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Movement patterns of striped bass (*Morone saxatilis*) in a tidal coastal embayment in New England

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ABSTRACT

Striped bass (*Morone saxatilis*) are important in commercial and recreational fisheries along the western Atlantic coastline. Although there is a good understanding of their seasonal migration patterns, less is known about the short-term movements of striped bass once they have reached New England coastal embayments during the summer months. Movement patterns were assessed by tagging 35 striped bass (38.5–80.5 cm TL) with acoustic transmitters and tracking them within a fixed array (n = 34 receivers) in Plymouth, Kingston, Duxbury (PKD) Bay, MA. The majority of tagged striped bass took up residency within PKD Bay for the summer months. Large juvenile through sub-adult (21–46 cm) and adult bass (>46 cm) remained residents of PKD Bay for periods of 6–75 days and appear to use the estuary as a vital summer foraging area before emigrating from the bay for their southward migration. Changes in activity space estimates were significant over the course of the season and increased with water temperature. There was a general increase of activity space preceding emigration where presence of striped bass was significantly related to water temperature and photoperiod. Various environmental factors influence striped bass movement, and it is important to understand individual patterns and behavioral ecology to make the most educated management decisions.

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1. Introduction

Striped bass (*Morone saxatilis*) are highly targeted along the Atlantic coastline of the United States and are an important source of revenue for the commercial and recreational fishing industries (Werner, 2004). Overfishing and poor environmental conditions caused the collapse of Atlantic striped bass stocks in the late 1970's (Karas, 1993). Since then, federal protection of the species coupled with strict state management regulations have aided in the coastwide recovery of the stock and a concomitant rejuvenation of commercial and recreational fisheries for the species. Despite the relative health of the striped bass fishery over the last decade (ASMFC, 2013), continual management is necessary to maintain sustainable fisheries in the face of issues such as habitat loss, lack of prey, fishing mortality, mycobacterial infections, and pollution (Karas, 1993). A healthy fishing industry is fundamental to the nation, especially in coastal regions, bringing both social and economic benefits with its popularity (Cooke and Cowx, 2004; Arlinghaus et al., 2007).

Striped bass are anadromous and highly migratory along the Atlantic coast of North America (Clark, 1968; Boreman and Lewis, 1987; Dorazio et al., 1994; Walter et al., 2003). A large percentage of striped bass follow a seasonal migration route (Clark, 1968), traveling south in the fall and north in the spring to spawn (Boreman and Lewis, 1987; Karas, 1993; Grothues et al., 2009). Coastal migratory stocks spend much of the summer in New England estuaries as well as offshore areas with large concentrations of seasonal forage fish (Kohlenstein 1981; Waldman and Fabrizio, 1994; Nelson et al., 2006; Mather et al., 2009). Studies on the movement patterns of striped bass have predominantly used external tagging methods (reviewed in Clark, 1968; Kohlenstein 1981; Boreman and Lewis, 1987; Dorazio et al., 1994; Waldman and Fabrizio, 1994). More recent methods have addressed topics examining seasonal activity patterns (Wingate and Secor, 2007; Pautzke et al., 2010), site fidelity and habitat use (Ng et al., 2007), spawning behavior (Hocutt et al., 1990; Douglas et al., 2009), and responses to tem-

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perature and drought (Baker and Jennings, 2005). Interestingly, striped bass movement patterns while on their summer grounds in New England coastal estuaries has just recently been focused upon (see Mather et al., 2009; Pautzke et al., 2010; Kneebone et al., 2014). Estuarine dependency during early life stages is obligate and remains important throughout the life of the fish (Secor et al., 2000). It is also believed that these estuaries provide important foraging grounds for striped bass before their annual migration (Nelson et al., 2006; Pautzke et al., 2010) and that striped bass have strong site fidelity to non-natal estuaries (Ng et al., 2007; Able et al., 2012). Recent acoustic tagging studies within the natal Hudson River, New York (Wingate and Secor, 2007) and non-natal Mullica River—Great Bay, New Jersey (Able and Grothues, 2007; Ng et al., 2007; Grothues et al., 2009) and Plum Island Estuary, Massachusetts (Pautzke et al., 2010) estuaries provide the first examples of multiple-detection movement data for individual coastal striped bass.

Quantifying movement patterns of fish in space and time is important for understanding the fundamentals of their natural history, ecological interactions, and habitat requirements (Cooke et al., 2008; O'Toole et al., 2010). A collective understanding of each of these dynamics is also critical for the effective management and conservation of exploited species (Lowe et al., 2003; Cooke et al., 2004). The objective of our study was to quantify the movement and activity patterns of large juvenile and adult striped bass in a New England bay. To do so, we capitalized on the use of acoustic transmitters within a large-scale fixed array deployed across a range of habitat types and predicted that striped bass would exhibit strong fidelity to PKD Bay over the extent of the summer and that activity would correlate to temperature of the bay.

2. Materials and methods

2.1. Study site

Plymouth, Kingston, and Duxbury (PKD) Bay is a coastal embayment located approximately 50 km south of Boston, Massachusetts (centered at 42° 42′41.59″N, 70° 47′41.89″W; Fig. 1) that serves as a popular fishing destination for recreational anglers targeting striped bass during the summer months (U.S. Fish and Wildlife Service, 2008). PKD Bay is bound on its east end by two barrier beaches separated by a 1.6 km wide inlet, connecting the embayment to Cape Cod Bay. Characteristics of PKD Bay include large channels surrounded by sand and mud flats, salt marshes, tidal creeks that can be exposed at low tide (Iwanowicz et al., 1974), as well as a small residential island (Clarks Island) whose northern portion consists of rocky outcroppings and eelgrass (*Zostera marina)* bed habitat. There are also several important freshwater inflows to PKD Bay, including Jones River in Kingston, the Back River and Bluefish River in Duxbury, and the Eel River in Plymouth. Tidal exchange is semidiurnal with a mean tidal amplitude of 3.2 m. On average, the total surface area of the bay fluctuates between 22.1 and 40.7 km^2 at mean low and mean high water, respectively, resulting in a 66.1% tidal exchange in water volume (Iwanowicz et al., 1974). PKD Bay is relatively shallow with a mean depth of 2–3 m and a maximum depth of 20 m at high tide.

2.2. Receiver array

An array of 34 fixed acoustic receivers (VR2W, Vemco Division, AMIRIX Systems Inc., Halifax, Nova Scotia) was deployed from May 5, 2011 through October 30, 2011 (Fig. 1). Receivers were deployed on the substrate approximately 1 m above the estuary floor, or suspended 1–2 m below the surface on a line attached to navigational markers. Receivers were arranged to maximize coverage in the bay while creating nodes that correspond with transitions between habitat types (e.g., shallow flat to deep channel). A curtain of receivers was deployed across the mouth of PKD Bay to capture movements of tagged fish in and out of the bay. Data from receivers were downloaded and receivers cleaned monthly during the deployment period. Thirteen water temperature loggers (model HOBO Pendant, Onset Computer Corporation, Onset, Massachusetts) were deployed at several receiver locations throughout the estuary (Fig. 1). The loggers were programmed to record temperature (°C) every 30 min with an accuracy of ±0.7 °C (range −20–70 °C, Onset Computer Corporation, Onset, Massachusetts).

Receiver working detection range was tested on a subset of receivers positioned at various depths and substrates immediately following deployment or the array (e.g. tidal flats and channels; Kneebone et al., 2012). During each trial, a stationary control tag was moored at 50, 100, 200, 300, 400, and 500 m away from the receiver in all four cardinal directions for 5 min. Time and GPS location were recorded, and the number of detections was monitored by a manual hydrophone (VR-100, Vemco Division, AMIRIX Systems Inc., Halifax, Nova Scotia) at each moored location. The detection radius of receivers ranged from ∼100 m in water depths <3 m to ∼350 m at depths >5 m. Also, the receivers positioned in 'deep' (>3 m at low tide) channels did not show a symmetrical detection range in all cardinal directions; the range was much greater along the axis of the channel and reduced in shallower water along each side of the channel. Although the overall detection range for some receivers was reduced during low tide, striped bass were mostly restricted to deeper channels during these periods (i.e., much of the submerged area goes dry at low tide), where the detection range remained high. Thus, striped bass could be detected throughout the entire tidal cycle and data correction to account for receiver range was unnecessary.

2.3. Capture and tagging

Striped bass were caught across a range of sizes and life stages using hook and line fishing techniques and gear across a range of habitats within PKD Bay. A variety of artificial lures, including soft plugs and fly lures were used ranging in size from 5 to 15 cm with 1–3 barbed hook points. Cut bait consisting of Atlantic mackerel (*Scomber scombrus*) and Atlantic menhaden (*Brevoortia tyrannus*) was also used when available. All striped bass were angled in less than 5 m of water.

Acoustic transmitters (model V9AP-1L, 9 mm diameter, 46 mm long, 6.3 g in air, 50 m depth range, min and max delay times 60 and 180 s, 160 day battery life; Vemco Inc., Halifax, Nova Scotia) were implanted in 35 striped bass during three separate periods in 2011: early-July, mid-August, and mid-September. Once landed, each fish was removed from the water, dehooked and anesthetized in a MS-222 bath (50–100 mg/L). Once fish were anesthetized (showing signs of stage-4 anesthesia, characterized by a complete loss of equilibrium and no response to handling (Summerfelt and Smith, 1990)), they were transferred to a V-shaped surgery table lined with pre-wetted neoprene and a small plastic hose connected to a pump (Little Giant, model PES-100, 95 gal/h, adjustable flow, Fort Wayne, Indiana) was placed in their mouth to deliver continuous fresh seawater running over the gills. Transmitters were then implanted in the body cavity through a small (2–3 cm) abdominal incision on the ventral side of the fish, and the incision closed with 2–3 interrupted sutures (Ethicon 3-0 PDS II, Johnson and Johnson, New Jersey). All surgeries were performed by the same trained surgeon. Immediately following surgery, striped bass were measured (total length (TL) to the nearest cm) and released into a floating mesh holding pen (1.2 m × 1.2 m × 1.2 m, 1.5 cm mesh, Memphis Net & Twine Co., Memphis, Tennessee) alongside the boat to recover. Fish were

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