ESTUARINE RESIDENCE, HABITAT USE, AND MOVEMENTS OF TRIPLETAIL

(_LOBOTES SURINAMENSIS_) IN THE OSSABAW SOUND ESTUARY, GEORGIA

by

MATTHEW KARL STREICH

(Under the Direction of Douglas L. Peterson)

ABSTRACT

The degree to which tripletail (_Lobotes surinamensis_) utilize estuaries is unknown. The objective of my study was to describe the estuarine residence and movements of tripletail within the Ossabaw Sound Estuary (OSE) in Georgia. In summer of 2010 and 2011, adult tripletail were surgically implanted with ultrasonic transmitters. Residence and movements were monitored using a stationary array of acoustic receivers and active telemetry. Nearly continuous estuarine residence was observed between March and November at sustained water temperatures above 21°C. Movements occurred with the tidal currents. Likely, this passive transport requires reduced energy demands normally associated with active swimming and osmoregulation and may be partially responsible for the species’ rapid growth rate. My study demonstrates that estuarine habitat use is an important component of tripletail life history; however, the seasonal occurrence observed reflects the migratory nature of tripletail. Future studies are needed to better understand the species potentially complex stock structure.

INDEX WORDS: Tripletail, _Lobotes surinamensis_, acoustic telemetry, estuary, residence, Ossabaw Sound, stock structure
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DEDICATION

To my parents, Jonathan and Jennifer, my sister, Rebecca, and my fiancé, Meg:

for their unreserved patience, love, and encouragement.
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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

The tripletail (*Lobotes surinamensis*) is a medium-sized, deep-bodied fish distributed circumglobally in tropical and subtropical seas (Gudger 1931; Fischer 1978). It is the only member of the perciform family, Lobotidae. In the western Atlantic Ocean, the species is distributed from Massachusetts, southward to Argentina and throughout the Gulf of Mexico and Caribbean Sea (Hoese and Moore 1998). Although one adult was recorded as far north as Nova Scotia, Canada (Gilhen and McAllister 1985), abundance is thought to decrease north of North Carolina (Hildebrand and Schroeder 1928; Gudger 1931). Juveniles and adults are found in shallow, nearshore habitats (Gudger 1931; Baughman 1941) as well as pelagic waters more than 160 km offshore (Caldwell 1955). Regardless of location, tripletail are commonly observed in close association with shaded structures including pilings, wrecks, flotsam, buoys, and *Sargassum* algae (Kelly 1923; Gudger 1931; Hughes 1937; Baughman 1941; Dooley 1972).

Tripletail populations support popular recreational fisheries and a few limited commercial fisheries where they occur (Gudger 1931; Baughman 1941). Data from the Marine Recreational Fisheries Statistics Survey (MRFSS) suggest that most of the recreational harvest along the US Atlantic coast usually occurs in Florida; however, the low number of angler intercepts prevents reliable estimates of harvest (NMFS 2010). Commercial harvest along the Atlantic coast has averaged less than 3 metric tons
annually since 2000, with approximately 90% of the catch originating from the east coast of Florida (NMFS 2010). A directed commercial fishery for tripletail does not exist in Georgia, but tripletail are encountered as bycatch in the commercial shrimp trawl fishery. If captured according to recreational regulations, tripletail may also be sold with a commercial fishing license. Current Georgia regulations require that gear be restricted to hook-and-line only and that harvested tripletail be a minimum of 457 mm total length (TL); there is a daily creel limit of 2 fish per person.

In recent years, the number of anglers targeting and harvesting tripletail in Georgia waters has increased (GADNR 2007). The greatest harvest occurs during the summer months (NMFS 2010), apparently coinciding with tripletail spawning (Gudger 1931; Baughman 1941; Merriner and Foster 1974; Ditty and Shaw 1994; Brown-Peterson and Franks 2001; Cooper 2002; Strelcheck et al. 2004). Increases in recreational fishing pressure on Georgia’s tripletail population, especially during the spawning season, suggest that effective management of this population may be needed to avoid localized overfishing. Unfortunately, basic biological information on tripletail life history is generally lacking or incomplete. Consequently, formal stock assessments, which are critical for quantifying the status and sustainability of the resource, have been hindered by the uncertainty surrounding the current knowledge of tripletail biology and population dynamics. Several reports and studies have focused on the life history parameters of Gulf populations of tripletail (Baughman 1941; Ditty and Shaw 1994; Franks et al. 1998; Brown-Peterson and Franks 2001; Franks et al. 2001; Franks et al. 2003; Strelcheck et al. 2004); however, few studies have investigated Atlantic stocks (Merriner and Foster 1974; Armstrong et al. 1996; Cooper 2002; Parr 2011). This minimal effort resulted in
significant knowledge gaps regarding habitat use, reproductive ecology, exploitation rates, adult movements, and population connectivity (GADNR 2007).

**Tripletail Life History**

Tripletail grow quickly and become sexually mature early in life. Individuals are capable of reaching lengths of 500 mm and weights of 4 kg by age 1 (Merriner and Foster 1974; Armstrong et al. 1996; Franks et al. 1998; Strelcheck et al. 2004). Several studies have found that total lengths of individuals from consecutive cohorts often overlap (Armstrong et al. 1996; Franks et al. 1998; Strelcheck et al. 2004; Parr 2011) and that females tend to be slightly heavier than males at similar lengths (Armstrong et al. 1996; Strelcheck et al. 2004). Rapid somatic growth does not seem to interfere with sexual development, as tripletail may also reach sexual maturity by age 1 at sizes of as little as 290 mm for males and 360 mm TL for females (Merriner and Foster 1974; Armstrong et al. 1996; Brown-Peterson and Franks 2001; Strelcheck et al. 2004). In Georgia, length at which 50% of females reached sexual maturity was estimated at 459 mm TL (Parr 2011). Corresponding ages at which 50% of the population reached sexual maturity were estimated at 0.55 years for males and 1.17 years for females (Parr 2011). The estimated maximum lifespan and weight of tripletail range from 7 to 10 years of age and approximately 20 kg, respectively (Merriner and Foster 1974).

Tripletail exhibit a protracted spawning season that may begin as early as April and may extend through September; peak spawning occurs in July and August (Ditty and Shaw 1994; Brown-Peterson and Franks 2001; Cooper 2002). Asynchronous oocyte development within the ovaries of females indicates that tripletail are a multiple
spawning species, with spawning bouts thought to occur every 3-5 days during the
spawning season (Brown-Peterson and Franks 2001). Brown-Peterson and Franks (2001)
estimated relative batch fecundity to be 47.6 eggs/g of ovary-free body weight, although
this estimate was based on a sample of only 5 fish. Observations of small juveniles in
North Carolina and Alabama waters (Merriner and Foster 1974) and gravid females near
Beaufort, North Carolina and Savannah, Georgia (Gudger 1931) suggest that at least
some fish spawn in estuarine and nearshore habitats or possibly the nearshore continental
shelf (Merriner and Foster 1974). However, early larvae (<5 mm SL) have been collected
on the outer shelf and in oceanic waters. Their occurrence suggests that at least some
spawning may occur in offshore pelagic habitats (Ditty and Shaw 1994). The hypothesis
of offshore spawning is supported by recent studies that have documented low numbers
of reproductively active (e.g., presence of hydrated oocytes) females in nearshore habitats
(Brown-Peterson and Franks 2001; Cooper 2002; Strelcheck et al. 2004; Parr 2011). Parr
(2011) found only 2 out of 102 females in samples collected from the nearshore waters of
Jekyll Island, Georgia were actively spawning.

Early larvae and juvenile tripletail are often found in the epipelagic zone in close
association with drifting seaweeds including Sargassum sp. (Ditty and Shaw 1994). As
early juveniles, tripletail grow rapidly during their first year of life, a trait that may
minimize the high predation risk in the epipelagic zone (Franks et al. 2001). During this
stage of development, the young may frequently drift on their sides just below the
surface—apparently mimicking flotsam—in a cryptic behavior thought to help them
avoid predation while possibly attracting small prey items seeking refuge beneath them
(Gudger 1931; Breder 1949).
Juvenile tripletail continue to exhibit rapid growth as they mature into adults; they use suction feeding to opportunistically consume a wide variety of pelagic, benthic, and demersal prey types (Breder 1925; Franks et al. 2003; Strelcheck et al. 2004). The most important food items are small fishes, particularly clupeids, followed by penaeid shrimp, portunid crabs, and squid (Merriner and Foster 1974). As tripletail grow larger, forage fishes seem to have greater importance in the diet (Strelcheck et al. 2004).

The seasonality of tripletail landings in the northern Gulf of Mexico and western Atlantic suggests that at least some fish regularly migrate northward into estuaries and sounds in the spring and return south in the fall or winter (Gudger 1931; Baughman 1941; Merriner and Foster 1974). Along the east coast of Florida, the species is most abundant during the spring, although they do occur year round and may overwinter in coastal waters (Cooper 2002). In Georgia, anecdotal reports from anglers suggest the species is present from late spring through summer, though corroborative studies are lacking. During this time, anglers observe adults and juveniles along the beachfronts of barrier islands and within the sounds and estuaries. Apart from knowledge of the species seasonal presence, the extent to which tripletail use estuaries is unknown (Ditty and Shaw 1994).

**Acoustic Telemetry**

Basic life history questions about fish movements, habitat use, and behavior may be effectively addressed using acoustic telemetry. Acoustic telemetry methods provide several advantages over conventional tagging. For example, data obtained from conventional tagging is limited to the point of initial capture; acquiring further
information on the animal’s location, and thus movement and habitat use, depends on subsequent recaptures, which may never occur. Additionally, subsequent data collection in a conventional tagging study may depend on recaptures and the reporting of these recaptures by anglers and commercial fishermen. Acoustic telemetry allows for the nearly continuous observations of individuals, and therefore, avoids or minimizes many of the limitations of conventional tagging (Winter 1996).

Recent advances in acoustic telemetry have allowed tracking of individuals over much larger geographic and temporal scales than previously possible. Previous studies have commonly applied active acoustic telemetry to answer questions regarding movements and habitat use of marine species over short-term or intermittent periods of time (e.g., Olla et al. 1974; Morrissey and Gruber 1993; Matern et al. 2000; Aguilar 2003; Ortega et al. 2009). The development of reliable, passive acoustic telemetry systems has allowed insights into broad-scale movement patterns, habitat use, seasonal occurrence or residency, and population connectivity—questions that would be difficult to address using short-term active tracking. Using an array of submerged, omni-directional hydrophones that detect and record the presence of nearby individuals tagged with uniquely coded transmitters, passive acoustic telemetry can provide a continuous monitoring area over multiple scales depending on array design.

In this thesis, I present new information about tripletail movements, habitat use, and residence in Georgia’s estuarine waters. Chapter 2 is a manuscript that describes the acoustic telemetry study designed to discern tripletail habitat use, movements, and seasonal occurrence within the Ossabaw Sound Estuary in Georgia. The final chapter provides a summary of the key findings of the study and management implications
concerning the conservation of this popular sportfish. Additionally, I provide suggestions for future areas of research.
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CHAPTER 2

ESTUARINE RESIDENCE, HABITAT USE, AND MOVEMENT PATTERNS OF TRIPLETAIL (*LOBOTES SURINAMENSIS*) IN THE OSSABAW SOUND ESTUARY, GEORGIA¹

¹ Streich, M. K., C. Kalinowsky, and D. L. Peterson. To be submitted to *Transactions of the American Fisheries Society*. 
Abstract

Tripletail (*Lobotes surinamensis*) support a popular recreational fishery along the coast of Georgia; however, studies about tripletail residency and movements within Georgia estuaries have not been conducted. The objective of our study was to describe estuarine movements and residency of tripletail in the Ossabaw Sound Estuary in Georgia. In summer of 2010 and 2011, adult tripletail (*n*=32; 421-710 mm TL) were captured with traditional angling methods and surgically implanted with ultrasonic transmitters. Tagged tripletail were detected within the estuary via a stationary array of acoustic receivers, which monitored the estuary continuously from June 2010 through May 2012. Manual tracking was conducted by using a portable hydrophone and homing. Tripletail were detected in the estuary from March through November at sustained water temperatures above 21°C; outside of this time, tripletail were absent from the stationary array. Movements were highly correlated with tidal stage; 100% of the tagged fish moved upstream with flood tides and returned to the Sound with the ebbing tide on a daily basis. During these movements, we observed tripletail as far upstream as rkm 33. Using acoustic telemetry, our study provides the first information on the spatial and temporal habitat use of tripletail within the South Atlantic Bight. Our results suggest that tripletail exhibit a high degree of residency in Georgia estuaries and that they use a large portion of the estuary during their daily movements. Although estuarine habitat use appeared to be an important component of tripletail life history in our study, future studies of population dynamics and winter movements are needed to better understand the potentially complex structure of tripletail stocks.
Introduction

The tripletail (*Lobotes surinamensis*) is a medium-sized, deep-bodied fish inhabiting tropical and subtropical seas worldwide (Gudger 1931; Fischer 1978). The tripletail is the only member of the perciform family Lobotidae. In the western Atlantic Ocean, the species is distributed from Massachusetts, southward to Argentina and throughout the Gulf of Mexico and Caribbean Sea (Hoese and Moore 1998). Although one adult was recorded as far north as Nova Scotia, Canada (Gilhen and McAllister 1985), greater abundances are observed south of Virginia (Hildebrand and Schroeder 1928; Gudger 1931). Juveniles and adults are found in a variety of habitats, from shallow nearshore waters (Gudger 1931; Baughman 1941) to pelagic waters more than 160 km offshore (Caldwell 1955). Regardless of location, tripletail frequently are observed in close association with shaded structures including pilings, wrecks, flotsam, buoys, and *Sargassum* algae (Kelly 1923; Gudger 1931; Hughes 1937; Baughman 1941; Dooley 1972).

The tripletail is a popular food fish, and the species supports popular recreational and limited commercial fisheries where it occurs (Gudger 1931; Baughman 1941). Marine Recreational Fisheries Statistics Survey (MRFSS) data suggest that most of the recreational harvest along the US Atlantic coast occurs in Florida and Georgia; however, the low number of angler intercepts prevents reliable estimates of the harvest (NMFS 2010). Commercial harvest along the Atlantic coast has averaged less than 3 metric tons annually since 2000, with approximately 90% of these landings also originating from the east coast of Florida (NMFS 2010). The greatest harvest occurs during the summer months (NMFS 2010), apparently coinciding with the tripletail spawning season (Gudger
1931; Baughman 1941; Ditty and Shaw 1994; Brown-Peterson and Franks 2001; Cooper 2002; Strelcheck et al. 2004). Several reports and studies have focused on the life history parameters of Gulf populations of tripletail (Baughman 1941; Ditty and Shaw 1994; Franks et al. 1998; Brown-Peterson and Franks 2001; Franks et al. 2001; Franks et al. 2003; Strelcheck et al. 2004); however, few studies have investigated Atlantic stocks (Merriner and Foster 1974; Armstrong et al. 1996; Cooper 2002; Parr 2011), leaving significant knowledge gaps regarding estuarine residence, seasonal habitat use, movements, exploitation rates, and reproductive ecology.

In recent years, the number of recreational anglers targeting and harvesting tripletail in Georgia has increased (GADNR 2007). Increases in recreational fishing pressure on Georgia’s tripletail population, especially during the spawning season, suggest that effective management of this population may be needed to avoid localized overfishing; however, basic information on tripletail life history is generally lacking or incomplete. Consequently, formal stock assessments, critical for quantifying the status and sustainability of the resource, have been hindered by the uncertainty surrounding the current knowledge of tripletail life history and population dynamics.

Understanding movement patterns of fishes is critical to identify the spatial and temporal scales at which a species should be managed, factors influencing these movements, and information regarding stock structure (Begg and Waldman 1999). Movement is a key process that allows fish to meet their energy demands in spatially and temporally changing environments (Schlosser and Angermeier 1995), while also allowing selection of habitats that help to maximize growth and survival (Gowan and Fausch 2002; Heupel and Simpfendorfer 2008). Examining processes that directly influence habitat
use, such as individual movement, can also aid in identifying environmental factors important to the species (White and Garrott 1990; Rogers and White 2007).

Acoustic telemetry has developed into an effective tool for answering basic life history questions about fish movements, habitat use, and behavior that would otherwise be difficult to answer (e.g., Humston et al. 2005). For example, conventional tagging necessarily limits data collection to the point of initial capture, as further information on the animal’s location depends on subsequent recaptures that may never occur. Furthermore, acoustic telemetry is more reliable than conventional tagging because recaptures may be fishery dependent, requiring cooperation of anglers and commercial fishermen. Acoustic telemetry avoids these limitations by allowing nearly continuous observations of individuals without the need for subsequent recaptures (Winter 1996).

Many researchers have applied acoustic telemetry to examine movements and habitat use of marine species over short-term or intermittent periods of time (e.g., Olla et al. 1974; Morrissey and Gruber 1993; Matern et al. 2000; Aguilar 2003; Ortega et al. 2009). These studies typically employ manual tracking using a portable receiver and hydrophone to actively locate transmitted individuals; however, recent technological advancements have facilitated tracking of individuals over much larger spatial and temporal scales than has been previously possible. Passive acoustic telemetry is becoming widespread and is commonly used to determine broad-scale movement patterns, habitat use, seasonal occurrence or residency, and population connectivity (e.g., Heupel et al. 2006; Able and Grothues 2007; Sakett et al. 2008; Fernandes et al. 2010). Passive acoustic telemetry relies on an array of stationary, submerged hydrophones that detect and record presence of nearby individuals carrying uniquely coded transmitters.
Unlike manual acoustic telemetry, passive acoustic telemetry can establish a nearly continuous monitoring area over multiple scales depending on the design of the receiver array.

Tripletail are observed seasonally in the bays, sounds, and estuaries of the northern Gulf of Mexico and US Atlantic coast from Florida to Virginia, with the greatest concentrations occurring during the summer months (Gudger 1931; Baughman 1941; Merriner and Foster 1974). However, apart from the species seasonal occurrence, the extent to which tripletail use estuaries is unknown (Ditty and Shaw 1994). In Georgia, angler reports suggest the species is present in local estuaries from April through October, but to date, the seasonal residence, movements, or habitat use of tripletail anywhere within the South Atlantic Bight have not been examined. Therefore, the goal of this study was to identify the seasonal residence and movement patterns of large juvenile and adult tripletail within a Georgia estuary using acoustic telemetry. The specific objective of the study was to describe residence, movement, and several aspects of estuarine habitat use over seasonal, diel, tidal, and hourly scales to improve the current knowledge of tripletail life history and ecology. These data will provide insight into the value of estuarine habitats, aspects of reproductive ecology, and information regarding stock structure—all of which will be critical to successful management of tripletail populations along the southeastern US Atlantic coast.
Methods

Study Area

The Ossabaw Sound Estuary (OSE) is located approximately 20 km south of Savannah, Georgia (Figure 2-1). Freshwater exchange with the Atlantic Ocean occurs through Ossabaw Sound, a 5.25 km wide opening between Wassaw Island to the north and Ossabaw Island to the south. Within Ossabaw Sound, Raccoon Key separates the mouths of the Ogeechee and Little Ogeechee rivers into the South Channel and North Channel, respectively. The Ogeechee River is the major source of freshwater input to Ossabaw Sound, providing a mean annual discharge of 115 m$^3$ s$^{-1}$ through the South Channel (Meyer et al. 1997).

Like other Georgia estuaries, the OSE is characterized by sand and mud substrates, large expanses of smooth cordgrass (*Spartina alterniflora*), and a large tidal range averaging 2.1 m (Johnson et al. 1974). Tidal currents usually range from 50 to 75 cm s$^{-1}$, with stronger currents observed during ebb tides than flood (Dörjes and Howard 1975). Raccoon Key prevents significant exchange of water between the two channels; as a result, consistently lower and more variable salinities occur in the South Channel (Wenner et al. 2005). In early spring 2010, the marsh dividing the Ogeechee and Little Ogeechee rivers at Seven Mile Bend was washed away and has likely increased the amount of freshwater entering the North Channel.

Fish Tagging

During June-July of 2010 and 2011, hook and line sampling was used to capture adult tripletail around fixed structures within the estuary during periods of low tidal current. Tackle consisted of 18.1- or 22.7-kg test braided line rigged with a slip-float, an
18.1-kg fluorocarbon leader, and an octopus hook baited with live white shrimp (*Litopenaeus setiferus*) or menhaden (*Brevoortia tyrannus*). Captured individuals were transported in an aerated livewell to the nearby University of Georgia Marine Extension Service Aquarium where they were measured (TL), weighed (kg), and surgically implanted with a coded, acoustic transmitter (Vemco V16-4H; Amirix Systems Inc.). Tripletail were placed ventral side up in a padded, V-shaped cradle with only the ventral surface of the fish above water (i.e., gills of the fish remained below water throughout the surgical procedure). A sterile scalpel was used to make a 3-4 cm incision between the pelvic fins and anus and slightly offset from the ventral midline. Sterilized transmitters were lightly coated with triple antibiotic ointment (Neosporin®; Johnson and Johnson Consumer Companies Inc.) and then inserted into the peritoneal cavity. The incision was closed with 3-4 absorbable Vicryl® sutures (2-0 needle; Ethicon, Inc.). Each transmitter had an expected battery life of 858 days and had a random signal repeat interval between 30 and 90 seconds to minimize continuous signal overlap. Fish were then externally tagged with a t-bar anchor tag (Hallprint Pty. Ltd.) with researcher contact information printed on the tag in case of angler recapture. After the tagging procedure, tripletail were held in a 2271-L recirculating tank for 1-2 days to ensure they had recovered from the surgery before they were released. If no surgical complications were observed during this period, the fish were returned to their original capture site and released. To increase the probability that recaptured tripletail would be reported by local anglers, contact information was also printed on the transmitters, and information about the study was presented to anglers at local meetings and printed in the state fishing regulations.
Acoustic Monitoring

Both passive and active telemetry methods were used to detect transmittered tripletail within the OSE. A stationary array of Vemco VR2W receivers was deployed to continuously monitor and record the presence of tagged individuals. Each receiver was equipped with an omni-directional hydrophone and recorded the date, time, and unique transmitter ID each time a transmittered fish swam within range of the receiver. A cinder block, polypropylene rope (1.27 cm), and a subsurface float were used to suspend receivers on their vertical axis, approximately 1 m above the seafloor. When possible, the cinder block was anchored to a piling or land to facilitate receiver recovery. Where possible, receivers were fixed directly to pilings using a custom-made stainless steel bracket bolted to the piling approximately 1 m below the mean low water mark. Range testing at the beginning of the study revealed a tag detection radius of approximately 400 m; however, range is known to vary depending on water depth, sea state, bottom substrates, and receiver degree of biofouling (Heupel et al. 2008). Similar detection ranges were observed for receivers deployed with either method. All receivers were spaced approximately 1-3 km apart, which eliminated the potential for simultaneous detections on multiple receivers.

At the beginning of the study in May 2010, the acoustic array consisted of 4 VR2W receivers. Receivers were positioned in a linear fashion along the North Channel to discern patterns of ingress, egress, and residency of tripletail within the monitoring area (Figure 2-1). In May 2011, eight additional receivers were deployed to expand the spatial coverage of the array, and hence, improve our ability to monitor seasonal movements and spatial distribution of tagged individuals within the study area.
Detections of tripletail on the two most upriver receivers prompted deployment of 6 additional receivers farther up the Little Ogeechee and Ogeechee rivers in July and September 2011 (2 in July, 4 in September). Once deployed, all receivers remained in place until the conclusion of the study in May 2012.

To facilitate interpretation of detection data, each receiver was assigned a habitat code and unique number indicating the habitat type and ranked distance of the receiver from the mouth of the sound. For example, the code “COS 1” was used to identify a receiver that was deployed in channel habitat in the outer sound (COS) and located nearest to the mouth of OS (the furthest receiver up river had a ranked distance of 18). Other habitat types included in this numbering system were “outer sound” (OS) - characterized by open water near the mouth of the Sound; channel habitat in the “inner sound” (CIS); open water within the inner sound but away from the channel (IS), and upriver marsh habitat (URM) which was located within one of the two river channels upstream of the Sound. Transmitter detection data were downloaded from all receivers at 3-6 week intervals throughout the study.

Detection data of tagged individuals from the stationary array were supplemented with active tracking of individuals using a portable receiver (Vemco VR100) and omni-directional (VH165) or directional hydrophone (VH110). Two methods of active telemetry were used between 15 June 2011 and 19 September 2011. The first method, conducted 2-3 times per week, employed a systematical searching of the study area with a search interval of 300-400 m. At each stop, the omni-directional hydrophone was lowered 1.5 m into the water for 100 s. If a fish was detected, the directional hydrophone was lowered into the water, and triangulation and homing were used until a reading of 95
dB or above was detected at a gain of 12 or less (approximately 3 m from fish). A global positioning system (GPS) was used to determine location, which was recorded, along with the date, time, transmitter number, tidal condition, and water depth. Water temperature, dissolved oxygen, and salinity were recorded with a portable water quality multi-meter (YSI® 85; Yellow Springs Instruments, Inc., Yellow Springs, Ohio). The second method of active tracking employed continuous tracking of individual fish for 4- to 6-hr periods or until contact was lost. Locations of transmitted fish and environmental data were recorded every 15-30 min as previously described to provide fine-scale data on movements and habitat use during various stages of the tidal cycle. Continuous tracking was conducted approximately once per week and opportunistically when actively moving fish were detected by the first method. Active telemetry of transmitter-tagged tripletail was normally conducted during daylight hours, but a few continuous tracks were also attempted at night.

Data Analysis—Estuarine Residence

Residence of tagged tripletail was assessed daily, with a fish considered resident in the OSE when more than one detection/day was recorded for that individual. Daily residence histories for each tagged tripletail were plotted to visually assess the temporal patterns of residency within the study area. Individual residence (IR) of each fish was calculated by dividing the number of days the individual was detected (DD) by the total fish days (TFD), calculated as the number of days between the first and last detection for that individual. Pearson’s product-moment correlation coefficient was used to analyze the relationship between residence measures (DD, TFD, and IR) and fish size. To determine patterns in residency for the entire population, the proportion of transmitter-tagged
individuals present per day was plotted against environmental variables including water temperature, photoperiod, and lunar phase. Water temperature data were obtained from NOAA Tides and Currents (station ID 8670870). Daily sunrise and sunset and lunar phase data were obtained from the U.S. Naval Observatory (Astronomical Applications Department; aa.usno.navy.mil/). Photoperiod was derived from daily sunrise and sunset times.

Data Analysis-Movement Patterns

Potential diel and tidal activity patterns were examined for all tagged tripletail that were detected for at least 4 days post-tagging. Initially, scatter plots of individual fish detections, coded by receiver, were examined visually to identify any obvious pattern in diel activity at specific locations (Appendix A, B). Total number of detections for all fish were summed into hourly bins (i.e., 03:00-03:59, 04:00-04:59, etc.) and plotted to visually assess daily variation in detection rates. To further investigate diel activity patterns of each fish, a G-test (Sokal and Rohlf 1995) was used to determine if the number of detections in each hourly bin was significantly different from a hypothetical, uniform distribution.

To determine potential effects of tide height on fish activity or hydrophone performance, the number of detections from individual receivers was binned in 20-cm increments of tide height. A G-test was again used to compare the frequency of detections by tide height with the frequency of tide heights that were observed during the monitoring period for that receiver. Because differences between the expected and observed distribution of detections could have several interpretations (i.e., temporal variation in detection efficiency versus actual activity of transmittered fish) the
proportion of all observed movements occurring with or against the tidal current were also determined. To minimize the possibility of misclassifying a movement as with-current or against-current, only movements between adjacent receivers occurring within a 3-hr span were included in this analysis. The relationship between movements that were observed from active tracking and the recorded water quality data was determined using Pearson’s product-moment correlation coefficient ($\alpha=0.05$).

Possible periodicity in the short-term movement patterns of tripletail related to diel or tidal cycles was examined using Lomb-Scargle periodograms (Lomb 1976; Scargle 1982). The Lomb-Scargle method is a type of spectral analysis that enables estimation of the power of periodic components of time-series data at all possible frequencies. To compute the Lomb-Scargle periodograms, detection data of each fish were summed into hourly bins and analyzed with program PAST (Hammer et al. 2001).

**Data Analysis-Space Use**

Temporal variation in habitat use within the OSE were first examined visually by using scatter plots of individual fish detections coded by receiver. This approach allowed the identification of broad-scale trends in space use (e.g., possible shift from inner to outer receivers). To further evaluate seasonal habitat use, the number of detections at each receiver per receiver-day (number of days receiver was deployed) and the number of individual fish visiting each receiver were calculated. To assess changes in site use over both time and space, mean daily detections at each receiver also were calculated monthly for each fish. These values were then averaged across all fish and evaluated for normality with the Shapiro-Wilk statistic and homogeneity of variances with Levene’s Test. When data were non-normal and standard transformations failed to adequately normalize the
data, rank transformations were applied and analyzed using an unbalanced two-way ANOVA as described by Conover and Iman (1981). The interaction of receiver and month, both considered fixed effects, was also included in the model to identify any potential trends in use of the OSE through time. Significant differences among means were evaluated using the Student-Newman-Keuls’ (SNK) multiple comparisons test. If a significant interaction was detected, a one-way ANOVA was performed to determine which combinations of receiver and month had greater mean daily detections. Because the number of receiver detections could be inflated by a “stationary individual”, the mean proportion of days that a fish visited each receiver was also assessed monthly. The Shapiro-Wilk statistic indicated that these data were also non-normal. Standard transformations were inadequate; therefore, data were rank transformed and analyzed with an unbalanced two-way ANOVA. The sequential addition of receivers throughout 2011 precluded any valid statistical analyses of combined receiver data. Therefore, to maintain data interpretability, changes in monthly mean daily detections and mean proportion of fish days were examined at selected individual receivers. Significant differences in these response variables were identified using a Kruskal-Wallis test. A Wilcoxon rank sum test was used to separate significant differences among the means. All statistical analyses of space use were performed in SAS 9.1 (SAS Institute, Cary, NC), and all test of significance were conducted at an $\alpha=0.05$. 


Results

Estuarine Residence

Over the 2 years of the study, a total of 32 individual tripletail were implanted with acoustic transmitters and released into the OSE (Table 2-1). In 2010, transmittered tripletail ranged in size from 42.1 to 71.0 cm TL (median TL=59.4 cm) compared to 42.7-67.8 cm (median TL=57.3 cm) in 2011. After release, most fish remained in the OSE throughout most of the summer, with only brief periods (usually <3 days) of absence from the receiver array. Only one fish was never detected after its release, and two fish were only detected for one day after their release. Subsequent searches for these individuals using active tracking methods showed that the fish had either died or shed their transmitters. Three other transmittered fish were harvested by recreational anglers (1 in 2010; 2 in 2011). All other tagged fish were monitored intermittently for periods ranging from 3 to 189 days (median TFD=100) (Table 2-1), yielding a median individual residence of 67% (range: 17-100%). The total number of detections recorded for individual fish varied from 55 to 7,966 with a total of 89,078 valid detections for all fish combined over the course of the study. Total length of individual tripletail was not significantly correlated were with residence time within the OSE (r=-0.13, p=-.50 for DD; r=-0.23, p=0.23 for TFD, r=-0.17, p=0.37 for IR).

Seasonal occurrence of tripletail within the OSE appeared to be influenced by water temperature (Figure 2-3), the start of estuarine residence was difficult to estimate because many fish were already present before tagging began. However, two of the fish tagged in 2010 (#572, #573) returned to the OSE as early as 17 April 2011, and three
individuals (#572, #402, #396) returned to the OSE between 21-26 March 2012. Water temperatures during these periods in both years were approximately 21°C.

Most fish left the estuary in early October in both years. Median date of departure was 8 October in 2010 (range=8 Aug. – 5 Nov.); 6 October in 2011 (range=16 Jun. – 24 Oct.); water temperature at time of median departure during both years was 24°C. In each year, the last detection was recorded in the OS when water temperatures had dropped to approximately 21°C. Decreases in daily residence also seemed to correspond with declines in mean daily water temperatures (Figure 2-3). Trends in daily residence did not appear to be correlated with changes in photoperiod or lunar phase.

**Movement Patterns**

Analysis of total combined tripletail detections by time of day revealed significant differences in hourly detections ($G_{adj}=2673$, df=23, $p<0.001$). Recorded detections were $\geq$ values from 21:00 to 11:00 and $\leq$ expected values from 11:00 and 21:00 (Figure 2-4). Significant differences were also observed for individual fish (G-test, df=23, $p<0.001$); however, scatter plots of individual fish detections did not suggest any difference in the timing of detections at individual receivers. Only 2 fish displayed a diel pattern as they were usually detected at the upriver receivers only at night. Although individual patterns were observed, no behavioral trend was identified for the overall population.

Analysis of detection frequency by tide height frequency at individual receivers indicated that tripletail detections occurred differently depending on tide height and receiver location (G-test, df=16, $p<0.001$). For example, the upriver marsh receivers (e.g., URM 12, URM 13, URM 14) had few detections at low tidal heights, but many detections at higher tidal heights (Figure 2-5). Some receivers located in the middle of
OS (e.g., COS 5) had few detections at the lowest and highest tidal heights (Figure 2-5), whereas others (e.g., CIS 6) had fewer than expected detections during periods of mid-level tidal heights (Figure 2-5).

Analyses of telemetry data from both passive and active tracking methods revealed a strong relationship between tripletail movement and tidal cycle. Lomb-Scargle periodograms supported the assertion that tripletail movements were tidally influenced, as dominant peaks were observed at 12.4 hrs for almost all fish (Table 2-2; Figure 2-6). In fact, both active and passive tracking showed that the fish always moved with the tidal current regardless of direction. In most instances, the fish reversed their direction of movement when the current changed on each subsequent tidal cycle. This often repeated pattern of tidal movement enabled some individuals to travel as far as 12 km during a single flood or ebb tide, facilitating regular access to the open waters near the mouth of OS as well as protected riverine waters. Interestingly, transmittered fish were rarely stationary at any receiver for more than 2-hr.

Active telemetry tracking yielded a total of 295 location estimates for 76% (13 of 17) of fish available, including 22 continuous tracks that averaged 277 min (sd=140 min) on 11 different individuals. Mean dissolved oxygen and salinity levels at these locations were 5.20 mg/L (range=3.20-6.21 mg/L) and 33.1 ppt (range=30.7-35.2 ppt), respectively. Of the 22 continuous tracks, eight recorded fish as they changed locations. Movement rates (mean=1.96 km/hr) of these individuals showed that the fish were passively drifting with the current throughout most of the tidal cycle which allowed them to remain at a relatively constant salinity throughout the active tracking period (Figure 2-7). Continuous tracks of stationary individuals showed that many individuals often held
positions on fixed structures (i.e., buoys and pilings) for several hours at a time (max observed time at structure was 11 hr 39 min; however, fish still resided at structure at termination of continuous track). Changes in salinity recorded for stationary individuals varied from 1.2-3.0 ppt within a single tidal cycle. Continuous tracks conducted at night (n=3) indicated similar patterns of tidally influenced movements.

**Space Use**

The spatial distribution of detections recorded over the 2 years of the study revealed that most habitat use was focused within the North Channel of the OSE, from the mouth of OS to approximately 8.5 km upriver. Sixty-seven percent (4 of 6) of receivers within this area were above the 75th percentile in detections/receiver-day (47) and number of fish detected (10; Table 2-3). Although all receivers detected tripletail, only 1 of 3 of receivers located in the South Channel and only 1 of 9 of receivers at upriver locations detected more than 10 individual fish. Receiver and month influenced mean daily detections in 2010, and the interaction of these two factors was significant (Figure 2-8; Table 2-4). Subsequent analyses revealed that significantly more (F₃=9.67-13.43, p<0.001) mean daily detections were recorded in channel habitats than those located in other areas during late summer and early fall (August -October). Monthly differences in mean daily detections were observed for receivers located within the inner and outer Sound (F₅ = 2.43-3.38, p<0.049), indicating that estuarine habitat use varied seasonally (Figure 2-8); the SNK test revealed that significantly fewer mean daily detections were recorded in summer (June and July) than fall (November) at channel habitats within the inner and outer Sound. In contrast, the number of mean daily detections was higher in June than in November for habitats located away from the
channel. A greater percentage of fish days also were spent at locations near channel habitats (COS 5, CIS 6, CIS 9) than those away from channel habitats (IS 8; $F_{3,187} = 15.66, p<0.001$). The effect of month on the percentage of fish days spent at a station was also significant ($F_{5,187} = 2.67, p=0.023$); individuals spent fewer fish days in all habitats monitored by the acoustic array during early summer than in late summer and early fall. In general, data from the fixed areas showed that habitat use of transmittered fish gradually shifted from inner sound habitats (IS 8, CIS 9) during the early summer, to outer sound habitats (COS 5, CIS 6) in the later summer and fall.

In 2011, monthly differences in mean daily detections and mean percentage of fish days at channel habitats within the inner and outer Sound were evaluated to further evaluate potential changes in seasonal habitat use of these areas during the period of estuarine residence. Mean daily detections were not significantly different during any month in the outer Sound ($H=4.17, df=3, p=0.244$) or inner Sound ($H=4.37, df=6, p=0.626$), nor were monthly differences in the mean percentage of fish days at these locations ($H=4.33, df=3, p=0.228$ and $H=6.18, df=6, p=0.403$, respectively). As was the case in 2010, graphs of mean daily detections and mean percentage of fish days spent in the OS during 2011 revealed a general trend of reduced habitat use in the lower OSE during June, July, and August and gradually increasing use from September to October (Figure 2-9). Scatter plots of detections of individual fish showed a variable pattern of space use within the OSE. Several fish (#397, #404, #572) exhibited brief periods of absence (or near absence) from the OS during July and August, followed by a return to the inner Sound or upriver habitats during late August and September (Appendix B). For example, in 2011, fish #572 was frequently detected in the inner sound during April and
May, but by late June had moved out past the mouth of OS. This fish did not to return until late August when it was again detected at receivers in both the inner and outer Sound. Interestingly, some individuals frequently used upriver habitats throughout their period of OSE residence (#392, #393, #400), while others (#395 and #397) only used these areas seasonally, gradually moving from OS upriver through the South Channel in the early fall—a total distance of approximately 33 km.

Active tracking revealed that 44% of the transmitted fish exhibited strong fidelity for specific structures at some point during their estuarine residence within the OSE. Of the 7 individuals that exhibited this behavior, five were commonly located just outside the mouth of OS under a single navigational buoy in either the North Channel or South Channel. These fish were located outside the range of the receiver array and were only detected by the stationary receivers when they moved into OS on the flood tide. Likewise, the remaining fish (n=2) were found almost daily, beneath a large channel marker within the estuary. Active tracking, however, showed that these fish would regularly leave the structure on either an ebb or flood tide, only to return again at the end of the tidal cycle. Four of the seven (57%) fish that exhibited site fidelity to specific structures were frequently detected at the same structure where they were initially captured. When fish were not observed at fixed structures, they were typically observed moving with the current along the edge of the river channel, but occasionally, they were also detected over shallow sandbars, near flooded marsh, and even within small tidal creeks.
Discussion

The results of this study provide new information regarding the behavior, seasonal movements, and estuarine habitat use of tripletail in Coastal Georgia. The high degree of residence observed for tripletail within the OSE indicates that estuarine habitats are essential for this seasonally abundant and popular sportfish. Sustained summer residence was typical for most individuals, and although most fish went undetected at some point during the study, these gaps in detection usually spanned only 1-3 days. Although these detection gaps could have resulted from environmental fluctuations that affected the detection range of our receivers, a more probable explanation is that the fish simply left the Sound intermittently. This inference was supported by data from active tracking that documented movements of fish as they either left the Sound and took up new positions at fixed structures located at the periphery or just outside of OS. Consequently, we suspect that the actual estuarine residence time of tripletail documented in this study, may have been higher than what we observed. Although seasonal patterns of estuarine residence were consistent regardless of fish size, most of the fish in our study were obviously mature adults (based on total length). Like most other migratory fishes, tripletail life history is probably comprised of several ontogenetic shifts in habitat use. Because demographic rates, and ultimately population productivity, are almost certainly affected by growth and survival at each of these different life stages, future studies should focus on the specific habitat needs of each discrete life stage.

The seasonal occurrence of tripletail within the OSE confirms the migratory nature of the species as previously reported by Merriner and Foster (1974). Timing of tagging precluded any quantified calculation of initiation of estuarine residence for most
tripletail in our study; however, two individuals tagged in 2010, and three individuals tagged in 2011, did return to the OSE in following years. Eighty percent of these arrivals occurred in late March or early April, when water temperatures reached 21°C. Likewise, most fish left the estuary in fall, as water temperatures dropped to 21°C, suggesting that water temperature may be an important proximate cue influencing both the timing and duration of estuarine residence. Although not previously reported for tripletail, similar migratory patterns have been documented for several other estuarine dependent fishes, including striped bass (*Morone saxatilis*; Able and Grothues 2007), tautog (*Tautoga onitis*; Cooper 1966), and Chinook salmon (*Oncorhynchus tshawytscha*; Keefer et al. 2008).

Tripletail were detected as often or more often then expected from dusk until mid-day and less than expected between mid-day and dusk. The trend of increased detection at night and decreased detection from mid-day until dusk suggests that tripletail may be more active at night; however, this inference should be regarded with some caution because variation in receiver detection has also been shown to follow a similar diel pattern (Heupel et al. 2008; Payne et al. 2010). Nonetheless, telemetry data from continuous tracking also showed that tripletail were especially active at night. Because diel activity patterns have not been previously reported for tripletail, I suggest that future studies employ the use of sentinel tags (Payne et al. 2010) to account for any potential diel variation in receiver detection ranges.

Tide height was likely an important factor influencing tripletail habitat use in our study. Data from stationary receivers showed that fish movements were not random, but rather, displayed a pattern that appeared to be influenced by current velocity and tide
height. Increased detections at higher tidal stages also suggested that some transmittered fish tended to visit certain areas at specific tide stages—further evidence that habitat use was dependent on daily tidal fluctuations. Some receivers recorded more detections during mid-tide heights and fewer detections during high or low tides, suggesting that fish moved past these locations during mid-tide stages. Other receivers, including those in riverine marsh habitats above OS, recorded very few detections at low tide heights but many detections during high tides, indicating that the fish only visited these areas during flood tides. These findings were further corroborated by the Lomb-Scargle periodograms, which indicated a dominant 12.4-hr periodicity (the precise duration of the normal tidal cycle) in the daily movements of most transmittered fish.

Previous research has shown that fine scale movements and habitat use of many other marine fishes are largely influenced by tidal stage. Young-of-the-year summer flounder (*Paralichthys dentatus*), for example, use tidal currents to move in and out of small tidal creeks to feed and potentially conserve energy (Rountree and Able 1992; Szedlmayer and Able 1993). Sandbar sharks (*Carcharhinus plumbeus*) in a summer nursery area in Virginia also moved into the estuary with the incoming tide and left the estuary with the outgoing tide (Conrath and Musick 2010). In our study, data from continuous tracking revealed that transmittered tripletail frequently drifted with the moving tide, sometime covering up to 12 km in a single tidal cycle. In addition to the potential energetic benefits of this behavior, this pattern of passive movement also allowed the animals to maintain themselves within a relative narrow range of salinities throughout the tidal cycle. Because osmoregulation in fishes may consume 10-50% of the total energy budget (Boeuf and Payan 2001), passive movements may allow tripletail to
forage over large areas within an estuary with minimal energetic expenditures. Although further studies of tripletail bioenergetics are needed to corroborate these inferences, the passive movement patterns observed in this study may help explain the rapid growth rates of tripletail previously documented by other researchers (Merriner and Foster 1974; Franks et al. 2001; Parr 2011). Still, some of the transmitted fish that we observed did not always move with tidal currents, but instead remained under fixed structures throughout the tidal cycle. In these instances, however, the structures used were always located within the OS, where the range of salinities observed was relatively narrow (30.7-35.2 ppt). These observations suggest that other environmental factors may also affect daily movements and habitat use during the period of estuarine residence.

Despite the variations in array configuration and receiver detection previously mentioned, our results suggested that in both years of the study, tripletail spent most of their time in the lower part of the OSE, particularly within the 8.5-km stretch of the North Channel just inshore of the mouth of OS. Although daily movements of the fish were more extensive than expected, the fish spent less time in the South Channel or upriver sites where previous studies have shown that salinities are typically lower and more variable (Wenner et al. 2005).

Variation in habitat use by transmitted individuals may explain why a more distinct shift in space use not evident in our study. For example, some fish were detected at the upriver receivers for the entire duration of their estuarine residence, while others moved from the inner to outer Sound in the early or mid summer and then returned to the inner Sound in the late summer and fall. Seven individuals showed strong site fidelity to specific fixed structures; four were detected almost daily at their capture site. Movements
to and from these structures occurred almost daily suggesting that this pattern of movement from a “home structure” may be a typical behavior pattern for at least some individuals within the population. During these movements, tripletail seemed to be transported by the tidal currents and followed the edge of the channel where they occasionally crossed over shallower sandbars. When fish moved to upriver sites, they often stayed close to the marsh grass, sometimes entering small tidal creeks. Other estuarine fish including the red drum (*Sciaenops ocellatus*) have been observed to move up rivers and onto the flooding marsh for feeding purposes (Collins et al. 2002). Future studies of tripletail foraging ecology might provide new insights regarding the purpose of the intra-estuarine movements observed in our study.

Although our data do not provide any direct evidence of spawning movements, several of the transmittered tripletail in our study left the OS. Active tracking was successful in locating these individuals and revealed that these fish established residence beneath channel markers just outside the mouth of the Sound. Because these movements occurred in summer – the known spawning period for the species (Ditty and Shaw 1994) – we suspect that these fish probably spawned somewhere in the nearshore (within 10 km) marine habitat. Interestingly, previous studies of tripletail reproductive biology have reported low incidences of reproductively active fish in inshore habitats (Cooper 2002; Parr 2011). Because these authors also used angling to obtain their samples, they hypothesized that spawning fish may not actively feed. Regardless, the extensive use of estuarine habitats during the summer months could make spawning adults particularly vulnerable to anglers. Confirmation of tripletail spawning within or near OS should be
investigated using a more expansive acoustic array in combination with regimented ichthyoplankton sampling protocol in both areas during the late summer months.

Understanding the dynamics of tripletail stock structure has other important implications for fisheries management. For example, if fidelity to specific regions or estuaries is higher than previously thought, over exploitation could result—at least in some localized areas. In our study, only four transmittered fish (14%) were captured by anglers, suggesting that the current exploitation rate of the OSE population is sustainable. Data regarding total annual mortality are lacking for the OSE as well as most other exploited populations in part because of the migratory nature of the species. Results for this study suggest that tripletail exhibit a high degree of estuarine fidelity with little mixing of populations from April to October; however, population dynamics and winter movements remain poorly understood. Future studies are needed to better understand the species potentially complex stock structure and to provide quantitative data on population dynamics to ensure effective management of increasingly popular recreational fisheries for tripletail within the South Atlantic Bight.
References


reserves may increase escapement of red drum. Fisheries 27: 20–24.


Table 2-1. Summary information for all 32 tripletail monitored within the Ossabaw Sound Estuary, Georgia between June 2010 and October 2011. TL=total length; DD=days detected; DDa¢t=days detected including active telemetry; TFD=total fish days; IR=individual residence; IRa¢t=individual residence including active telemetry. The three shaded rows indicate fish that were excluded from analyses.

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<th>DD (d)</th>
<th>DDa¢t (d)</th>
<th>TFD (d)</th>
<th>IR (%)</th>
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Table 2-2. Results of Lomb-Scargle periodogram analyses performed on hourly detection data for tripletail monitored within the Ossabaw Sound Estuary, Georgia between June 2010 and October 2011. Primary peak represents dominant periodicity (h) in movement pattern. Secondary peak represents any subordinate patterns that were detected.

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Table 2-3. Receiver days, total detections, detections per receiver day, and number of fish detected at receivers deployed within the Ossabaw Sound Estuary between June 2010 and October 2011. Receiver habitat codes: COS=channel outer sound; OS=outer sound; CIS=channel inner sound; IS=inner sound; URM=upriver marsh. Number after habitat coding is receiver rank from closest to mouth of sound (1) to farthest upriver (18). RKM is river kilometer of receiver location. Receiver days are the number of days within monitoring period. When two numbers are present in fish detected column, numbers indicate number of fish detected in 2010 and 2011, respectively.

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<th>Total Detections</th>
<th>Detects/Receiver Day</th>
<th>Fish Detected</th>
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Table 2-4. Results of a two-way ANOVA on mean daily detections recorded for tripletail monitored within the Ossabaw Sound Estuary, Georgia in 2010. Bold numbering denotes statistical significance at $\alpha = 0.05$.

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Figure 2-1. Map of the Ossabaw Sound Estuary in Georgia. Individual receiver locations are indicated by the black circles, while the dashed line represents the 6-m depth contour.
Figure 2-2. Abacus plots depicting daily residence (gray shading) and angler recaptures (x) of individual tripletail within the Ossabaw Sound Estuary, Georgia in a) 2010 and b) 2011.
Figure 2-3. Proportion of tripletail resident per day (gray shading), number of tripletail tagged (dashed black line), and mean daily water temperature (solid blue line) within the Ossabaw Sound Estuary, Georgia in a) 2010 and b) 2011.
Figure 2-4. Total detections per hourly bin (00:00 = 00:00 – 00:59; 01:00 = 01:00 – 01:59, etc.) recorded from tripletail monitored within the Ossabaw Sound Estuary between June 2010 and October 2011. Solid black line represents the expected distribution of equal hourly detections.
Figure 2-5. Number of detections recorded per tide height bin for tripletail monitored within the Ossabaw Sound Estuary, Georgia at a) CIS 6, an inner Ossabaw Sound receiver, b) COS 5, an outer Ossabaw Sound receiver, and c) URM 14, an upriver receiver. Tide height bins: -0.499 = -0.499 to -0.300 m). Solid black line denotes the expected number of detections based on proportion of tides observed within each bin.
Figure 2-6. Lomb-Scargle (L-S) periodogram of 4,583 hrs of detection data recorded for tripletail (n=17) monitored between 04/17/11 and 10/24/11 within the Ossabaw Sound Estuary, Georgia. Peak L-S magnitude occurred at 12.4 hours, corresponding to the length of tidal cycle.
Figure 2-7. Continuous track of fish #405 displaying tidal movement typical of all tripletail monitored within the Ossabaw Sound Estuary, Georgia (a). Sequential fish locations (white circles) and corresponding time and salinity are indicated. Tide height associated with each location is displayed on the graph of tide height (b).
Figure 2-8. Mean daily detections and mean percentage of fish days at each of the receivers that monitored the Ossabaw Sound Estuary in 2010. Receivers are ordered from closest to the mouth of Ossabaw Sound (COS 5) to furthest upriver (CIS 9). Bars represent monthly values. Error bars represent ± 1 SE. Monthly means with different letters indicate statistical significance at $\alpha = 0.05$. ** Indicates statistically different receiver mean at $\alpha = 0.05$. Note: Statistical test was performed on the ranked data.
Figure 2-9. Mean proportion of fish days detected and mean daily detections at receivers COS 3 (a, c) and CIS 6 (b, d) within the Ossabaw Sound Estuary in 2011. Error bars represent ± 1 SE. April and May values at OS 12 were the result of one return fish (#572).
CHAPTER 3
CONCLUSIONS

My study provides new information regarding residency of tripletail in Georgia’s marine waters and demonstrates that estuarine habitat use is an important component of tripletail life history. Tripletail are resident within the Ossabaw Sound Estuary (OSE) as early as late-March and thereafter remain until water temperatures decline to about 21°C in late October or early November. The combination of passive and active tracking methods used in my study revealed that estuarine residence was nearly continuous throughout the summer months. Active tracking also showed that tripletail used tidal currents during their daily movements to traverse a large portion of the OSE. Although further studies of tripletail ecology are needed, my data suggest that the tidally influenced movements of tripletail that I observed probably help the fish reduce energy demands associated with both active swimming and osmoregulation. Given their extremely rapid growth rates, these findings may provide key insights into the life history and ecology of the species.

Only two of the transmitted fish were caught by anglers in each year of the study, which suggests that fishing mortality in the OSE is probably not currently excessive; however, harvest rates during the late fall and winter months are unknown. The strong site fidelity observed in the OSE suggests that little mixing of fish occurs between estuaries between April and October; however, mixing may occur during fall or
spring migrations as return rates were relatively low. Further studies are needed to better understand how population dynamics and genetic mixing affect the sustainability of current recreational fisheries in Georgia waters.

Understanding the dynamics of tripletail stock structure has important implications for fisheries management. For example, if fidelity to specific regions or estuaries is strong, localized exploitation could lead to localized population suppression and thus require localized management. Furthermore, current information suggests that tripletail spawn offshore (Ditty and Shaw 1994; Brown-Peterson and Franks 2001; Cooper 2002; Parr 2011); however, fish in this study remained inshore throughout the summer spawning season. Most of the tripletail monitored in this study were larger than the minimum legal size limit (457 cm). If these estuarine residents were not spawning, they probably were vulnerable to harvest before they had spawned—a situation that could lead to rapid overexploitation if the popularity of the fishery continues to grow.

Consequently, I suggest that identification of the spawning stock should be the highest research/management priority. Although harvest rates of the estuarine population appeared to be relatively low (14%), the migratory nature of the species (Merriner and Foster 1974) makes estimation of annual mortality rates difficult. Effective fisheries management will require an understanding of how fishing effort and mortality are distributed (Grimes et al. 1987). Future studies focusing on population dynamics and winter movements are needed to better understand the potentially complex structure of tripletail stocks.
References


Appendix A. Detection Scatter Plots 2010.

This section contains the time-series of detections coded by receiver location for individual tripletail monitored within the Ossabaw Sound Estuary, Georgia, in 2010. Legend symbols below x-axis indicate receiver locations, which are arranged from outermost to farthest upriver. Sixteen scatter plots are included in this section, as tripletail #577 was never detected.

Scatter plots included in this section (16 pp, 1 scatter plot per page):

Fish #565
Fish #566
Fish #567
Fish #568
Fish #569
Fish #570
Fish #571
Fish #572
Fish #573
Fish #574
Fish #575
Fish #576
Fish #578
Fish #579
Fish #895
Fish #898
Fish #565

Date


Time of Day

00:00 04:00 08:00 12:00 16:00 20:00

COS 5 CIS 6 IS 8 CIS 9
Fish #568

Date

Time of Day

24-Jun 1-Jul 8-Jul 15-Jul 22-Jul 29-Jul

COS 5  CIS 6  IS 8  CIS 9
Fish #569
Fish #572

[Graph showing data with legend: COS 5, CIS 6, IS 8, CIS 9]
Appendix B. Detection Scatter Plots 2011.

This section contains the time-series of detections coded by receiver location for individual tripletail monitored within the Ossabaw Sound Estuary, Georgia, in 2011. Legend symbols below x-axis indicate receiver locations, which are arranged from outermost to farthest upriver. Seventeen scatter plots are included in this section.

Scatter plots included in this section (17 pp, 1 scatter plot per page):

Fish #392
Fish #393
Fish #394
Fish #395
Fish #396
Fish #397
Fish #398
Fish #399
Fish #400
Fish #401
Fish #402
Fish #403
Fish #404
Fish #405
Fish #406
Fish #572
Fish #573
Fish #392

Date

Time of Day

5-Jun  20-Jun  5-Jul  20-Jul  4-Aug  19-Aug

COS 3  CIS 6  IS 8  CIS 9  URM 11  URM 12  URM 13  URM 14
Fish #403

Date

Time of Day

COS 4  CIS 7  IS 8  CIS 9  URM 11
Fish #406
Fish #572

![Graph showing data points over time and date]