minisonde did not record hypoxic conditions during trial 22 because it was deployed approximately 35 hours into the trial, after conditions had returned to normoxia. In trials that hypoxic or near hypoxic conditions were recorded by minisondes, but not during daily observations, the hypoxic events occurred during intervals between daily observations. Thus, all but one of the hypoxic events (Trial 7) lasted less than 24 hours while fish were being held in net pens. Although a mortality occurred during trial 22, this fish died immediately after angling and did not experience net pen hypoxia. Similarly, the single mortality that occurred during trial 12 died prior to the development of hypoxic conditions. Therefore, no mortalities occurred in trials in which hypoxic events were recorded. However, hypoxic events may have occurred in between daily readings when minisondes were not deployed.

Two of the seven mortalities were not recovered for necropsy analysis. One mortality was inadvertently discarded prior to dissection by project personnel. The other was observed dead within the net pen; however, due to adverse conditions (strong winds and approximately 1 m wave heights) this fish was not retrieved. Upon returning when conditions permitted, the fish was no longer within the net pen. The 5 remaining mortalities were retrieved from the net pen and necropsied to determine possible factors of mortality. Fish sex was correctly classified in the field for all necropsied fish. This same procedure was also 100% accurate in the sex determination of necropsied fish during the 2002 field season. (P. S. Rand, North Carolina State University, personal observation). Thus, it appears that documenting the presence or absence of these audible distress calls is an accurate non-lethal method for determination of sex in the field.

All necropsied individuals suffered gross internal hemorrhaging and showed signs of severe trauma. The two individuals that died immediately after landing showed evidence of internal tissue damage from deep hooking. The hook ventrally pierced the esophagus and imbedded into the pericardium of one individual. The other individual had a hook pierce the esophagus and puncture the pericardium. The remaining necropsied fish survived for a period after release into the pen. The hook pierced one of these individuals in the esophagus and appeared to macerate the liver. The remaining two necropsied individuals were originally recorded as hooked in the maxilla. However, upon necropsy analysis both fish had gross internal hemorrhaging and injuries indicative of gut hooking. One of these fish possessed a 75 mm tear in the esophagus, which appeared to continue through the pericardial chamber before terminating in the buccal cavity. The other fish exhibited a small laceration in the uppermost ventral portion of the esophagus and a laceration was evident in the pericardium. These observations indicate that the hooks originally pierced the esophagus posterior to the pharyngeal teeth prior to lodging in the maxilla at the time of landing.

All red drum held for 3 d and released retained their dart tags. Of the 34 gut hooked red drum held for 3 d and released alive, 18 fish still had signs of gut hook retention (i.e. visible hook and/or leader). Fourteen of these deep hooked red drum showed no sign of hook or leader upon release. Either the hook and leader were ingested or the hook was regurgitated and expelled out of the body through the mouth. Gut hook retention data for two released red drum were not recorded due to adverse weather conditions.

Discussion

Ultrasonic Telemetry vs. Confinement

Hooking mortality studies that directly assess mortality typically conform to two general strategies: 1) biotelemetry, either by actively monitoring fish (i.e. radio and ultrasonic telemetry) or indirectly through the use of archival or satellite tags (Jolley and Irby 1979; Bendock and Alexandersdottir 1993; Lee and Bergersen 1996; Bettoli and Osbourne 1998; Bettoli et al. 2000; Whoriskey et al. 2000; Arendt and Lucy 2002; Brill et al. 2002; Goodyear 2002; Lucy and Machen 2002) or 2) confinement, either by holding individuals in the laboratory or the field (e.g. Dotson 1982; Nufer and Alexander 1982; Hegen et al. 1984; Clapp and Clark 1989; DuBois et al. 1994; Nelson 1998; Taylor et al. 2001). Both methods have their advantages and disadvantages depending on the study species and study area.

The primary advantage of biotelemetry is that fish are released back into the study system immediately after landing. Therefore, individuals can resume normal behavior and will not suffer artifacts of caging, which can bias mortality estimates. Moreover, information regarding post-release movement and behavior can generally be gathered with little additional effort on the part of researchers. However, tracking and monitoring released fish can be extremely labor intensive and the cost of the required equipment prohibitively high, especially when purchasing satellite monitoring time and tags. Moreover, sample sizes are generally reduced using this method due to the amount of time necessary to track most fish species. This is particularly true for ultrasonic telemetry in large, open systems. As a result, studies using confinement can be less labor intensive and more cost effective when compared to biotelemetry. Furthermore, when conducting experiments in the laboratory, environmental variables (e.g. temperature, salinity, photoperiod, etc.) can be easily manipulated. After the experimental period, fish (survivors and mortalities) are readily available for further analysis, such as necropsies.

Ultrasonic telemetry was chosen in 2000, because it was believed that the large size of adult red drum and the inherent nature of the Neuse River (i.e. high frequency of thunderstorms, wind-events, and episodic hypoxia) precluded confinement, and laboratory facilities were not in reasonable proximity to the study area. It was also believed that red drum movement was fairly restrictive, based on anecdotal reports from fishers in the area. Furthermore, the retrievable tag-float assembly modified from Osbourne and Bettoli (1998), allowed for the reuse of transmitters; thus lowering the expected cost of the present study. However, ultrasonic telemetry indicated that red drum movement was greater than expected. Moreover, the large, open nature of the lower Neuse River allowed the emigration of tagged individuals from the study area. Frequent thunderstorms and wind events often lowered transmitter detection levels, which limited tracking ability. Therefore, in 2001, ultrasonic telemetry was abandoned and confinement of red drum was used to determine mortality. This methodology generated a much larger sample size and was found to be more effective. Given the results of both years of this study, the confinement of adult red drum in future hooking mortality studies is recommended.

Hooking Mortality

The short-term post-hooking mortality rates (5.9% and 6.7%) presented in this study are, with one exception, fairly consistent with rates reported for red drum by other researchers (Table 2.1). Jordan and Woodward (1992) reported a mortality rate of 16% for juveniles caught with single hooks in Georgia. Matlock et al. (1993) reported a mortality rate of 4.1% for red drum caught with single and treble hook baits and lures in Texas. Two Louisiana studies estimated short-term mortality rates of 3.5% and 5.0% for red drum caught with single and treble hooks, and j-style hooks and circle hooks, respectively (R. G. Thomas, Louisiana Department of Fish and Game, personal communication). Similarly, a Florida study estimated a mortality rate of 2.8% for red drum caught with baited single hooks (R. F. Heagley, Florida Marine Research Institute, personal communication). Gearhart (2002) observed a mortality rate of 6.8% for red drum caught from several areas of the Pamlico Sound, North Carolina. Discard mortality rates from trotlines have also been reported to be extremely low for red drum (Table 2.1). Martin et al (1987a, 1987b) reported that no red drum caught on circle hook trotlines were dead upon retrieval, and 0.2% died within 24 hours. In conclusion, the observed rates of post-release mortality (5.9% and 6.7%) are within the range (2.8-16%) reported for recreational catch-and-release studies conducted on red drum in marine and estuarine waters.

Although the majority of red drum hooking mortality rates have been fairly low (<10 %), Childress (1989a) reported a mortality rate of 44.7% for red drum angled in a Texas freshwater reservoir. Red drum are euryhaline fish and effective osmoregulators that can tolerate a wide range of salinities (Neill 1990). However, the additional metabolic demand of maintaining proper ionic balance in a freshwater environment most likely exacerbated capture stress and was probably a significant factor in mortality.

Differences in mortality risks associated with high and low salinities have been reported for several diadromous species (Muoneke and Childress 1994). However, the salinity in which fish were caught is typically related to life history stage, which may be affected by physiological state (e.g. breeding status, migration stress, feeding/non-feeding). Few studies have examined the effect of salinity on the mortality of estuarine species, where salinity changes are less dramatic, but typically more rapid than those experienced by diadromous species. Although the range of salinities reported in this study was narrow (14-20 psu), salinity of surface waters was significantly related to mortality. Likewise, Gearhart (2002) reported a significantly higher mortality rate for red drum angled in low salinity (Pamlico River: 10.2-13.5 psu) compared to high salinity areas (Outer Banks: 12.3-26.2 psu) of the Pamlico Sound. These data suggest that salinity may affect the mortality of caught and released euryhaline estuarine fish.

In 2001, hook position was significantly related to red drum hooking mortality. Given the results of the logistic regression model and necropsy analysis, the resulting trauma induced by deep hooking appeared to be the primary factor affecting mortality. In a review of numerous post-hooking mortality studies, Muoneke and Childress (1994) concluded that the anatomical location of the hook wound appears to be the most important factor in hooking mortality for many fish species. The hooking of critical areas (e.g. gills, esophagus, gut region) and the presence of bleeding have been reported to be associated with post-hooking mortality of Atlantic salmon *Salmo salar* (Warner 1978; Warner and Johnsohn 1978), blue cod *Parapercis colias* (Carbines 1999), bluefish (Ayvazian et al. 2001), chinook salmon

Oncorhynchus tshawytscha (Bendock and Alexandersdottir 1993; Grover et al. 2002), rainbow trout *Oncorhynchus mykiss* (Schill 1996; Schisler and Bergersen 1996), coho salmon *Oncorhynchus kisutch* (Vincent-Lang et al. 1993), cutthroat trout *Oncorhynchus clarkii* (Hunsaker et al. 1970; Pauly and Thomas 1993), lake trout *Salvelinus namaycush* (Persons and Hirsch 1994), largemouth bass *Micropteus salmoides* (Pelzman 1978; Cook et al. 2003), northern pike *Esox lucuis* (Dubois et al. 1994), red drum (Jordan and Woodward 1992; see Gearhart 2002), common snook *Centropomus undecimalis,* (Taylor et al. 2001), southern flounder *Paralichthys lethostigma* (Gearhart 2002), spotted sea trout *Cynoscion nebulosus* (Murphy et al. 1995; Gearhart 2002), striped bass *Morone saxatilis* (Diodati and Richards 1996; Nelson 1998; Lukacovic and Uphoff 2002), summer flounder *Paralichthys dentatus* (Gearhart 2000; Malchoff et al. 2002), weakfish *Cynoscion regalis*, and others (see Muoneke and Childress 1994 for review). Furthermore, Jordan and Woodward (1992) reported that although red drum hooked in the gill and esophagus comprised only a small percentage of total landings (<15%), they exhibited elevated mortality rates of 32% and 53%, respectively.

The expected risk of post-release mortality for angled red drum may be best viewed as a joint probability of hook piercing location (affected significantly by hook type), and subsequent mortality risk (affected significantly by hook piercing location). The ultimate mortality rate may also be influenced to some extent by salinity. A similar two-step process has been proposed for chinook and coho salmon by Gjernes et al. (1993).

In 2001, circle hooks produced significantly lower deep hooking rates than j-style hooks (4.17% vs. 52.27%). In 2000, circle hooks also produced lower deep hooking rates than j-style hooks in (12.5% vs. 87.5%), but this relationship was not significant, most likely due to low sample size (n = 22). The propensity for circle hooks to not hook in-critical areas hase been shown for a wide variety of recreational and commercial fisheries, including those involving red drum (McEachron et al. 1985; Martin et al. 1987a; Martin et al. 1987b), black drum *Pogonias cromis* (McEachron et al. 1985), Pacific sailfish *Istiphorus platypterus* (Prince et al. 2002), Atalntic bluefin tuna *Thunnus thynnus* (Skomal 2002), yellowfin tuna *Thunnus albaceras* (Falterman and Graves 2002), striped bass (Caruso 2000; Hand 2001; R. Lukacovic, Maryland Division of Natural Resources, personal communication), and Pacific halibut *Hippoglossus stenolepis* (Kaimmer and Trumble 1998). Furthermore, several studies have reported that circle hooks were less likely to hook in critical areas in comparison with more conventional hook types (Falterman and Graves 2002; Skomal et al. 2002; Zimmerman and Bochenek 2002; Cooke et al. 2003). Therefore, the results of this study are consistent with most studies focused on the use of circle hooks as an approach to reduce the likelihood of deep hooking.

Although no significant difference in mortality was found between hook types during 2001, all individuals captured with circle hooks survived the holding period, compared with a mortality rate of 8.5% for those fish landed with j-style hooks. Similarly, mortality rates for fish caught on circle hooks and j-style hooks in 2000 were 0% and 9.1%, respectively. In prior research, circle hooks have typically resulted in low mortality rates, which are often less than those measured for other hook types. A Maryland study determined mortality rates of 0.8% and 9.1% for striped bass caught with circle and j-style hooks, respectively (R. Lukacovic, Maryland Division of Natural Resources, personal communication). In Louisiana, the post-hooking mortality for adult red drum was 3% for circle hooks and 7% for conventional hooks (R. G. Thomas, Louisiana Department of Fish and Game, personal communication). Curaso (2000) reported that the mortality rate of striped bass caught on circle hooks (3%) was far lower than j-style hooks (15.5 %). The mortality rates of channel catfish caught on circle hook, straight-shank hook, and kahle hook trotlines were 8%, 15.5 % and 27.4%, respectively (Ott and Storey 1991). Martin et al. (1987a, 1987b) reported mortality rates of 0% and 0.2% for red drum captured on circle hook trotlines. Cooke et al (2003) reported a mortality rate of 5.1% for largemouth bass caught with circle hooks, which was slightly less than fish caught with octopus hooks (6.6%). Chinook salmon caught from the California drift mooch fishery exhibited a relatively high mortality rate (42.2 %; Grover et al. 2002). However, the authors reasoned that this was most likely related to the inherent nature of current drift mooching techniques and that changes in fishing practices could lower mortality rates.

Due to the propensity of circle hook to lodge in the mouth and jaw area, very few circle hook caught fish were deep hooked fish. This may make it difficult to truly determine the fate of fish caught with circle hooks deep, which could also make comparisons concerning mortality rates between hook types difficult. For example, even if circle hooks are taken deep less often (as opposed to shallow hooking), overall mortality may be high if mortality for deep hooked fish is excessively high (i.e. far greater in comparison to j-style hooks). The larger size and shape of circle hooks could do more damage than j-style hooks when taken deep and they may also take longer to dissolve or dislodge from internal tissue. Likewise, a circle hook is a larger obstruction within the oral cavity and may effect feeding and/or fish behavior to a greater extent. However, considering the low deep hooking rate (4.2%) of circle hooks used in this study, it is unlikely that the deep hooking mortality rate is high enough to markedly increase overall mortality. For example, given the hooking percentages and associated mortality rates reported in this study, even if the deep hooking rate of circle hooks is conservatively adjusted to 10%, the deep hooking mortality rate of circle hooks would have to be > 80% to exceed the overall mortality rate of j-style hooks. Therefore, the results of the present study, in concert with results of these other referenced studies, provide strong evidence that the use of circle hooks will very likely reduce overall catch-and-release mortality rates relative to that observed using more conventional hook styles.

The latest Atlantic coast red drum stock assessment (2000) listed the evaluation of the effect of water temperature and depth of capture on red catch-and-release mortality as research needs (Vaughn and Carmichael 2001). Elevated water temperatures have the potential to affect mortality risk by increasing the metabolic rate and stress level of fish experiencing exhaustive exercise and/or physical injury (i.e. the angling process). However, the magnitude of this effect is most likely influenced by the inherent physiology of the fish (i.e. species effect), physiological state at capture, ambient environmental conditions, and other extrinsic factors. Results of effects of temperature on mortality risk have shown mixed results, with studies reporting both a significant relationship between mortality and season (i.e. summer vs. winter) and water temperature (e.g. Childress 1989b; Muoneke 1992; Wilde 2000; Neal et al. 2001) and a non-significant relationship (e.g. Hegan 1984; Taylor and White 1992; Muoneke 1993; Martin et al. 1987a; Taylor et al. 2001). In the present, study water temperature at capture was not significantly related to red drum mortality. Temperature may not have had either a direct or an indirect effect on hooking mortality in the present study because of the narrow range of temperatures experienced by fish (23.6 – 29.9 °C; mean = 27.2°C). Furthermore, red drum are rather robust and can tolerate temperatures up to 33°C under estuarine conditions (Neill 1990). It is important to note that all of the fish caught in the present study were landed in the evening (typically around sunset), and thus the fish were not exposed to direct sunlight and extreme air temperatures.

Rapid ascent from depths during angling may cause the expansion of gasses within the body cavity, especially the swimbladder and cranial region, which could potentially cause internal hemorrhaging, rupture of the swimbladder, and organ displacement and damage. In the present study, depth was not significantly related to red drum hooking mortality. It is important to note that the maximum depth of the lower Neuse River is approximately 6 m and red drum are typically angled at depths of 2.5-3.5 m within this system. These depths are most likely not great enough to cause significant gas bladder inflation leading to elevated mortality risk. However, in a Louisiana study, several adult red drum required venting after angling from a depth of approximately 5 m (R.G. Thomas, Louisiana Department of Fish and Game, personal communication). In this latter study, all vented red drum survived a 3-d holding period. Although the effect of depth appears to be variable among fish species (most likely depending on a particular species' physiology), these factors also have the potential to increase susceptibility to predation due to the inability to submerge and evade predators (i.e. Hubbard and Miranda 1989; Loftus et al.1988; Muoneke and Childress 1994; Gitschlag and Renaud 1994; Dedual 1996; Wilson and Burns 1996; Collins et al. 1999). Adult red drum are large fish and one of the dominant predators in the Neuse River Estuary; therefore, it is highly unlikely that the effects of possible gas bladder inflation or exhaustion would increase predation risk.

The effect of size on the mortality of recreationally caught fish has been variable within and among taxonomic groups (Muoneke and Childress 1994). The association between mortality and fish length may be related to ontogenetic stage, physiological state or difficulty in landing and handling. Although fish that died in this study were on average smaller than survivors, the difference was not significant. This could have resulted from the fact that all fish were fairly similar (i.e. they were all adults caught within a relatively narrow size range, 928-1180 mm FL). These results appear consistent with those reported in other red drum hooking mortality studies. The length of sub-legal (199-355 mm) red drum caught in Georgia had little overall affect on mortality (Jordan 1991). Gearhardt (2002) reported that fish the length of red drum caught in North Carolina was not significantly related to mortality. Mortality rates between legal (> 406 mm) and sublegal (< 406 mm) red drum caught in Louisiana were not significantly different (R. G. Thomas, Louisiana Department of Fish and Game, personal communication). Conversely, Childress (1989a) reported that mortality rates increased with the size of red drum caught in a Texas freshwater reservoir.

Because most adult red drum caught in the Pamlico Sound are caught in conjunction with their spawning migration, fish sex could have an affect on mortality, possibly mediated through increased aggression, which may increase the probability of hooking in vital areas (Muoneke and Childress 1994), or by exacerbating the physiological stresses involved with spawning. Although the sex of caught and released adult red drum did not appear to affect mortality, females were significantly more likely to hook deep than males in 2001.

This was surprising because if increased aggression is driving the higher propensity of deep hooking, one might expect this to be exhibited by males. However, male red drum do not use nests or spawning beds and in the present study, swam in mobile mixed schools and did not appear to defend territories, actions which may lead to increased aggression in fish. The mechanisms that caused the sex-hook position relationship in 2001 are unclear. However, fish size did not appear to affect this relationship, as there was no significant difference between the sizes of fish in relation to hook position, hook type, or sex. Future research that records how fish of both sexes interact with terminal tackle type may help resolve this question.

In the present study, landing times did not significantly affect mortality. It appeared that the landing times reported were within a conservative range of time that did not lead to critical stress levels that could elevate mortality risk for adult red drum. Marnell and Hunsaker (1970) did not show a difference in mortality for cutthroat trout played for 0 (4%), 5 (6 %) and 10 (5 %) minutes. A Wisconsin study showed that the flag time (the time from bait strike until landing) of northern pike angled through ice was unrelated to mortality (DuBois et al. 1994). Vincent-Lang et al. (1993) reported that the landing times of coho salmon (assigned to two separate groups, based on elapsed landing times of <1 min or >1 min) were not significantly related to mortality. Landing time was not significantly related to the post hooking mortality of New Zealand rainbow trout (Dedual 1996). Jolly and Irby (1979) caught and angled Atlantic sailfish *Istiophorus platypterus* over periods ranging from 8 to 20 min. Based on post-release acoustic tracking data, landing times did not appear to affect mortality. Conversely, Schisler and Bergensen (1996) reported that probability of mortality for rainbow trout increased with playing time (0-5 min); however, mortality increased far greater when fish were played and held out of water.

It should be noted that landing time may not be a reliable proxy for physiological stress experienced by the fish. A more appropriate measure might be cumulative tension acting on the line over the elapsed landing period. Based on the main conclusion that the proximate cause of mortality was internal tissue and organ damage, it is speculated here that mortality risk could be inversely related to landing time, with the implied assumption that decreased landing times are a result of a substantial increase in line tension. This increase in line tension could place greater force on the lodged hook point, resulting in more extensive internal damage than would otherwise be the case. Although several studies have intentionally "played" fish to varying degrees of exhaustion (e.g. Marnell and Hunsaker 1970; Dotson 1982), the effect of cumulative line tension on catch-and-release mortality has not been addressed in the literature.

After landing, fish often experience periods of air exposure while fish are handled on board. This process can potentially compound the amount of stress already experienced by an exercised fish (Ferguson and Tufts 1992; Cooke et al. 2001). Although in the present study, handling times varied (0.87 to 7.12 min; mean 3.09 min), air exposure was minimized as much as possible. This was often difficult because several red drum were commonly processed at one time due to multiple catches. However, the amount of time taken to handle fish was not significantly related to mortality. Vincent-Lang et al. (1993) reported that handling time (< 1 min or > 1 min) was unrelated to the mortality of coho salmon. However, the amount of time rainbow trout were exposed to air following landing significantly increased the probability of mortality (Schisler and Bergersen 1996). Bettoli and Osbourne (1998) noted that the handling times of striped bass that suffered mortality after release was significantly higher than handling time for those fish that survived. Conversely, DuBois et al. (1994) reported mortality was greater for northern pike subjected to shorter handling times. The authors suggest this may have been a result of less careful hook removal techniques.

In addition to air exposure, handling encompasses the degree of care fish receive. In this study, responsible handling techniques were intentionally practiced. Fish were generally supported with both hands, and lifting fish by the lip or by the operculum was avoided. These careful handling practices may have contributed to the non-significant effect of landing time on mortality and the generally high survivorship observed in this study. Childress (1987b) reported that the type of handling (including method of lifting fish and frequency of dropping fish to the ground) was significantly related to mortality for white crappie and black crappie. However, Carbines (1999) did not report a significant difference in mortality for blue cod subjected to “good” handling techniques (i.e. use of wet cotton gloves and gentle placement back into water) and roughing (use of bare hands and tossing fish back into water). Hulbert and Engstrom-Heg (1980) reported that mortality of brown trout was unaffected by handling with either wet or dry hands. Hegan et al. (1984) reported that mortality of spotted sea trout was unaffected by the degree of handling (i.e. limited handling or air exposure, squeezing, and dropping). However, there was a significant effect due to location (bay system), which may have been due to differing handling techniques of anglers, which were nested within bay systems.

The use of field enclosures to hold fish required the use of tanks to transport red drum from fishing sites to net pens. Although an attempt to mitigate transport stress was made by utilizing fishing sites near nets pens as much as possible and circulating water through holding tanks, multiple catches of red drum and rough conditions often lengthened transport times. In fact, several transport times exceeded 15 min with a maximum of 32.1 min. However, the time fish were subjected to transport did not significantly affect mortality. Similarly, Dedual (1996) reported a maximum transit time of 31 min and concluded that transit was not significantly related to the mortality of rainbow trout.

One of the major concerns with holding red drum in field enclosures (net pens) for observation was hypoxia. The lower Neuse River is often prone to short-term hypoxia during the summer months due to stratification (Luettich et al. 2000; Selberg et al. 2001; Buzzelli et al. 2002). Many workers have correlated low levels of dissolved oxygen with increased fish stress and mortality (EPA 2000; Miller et al. 2002). In addition to directly induced mortality, hypoxia could also increase confinement stress if fish attempt to actively avoid the lower hypoxic waters. However, hypoxic events did not appear to affect mortality in the present study. All fish that experienced hypoxic or near hypoxic events survived the 3-d holding period. Furthermore, given that pynoclines were 0.5-1.5m from the bottom and total water depth was 2.4m, fish could avoid low oxygen conditions.

A very low rate of bleeding was observed for fish in both years of this study. This result was unexpected, especially for the fish hooked in the esophagus and gut region, where more vital tissue is present. A pilot study performed in 1999 and anecdotal evidence indicated a much higher bleeding probability for deep hooked adult red drum caught with tackle identical to that used in the present study. In 2000, one fish (4.5%) showed signs of bleeding. This fish was hooked in the gut with a circle hook and displayed severe bleeding; however, it survived the 3-d mortality period. In 2001, only two fish (1.8%) showed signs of bleeding: one caught with a circle hook in the corner of the mouth and the other with a j-style hook lodged deep. At the time of landing, the extent of bleeding in these individuals was concluded to be mild. However, necropsy analysis of the bleeding fish caught on a j-style hook indicated extensive internal bleeding and trauma. Furthermore, both of the immediate mortalities (< 20 min) did not exhibit any indication of bleeding at the time of capture. Necropsies indicated that both fish suffered gross internal injury. Therefore, in this study, observed bleeding did not appear to be a good indicator of injury and the use of this metric to gauge mortality risk in future studies is discouraged.

The necropsy results presented in this study appear consistent with those noted in other studies. Mortalities of red snapper caught on j-style hooks possessed hooks that punctured the esophagus and pericardial cavity and macerated the liver (K. Burns, Mote Marine Laboratory, personal communication). Curaso (2000) reported that all deep hooked striped bass mortalities displayed hook points that either punctured the heart and macerated the liver, gill arch, nephrops, or intestine. Burdicki and Wydoski (1987) reported that bluegills hooked in the esophagus possessed ruptured pericardial cavities that contained clotted blood. Necropsies of deep hooked rainbow trout showed that 87% of fish received hook induced injuries to vital areas (i.e. liver, pericardium, gills; Schill 1996) However, 95% of surviving deep hooked (n = 24) fish possessed hooks in the esophagus and anterior portion of the stomach wall. Weildein (1989) reported that several surviving (20 d) deep hooked smallmouth bass displayed hooks that pierced the esophagus or stomach wall and internal organs. One fish possessed a hook that compromised the pericardial cavity and embedded in the heart. Studies comparing internal injuries of fish that suffered mortality with those that survived following deep hooking injuries may help illuminate the factors responsible for mortality.

Hook Performance and Effectiveness

The shape, gauge, size and offset of hooks all likely play a role in their hooking performance and effectiveness, but assessing their relative importance was beyond the scope of the present study. The 16/0 circle hook used was a significantly larger hook (size and gauge) than the 7/0 j-style hook to which comparisons were made (Figure 2.2). Therefore, in this case it is difficult to address hook functionality strictly due to hook shape. However, it is still useful to conduct additional analyses beyond post-release mortality risk to compare the relative performance of these two hook types with regards to size selectivity. In both years, the mean fork length of fish caught with circle hooks were slightly smaller than j-style hooks, but these differences were not significant. Given the larger size and shape of the circle hooks used in this study, one might expect circle hooks to exclude smaller sized red drum. Several studies have reported size selectivity among different sized hooks of similar type (e.g. Carbines 1999). However, with few exceptions (e.g. McEachron et al. 1985), most studies comparing circle hooks with more conventional hooks of comparable sizes have reported no evidence of size selectivity. Hand (2001) reported that the mean length of striped bass caught on several sizes of circle (non-offset and offset) and j-style hooks were not significantly different. Likewise, Curaso (2000) reported the mean lengths of striped bass caught on 10/0 circle hooks and 7/0 j-style hooks were not significantly different. Woll et al. (2001) did not find evidence of size selectivity for Greenland halibut caught on EZ (a hook type used commonly in the Norwegian longline fishery) 12/0 hooks and three types of 14/0 circle hooks. It is assumed, therefore, that although the size and shape difference between the hooks used in this study may have had some affect on certain aspects of hook performance and effectiveness (e.g. hook position and CPUE), they did not appear to affect the size of red drum catch.

While higher catches using j-style hooks were estimated in this study, one should not confidently draw the conclusion that j-style hooks are more effective at catching adult red drum. In 2001, approximately 20% fewer fish after adjusting for effort were caught with circle hooks. Furthermore, no significant difference was found between the number of fish caught on j-style and circle hooks in 2000, albeit the sample size was smaller (n = 22). While the hook type could play some role in this, other confounding factors play a role in defining the likelihood of initial hook set and retention during the landing period. This was not the focus of the present study; hence, this information was not recorded during fishing, nor was ancillary data noted that could aid in explaining hooking effectiveness, such as number of missed fish per hook type and angler experience.

Studies that have investigated hooking effectiveness of j-style and circle hooks in both the recreational and commercial fisheries have reached different conclusions. Although, circle hooks have shown higher capture efficiencies or CPUEs with trotline, longline and recreational fisheries targeting large pelagic fishes (e.g. McEachron et al. 1985; Woll et al. 2001; Falterman and Graves 2002; Trumble et al. 2002), several studies from more traditional inshore and inland fisheries (e.g. centrarchids, moronids) have indicated otherwise. Prince et al. (2002) reported that circle hooks were nearly two times as effective at catching Pacific sailfish *Istiophorus platypterus* compared to j-style hooks. Curaso (2000) reported a higher, but non-significant likelihood of initial hook setting for striped bass caught with circle hooks compared to j-style hooks. The catching success of juvenile bluefin tuna caught with circle and j-style hooks were similar; however, circle hooks performed significantly better at holding fish once hooked than straight hooks (Skomal et al. 2002). Curaso (2000) reported a higher, but non-significant likelihood of initial hook setting for striped bass caught with circle hooks compared to j-style hooks. Conversely, several investigators have reported a significantly higher hooking effectiveness for striped bass using j-style hooks compared to circle hooks in the recreational fishery (Hand 2001; R. Lukacovic, Maryland Division of Natural Resources, personal communication). Cooke at al. (2003) reported that capture efficiency of largemouth bass caught with octopus (j-style) hooks was two-times greater than for circle hooks. Furthermore, Cooke et al. (in press) reported rock bass *Ambloplites rupestris* caught with circle hooks were twice as difficult to land compared to 3 other conventional hook types.

Non-offset circle hooks were employed in the present study. The unique shape of circle hooks appears to be the primary factor causing the observed low deep hooking and mortality rates. The point of the circle hook bends toward and becomes nearly perpendicular with the shank of the hook (see Figure 2.2). There is no exposed point; thus, reducing the likelihood to lodge in or damage critical soft tissue (e.g. gut region and esophagus). Even if a circle hook is swallowed, it may be pulled free without embedding in the gut region. However, the point of an offset circle hook extends beyond the plane of the shank. Therefore, the point of the hook is exposed and more likely to lodge in or tear soft tissue. Several workers have examined the consequences of off-setting circle hooks. Results of these studies indicate that offset circle hooks may be more likely to hook in critical areas than non-offset circle hooks of similar size. Offset 5/0 circle hooks produced higher rates of deep hooking (12.5%) and bleeding (7.8%) compared to non-offset 5/0 circle hooks (5.9% and 0%, respectively) for striped bass angled in the Roanoke River, NC (Hand 2001). Although no differences in bleeding were found between minor offset (approximately 4º), severe offset (approximately 15º) and non offset circle hooks, severe offset circle hooks had a deep hooking percentage roughly three times greater than for minor offset and non-offset circle hooks used to live bait Atlantic sailfish (Prince et al.2002). These data indicate that offsetting circle hooks may negate any functional advantage gained by hook design intended to reduce the likelihood of deep hooking.

Following the holding period, the hook and leader were not located in nearly 44% of the gut hooked red drum. Because of the relatively brief holding period, the probability of hook deterioration is unlikely. Thus, it can be concluded that the hook and leader were either swallowed or regurgitated. There are anecdotal reports of anglers catching red drum with hooks passing through their vents (G. Beckwith, Down East Guide Service, personal observation). Given that a high percentage of the red drum diet consists of crustaceans (Miles 1950; Simmons and Breuer 1962; Yokel 1966; Boothby and Avault 1971; Bass and Avault 1795; Overstreet and Heard 1978; Llaso et al. 1998; Scharf and Schlicht 2000), individuals might be able to successfully pass a sharp object such as a hook. However, red drum could also simply regurgitate hooks. Although no study has addressed the fate of hooks lodged deep in red drum, Schill (1996) reported that 74% of hatchery-reared and 60% of wild deep hooked rainbow trout regurgitated hooks after 60d and 29-34d observation periods, respectively. However, Marnell (1969) reported no shedding of hooks for wild cutthroat trout held for several weeks. There is a clear need for research to determine the fate of hooks lodged deep in red drum. This could be better evaluated with longer term holding trials and closer observation of fish during the containment period.

Furthermore, given that a high number of adult red drum shed hooks lodged deep, and the likelihood of anglers (especially those with limited experience) causing additional internal tissue and organ damage while attempting to extract deep hooks, the practice of cutting the leader and leaving the lodged hook intact in deep hooked fish is recommended. A number of studies have shown fish tend to exhibit higher survival rates when hooks are not removed prior to release (Mason and Hunt 1967, Warner 1979, Weidlein 1989, Bugley and Shepherd 1991, Schill 1996). Conversely, Jordan and Woodward (1992) reported higher survival of juvenile red drum when hooks were removed. However, no gut hooking was reported in this latter study and hooks were removed solely from the gill and esophagus.

Management implications and future research recommendations

The estimates of red drum hooking mortality presented in this study were fairly low and comparable with most other red drum hooking mortality studies. Currently, the Atlantic coast red drum stock assessment (northern and southern region) assumes a recreational catch-and-release mortality rate of 10% (Vaughn and Carmichael 2000). Directly extrapolating the mortality results presented in this study to the recreational fishery of adult red drum could be problematic for a number of reasons. First, it is imperative to identify the composition of hook types commonly used by recreational anglers. A recent survey conducted by NC DMF has provided some insight into this, but a more extensive survey is required. Second, the mortality rates presented in this study should be viewed as a conservative or "best-case scenario" given the excellent quality fishing gear used in the study (stout rods and reels fitted with proper test lines) and the focused instruction all personnel and volunteers received on proper techniques for landing and handling these fish. While none of the measures used during 2001 to gauge landing and handling stress were found to be significant in this analysis, angling techniques to help minimize stress and trauma were specifically adopted. The possible deleterious physiological consequences of exhaustive exercise on fish are well documented. Fighting fish with lighter grade gear and tackle could prolong landing times and increase the amount of stress fish suffer as a result of angling. Conversely, overly aggressive techniques to land a fish quickly could lead to greater internal tissue and organ damage, which could increase overall mortality risk. Gaining a better understanding of how anglers in the fishery treat their catch would be valuable information. However, this effort may be fraught with difficulty. The fishing grounds are relatively remote, the access points are dispersed over a wide area, and much of the fishing occurs after sunset. Therefore, it could become extremely difficult to objectively assess the full range of techniques used in landing and handling red drum in this fishery.

One clear management action that is warranted is to either promote or require adoption of terminal gear that reduces the likelihood of deep hooking. In the present study, circle hooks were significantly less likely to hook in critical areas and produced a lower mortality rate in comparison with j-style hooks. Therefore, the use of circle hooks in the adult red drum recreational fishery is recommended. However, further research regarding the fate of fish caught deep with circle hooks is also recommend to better understand the relationship between hooking position and gear type.

In addition to hook hype, other terminal gear attributes (including leader length and fixed vs. slip weights) are likely to play an important role in the incidence of deep hooking. Owen Lupton, a resident of Oriental, NC, and an avid angler with years of experience fishing for red drum, has popularized the "Owen rig”. This rig consists of a short 5-6 in. (12.7-15.2 cm) leader with a crimped 3 oz. (85.1 g) egg weight (Figure 2.9). This design causes nearly immediate tension on the leader once a fish takes the bait. In comparison, the slip-rig design used in the present study allows fish to run with the bait before tension is applied by the weight. This period appears to be sufficiently long to permit many fish to swallow the bait and allow the hook to lodge beyond the pharyngeal teeth. There are preliminary data that indicate that the Owen rig (fit with a 14/0 circle hook) is capable of achieving probabilities of gut hooking that are markedly lower than those reported for the terminal gear used in the present study (G. Beckwith, Down East Guide Service, unpublished data). To date, the North Carolina Sea Grant Program has distributed over 100 “Owen” rigs to North Carolina red drum anglers. The results of this study speak strongly toward the need to educate the angling public about the importance of using proper gear when targeting adult red drum.

One of the major concerns fishers may have with using circle hooks is hooking effectiveness. Some anglers may be resistant to using circle hooks if they appear to reduce overall catches. In the present study, the data appear to suggest that circle hooks catch fewer adult red drum than j-style hooks; however, this study was not designed to directly address this question and these specific results should be viewed with some caution. Therefore, further research specifically designed to determine the effectiveness of circle hooks and more conventional hook types (of differing sizes) is recommended for the red drum recreational fishery.

Although not addressed in this study, future research that examines the effect of catch-and-release angling on red drum reproductive potential is recommended. Due to the spawning migration pattern of red drum, the majority of landings occur within the spawning period. During the course of this study, numerous milt-flowing males were caught. Furthermore, Ross et al. (1995) collected ripe and partially spent males and well-developed, ripe, and partially spent females in the estuarine portions and associated near-shore ocean waters of Pamlico Sound during August and September. The angling process (landing and handling) can be stressful (as indicated by increased levels of cortisol and lactic acid, acid-base disturbance, hyperchloremia, hyperglycemia, and other indicators) on fish, including red drum (Beggs et al. 1980; Gustaveson et al. 1991; Pankhurst and Sharples 1992; Booth et al. 1994; Kieffer et al. 1995; Brobbel et al. 1996; Wilkie et al. 1996; Gallman et al. 1999).

Gallman et al. (1999) reported that serum cortisol concentrations, plasma glucose concentration, plasma lactate concentrations, and plasma osmolalities increased significantly with increasing playing time (10-350 s) for wild and hatchery produced red drum. Furthermore, hooking and heightened stress levels have been reported to negatively affect behavior (Cook et al. 2000; Davis and Olla 2001) and several physiological processes such as growth (Clapp and Clark 1989; see Pankhurst and Van Der Kraak 1997), immune system function (Pickering and Duston 1983) and reproduction (Carragher et al. 1989, Cambell et al. 1992; see Pankhust and Van Der Kraak 1997). Presently, no study has directly examined the effects of angling on red drum reproduction.

The use of autopsies on both survivors and mortalities in future post-hooking mortality studies is recommended. In the present study, necropsies aided in determining the specific direct factors of mortality (e.g. puncture of pericardium, maceration of specific internal organs). Two of the mortalities in 2000 were originally scored as shallow hooked. Without performing necropsies, deep hooking rates would have been biased low and the associated mortality rates would have been inaccurate. Similarly, Belle (1997) reported that numerous upper palate injuries sustained by troll-caught juvenile Atlantic bluefin tuna were only evident after conducting necropsies on mortalities. Furthermore, autopsies of surviving fish would provide an assessment of true hooking position and enable researchers to compare the internal condition of survivors and mortalities. These results have important implications for studies investigating the prevalence of deep vs. shallow hooking and associated mortality rates through test fishing. Deep hooking rates may be biased low given the possibility of misclassified shallow hooked fish that may (or may not) have sustained internal injuries deep in the esophagus or gut region from hook point tears that occurred at some point prior to the time of landing. Given this scenario, the true deep hooking mortality rate may be underestimated due to misclassified fish that survived and conversely, the true shallow hooking morality rate may be overestimated due to misclassified fish that died. Thus, a better variable to focus on in future studies of post-release mortality rates may be the location of hook wound, not the anatomical location of the hook at the time of landing.

Chapter Three

Meso-scale movement of Adult Red Drum *Sciaenops ocellatus* in the Neuse River, North Carolina

An understanding of the life history, distribution, and movements of exploited species are critical to their effective management. Although red drum have been managed for nearly two decades, little is known about the movements of adult red drum in North Carolina and throughout its range. This gap has been highlighted in the latest red drum stock assessment (applied to both northern and southern regions; Vaughn and Carmichael 2000) and the North Carolina Red Drum Fishery Management Plan (NCDMF 2001). Quantifying movement within and between critical habitats used for feeding and reproduction can provide evidence for the existence of stock, or metapopulation, structure within the population. An understanding of the nature of these movements may serve as an important step toward developing a conservation plan to prevent the species from being overexploited or negatively impacted by the degradation or alteration of critical habitat.

The movement of adult red drum has been investigated through conventional tagging and, more recently, with biotelemetry. Conventional tagging allows researchers to quantify minimum distance traveled over an elapsed period of time (hereafter referred to as macro-scale movements), net direction of movement, and, under certain circumstances, vital attributes of the population (e.g. mortality rates, population abundance). A volunteer tagging program for red drum has been in existence for over ten years in North Carolina, and over 14,000 individuals have been tagged by DMF personnel and a network of angler volunteers (Marks and DiDomenico 1996; Daniel 1998). Because this approach involves recapturing the animal, this method is not appropriate for providing data on smaller time- and space-scale movements (hereafter referred to as meso-scale movements), which may help identify critical habitat for foraging and spawning. Quantifying meso-scale movements and distribution in marine fishes, and identifying the mechanisms that can maintain meso-scale spatial distributions, has been identified as a critical uncertainty in modern fisheries management (Thorrold et al. 2001).

In recent years, biotelemetry has been successfully used to document the movements of many freshwater and marine fishes (e.g. Yamanaka and Richards 1993; Szedlmayer and Able 1993; Carl et al. 1995; Carmichael et al. 1998; Hinch and Rand 1998; Jones and Rogers 1998; Zeller 1998; Snedden et al. 1999; Hissmann et al. 2000; Collins et al. 2002), including red drum (Carr and Chaney 1976; Nicholson and Jordan 1994; Nicholson et al. 1996). Although biotelemetry can be labor intensive, expensive and affected by adverse environmental conditions, it can provide unique information regarding meso-scale movements, habitat utilization, behavior, and changes in the physiological state of fish *in situ*.

The lower Neuse River is characterized by expansive shallow sandy areas, deep muddy channel portions, and marsh-edge habitat. The period from July to October encompasses an important season for both feeding and reproduction in this species. The method of biotelemetry can provide a unique perspective on how meso-scale movements during this time may serve to maintain spatial structure of red drum schools in this relatively homogeneous habitat.

This study focuses on the use of biotelemetry to quantify meso-scale movements of adult red drum in the Neuse River Estuary. The study has the following objectives: 1) determine whether movement and distribution of ultrasonically tagged red drum are random within the estuarine study area, and document whether there are difference with respect to sex or time of day, 2) provide evidence of aggregation formation by documenting taxis among individuals revealed through co-occurrences of tagged individuals *in situ*, and 3) document the duration of residency in the area over the period from July to October to determine if the period encompasses the presumed spawning season.

Methods

Study Area

The study area is the lower Neuse River located in east-central North Carolina, USA (Figure 2.1). The estuarine portion of the Neuse River is a shallow drowned river valley with a mean depth of 3.6 meters, mean width of 6.5 km and length of 70 km (Luettich et al. in press). The Neuse River Estuary is part of the larger Pamlico Sound Estuary System, which also includes the Pamlico and Bay river systems. The Pamlico Sound Estuary System (along with the Albemarle and Croatan Sounds) is part of the largest lagoonal system and after the Chesapeake Bay is the second largest estuary system in the United States (Xie and Eggleston 1999). The average depth of the Pamlico Sound is about 4-5 m; however, the depth may vary from 2 to 3 m on shoals and bars to 7-8 m in the deeper portions (Xie and Eggleston 1999). It is separated from the Atlantic Ocean by a chain of barrier islands, commonly referred to as the “Outer Banks.” Inlets between these barrier islands (e.g. Hatteras, Ocracoke, and Oregon Inlets) provide a tidal flux of seawater. Due to the narrow widths of these inlets and the wide and shallow nature of the Pamlico Sound System, it is considered principally wind driven

(Pietrafesa et al. 1986; Xie and Eggleston 1999; Luettich et al. in press) with a negligible tidal signature at the mouths of connecting rivers (Luettich et al. in press).

Tracking

All red drum were captured using recreational angling techniques common to the red drum fishery from the lower Neuse River, North Carolina (Figure 2.1). Tackle included baited (cut striped mullet, *Mugil cephalus)* Gamakatsu 7/0 octopus hooks (Style: 02417) or Mustad 16/0 circle hooks (Style: 39960D) used with heavy grade rods and reels (Figure 2.2). Fish were landed with no extraneous “playing” and either netted with a nylon net or gently lifted from the water by hand. Hooks were removed by hand on all fish hooked above the pharyngeal teeth while the leaders were cut on all gut hooked fish. Red drum possess large pharyngeal teeth; therefore, this procedure most likely represents typical angler behavior. Following landing, fish were tagged with a transmitter (Sonotronics Model CHP-87-S) attached to a PVC closed cell foam float. The tag-float assembly (modified from Osbourne and Bettoli 1998) was connected to a stainless steel dart via dissolvable polyglactin suture (Vicryl, Ethicon) that was inserted into the dorsal musculature. Fish that required resuscitation were submersed, cradled upright, and held by the caudal peduncle, which was moved back and forth until the fish regained equilibrium.

Fish size (total length, fork length, standard length and girth), surface and bottom water temperature, salinity, and dissolved oxygen, air temperature, depth of capture, and geographic location (GPS coordinates) were recorded for each fish landed. Drumming fish were assumed to be male, and all others were identified as female. Identification of males was also confirmed in some cases by release of milt from the urogenital pore.

The tag-float assembly (excluding the stainless steel dart) weighed 26 g in air and exerted approximately 8 g of positive buoyancy. The suture material dissolved in approximately a month and tag-float assembly was then free to float to the surface for recovery and refurbishment. Transmitters had a guaranteed life of 7 months and were coded with unique frequencies and pulse intervals for individual identification. The published range of transmitters was 3 km, although in practice, wave action, boat activity (running motors and depth finders), and stratification severely reduced detection and position accuracy. To determine the maximum detection distance, transmitters were submerged at fixed points on several occasions under differing conditions. The boat was driven away from the tag in several directions and the distance at which the tag was no longer detected was recorded. Under most conditions in the lower Neuse River detection levels of transmitters averaged approximately 2 km. The position accuracy was also determined for transmitters. On several occasions transmitters were submerged at locations unknown to both the boat and hydrophone/receiver operator. The distance between the true location and the location estimated by the hydrophone/receiver operator for the submerged transmitters were calculated. Under most conditions, the positional error was less than 4 m.

Two tracking techniques were employed in this study. Attempts were made to track two released fish for 72 consecutive hours post release (hereafter referred to as intensive tracking). However, this intensive tracking method was exceedingly labor intensive and would have yielded an extremely low sample size. Furthermore, the high frequency of thunderstorms and strong wind events made it difficult to track fish continuously for extended periods of time. Therefore, the remaining fish were tracked by a series of waypoints spaced approximately 2 km apart over most of the lower Neuse River (hereafter referred to as non-intensive tracking; Figure 2.3). At each waypoint, a unidirectional hydrophone was used to scan the range of possible frequencies to detect tagged fish. Attempts were made to locate tagged fish on 3 consecutive days (72 hours) post release. Searches typically began in the vicinity of the last recorded location for individual fish and moved progressively further from that location if no fish were detected. Upon detecting a fish, the boat was positioned so the transmitter ping strength was equal in all directions (i.e. 360°). If more than one fish was detected at a given waypoint, attempts were made to relocate the fish closest to the tracking vessel first. After all relocations were recorded hydrophone monitoring began again at the nearest waypoint. In addition, a number of other additional positions were periodically monitored for the presence of tagged red drum to augment the monitoring. These positions included locations in Adams Creek, South River and the Neuse River proper. For each relocation, transmitter frequency and pulse interval, time, date, location (GPS coordinates), depth, air temperature, surface and bottom water temperature, salinity (psu, practical salinity unit), and dissolved oxygen were recorded.

Analyses

A Wilcoxon rank sum test was used to test the null hypothesis that there was significant difference between the fork lengths of male and female red drum.

Relocation positions and fish movements were visually rendered using Arcview (ESRI, Environmental Science Research Institute) and the Arcview Animal Movement Extension (Hooge et al. 1999). Movements of individual red drum are represented by the shortest straight-line distance between successive relocation positions. This method underestimates the true distance traveled because fish movements are rarely linear, especially when time intervals between relocations are large. Furthermore, this measurement is highly dependent on the number of relocations per fish, which was variable (1-14 relocations per fish). Daily movement rates (km d^{-1}) for individual red drum were calculated by determining the distanced traveled (km) during the time between successive relocation positions, adjusted to a 24-h interval. Mean (±SE) movement rates (km d^{-1}) were calculated from daily movement rates of individual red drum. A Wilcoxon rank sum test was used to compare mean daily movement rates of male and female tagged red drum (SAS 1990).

To determine habitat availability, the percentage of available depths within the study area was calculated in 1-m intervals from a coverage of bathymetric soundings obtained from the National Ocean Service (NOS-NOAA) augmented with soundings taken in the field. The percentage of depths utilized in 1-m intervals by tagged adult red drum (with at least a 6-h interval in between successive relocations) was also calculated. Quade's method (Quade 1979; Alldredge and Ratti 1986; Alldredge and Ratti 1992) was used to test whether fish used depths in proportion to their availability. This test is a non-parametric equivalent to an analysis of variance of a randomized block design. Data from one individual form the "blocks" and the habitat types (e.g. depth intervals) are the "treatments." Differences between usage and availability of the different habitat types are ranked and individuals with the greatest number of observations are given the greatest weight in calculating ranks. Although the Quade method does not assume independence of observations within individuals, a 6-h relocation interval was chosen to reduce serial autocorrelation. To determine which depth interval was disproportionately used by adult red drum, Least squares Difference (LSD)-type multiple comparison tests were used (Conover 1980; Alldredge and Ratti 1986).

Successive angles of movements for individual red drum were calculated with the program JACKEM (G. Bell, North Carolina State University). Individual angles are calculated by determining the angle of the movement vector between successive relocation positions on a Cartesian plane. Upon visual inspection, most red drum movement appeared bi-modally distributed, primarily characterized by up-and downriver (i.e. east-west) movements. Data having two modes in opposite directions (“axial”) can cause *r* (length of the mean vector) to be too small, which could result in one to falsely conclude that there is no significant direction. Therefore, the movement angles of fish were doubled (Zar 1991). Rayleigh’s tests were computed for all red drum with at least three relocations to test whether the movement of individual red drum were randomly distributed around a circle using Oriana (Kovach Computing Services). A Watson’s two-sample U^2 test was used to test the null hypothesis there was no significant difference between the mean angles of male and female red drum (Zar 1991).

A Wilcoxon signed-rank test for paired data was used to test for differences between day and night relocation depths (StatXact, Cytel). A Wilcoxon rank sum test was used to test the null hypothesis that there was no significant difference between day and night relocation depths of male and female red drum (SAS 1990). Summary statistics were calculated using SAS (SAS 1990). A significance level of 0.05 was chosen for statistical analyses.

Results

Twenty-two adult red drum were caught, tagged with ultrasonic transmitters and released from 11 July to 25 September 2000. Fork lengths ranged from 928-1180 mm (mean 1052±13.25 mm; Figure 2.5). There was no significant difference between the fork lengths of the13 female and 8 male red drum tagged and released in the 2000 field season (Table 3.1; Wilcoxon rank sum test; $P = 0.082$). At capture locations, surface and bottom temperatures, salinities and dissolved oxygen concentrations were similar. Surface and bottom water temperatures averaged 27.1°C (25.4°C to 29°C) and 26.6°C (25.4°C to 28.7°C); surface and bottom salinity averaged 14.5 psu (7.1 psu to 18.3 psu) and 15.8 psu (7.7 psu to 27.6 psu); surface and bottom dissolved oxygen concentration averaged 7.76 mg/l (6.02 mg/l to 9.03 mg/l) and 7.01 (4.79 mg/l to 8.86 mg/l). Capture depths averaged 3.35 m and ranged from 1.62 m to 5.79 m.

Of the 22 tagged and released red drum, at least one relocation was obtained for 19 fish. From 11 July to 3 October 2000, 99 relocations were recorded for the 19 fish (1-13 relocations/fish; mean 5; Figure 3.1). Generally, when fish were detected one observation was recorded per fish per day, except during intensive tracking where attempts were made to track fish continuously (i.e. rd2 and rd3). The median relocation interval (i.e. time between successive relocations) for all tagged red drum was 1.2 d, and intervals ranged from 0.1 d to 26.7 (mean±SE 3.2±0.48 d). Mean daily movement rates of individual red drum ranged from 0.65 to 11.35 km d^{-1} (mean 3.26 km d^{-1}). However, the median rate was 2.87 km d^{-1}, and nearly 89% of individual movements rates were below 5.0 km d^{-1} (Table 3.1). Relocation depths varied from 0.38 m to 6.55 m (mean±SE 3.8±0.17 m). Surface and bottom temperatures at relocation sites were similar (means 26.3°C and 25.9°C, respectively). Surface salinities varied from 7.1 psu to 18.7 psu (mean 14.3 psu) and bottom salinities varied from 7.7 psu to 27.6 psu (mean 15.8 psu). Surface dissolved oxygen concentration averaged 7.21 mg/l and varied from 5 mg/l to 9.86 mg/l, whereas bottom dissolved oxygen concentrations averaged 5.22 mg/l and varied from 0.06 mg/l to 9.76 mg/l. Although red drum were occasionally located at positions with hypoxia (< 2 mg/l dissolved oxygen) in the bottom waters, in none of these instances were low oxygen conditions recorded in surface waters.

During the course of this study, one tagged fish died shortly after release. This fish was caught with a 7/0 regular hook that was lodged in the gut region. There was no noticeable bleeding or distended stomach at landing; however, it appeared noticeably lethargic in comparison to other fish landed. Upon release, this fish was held by the caudal peduncle and moved back and forth in a swimming motion. The fish momentarily swam off, floated upon the water's surface for approximately 6 minutes, and then submerged. On three successive days post-release this fish exhibited no movement from the tagging location.

The stress of capture (i.e. angling) could affect fish movement after release. Most red drum appeared lively after release and swam away from release locations immediately after release. Only one fish exhibited any bleeding and three fish (including the bleeding individual) required a fair degree of resuscitation, one of which died shortly after release. Therefore, the effect of capture on red drum was deemed minimal and all relocations were included in the movement analysis

Attempts to track the second (rd2) and third (rd3) fish continuously for 72 hours were largely unsuccessful. Strong wind events (> 15-20 knots) terminated both tracking sessions at 27 h and 17 h, respectively. However, both fish were relocated several times during these sessions and appeared to exhibit similar meandering movement patterns. After release, fish rd2 was located among of school of other red drum feeding on what appeared to be striped mullet at the surface for several hours. Fish rd 3 was located several times among shallow water sloughs (~ 1m) near the mouth of South River. This made tracking difficult because sandbars attenuated the transmitter's acoustic signal and restricted boat movement. Both fish were relocated at later times during non-intensive tracking.

Most adult red drum appeared to exhibit a noticable upriver-downriver ("longshore") movement pattern in the lower Neuse River. Relocations for these fish alternated between upriver localities (e.g. Adams Creek and South River) and downriver localities (e.g. Rattan Bay and the northern edge of Cedar Island; Figure 3.2). Furthermore, 7 of the 13 Rayleigh's test performed on individual red drum with at least three relocations indicated that red drum movement was not uniformly distributed around a circle. (Table 3.1).

Red drum did not appear to use available depths in proportion to its availability (Quade's method: $T_1 = 7.59$; $P = < 0.001$). In general, fish used the 3-5-m depth interval in greater proportion and the 6-m depth in lesser proportion than available (Figure 3.3). Multiple comparison tests grouped the (1) 0, 3, 4, and 7 depth classes, (2) 0, 1, and 7 m depth classes, and (3) 1, 2, and 5 m depth classes. Although red drum were typically located at greater water depths during the day (mean±SE 4.29±0.23 m) than the night (mean±SE 3.66±0.29 m), this difference was not significant (Wilcoxon signed-rank test: $P = 0.077$).

There was no significant difference between the mean angles (Watson's two-sample U^2 test: $0.2 < P < 0.5$) and movement rates (Wilcoxon rank sum test; $P = 0.4068$) of male (3.25±0.62 km $d^{-1)}$ and female (5.50±2.08 km d^{-1}) tagged and released red drum. Furthermore, the difference between day and night relocation depths for male and female red drum was not significantly different (Wilcoxon rank sum test: $P = 0.5610$).

On 14 separate occasions, two red drum were located in close proximity to each other (~5 m to 300m), constituting a co-occurrence (Figure 3.4). In the present study, 14 red drum had co-occurrences recorded (Table 3.2). Five red drum experienced one co-occurrence, six red drum experienced two co-occurrences, two red drum experienced three co-occurrences and one fish experienced five co-occurrences. All observed co-occurrences involved a unique combination of individual fish. Six co-occurrences occurred during the day and eight occurred at night (Table 3.2). Co-occurrences were recorded in depths of 1.25 m to 6.06 m (mean = 4.25 m). Male-male (n = 1), male-female (n = 8), and female-female (n = 4) co-occurrences were recorded (Table 3.2). The majority (85.7%) of co-occurrences involved individuals that were not tagged and released together. However, on two occasions, co-occurrences involved fish that had been tagged and released together. In both these instances, fish were relocated at least once prior in different locations than the co-occurrence.

Discussion

Although attempts to track fish in the lower Neuse River were often hampered by adverse environmental conditions, biotelemetry proved to be an effective method for examining adult red drum movement. During the course of this study, 81.8% of tagged and released red drum (excluding the single mortality) were relocated at least once. Ultrasonic telemetry also produced a similar relocation rate for adult (77.2%) red drum tagged and released in the Altamaha Estuary, Georgia (Nicholson and Jordan 1994). However, the relocation rate of sub- and young adult red drum within this system was considerably lower (25.8%; Nicholson et al. 1996).

Prior to this study, adult red drum movement in the lower Neuse River was thought to be restricted, based on anecdotal accounts. Large numbers of red drum are caught by fishers in the same location on successive occasions throughout the summer and early fall; thus, red drum were assumed to exhibit high site fidelity to specific locations. Nicholson and Jordan

(1994) noted that ultrasonically tagged red drum in the Altamaha River, Georgia, were often relocated repeatedly at specific sites. Although three of five large red drum tagged with ultrasonic transmitters in the Mosquito lagoon, Florida appeared to leave the study area after tagging, two fish appeared to occupy clearly defined “territories” of roughly 0.27 km^2 and 0.25 km^2 for minimum periods of 11 and 26 days, respectively (Carr and Smith 1977). In the present study, most fish were highly mobile (mean movement rate = 3.26±0.6 km d^{-1}), occasionally travelling 6 km per day and as much as 13.8 km in 28.5 hours. Furthermore, most red drum appeared to exhibit a longshore movement pattern, traveling up-and downriver along the southern edge of the Neuse River from South River to the northern edge of Cedar Island.

Although red drum did not appear to exhibit fidelity to specific locations within the lower Neuse River, fish did appear to exhibit a seasonal fidelity to the greater study area in the lower Neuse River during the summer and fall months. Individual fish were located repeatedly in the lower Neuse River for up to 37 days (Table 3.1). Similarly, adult red drum in Georgia appeared to exhibit a seasonal fidelity to inshore areas (i.e. the Altamaha River) during the summer and fall months (Nicholson and Jordan 1994). Carr and Smith (1977) reported that some red drum were consistently relocated within the Mosquito lagoon, Florida during September and October. In the present study, it is important to note that given the high rate of movement and long intervals between some relocations, the search area was most likely too small to accurately determine the full range of red drum movement. At least some of these fish likely made excursions into the Pamlico Sound proper, and perhaps to sites upriver of the study area. In a 1999 pilot study, red drum tagged and released in the lower Neuse River were relocated several km from the river mouth.

Interestingly, no telemetred red drum were relocated along the north side of the Neuse River (Figure 3.1). Catches from the recreational fishery are common along the north bank of the lower Neuse River throughout the summer and early fall. Moreover, tagged red drum certainly posses the ability to travel across Neuse River, which is approximately 10 km at its widest point. Given the intervals between most relocations, it is likely that some fish could have moved to the north shore and back undetected. It is also of interest that no red drum were relocated at positions less than approximately 2 km downriver of the mouth of Adams Creek (Figure 3.1). Catches of adult fish are not particularly common in these areas, but do occur. Although the waypoints did not extend into the South River or Adams Creek, a several km stretch of both waterways were occasionally checked for tagged red drum. No fish were relocated in either tributary during this study.

The failure to record relocations of tagged red drum within the Pamlico Sound proper, along the northern bank of the lower Neuse River and at upriver sites of the study area was likely affected by the distribution of search effort. Although efforts were made to survey the entire study equally, the majority of effort was distributed along the southern edge of the lower Neuse River (Figure 3.5). High wind and wave conditions often limited tracking near and outside of the mouth of the Neuse River. Furthermore, because tracking typically began in areas where fish were last relocated, areas where red drum were typically relocated (i.e. the south side of Neuse River) received the majority of monitoring effort.

Fish were located in depths ranging from the minimum allowed by the draft of the tracking vessel to nearly the maximum of the Neuse River. Nicholson and Jordan (1994) reported that several ultrasonically tagged adult red drum in the Altamaha River, Georgia were located in holes at depths of 6-12 m, where they exhibited limited movement for approximately two weeks. However, in the present study, red drum were typically located in depths of 3-5 m (Figure 3.2). In general, red drum did not appear to utilize water depth in relation to its availability. Fish tended to avoid the deeper potions of the Neuse River (6-7 m), while utilizing mid-depths (3-5 m) proportionately greater than what was available.

Red drum are schooling fish and tagged individuals were observed in the company of both tagged and non-tagged red drum. It appears that membership within specific schools was ephemeral, as individual co-occurrences were non-replicated events. Prior or following a co-occurrence, the red drum involved were not found in close proximity and often were located greater than 2.5 km apart from each other. Co-occurrences were recorded at varying depths and across diel periods. All co-occurrences prior to 9 September 2000 occurred during the daylight hours, and all co-occurrences afterwards occurred at night (Table 3.2). This most likely resulted from an increase in nighttime tracking effort in mid-September to early October because high wind conditions often limited daytime tracking from approximately 12:00 noon until sunset.

Given the high frequency and ephemeral nature of co-occurrences, the mobile nature of fish movement, the length of seasonal residency, and the observed longshore movement pattern, adult red drum appear to form short-term “loose” aggregations composed of variable membership within the Neuse River during the summer and early fall months. These data suggest that adult red drum form temporary associations as they move up and down the lower Neuse River. These associations could be a result of random encounters resulting from fish movement within the study area, but the relatively high frequency of these co-occurrences (29% of relocations), and close proximity of these individual associations are inconsistent with the idea that tagged individuals move randomly relative to conspecifics present in the study area. These associations may be related to feeding behavior. However, it is just as likely that these associations are related to spawning activity given that these observations were made over a period that encompasses the presumed spawning season for this species. These results may point to the existence of a greatly protracted spawning period characterized by batch spawning within small, ephemeral aggregations. A study focused on documenting the spatial and temporal distribution of male red drum vocalizations and the presence of red drum eggs and larvae within the study area may help better resolve the spawning aggregation structure used by these fish.

Fish sex did not appear to affect the movements of adult red drum in the lower Neuse River. The bearnings (i.e. movement angles), movement rates and difference between night and day relocation depths were similar among males and females. Furthermore, both sexes appeared to exhibit similar longshore movement patterns. Red drum are schooling fish and aggregate spawners; thus, similar movement patterns between the sexes would not be unexpected.

Adult red drum were located at up-river sites in the western Pamlico Sound during the period of peak spawning. Ripe adults (i.e. milt-flowing males and females in eminent spawning condition) have been collected from this area during the spawning period (Ross et al. 1995; Marks and DiDomenico 1996; P. S. Rand, North Carolina State University, unpublished data). Nicholson and Jordan (1994) also located adult red drum > 20 km in the Altamaha River System during the summer and early fall months. Several of these fish (both males and females) were in advanced stages of gonadal development. Recent evidence indicates that red drum may be spawning in the lower salinity areas of the Western Pamlico Sound. In addition to the collection of ripe adults, courtship vocalizations were recorded at several locations within the lower Neuse River during 2000 and eggs were collected near the mouth of the Bay River (Luczkovich et al. 1999). This corroborates evidence that up-river areas are important for red drum spawning (Nicholson and Jordan 1994), either as pre-spawn staging areas, or as recent evidence indicates, spawning aggregation sites. In either case, the lower Neuse River and similar areas of the western Pamlico Sound serve as important habitat for red drum in North Carolina.

Although tracking continued until 25 October 2000, no red drum were located after 3 October 2000. Ross et al. (1995) noted that as the numbers of adults found in North Carolina estuarine waters declined in October and November, they became more prevalent around the outer bars of Hatteras, Ocracoke, and Drum Inlets. A cold front passed over eastern North Carolina (8-9 October 2000), which dropped air temperatures to 3.3°C and water temperatures to 16.4°C. The sudden drop in water temperature may have been the primary factor for red drum movement from the study area.

No transmitters were recovered during this study. This was surprising because nearly 20% of transmitters used in a 1999 pilot study were recovered. However, floats were constructed from polyethylene tubing in 1999, as opposed to PVC closed cell foam used in 2000 study. Although initial testing indicated the PVC foam floats preformed well under estuarine conditions, this design may have affected the recovery rate of transmitters.

The 1-month lifespan of the dissolvable suture prohibited longer term tracking of fish throughout the entire study period. A permanent tagging method (e.g. internal) is recommended for future studies examining the movement of red drum in the western Pamlico Sound. This method could allow for relocation of adults during the fall emigration and the overwintering period. Alternatively, transmitters also could be programmed to switch off during the overwintering period and switch back on the following spring. Depending on the transmitter life, researchers could determine if fish tagged in the lower Neuse River return the following year. Nicholson and Jordan (1994) reported that adult red drum returned to the same shoal areas in the spring after overwintering offshore and in the fall after moving from up-river pre-spawn staging areas. An understanding of how red drum use habitat over longer time periods and the amount of straying/mixing between red drum stocks are critical in determining population structure, understanding possible meta-population dynamics and in the effective management of this long-lived and exploited species.

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TABLE 2.1. – Summary of key parameters and observed mortality rates in post-hooking mortality studies of red drum (Adapted from Muoneke and Childress 1994).

Size TL(mm)	N	Days	Con	Temp	Htype	Hsize	Bait	Gear	%mort	GHM	WLHM	Inj	Hab	State	Year	Ref.
~ 548[a, b]	146	0		25.0-30.5	3	8/0	1	2	0				2	TX	1985-1986	Martin et al. 1987a
278-740[a]	968	2	1	12-31	3	8/0	1	2	0.2			4	2	TX	1985	Martin et al. 1987b
<508 - >762	38	3	1	25-34	1, 4		2	1	44.7			3	1	TX	1988	Childress 1989
199-355[a]	513	14	1	28-30	1	4 to 3/0	1	1	16	+[f]	+	4	2	GA	1988-89	Jordan and Woodward 1992
429-837	121	3	1	27.6-30.3	6	6[e]	2	1	4.1	-			2	TX	1989-90	Matlock et al. 1993
<406 - > 406	743	3-7	2	13-28	6		2	1	3.5	+		4	2	LA	1993-1995	R. G. Thomas, *pers. comm*.
1032[b]	64	3-7	2		1,3	7/0, 13/0	1	1	5.0	-		4	2	LA	1996	R. G. Thomas *pers. comm.*
186-730	80	2, 17	1,2	23-29	1	#1	1	1	2.8			4	2	FL	1996	R. F. Heagley *pers. comm.*
972-1260[c]	17	3	3	21-29	1, 3	7/0, 16/0	1	1	5.9				2	NC	2000	This volume
	191	3	1	16.6-27.6	1, 4		2	1	6.8[d]		+	4[d]	2	NC	2000-2001	Gearhart 2002
880-1250[c]	104	3	1	23.6-29.9	1,3	7/0, 16/0	1	1	6.7	-	+	4	2	NC	2001	This volume

Note: Size: Total length; Con: Confinement, 1 = pens, 2 = laboratory confinement, 3 = not confined (ultrasonic telemetry); Temp: Celsius; Htype: hook type, 1 = single, 2 = treble, 3 = circle, 4 = single lures, 5 = treble lures, 6 = natural and lure, single and treble; Hsize: hook size; Bait: 1 = baited, 2 = baited and unbaited; Gear: 1 = recreational hook and line, 2 = trotline; %mort: overall mortality; GHM: mortality significantly correlated with gear type, + = yes, - = no; WLHM: wound location significantly related to mortality, + = yes, - = no; Inj: anatomical location associated with most injury; 1= mouth, 2= gill, 3 = esophagus, 4 = gut region 5 = other; Hab: habitat captured from, 1 = freshwater, 2 = marine/estuarine

[a] Measurement type unspecified

[b] Mean

[c] Fork length

[d] calculated from data

[e] Number 6 treble hook, single hook size unstated

[f] postulated; see Jordan and Woodward 1992

TABLE 2.2. - Field data and fates of adult red drum angled with recreational hook and line gear from the Neuse River, North Carolina, summer and fall 2001. Assumed escaped fish are red drum that likely escaped from the net pens prior to the end of the holding period. Fish excluded from the model indicate fish that survived the holding period, but incomplete data were recorded. Trial numbers in bold indicated trials where hypoxic or near hypoxic conditions (< 2.5 mg/l dissolved oxygen) were recorded. For mean temperature the ranges are noted in parentheses.

Date of capture	Trial	Net Pen	Number of drum	Mean Temperature (ºC)	Assumed Escaped	Excluded From model	Mortalities
24 Jun 01	1	South	2	27.4	1		1
17 Jul 01	2	South	2	27.3 (26-28.8)			1
21 Jul 01	3	North	2	26.7 (26.4-27)			
22 Jul 01	4	South	8	27 (26.8-27.2)			
25 Jul 01	5	South	1	26.7(25.8-27.3)			
2 Aug 01	6	North	5	28.5 (25.7-27.6)			
5 Aug 01	**7**	North	2	28.9 (28.5-29.3)			
6 Aug 01	8	South	13	29.2 (28.6-29.9)			1
12 Aug 01	9	South	11	28.6 (27.6-29.8)			2
13 Aug 01	**10**	North	1	28.1 (27.5-28.6)			
16 Aug 01	11	South	4	28.5 (27.9-29.2)			
19 Aug 01	**12**	South	7	28 (27.5-28.3)			1
20 Aug 01	13	North	2	28 (27.1-29.1)			
22 Aug 01	14	South	2	27.7 (26.4-29)			
24-25 Aug 01	15	North	7	27.5 (26.3-28.4)			
31 Aug 01	16	North	1	26.8 (26.7-26.8)			
10 Sep 01	**17**	South	2	26.4 (25.9-26.8)			
11 Sep 01	18	North	4	26.3 (25.9-26.6)	2		
13 Sep 01	**19**	South	10	25.8	5		
18-19 Sep 01	20	North	12	24.2 (23.6-25.1)		5	
18-19 Sep 01	21	South	9	24.6 (24-25.6)		3	
23 Sep 01	**22**	North	5	25.4 (24.8-26)			1
Total			112		8	8	7

TABLE 2.3. – Number of fish shallow hooked and deep hooked by hook type for adult red drum angled with recreational hook and line gear, summer and fall 2000 (percentages by hook type in parentheses).

Hook type	Shallow hooked	Deep hooked	Total
J-style	6 (42.86)	8 (57.14)	14
Circle	7 (87.5)	1 (12.5)	8
Total	13	9	22

Table 2.4 Test statistics and p-values for the stepwise logistic regression analysis of the independent variables on the hooking position of adult red drum angled with recreational hook and line gear, summer and fall 2000.

Independent variable	χ^2	*P*
Hook type	3.4778	0.0622
Sex	1.3516	0.245
Fork length	1.7965	0.1801
Temperature at capture	0.3810	0.5371
Salinity at capture	0.5434	0.4610
Depth at capture	0.9658	0.3257

TABLE 2.5. - Mortality rates of adult red drum caught with recreational hook and line gear, summer and fall 2000 by hook position and hook type. Parentheses indicate the number of fish utilized to obtain each mortality rate.

Hook Type	Shallow hooked	Deep hooked	Total
J-style	0 (6)	20 (5)	9.09 (11)
Circle	0 (5)	0 (1)	0 (6)
Total	0 (11)	16.67(6)	5.9 (17)

Table 2.6 Test statistics and p-values for the stepwise logistic regression analysis of the independent variables on the hooking position of adult red drum angled with recreational hook and line gear, summer and fall 2001.

Independent Variable	χ^2	*P*
Hook type	9.6633	**0.0019**
Sex	5.9377	**0.0148**
Fork length	0.7597	0.3834
Temperature at capture	3.19	0.0741
Salinity at capture	0.1105	0.7396
Depth at capture	2.7278	0.0986

P < 0.05

TABLE 2.7 – Number of fish shallow hooked and deep hooked by hook type for adult red drum angled with recreational hook and line gear, summer and fall 2001 (percentages by hook type in parentheses).

Hook type	Shallow hooked	Deep hooked	Total
J-style	42 (47.73)	46 (52.27)	88
Circle	23 (95.83)	1 (4.17)	24
Total	65	47	112

TABLE 2.8. - Test statistics and p-values for the stepwise logistic regression analysis of the independent variables on the mortality rate of adult red drum angled with recreational hook and line gear, summer and fall 2001.

Independent Variable	Statistic	*P*
Sex	0.2797	0.7033
Fork length	0.00878	0.276
Temperature at capture	0.0029	0.125
Salinity at capture	0.00011	**0.0015**
Depth at capture	0.0296	0.5982
Landing time	0.00094	0.906
Handling time	0.00085	0.3939
Transport time	0.00026	0.5853
Hook type	0.151	0.3459
Hook position	0.0115	**0.0116**

P < 0.05

TABLE 2.9. - Mortality rates of adult red drum caught with recreational hook and line gear, summer and fall 2001 by hook position and hook type. Parentheses indicate the number of fish utilized to obtain each mortality rate.

Hook Type	Shallow hooked	Deep hooked	Total
J-style	0 (39)	16.28 (43)	8.54 (82)
Circle	0 (21)	0 (1)	0 (22)
Total	0 (60)	15.91(44)	6.73 (104)

TABLE 3.1. Release date, size, sex, track time, number of relocations, mean movement rate (±SE), p-values for Rayleigh's tests and mean vector length (r) of adult red drum tagged with ultrasonic transmitters and released in the lower Neuse River summer and fall 2000. Asterisks indicate fish with no recorded relocations.

Fish	Date	FL(mm)	Sex	Track time (d)	Number of Relocations	Mean movement (km d^{-1})	Rayleigh's test *p*-value	(*r*) mean vector length
rd1	7/11/00	960	M	11.27	2	3.59±2.45		
rd2	7/22/00	1042	F	37.60	13	3.95±1.46	**0.03**	0.52
rd3	8/1/00	1156	F	3.84	11	11.35±7.30	0.07	0.49
rd4	8/6/00	928	M	22.61	3	2.73±2.14	**0.04**	0.99
rd5*	8/6/00	1180	M					
rd6	8/6/00	1006	F	n/a	3	n/a		
rd7	8/20/00	1055	F	27.99	10	2.97±0.86	0.12	0.72
rd8*	8/21/00	1045	M					
rd9	8/21/00	1017	M	1.81	2	5.26±4.05	0.14	1.0
rd10	8/21/00	1060	F	37.27	8	1.56±0.75	**0.01**	0.74
rd11	8/27/00	1050	M	17.18	5	1.95±1.27	0.55	0.36
rd12	8/27/00	1130	F	21.27	6	4.83±1.93	**0.01**	0.86
rd13	8/28/00	1063	F	20.30	4	2.87±0.79	0.08	0.59
rd14	9/2/00	1074	M	15.30	3	3.45±2.28	**< 0.01**	0.93
rd15	9/2/00	1058	F	15.33	8	2.56±0.81	0.20	0.45
rd16	9/10/00	995	M	17.14	7	2.02±1.09	0.08	0.59
rd17	9/10/00	1050	M	22.26	6	4.06±1.51	**< 0.01**	0.93
rd18*	9/10/00	1118	F					
rd19	9/15/00	1015	F	2.28	1			
rd20	9/15/00	998	F	17.21	3	0.65±0.20	**0.04**	0.99
rd21	9/25/00	1010	F	7.18	2	0.83±0.14		
rd22	9/25/00	1130	F	7.15	2	0.73±0.49		

***P* < 0.05**

Table 3.2. Date, time, time of day, and depth of co-occurrences of adult red drum tagged with ultrasonic transmitters and released in the lower Neuse River, summer and fall 2000. The individual fish involved and their sex, are identified in the last column.

Date	Time	Time period	Depth (m)	Fish involved (sex)
8/2/2000	12:55	Day	4.42	rd2 (F) rd3 (F)
8/23/2000	9:25	Day	4.57	rd4 (M) rd7(F)
8/29/2000	16:31	Day	6.07	rd7 (F) rd12 (F)
8/31/2000	13:47	Day	4.75	rd11 (M) rd13 (F)
9/3/2000	18:20	Day	4.66	rd14 (M) rd15 (F)
9/12/2000	18:25	Day	4.82	rd16 (M) rd17 (M)
9/12/2000	20:45	Night	1.25	rd7 (F) rd15 (F)
9/13/2000	23:32	Night	5.12	rd7 (F) rd17(M)
9/17/2000	20:13	Night	3.81	rd7 (F) rd16 (M)
9/18/2000	0:12	Night	4.24	rd17 (M) rd20 (F)
9/18/2000	0:40	Night	3.38	rd12 (F) rd19 (F)
9/18/2000	2:02	Night	4.48	rd13 (F) rd14 (M)
9/27/2000	22:35	Night	3.99	rd16 (M) rd22 (F)
10/2/2000	23:16	Night	3.93	rd20 (F) rd22 (F)

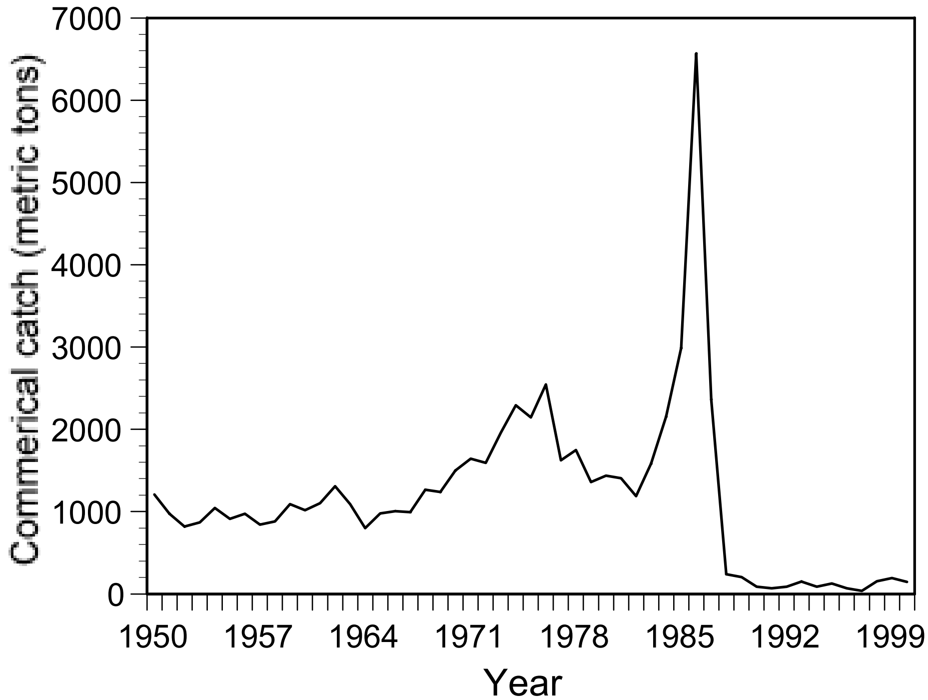


FIGURE 1.1. - United States red drum commercial catch, 1950-2000 (Source: National Marine Fisheries Service, Fishery Statistics and Economics Division)

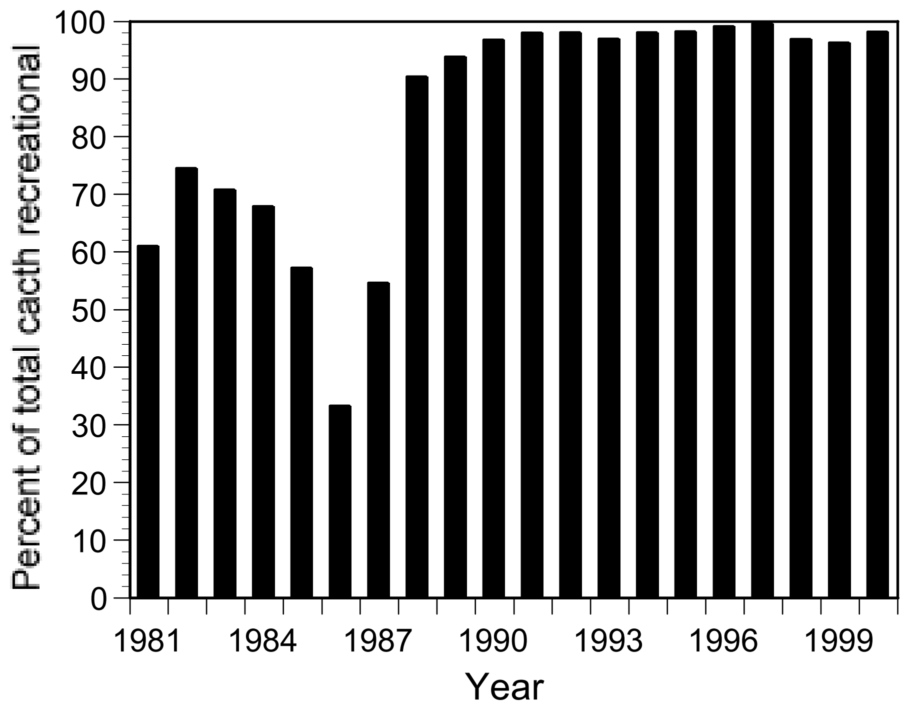


FIGURE 1.2. - Percent of total United States red drum catch resulting from recreational sources by weight, 1981-2000. (Source: National Marine Fisheries Service, Fishery Statistics and Economics Division).

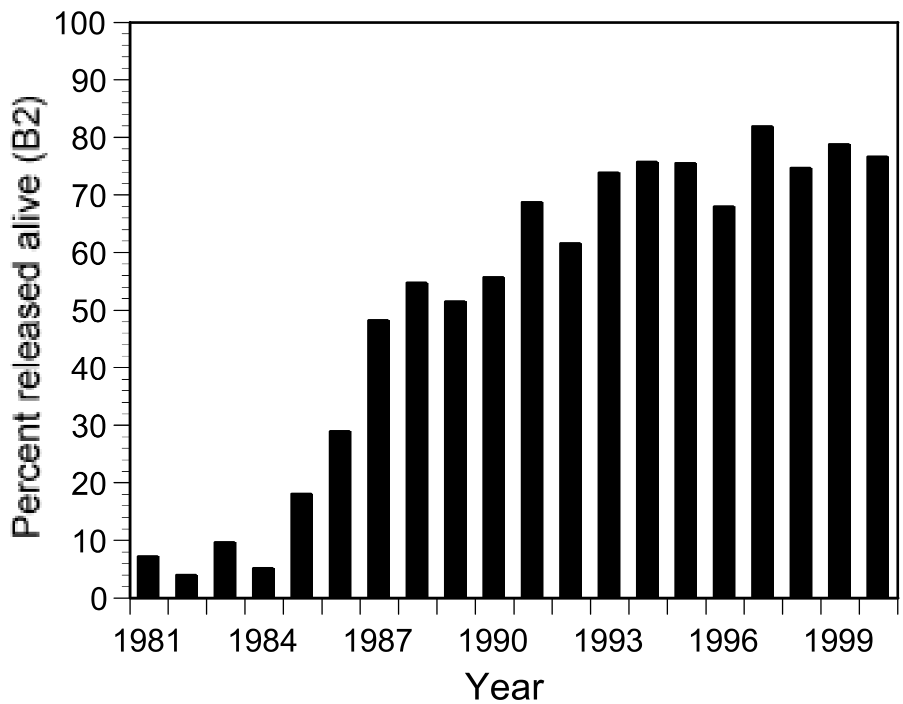


FIGURE 1.3. - Percent of total Atlantic Coast recreational red drum catch released alive, 1981-2000. (Source: National Marine Fisheries Service, Fishery Statistics and Economics Division).

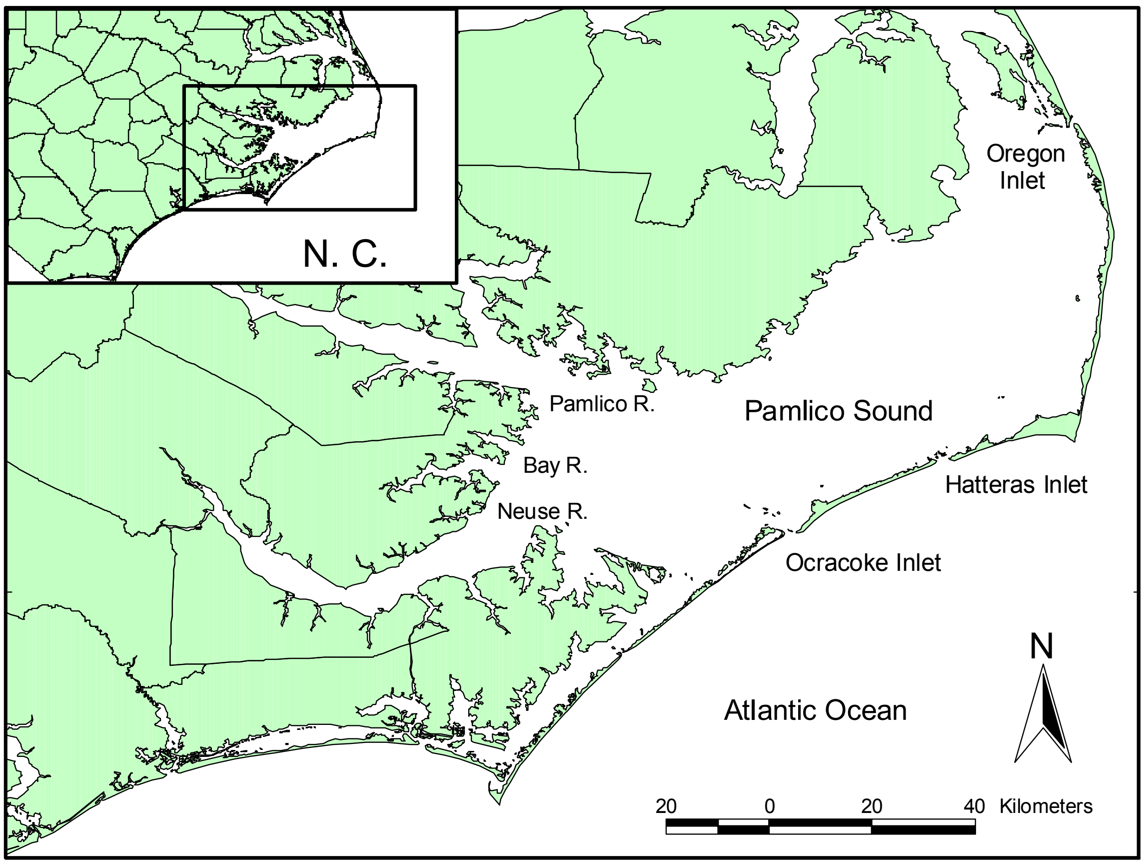


FIGURE 2.1. – Map of the Pamlico Sound Estuary System.

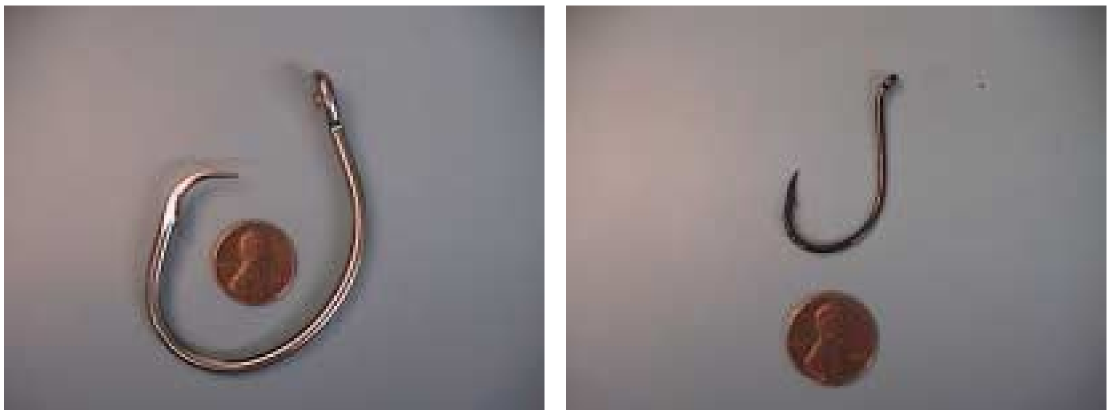


FIGURE 2.2. - Photographs of the 16/0 circle hook (left) and 7/0 j-style hook (right) used to catch adult red drum with recreational hook and line gear from the Neuse River, North Carolina, during summer and fall 2001.

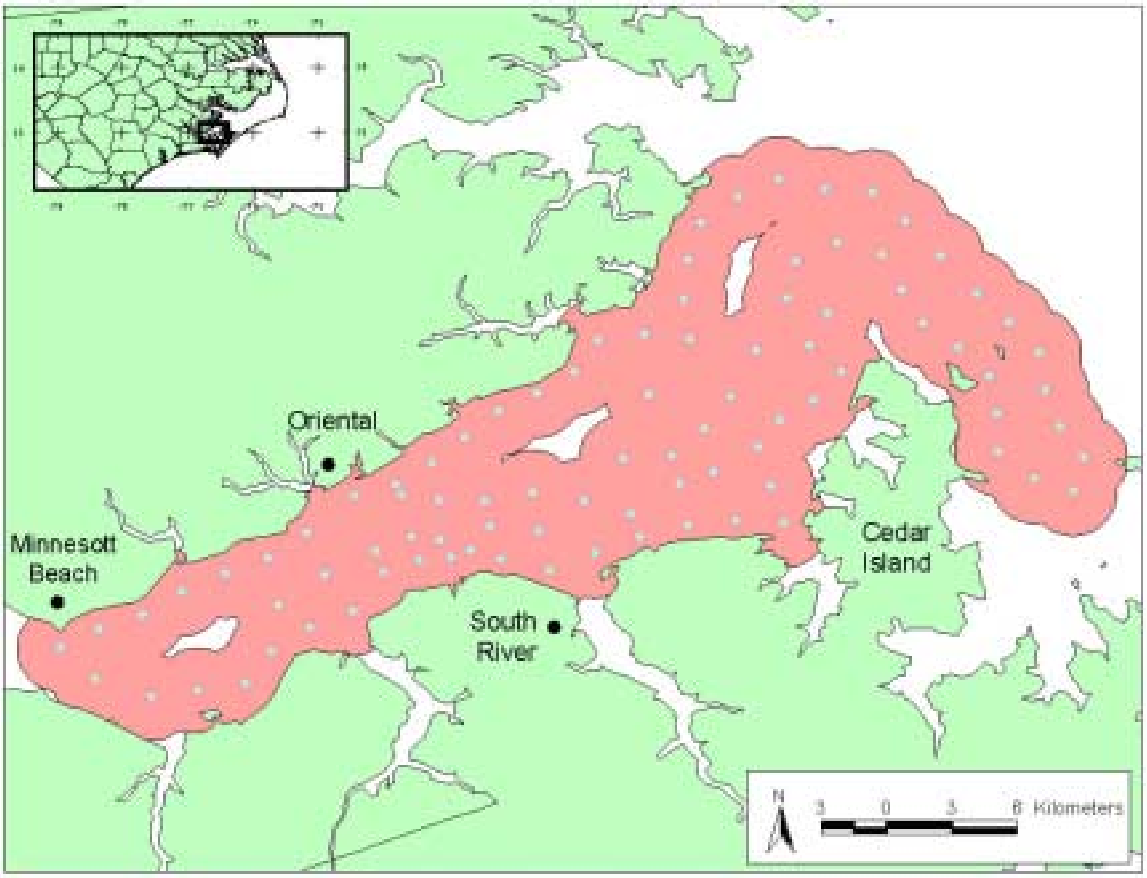


FIGURE 2.3 – Map of the waypoint positions used to track adult red drum tagged with ultrasonic transmitters in the lower Neuse River, summer and fall 2000. Shaded area indicates a 2km effective range surrounding each waypoint.

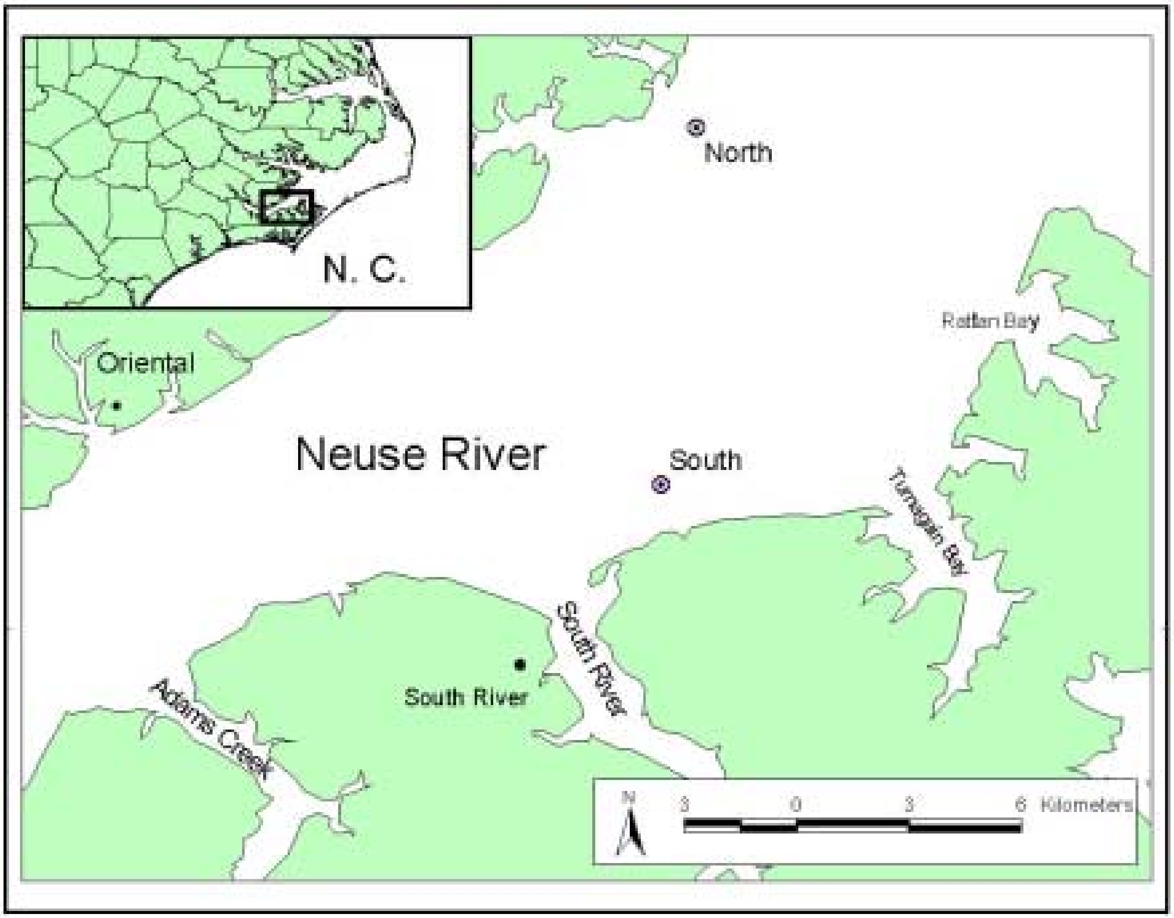


FIGURE 2.4. - Map of the lower Neuse River, North Carolina indicating locations of net pens used to hold adult red drum to assess short-term catch-and-release mortality, summer and fall 2001.

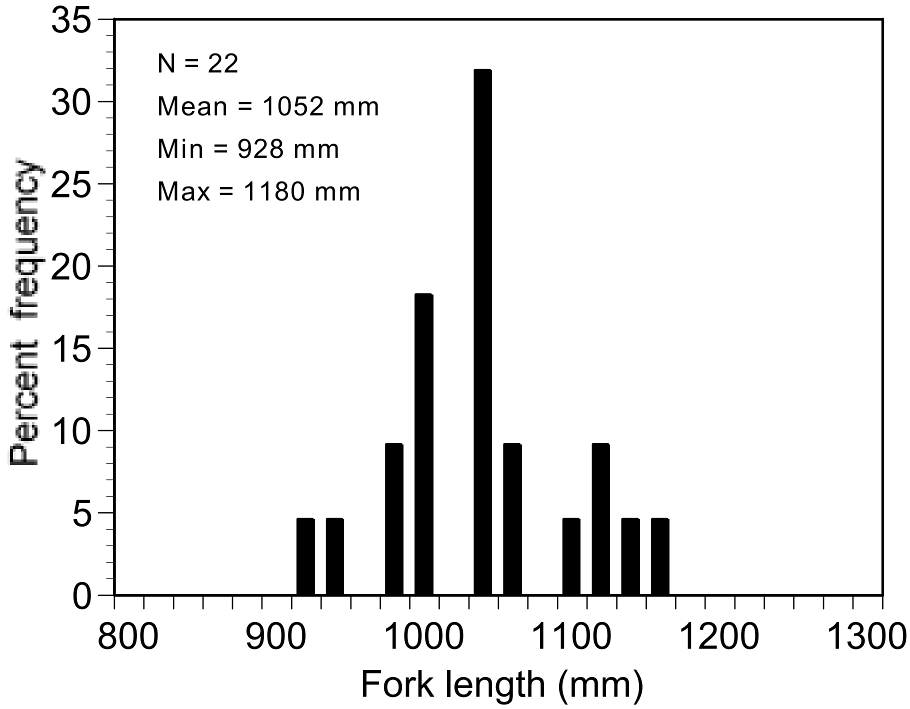


FIGURE 2.5. - Length frequencies of adult red drum caught with recreational hook and line gear and tracked via ultrasonic telemetry to assess (3-d) catch-and-release mortality during summer and fall 2001.

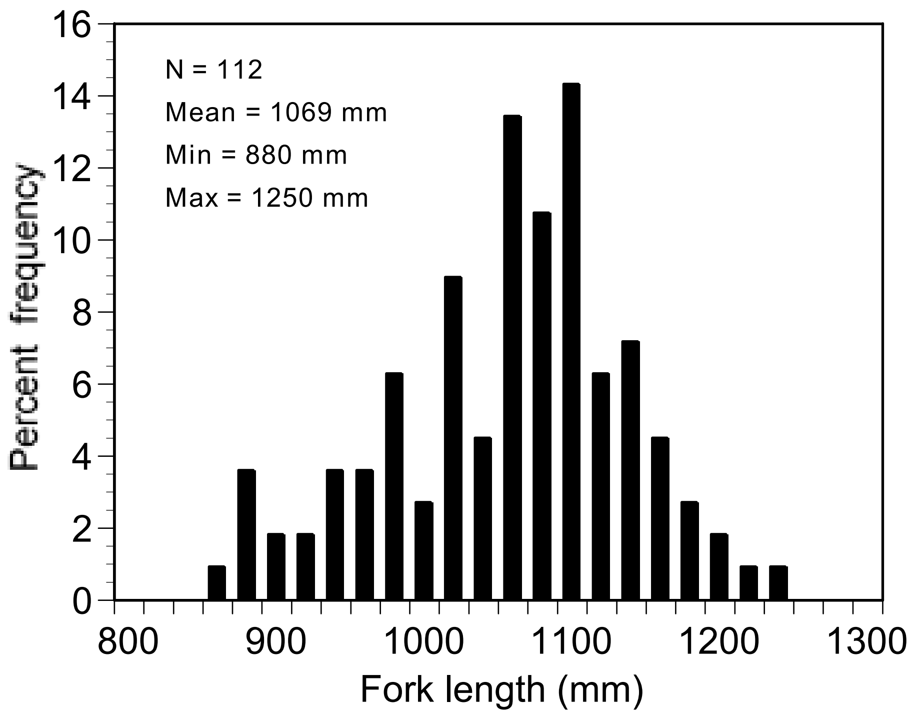


FIGURE 2.6. - Length frequencies of adult red drum caught with recreational hook and line gear and held in net pens to assess short-term (3-d) catch-and-release mortality during summer and fall 2001.

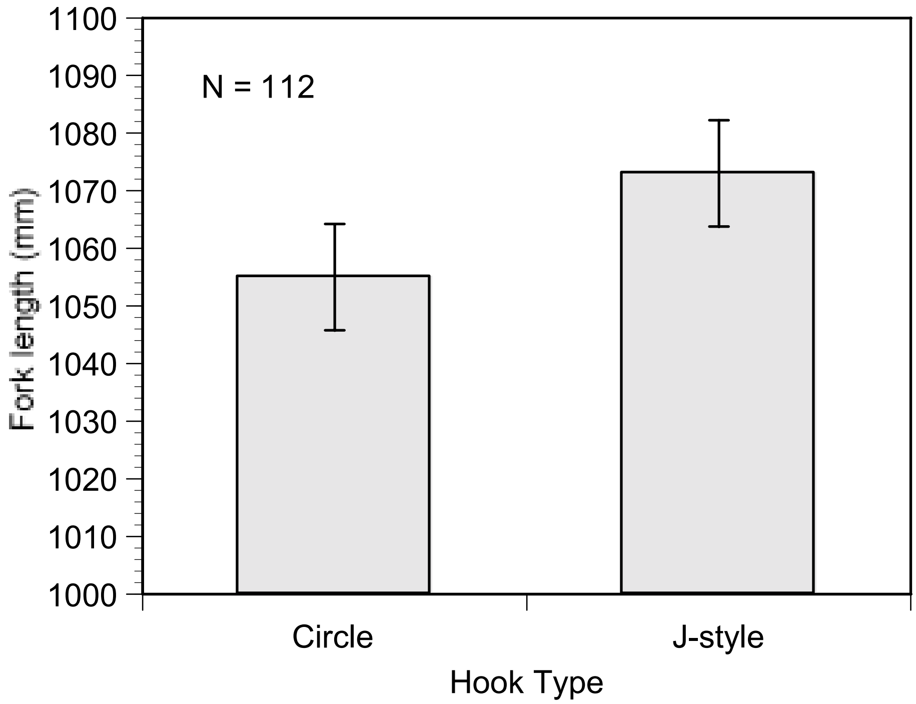


FIGURE 2.7. - Mean fork lengths of adult red drum caught on circle and j-style hooks with recreational hook and line gear, summer and fall 2001. Bars indicate one standard error.

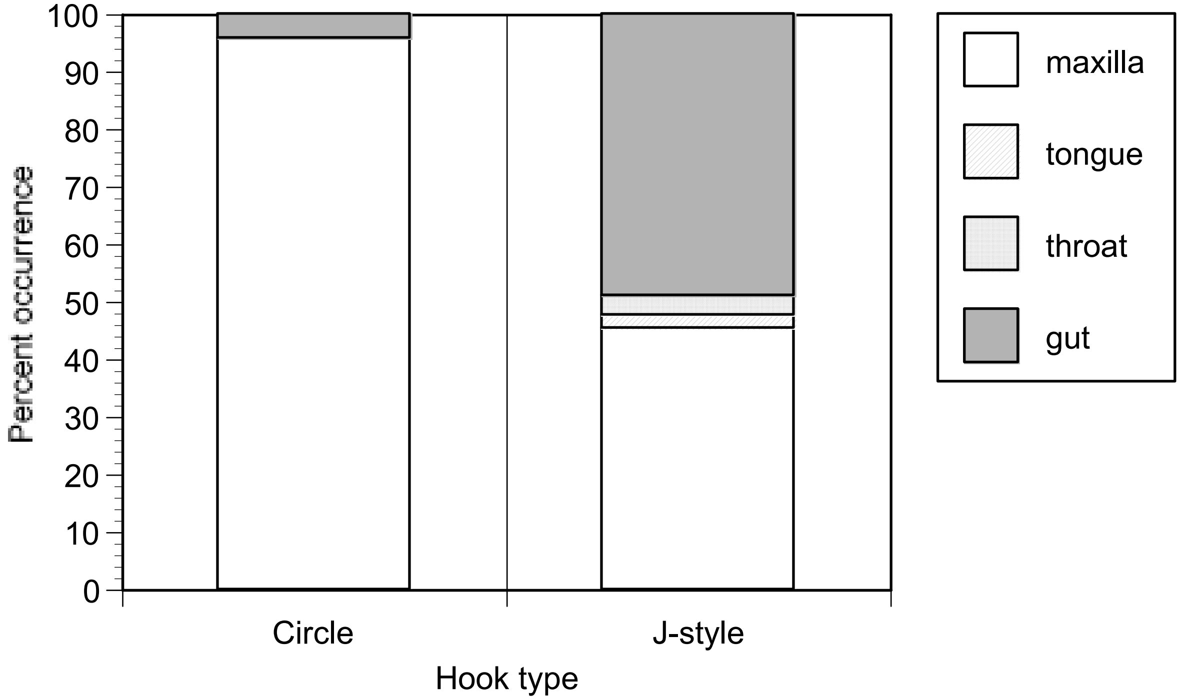


FIGURE 2.8. - Hook piercing locations for circle and j-style hooks used for landing adult red drum with recreational hook and line gear during summer and fall of 2001.

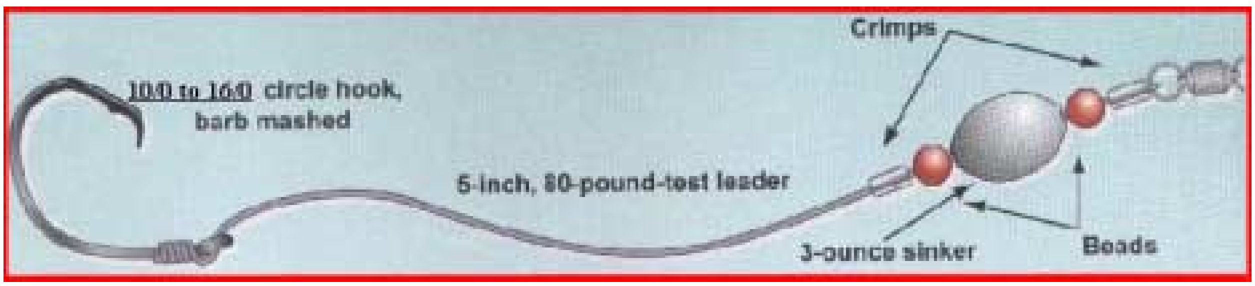


FIGURE 2.9. Schematic diagram of the “Owen” rig distributed by the North Carolina Sea Grant Program to North Carolina red drum anglers.

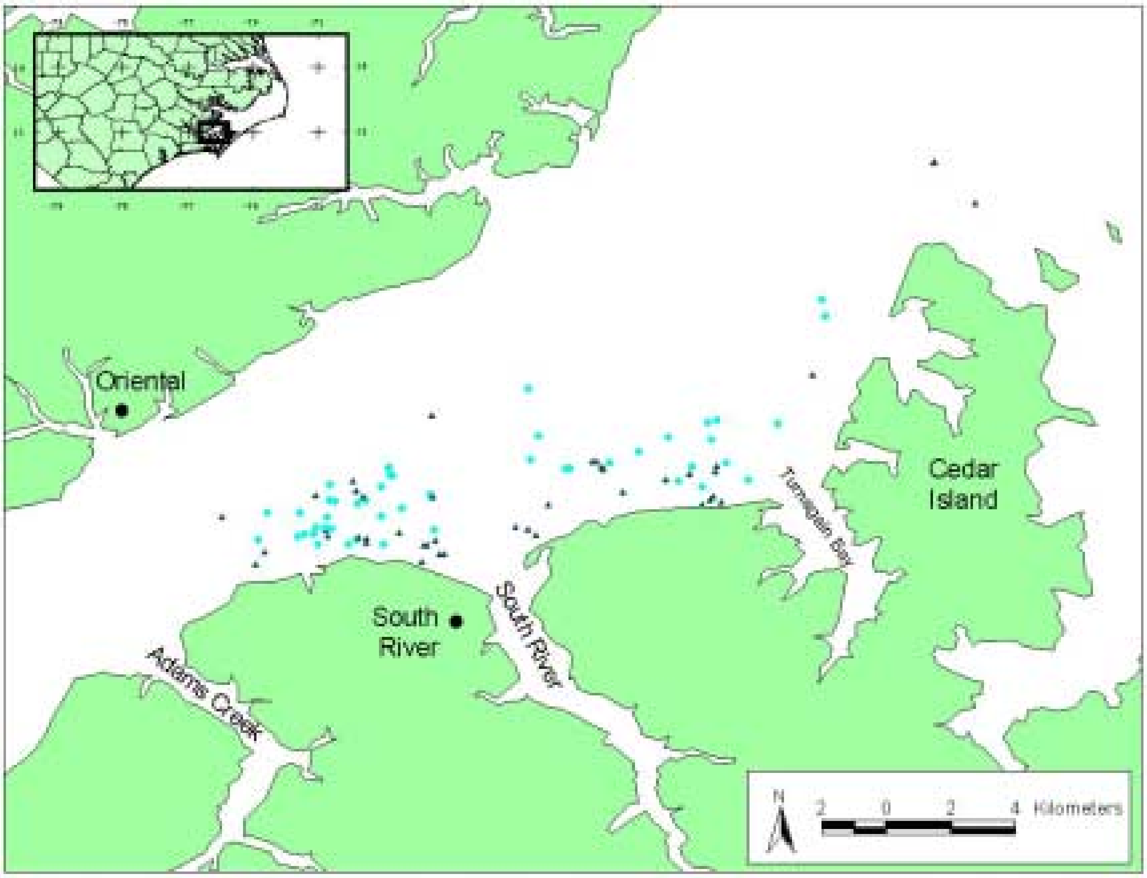


FIGURE 3.1. - Relocation positions for adult red drum tagged with ultrasonic transmitters and released in the lower Neuse River summer and fall 2000. Light blue circle indicate day relocations and dark blue triangles indicate night relocations.

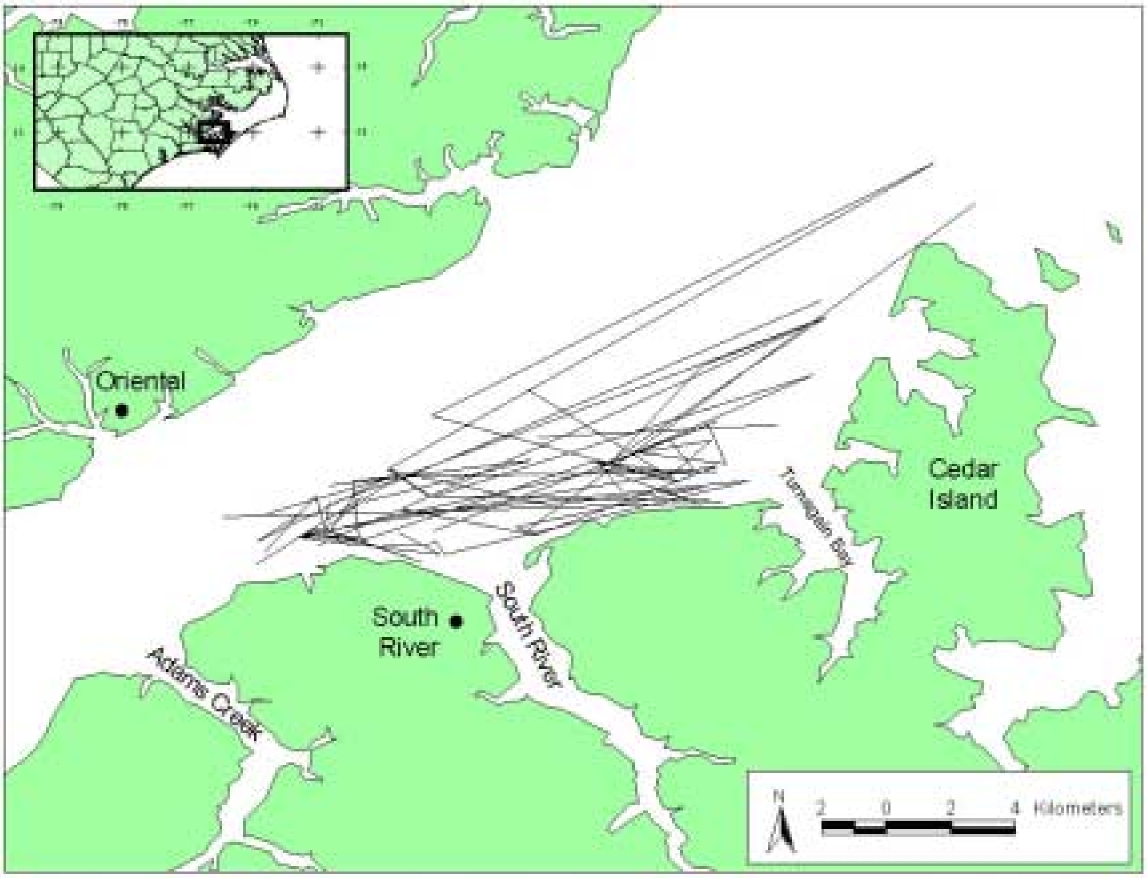


FIGURE 3.2. - Telemetry tracks of adult red drum tagged with ultrasonic transmitters and released in the lower Neuse River summer and fall 2000.

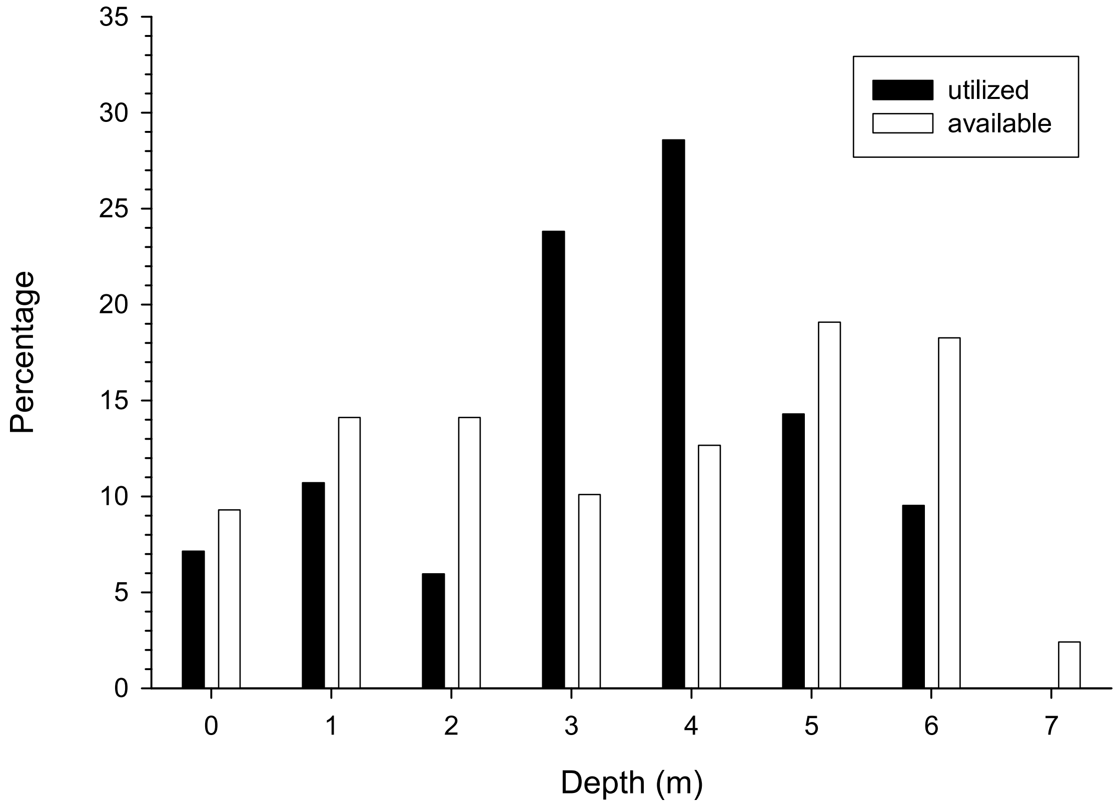


Figure 3.3 - Percentage of habitat by depth of the lower Neuse River study area and the percentage of habitat by depth utilized by adult red drum (with > than 6-h between successive relocations) tagged with ultrasonic transmitters within the lower Neuse River study area during the summer and fall 2000.

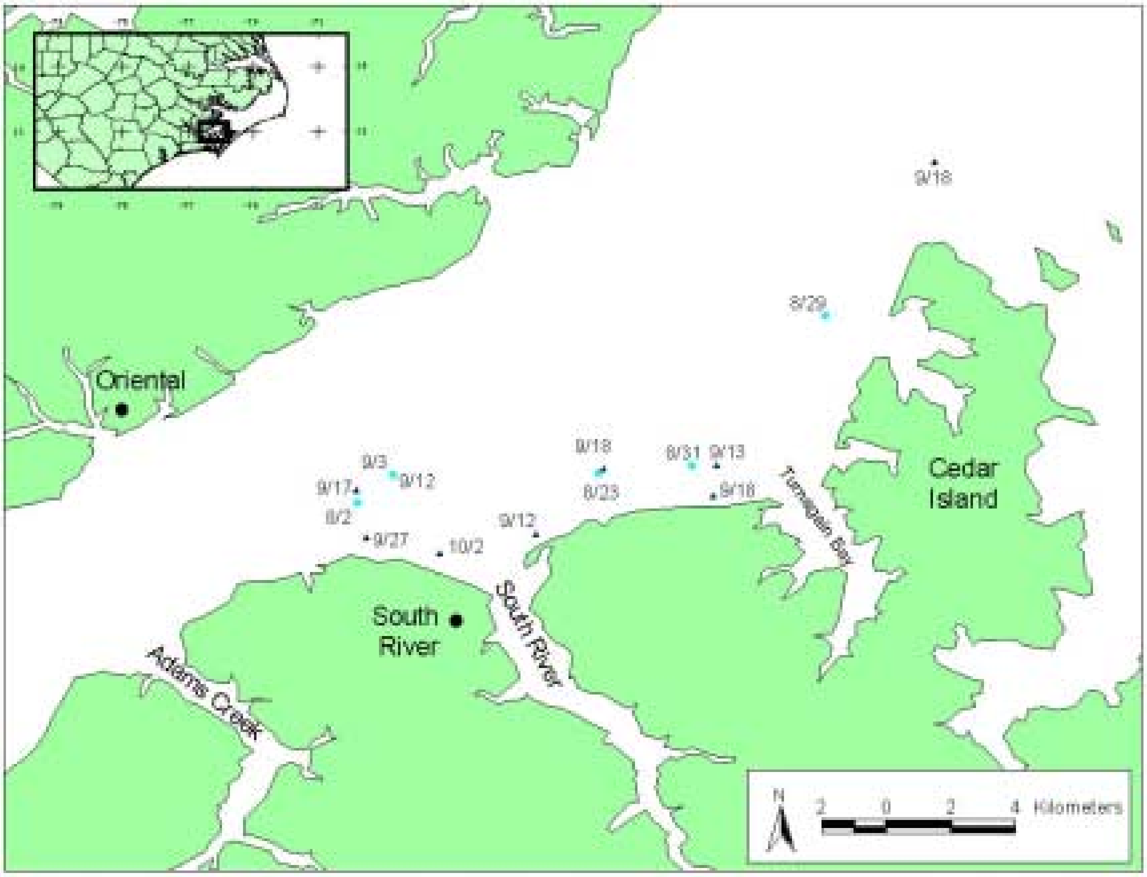


FIGURE 3.4. - Co-occurrence locations of adult red drum tagged with ultrasonic transmitters and released in the lower Neuse River summer and fall 2000. Light blue circle indicate day co-occurrences and dark blue triangles indicate night co-occurrences.

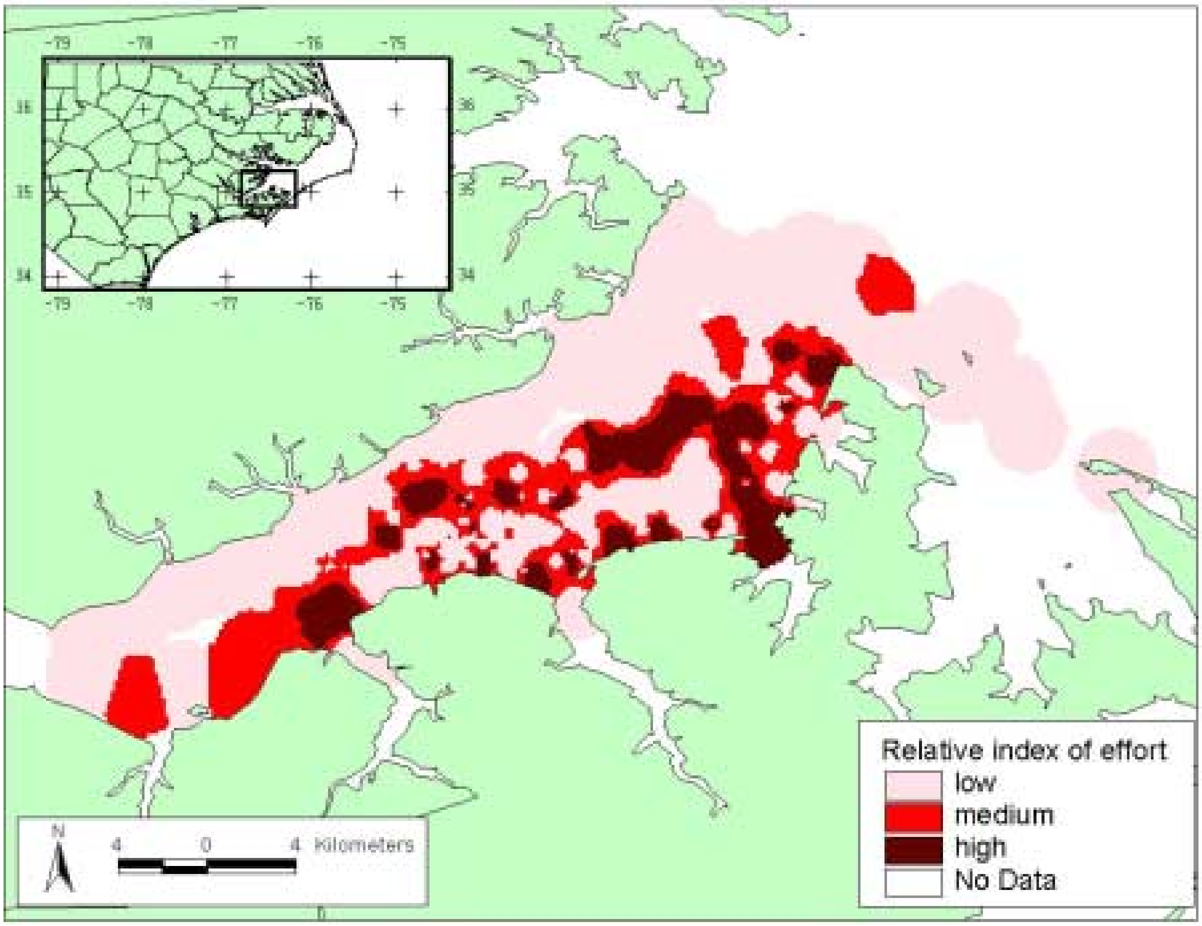
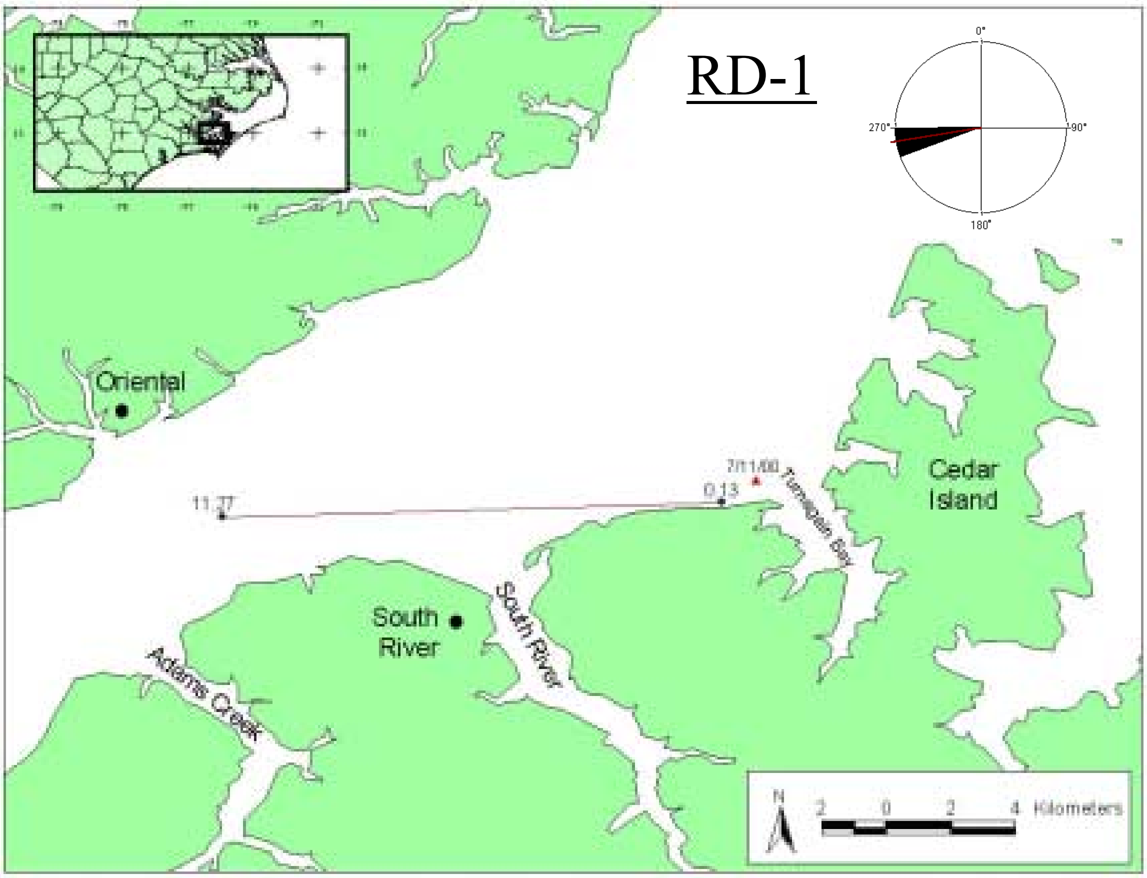
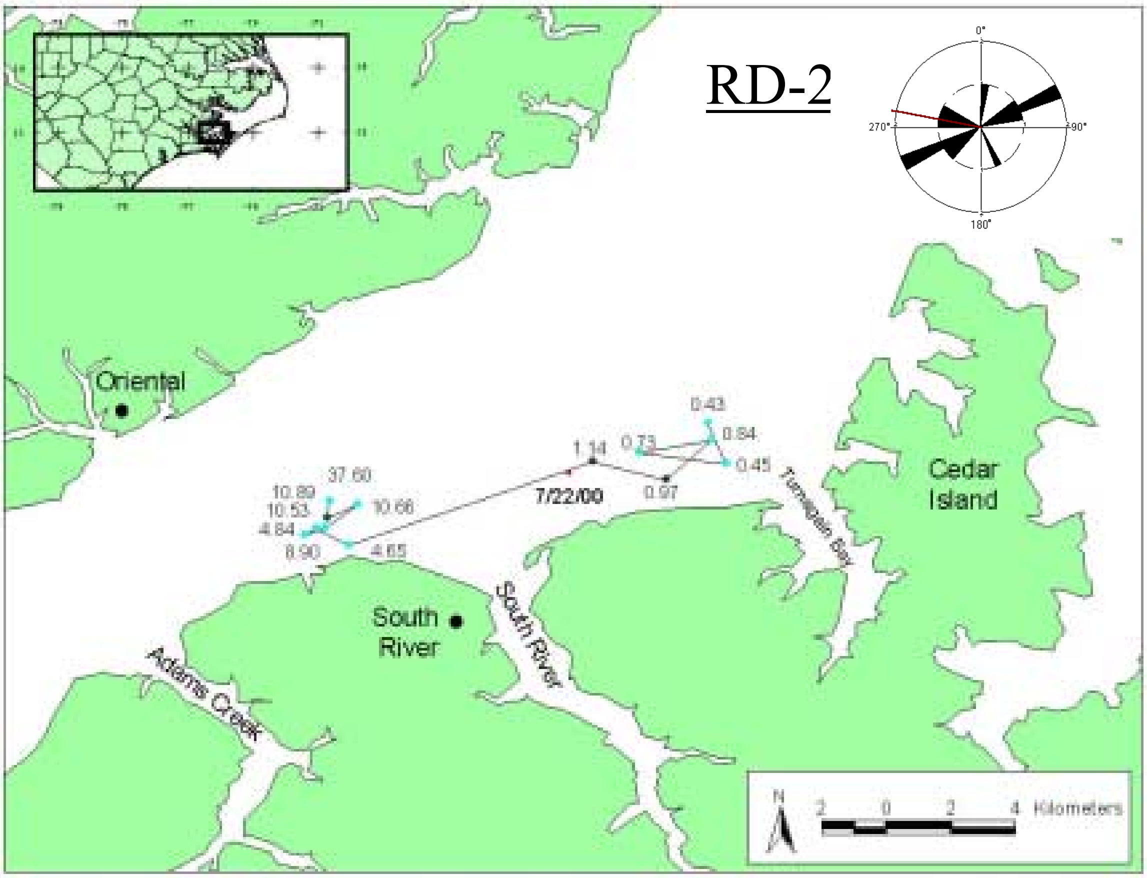
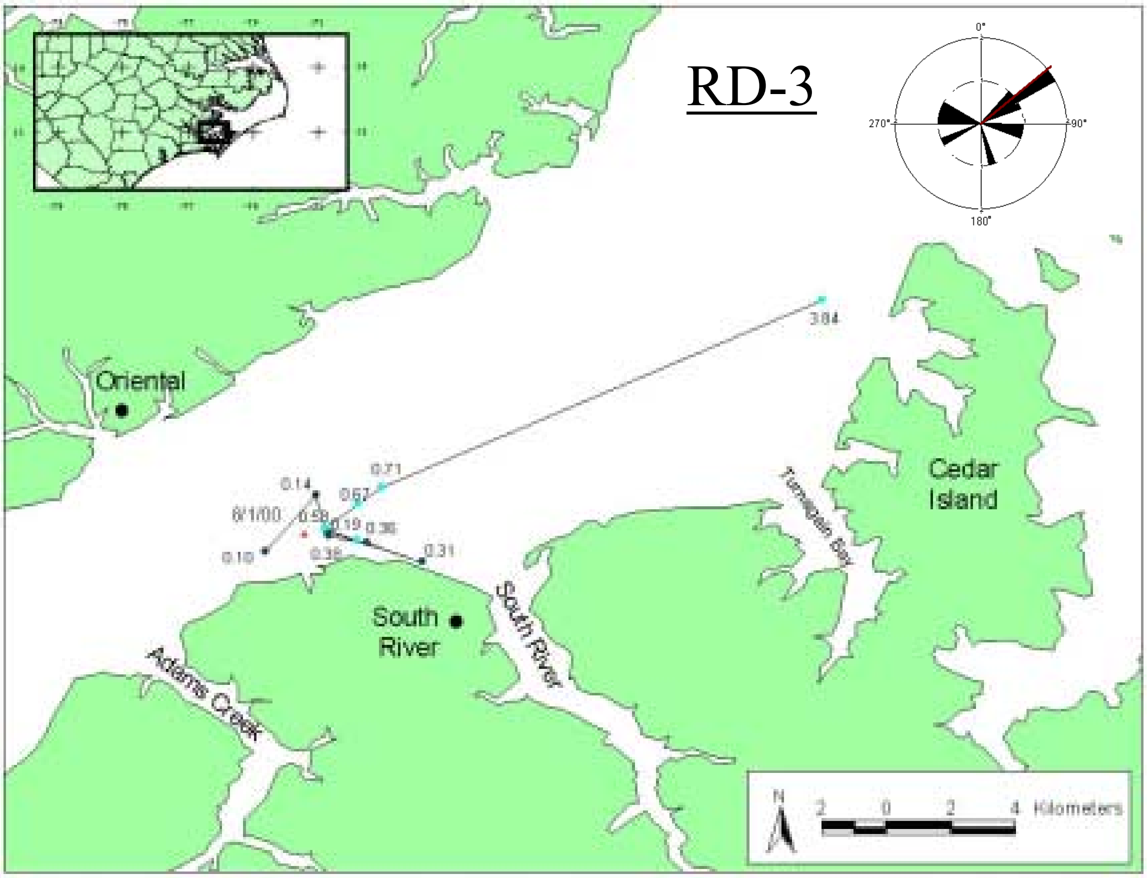


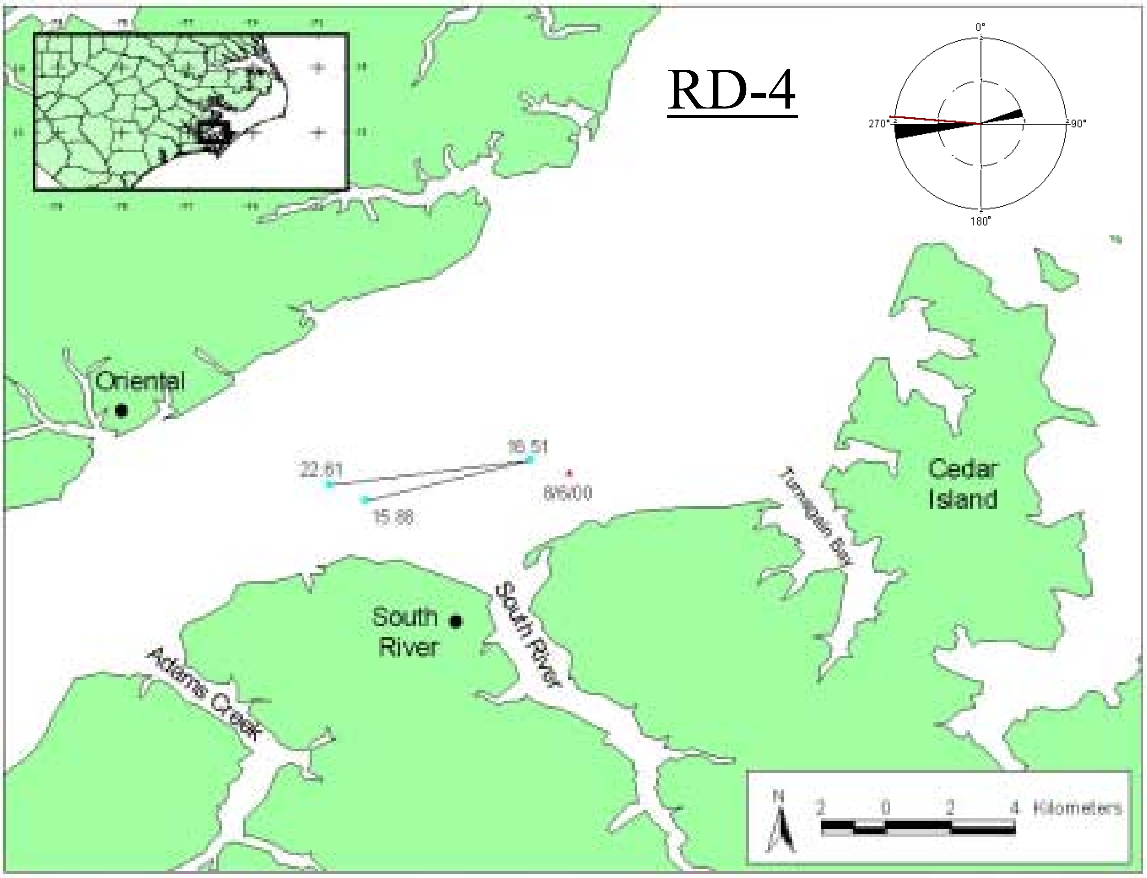
FIGURE 3.5 – Distribution of effort used to track adult red drum tagged with ultrasonic transmitters and released in the lower Neuse River, North Carolina summer and fall 2000.

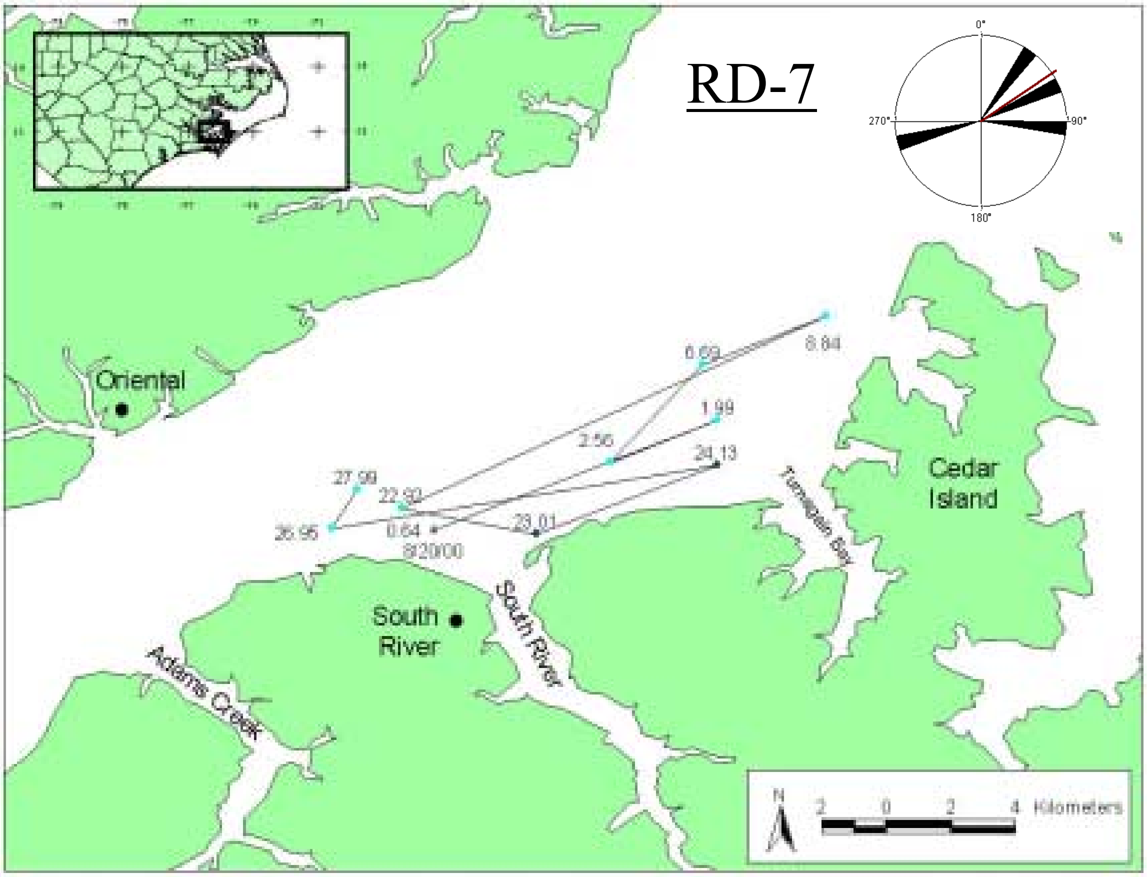
APPENDIX 1. Telemetry tracks of 18 tagged and released red drum in the lower Neuse River summer and fall 2000. Light blue circles indicate day relocations and dark blue circles indicate night relocations with values indicating time from release in days. Dark red triangles indicate relocation location with release date. Rose plots indicate the frequency of observations in ten-degree classes represented by the radius of the wedge. Red lines indicate mean angles.

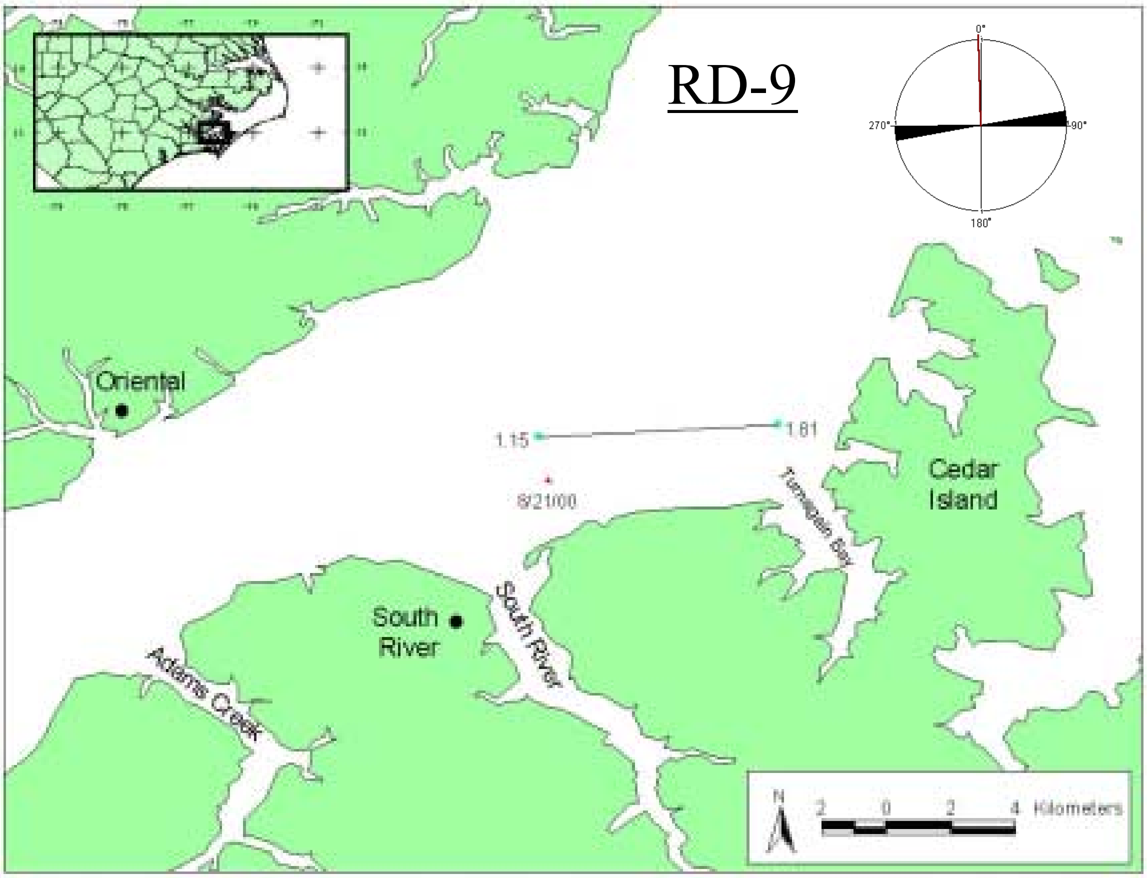

RD-1
0°
270°
90°
180°
Oriental
7/11/00
0.13
11.77
Turnagain Bay
Cedar
Island
South
River
South River
Adams Creek
N
2 0 2 4 Kilometers

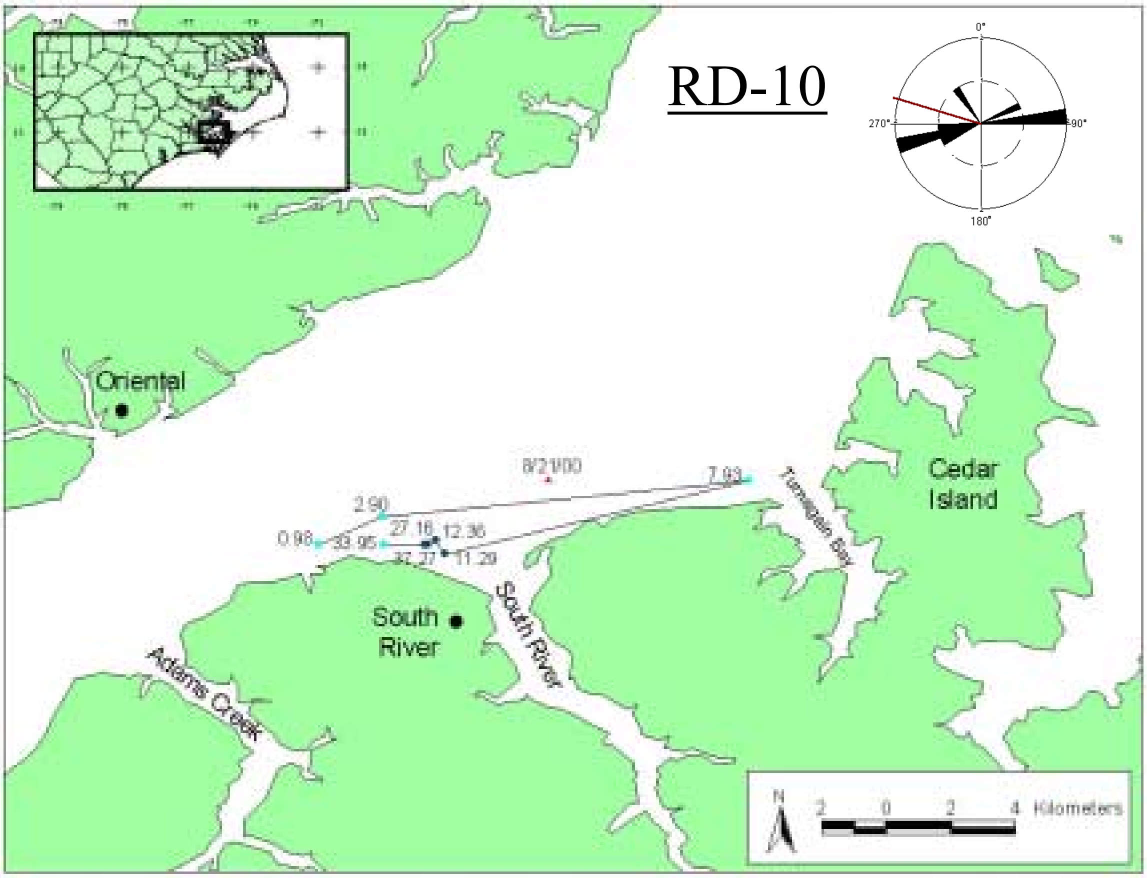

RD-2
0°
90°
180°
270°
Oriental
37.60
10.89
10.53
10.66
4.84
8.90
4.65
1.14
0.73
0.43
0.84
0.45
0.97
7/22/00
Cedar
Island
Turnagain Bay
South
River
South River
Adams Creek
N
2 0 2 4 Kilometers

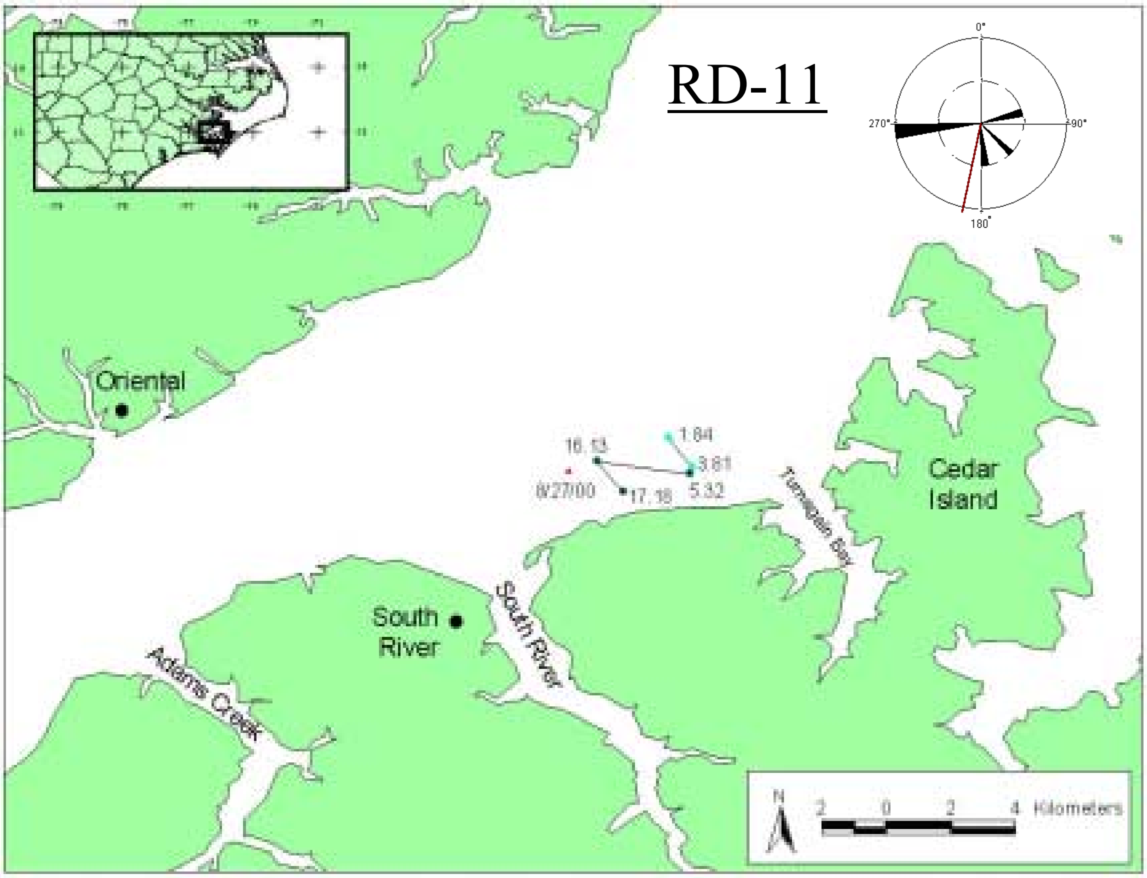

RD-3
0°
270°
90°
180°
3.04
Oriental
Cedar
Island
0.71
0.67
0.14
6/1/00
0.59
0.19
0.36
0.10
0.38
0.31
Turnagain Bay
South
River
South River
Adams Creek
N
2 0 2 4 Kilometers

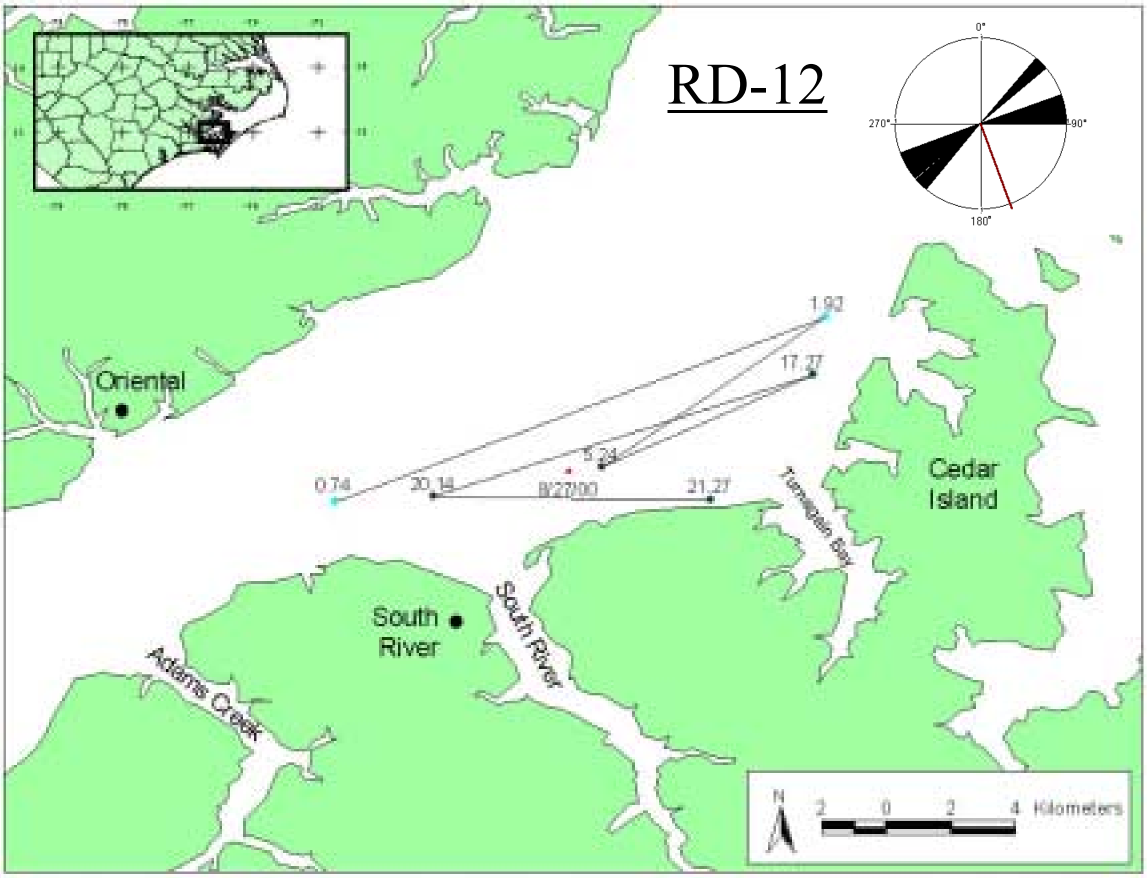

RD-4
0°
270°
90°
180°
Oriental
22.81
16.51
15.88
8/6/00
Cedar
Island
Turnagain Bay
South
River
South River
Adams Creek
N
2 0 2 4 Kilometers


RD-7
0°
90°
180°
270°
Oriental
Cedar Island
South River
South River
Adams Creek
Turnagain Bay
6.69
8.84
1.99
2.56
24.13
27.99
22.90
26.95
0.64
8/20/00
23.01
N
2 0 2 4 Kilometers

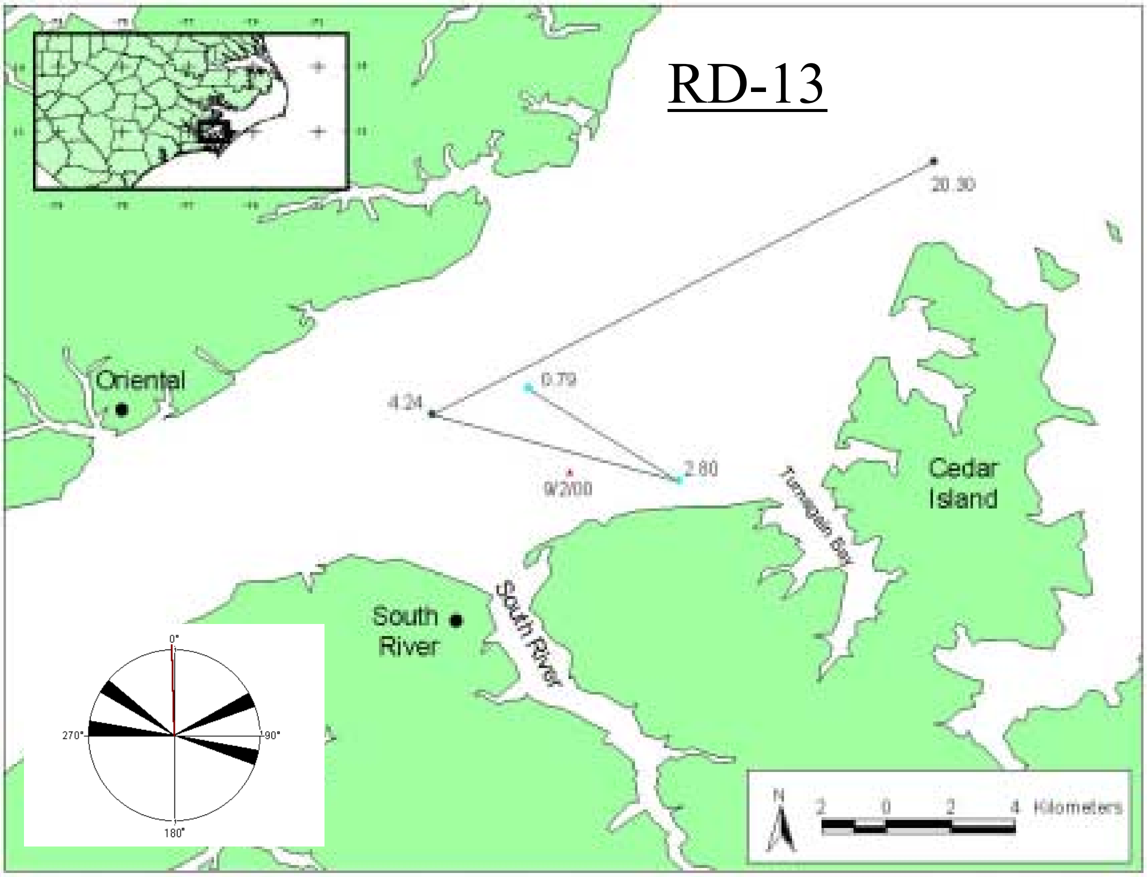

RD-9
0°
270°
90°
180°
Oriental
1.15
1.81
8/21/00
Cedar
Island
Turnagain Bay
South River
South
River
Adams Creek
N
2 0 2 4 Kilometers

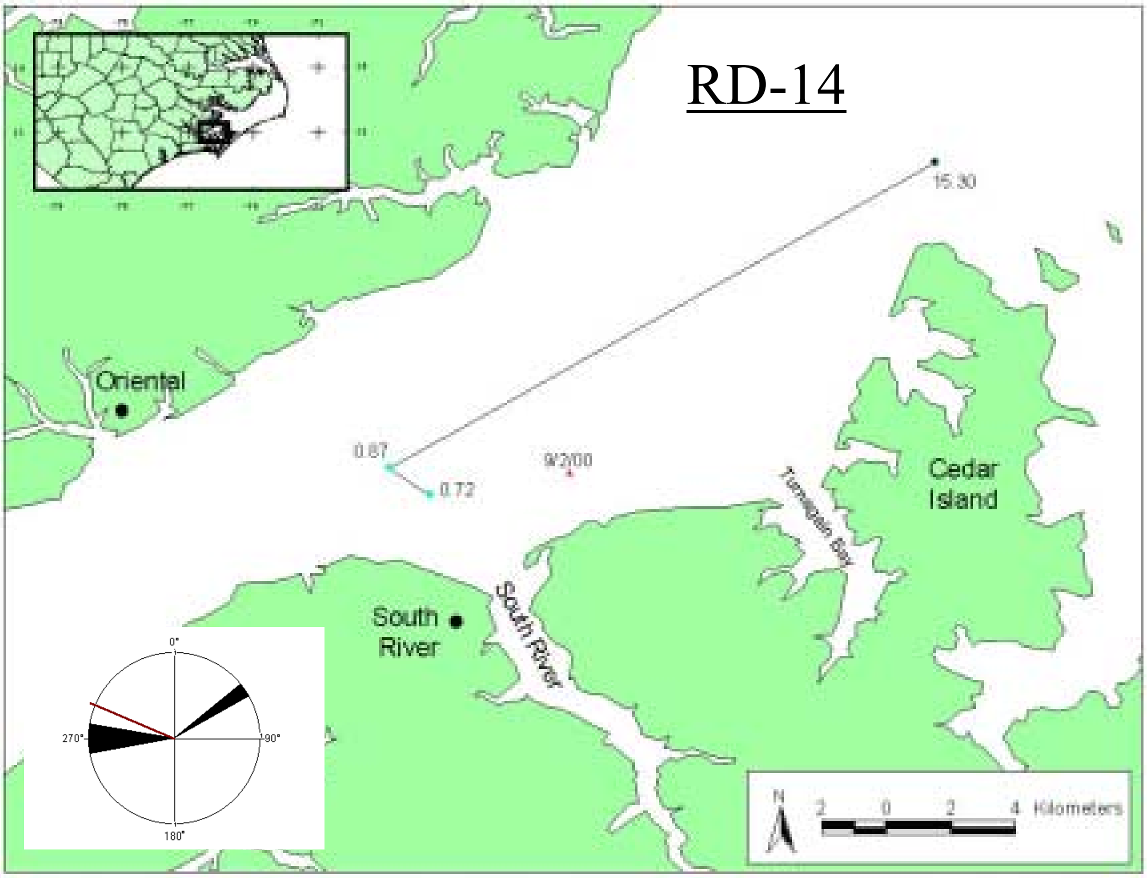

RD-10
0°
270°
90°
180°
Oriental
8/21/00
7.93
2.90
0.98
33.95
27.18
12.36
37.27
11.29
Cedar
Island
South
River
South River
Adams Creek
N
2
0
2
4
Kilometers

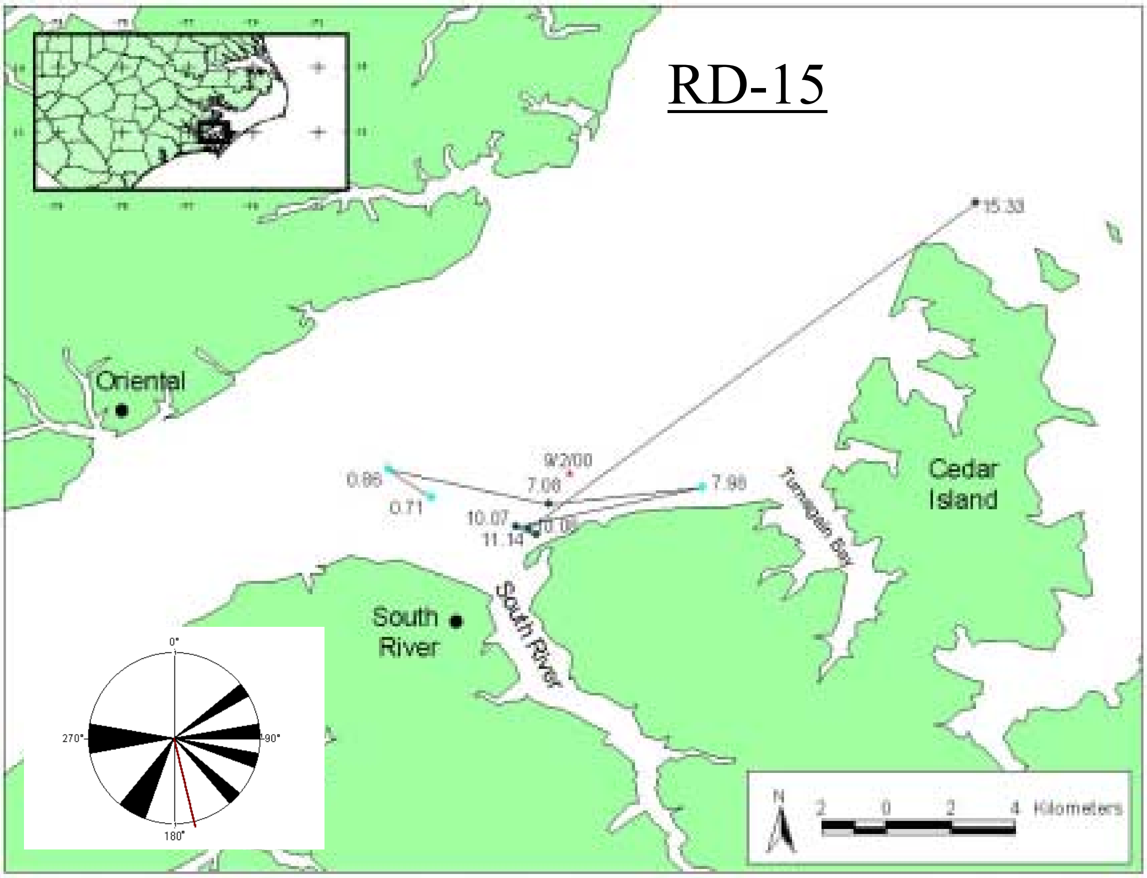

RD-11
0°
270°
90°
180°
Oriental
16.13
1.84
3.81
8/27/00
17.18
5.32
Turnagain Bay
Cedar Island
South River
South River
Adams Creek
N
2 0 2 4 Kilometers

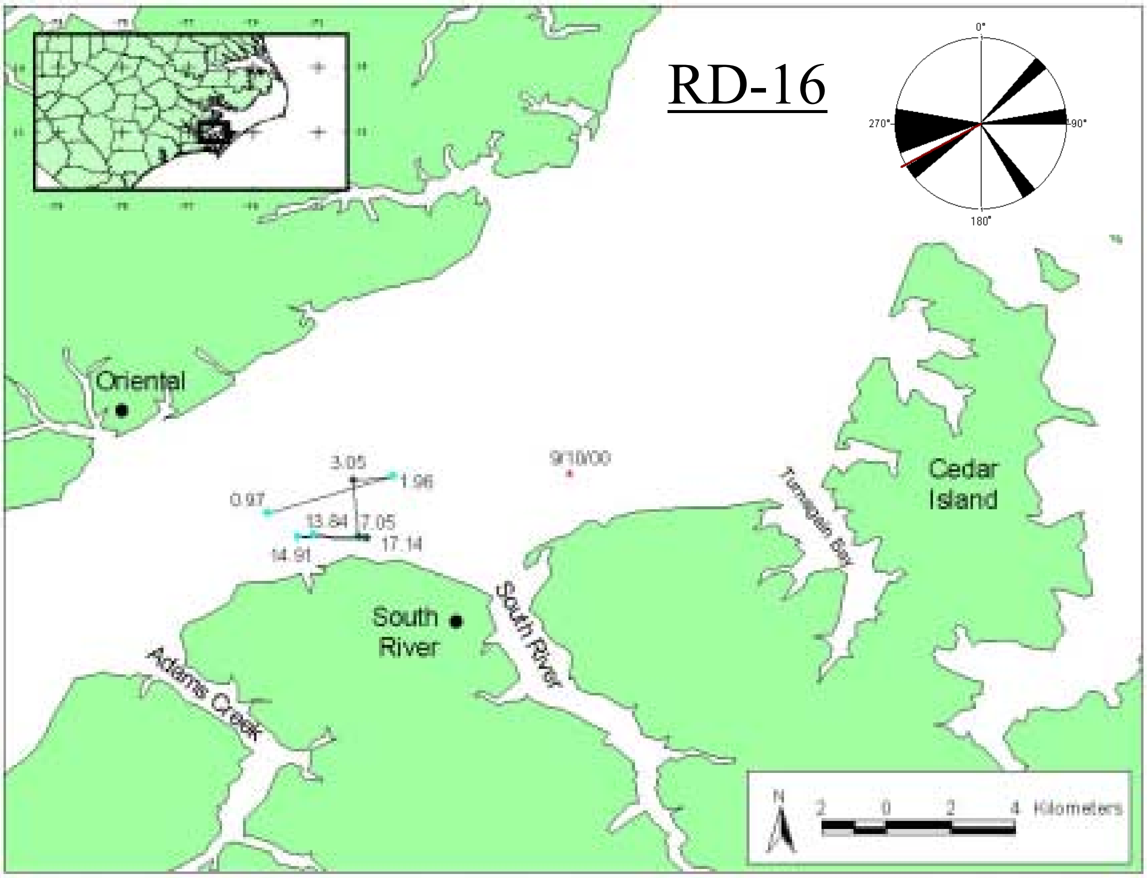


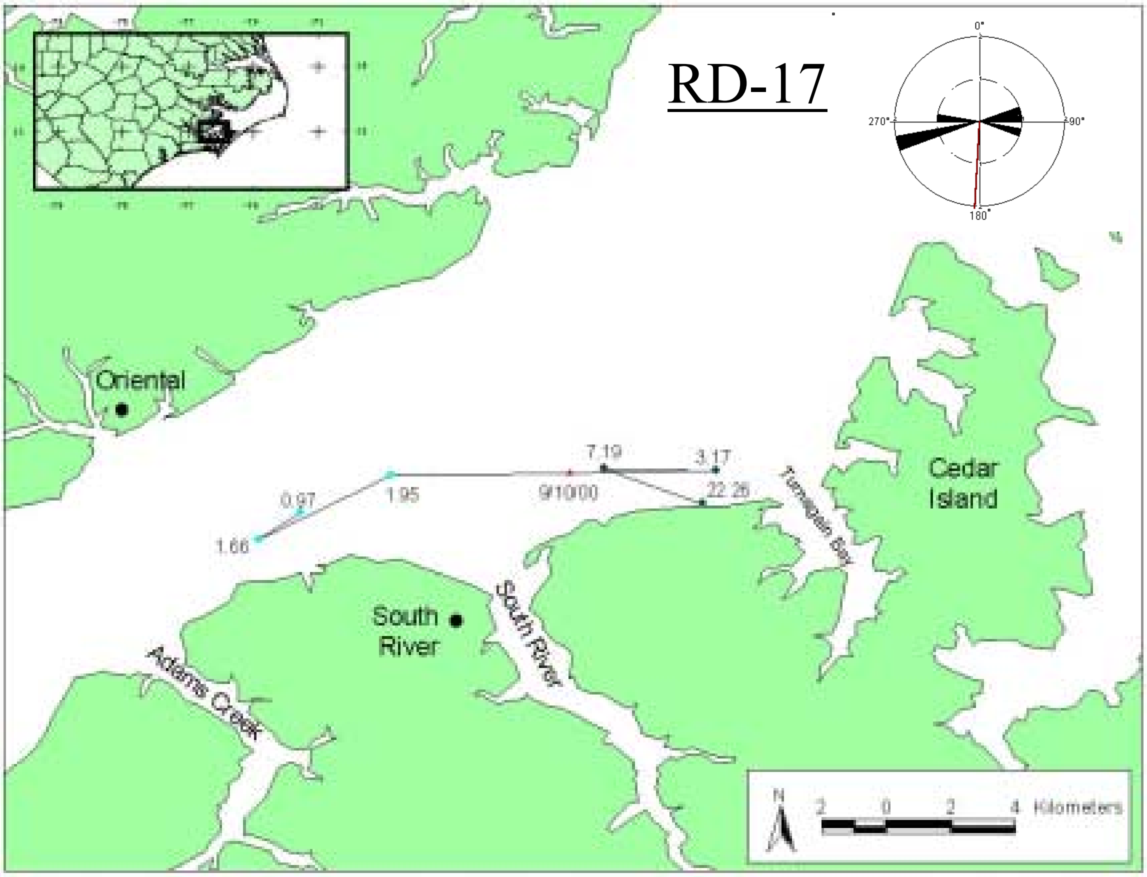
RD-12
0°
270°
90°
180°
1.92
17.77
Oriental
5.24
0.74
20.14
8/27/00
21.27
Cedar
Island
Turnagain Bay
South
River
South River
Adams Creek
N
2
0
2
4
Kilometers

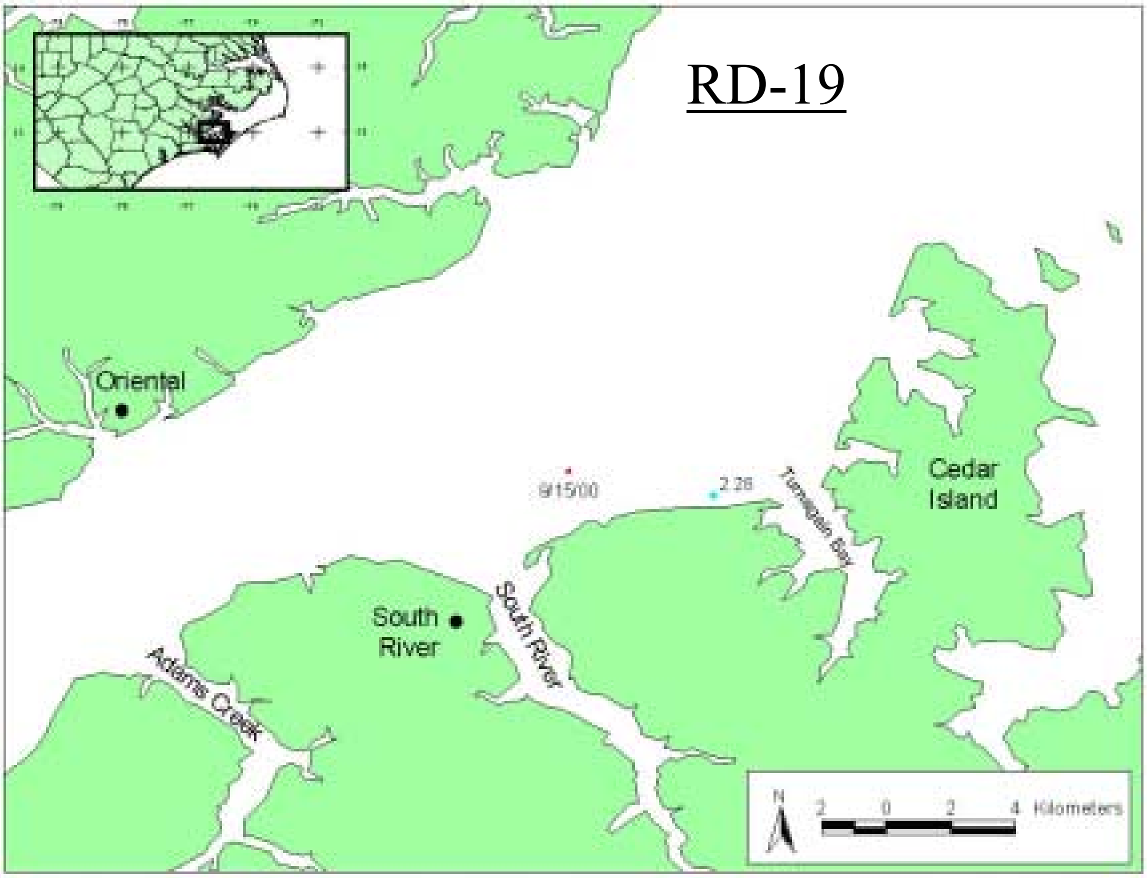

RD-13
20.30
0.79
4.24
2.80
9/2/00
Oriental
Cedar
Island
Turnagain Bay
South
River
South River
0°
270°
90°
180°
N
2 0 2 4 Kilometers

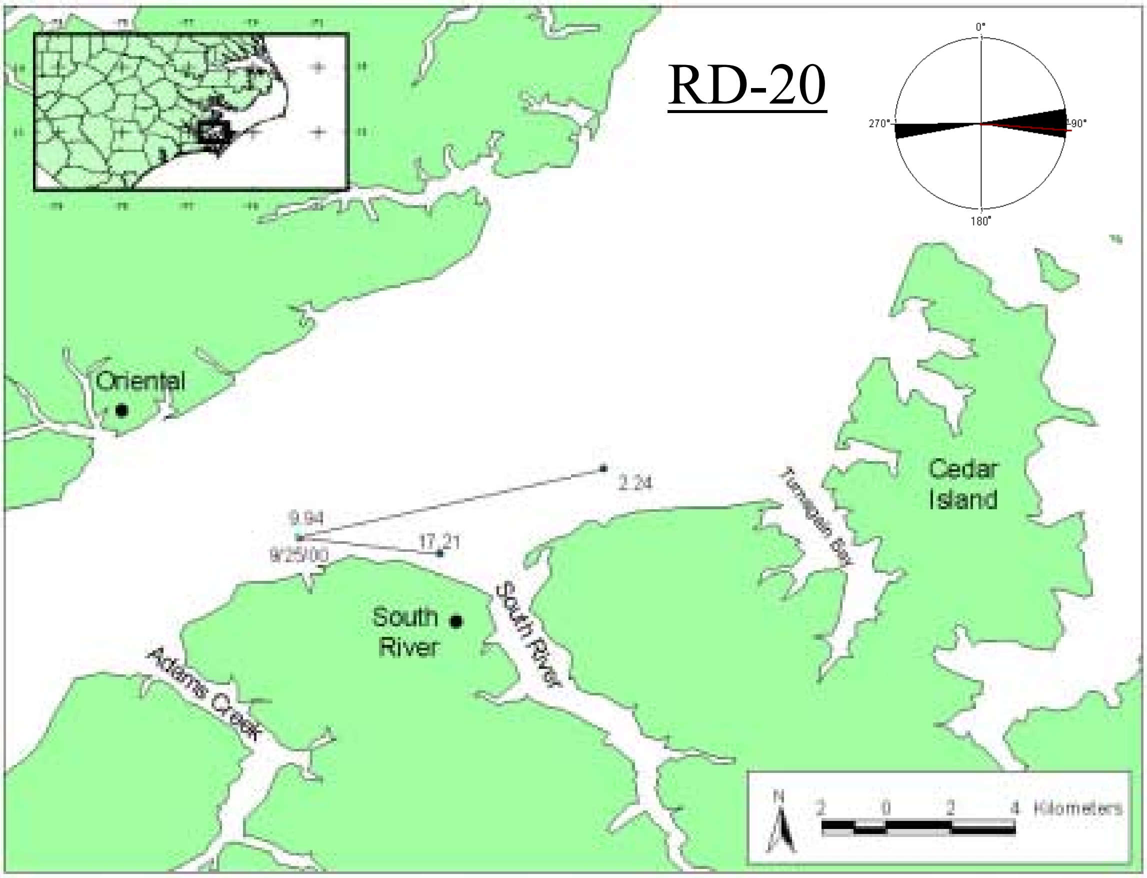

RD-14
15.30
Oriental
0.67
0.72
9/2/00
Cedar
Island
Turnagain Bay
South
River
South River
0°
270°
90°
180°
N
2
0
2
4
Kilometers

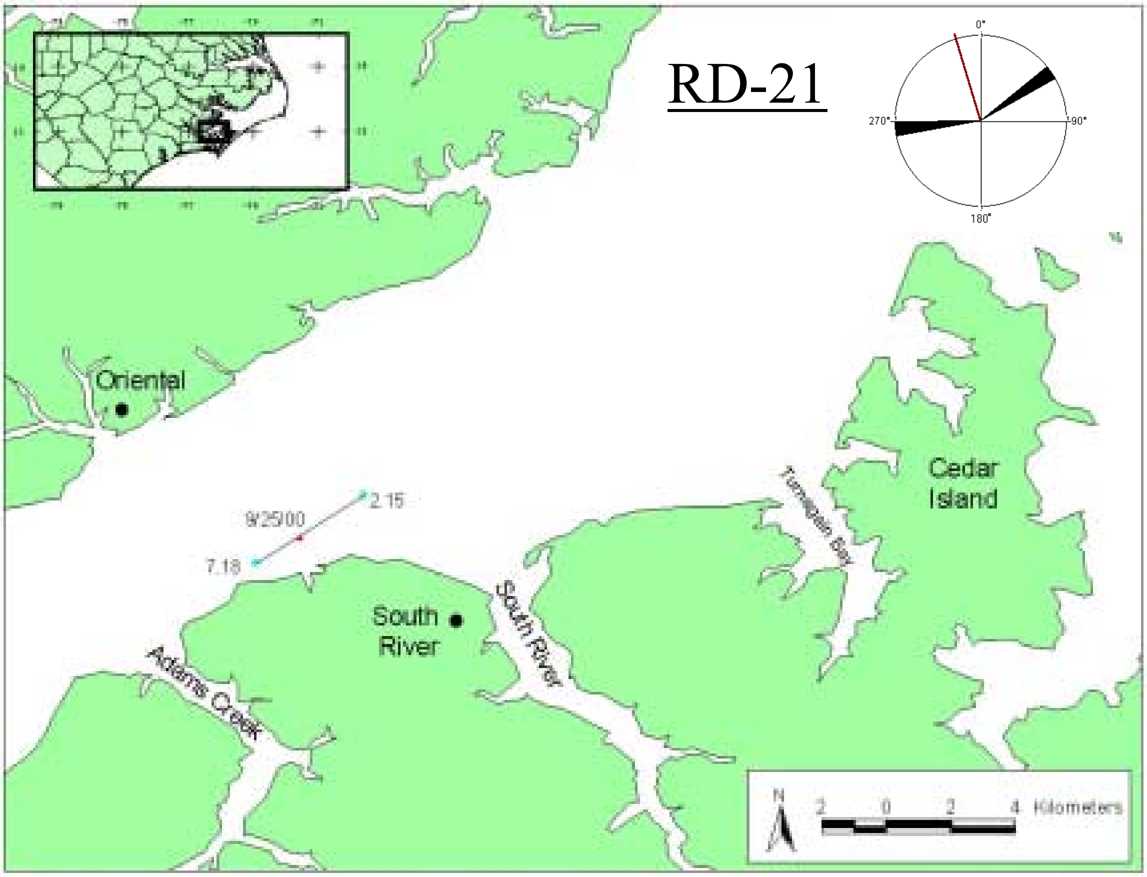

RD-15
Oriental
South River
South River
Cedar Island
Turnagain Bay
15.33
9/2/00
7.08
7.98
0.86
0.71
10.07
11.14
0°
90°
180°
270°
N
2 0 2 4 Kilometers

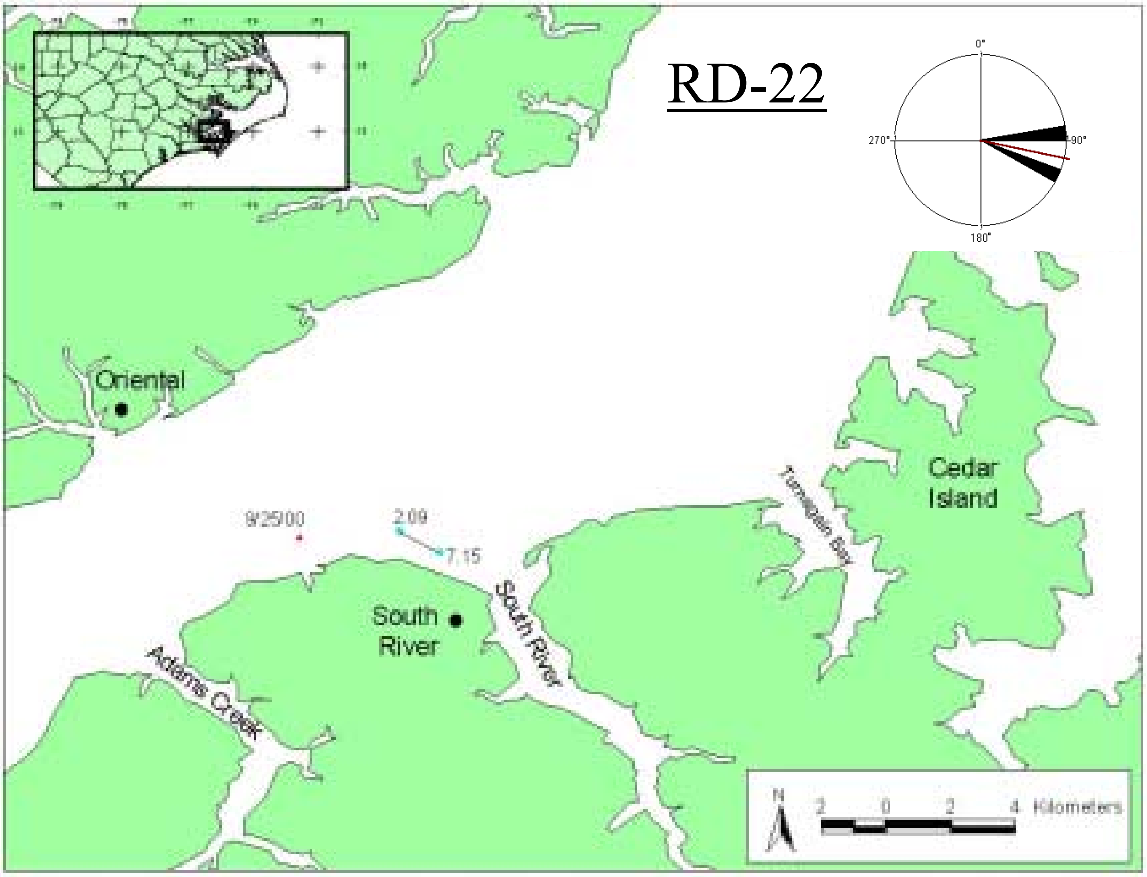

RD-16
0°
90°
180°
270°
Oriental
3.05
1.96
0.97
13.84
7.05
17.14
14.91
9/10/00
Cedar
Island
South
River
South River
Adams Creek
N
2
0
2
4
Kilometers


RD-17
0°
270°
90°
180°
Oriental
7.19
3.17
0.97
1.95
9/10/00
22.26
1.66
Cedar
Island
Turnagain Bay
South
River
South River
Adams Creek
N
2 0 2 4 Kilometers


RD-19
Oriental
9/15/00
2.26
Turnagain Bay
Cedar
Island
South
River
South River
Adams Creek
N
2 0 2 4 Kilometers


RD-20
0°
270°
90°
180°
Oriental
9.94
2.24
9/25/00
17.21
Cedar
Island
South
River
South River
Adams Creek
N
2
0
2
4
Kilometers


RD-21
0°
90°
180°
270°
Oriental
9/25/00
2.15
7.18
South
River
South River
Adams Creek
Turnagain Bay
Cedar
Island
N
2 0 2 4 Kilometers


RD-22
0°
270°
90°
180°
Oriental
Cedar
Island
Turnagain Bay
9/25/00
2.09
7.15
South
River
South River
Adams Creek
N
2
0
2
4
Kilometers