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ARTICLE

Movement Patterns and Residence of Adult Winter Flounder within a Long Island Estuary

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Abstract
We implanted individually coded acoustic transmitters into 40 adult winter flounder *Pseudopleuronectes americanus* (mean total length = 320 mm; range = 240–423 mm) and monitored them by use of passive acoustic telemetry from September 2007 to April 2009 to classify spatial and temporal movement patterns and quantify residency in Shinnecock Bay, eastern Long Island, New York. Overall, 94,250 valid detections were received. Winter flounder remained inshore, and 89% of the total detections occurred between May and October when bottom water temperature exceeded 15°C. Residency in Shinnecock Bay was dependent on time of release and varied greatly from a few weeks to more than 6 months; total presence (number of days on which individual fish were detected within the bay) averaged 22.0 d (range = 1–132 d). Tracked winter flounder were classified as exhibiting three movement patterns: (1) inner bay movements (short term versus long term), (2) dispersal to offshore waters, and (3) connectivity to other inshore areas. The first two patterns were consistent with historical notions of spatially overlapping resident and migratory individuals, whereas fish that displayed the third pattern may have exhibited a larger home range. These results provide insight into winter flounder movements, residency, and stock structure in a coastal bay of Long Island and provide important information for management. The interaction of exploitation and divergent migration behaviors may be a factor contributing to the winter flounder's decline in Long Island bays; however, more work will be required to obtain a full understanding of the spatial behavior and stock structure of this species.

Estuaries provide essential habitat and nursery grounds for many commercially important species, including flatfish. Decades of coastal land development, pollution, and climate change have degraded the health of estuarine ecosystems throughout the northeastern USA (Roman et al. 2000; Roessig et al. 2004). These impacts, in combination with overfishing, have resulted in historically low abundance levels of the once-widespread and abundant winter flounder *Pseudopleuronectes americanus* (Taylor and Danila 2005; ASMFC 2006; Manderson 2008). The winter flounder population off the south shore of Long Island, New York, exemplifies a declining trend in inshore abundance while the species remains comparatively more abundant offshore (ASMFC 2009). Declines in winter flounder stocks have impaired fisheries, especially in New York, where commercial catch is currently less than 9% of peak levels observed in the 1980s and recreational catch is less than 2% of peak levels (NMFS 2007; National Marine Fisheries Service, Fisheries Statistics Division, personal communication).

Traditionally, stocks are defined by the populations' geographical occurrence or by human activities that affect the productivity of the populations or fisheries (Secor 1999). Contingents, defined as subpopulations of fish aggregations that display divergent migration behaviors or habitat use, may also exist within a population (Hjort 1914; Secor 1999). Winter flounder throughout the northeastern USA are separated into three distinct stocks that display different maximum sizes, growth rates, and ages at maturity: the Gulf of Maine, southern New England–Middle Atlantic Bight, and Georges Bank stocks (Brown and Gabriel 1998; Klein-MacPhee 2002). However, inshore residence of winter flounder in New York has been

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suggested (Lobell 1939; Poole 1966; Howe et al. 1976). Two distinct behavioral groups have historically been identified: an inshore contingent that is present in coastal bays year-round (i.e., "bay fish" or "resident fish"), and an offshore contingent of larger individuals that travel inshore during winter to spawn (i.e., "offshore fish" or "dispersive fish"; Lobell 1939; Perlmutter 1947; Secor 1999). Both groups overlap in spatial distribution during spawning, although it is unclear whether temporal variation exists (Lobell 1939; Perlmutter 1947; Yencho 2009). After spawning in early spring, some winter flounder disperse, while others remain resident (Lobell 1939; Perlmutter 1947). Recent evidence of two spawning peaks and subsequent settlement peaks suggests the existence of some structuring between dispersive and resident groups (Yencho 2009). In this paper, we will refer to these groups as resident and dispersive; however, whether these groups represent contingents or genetically separate stocks is unclear.

Research has highlighted the importance of conserving life history diversity, or biocomplexity, within fish stocks by maintaining all life history strategies so as to sustain stability and resiliency to future environmental change (Hilborn et al. 2003; Kerr et al. 2010). Spatial structure within populations may buffer one life history strategy against competition and unfavorable environmental conditions (Secor 2007; Kerr et al. 2010). Assessment of a stock's health must consider all spawning components because productivity of each component may vary under different environmental scenarios (Hilborn et al. 2003). For example, solely focusing on one component (e.g., dispersive fish) may lead to decline and extinction if environmental conditions change in favor of an alternate strategy (e.g., resident fish) that declined during the previous regime. In Long Island bays, winter flounder may be exhibiting partial migration, wherein a portion of the population remains resident within the natal habitat while the remaining individuals exhibit migratory behavior (Lundberg 1988; Dingle 1996; Kerr et al. 2009).

Migrations undertaken by winter flounder in the northwestern Atlantic have been related to several factors, including spawning, environmental conditions, ice formation, and turbulence (McCracken 1963; Van Guelpen and Davis 1979; Pereira et al. 1999; Wuenschel et al. 2009). Many studies have observed that adult winter flounder return (or home) to the same spawning grounds year after year (Saila 1961; McCracken 1963; Howe and Coates 1975; Saucerman and Deegan 1991; Phelan 1992). Winter flounder north of Cape Cod exhibit localized seasonal movements within bays, whereas those south of Cape Cod move offshore when temperatures surpass 15°C and then return inshore to spawn (Lobell 1939; Perlmutter 1947; McCracken 1963; Howe and Coates 1975; Phelan 1992; Wuenschel et al. 2009). However, winter flounder were observed inshore in Great South Bay, New York, when bottom temperatures exceeded 24°C (Olla et al. 1969). The physical environment of Long Island exposes winter flounder to extreme seasonal conditions ranging from exceedingly warm (up to 30°C; Nichols 1918) to below-freezing temperatures and ice cover. Cold temperatures may induce migratory behavior through the creation of turbulence from strong winds and drifting pack ice (Van Guelpen and Davis 1979).

If winter flounder in Long Island estuaries conform to historical observations of resident and dispersive contingents, there will be important implications regarding the ecological and behavioral responses of this species to habitat quality and environmental fluctuations, including those expected under climate change. Unfavorable water temperatures and poor water quality resulting from land runoff, harmful algal blooms, and exploitation may differentially impact the survival and recruitment of inshore resident winter flounder compared with the winter flounder that move offshore. Given the declining inshore abundance of winter flounder, research examining movement patterns and residency in relation to the environment within Long Island bays is imperative. This information will benefit winter flounder management and will allow us to decipher the population structure of winter flounder by identifying life cycle strategies. Our objective was to monitor adult winter flounder behavior by utilizing underwater acoustic telemetry to examine movement patterns and quantify residency within a coastal bay of Long Island.

METHODS

Study site.—Shinnecock Bay is a barrier beach and lagoonal estuary located on the south shore of Long Island, approximately 120 km east of New York City (Figure 1). It connects to the Atlantic Ocean by a dynamic inlet where tidal velocities average 2.5 knots/s (USFWS 1997). A man-made canal controls water flow and prevents Shinnecock Bay waters from flowing north into Peconic Bay (USFWS 1997). Shinnecock Bay has a mean tidal range of 0.88 m at the inlet (Buonaiuto and Bokuniewicz 2008), an average salinity of 30‰ (Green and Chambers 2007), and annual water temperatures ranging from −2°C to 24°C; ice cover is possible in the bay during winter. Shinnecock Bay encompasses an area of 39 km^2 and is relatively shallow; the average depth is 3 m for the eastern portion but less than 2 m for the western portion (USFWS 1997; Green and Chambers 2007).

Collection and preparation of adult winter flounder.—A trawl survey with a stratified random sampling design was conducted bimonthly during daylight between April and August 2007 and monthly between May and August 2008 to collect adult winter flounder. Trawl stations were randomly selected by dividing the eastern portion of Shinnecock Bay into numbered boxes of equal size and using a random number generator to determine which box would be sampled. To increase sample size, additional trawling occurred from September to November 2007 (1 d/month), January to March 2008 (1 d/month), and May to July 2008 (2 d/month). A 9-m otter trawl with 0.6-cm mesh at the cod end was towed by the R/V *Pritchard* during April–July 2007 (8-min tows) and by the R/V *Shinnecock* during August–November 2007 and January–August 2008 (5-min tows). Trawling throughout the year and during periods when

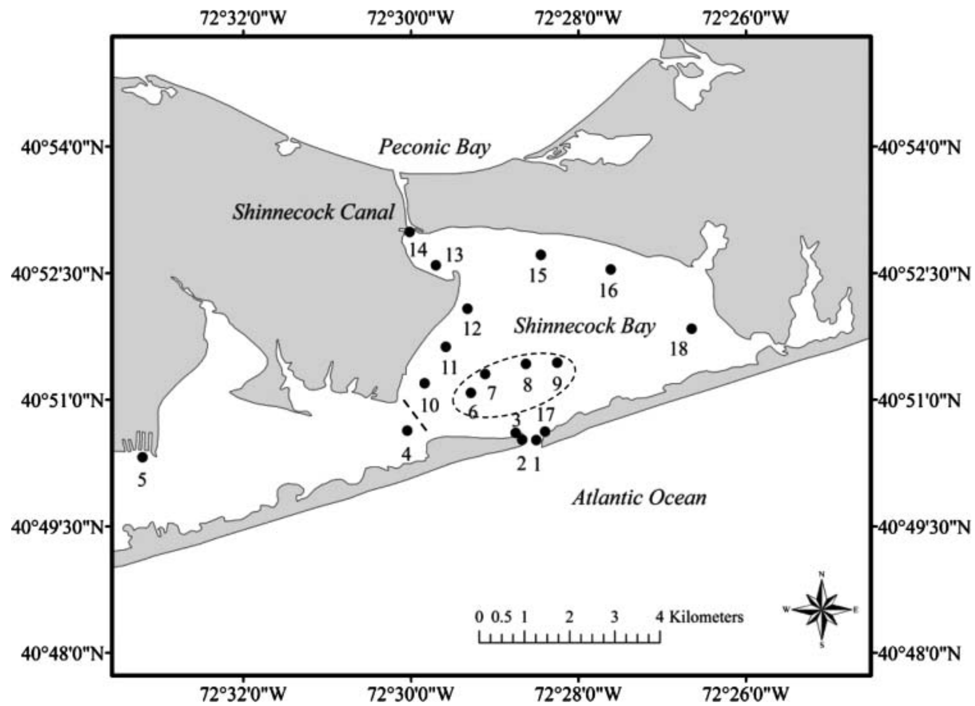

FIGURE 1. Map of Shinnecock Bay, Long Island, New York. Dots represent positions of acoustic receivers. Dashed ellipse identifies the high-density area (described in Results). Dashed line represents Ponquogue Bridge, which separates the eastern and western portions of the bay.

both contingents were believed to be inshore (fall–winter) reduced the possibility of selecting one behavioral group over the other.

Upon capture, winter flounder were measured for total length (TL; mm), and healthy adults larger than 240 mm (Perlmutter 1947) were fitted with acoustic transmitters (Model V9-1 L-R64K, 69 kHz, 9 × 24 mm; VEMCO Ltd.). Transmitters were surgically implanted within the peritoneal cavity of each winter flounder by following procedures that were approved by the Institutional Animal Care and Use Committee at Stony Brook University. The first batch ($n = 8$) of captured winter flounder was transported to the Stony Brook-Southampton Marine Station on August 13, 2007; these fish were fitted with transmitters and monitored for transmitter retention and mortality. Five fish from this batch were released on September 8, 2007, and the remaining three fish were released on September 25, 2007; all were released at the site of capture. All winter flounder in subsequent collections were fitted with transmitters onboard, held in a holding tank for observation ($\leq$30 min), and released at the site of capture upon their recovery.

Acoustic transmitters had a power output of 142–150 dB referenced to 1 μPa at 1 m, and the estimated battery life was dependent on power output and transmitter delay. Thirty-one transmitters were programmed to emit transmissions every 150–300 s (battery life ∼ 400 d), and nine transmitters (deployed in year 2) emitted transmissions every 40–120 s (battery life ∼ 200 d). Transmission frequency was changed to increase detection probability in the final year of monitoring. Although flatfish tend to swim intermittently, they are capable of swimming continuously at approximately 1 body length/s for a considerable period at high temperatures (He 2003). Based on this observation and on an average TL of 320 mm, transmitters with greater transmission frequency provided greater detection of winter flounder migrating past receivers because fish in this study traveled as much as 48 m in 150 s (or 96 m in 300 s). Field tests indicated a mean receiver range of 350 m, although this varied with hydrographic and atmospheric conditions.

Passive tracking of winter flounder.—Winter flounder were tracked passively at 18 stations (Figure 1) by use of VR2W receivers (diameter = 308 × 73 mm; VEMCO Ltd.), which are submersible, single-channel acoustic receivers that are capable of identifying coded acoustic transmitters. When a winter flounder swam within range, the VR2W recorded the transmitter's identity and the date and time of detection. Twelve stations were located in open water (Table 1) and each contained a VR2W mounted on a concrete block; at the remaining stations, the VR2W was directly attached to pilings (stations 4 and 14) or jetties (stations 1–3 and 17). Receiver performance (code detection efficiency and rejection coefficient) was analyzed as described by Simpfendorfer et al. (2008).

Interpretation of telemetry data.—All transmitters were tested in the laboratory and were assumed to work properly after deployment. If a transmitter was recorded continuously at the same location for at least 2 months, the individual associated with that transmitter was excluded from analysis and was assumed to have died. In addition, single detections within

TABLE 1. Summary of passive acoustic receiver (VR2W) stations used to detect acoustic-tagged winter flounder in Shinnecock Bay, Long Island. Asterisks indicate receiver loss.

Station number	Number of fish detected	Number of detections	Monitoring period	Location
1	3	15	Jun 1, 2008–May 24, 2009	Inside inlet
2	7	62	Dec 28, 2007–May 24, 2009	Inside inlet
3	5	40	Aug 20, 2007–Apr 26, 2009	Bayside of inlet
4	1	98	Dec 28, 2007–May 8, 2009	Bridge
5			Mar 20, 2008*	Open water
6	4	55,525	Mar 20, 2008–Apr 6, 2009	Open water
7	9	2,665	Mar 20–Aug 28, 2008*	Open water
8	15	20,498	Mar 20, 2008–Apr 6, 2009	Open water
9	17	14,108	Mar 20, 2008–Apr 6, 2009	Open water
10	0	0	Jun 12–Dec 14, 2008	Open water
11	1	36	Jun 12–Dec 14, 2008	Open water
12	1	19	Jun 12–Dec 14, 2008	Open water
13	1	10	Jun 12–Dec 14, 2008	Open water
14	3	355	Jul 26, 2007–Apr 14, 2009	Marina
15	0	0	Jun 26–Dec 14, 2008	Open water
16	0	0	Jun 26–Dec 14, 2008	Open water
17	11	234	Aug 20, 2007–Dec 14, 2008	Bayside of inlet
18	1	585	Jul 10–Aug 28, 2008*	Open water
Total		94,250		

a 1-h period were removed from analyses to minimize false detections. If a fish was not detected on any of the VR2W receivers, including those gating the bay, there were four possible explanations: (1) the fish entered an unmonitored region of the bay, (2) it was consumed by a predator, (3) it was harvested during the fishing season (April–May), or (4) it left the bay undetected.

To determine whether a winter flounder was entering or leaving the bay through Shinnecock Inlet, this site was gated by placing four VR2W receivers around the inlet: two bayside (north) and two inside the inlet (south; Figure 1). In addition, receivers at Shinnecock Canal and Ponquogue Bridge monitored alternative exits. Tracking of movements in and out of Shinnecock Inlet was essential in identifying resident and dispersive winter flounder. If winter flounder displayed inner bay movements for more than 6 months, they were classified as resident individuals. Those that exited in spring or summer were identified as dispersive individuals.

Residence time.—To establish the degree of site fidelity for winter flounder in the study area, a residency index (I_R) was calculated as

$$I_R = N_{\text{total}}/N_L,$$

where N_{total} is the total number of days on which a winter flounder was detected and N_L is the time at liberty (i.e., the number of days between the deployment date and the date of last detection; Topping et al. 2006; Abecasis and Erzini 2008). Residency was also described in terms of total presence (total number of days on which an individual was detected within the bay) and continuous presence (number of consecutive days for which an individual was detected; Collins et al. 2007). A t-test assuming equal variances ($\alpha = 0.05$) evaluated whether there were significant differences in both total presence and continuous presence between small (<300 mm TL) and large (≥300 mm TL) individuals. Winter flounder size was regressed against I_R to determine whether there was a significant difference in residency between large and small individuals. A single-factor analysis of variance (ANOVA; $\alpha = 0.05$) was used to determine whether there were significant differences in I_R for winter flounder that were deployed during different seasons.

Receiver catch per unit of effort.—For each day, receiver catch per unit of effort (CPUE) was calculated as

$$\text{CPUE} = R_d/R_t,$$

where R_d is the number of receivers with detections and R_t is the total number of active receivers (see Table 1 for monitoring periods). High CPUE indicated detections by many receivers, whereas low CPUE indicated that few or no receivers detected winter flounder. Receiver CPUE between groups based on time of deployment was tested by use of a nonparametric Wilcoxon's signed rank test with a continuity correction in R software (R Development Core Team 2010). In addition, to represent

TABLE 2. Summary description of acoustic-tagged winter flounder (TL = total length), including deployment date and detection at receiver (VR2W) stations in Shinnecock Bay, Long Island, for three migration classes designated based on movement patterns (inner bay movements, dispersal to offshore, and connectivity to other inshore areas).

Fish number	Fish TL (mm)	Deployment date	Last detection date	Number of detections	Stations
Inner bay movements (mean TL = 297 mm, SE = 13)					
2	351	Sep 8, 2007	May 30, 2008	11	2, 3, 7–9
3	351	Sep 8, 2007	Sep 6, 2008	2,104	7, 8, 14
8	388	Sep 25, 2007	Aug 27, 2008	734	6–9, 17
10	346	Sep 28, 2007	Apr 3, 2008	8	7
18[a]	240	May 14, 2008	Jun 12, 2008	30	8, 9
23	380	May 29, 2008	Oct 2, 2008	1,175	6–8
25	280	Jun 27, 2008	Aug 13, 2008	906	8
31[a]	265	Jul 9, 2008	Jul 16, 2008	102	9
32	254	Jul 9, 2008	Nov 30, 2008	836	9
33[a]	254	Jul 9, 2008	Jul 10, 2008	41	9
34	271	Jul 9, 2008	Apr 27, 2009	1,322	9
35[a]	255	Jul 9, 2008	Jul 16, 2008	600	7–9, 18
36[a]	266	Jul 9, 2008	Jul 29, 2008	5,069	8, 9
37	280	Jul 9, 2008	Aug 16, 2008	467	9
40	271	Jul 28, 2008	Dec 9, 2008	4,633	8, 9
Total				18,038	
Dispersal to offshore waters (mean TL = 318 mm, SE = 15)					
9	380	Sep 28, 2007	Nov 1, 2007	34	17
14	395	Jan 10, 2008	May 7, 2008	11	3, 17
16	310	Apr 11, 2008	Apr 26, 2008	15	2, 9, 17
17	320	May 14, 2008	Apr 1, 2009	128	2, 8, 9, 17
19	250	May 14, 2008	May 28, 2008	2,004	2, 8, 9, 17
20	330	May 14, 2008	May 16, 2008	26	17
21	375	May 29, 2008	Jun 22, 2008	64	1, 6–8
24	270	Jun 27, 2008	Jun 30, 2008	36	2, 3, 17
26	260	Jun 27, 2008	Jul 1, 2008	5	17
28	290	Jun 27, 2008	Jun 29, 2008	99	2, 3, 8
30	314	Jul 9, 2008	Jul 15, 2008	46	9, 17
Total				2,468	
Connectivity to other inshore areas (mean TL = 346 mm, SE = 35)					
11	348	Sep 28, 2007	Feb 12, 2008	57	14
27	405	Jun 27, 2008	Oct 10, 2008	8,496	7–9, 12–14
29	285	Jun 27, 2008	Nov 15, 2008	65,191	4, 6–9, 11, 17
Total				73,744	

[a]Fish that exhibited short-term (<1 month) inner bay movements.

regional preferences, the core monitor for each individual was identified as the receiver with the greatest number of detections (Topping et al. 2006).

RESULTS

Collection, Preparation, and Tracking of Winter Flounder

In total, 40 adult winter flounder were captured and fitted with acoustic transmitters over the duration of the project (13 fish in 2007; 27 fish in 2008). Of these, 29 were detected during this study and their movements were classified based on spatial and temporal patterns (Table 2). Monitoring of fish from the first batch indicated 100% retention of transmitters and no transmitter-related mortality. Overall, none of the winter flounder were in spawning condition when captured. The gating of Shinnecock Inlet took longer than expected due to environmental difficulties, and as a result only two VR2W receivers were in place at the commencement of the study (see Table 1 for monitoring periods). The third VR2W unit was added at the inlet in December 2007, and the fourth was added in June 2008. Although Ponquogue Bridge and Shinnecock Canal were each gated with receivers at the beginning of the study, one receiver was removed from each site due to minimal winter flounder detections; these two receivers were placed at stations 15 and 16 to increase coverage elsewhere. Overall, the acoustic array received 94,250 valid detections (Table 1). Receivers performed well in terms of code detection efficiency, and more codes were detected in the high-density area, a relatively deep (2–4-m) region north of the sandbar, which was characterized by beds of eelgrass *Zostera* spp. interspersed with sandy patches (Figure 1). In contrast, fewer codes were detected in major boating channels. The mean number of detections per synch was 0.395, suggesting that 39.5% of transmitted codes were detected, a result similar to the findings of Simpfendorfer et al. (2008). The rejection coefficient by station ranged from 0.00 to 0.09 rejections/synch and averaged 0.02 rejections/synch.

Residency and Site Fidelity

Data on winter flounder presence within the study area indicated variation in residency over the 20-month period of monitoring (Figure 2). Three groups of winter flounder were recognized based on time of deployment: (1) 13 fish that were deployed in summer–fall 2007 (fish numbers 1–13); (2) 10 fish that were deployed in winter–spring 2008 (fish numbers 14–23); and (3) 17 fish that were deployed in summer 2008 (fish numbers 24–40). Among the winter flounder from deployment group 1, six fish were detected: fish 11 left the bay via Shinnecock Canal in February 2008, fish 9 was detected by part of the inlet receiver gate in October 2007, and four individuals (fish 2, 3, 8, and 10) spent 1 week to 5 months in the high-density area.

Among the individuals released in 2008, 23 fish were detected (group 2: 8 fish detected; group 3: 15 fish detected). Within group 2, fish 18 was present in the high-density area for less than 2 months, whereas fish 23 remained in the high-density area for 5 months. Fish 16, 17, and 19 exited the bay through the inlet within 2 weeks of release; fish 14 and 20 were detected on bayside receivers; and fish 21 was detected inside the inlet. Within group 3, five individuals (fish 25, 31, 33, 36, and 37) were present for less than 2 months in the high-density area, whereas three individuals (fish 32, 34, and 40) remained in this region for 3–9 months. Fish 35 traveled between the southeastern corner of Shinnecock Bay and the high-density area. Fish 24, 26, and 28 exited the bay through the inlet within 2 weeks of release; and fish 30 was detected bayside. Fish 27 left through Shinnecock Canal in October, whereas fish 29 traveled underneath Ponquogue Bridge in November.

The I_R values for winter flounder averaged 0.39 (SE = 0.06) and ranged from 0.01 to 1.00 (Figure 3a). A significant negative relationship existed between winter flounder size and I_R (n = 29, slope = −0.03, intercept = 1.41, $r^2 = 0.30$, $P = 0.002$). In addition, there was a significant difference in mean I_R among the three deployment groups (ANOVA: df = 28, $P = 0.0003$). Fish that were released during summer 2008 (group 3) exhibited the largest average I_R (0.55; SE = 0.07; n = 15), while fish that were released in summer–fall 2007 (group 1) displayed the smallest average I_R (0.07; SE = 0.03; n = 6). Total presence averaged 22.0 d (SE = 5.6) and ranged between 1 and 132 d (Figure 3b). There was no significant difference in total presence between small (<300 mm) and large (≥300 mm) individuals (t-test: df = 27, $P = 0.46$). In addition, there was no significant difference in mean total presence among the three deployment groups (ANOVA: df = 28, $P = 0.45$). Continuous presence averaged 10.0 d (SE = 3.0) and ranged between 1 and 81 d (Figure 3c). Continuous presence also did not differ between small and large winter flounder (t-test: df = 27, $P = 0.35$) or among the three deployment groups (ANOVA: df = 28, $P = 0.19$). The most common interval for both total and continuous presence was 1–5 d.

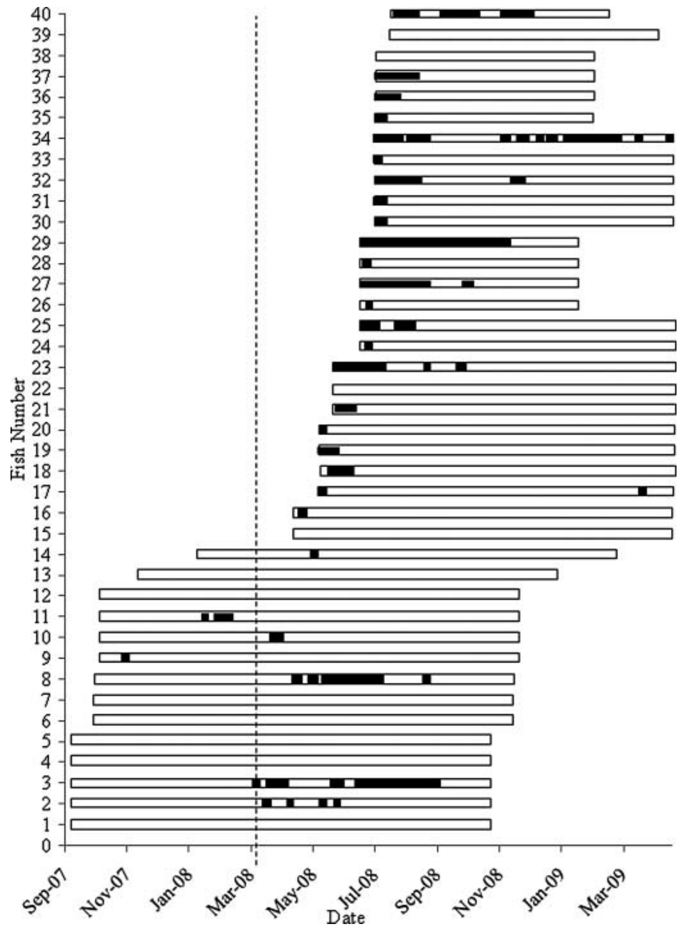

FIGURE 2. Detections of acoustic-tagged winter flounder from three deployment groups (group 1 = summer–fall 2007, fish numbers 1–13; group 2 = winter–spring 2008, fish numbers 14–23; group 3 = summer 2008, fish numbers 24–40) in Shinnecock Bay, Long Island (open rectangles = expected battery life of transmitter; filled regions = dates of detection; dotted line = date when the acoustic array was complete; see Table 1 for monitoring periods used at each station).

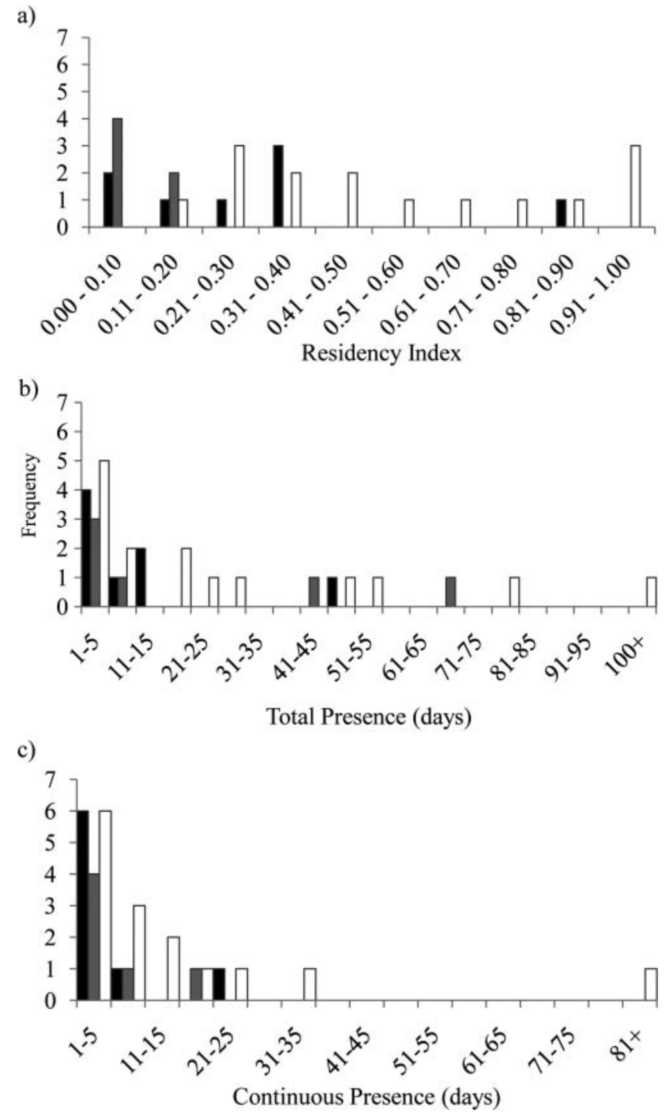

FIGURE 3. Temporal distribution data for acoustically monitored winter flounder from three deployment groups (gray bars = group 1; black bars = group 2; white bars = group 3; see Figure 2 for group descriptions) in Shinnecock Bay, Long Island: **(a)** residency index (see Methods), **(b)** total presence (total number of days on which a fish was detected within the bay), and **(c)** continuous presence (number of consecutive days for which a fish was detected within the bay).

Receiver Catch per Unit of Effort

Receiver CPUE peaked at 0.018 during May 2008 (Figure 4), when 36% of receivers detected winter flounder (five of the detected fish were released in May); CPUE remained near 0.00 between November 2008 and April 2009. Low CPUE values were obtained for fish that were released during summer–fall 2007 (group 1); the peak CPUE for these fish (0.02) was observed during late-May 2008 (Figure 4). For fish that were released in winter–spring 2008 (group 2), CPUE decreased from April to June 2008 and then remained near 0.00 for the duration of the study (Figure 4). The CPUE was high for winter flounder that were deployed in summer 2008 (group 3), and the CPUE for this group peaked in June 2008 (Figure 4). Overall, 98.5% of the total detections were made at stations 6–9, which constituted the high-density area. For 69% of the fish, core monitors were located in the high-density area; station 9 was the most common core monitor. For 24% of the fish, the core monitors were inlet receivers. Receiver CPUE differed significantly between deployment group 2 ($n = 66$ d; mean CPUE = 0.015) and group 1 ($n = 110$ d; mean = 0.009; Wilcoxon's signed rank test: $P = 0.002$), between group 2 and group 3 ($n = 189$ d; mean = 0.005; $P = 2.2 \times 10^{-16}$), and between group 1 and group 3 ($P = 2.2 \times 10^{-16}$).

Classification of Movements

Three types of winter flounder migratory patterns were apparent during our study: (1) inner bay movements, (2) dispersal to offshore waters, and (3) connectivity to other inshore areas (Figure 5). Of the 29 tracked winter flounder, 17% spent less than 1 month within the high-density area, 24% spent between 1 and 5 months there, and 10% were long-term inhabitants, remaining in the high-density area for 6–9 months. Twenty-one percent of the fish traveled through the inlet, whereas 17% were inconclusively assigned because they were detected at only part of the inlet receiver gate. The remaining 10% entered adjacent inshore waters.

DISCUSSION

In this study, adult winter flounder movement was investigated and inshore residency was quantified by use of long-term passive tracking. Adult winter flounder were documented as occupying Shinnecock Bay during all seasons, and the abundance of monitored individuals peaked during summer. The majority of winter flounder did not vacate inshore waters when bottom temperatures surpassed 15°C, in contrast to expectations from the literature (McCracken 1963; Howe and Coates 1975; Phelan 1992; Wuenschel et al. 2009). Eighty-nine percent of total receiver detections occurred between May and October, when winter flounder should have been offshore in cooler water. In contrast, few fish were detected between October and April, when they should have been inshore to spawn. Overall, the monitored winter flounder in Shinnecock Bay were classified as demonstrating three common movement patterns: (1) inner bay movements, (2) dispersal to offshore waters, and (3) connectivity to other inshore areas. The residence and movement patterns of at least three fish were consistent with the historical notion of residents (Lobell 1939) because these individuals remained in the bay long term during warm summer months and were not detected as leaving the bay. These three winter flounder may represent the life history strategy that supported both commercial and recreational fishing several decades ago (Lobell 1939; Poole 1969). The relative abundance and presence of winter flounder from the summer 2008 deployment group (group 3) may be indicative of a resident contingent or a separate population.

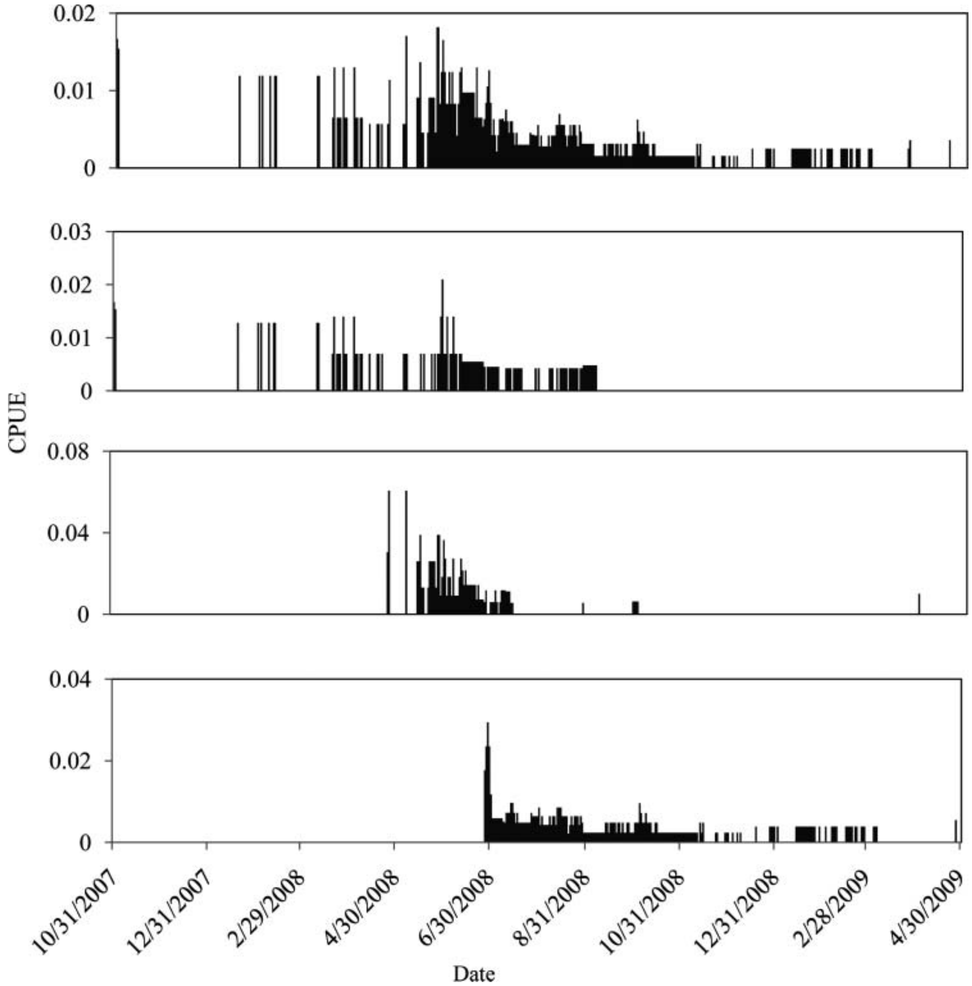

FIGURE 4. Receiver catch per unit of effort (CPUE; defined in Methods) estimated on a daily basis for acoustic-tagged winter flounder in Shinnecock Bay, Long Island; panels (from top to bottom) depict all deployment groups combined, group 1, group 2, and group 3 (see Figure 2 for group descriptions). Note the difference in scale on the ordinate.

Based on year-round tag returns, Lobell (1939) suggested the existence of a resident population of winter flounder in Great South Bay and other south shore bays. In our study, most winter flounder were collected inshore between May and August, when bottom water temperatures exceeded 15°C. In contrast, ocean surveys conducted in coastal waters of Long Island (10–30-m depths) and areas adjacent to Shinnecock Bay indicated that the peak abundance of adult winter flounder occurred during fall and spring and that winter flounder were completely absent during summer (M.G.F., unpublished data). Olla et al. (1969) found winter flounder (150–360 mm) in Great South Bay when bottom temperatures ranged from 17.2°C to 24°C. Here, we provide further evidence that adult winter flounder are present inshore during periods when they are expected to be offshore, although the predominance of fish from the summer 2008 deployment group may have biased this result. In addition, three winter flounder in Shinnecock Bay exhibited long-term residency (>6 months) consistent with the historical notion of resident winter flounder. Large winter flounder displayed decreased residency compared with small individuals, possibly as a result of the size difference between resident and dispersive individuals, which was originally hypothesized by Lobell (1939). Our results indicate that fish deployed in summer displayed higher residency than those deployed in fall–winter, possibly reflecting the dispersive behavior of fall–winter individuals. Although we detected a significant difference in residency based on time of deployment, our results should be interpreted cautiously because of the large discrepancy in sample sizes.

It is clear that winter flounder are present in Shinnecock Bay during the summer; however, it is unclear whether these individuals represent (1) a unique behavioral contingent within the population, (2) a genetically distinct population, or (3) a portion of a single population wherein individuals make annual decisions to disperse or remain resident. Individuals that were classified as dispersive were probably migratory individuals that consistently returned inshore to spawn. In addition,

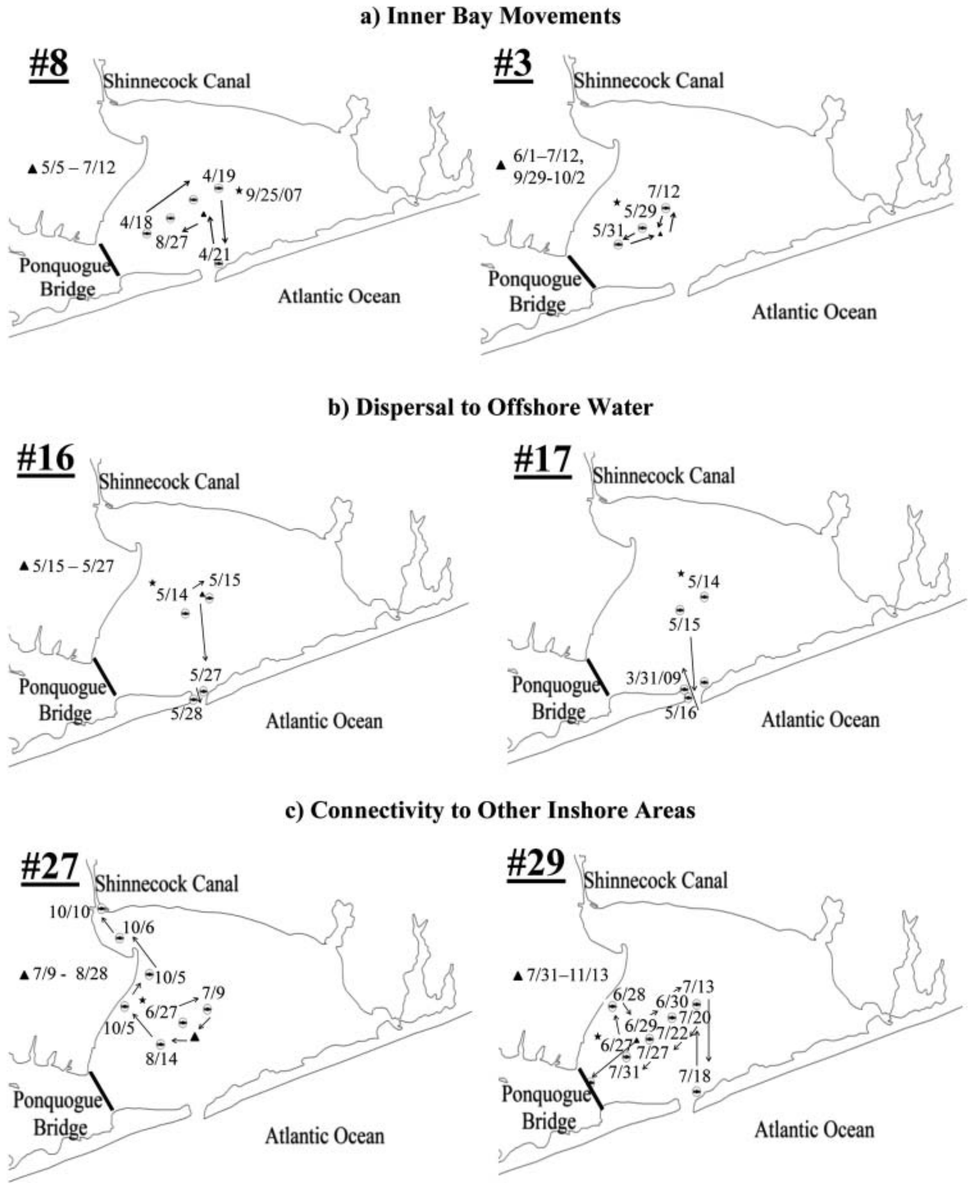

FIGURE 5. Movement patterns of six acoustic-tagged winter flounder in Shinnecock Bay, Long Island, representing examples of **(a)** inner bay movements (fish numbers 8 and 3), **(b)** dispersal to offshore waters (fish numbers 16 and 17), and **(c)** connectivity to other inshore areas (fish numbers 27 and 29). Circles represent location, stars indicate deployment date, arrows show directional tracks, and triangles represent dates of presence in region. All dates are in 2008 unless otherwise noted. Map is based on National Oceanic and Atmospheric Administration shoreline data.

fish that exited through Shinnecock Canal or underneath Ponquogue Bridge may have been part of a resident group with a wider inshore range spanning the south shore bays and perhaps the Peconic Bays.

Although it is commonly believed that winter flounder move offshore when inshore temperatures increase during summer months, adult winter flounder are capable of withstanding warm temperatures through behavioral modifications, including burial in sediment, reduced swim speeds, and inactivity (Olla et al. 1969; He 2003). Winter flounder can escape warm bottom waters by burying up to 6 cm into the sediment, where temperatures remain roughly 4°C cooler (Olla et al. 1969). However, this behavior drastically reduces their detectability by telemetry. Our ongoing field testing has indicated that transmitters buried in sand are detectible but at a drastically reduced range, resulting in a much smaller detection area. In addition to burying in sediment, winter flounder can reduce swim speed or become inactive to conserve energy (Olla et al. 1969; He 2003). Although winter flounder in Shinnecock Bay appear to tolerate warm waters, extreme temperatures combined with low oxygen levels can cause mass mortality events, as was observed in Moriches Bay, Long Island (Nichols 1918). Previous studies identified temperatures greater than 26.5°C as causing mortality of adult winter flounder (McCracken 1963; Hoff and Westman 1966).

The lack of monitored winter flounder in the high-density area from November to April (with the exception of one individual) was noteworthy because this period is believed to be the time of spawning. This result indicates that spawning probably does not occur within the high-density area even though it contains eelgrass habitat that is considered suitable for winter flounder young of the year. Many factors may be responsible for this sudden absence of winter flounder, such as emigration to an unmonitored region of the bay, predatory events, or other sources of mortality. One possible explanation may include the increased presence of harbor seals *Phoca vitulina*, gray seals *Halichoerus grypus*, and harp seals *Pagophilus groenlandica* in the bay—particularly in the high-density area—between November and May (USFWS 1997). Thus, appearance of these seasonal predators may be placing additional pressure on winter flounder numbers through predation. Although seals feed heavily on gadids and flatfishes (Harkönen 1987; Bowen and Harrison 1994; Hall et al. 1998; Berg et al. 2002), the low abundance of gadids in Shinnecock Bay (M.G.F., unpublished data) may cause a shift in predatory pressure toward flatfishes. Historically, winter flounder were abundant in Shinnecock Bay and may have provided a substantial food source for visiting seals.

The stochastic behavior of animals and the unpredictable nature of the environment make telemetry studies susceptible to uncertainty. The ability of flatfish to bury themselves may reduce the probability of detection and, when coupled with poor environmental conditions, could influence residency estimates. In an attempt to eliminate this source of uncertainty, we quantified residency by daily intervals rather than by hourly intervals so that the frequency of detections (depending on distance from receiver or burial behavior) would not influence residence estimates. We also tried to improve the probability of detection in year 2 by introducing transmitters with a greater transmission frequency. Although our collection efforts were designed to capture members of both contingents, temporal and spatial variation in spawning may have reduced the probability of capturing dispersive winter flounder.

The performance of inlet receivers during the study was dependent on hydrographic conditions, boat traffic, and biological activity and remains a source of uncertainty. Background noise and sea-state conditions may have prevented detection of complete transmissions or may have reduced the frequency of detections. In addition, incomplete gating at the initiation of this study may have masked the occurrence of dispersive winter flounder from deployment group 1 because this was the only group that was exposed to an incomplete gate. Although receiver CPUE differed significantly between groups, this difference may be attributable to different sample sizes. In addition, winter flounder from group 1 were tracked by fewer receivers. In an attempt to improve detection for year 2, we used transmitters that emitted pulses more frequently. To avoid bias resulting from the use of transmitters with different transmission frequencies, the CPUE was estimated on a daily basis and standardized for the number of available transmissions. However, no noticeable differences in estimated CPUE values or trends were observed when adjusted for transmission frequency, and this standardization was not used in the final estimates. Our data interpretation should be considered an underestimation of winter flounder movements because of the many uncertainties inherent in telemetry studies, including receiver performance, incomplete detections, and animal behavior.

Management Implications

Winter flounder movements in Shinnecock Bay deviated from the expected behavior for this species south of Cape Cod in terms of inshore residency and response to the seasonal environment. This study provides supporting evidence that winter flounder in Long Island bays exhibit a complex stock structure that warrants further investigation to identify biological traits exhibited by resident and dispersive groups (e.g., genetic differences, morphometrics, and spawning connectivity). Complex stock structure may be more common in winter flounder than previously thought: recent research indicates that young of the year in Narragansett Bay, Rhode Island, represent up to 16 distinct genetic populations (Buckley et al. 2008). Research is necessary to determine whether winter flounder display partial migration (i.e., resident and dispersive individuals within a single population) or whether these contingents are instead genetically distinct populations. Resolving the stock structure and migratory behavior of Long Island winter flounder is crucial to determine the impacts of local harvest on the sustainability of the species. If resident winter flounder represent a separate genetic population, the seasonally more abundant dispersive population may mask a long-term decline in resident winter flounder that once supported Long Island fisheries (Lobell 1939) and may eventually lead to extirpation of residents. This outcome would require management of each population separately based on population-specific life history variables. On the other hand, if resident and dispersive winter flounder are contingents within a single genetically distinct population that exhibit partial migration, the relative impact of harvest on resident and dispersive individuals can be complex (Gross 1991; Kerr et al. 2009). Management would need to consider the relative abundance of each contingent through habitat or other conservation efforts aimed at a specific contingent (Kerr et al. 2010). Under this scenario, even if all resident individuals are eliminated by fishing, this contingent could be re-established from the population. Movement patterns and residency of winter flounder are paramount for describing stock structure of this species in Long Island bays. Our results provide insight into winter flounder movements in a coastal bay of Long Island, which may help to identify potential reasons for a general decline in winter flounder; however, much work remains to fully understand the stock structure of this species.

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