Abstract—We determined the distribution of multiple (n=68; 508–978 mm total length [TL]) striped bass (*Morone saxatilis*) along the estuarine salinity gradient in the Mullica River–Great Bay in southern New Jersey over two years to determine the diversity of habitat use and the movements of striped bass. Ultrasonically tagged fish were detected in this estuarine area by means of wireless hydrophones deployed at four gates inside the entrance of the study area and farther up to tidal freshwater (38 km). Numerous individuals frequently departed and returned to the estuary, primarily in the spring and late fall over periods of 15–731 days at liberty. The period of residency and degree of movement of individuals to and from the estuary varied extensively among seasons and years. The diversity of movements in and out of, as well as within, the estuary differed from the less-complex patterns reported in earlier studies, perhaps because of the comprehensive and synoptic nature of this study.

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Diversity of estuarine movements of striped bass (*Morone saxatilis*): a synoptic examination of an estuarine system in southern New Jersey

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Striped bass (*Morone saxatilis*) are an economically and ecologically important species along most coasts of the United States, and especially along the east coast and into Canada (Klein-MacPhee, 2002). The degree to which this species uses estuaries along the east coast appears to vary among and within estuaries. From North Carolina southward most striped bass remain in rivers and estuaries (Haeseker et al., 1996; Bjorgo et al., 2000), as does the northernmost population in the Gulf of St. Lawrence (Coutant, 1985). North of North Carolina to the Bay of Fundy, striped bass can be highly migratory (Waldman et al., 1990; Rulifson and Dadswell, 1995). Much of the research effort in this region has focused on the coastal migrations and there has been less effort on within-estuary movements. Both coastal and within-estuary movements have become more important to understand because 1) the recovery of the species (Wooley et al., 1990; Richards and Rago, 1999), especially at the current higher densities, may influence its movement patterns, and 2) there is the possibility that there are distinct contingents, including estuarine residents, that are critical to understanding stock structure for fishes in general (Begg and Waldman, 1999), but especially for striped bass (Secor et al., 2001).

In the past, most attempts to examine estuarine movements have been based on fish caught in local fisheries (Rulifson and Dadswell, 1995) and tagged-recaptured fish (Boreman and Lewis, 1987; Waldman et al., 1990). However, in recent years the development of otolith microchemistry has helped scientists to recognize the importance of distinct substocks or contingents and their migrations (Secor, 1999) that have the potential to be indicative of homing (Thorrold et al., 2001; Gillanders, 2005). These concepts have been applied to striped bass as well, and resident, mesohaline, and coastal migratory contingents have been recognized within the same estuarine and river system (Secor, 1999; Zlokovitz et al., 2003), as well as the annual variation in the migratory patterns of these contingents (Morris et al., 2003). Additionally, the development of biotelemetry in general (Cooke et al., 2004; Heupel et al., 2006) and smaller ultrasonic tags and passive receivers has increased the possibility for more accurate and frequent detection of fish and has enhanced our ability to study fish movements (Arnold and Dewar, 2001; Sibert and Nielsen, 2001). These efforts conducted on striped bass previously focused on introduced populations in freshwater reservoirs (e.g., Jackson and Hightower, 2001; Young and Isley, 2002), with exceptions in North Carolina (Haeseker et al., 1996; Carmichael et al 1998), Maryland (Hocutt et al., 1990), and New Jersey (Tupper and Able, 2000). More detailed studies are necessary to determine how estuarine and ocean use varies among individuals over seasons and years. This is especially necessary because much of the past focus has been on large estuarine and river systems such as the

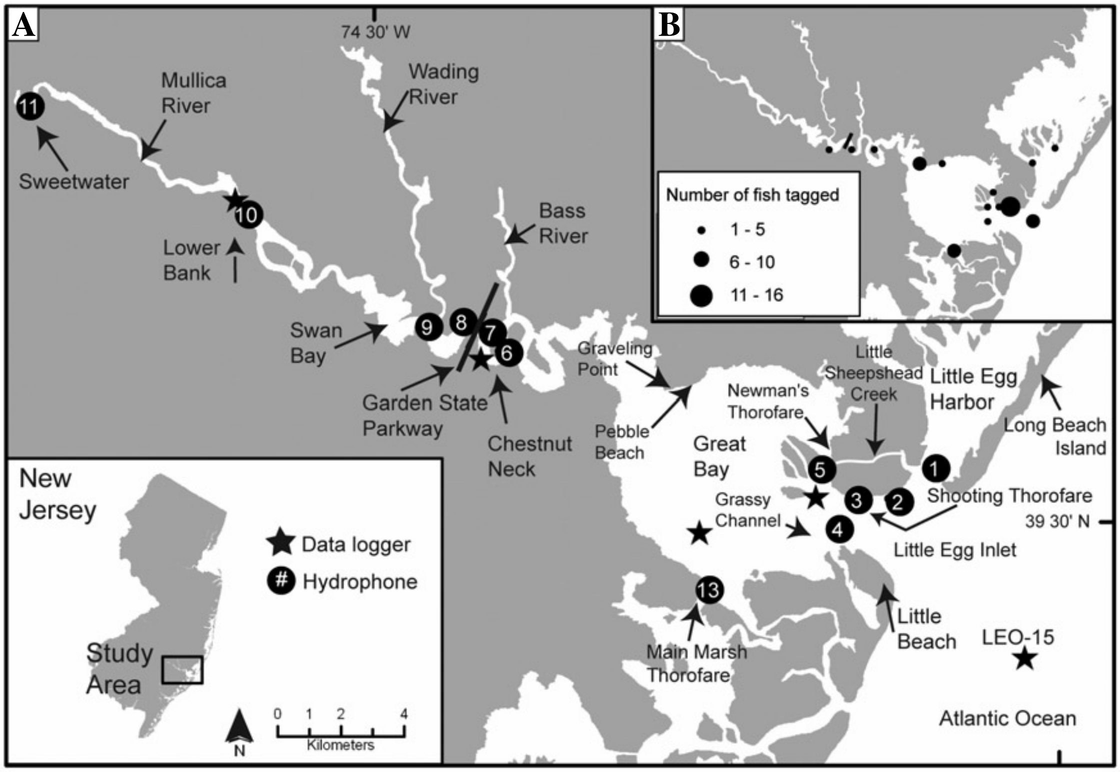

Figure 1

Mullica River–Great Bay study site and important localities (**A**) and location of fish tagging and release sites (**B**) during 2003 and 2004. Hydrophone 12 was not deployed during this period and is not shown.

Hudson River (Secor et al., 2001; Zlokovitz et al., 2003) or Chesapeake Bay (Secor, 2000a, 2000b). Relatively little attention has been directed to small coastal bay and estuarine systems that, owing to scale, may have very different dynamics.

The purpose of this study was to determine the annual, seasonal, and episodic patterns of residency and movements for large juvenile and adult striped bass along an estuarine gradient in a small drowned-river-valley estuary. Although most previous telemetry and tracking studies focused on one fish at a time, the estuarine system used in the present study allowed for synoptic observations of numerous individuals. Throughout this study there was an emphasis on individual behavior, an approach that has provided important insight into the stock structure of other fishes (Sutherland, 1996; Slotte and Fiksen, 2000).

Materials and methods

Study site

The Mullica River–Great Bay estuary (Fig. 1) is one of the few remaining relatively undisturbed estuaries in the northeastern United States because there is little agricultural or industrial development in the watershed and human population density is relatively low (Kennish, 2004). This relatively small watershed (1474 km^2; Kennish, 2004) that comprises several tributaries (Batsto, Wading, and Bass Rivers) is part of the Jacques Cousteau National Estuarine Research Reserve (JCNERR) and drains the Pinelands National Reserve at a mean monthly stream flow of approximately 1.7 to 4.2×10^8 L/d (Rhodehamel, 1998) (Fig. 1). Much of the 280 km of shoreline in this watershed consists of cordgrass (*Spartina alterniflora*) dominated salt marsh, and has a tidal range between 0.7 m (in Little Egg Harbor) and 1.1 m (near the mouth of Great Bay). Mean salinity of 29 at the entrance to the bay drops sharply to about 8 within 30 linear km upriver; the inflection point corresponds to a steep decrease in pH from 8.0 to 6.0 owing to tannins leached from the pine-forested watershed (Kennish, 2004). The majority of water exits into the ocean through the narrow but deep (20 m) Little Egg Inlet and to a lesser extent through the Main Marsh Thorofare, an intra-estuarine connection that is part of the Intra-Coastal Waterway (ICW) (Chant et al., 1996).

Estuarine observatory

Wireless hydrophones were deployed at a series of gates in order to enhance detection of tagged striped bass while in residence or moving along the estuarine gradient (Fig. 1). At the entrance to the estuary (Little Egg Inlet) hydrophones 2, 3, and 4 (recorded as positioned

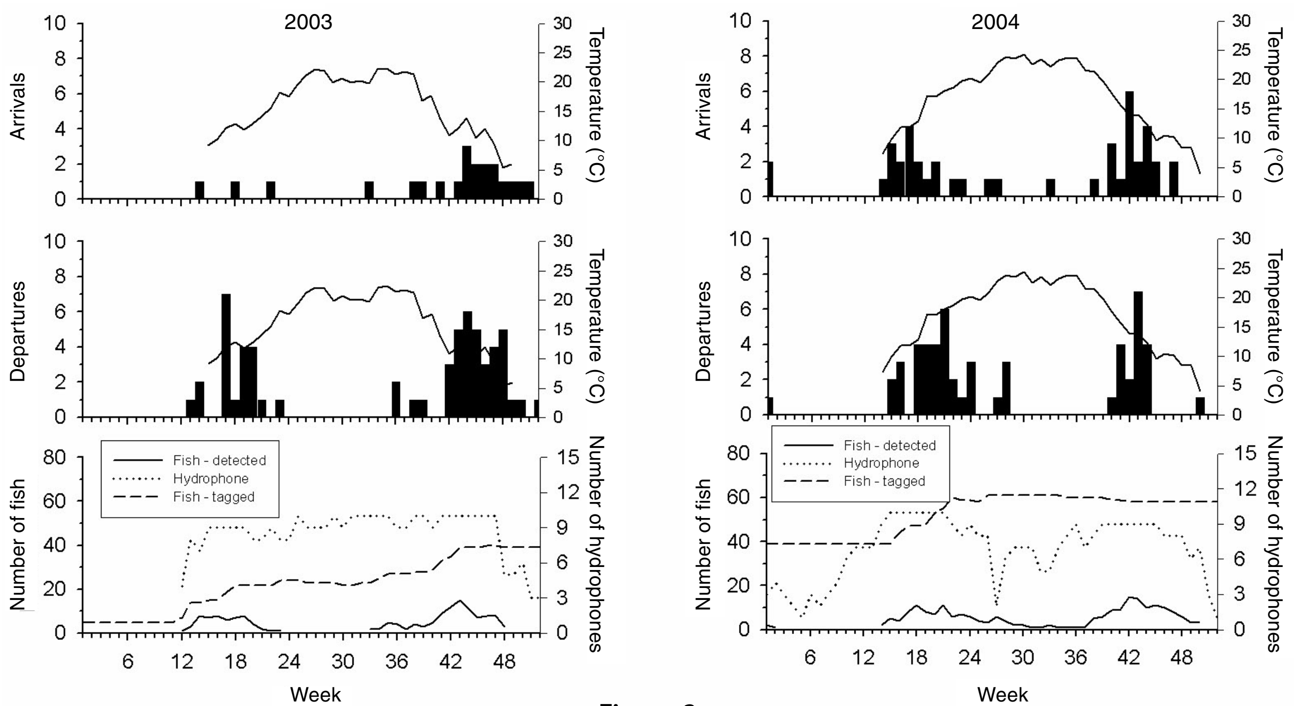

Figure 2

Arrivals and departures of tagged striped bass (*Morone saxatilis*), number of active hydrophones, and number of fish tagged (available) and detected in the system during 2003 and 2004. Number of fish detected in the system and number of active hydrophones included all data combined within each week. Temperature data were collected at a Jacques Cousteau National Estuarine Research Reserve data logger in lower Great Bay (Fig. 1).

at 0 km) were arranged to take advantage of local topography, such as at sand bars, channels, etc. to detect fish moving along several passages. The entrance to Little Egg Harbor was monitored by hydrophone 1 (considered to be 0 km from the inlet for the purposes of this study). This same hydrophone, along with no. 5, also served to identify fish moving through a deep (to 7 m) channel (Little Sheepshead Creek) between Little Egg Harbor and Great Bay. The channel exiting Great Bay to the south (Main Marsh Thorofare) was monitored by hydrophone 13 (4.5 km from the inlet), although this hydrophone was deployed later than the others. Hydrophone 5 (4.5 km from the inlet) also served to monitor fish passing through the deepest channel in Great Bay (Newmans Thorofare). The next gate upstream was located in the Mullica River (hydrophones 6, 7, 8, 9; approximately 18 km from the inlet). Hydrophones 6 and 8 were removed after a test period because they were largely redundant. Farther upstream the next gate consisted of a single hydrophone (no. 10; 28.3 km from the inlet) just above the saltwater-freshwater interface. On occasion, another hydrophone (no. 11; 38.1 km from the inlet) was deployed farther upstream in tidal freshwater. The total number of hydrophones deployed over the period of the study is indicated in Figure 2. Additional details of this estuarine system (referred to as an "observatory") are provided in Grothues et al. (2005). Our ability to detect tagged fish in certain portions of the estuary was affected by the times of hydrophone deployment and, occasionally, by aperiodic retrieval of the hydrophones because of poor weather conditions (ice formation in the winter of 2003–04) or equipment malfunction (Fig. 2).

Striped bass bearing surgically implanted acoustic transmitters (76.8 KHz) with an individual identification code were detected when they came within range (approximately 500 m; Grothues et al., 2005) of moored wireless hydrophones (WHS-1100, Lotek Wireless, Inc., St. Johns, Newfoundland, Canada), which were suspended at a depth of 3.2 m where surrounding total water depth reached a depth of 10 m. Wireless hydrophones transmitted received sound in the 76.8 KHz band by a VHF radio frequency unique to the unit (between 148 and 152 MHz) to shore-based receivers for the interpretation and logging of the data in real time (see Grothues et al., 2005, for additional details). The JCNERR study area also provided useful infrastructure for routine environmental monitoring. Permanent instrumentation included data loggers used to record salinity, temperature, pH, and water depth (Kennish and O'Donnell, 2002) along the estuarine gradient (Fig. 1).

Tagging technique

Fish were collected by hook and line from 2 November 2002 to 2 November 2004 in the study area. Immediately after capture, each individual was anesthetized in a cooler containing 0.4–0.6 g/liter of MS-222 (Sigma-Aldrich Corporation, St. Louis, MO). A transmitter (CAFT 16-3, Lotek Wireless Inc., St. Johns, Newfoundland, Canada) was then surgically implanted in the body cavity. The incision was closed with absorbable ethalon monofilament sutures and treated with antibiotic ointment. An external tag (Floy Tag, Inc., Seattle, WA), with printed contact information, was anchored into the flesh to allow fishermen to report capture later to the study crew. While still anesthetized, the fish was measured (mm total length, TL), injected with Liquamyacin®Pfizer at 0.1 mg/kg fish weight as a prophylactic against latent infection. Each fish was then placed in clean, ambient water until it showed normal swimming ability at which time it was released at the capture site. On occasion, fish were held for short periods of time (two hours) before release. However, one fish was held for four days at Rutgers University Marine Field Station (RUMFS) before surgery and then taken to the site of capture and released.

Data analyses

The sampling unit (n) used in the analyses of telemetry data was an individual tagged fish because this approach places equal importance on the movements of each fish (Rogers and White, in press). For the purpose of this study, immigration of a tagged fish occurred when the first detection of a fish tagged in 2002 was recorded after January 2003 at or near an entrance to the estuary. Emigration was determined by detection at one of the entrances to the estuary followed by no detections of that individual for two consecutive weeks, presumably because it left the estuary for the ocean or an adjacent bay. In order to measure swimming speed, we used the last detection at a hydrophone at one gate and the first detection at the next gate to determine time of travel and distance between hydrophones.

Results

Environmental parameters

Pronounced seasonal changes in temperature and dissolved oxygen occurred consistently throughout the estuary, and salinity and pH decreased in the river (Fig. 3). Temperatures approached, and probably reached, 0°C during both winters but reached maximum temperatures of approximately 25°C farther up the estuary during summer. Temperatures near Little Egg Inlet were consistently cooler than elsewhere in the estuary during both years. Dissolved oxygen values followed the same seasonal trend, except that values were highest in the winter, near 14 mg/L, and lowest in the summer, at 4–6 mg/L, but in both years values at Little Egg Inlet were higher than farther up the estuary. The salinity varied distinctly with distance up the estuary. The values at Little Egg Inlet averaged 28.6 (16.8–32.7) during both years, whereas those upstream at Chestnut Neck (mean=13.8, range 0.9–24.4) and Lower Bank (mean=2.1, range 0–13.4) were much lower. Although there were no data collected at Sweetwater during the 2005 study period, the salinity values averaged 0.1 (range: 0.02–5.1). The estuary differs from many others in the Middle Atlantic Bight in that pH values in the upper portions of the study area are naturally low (Lower Bank, mean 5.9, range=4–7.4). These values tended to be lowest in the spring and winter, presumably because of higher runoff associated with more precipitation and because of lower salinities at that time of the year.

General characteristics of ultrasonically tagged fish

During the study period, 68 striped bass (range 483–978 mm TL) were tagged and tracked through the Mullica River–Great Bay study area. Most of these fish were tagged in Great Bay (n=61), especially in the lower bay near Little Egg Inlet and Shooting Thorofare, although a number were also tagged at Graveling Point and Pebble Beach (Fig. 1B). Most fish were tagged in the fall and spring of 2003 and spring of 2004. The duration of detection of these tagged fish varied greatly among individuals. Some individuals (n=3) were detected only immediately after tagging and not again. Some were detected only during one season or one year (n=3), others (n=5) were detected in both years, and two individuals were detected for almost the entire duration of this study. The mean duration in the study area for fish tagged in 2003 was 43.5 days and in 2004 was 20.0 days. Several fish were captured by anglers within the estuary (n=4), outside the estuary elsewhere in New Jersey (n=5), on the south shore of Long Island (n=1), coastal New Hampshire (n=1) and one was detected by similar hydrophones in the Saco River, Maine (Carter[1]).

The overlap in time between hydrophone deployment and the time of initial tagging of each fish and their exit and re-entry into the estuary determined the frequency and duration of tag detections (Fig. 2). Overall the rate of detection was high; over 97% of all tagged fish were detected after tagging. The number of detections for each individual varied markedly and ranged from 22 to 75,603 contacts; the total number of contacts for all fish was 501,760 over the course of the study. Of the fish tagged and subsequently detected, duration at liberty varied from 15 to 731 days. Most fish were detected by more than one hydrophone and numerous individuals were detected by 2–10 hydrophones.

Annual and seasonal visits to the estuary

The patterns of estuarine use by tagged striped bass were diverse and varied by individual, season, and year. We characterized individual tagged fish by their use of the estuary, either as resident fish (never detected

[1] Carter, J. 2005. Personal observ. Department of Life Sciences, Univ. New England, 11 Hills Beach Road, Biddeford, ME 04005.

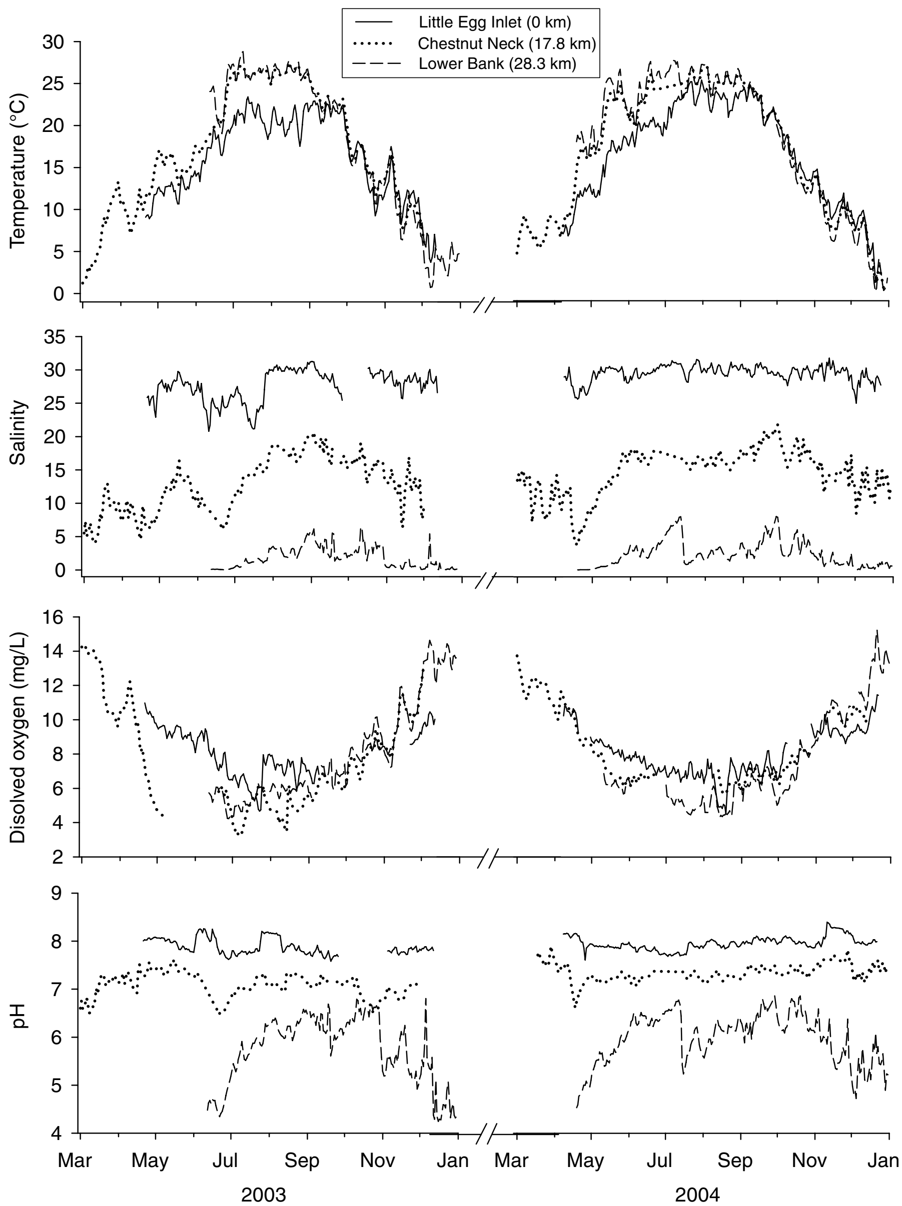

Figure 3

Monthly and annual variation in environmental parameters of the water column during 2003 and 2004 based on Jacques Cousteau National Estuarine Research Reserve data loggers. See Figure 1 for location of data loggers. Some values are missing because of ice cover and because we were unable to download data during winter.

leaving the estuary), seasonal inlet visitors (detected only at the inlet gate by hydrophones 1–4), seasonal estuarine visitors, (within the estuary gate at hydrophones 13, 5–9), or as seasonal river visitors (within the river gate at hydrophones 10, 11) (Fig. 1). The consistency of these four patterns varied with individual fish. Of the total number of tagged fish that could be classified (n=64), 67.1% displayed a single pattern, 31.2% displayed two patterns, and 1.5% exhibited three of the above patterns. Of these patterns there were 105 total classifications. The residents made up 2.8% of all estuarine use patterns. The seasonal inlet visitors made up 36.1%, seasonal estuarine visitors made up 49.5% , and seasonal river visitors made up 11.4% of all estuarine-use patterns. Of these, 58% of all tagged fish (n=67) that left the system returned in later seasons(42%) and years (16%) (proportions were standardized to two-year tags at large for one year).

Seasonal occurrence in the estuary was the result of departure and re-entry of individual fish (Fig. 2). The number of departures for individuals ranged from 0 to 7, whereas arrivals ranged from 0 to 6. In both years most departures and arrivals occurred in the spring and during the fall and early winter and not during mid-winter or summer. In 2003, most departures (n=27) from the estuary occurred between weeks 12 and 21 (late March–May) and again between weeks 39 and 48 (late September–mid November), whereas in 2004 departures (n=14) occurred later, during weeks 17–23 (mid May–mid June) and later (n=4) in weeks 27 and 45 (mid July and early November (Fig. 2). In 2003, most arrivals (n=4) were detected during weeks 40–46 (beginning October and early November) and earlier (n=2) during weeks 16–20 (mid May–beginning June), whereas in 2004 most arrivals (n=7) occurred during weeks 12–20 (mid March–beginning June) and later (n=17) during weeks 37–46 (mid September–mid November).

The departure and arrival times (Fig. 2) corresponded with the seasonal increase and decrease, respectively, of estuarine inlet temperatures (Fig. 3). In both years the number of departures (21% of total fish) and arrivals (21%) was low at temperatures <10°C and >20°C, respectively. During the period between these temperatures (when 79% of both departures and arrivals occurred), departures occurred at a mean of 13.9°C and arrivals occurred at a mean of 14.0°C. These temperatures typically occurred during the spring and fall (Fig. 3).

Patterns of arrival and departure were especially interesting for several individuals that revisited the study area during 2003 and 2004. The best evidence for frequent, seasonal re-entry and departure from the study estuary comes from the redetection of six striped bass tagged on 2 April 2003 at Graveling Point (Fig. 4). Of these, four returned and departed on several occasions. For three of these individuals (tags 95, 97, 99) the pattern of the timing of return and departure was nearly the same over several seasons (winter 2003, spring and winter 2004). Another individual (with tag 96) was redetected only once, but it reappeared (spring 2004) at the same time as the other individuals. Even those fish that were not redetected during a later season or year typically departed the estuary at the same approximate time (spring 2003 and spring 2004) as the other fish (Fig. 2). The close agreement in seasonal arrival to and departure from the estuary is probably the result of seasonal migrations during which fish enter this estuary, and probably other estuaries, on their migration south in the winter and north in the spring.

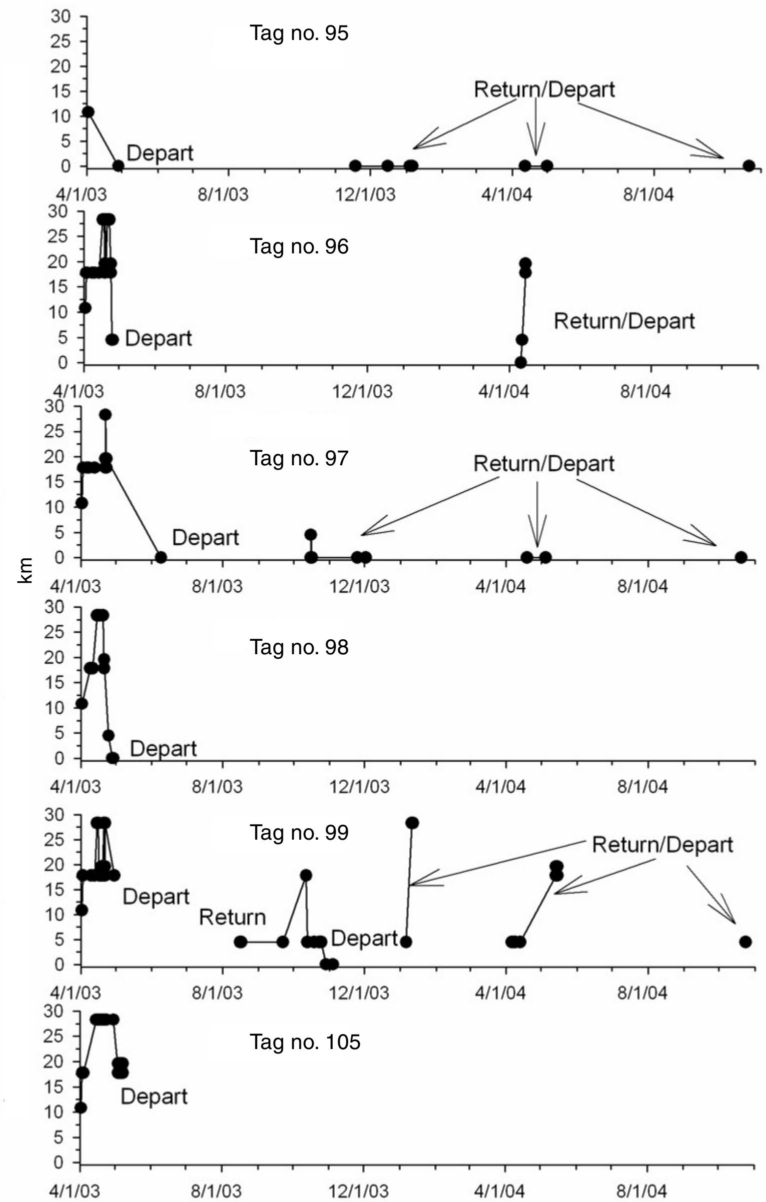

Figure 4

Occurrence and distribution of selected individual striped bass (*Morone saxatilis*) tagged on 2 April 2003 at Graveling Point. Filled circles indicate when there were detections by hydrophones. Distance upstream is from Little Egg Inlet gate (hydrophones 1–4, 13, reported as 0 km from the inlet) to Chestnut Neck gate (hydrophones 6–8, 18 km from the inlet), Lower Bank gate (hydrophone 10, 28 km from the inlet), and Sweetwater gate (hydrophone 12, 38 km from the inlet).

For fish that left the estuary, the last detection was most frequent in the vicinity of Little Egg Inlet where most detections occurred at hydrophones 2 (33%), 1 (23 %), and 4 (20%). Other final detections also occurred within the estuary at hydrophones 6 (9%), 7 (6%), 13 (3%), 5 (3%), and 8 (<1%). The last detection at relatively long distances from the inlet (hydrophones 6, 7, 8) may have resulted from departures during periods before hydrophone 13 was deployed.

Spatial and temporal patterns of striped bass within the estuary

Fish moved, as evidenced by hydrophone detections at selected gates, in a variable manner with respect to areas in the study site, seasons, and years (Figs. 4 and 5). Fish were frequently detected in the polyhaline portions near the inlet and in the estuary and less consistently in the river. The distribution of fish in the estuary varied by season; fish were detected at the inlet gate (hydrophones 1–4) during all seasons, whereas fish detected in spring were more frequently found farther up at the estuary gate (hydrophones 5–9, 13) or farther upstream at the river gate (hydrophones 10–11). However, few fish were detected during the winter at any gate. These general patterns of estuarine use varied between years. A strong peak in estuarine users occurred in the spring (weeks 14–21) of 2003, but there were fewer users in 2004. Modest peaks in inlet and estuarine users occurred in the fall (weeks 34–48) in both years. The sole peak in river use occurred in spring (weeks 14–20) of 2003.

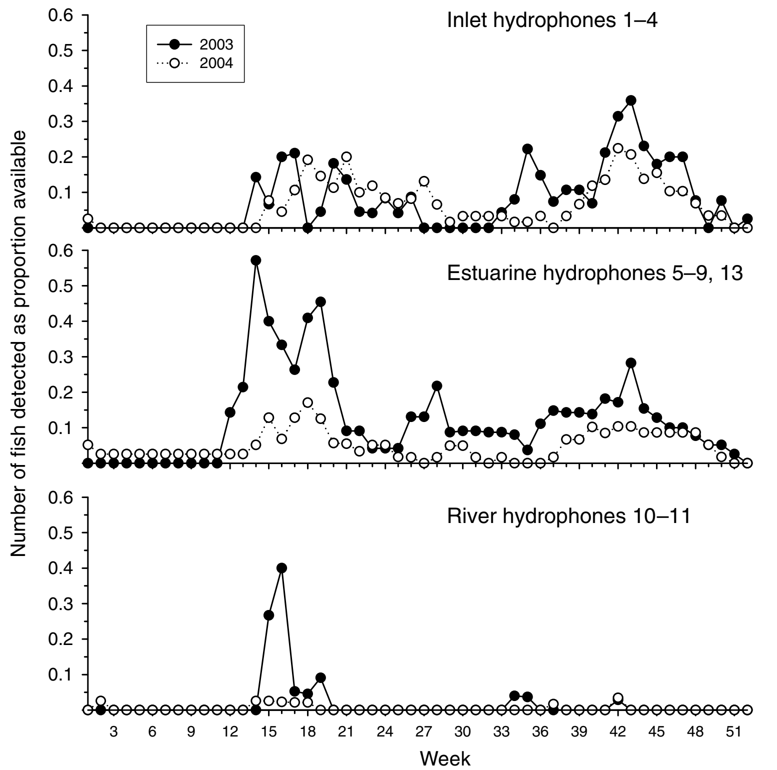

Figure 5

Annual variation in number of fish detected, by week in the inlet, by estuary, and at river gates. See Figure 1 for locations of gates.

The degree of residency and movements within the estuary varied among individuals over time for a given individual. Some individuals were resident in one portion of the estuary for long periods of time. This finding was substantiated by the long duration of detections for some individuals in the vicinity of the inlet. For example, two fish (n=1273 contacts and 280 cumulative hours of detection) spent 91% and 58% of their time, respectively, at the inlet, even though they were detected at two other gates. Together these types of patterns account for the preponderance of detections in the vicinity of the inlet and for the somewhat lower detections upstream. Another fish, with one of the longer time records (n=1190 hours of detection) was detected at all gates in the study area. Alternatively, some fish were consistently detected farther up the estuary. For example, one fish (n=154.5 hours detected) was detected frequently in the vicinity of Chestnut Neck (75% of the time).

Other individuals, although not detected as frequently, appeared to be resident for relatively long periods. For example, two fish were consistently found farther up the estuary over several months and we interpreted this period as residency. The lack of frequent detections implies that this residency occurred in areas between hydrophone gates. Active telemetry of individual fish confirms this interpretation (Ng, 2006; Ng et al., in press). Movements in the study area were often dynamic; individual fish moved large distances over short periods. Several individuals moved quickly upstream after being tagged lower in the estuary during the spring. Of six individuals tagged on 2 April 2003, five moved upstream 7–10 km into the area of the freshwater-saltwater interface (near Lower Bank, approximately 28.3 km from Little Egg Inlet) or farther into completely freshwater in the vicinity of Sweetwater (approximately 38.1 km from Little Egg Inlet) (Fig. 4). These same upstream movements occurred for 3 of 4 fish tagged at Graveling Point on 2 May 2003. More extensive movements were detected for all 3 fish tagged on 22 April 2004 at Little Egg Inlet. All of these fish moved 17–19 km upstream and were detected at the same locations as those of the previous fish.

Upstream movements were relatively quick. The speed of fish passing upstream from Little Egg Inlet to Chestnut Neck ranged from 0.3 to 2.4 km/h (n=10 fish) and from Chestnut Neck to Lower Bank ranged from 0.09 to 0.5 km/h (n=11 fish). The subsequent movement downstream followed quickly (within a few days) for most fish, but the range of speeds during these movements overlapped with the speed of upstream movements from Lower Bank to Chestnut Neck (0.1–0.3 km/h, n=11 fish) and from Chestnut Neck to Little Egg Inlet (0.1–2.2 km/h, n=12). Perhaps the slower movements between Chestnut Neck and Lower Bank reflect the steeper gradients in salinity, temperature, and especially pH in this region (Fig. 3). Although most of these movements occurred during the spring, others of similar magnitude occurred at other times of the year, as was the case for one fish during the winter of 2004 (Tag no. 99, Fig. 4).

Discussion

Annual and seasonal visits to the estuary

The seasonal visits of many tagged striped bass to this estuary reflect their seasonal migrations up and down the east coast of the United States. This seasonal migration to the south in the fall and winter and to the north in the spring and summer has been observed from prior tag-recapture studies (e.g., Boreman and Lewis, 1987; Waldman et al., 1990). The coastal ocean migrations of larger juvenile and adult striped bass must influence the timing and duration of their occurrence in estuaries. These patterns differ along the east coast of the United States and thus have to be taken into consideration when evaluating occurrences in the study area. In general, populations from North Carolina and southward are considered riverine and do not make coastal migrations, whereas those from Chesapeake Bay to the Bay of Fundy are generally considered to be anadromous and highly migratory (see Rulifson and Dadswell, 1995; Haeseker et al., 1996; Bjorgo et al., 2000 for reviews of the relevant literature), with the exception of the population of the St. Lawrence estuary which is believed to be resident (Coutant, 1985). Thus, it is not surprising that large juvenile and adult striped bass from the Mullica River–Great Bay estuary frequently left the estuary for extended periods. This interpretation is supported by the recapture by hook and line of fish we tagged in the study area at a variety of locations along the coast (northern New Jersey, south shore of Long Island, New Hampshire) and implies the same seasonal migration pattern. Further support is based on the detection of one striped bass tagged in the Mullica River–Great Bay and later detected in the Saco River, Maine, in a similar observation site (Carter[2]) and fish tagged at Saco River, Maine, that have been detected in the southern New Jersey study estuary (n=3) (Able and Grothues, pers. observ.). Earlier tag-recapture studies found striped bass in the Mullica River–Great Bay estuarine system that had been tagged on the south shore of Long Island and northern New Jersey (Clark, 1968).

This study is one of the few that presents data on the high (58%) and seasonal rate of return to an estuary. Most of these returns occurred in the spring and fall when water temperatures were 10–20°C. Annual returns to the same estuary have also been reported in Chesapeake Bay tributaries for a few individuals (n=9) where the returns were assumed to be related to spawning (Hocutt et al., 1990). Many of the instances of fidelity of tagged striped bass to the Mullica River–Great Bay system were the result of detections at the inlet and not farther up the estuary. One possible interpretation is that these fish enter numerous inlets during the north and south coastal ocean migrations, thus providing the relatively high frequency of detections at the study site. This idea could be tested at observation sites in other estuaries.

Spatial and temporal patterns within the estuary

Movements within the estuary were frequently dynamic and were most likely to occur in the spring and fall. The spring movements of several fish tagged near Little Egg Inlet and near Chestnut Neck were commonly upstream to the vicinity of the freshwater-saltwater interface (Fig. 4). These were typically quick movements followed by similarly rapid movements downstream and into the ocean. The short duration in the riverine portion of the study area may reflect the avoidance of the low pH that typically occurs in this system (Fig. 3). These brief visits in the study area were very different from those found in a pilot study (n=4 males, 5 females) in upper Chesapeake Bay tributaries, which indicated a long residence time in the spawning areas (30 days) at least for males (Hocutt et al., 1990). Similarly, in the Roanoke River in North Carolina males remained on the spawning grounds for 21–22 days and females for 8–11 days in different years (Carmichael et al., 1998). The timing and types of movement in the study area, although consistent with an upstream movement for spawning, do not appear to be consistently successful. Some spawning does occur in the upstream portion of the estuary (see Hoff[3] for accounts of egg and larvae collections). However, numerous collections in this estuary with a variety of gears, such as otter trawls (Martino and Able, 2003), seines (Able et al., 1996), traps (Able et al., 2006), and weirs (Able et al., 1996), have yielded less than 20 young-of-the-year (YOY) (<100 mm FL) striped bass. Over the same period, we have frequently collected numerous YOY striped bass in

[2] Carter, J. 2005. Unpubl. data. Department of Life Sciences, Univ. New England, 11 Hills Beach Road, Biddeford, ME 04005.

[3] Hoff, H. K. 1976. The life history of striped bass, *Morone saxatilis* (Walbaum), in the Great Bay-Mullica River estuary and in the vicinity of Little Egg Inlet. *In* Ecological studies in the bays and other waterways near Little Egg Inlet and in the ocean in the vicinity of the proposed site for the Atlantic Generating Sation, New Jersey (C. D. Milstein, and D. L. Thomas, eds.), p. 43–53. Progress Report for the period January–December 1975. Public Service Electric and Gas Company, 80 Park Plaza T-17-A, Newark, NJ 07101.

similar sampling programs in Delaware Bay (Nemerson and Able, 2003) and in the New York–New Jersey Harbor Estuary (Able and Duffy-Anderson, 2006). The short period of residency in upstream portions of the Mullica River may indicate the testing and then rejection of the area as a spawning site.

This study confirms that there are multiple ways in which striped bass use small estuaries, such as that of the study area, as there are multiple ways in which striped bass use larger systems such as the Hudson River (e.g., Secor et al. 2001). Further, the movement patterns observed in this study may be more diverse and variable than previously reported because the same fish can exhibit different patterns in different seasons and years. This diversity implies that the behavior at the individual level may be as, or more important (Sutherland, 1996; Slotte and Fikson, 2000) than, that at the level of the stock, contingent, or population level and thus is necessary to understand how striped bass use estuarine ecosystems and how biologists can manage natural populations.

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