SITE FIDELITY, HOME RANGE, AND DAILY MOVEMENTS OF WHITE PERCH, 
MORONE AMERICANA, AND STRIPED BASS, MORONE SAXATILIS, IN TWO 
SMALL TRIBUTARIES OF THE YORK RIVER, VIRGINIA

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Master of Science

by
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APPROVAL SHEET

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Striped bass (*Morone saxatilis*) and white perch (*M. americana*) are two common species residing within Chesapeake Bay and its tributaries. These congeners are both commercially and recreationally important species. White perch are permanent residents in the Bay, while striped bass are only residents during the first few years of their life. During these initial years, striped bass co-occur with white perch. There is very little known about white perch and resident striped bass site fidelity and home range. This acoustic tagging study aims to examine site fidelity and home range of both species and determine if there is any spatial competition between these congeners.

Sixteen white perch and sixteen striped bass residing in two small tributaries of the York River were utilized for this experiment. White perch exhibited a high degree of site fidelity along with a small home range. The minimum convex polygon (MCP) and minimum stream polygon (MSP) methods were utilized to measure home range size. The average MCP/MSP was 0.114 km$^2$. Kernel densities were also examined to understand their utilization distribution within their home range. The output contours considered were the 95% contour (total home range) and the 50% contour (core area of activity). The kernel method areas were 0.0128 km$^2$ and 0.0021 km$^2$, respectively. White perch, in the Poropotank River, typically had two core areas of activity which often correlated to the tidal stage. They were often found during high tide upon the flooded marsh or up in shallow creeks and in the relatively deep main channels during low tide. However, white perch in the Queen Creek only had one core area of activity and they were always associated with submerged structure. White perch did not show any movement with sudden changes in salinity and/or temperature resulting from tropical depressions or Hurricane Isabel. They also did not display any change in behavior associated with episodic hypoxia within the creeks.

Striped bass did not exhibit a high degree of site fidelity. In the Poropotank River, 58% of the striped bass displayed site fidelity, while zero striped bass exhibited it in Queen Creek. Local hypoxia events could explain the lack of site fidelity within Queen Creek. The home range data might be under-estimated due to the inability to track in the York River. The average MCP/MSP was 0.36 km$^2$ and the average 95% and 50% kernel densities were 0.02 km$^2$ and 0.002 km$^2$, respectively. Only two striped bass displayed a tidal interaction, utilizing the slack high water to flood up upon marsh corners or sandy beaches. Two other striped bass also displayed a lunar periodicity. Both fish would enter and leave the Poropotank River during the days surrounding new and full moons. Striped bass also did not display any change in behavior associated with sudden changes in temperature and/or salinity due to tropical depressions or Hurricane Isabel.

There was very little space competition between these two congeners. White perch occupied 8.5% of the striped bass overall home range. The spatial overlap did increase when only core areas were examined. The two species shared a common core area in a small rivulet of the Poropotank River. This common core area was one third of the striped bass cumulative core area. Nevertheless, there very little evidence of spatial competition or resource partitioning between white perch and striped bass.
SITE FIDELITY, HOME RANGE, AND DAILY MOVEMENTS OF WHITE PERCH, *MORONE AMERICANA*, AND STRIPED BASS, *MORONE SAXATILIS*, IN TWO SMALL TRIBUTARIES OF THE YORK RIVER, VIRGINIA
Introduction

Life History

Striped bass (*Morone saxatilis*) and white perch (*Morone americana*) are both important commercial and recreational species in Chesapeake Bay and its tributaries. Historically, striped bass occurred in high abundance, but their numbers drastically declined until the 1980’s. In 1981, the Atlantic States Marine Fisheries Commission (ASMFC) developed an interstate management plan for striped bass (Collette and Klein-MacPhee 2002). The plan was adopted by the Virginia Marine Resource Commission (VMRC) in March 1982 and was eventually adopted by all states from Maine to North Carolina. In 1984, Congress passed the Atlantic Striped Bass Conservation Act which mandated each state must adhere to all provisions in the interstate fisheries management plan (Austin et al. 2004). Since then, the striped bass stock has made a notable recovery and in 1995 was declared fully recovered.

White perch have also occurred in large numbers and have experienced declines in population biomass. Annual estimates of young-of-the-year abundance have closely mirrored those of striped bass. Their decline has been attributed to loss of habitat, fish kills due to low oxygen levels, and over-fishing (St. Pierre and Davis 1972; St. Pierre and Hoagman 1975). Nevertheless, numbers of white perch are still abundant enough to not warrant a fisheries management plan.
Striped bass and white perch share a similar life history strategy. The congeners have extremely similar mating habits and early life niches. Striped bass are anadromous fish, residing in coastal marine waters and utilizing tidal fresh waters to spawn. White perch on the other hand are semi-anadromous, using tidal fresh water to spawn, but residing in mesohaline river water rather than coastal marine.

Chesapeake Bay and its tributaries are the major spawning areas for white perch and striped bass on the east coast (Merriman 1941; Raney 1957; Able and Fahay 1998). Their spawning season is primarily in April when water temperatures reach approximately 16°C in the tidal freshwater regions of the rivers. The eggs hatch a few days after being spawned and fertilized. The larvae then begin to slowly advect down river. The larvae of the two species feed upon zooplankton. Limburg et al. (1997) found that white perch and striped bass larvae in the Hudson River prey mostly upon cladocerans and copepods.

Juvenile white perch and striped bass continue to slowly move downstream into brackish water throughout the summer. They are first collected in the Virginia juvenile striped bass seine surveys in early July (Austin et al. 2004). They often reside on sandy bottoms, but can also be found deep in the main channel and upon muddy banks (Boynton et al. 1981). The juvenile stage of the congeners also shares similar prey items. Ruderhausen and Loesch (2001) reported that juveniles of both species prey opportunistically upon planktonic and epibenthic prey items. Their prey shifts from planktonic to epibenthic with increasing length. Striped bass also begin to feed upon fish during their juvenile stage.
White perch remain in the estuarine portion of the river often residing in the same river system their entire life (Mansueti 1957; Bowen 1987; Kraus and Secor 2004). Striped bass are thought to reside in the estuary until approximately age four at which point they begin their coastal migrations (Dorazio et al. 1994). The diet of these two congeners begins to diversify and separate during these years at which time white perch and striped bass both begin to feed more heavily upon polychaetes and crustaceans. Striped bass, however, begin to feed more extensively on other teleosts. White perch do not begin to feed upon other fish until they are approximately 200 millimeters and even then it is a smaller portion of their diet.

**Movement Studies**

Many acoustic tagging studies have concentrated on the spawning migrations or annual migrations, very few studies have examined the daily movement patterns of striped bass or white perch in a river or bay system (Carmichael et al. 1998; Bjorgo et al. 2000; Jackson and Hightower 2001). Striped bass tagging studies are far more numerous than white perch tagging studies. This is due to the larger monetary value and larger migrations undertaken by adult striped bass. White perch undergo a spawning migration, but its distance is far less than the distance traveled by striped bass.

Striped bass migrations have been known to occur strictly upstream and downstream in one river (Dudley et al. 1977) or transverse many states from Chesapeake Bay to the Hudson River (Merriman 1941). It is hypothesized that striped bass populations south of Virginia do not undergo a coastal migration. Acoustic tagging studies that have occurred on the Roanoke River, Combahee River, and Savannah River
show that southern striped bass populations reside mostly, if not strictly, in their natal river system. Striped bass that spawn in the Roanoke River were found to reside in Albemarle Sound during the summer and rarely entered the coastal waters even when temperature conditions deteriorated severely (Haesaker et al. 1996). In Georgia and South Carolina, striped bass have been observed to move upstream after their spawning run. This is due to the upstream water often being at least 5 °C cooler than the lower sections of the rivers. They utilize this thermal refuge for the duration of the summer until river temperatures begin to decrease in the fall (Dudley et al. 1977; Coutant 1985; Bjorgo et al. 2000).

Populations of striped bass from Chesapeake Bay to New England migrate much greater distances than their southern counterpart. They have often been tagged in winter and early spring in Chesapeake Bay and then caught in the summer in the Mid-Atlantic up to New England (Massman and Pacheco 1961). Striped bass, after their spawning run, travel northward seeking cooler water to reside in for the summer months. In the fall, they migrate back to the south to over-winter in warmer water (Kohlenstein 1981; Boreman and Lewis 1987; Dorazio et al. 1994). It has been hypothesized that striped bass off of Long Island may use bottom water currents during their northward spring migration and surface currents during their fall southward migration (Hickey 1981).

The Saint Lawrence estuary is the northern extreme of the striped bass’s range. Striped bass residing within this estuary do not participate in the migration southward in the fall. Instead, they migrate upstream to overwinter in the lakes and move downstream in the spring to spawn (Rulifson et al. 1987). Rulifson et al. (1987) also described some individuals spawning during the fall in the Saint Lawrence estuary.
Seasonal spatial distributions of striped bass seem to be dominated by temperature and dissolved oxygen. The thermal niche of striped bass is described to be between 19-23 °C for adults and as high as 28°C for juveniles and sub-adults (Coutant 1985). Temperatures above this optimal range will elevate metabolic rates and increase dissolved oxygen demand. Dissolved oxygen levels below 6 mg/L can lower fish production, while concentrations lower that 2-3 mg/L are physiologically critical for the metabolism of most fishes (Coutant 1985; Chapman 1986). Striped bass in the Combahee River, South Carolina and in some fresh water lakes in Tennessee were all recorded moving with temperature fluctuations. The fish remained in water temperature generally between 20 and 25 °C (Bjorgo et al. 2000; Coutant and Carroll 1980). Striped bass tagged in the Savannah River during the late autumn and winter were actively tracked to examine movement patterns. They showed no general movement pattern and were typically never found more than a few meters from were they were tagged (Dudley et al. 1977).

Adult striped bass in the J. Strom Thurmond Reservoir, South Carolina-Georgia were found to have high site fidelity in their summering and wintering areas. These striped bass also avoided temperatures above 25.1 °C and dissolved oxygen concentrations less than 2.3 mg/L (Young and Isely 2002). Haesekar et al. (1996) found striped bass within Albemarle Sound, North Carolina resided in waters well above suitable temperature levels, but always remained in water with suitable dissolved oxygen levels. Tupper and Able (2000) ultrasonically tracked adult striped bass daily during the summer and reported that striped bass move against the tidal flow in Delaware Bay marsh creeks.
They also found striped bass to avoid upper reaches of creeks with low dissolved oxygen concentrations.

Historically, studies have overlooked the period before age-3, when striped bass are immature and presumed to reside in the rivers and estuaries year round. There is little known about striped bass at this age, specifically, their behavioral interactions with tide, their residency, or site fidelity. This could be a critical time in their life history. If striped bass have high site fidelity this may make them more susceptible to disturbances and habitat destruction. A small home range may also dictate their diets and therefore, striped bass diets may differ depending upon location.

Secor and Piccoli (1996) analyzed striped bass in the Hudson River by chemical microanalysis of their otoliths. They found that age-2 and age-3 striped bass (immature) spend a majority of their time in mesohaline water. They also noted that striped bass that were caught in the same location at the same time had the exact same otolith microchemistry. This implies that they resided together from the time they were juveniles. The apparent formation of permanent aggregations within Hudson River striped bass might be used as evidence for Clark’s contingent hypothesis (Clark 1968; Secor 1999). Clark’s (1968) contingents hypothesis states that striped bass in a system (e. g. the Hudson River) form two groups or contingents, a coastal migratory group and a riverine group, in order to ensure survival in case adverse conditions affect one of the contingents. Secor (1999) observed three spatially discrete cohorts of Hudson River striped bass; a resident group, a lower estuary group, and a coastal migratory group. The behavior patterns described by the otolith microchemistry persisted throughout the lives of juveniles and adults.
The formation of different striped bass contingents is theorized to be an ecological mechanism to ensure survival (Clark 1968). The larger an area a species can claim the less chance it has of collapsing due to a localized event. However, over time this spreading out of the population begins to form distinct groups and eventually contingents. Another way to look at it is the difference between “retentive” and “exploratory” behavior (Secor 1999). Some striped bass remain relatively close to their spawning grounds, while others venture off and explore new territory. Exploratory striped bass may increase their fitness by finding more productive feeding grounds or areas with better environmental conditions. If the pattern observed in Hudson River striped bass also occurs in immature Chesapeake Bay striped bass then one might hypothesize that contingents remain in the rivers and tidal marshes and the other groups occupy the open water of the Bay. This could possibly affect models that incorporate diet data. The diet of a striped bass residing in the Bay will not be representative of the diet of a striped bass utilizing marsh creeks.

The contingent hypothesis may also explain aspects of white perch behavior. Kraus and Secor (2004) utilized otolith microchemistry to examine the dynamics of spatially structured populations. They observed that juvenile white perch either reside strictly in brackish water or in tidal fresh water. This choice affected their growth rate and population size; the brackish contingent grew faster and was more abundant during high juvenile abundance years, while the tidally fresh water contingent grew slower and was disproportionately greater in numbers during low juvenile abundance years. The researchers hypothesized that the brackish contingent is important for maintaining abundance and high productivity, while the fresh water contingent sustains a small but
crucial reproductive segment of the population. Kraus and Secor (2004) could not extend their hypothesis further than the juvenile stage of white perch and a further look into adult movements would provide information on whether or not the contingents remain after the juvenile stage.

Tagging studies have only used conventional tags to record the range of white perch. Mansuetti (1957) tagged over three thousand white perch in the Patuxent Estuary, Maryland. He concluded that white perch rarely move outside the river system they inhabit. White perch residing in the Bay of Quinte in Lake Ontario, Canada were found to make no long range movements and almost half of the recaptured fish were caught at the tagging site (Sheri 1972). White perch were also tagged in the Connecticut River and one third of the recaptures were at the tagging site. This study did, however, find white perch to move further and occasionally out of the river system into the Long Island Sound (Maltezos et al. 1980).

A morphometric study of white perch supported this claim and found significantly different subpopulations in other tributaries and areas of Chesapeake Bay (Woolcott 1962). Two different mitochondrial DNA analyses of Chesapeake Bay white perch also concurred with the meristic and tagging experiments. Bowen (1987) analyzed white perch from the Potomac, Rappahannock, York, and James River and found three out of the four tributaries contained at least one unique haplotype at fixed differences. The York River population did not display a unique haplotype. The mitochondrial DNA analyses performed by Mulligan and Chapman (1989) demonstrated three separate populations within the Bay and its tributaries, a James and York River population, a Potomac population, and a population that includes the Patuxent and every tributary north
of it. It is hypothesized that a salinity barrier at the mouths of the rivers creates these distinct populations.

Local movements of white perch have not been extensively studied. They have been observed to make long, broad spring movements from the lower or mid-estuary to upstream tidal fresh water for spawning. Summer movements and early fall movements have been shown to be random and localized. During fall and winter, white perch usually move to deep water and do not migrate back until the spring (Mansuetti 1957). These small home ranges and relatively restricted movements mean white perch are more susceptible to fish kills or habitat destruction (St. Pierre and Hoagman 1975). Unfortunately, conventional tag-recapture methods provide limited data on location and site fidelity or a home range can not be calculated. An acoustic tagging study would aid in describing home range and site fidelity for these species.

Analysis of Home Range

Understanding an animal’s spatial dynamics is essential in evaluating the ecological processes that affect the animal. Home range, site fidelity, and utilization distribution are all important pieces needed to fully comprehend an animal’s diet, mating behavior, and other aspects of their life history. The most commonly cited definition of home range is, “that area traversed by the individual in its normal activities of food gathering, mating, and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as in part of the home range” (Burt 1943). Recently, many scientists have begun to define home range further and have developed a term known as utilization distribution. Utilization distribution is based upon the bivariate
probability density function that gives the probability of finding an animal at a particular
location on a plane. Thus, it is a probabilistic model of home range that describes the
relative amount of time that an animal spends in any place within its home range (Jenrich
and Turner 1969; Anderson 1982; Worton 1989; Seaman and Powell 1996; Vokoun
2003).

Home range has biological meaning only when the assumptions of the individual
home range model are met and the limitations understood. An animal must exhibit site
fidelity for a home range to exist. Site fidelity exists when the area that an individual
utilizes is smaller than the area used if an individual’s movement was random (Danielson
and Swihart 1987; Spencer et al. 1990). Hooge et al. (2001) created an extension of the
Monte Carlo random walk test (developed by Spencer et al. 1990) to use the actual
sequence of distances traveled by the animal during each time interval to generate a user-
specified number of random walks. Their program (Animal Movement Analyst
Extension) then calculates for each walk both the mean squared distance from the center
of activity and the linearity of the path. These values measure data dispersion and
directed movement, respectively. The actual movement path is compared to the random
walks to determine if there is any significance. Animals exhibiting site fidelity should
exhibit neither significant dispersion nor significant linearity.

A home range can be quantified once site fidelity has been established. There are
many different methods to determine home range, from the most basic methods to
complicated probabilistic techniques. The simplest home range method is the minimum
convex polygon (MCP) method. MCP simply connects the points located on the outside
of an animal’s home range. This method is subject to sample size and is greatly affected by outliers (Mohr 1947, Hooge et al. 2001).

The Jenrich-Turner home range is another quick and simple method. It is an algorithm that assumes the data follow a bivariate normal distribution. However, this is not always followed by animals in the wild (Jenrich and Turner 1969). This method, like MCP, is chiefly useful for comparison with older studies.

The harmonic mean method describes the intensity of use of the home range. This technique is useful in determining animal activity centers. The activity area is related directly to the frequency of occurrence of an individual within its home range (Dixon and Chapman 1980). Unfortunately, the method does not produce a probability density leaving researchers with a limited probabilistic interpretation (Worton 1989).

One of the most robust home range techniques is the kernel home range method. Kernel methods free the utilization density estimate from parametric assumptions and provide a means of smoothing locational data to make more efficient use of them than a histogram (Silverman 1986). Kernel methods can output utilization distributions and allow scientists to examine not only the home range extent, but core areas of activity as well.

The smoothing parameter is the window width in the kernel method, which allows the user to select the amount of detail within the final product. The fixed kernel method only uses one window width for all of the data points (Worton 1989). The window width can be chosen by a least-squares cross-validation (LSCV) function, reference smoothing function, or an ad hoc value. The LSCV function minimizes the squared distance between the fitted surface and the target surface, integrated over the area (Silverman
The reference smoothing function is based upon the number of locations and the standard deviation of the x coordinates, with the y coordinates transformed throughout the calculations to have the same standard deviation (Worton 1989). The LSCV function is most widely used, however, it has been known to fail at large sample sizes and with animals that have high site fidelity and intensively used core areas (Hemson et al. 2005). The reference smoothing function has often been shown to over smooth the kernel estimate (Worton 1995; Seaman and Powell 1996). The ad hoc value is not a mathematical value, but is defined by the user for the best fit of the data. This method allows for kernels to not overlie on areas impossible for animals to inhabit and a fixed ad hoc value can allow statistical comparisons between individuals. Kernel densities can not be compared if they do not share an equal window width (Silverman 1986).

Vokoun (2003) reasoned that using kernel density estimates for stream fishes has advantages over the traditional practice of reporting linear home ranges as the distance between the most upstream and farthest downstream relocations of an individual fish. This is because kernel density estimates can describe what sections of the stream are important to fishes, instead of only describing the area a fish traversed.

**Surgery**

Biotelemetry has been used to study fish ecology since the 1970’s (Ichihara et al. 1972; Hart and Summerfelt 1975). In those thirty years, there have been many different techniques and tools designed to implant tags. Presently, there is still much debate over what type of anesthesia to use and how to close the wound. Clove oil, MS-222, benzocaine, and quinaldine sulphate are the common anesthetics used during fish
surgeries. All of these drugs induce a loss of equilibrium in fish after approximately three to five minutes (Ortuno et al. 2003). Clove oil and MS-222 are the most widely used anesthetics due to their lack of side effects. MS-222 is the only anesthetic licensed for use on fish for human consumption.

Another point of controversy is how to close the wound after implantation of the tag. Sutures, skin staplers, and glue are the three different methods prevalent in the scientific literature (Swanberg et al. 1999; Wagner et al. 2000; Eristhee et al. 2001). Surgical staples and sutures are the most common methods and each has their own strengths and weaknesses. Sutures are used widely due to their ability to hold a wound tightly together when utilized correctly (Wagner et al. 2000). However, they require a high level of experience and often take a longer time than other methods. Surgical staples are quick and sterile and when compared to sutures they often have less incidence of abdominal bleeding. Other benefits of staples are that they do not loosen and the technique requires less practice to perfect than sutures (Swanberg et al. 1999).

**Objectives**

The objectives of this experiment were to determine the site fidelity, home range, and daily movements of striped bass and white perch residing in two small tributaries of the York River. Habitat and habitat utilization would also be observed for differences between the two species. It was hypothesized that both congeneres would display site fidelity and have similar home ranges. The two species would overlap in space, but utilize the area differently by having opposite tidal interactions. The congeneres would have two overlapping core areas of activity, but utilize them during different times.
White perch would remain in the main channel during slack low water and move up onto the marsh surface during slack high water. Striped bass would move up small creeks during slack low water and remain in the deep channels during slack high water. It was also hypothesized that there would not be a significant difference in home range size or behavior between the two waterways.
METHODS

Location

The locations of the study sites are the lower Poropotank River and Queen Creek, Virginia. Each waterway drains into the York River; the Poropotank River at river kilometer 37 and Queen Creek at river kilometer 21 (Figure 1). Both bodies of water are dominated by marshes with *Spartina alterniflora* and *Spartina cynosuroides* as the prominent vegetation (Silberhorn 1974; Berman et al. 1999). The Poropotank River begins with Poropotank Bay and Morris Bay, both averaging a depth of one meter. Between the two bays are two short stretches of water with an average depth of three meters. The Poropotank River continues to the northeast averaging depths of two meters until the water becomes tidally fresh. The average salinity for the lower Poropotank is approximately 10 ppt. The bottom type is dominated by mud, except for the small stretch of water between the two bays where it is a mix of a live oyster reef, sand, and mud.

Queen Creek begins with a shallow bay and a dredged narrow channel. The river continues in a northwest fashion with an average depth of 2.1 meters until the water becomes tidally fresh. The creek is fed by three reservoirs, the largest of them being Queens Lake. The average salinity for lower Queen Creek is approximately 12 ppt. The sediment type is first dominated by mud, but quickly changes over to a live oyster reef and mud. Queen Creek is also dominated by submerged objects and relict piers. Queen Creek contained significantly more structure than the Poropotank River.

The abundance of certain fauna also differed between the two creeks. Queen
Figure 1. Map of the study sites, Queen Creek and the Poropotank River, and their location on the York River.
Creek had a higher abundance of individuals preferring higher salinities. These species included bay anchovy (Anchoa mitchilli), silver perch (Bairdeilla crysoura), and spadefish (something). The Poropotank River contained a greater abundance of species associated with less saline water. These species included longnose gar (Lepistoseus osseus), juvenile striped bass, and channel catfish (Ictularis punctatis) (McGrath unpublished data). The two waterways have similar salinities; therefore, these species abundance differences are probably a result of their location in the York River. Queen Creek is closer to the mouth of the York River and is more accessible to higher salinity fishes, while the Poropotank River is easier accessed by freshwater and low salinity species.

Tagging

Sampling began in June and ended in September during the summers of 2003 and 2004. Sixteen striped bass and sixteen white perch were caught by tended monofilament gill nets (7.6 cm. mesh) in the Poropotank River and Queen Creek. The gill nets were set for a maximum of twenty minutes. In 2003, eight striped bass and eight white perch (>200 mm fork length) were caught and tagged in the Poropotank River. Each species was implanted with a Sonotronics IBT-96-1 ultrasonic tag. The tag is 25 mm long, 8 mm in diameter, 1.5 grams, and has a lifespan of at least 21 days. In 2004, eight striped bass and eight white perch were tagged in the Poropotank River and Queen Creek. White perch were again tagged with Sonotronics IBT-96-1 tags, but striped bass were tagged with Sonotronics IBT-96-2 tags. The IBT-96-2 tags are 28 mm long, 9.5 mm in diameter, 2.5 grams, and have a lifespan of at least 60 days. The tags were upgraded in 2004.
because the striped bass used for tagging were larger than the white perch and could be implanted with a slightly larger tag. In 2003, two of each species were surgically fitted with an ultrasonic tag each month. In 2004, one striped bass and one white perch were tagged in each waterway every month of the project.

The process of tagging followed the methods in Tupper and Able (2000). In summary, the fish were anesthetized with 120 mg/L of MS-222 until fully sedated. Five rows of scales were removed on the ventral portion of the fish posterior to the pelvic fin. A small lateral incision was made just anterior to the anal fin, the tag was covered in antibiotic cream, inserted inside the abdominal cavity, and then the wound was closed with surgical staples (ReflexOne Surgical Staples). The wound was then covered in antibiotic cream and the fish was allowed to recover for approximately twenty minutes. After the fish recovered from the anesthesia it was released exactly where it was caught.

Tracking

Each fish was actively tracked using a hydrophone, an ultrasonic receiver, and a GPS for the duration of the tag. Tracking consisted of systematically searching an area until a fish was located. After locating a tagged fish, the fish was followed from a small boat using the hydrophone and receiver. At fifteen-minute intervals the following were recorded: the transmitter frequency and pulse interval, time, date, latitude, longitude, water temperature, salinity, and dissolved oxygen. Data collection continued at fifteen-minute intervals for a period of four hours, at which time a new fish was located (Tupper and Able 2000). Multiple fish were recorded at once if the fish were in the same general area. A total of thirty two fish were tagged throughout both summers. The GPS
coordinates were incorporated into the program ArcView® where home range and tidal patterns were analyzed using the ArcView® extensions, Animal Movement Analyst Extension (AMAE) and Spatial Analyst 1.1 extension.

Home Range Analysis

Fish position fixes were incorporated onto digitized site maps. Minimum convex polygons (MCPs) and minimum stream polygons (MSPs) were first utilized to quantify the extent of the area utilized by each fish. Minimum convex polygons are polygons constructed by connecting the outer points of animal’s movements. Although this home range method is one of the simplest and widely used methods, it does not work well with small, winding creeks and rivers due to much of the area between two points containing land (Hooge et al. 2001). Therefore, minimum stream polygons were invented; minimum stream polygons are constructed by finding the outermost points of a fish’s distribution and connecting them by following the stream’s banks. The end result is a polygon covering the area of which a fish had to swim to reach the furthest points of its distribution. Mean MCP/MSP sizes of white perch and striped bass were analyzed with Student’s t-test in SAS to examine if there are any differences between the two congeners.

AMAE was then utilized to determine the probabilistic home range. Probabilistic home range techniques are better than minimum convex polygons for describing how animals actually use the area within their home ranges. (Jenrich and Turner 1969, Anderson 1982, Worton 1989). One of the most robust techniques of probabilistic home ranges is the kernel density home range (Worton 1989). We utilized the fixed kernel
method and an ad hoc value of $h$, the smoothing parameter, at 15.0. This value was selected because it was fine enough to not show much of each fish’s distribution on land, but not so fine as to show spurious structures. This common smoothing factor will also allow statistical comparisons between fish and between species (Silverman 1986).

AMAE interpolates all position fixes using kernel estimates of density, and displays output contours based on the probability of locating the fish at that position. The kernel density output contours considered in this project were the 95% contour as the area the animal actually uses and the 50% contour as the core area of activity (Hooge et al. 2001). The program identified preferred sites within the MCP/MSP. Mean kernel home range sizes of white perch and striped bass were analyzed with Student’s t-test in SAS to examine if there are any differences between the two congers. Cumulative home ranges were also calculated for both the MCP/MSP areas and the 95% kernel density areas. They were calculated by computing the home range for day one positions of an individual, then day one plus day two and so on until the full home range was achieved. This was repeated for every individual that displayed site fidelity and then the results were graphed. This was used to determine if the life span of the tag was long enough to determine the congener’s home range.

Fish tracks were also analyzed to examine tidal interactions. Tidal stages were broken into four parts: slack before ebb, ebb, slack before flood, and flood. Slack before ebb tide positions consisted of all positions found with in an hour on either side of slack high tide. Ebb positions were all fish tracks located an hour after slack high tide and an hour before slack low tide. Slack before flood tide positions consisted of all fish locations between the hours on either side of slack low tide. Flood positions were all fish
locations between the hour after slack low tide and an hour before slack high tide. Tidal stage positions were plotted on maps of the waterways and analyzed for any patterns. Salinity, temperature and dissolved oxygen were also examined for any effects upon the tagged fish. In particular, low oxygen events or anomalous rain events, such as hurricane Isabel, were scrutinized for any consequences toward the tagged fish.

Diet analysis

A small-scale stomach content survey was also implemented in the second year of the project. Striped bass (n=12) and white perch (n=12) caught in the gillnet and not used in the tagging study had their stomachs removed and placed into a jar of 95% ethanol. In the lab, stomach contents were enumerated and separated to the lowest possible taxon. Schoener’s Index (Hurlburt 1978) was used to test for overlap in striped bass and white perch diets: $C_{xy} = 1 - 0.5 \sum |p_{xi} - p_{yi}|$ where $p_{xi}$ is the proportion of striped bass that contain prey i, and $p_{yi}$ is the proportion of white perch that contain prey i. A Schoener’s Index value of 1.0 indicates complete diet overlap and 0.0 indicates no overlap. This small survey was utilized to help explain movement patterns and examine any differences in the diets of the two congeners residing in Queen Creek and the Poropotank River.
RESULTS

Environmental Parameters

Environmental conditions remained relatively stable over the two years of this study. There were no significant differences between the average salinities, dissolved oxygen, or temperatures associated with tagged striped bass versus white perch (p=0.36, 0.97, and 0.38, respectively). Dissolved oxygen was the most stable parameter during both years of tracking, averaging 5.7 mg/L for both congeners. Hypoxic events were rarely observed and never lasted longer than two hours. However, hypoxic events and lower dissolved oxygen concentrations were more common in Queen Creek than the Poropotank River (Figure 2).

White perch were found in salinities ranging from 0.2 - 10.8 ppt. Water temperatures where fish were located ranged from 20.00 – 32.3 °C over the course of both summers (Table 1). Striped bass were located in salinities of 2.1 - 10.8 ppt. and were found in temperatures ranging from 15.0 – 31.3 °C (Table 2), however, most of the summer months the water temperatures were above 25 °C (Figure 3). Hurricane Isabel in 2003 and five tropical depressions in 2004 had the most significant impact upon the environmental conditions. The storms quickly decreased temperatures by 2 °C and salinities by 2 ppt.

White Perch

Fifteen of sixteen white perch were successfully tagged and tracked in 2003 and
Figure 2. Dissolved oxygen concentration in 2004 for the Poropotank River and Queen Creek.
Dissolved Oxygen Concentrations in 2004

Poropotank River
Queen Creek

Dissolved Oxygen Concentrations in 2004
Table 1. Environmental parameters for the fifteen successfully tagged white perch during the course of the experiment. The parameters are the lowest, highest, and an average of the salinity, dissolved oxygen, and temperature readings while tracking each fish (n=15).

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<th>Salinity high (ppt.)</th>
<th>Avg. Salinity (ppt.)</th>
<th>DO low (mg/L)</th>
<th>DO high (mg/L)</th>
<th>Avg. DO (mg/L)</th>
<th>Temp. low (°C)</th>
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Table 2. Environmental parameters for all of the tagged striped bass during the course of the experiment. The parameters are the lowest, highest, and an average of the salinity, dissolved oxygen, and temperature readings while tracking each fish (n=16).

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Figure 3. Temperature values in 2004 for the Poropotank River and Queen Creek.
Temperature Values during 2004

Temperature (°C)


Time (days)

Poropotank River
Queen Creek
2004. In 2003, one fish ceased moving after two days and it was determined that it either had died or dropped its tag. This fish was excluded from all analyses. White perch were tracked an average of 20.8 days ($\sigma = 8.1$) and their locations recorded an average of 138.8 times ($\sigma = 56.3$) (Table 3).

The Monte Carlo random walk test concluded 73% of the white perch tracked displayed site fidelity. There was no difference between the two water bodies; eight of the eleven fish tagged in the Poropotank River and three of the four fish tagged in Queen Creek demonstrated site fidelity. Two of the four fish that did not exhibit site fidelity undertook a flight response after surgery. Both fish swam up the creek for 3 days and then either remained at its new upstream location or swam back and settled in its original capture location.

The average in-stream distance (line drawn which remains within the stream connecting the most upstream point to the most downstream point) for white perch with site fidelity was 1.37 kilometers ($\sigma = 1.6$). However, this average was greatly skewed by three fish that swam over three kilometers. Minimum convex polygons (MCP) and minimum stream polygons (MSP) were calculated for each fish who demonstrated site fidelity. There was no significant difference between the two water bodies ($p= 0.12$). The average MCP/MSP was 0.114 km$^2$ ($\sigma=0.16$) (Figure 4). The majority of fish inhabited an area less than 0.1 km$^2$. The same three fish that had large in-stream distances had home ranges extending between 0.2 – 0.5 km$^2$.

Kernel densities were examined next to determine the utilization distribution of each fish within its overall range. White perch in this study averaged 0.0116 km$^2$. ($\sigma=0.0066$) and 0.00174 km$^2$. ($\sigma=0.0011$) for the 95% kernel and 50% kernel,
Table 3. Location, number of days tracked, number of point locations, and in-stream distance for each tagged white perch (n=16).

<table>
<thead>
<tr>
<th>White Perch #</th>
<th>Location</th>
<th>Days</th>
<th>Size (mm)</th>
<th>Point Locations</th>
<th>Site Fidelity</th>
<th>In-stream Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poropotank</td>
<td>Died</td>
<td>225</td>
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<td>NA</td>
<td>NA</td>
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<tr>
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<td>68</td>
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<td>2.99</td>
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Figure 4. Minimum convex polygon (MCP) and minimum stream polygon (MSP) results for white perch with site fidelity.
respectively (Figure 5). There was no statistically significant difference for the 95% or 50% kernel density sizes between the water bodies (p=0.5 and 0.3, respectively). The 50% kernel typically either produced two core areas of activity or two core areas could be deduced for white perch located in the Poropotank River. One core area of activity was usually associated with the main channel, while the second core area of activity was associated with the marsh surface or shallow creeks (Figure 6). In Queen Creek, however, each fish had one core area of activity which was always associated with submerged structure (Figure 7).

Cumulative MCPs/MSPs demonstrated fifteen days of tagging was the minimum needed to document the full home range of white perch (Figure 8). However, cumulative 95% kernel densities did not show a leveling off trend until after 20 days (Figure 9). This trend would not have been noticed if some tags did not last beyond their life expectancy.

Tidal interactions were examined to help explain core areas and general movement of white perch. In the Poropotank River, most fish locations during high tide were located either upon the flooded marsh surface or up shallow creeks. During the ebb tide, the fish would swim back to the main channels to remain in deeper water for low tide. These tidal positions were always associated with the two core areas of activity (Figure 10). White perch typically moved with the tide, however, one fish repeatedly swam against the tidal flow of water.

In Queen Creek, white perch rarely displayed any tidal interactions. Only once did a fish move up onto the marsh surface during high tide. Another fish, one that did not display site fidelity due to a flight response, undertook tidal movements once it returned to its capture site. It moved with the tide between two locations containing submerged
Figure 5. White perch home range results for the 95% and 50% kernel density (KD).
Figure 6. Kernel densities for white perch in the Poropotank River. A) White perch #3 had one core area located in the main channel and one core area in a very shallow marsh creek. B) White perch #7 had one core area located in the main channel and one core area located upon the marsh surface.
Figure 7. White perch utilization distributions in Queen Creek. (A) The core area is associated with a relict dock. (B) The core area is associated with submerged dock pilings and a small oyster reef.
Figure 8. White perch cumulative minimum convex polygons and minimum stream polygons.
Figure 9. White perch cumulative 95% kernel densities.
Figure 10. Slack tide locations of white perch in the Poropotank River A) White perch #3’s low tide locations are in the main channel, while the high tide locations are either up the very shallow creek or on the marsh surface. B) White perch #7’s low tide locations are in the main channel, while the high tide locations are upon the marsh surface.
A)  less than 1 foot deep @ low tide

B)  Dry during low tide

White perch #3
- Red dots: High tide
- Yellow dots: Low tide

White perch #7
- Red dots: High tide
- Yellow dots: Low tide
pilings (Figure 11).

Significant environmental changes were limited to large rain or short hypoxic events. Hurricane Isabel (in 2003) and five large tropical depressions (in 2004) resulted in slight short term decreases in temperature, dissolved oxygen, and salinity. Fish were often tracked through the tropical depressions and the one perch tagged during Isabel was located the next field day (four days later). There was no indication of any environmental effect upon fish movements or locations (Figure 12). Each fish continued with its previously observed routine and did not seem to be affected by the unusual rain events or rapid hypoxic events.

Striped Bass

All sixteen surgeries upon the striped bass in this experiment were presumed successful. Each fish appeared healthy and swam actively upon release and any difficulty in tracking was assumed to be due to the fish leaving the tracking area. Striped bass were tracked an average of 24 days ($\sigma = 22.1$) with a low of one day and high of 76 days. Striped bass locations were recorded an average of 126 times ($\sigma = 137.2$) (Table 4).

Only 43.7% of striped bass displayed site fidelity during the course of this experiment. However, this number is skewed by the striped bass tagged in Queen Creek. None of the four tagged fish displayed site fidelity and not one remained in the creek longer than one week. The receiver utilized in this experiment did not have a gain knob, which made tracking these fish into the York River very difficult. The background noise of boats and water rushing by the receiver often drowned out the faint sound of a tag. This problem was not unique to Queen Creek; several times a striped bass was tracked
Figure 11. White perch #13 displaying tidal interactions in Queen Creek. The high tide locations were associated with a relic dock, while the low tide locations were associated with submerged pilings and an oyster reef.
Figure 12. Pre and post hurricane *Isabel* locations of white perch #7.
White perch #7

- Pre-Isabel
- Post-Isabel

0.2 0 0.2 Kilometers
Table 4. Location, number of days tracked, site fidelity, and in-stream distance for each tagged striped bass (n=16).

<table>
<thead>
<tr>
<th>Striped bass #</th>
<th>Location</th>
<th>Days Tracked</th>
<th>Size (mm)</th>
<th>Point Locations</th>
<th>Site Fidelity</th>
<th>In-stream Distance (km)</th>
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<tbody>
<tr>
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</table>
leaving the Poropotank River and the signal was lost once the fish entered the York River. Striped bass tagged in the Poropotank River typically remained around their tagging location for the duration of their tag and seven out of twelve of those fish displayed site fidelity. The five fish that did not display site fidelity were either: never heard from after the initial tagging day (two fish), disappeared after two weeks (one fish), or only appeared in the tracking region periodically (two fish). The fish that appeared periodically were most likely in the York River during times they were absent and might have displayed site fidelity if tracking within the York River was more successful. The average in-stream distance for striped bass who displayed site fidelity was 1.1 kilometers ($\sigma = 0.82$). However, this average could be on the low side due to the inability of tracking in the York River. Minimum convex polygons and minimum stream polygons ranged from 0.03 -1.19 km$^2$, but averaged 0.36 km$^2$ ($\sigma=0.46$). Most of the MCPs/MSPs were below the average; only the two striped bass that were tracked moving into the York River were higher than the average (Figure 13).

Kernel densities were much more uniform than the MCPs/MSPs recorded for striped bass. The average 95% kernel density was 0.02 km$^2$ ($\sigma=0.0083$) and the average 50% kernel density was 0.002 km$^2$ ($\sigma=0.0008$). All seven of the striped bass that displayed site fidelity were on the same order of magnitude for both kernel densities (Figure 14). The 50% kernel densities either produced two core areas of activity or two areas could be deduced in six out of the seven striped bass. Core area locations were common between all seven of the striped bass. Five fish utilized the deepest portion of the main channel as one of their core areas. The other core areas were all associated with corners of marsh land near the deep channel (Figure 15).
Figure 13. Minimum convex polygon (MCP) and minimum stream polygon (MSP) results for striped bass.
Figure 14. Striped bass home range results for the 95% and 50% kernel density.
Striped Bass

Area (sq. km.)

95% kernel density
50% kernel density

Striped Bass

1 2 3 4 5 6 7

Area (sq. km.)

0.00 0.01 0.02 0.03 0.04 0.05
Figure 15. Striped bass kernel densities in the Poropotank River. A) Striped bass #4 had one core area associated with the main channel and one core area with a marsh corner. B) Striped bass #11 also had one core area associated with the main channel and one core area with a marsh corner.
A) Striped bass #4

B) Striped Bass #11
Cumulative MCPs/MSPs for striped bass tagged in 2003 indicated that at least 23 days of tagging were needed to realize the full home range. However in 2004, fish displaying site fidelity also appeared to have reached the full extent of their home range, but after forty days they expanded their home range (Figure 16). The sixty day tags demonstrated that at least 50 days are needed to document the full home range of striped bass. The cumulative 95% kernel densities never displayed a leveling off trend, even after sixty days of being tagged (Figure 17).

Only two out of the seven striped bass displayed a tidal interaction. Their high tide core area was either associated with a flooded sandy beach or shallow creek. Their low tide core area was associated with the deep portion of the main channel (Figure 18). The other five fish did not display any tidal interaction. Tidal flow did not appear to affect the swimming direction of tagged striped bass.

Although tidal forces were not a strong determinant of striped bass position, lunar phase seemed to dictate movement of at least two striped bass with site fidelity and one without site fidelity in 2004. The sixty day tags allowed for striped bass to be observed over two lunar cycles and permitted observation of a pattern of striped bass movement in and out of the Poropotank only around Spring tides (Figure 19).

Environmental impacts were more difficult to assess with striped bass. The low oxygen levels in Queen Creek might explain why not one striped bass remained within the creek for the life span of the tag. Striped bass were never observed fleeing a hypoxic event, but hypoxic events might have been greatest at night when tracking ceased. Striped bass did not seem affected by extreme rain events, such as Hurricane Isabel, and were often tracked through tropical depressions, without varying from their previously
Figure 16. Striped bass cumulative minimum convex polygons and minimum stream polygons.
Figure 17. Striped bass cumulative 95% kernel densities.
Figure 18. Slack tidal positions for striped bass in the Poropotank River. A) Striped bass #3’s high tide positions were located either on a flooded marsh corner or sandy beach. Its low tide positions were located in the main channel. B) Striped bass #4’s high tide positions were located with marsh corners and its low tide positions were associated with the main channel.
A) Sandy beach

B) Striped bass #3
- High tide
- Low tide

Striped bass #4
- High tide
- Low tide
Figure 19. Striped bass #8’s lunar phase locations and movement pattern.
Striped bass #8

- Date tagged
- 3 days until full moon; leaving
- 1 day until new moon; returning
- 3 days after new moon; leaving
- 1 day until full moon; returning
- 1 day after full moon; stationary
- 3 days after full moon; leaving
observed routine. One striped bass was at liberty during Hurricane Isabel. It was located the day before the hurricane and upon the next day in the field in the same location (Figure 20).

*Competition between Striped Bass and White Perch*

Striped bass had a larger mean MCP/MSP, 95% kernel density, and 50% kernel density than white perch. However, only the 95% kernel density was significantly different (p-value = 0.002). The MCP/MSP (p-value = 0.12) and 50% kernel density (p-value = 0.38) were not significantly different. This result held true even when only white perch from the Poropotank River were included in the test.

Space competition was also analyzed between white perch and striped bass. The seven striped bass and the five white perch that displayed site fidelity and occupied the lower Poropotank River were utilized for this analysis. Striped bass positions were combined to compute a total area for the MCP/MSP of 1.23 km\(^2\). White perch positions were also combined and resulted in a much smaller total area for the MCP/MSP of 0.105 km\(^2\). The white perch total MCP/MSP was completely contained within the striped bass total MCP/MSP and covered only 8.5% of the total striped bass home range in the Poropotank River (Figure 21).

The total area of the 50% kernel density for striped bass was also larger than the white perch’s, 0.015 km\(^2\) and 0.0078 km\(^2\) respectively. However, the degree of overlap for the total 50% kernel density was greater (Figure 22). White perch and striped bass had a common core area at the mouth of a small channel in the Poropotank River. This locale was approximately one third of the striped bass’ total core area. This is the same
Figure 20. Pre and post hurricane *Isabel* positions for striped bass #3.
Table 5. Comparisons of average home range and utilization distribution areas for white perch and striped bass with associated p-values.

<table>
<thead>
<tr>
<th></th>
<th>Average MCP/MSP (st. dev.) (km²)</th>
<th>Average 95% kernel density (st. dev.) (km²)</th>
<th>Average 50% kernel density (st. dev.) (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Striped bass</strong></td>
<td>0.36 (0.46)</td>
<td>0.02 (0.0083)</td>
<td>0.002 (0.0008)</td>
</tr>
<tr>
<td><strong>White perch</strong></td>
<td>0.114 (0.16)</td>
<td>0.0116 (0.0066)</td>
<td>0.00174 (0.0011)</td>
</tr>
<tr>
<td><strong>P-value</strong></td>
<td>0.12</td>
<td>0.002</td>
<td>0.38</td>
</tr>
</tbody>
</table>
Figure 21. Total area of MCP/MSPs for white perch and striped bass.
Figure 22. Total area of 50% kernel densities for striped bass and white perch.
Striped bass 50% KD
White perch 50% KD
location that the gillnets were set because of the chance of catching both white perch and striped bass at the same time. Unfortunately, no striped bass remained within Queen Creek to make any conclusions about space competition. However, the observation that gillnets set in Queen Creek would almost always contain several white perch and striped bass indicates that further study might reveal spatial interactions.

The by-catch of white perch and striped bass caught within gillnets were utilized for a stomach content comparison between the two species. Twelve white perch and twelve striped bass stomach contents were analyzed for any evidence of diet competition. The white fingered mud crab (*Rhithropanopeus harrisii*) was the most common white perch prey item. It made up 52% of its diet by weight (n=12) (Figure 23). Young-of-the-year menhaden (*Brevoortia tyrannus*) was the majority prey item of striped bass and made up 96% of its diet by weight (n=12) (Figure 24). The blue crab (*Calinectes sapidus*) was the only common prey item between both species. The Schoener’s Index value was 0.056.
Figure 23. White perch diet composition by weight (n=12).
White Perch
(% by wt.)

- Mud crab
- Fiddler crab
- Grass shrimp
- Lined seahorse
- Polychaete
- Blue crab
- Amphipod
- Hydroid

80
Figure 24. Striped bass diet composition by weight (n=12).
Striped Bass
(% by wt.)

- Menhaden
- Bay anchovy
- Mummichog
- Unidentified fish parts
- Gastropod
- Blue crab
- Fish lice
- Detritus
DISCUSSION

White Perch

White perch consistently remained within the creek or river system and usually did not travel farther than one kilometer during the months of tracking. Their summer and early fall movements within their range generally contained neither significant dispersion nor linearity indicating site fidelity. Site fidelity is a common characteristic of coral reef species and other fishes associated with structure. It is an important trait for fishes whose prey might be concentrated and/or they may need refuge from larger predators. Site fidelity allows for intimate knowledge of one’s area and may enhance survival rate.

Once site fidelity is established the next question is ‘how extensive is their range during daily activities?’ We employed minimum convex polygons because it is the most traditional method and minimum stream polygons because of the multiple streams and bends associated with the river. However, before any home range data are examined, it should be determined that the length of tracking time was sufficient enough to encompass the fish’s entire range. Tag duration is often not examined in home range studies, but this trend should change with the simplicity cumulative home range curves. The cumulative MCP/MSP and 95% kernel density data suggests that our 21-day tag was sufficient to capture a white perch’s home range and utilization distribution.
The MCPs/MSPs calculated in this study were very small and often on the order of $10^{-2} \text{ km}^2$. This small summer home range is best understood by comparing it to other fish species. There have been, however, few home range studies within the oligohaline to mesohaline portion of the estuary. However, there has been exhaustive research upon marine fish associated with structure and upon fresh water species. Many structure oriented marine fish of comparable size had similar home range sizes to white perch. The home ranges for these fish were on the order of $10^{-2} \text{ km}^2$, which is equal to most of the white perch in this study (Noda et al. 1994; Zeller 1997; Meyer et al. 2000; Eristhee and Oxenford 2001; Bolden 2002).

Minns (1995) wrote a comprehensive literature review on the home ranges of many fresh water river and lake species. He produced regression models of fish size versus home range for both riverine and lake residents. The lake inhabitants had a greater home range at all fish sizes than did the river inhabitants. Minns (1995) hypothesized this home range size difference might be due to fish within rivers often having their prey items drift to them, while lake inhabitants must visit “food-producing areas” to obtain their prey items. White perch used in this study had a greater home range compared to similar sized riverine residents, but were comparable to species residing within lakes. Minns also included two papers describing the home ranges of juvenile American eels in estuarine creeks. Their home ranges were also comparable to lake residents and he dismissed the data as outliers. Estuarine residents behaving like lake inhabitants may seem counter-intuitive because marsh streams often have strong currents like rivers, however, much of a large white perch’s diet does not passively drift. White perch at these large sizes often prey upon food items that remain in one location of the marsh
creek, such as polychaetes, mud and fiddler crabs, and killifish. In addition, crabs and larval killifish might only be accessible to the white perch during the slack flood tide when they can search upon the flooded marsh surface. The behavior of visiting food producing areas can be examined by looking at an animal’s utilization distribution.

This study employed kernel densities to examine the utilization distribution and found the area actually used by white perch was much smaller than its overall range. In fact, the average 95% kernel density was 10% of the average MCP/MSP, while the core area was only 1% of the average fish’s range. The core areas of white perch were often localized to either a submerged structure or to specific locations within a small creek. The kernel densities also allowed us to describe important habitats for the tagged white perch.

The original hypothesis was that white perch would have two core areas of activity. This hypothesis was supported in 2003, when we only tagged within the Poropotank River. In 2004 however, fish that exhibited site fidelity in Queen Creek had only one core area of activity, while white perch in the Poropotank River continued to contain two cores areas of activity within their home range. The topography and flora of each waterway were examined in order to explain this phenomenon.

White perch tagged in Queen Creek were almost exclusively associated with structure. Submerged dock pilings were the preferred habitat sites. Bridge overpasses, rock dams, small oyster reefs and submerged trees were also utilized. Only once, during the four months of tracking in Queen Creek, was a white perch observed swimming up a small tidal marsh creek or upon the flooded marsh surface. This is probably due to the small amount of available marsh habitat versus the vast area of submerged structure.
Queen Creek is on the south-western side of the York River. Steep banks and sandier sediment dominate that side of the river deterring small creek and marsh formation.

White perch tagged in the Poropotank River were typically not associated with any known structure. Only two fish were associated with either downed trees or dock pilings. These two fish were the only fish in the Poropotank to have one core area of activity. The other nine white perch displaying site fidelity had two core areas of activity. All of these fish were associated with small marsh channels and the marsh surface. The shallower topography of the estuarine portion of the Poropotank allows for the river to be dominated by *Spartina alterniflora* and small marsh creeks and rivulets. White perch often utilized this greater number of marsh rivulets and greater area of marsh surface.

Tidal locations were then analyzed along with the core areas of activity to further explain white perch behavior. White perch in Queen Creek often did not display any tidal periodicity. They usually remained at one location or underwent rapid movements from one structure to another. These rapid movements were always with the tidal flow of water and did not occur at any regular schedule, but appeared to be random. However, one fish that did not display site fidelity did display a tidal interaction moving with the tide between two submerged pilings. This selective stream transport was also utilized by most of the white perch in the Poropotank River and is a common trait for fish to minimize energy (Harden-Jones et al. 1979; Szedlemeyer and Able 1993; Forward and Tankersley 2001).

White perch residing in the Poropotank River often displayed a tidal periodicity. Tagged fish on average had one core area of activity upon the flooded marsh during slack
high tide and one core area in the main channel during slack low tide. White perch presumably utilize the main channel to seek refuge from avian predators. The main creek provides more protection during slack low water when the marsh surface or marsh rivulets could be less than ½ meter to completely dry. It is also hypothesized that white perch are either seeking refuge from larger predators within the main creek or preying on the organisms upon the marsh during the slack high water. The sizes of white perch utilized in this study do not have many fish predators. They may have to take refuge from the occasional large striped bass, but it is more likely they move up onto the marsh to feed. Many studies have found greater gut fullness indices on high or ebbing tides than low or flooding tides. Common prey items in these studies consisted mostly of prey species that reside in vegetated intertidal marshes (reviewed by Kneib 1997). The marsh rivulets and marsh surfaces are the food producing areas that Minns (1995) hypothesized lake residents need to visit in order to feed.

White perch diets reflect this marsh vegetation foraging strategy. They often consume common marsh inhabitants, such as polychaetes, amphipods, grass shrimp, mud crabs, fiddler crabs, and mummichogs (Weisberg and Janicki 1990; St. Hilaire et al. 2002). It would be interesting to examine if any diet differences exist between white perch associated with structure and white perch associated with the marsh surface. The results in the stomach analyses of this study revealed completely different diets. White perch in Queen Creek fed upon amphipods and polychaetes, while fish in the Poropotank River fed upon crabs and grass shrimp. The different utilization distributions and stomach data in this experiment warrant further diet studies between habitats such as Queen Creek and the Poropotank River.
There was little sign of any environmental impacts upon white perch site fidelity or movement. The white perch in this experiment did not seem to be affected by the episodic hypoxia in Queen Creek. There was also no indication that small changes in temperature or salinity had an affect upon white perch. Most of the environmental changes were due to large rain events. White perch can tolerate a broad range of salinities and temperatures, which may allow them to tolerate sudden surges of cooler, fresher water.

**Striped Bass**

Striped bass were difficult to find in many creeks along the York River. Striped bass were eventually located in Queen Creek around the various structures. Unfortunately, no striped bass tagged within Queen Creek remained longer than one week. Thus, these individuals could not be compared to the striped bass in the Poropotank River. Nonetheless, important data were obtained about striped bass home range and habitat utilization within the Poropotank River. Summer and early fall site fidelity was almost 60% within this river and possibly would have been greater if tracking had been more successful in the York River.

Why are there seasonal resident striped bass in the Poropotank River, while it appears that there are none in other creeks that appear similar? One possibility is that the Poropotank River has less of a hypoxia problem than smaller creeks due to its size and volume of water moving in and out. Queen Creek is comparable in size, but it had more hypoxic events than the Poropotank River. This may be due to the way the creek drains because of the three reservoirs supplying it with fresh water. If the three reservoirs have
low dissolved oxygen concentrations, then during strong rain events a large supply of fresh, low dissolved oxygen water would move down the creek. Striped bass’ tendency to leave areas of hypoxia has been well documented and has been found in other acoustic tagging studies (Haeseker et al. 1996; Young and Isely 2002; Bettoli 2005). High water temperatures also elevate striped bass metabolism and their need for dissolved oxygen (Coutant 1985). Although the temperatures associated with Queen Creek were the same as the Poropotank River, the combination of high temperatures and lower dissolved oxygen may create unsuitable habitat for striped bass. Queen Creek may simply be a temporary feeding location for striped bass resident within the York River.

A second hypothesis is the possibility of two separate contingents within the York River. Secor (1999) described three spatially discrete contingents in the Hudson River. The fish were separated into groups of resident, mesohaline, and coastal fish. Simplifying these three contingents, they can be managed as fish that migrated away from their nursery grounds and fish that remained upon their nursery grounds. In the York River, we may have a population that remains near the nursery grounds and has retentive behavior, i.e. striped bass caught in the Poropotank River, and one population that is more exploratory, i.e. striped bass caught in Queen Creek.

The higher abundance of juvenile striped bass in the Poropotank River indicates that it maybe a more important nursery than Queen Creek (McGrath unpublished data). This may result in some fish remaining in or near the Poropotank River and being site faithful to that area. Queen Creek appears not to be an important nursery ground and striped bass found there may be more exploratory in nature and either do not display site fidelity at all or have a much larger home range. The recent literature of site fidelity in
striped bass and the presence of site fidelity in the Poropotank indicate that striped bass visiting Queen Creek probably have larger home ranges (Jackson and Hightower 2001; Young and Isely 2002). The home ranges of striped bass tagged within the Poropotank River can still be utilized for that local population of striped bass or possibly comparisons to future tagged striped bass and other estuarine species. However, when using these data, it should be remembered that the areas are probably smaller than the actual ranges and may only be applicable to the summer and early fall.

First, the cumulative MCP/MSP and 95% kernel density curves should be consulted to verify our tag durations. Both curves show that the 21 day tags were not long enough to understand a striped bass’ spatial dynamics. It appears the sixty day tags were adequate enough to understand the overall home range of immature striped bass in the Poropotank River. However, the cumulative kernel density never leveled off even after sixty days. This means the kernel densities may all be underestimates. The area each striped bass utilizes within its home range may be greater than what was concluded. This stresses the need for longer duration tags for species that are highly mobile and employing the largest tag possible for the species being tracked. Shorter duration tags will begin to answer some questions such as daily movements or tidal influences, but problems involving lunar cycles, seasons, or even longer cycles need longer duration tags.

The cumulative MCP/MSP has demonstrated that our average MCP/MSP may be underestimated as the fish tagged in 2003 were implanted with 21 day tags. This minimum MCP/MSP should not be too far from reality due to the minimal increase after forty days by the three other fish. Therefore, we can also compare the average
MCP/MSP to other tagged fish. The tagged striped bass, like their congeners, also fall within Minns (1995) fitted regression for lake fish. This result is not surprising due to the diet of striped bass. Striped bass often do not feed on passive organisms within the river. Their diet depends heavily upon organisms that can fight the current and avoid predators. This forces striped bass to search and find their prey similar to fish that inhabit lakes.

Striped bass displaying site fidelity could also be compared to fish that are associated with structure. The average MCP/MSP of striped bass is very similar to other acoustically tagged fish that are known to associate with structure. Striped bass have been known to congregate around structure (Harding and Mann 2003). Haesakar et al. (1996) found striped bass to congregate around structure and in deep holes. Bridge overpasses and oyster reefs are popular locations for striped bass anglers. The deep channel in the Poropotank River, one of the core areas in which striped bass congregated, contains a small oyster reef and although striped bass did not display site fidelity to Queen Creek all of the fish were caught amongst submerged pilings indicating structure association.

The next step is to examine how the striped bass utilized the space within their home range. This is accomplished by analyzing the size and placement of their kernel densities. The cumulative kernel density graph demonstrated that the average area acquired from the kernel densities is probably lower than the actual area. However, they can be used at least as a low estimate of striped bass space utilization. The averages achieved were much smaller than the overall home range. The 95% kernel density was only 5.5% of the overall home range, while the 50% kernel density was 0.55% of the home range. These percentages for striped bass are half of the white perch results. That makes these numbers even more difficult to believe and the lack of kernel density area in
the York River is the main flaw in this analyses. Further studies should use longer
duration tags and equipment suited for tracking in larger rivers. The lack of York River
data dismisses a large important area utilized by striped bass.

The placement of the core areas allowed for further description of preferred
striped bass habitat. A common core area location was within the deepest part of the
main Poropotank River (approximately 3.6 meters). This deep hole was located between
the two bays and might have served as refuge from the fast moving current or as a
feeding area upon prey species that reside in the main channel, such as menhaden. This
core area also contained a living oyster reef, which is known to be a preferred habitat of
striped bass (Harding and Mann 2003).

Other core area locations were associated with marsh corners or a sandy beach.
The sandy beach was only a core area for one striped bass, but this fish also was one of
the few striped bass to display a tidal interaction. The striped bass would remain in the
deep hole during the slack before ebb and then with the flood tide, move up onto the
shallow (approximately 1.2 meters) sandy shelf and swim amongst the few patches of S.
alterniflora. The marsh corners were also relatively shallow and often had eddies
associated with them. These eddies often concentrate prey items and could also provide
the striped bass with refuge from the current. The marsh corners, when flooded, would
also provide access to prey items that might live upon a flooded marsh, such a blue crabs
or killifish.

Tupper and Able (2000) found larger striped bass to move against tidal flow in
New Jersey estuaries. They hypothesized this action was driven by the ability to
consume the prey that falls off the marsh surface during an ebbing tide. In this
experiment, only two striped bass displayed a tidal periodicity and both of them went
with the tidal flow of water. One striped bass moved with the tide upon the sandy beach,
while the other striped bass moved from the deep hole with the tide to the entrance of the
small creek. The lack of tidal interaction for the other five was unexpected and
contradictory to the original hypothesis. It appears from these data that the tagged striped
bass are not energetically bound to move with the direction of the current.

Striped bass also displayed a lunar phase interaction during the second year of this
study. Behavior associated with lunar cycles is common in many fishes, especially
during the spawning period. Lunar periodicity has also been found in migrating fish.
The extraordinary high tides that occur with new and full moons help fish to either leave
or enter a river system (Helfman et al. 1997). Striped bass residing in both the
Poropotank River and York River probably displayed lunar periodicity due to the very
shallow bay entering the Poropotank River.

The two fish that displayed the lunar periodicity only entered the Poropotank
River on the days surrounding a Spring tide. One of the two fish would only stay within
the Poropotank River for the six days before and after new and full moons. As the tides
became less extreme this fish would leave the Poropotank River and most likely remain
in the adjacent York River. The height of the tides when the fish moved in and out was
always at least three feet above mean low water. This would make the Poropotank Bay
six feet deep and safe enough for a striped bass to enter or leave the Poropotank River
undetected by avian predators.

Finally, environmental impacts were analyzed on the tagged striped bass. Striped
bass did not show any effects due to the many large rain events that occurred during both
summers. They were often tracked during tropical depressions and they did not change from their previously observed behavior. Hurricane *Isabel* also did not appear to have any impact upon the one striped bass that had an active tag throughout the storm. Striped bass appear to be able to find refuge or are large enough to fight any excess current brought on by larger volumes of water or stronger winds.

Striped bass were also not affected by temperature in the Poropotank River. Literature regarding the thermal niche of striped bass states that they prefer temperatures below 25 °C. Striped bass residing in the Poropotank River were almost always found in water temperatures above 25 °C, sometimes in water as hot as 30 °C. These temperatures increase metabolic demand and decrease productivity (Coutant 1985). Haeseker (1996) also found striped bass to occupy areas with temperatures above their thermal niche, as long as the dissolved oxygen concentrations remained sufficiently high.

*White perch and Striped Bass Competition*

Another goal of this experiment was to examine if white perch and striped bass compete for space during a specific stage in their life cycle. It is known that the two congeners overlap in space and diet during their juvenile years. But as the fish grow larger and older their diets slightly diverge and striped bass become more dependent upon fish, while white perch prey upon crabs, fish, and polychaetes. However, at least during a striped bass’ immature years they still overlap with white perch spatially.

It was originally hypothesized that the two congeners would resolve this spatial problem by occupying the same home range, but utilize the area within it differently. The congeners did occupy the same area in both between the bays in the Poropotank
River and in lower Queen Creek, but there was little evidence of spatial competition. In lower Queen Creek, the striped bass were not permanent residents and hence there was no competition for space.

The home ranges and utilization distributions of the two congeners were only significantly different with the 95 % kernel density. However, the striped bass home range and utilization distributions are believed to be under-estimated and a significant difference probably does exist between the two congeners. This difference could be due to the size differences in the tagged fish. McNab (1963) was one the first to show that home range size increases with body size in mammals, birds, and reptiles. This hypothesis has been extended to fish both in the marine and freshwater environments (Larson 1980; Minns 1995; Bell and Kramer 2000; Jones 2005) In the Poropotank River, white perch only occupied eight percent of the striped bass’ home range. This small percentage does not appear to be much of an overlap, but if the time spent in the same region is examined the overlap becomes greater. In order to do this, we looked at the 50% kernel densities or core areas. The congeners shared a common core area together at the mouth of the small creek. This creek is abundant with marsh edges and eddies and was the location where every fish tagged in that region of the river was caught. This common core region made up one third of the cumulative striped bass core area.

Although the congeners overlapped more in their core regions, this is still not conclusive evidence of space competition. They may have been found in the same area sometimes, but the way they utilized their habitat was completely different. White perch utilized the flooded marsh much more often, while striped bass tended to remain in the
main stem of the Poropotank River. Striped bass did use marsh edges during flood tides, but these were often not areas where white perch dwelled. The diet data also drew the same conclusion. The white perch’s diet of mud crabs was more associated with the marsh surface than the pelagic diet of the striped bass.

**Final Conclusion**

This acoustic tracking study has provided valuable knowledge about the home range and habitat utilization of white perch and striped bass in summer and fall. It is not known if behavior of striped bass and white perch is similar during other seasons. The striped bass results were confounded by the inability to track fish in the York River, however if mid-river tracking had been more successful, we might have documented that striped bass have a higher degree of site fidelity and have a much larger home range.

White perch often displayed site fidelity and had relatively small home ranges. These characteristics make the species ideal for toxicity studies, but also make it vulnerable to local stresses. In 1972 and 1973, St. Pierre and Hoagman (1975) found a sharp reduction of white perch in the James River. The cause of the decline was not known, but due to the isolation of James River white perch from the other Virginian rivers, the population took many years to recover. My data show that a catastrophic event is not required to negatively affect white perch. Removal of structure or filling in of marshes will decrease the area inhabited by white perch. Destruction of habitat is one of the leading factors in animal population decline.

White perch in the Poropotank River definitively displayed a tidal interaction, while white perch in Queen Creek did not. This behavioral difference in water bodies
was also evident by the amount of core areas. The Poropotank River white perch contained two core areas of activity one associated with the intertidal creeks and the marsh surface, the other associated with the main channel. In Queen Creek, only one core area was observed and it was always associated with structure. The size of their home ranges compared with other fishes concurred with both behavioral conclusions. White perch were found to have similar home range sizes to structure orientated fishes, as well as, fishes that need to move in order to visit food producing areas.

Striped bass home range sizes were also on the same order of magnitude as other fishes associated with structure and fishes that visit food producing areas. Striped bass were mainly found around structure in this experiment, but they were also observed moving around marsh edges and sandy beaches. Most of the striped bass tagged did not display any daily tidal interaction, but a few exhibited a monthly lunar periodicity. This lunar phase interaction possibly allows them to enter and leave the Poropotank under the protection of deeper water.

There was very little spatial competition between these two congeners. The data obtained in this experiment illustrated striped bass and white perch home ranges are similar to other fish species that are associated with structure and similar sized lake residents. The two congeners did share a portion of their home ranges, but did not show any sign of resource partitioning by utilizing the area at different stages of the tide or by feeding upon the same prey items. The area shared by the two congeners was an important location and both species utilized it as a core region in their home range. The two species were found to coexist in this relatively small area, however, resource partitioning was excluded due to the fact most of the striped bass appeared to have
different diets, did not display a tidal interaction, and also had a larger home range. It appears that striped bass and white perch only compete during their larval and early juvenile stages.
LITERATURE CITED


