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White perch *Morone americana* (Gmelin, 1789) habitat choice and movements: Comparisons between *Phragmites*-invaded and *Spartina* reference marsh creeks based on acoustic telemetry

K.M.M. Jones [a], P.E. McGrath [b], K.W. Able [c,*]

[a] Department of Biology, Cape Breton University, 1250 Grand Lake Road, Sydney, Nova Scotia B1P 6L2, Canada
[b] Virginia Institute of Marine Science, College of William and Mary, P.O. Box 1346, Gloucester Point, VA 23072, USA
[c] Marine Field Station, Institute of Marine and Coastal Sciences, Rutgers University, 800 c/o 132 Great Bay Boulevard, Tuckerton, NJ 08087-2004, USA

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ABSTRACT

An investigation of the effects of the *Phragmites* invasion on movements and habitat use focused on ultrasonic telemetry of white perch (*Morone americana*) throughout Alloway Creek, Delaware Bay, New Jersey. Of the individuals tracked (192–266 mm FL), there was high site fidelity (19 out of 30 individuals) but there was also variability in movement patterns, home range size, and habitat use. On average, individual fish spent most of their time stationary (67%), and substantially less time moving (22%) and tended to move up creek with flooding tides, and down creek with ebbing tides. Higher movement levels occurred at mid-ebb and mid-flood stages when water velocity was at its highest. Eighteen individuals had tidal excursions — either long distance movements with the tide or excursions onto the marsh surface or into shallow creeks at high tide. Individuals originally tagged in *Spartina* creeks tended to utilize only *Spartina* areas (12/13 tagged fish stayed in *Spartina*), whereas none of the individuals tagged in *Phragmites* creeks stayed in *Phragmites* areas (0 out of 5 tagged fish). These results suggest that the tagged individuals did not prefer *Phragmites* habitats. Further, this study indicates that it is important to consider animal behavior such as movement patterns, home range area and habitat use when evaluating the effectiveness of restoration programs. Such measures can provide insight into why altered habitats differ from reference sites in terms of quality, identify critical resources for animals and enhance our understanding of how animals contribute to ecosystem function.

1. Introduction

Over the past several decades, marshes formerly dominated by *Spartina* spp. (hereafter *Spartina*) have been invaded by the common reed, *Phragmites australis* (Cav.) Trin. ex Steud (hereafter *Phragmites*), throughout the northeastern United States (Chambers et al., 1999; Havens et al., 1997; Meyerson et al., 2000; Windham and Lathrop, 1999) and including Delaware Bay (Weinstein and Balletto, 1999). The *Phragmites* invasion has resulted in considerable interest in its effects on the ecological functions of marsh habitat. Studies have suggested that the clearest impacts of *Phragmites* occur on the marsh surface (Weinstein and Balletto, 1999; Windham and Lathrop, 1999). The hydrological and physical changes that accompany the conversion of a *Spartina*-dominated marsh to a *Phragmites*-dominated marsh have deleterious effects on the presence of early life stages of mummichog *Fundulus heteroclitus* (Linnaeus, 1766) (Able and Hagan, 2000, 2003; Able et al., 2003, 2008; Hunter et al., 2006; Raichel et al., 2003) and other small prey fishes (e.g. Able and Fahay, 1998; Able et al., 2004; Grothues and Able, 2003a,b; Nemerson and Able, 2004). Few studies have investigated the impact of the *Phragmites* invasion on higher trophic levels, such as piscivorous fishes that utilize the intertidal and subtidal marsh creeks except our own (Nemerson and Able, 2004; Neuman et al., 2004).

Our prior studies have determined that if there are impacts on marsh surface assemblages that are going to be detected in higher trophic levels, white perch would be the best focal species for investigation. This is due to three main reasons: 1) this species is the numerically dominant piscivorous predator in oligohaline marshes of Delaware Bay (Able et al., 2001, 2007, 2009; Jones and Able, in review), 2) they are considered marsh residents for much of the year (Mansueti, 1961) and appear to have a limited home range during certain times of the year (McGrath and Austin, 2009), and 3) fundulids figure more prominently in their diets compared with other predators in marshes (Nemerson and Able, 2004). Our primary objective was to evaluate

* Corresponding author at: 132 Great Bay Blvd, Tuckerton, NJ 08087, USA. Tel.: +1 609 296 5260x230.
E-mail address: able@marine.rutgers.edu (K.W. Able).

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the response of white perch to marsh restoration by investigating differences in home range and movement patterns in habitats that are *Phragmites*-dominated, *Spartina*-dominated, and approximately equal in densities of *Spartina* and *Phragmites* (mixed) by comparing: 1) movement patterns, 2) site fidelity, and 3) home range size. Incorporating measures of animal behavior such as home range and activity patterns into evaluations of restoration success provides critical information about why reference and restoration sites may differ in habitat quality (e.g. Lindell, 2008; Persson and Stenberg, 2006), identifies critical resources for animals, and documents how animals contribute to ecosystem function (Lindell, 2008).

2. Materials and methods

2.1. Study sites

Delaware Bay, one of the largest estuaries on the east coast of the United States is the site of one of the world's largest (5040 ha) tidal marsh restoration projects (Weinstein et al., 2001). It has been designed and implemented by the Estuary Enhancement Program (EEP) of the Public Service Enterprise Group (PSEG) to increase fish production to mitigate the loss of nekton to once-through cooling at the Salem Generating Station in Delaware Bay (Balletto et al., 2005; Weinstein et al., 2001). In the lower salinity portions of the upper Delaware Bay, the restoration focus was on the eradication of the common invasive reed, *P. australis*. Eradication treatments using Rodeo and a surfactant followed by prescribed burning occurred from 1996 throughout the duration of this project, as part of the Public Service Enterprise Group—Estuary Enhancement Program (PSEG—EEP).

This study occurred at Alloway Creek (N 39° 29′ W 75° 31′; Fig. 1), and is described in detail elsewhere (Able et al., 2001) including initial observations of the response to restoration of former *Phragmites* dominated habitats (Jones and Able, in review). All white perch tagged in this study were captured in intertidal or subtidal creeks adjacent to marshes dominated by three types of habitats: 1) monoculture stands of *P. australis* (*Phragmites* sites), 2) monoculture stands of *Spartina* spp. (*Spartina* sites), or 3) a combination of mixed vegetation, i.e. creeks that had different vegetations on either side of the creek, or had heterogeneous patches of *Phragmites*, *Spartina*, and/or marsh treated for *Phragmites* control.

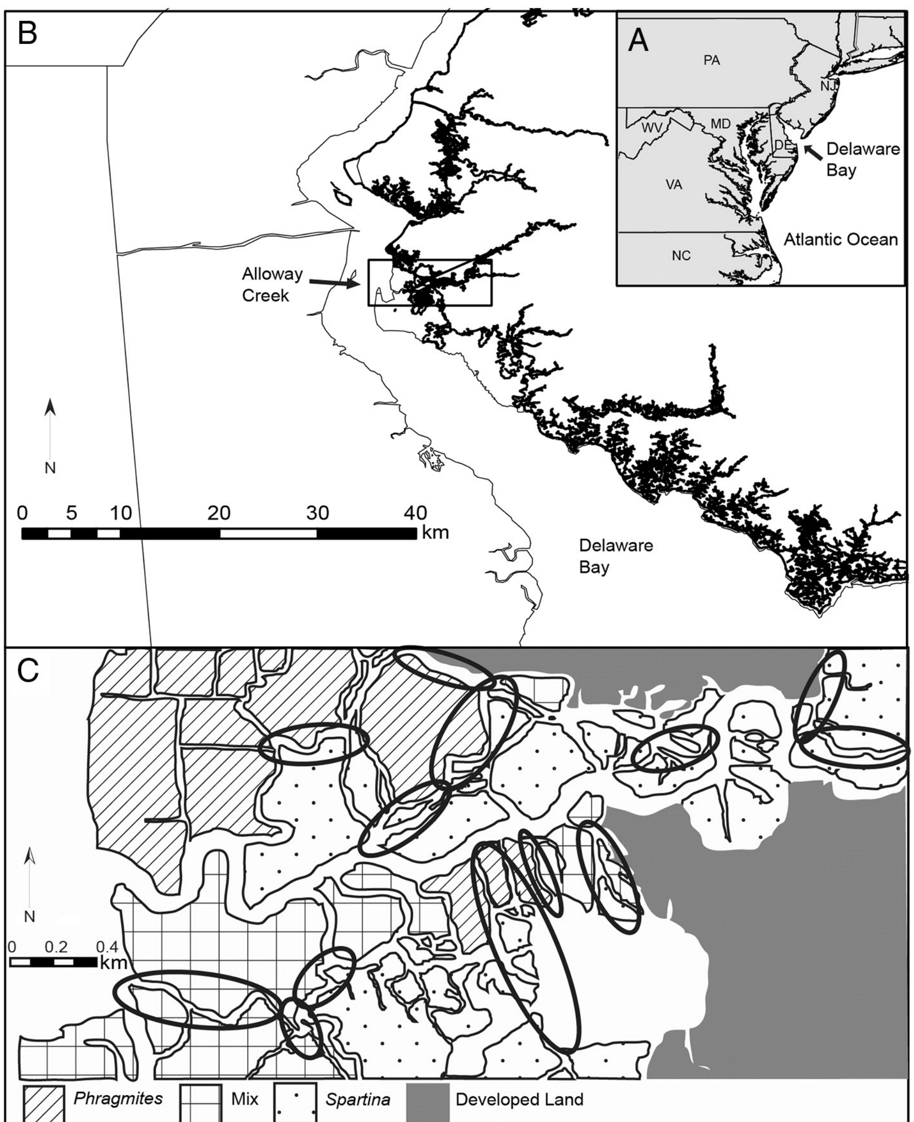

Fig. 1. Delaware Bay study area: A) location of Delaware Bay and B) location of Alloway Creek. C) Marsh vegetation designations within the Alloway Creek system. Locations of fish tracking areas are depicted by ellipses in each habitat type.

2.2. Specimen capture and tagging

White perch (n = 5) were caught and tagged during a preliminary study in the fall of 2011 and then a larger number of fish (n = 25) were tagged during the summer and fall of 2002. White perch were caught using monofilament experimental gill nets (5 multi-mesh panels; 2.4 m high × 13.5 m wide; mesh sizes of 2.5, 3.8, 5.1, 6.4, or 7.6 cm). Four nets were deployed at one time for 30 ± 5 min. All white perch caught in the gill net were measured (fork length (FL); ±1.0 mm) and only those perch >200 mm FL (with two exceptions: 192 and 195 mm) were used for this study.

Ultrasonic transmitters (Sonotronics Mini Sonic Pinger (IBT-96-1), 23 mm × 8 mm, 21 day battery life, 1.5 g in water) were surgically implanted in the peritoneal cavities following procedures previously used (Mulford, 1984; Tupper and Able, 2000). Each individual was anesthetized in a bucket containing 120 mg L^{-1} of MS-222 (Sigma) dissolved in ambient Alloway Creek water. An incision was made approximately mid-way between the anus and the base of the pelvic fins with a sterilized disposable scalpel. The sonic tag was coated in Neosporin® antibiotic ointment, inserted into the body cavity and the incision was closed with a skin stapler. The staples and incision were then coated in Neosporin® and the fish was placed in a recovery tank for 20 min. Tagged fish appeared to be fully recovered prior to release at the location of capture. Minimal impacts of surgery and tag implantation were revealed during a tag retention study conducted at RUMFS in 2001 (unpublished data).

2.3. Tracking of tagged fish

All fish were tracked using a USR-5W receiver (Sonotronics) and a DH-4 directional hydrophone (Sonotronics) from a 4.9 m long Boston Whaler or 3.8 m long Perception kayak. The boat/kayak operator wore headphones to monitor the signal, and turned the hydrophone to locate the direction of maximum signal strength. Tracking fish by kayak has been used in other studies (e.g. Meyer and Holland, 2001) and is beneficial in shallow water and narrow intertidal creeks, such as our study site at Alloway Creek.

Fish tracked by investigators in a Boston Whaler had GPS coordinates (Garmin eTrex) and environmental parameters (dissolved oxygen, temperature, and salinity; YSI Model 85) recorded every 15 min. The locations of fish tracked by kayaks were plotted on waterproof maps. Positional data and environmental parameters were also collected when the support vessel rendezvoused with the kayak. For both types of tracking, the dominant above-ground marsh vegetation was recorded every 15 min.

Each fish was tracked continuously for a minimum of four consecutive hours post-surgery. After the initial four hour observation period, fish were tracked during the day and night (from 08:00 to 24:00–02:00 the next morning) on numerous tracking sessions, lasting for a total of 4 to 18 h. Two kayaks and a motor boat tracked three individual fish per tracking session. However, the larger boat would also determine “snapshot” locations of other white perch while en route to rendezvous with the kayaks. Fish searches lasted anywhere from 20 min to 1 h until either the fish was found, or the search was aborted to move onto another fish.

2.4. Data analysis

Coordinates (GPS) of fish locations were incorporated into ArcView® 3.1 and analyzed with respect to temperature, salinity, dissolved oxygen, tidal stage, and time of day. Tidal stage was broken into three equal time frames for both ebb and flood tides. Time of day was divided into day and night based on the time of sunrise and sunset. Data associated with tidal stages and times of day were interpreted as percentages and therefore were not analyzed statistically.

Fish locations were analyzed with the Animal Movement Analyst Extension (AMAE) 2.2 and Spatial Analyst Extension 1.1 (Hooge and Eichenlaub, 1997). Statistical analysis began with a Monte Carlo random walk simulation to test for site fidelity. One thousand random walks were compared to a fish's actual path. Site fidelity is confirmed when the actual path has neither significant dispersion nor significant linearity compared to the random walks (Hooge et al., 2001). Further analyses of home range and utilization distributions were only performed if site fidelity was established.

Minimum Convex Polygons (MCPs), constructed by connecting the outer points of an animal's movements, were used to quantify the home range of each fish displaying site fidelity. In the present study, MCPs were corrected by removing any area covered by land and forcing polygons to follow the marsh creek banks. Cumulative home ranges were calculated with MCPs to decide if the life span of the tag was long enough to determine a white perch's home range area. Cumulative home ranges were produced by plotting the area tracked after day one, day one and two, and so on until the full home range was achieved. Where the graphs start to asymptote indicates the number of days required to understand the full home range area (McGrath and Austin, 2009; Odum and Kuenzler, 1955).

Kernel density (KD) estimation was used to determine the distributions and preferred sites within the home range area (Anderson, 1982; Hemson et al., 2005; Jenrich and Turner, 1969; Worton, 1989). A value of 15.0 was selected for the smoothing parameter, h, (Silverman, 1986) because it was fine enough so as not to show much of each fish's range on land, did not depict irrelevant ranges, and allowed for comparison to McGrath and Austin (2009). Using a common smoothing factor also enabled statistical comparisons among fish. The kernel density isopleths used in this analysis were the 95% contour (95% KD) as the total utilization distribution and the 50% contour (50% KD) as the core area of activity (Hooge et al., 2001). The home range parameters (MCP, 95% KD, 50% KD, and number of core areas) were statistically compared between the three habitats using a single factor ANOVA at a probability level of 5%.

3. Results

3.1. Characteristics of tagged fish

During the preliminary tracking study in 2001, five white perch were caught, tagged, and tracked between September 19 and October 11 at various locations throughout Alloway Creek. The data from these five fish are presented with the data from the 25 fish that were caught, tagged, and tracked in 2002 between June 20 and October 8 (Table 1). *Phragmites* and mixed vegetation habitats each had two fish that were not detected after the date of tagging. These four fish were removed from all subsequent analyses. During both years, tagged white perch were successfully located 2880 times, tracked for 961 h, and had a total of 437 days at liberty. Tagged white perch ranged in size from 192 to 266 mm FL and were of similar mean size in the three types of habitats (*Spartina* = 218.6 ± 18.9 mm;mixed = 222.5 ± 20.6 mm; *Phragmites* = 211.4 ± 4.8 mm). Thirteen white perch were tagged in *Spartina* habitat, while five fish were tagged in habitat dominated by *Phragmites*. The other 12 fish were tagged in a location with a mix of *Spartina* and *Phragmites*.

Tagged white perch, on average, were located more often when tracked in either *Spartina* (16.5 ± 6.0 days; 42.0 ± 20.1 h; 103.5 ± 34.2 acoustic contacts) or mixed vegetation (16.8 ± 10.2 days; 29.3 ± 15.6 h; 107.3 ± 56.5 acoustic contacts) and much less often in *Phragmites* (4.4 ± 4.1 days; 12.4 ± 10.5 h; 49.4 ± 41.8 acoustic contacts) (Table 1). Tagged white perch were more often relocated in the same location than a new location, 67% versus 23% of the acoustic contacts, regardless of habitat type. Movements to a new position occurred during all stages of the tide but slightly more frequently during mid-flood tide (Fig. 2). Eighteen of the twenty six tagged white perch

Table 1
Characteristics of individual white perch in Alloway Creek, Delaware Bay. MCP = minimum convex polygon area, KD = kernel density (95%, 50%) area, and number of core areas.

Year	Marsh habitat	ID	Size (mm FL)	Date caught	Days tracked	Hours tracked	Acoustic contacts	Site fidelity	MCP (km^2)	95% KD (km^2)	50% KD (km^2)	Core areas
2001	SPART	1	209	Sept. 19	21	44.25	148	YES	0.171	0.042	0.003	3
	MIXED	2	220	Sept. 20	22	19.75	72	NO	NA	NA	NA	NA
	MIXED	3	250	Sept. 25	5	23.5	94	NO	NA	NA	NA	NA
	PHRAG	4	216	Sept. 26	1	6.75	28	NO	NA	NA	NA	NA
	PHRAG	5	215	Oct. 2	4	7.5	29	NO	NA	NA	NA	NA
2002	MIXED	6	250	June 20	28	41.25	165	YES	0.232	0.052	0.002	6
	MIXED	7	228	June 20	28	40.25	161	YES	0.047	0.033	0.003	5
	PHRAG	8	204	June 20	11	29.5	118	NO	NA	NA	NA	NA
	MIXED	9	244	June 24	1	1.75	7	NO	NA	NA	NA	NA
	MIXED	10	210	June 25	1	2	12	NO	NA	NA	NA	NA
	SPART	11	222	July 22	15	60	169	YES	0.015	0.011	0.001	1
	SPART	12	212	July 22	18	37.25	111	YES	0.028	0.013	0.001	1
	PHRAG	13	212	July 23	1	3.25	13	NO	NA	NA	NA	NA
	MIXED	14	234	July 25	21	40	140	YES	0.053	0.022	0.001	1
	MIXED	15	192	July 25	15	34.25	154	NO	NA	NA	NA	NA
	MIXED	16	234	July 29	23	41.75	149	YES	0.077	0.016	0.002	1
	SPART	17	201	Aug. 19	24	39.25	131	YES	0.007	0.010	0.001	2
	SPART	18	221	Aug. 19	9	35	140	YES	0.125	0.023	0.002	3
	MIXED	19	200	Aug. 20	29	50.75	158	YES	0.026	0.019	0.001	2
	MIXED	20	211	Aug. 21	16	24	93	YES	0.014	0.021	0.001	1
	SPART	21	228	Sept. 2	8	21.25	77	YES	0.003	0.006	0.001	1
	SPART	22	200	Sept. 2	5	19.25	70	YES	0.010	0.011	0.002	3
	PHRAG	23	210	Sept. 2	5	15	59	NO	NA	NA	NA	NA
	SPART	24	204	Sept. 16	18	42	98	YES	0.016	0.009	0.001	2
	SPART	25	220	Sept. 16	23	72.25	98	YES	0.006	0.005	0.002	1
	SPART	26	195	Sept. 16	23	79.5	78	YES	0.014	0.008	0.001	1
	SPART	27	266	Sept. 16	18	56.75	94	YES	0.003	0.005	0.001	1
	MIXED	28	197	Sept. 19	12	32.75	83	YES	0.007	0.012	0.002	3
	SPART	29	229	Sept. 23	16	18.75	58	NO	NA	NA	NA	NA
	SPART	30	235	Sept. 23	16	21	73	YES	0.012	0.020	0.002	2

underwent at least one tidal excursion, i.e. either a long distance movement with the tide or movement onto the marsh surface or into shallow creeks at high tide. Tidal excursions occurred in all three habitat types, although it was more common for fish located in *Spartina*. Movements to a new position were slightly more often at night (27%) versus during the day (23%) (Fig. 3).

The environmental conditions were consistent throughout Alloway Creek. Temperature and salinity values rose through the summer and both began to decrease in September. Temperature ranged between 14.2 and 31.4 °C and salinity ranged between 1.1 and 10.8 ppt. The dissolved oxygen levels had an inverse relationship with temperature and ranged between 3.71 and 10.07 mg L^{-1}. A visual examination of tagged fish positions overlaid with the environmental parameters did not present any clear correlations.

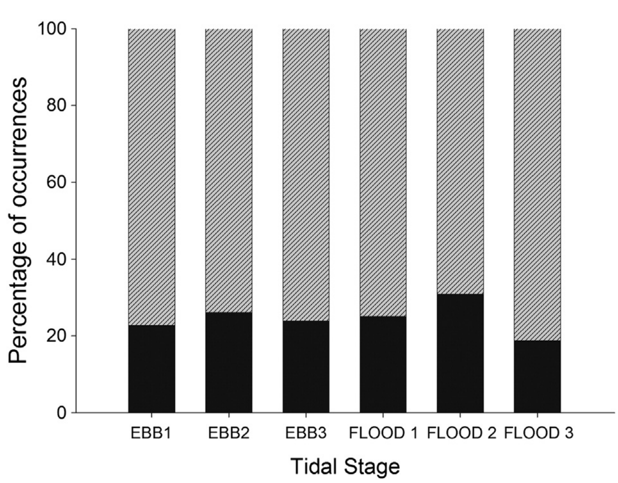

Fig. 2. Percentage of acoustic contacts for tracked white perch found to be moving (black bars) or stationary (diagonal bars). Observations are pooled within tidal stage.

3.2. Habitat preference

Tagged white perch preferred *Spartina* and mixed habitat marshes over *Phragmites* based on several measures. White perch tagged and tracked in *Spartina* and the mixed habitat displayed a high degree of site fidelity, 92% and 70% respectively. One individual tracked in *Spartina* was caught in the same area one year after being tagged. None of the fish tracked in *Phragmites* displayed site fidelity and therefore, white perch tracked in *Phragmites* were excluded from analyses of home range. Cumulative home ranges for most of the white perch tracked (16 of 19) depicted a plateau after 17 days in both *Spartina* and mixed habitat types (Fig. 4). Of the other three fish, one fish began to plateau after 20 days, another fish was not relocated after the tenth day, and another fish's home range continued to increase throughout the life of the tag.

All of the home range measures indicated no difference between the *Spartina* and mixed habitats (Fig. 5). There was no significant difference between the MCPs ($p = 0.32$) for white perch tracked in *Spartina* (avg. mcp = 0.034 km^2) and mixed habitat (0.065 km^2). There was also no significant difference between the 95% and 50% kernel density area estimate ($p = 0.06$ and 0.53, respectively) for white perch tracked in *Spartina* (95% KD = 0.014 km^2; 50% KD = 0.002 km^2) and mixed habitats (95% KD = 0.025 km^2; 50% KD = 0.002 km^2). Also, the number of core areas between white perched tracked in *Spartina* (avg. = 1.75 core locations) and mixed habitat (avg. = 2.71 core locations) was not significantly different ($p = 0.17$).

4. Discussion

4.1. Limitations of the study

There are potentially several limitations to this study, and most of them are consistent with an acoustic telemetry approach. First, there is always concern about the effects of surgery during tagging (e.g. Lee et al., 2013). The fact that a high proportion of tagged individuals established home ranges and made regular tidal excursions within the study period implies that they were behaving normally. Second, some fish were undetected after tagging. One interpretation is that they left the study area. Part of the explanation for this could be turnover due to the natural movements of some individuals of the population (Booth et al., 2013; Rodriguez, 2002). Further, our experience with acoustic telemetry techniques with six other estuarine species implies that this is not a major problem (Able et al., 2013) including for white perch (McGrath and Austin, 2009). Third, fewer individuals were tagged in *Phragmites* habitats but this may have been due to their reduced availability in this habitat type. Fourth, we focused only on adults but this was because they were of a size most amenable to surgical implantation of tags. Fifth, we focused only on summer and fall so cannot account for behavior in other seasons. However, the focus on these seasons allowed us to eliminate reproduction, which occurs in the spring, from consideration in any behaviors observed. Sixth, there was a relatively short period of tracking for individuals. This was due in part to the small size, and thus short battery life, of tags available. Despite this, fish were tracked long enough to establish home ranges and demonstrate tidal excursions to presumed high tide feeding areas. Seventh, the mixed habitats, while reflecting a common type of habitat in upper Delaware Bay, did not allow a clear understanding of habitat use between the natural (*Spartina*) and invaded (*Phragmites*) marsh. This distinction is further confounded by the different stages of the *Phragmites* invasion and their differing ecological functions (Able et al., 2003).

4.2. Habitat preference and movements

There was a stark contrast in the behavior of white perch tagged in *Phragmites* relative to those tagged in *Spartina* and mixed habitats based on several measures. Together these indicated a non-preference for *Phragmites*. White perch tagged in *Phragmites* were difficult to locate or moved into a bordering habitat of mixed vegetation after 4–11 days, while a high proportion (82.6%) of individuals tagged in *Spartina* and mixed vegetation marshes displayed site fidelity. The differences in the behavioral response to the different habitats cannot be due to differences in the aquatic environment because temperature, salinity and dissolved oxygen were similar across all marsh habitat types, largely due to their close proximity. The differences in behavior between *Phragmites* and the other habitats may be due to marsh morphology and access to feeding sites. Typically, *Phragmites* dominated marshes, late in the invasion, as in the study site, have reduced number and size of intertidal creeks and the marsh surface becomes elevated and drier thus access to these habitats may not be possible (Able et al., 2003; Hagan et al., 2007; Hunter et al., 2006). Alternatively, these subhabitats are typical of *Spartina* marshes and likely in the mixed marshes because they have some *Spartina* and the *Phragmites* are at earlier stages in the invasion and thus still contain these same subhabitats (Able et al., 2003). The loss of these subhabitats during a *Phragmites* invasion reduces the available food because the invasion changes the benthic microalgal production, as detected by stable isotopes in the dominant fish (mummichog, *F. heteroclitus*) (Currin et al., 2003), the invertebrate prey (Angradi et al., 2001; Raichel et al., 2003), and the abundance (Able et al., 2003; Hunter et al., 2006) and production of *F. heteroclitus* (Hagan et al., 2007) a common prey for white perch (Nemerson and Able, 2004). Thus, reduced food abundance may cause the reduced use of *Phragmites* marshes by tagged white perch. It should be noted that other studies have not found differences in juvenile and adult white perch abundance based on more traditional net sampling techniques in the same or nearby marshes (Grothues and Able, 2003a,b).

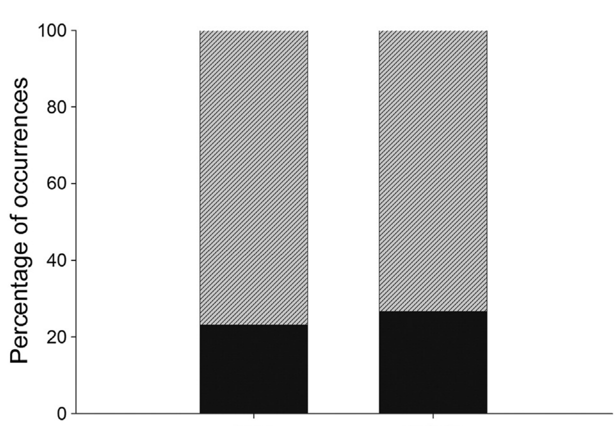

Fig. 3. Percentage of acoustic contacts for tracked white perch found to be moving (black bars) or stationary (diagonal bars). Observations are pooled within time of day.

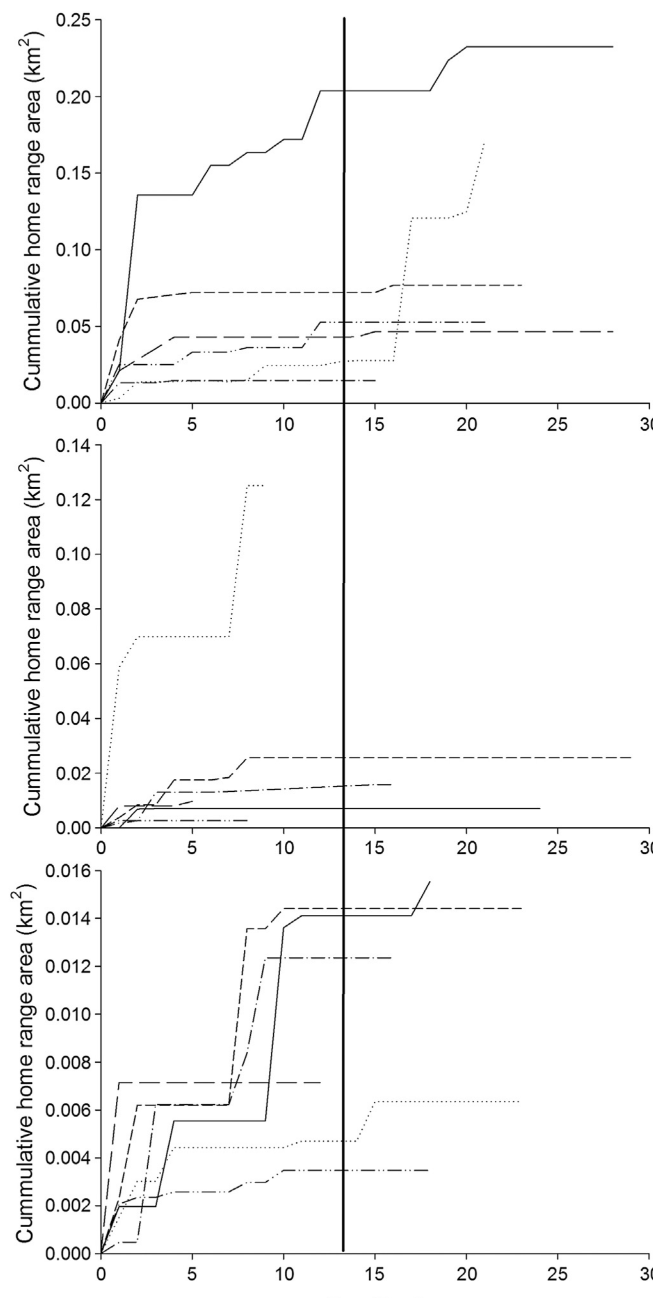

Fig. 4. Home range establishment (vertical line) in tagged white perch for Alloway Creek, Delaware Bay.

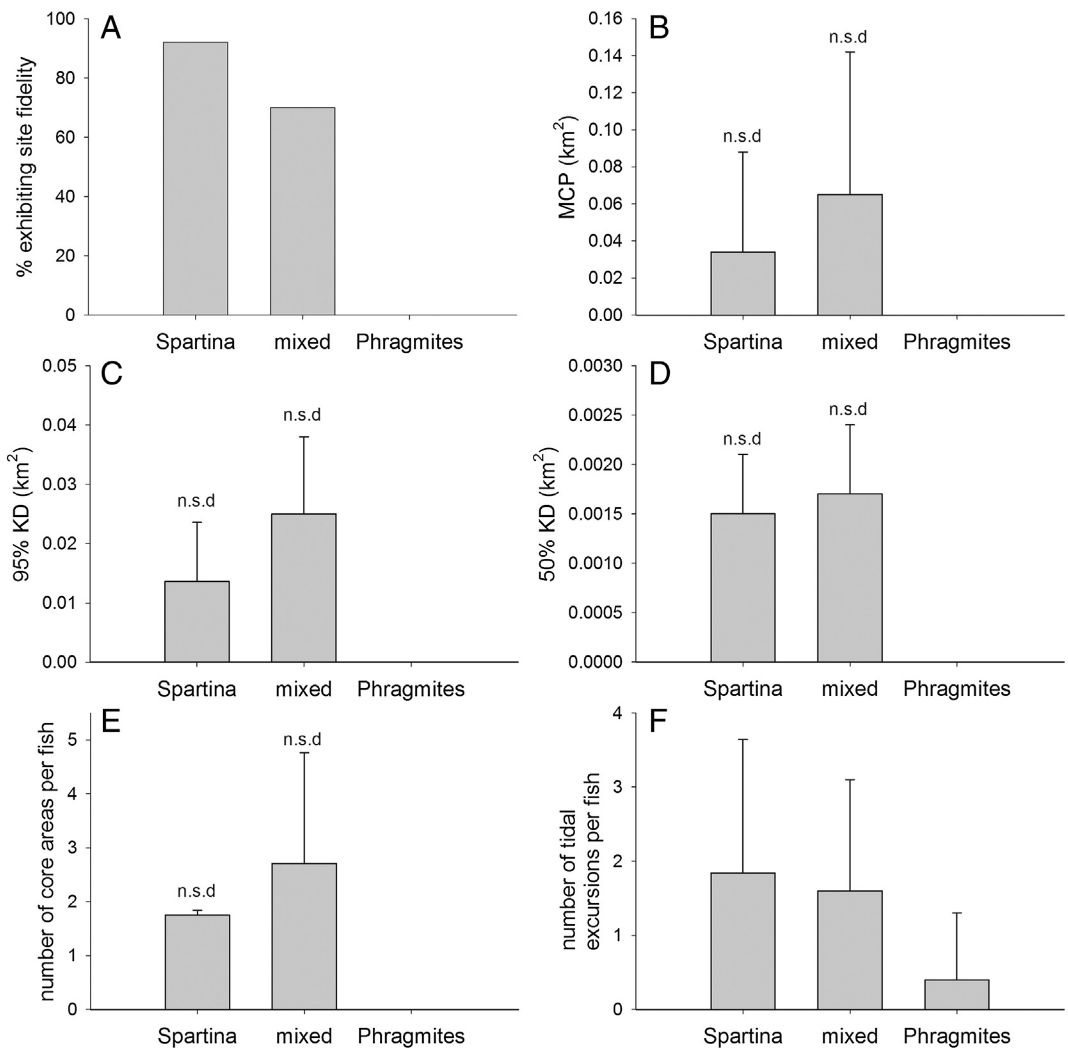

Fig. 5. Characteristics of tracked white perch movements in Alloway Creek in Delaware Bay including: percent exhibiting site fidelity by habitat (A), minimum convex polygon (km^2) by habitat (B), 95% kernel density (KD) (km^2) by habitat (C), 50% KD (km^2) by habitat (D), number of core areas (E), and number of tidal excursions (F).

White perch tagged in *Spartina* and mixed habitats often displayed similar behaviors. Home range and core area sizes were not significantly different. The sizes of these areas were also comparable to white perch tagged in a *Spartina* dominated habitat in Virginia (McGrath and Austin, 2009). The core areas, areas where relocations were most common, used by white perch in this Alloway Creek study were much smaller than the total area used. A small core area which provides the necessary elements for survival is the most energetically favorable condition (Persson and Stenberg, 2006). When white perch did move, the movements were direct and typically to another core area of use. This stationary nature with brief periods of directed movements was also described in an estuarine congener of white perch, striped bass (Ng et al., 2007; Tupper and Able, 2000).

The directed movements typically occurred with the tide at peak ebb or flood stages and were more often during the night. Movement at night may reduce the risk of predation due to light limitation for visual predators (Horodysky et al., 2010). Movement with the tide has been documented in juveniles (Kimball and Able, 2007, 2012) and adults (McGrath and Austin, 2009) of white perch and other species that use marshes (Tupper and Able, 2000). Tidal movements reduce the amount of energy needed to move from one location to another. Many of the tagged white perch, regardless of vegetation, underwent tidal excursions during the flood tide. In the *Phragmites* marsh, tidal excursions only consisted of swimming up a shallow tidal creek, while fish tagged in *Spartina* also exploited the flooded marsh surface. Tidal excursions by white perch were theorized by McGrath and Austin (2009) to be foraging movements for prey items that live on the marsh surface or in the tiny rivulets that feed the larger bodies of water. Many fishes enter intertidal areas, feed heavily, and then return to deeper water as the tide ebbs, resulting in rhythmic patterns of food intake in both quantity (Black and Miller, 1991; Healey, 1971; Miller and Dunn, 1980; Weisberg et al., 1981) and taxonomic composition (Ansell and Gibson, 1990).

Although the movements and home ranges of white perch in *Spartina* and mixed habitats were similar, it is worthwhile to note that the fish inhabiting the mixed habitat seem to be intermediate between white perch tagged in *Spartina* and *Phragmites*. Almost all of the fish tagged in *Spartina* displayed site fidelity, compared to 70% for the mixed habitat. Also the size of the home range and core areas were always smaller for white perch tagged in *Spartina*, suggesting that resources were higher in this habitat. *Spartina* may provide white perch with a greater density of locations to undergo tidal excursions as previously indicated. The greater high tide access to the marsh surface via intertidal creeks may decrease the need for a larger home range.

5. Implications

This study and others (Belanger and Rodriguez, 2002; Kerr et al., 2009; Rodriguez, 2002; van Moorter et al., 2013) indicate that it is critical to consider fish behaviors such as movement patterns and home range in order to better understand habitat preferences and this may be especially applicable in habitat restoration programs (Lindell, 2008). Such measures can provide important insights into the functional differences between altered and natural reference sites in terms of mechanisms responsible for habitat preference, identification of critical resources, habitat quality, and how individuals contribute to ecosystem function. A common behavior in estuaries is the use of tides to provide for transport, prevent displacement, or provide access to spawning and feeding areas (Gibson, 1973; Miller and Dunn, 1980). In this instance, high tides likely provided access to intertidal creeks for foraging opportunities on the resident resources such as mummichogs and crustaceans. In turn, these feeding movements provide for trophic transfers from marshes to other parts of the estuary (Able et al., 2007, 2009). The invasion by *Phragmites*, especially in the later stages, likely prevents these tidal based feeding opportunities and thus reduced habitat quality and, as in this study, result in lower use of *Phragmites* habitats.

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