MOVEMENT OF SUMMER FLOUNDER (*PARALICHTHYS DENTATUS*): APPLICATION OF TELEMETRY TO UNDERSTAND ECOLOGY AND BYCATCH DISCARD MORTALITY

by

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ABSTRACT OF THE THESIS

Movement of summer flounder (*Paralichthys dentatus*): application of telemetry to understand ecology and bycatch discard mortality

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Summer flounder, *Paralichthys dentatus*, is a commercially and recreationally important flatfish species along the east coast of the United States. There are some clear and important data gaps in our understanding of summer flounder and their ecology. In this study we address two of those data gaps using acoustic telemetry; discard mortality in the commercial trawl fishery and the potential for pelagic behavior. Discard mortality studies to date rely on potentially biased on-deck evaluation of immediate mortality, and evaluation of delayed mortality through holding captured fish to determine survival. Telemetry of ultrasonically tagged fish provides a technique for evaluating fish bycatch discard mortality, and especially latent mortality, under natural conditions in the sea. For summer flounder along the eastern United States, an 80% discard mortality is assumed but not verified. There is also a growing body of literature on flatfish species exhibiting pelagic behaviors for various essential functions. In captivity, summer flounder use “stroke and glide” behavior in the water column and they can feed actively there. To determine the discard mortality, and explore their potential vertical movement, adult summer flounder were collected from a commercial trawl vessel and tagged and released in a fixed hydrophone array on 15 September 2009 off Brigantine, New Jersey. In 2010, an additional set of summer flounder were collected in the Great Bay – Mullica River estuary, tagged, and released into an array nearby the 2009 site for further examination of pelagic behaviors. Fish were re-detected both alive and dead within the array and during mobile tracking. Pressure sensing tags recorded depth at a resolution of 0.68 meters. Signal values indicating depths two meters or greater above an individual's greatest depth were considered to be pelagic in nature. Fish of poor initial health and dead individuals were redetected after the storm in a concentrated area inshore of the release site and were presumed dead. The final discard mortality estimate from the commercial trawl, combining on-deck mortality (32.7%) and latent mortality (49.0%), was 81.7%; similar to prior estimates. Latent mortality contributed at least as much to total discard mortality as on-deck mortality. The individual depth profiles show clear patterns of active pelagic behavior in 6 out of 14 live fish in 2009 and 6 out of 11 live fish in 2010. The mean percent of time above a 2-meter floor was 16.8% with a standard deviation of 24.4% in 2009, and 1.2%, with a standard deviation of 3.0% in 2010. This pelagic behavior occurred more frequently (86.0%) during nighttime, but there were no other obvious environmental correlates.

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- CHAPTER 1 -

GENERAL INTRODUCTION

Summer flounder, *Paralichthys dentatus*, is a commercially and recreationally important flatfish species along the east coast of the United States. It is most abundant from Cape Cod, Massachusetts to Cape Fear, North Carolina, but ranges from Nova Scotia to Florida (Able & Fahay 2010). The 2010 commercial fishery from Maine to North Carolina reported a catch of 6,081 metric tons, or 13,406,000 lbs, while the recreational fishery reported landings of 2,253 metric tons, or 4,967,000 lbs (Terceiro 2011). If the 2009 average ex-vessel price per pound ($ 1.88/lb) is applied to these landings, the combined value of the landed summer flounder for 2010 is approximately $34.5 million (Mid-Atlantic Fishery Management Council 2010). Summer flounder is not only an economically important species, but is one of the most important sport fish along the east coast.

Summer flounder management began in 1988 in accordance with the Magnuson-Stevens Act of 1976 as a joint effort by the Atlantic States Marine Fisheries Commission, the Mid-Atlantic Fishery Management Council, and the individual states involved (Mid-Atlantic Fishery Management Council 1988). The fish stock was at its lowest during the late 1980's, falling to its lowest Spawning Stock Biomass (SSB) estimate in 1989 at 7,069 metric tons. As a result, management imposed commercial quotas and recreational harvest limits in 1993 and the SSB began to increase, but not as quickly as anticipated. In the late 1990's stricter fishing regulations were enacted and the SSB has steadily increased. The stock is currently still in a rebuilding state, with a target SSB of 60,074 metric tons by January 1, 2013, though the 2010 SSB estimate was 60,238 metric tons (Terceiro 2011).

Due to the importance of the fishery, there is pressure to reduce management limits by increasing quotas and reducing harvest limits. This has increased in recent years as the SSB estimates have been approaching (and have now reached) the 2013 target (Terceiro 2011). Yet, due to the uncertain nature of fisheries science, mangers have been tentative about relaxing regulations at this point. There are many questions on how to move forward in the management of summer flounder.

One way to approach these questions and the uncertainty of stock assessments is through new research approaches. Recent technological innovations allow for observation of individual fish with greater detail than previously available. One such innovation has been the increased availability of acoustic tags and sensors, providing a more holistic view of an individual's behavior including fine scale movements, depth, temperature, salinity, and even heart rate (Block et al. 1992, Dewar et al. 1999). These improvements in our ability to observe individuals in-situ provide new tools to examine old questions in new ways as well as methods to approach new questions about important species like summer flounder.

There are some clear and important data gaps in our understanding of summer flounder and their ecology. In this study we address two of those data gaps using acoustic telemetry, moving our understanding of the species forward with both direct and indirect implications for management. In Chapter Two the issue of discard mortality is approached with new methodologies. Specifically, it explores the use of acoustic telemetry movement data to determine mortality of trawl-caught summer flounder to determine a discard mortality rate, a value with substantial impact on the fishery management. Chapter Three continues the use of acoustic telemetry, with pressure sensitive tags, to investigate the occurrence of pelagic behavior in summer flounder because we recognize more and more flatfish exhibit such behavior with potential ecological and commercial implications.

- CHAPTER 2 –

EVALUATING DISCARD MORTALITY OF SUMMER FLOUNDER (*PARALICHTHYS DENTATUS*) IN THE COMMERCIAL TRAWL FISHERY: DEVELOPING ACOUSTIC TELEMETRY TECHNIQUES

Abstract

Fish bycatch discard mortality is one of the most significant issues influencing marine fisheries management worldwide. Discard mortality studies to date rely on potentially biased on-deck evaluation of immediate mortality or reflex impairment, and evaluation of delayed mortality through holding captured fish for varying lengths of time to determine survival. Telemetry of ultrasonically tagged fish provides a technique for evaluating fish bycatch discard mortality, and especially latent mortality, under natural conditions in the sea. For summer flounder (*Paralichthys dentatus*), along the eastern United States, an 80% discard mortality is assumed but not verified. To determine the mortality of discarded fish, both live (n = 41; excellent condition = 4, good condition = 16, poor condition = 21) and dead (n = 16) summer flounder from commercial fishery-length tows were tagged and released in a fixed hydrophone array (mean depth of 8.8 meters) on 15 September 2009 off Brigantine, New Jersey. We were able to re-detect both live and dead fish within the array and during mobile tracking for approximately 24 hours before a storm. Fish of poor initial health and known dead fish were redetected after the storm in a concentrated area inshore of the release site and were presumed dead. Live fish exited the array offshore, as is typical in the fall migration. The final discard mortality estimate, combining on-deck mortality (32.7%) and latent mortality (49.0%), was 81.7%; similar to current estimates. Latent mortality contributed at least as much to total discard mortality

as on-deck mortality, confirming assumptions of earlier assessments. Several new telemetry metrics can lead to a better understanding of these important latent effects.

2.1. Introduction

Fish bycatch discard mortality is one of the most significant issues influencing marine fisheries management in the world (Davis 2002, Kennelly & Broadhurst 2002) and in the U.S. (Harrington et al. 2005) and this applies to summer flounder, *Paralichthys dentatus*. This species is one of the most commercially and recreationally important fish species along the east coast of the United States. The species is most abundant from Cape Cod, Massachusetts to Cape Fear, North Carolina, but range from Nova Scotia to Florida (Able & Fahay 2010). The commercial fishery from Maine to North Carolina reported a catch of 4,848 metric tons in 2009. Approximately 5-10% (242-485 metric tons) of the summer flounder commercial landings were calculated to be loss from discards of the otter trawl and scallop dredge fisheries in 2009. Calculations are based on an assumed 80% discard mortality rate (Terceiro 2010) stemming from the 2nd Amendment to the Fisheries Management Plan in 1991, where the discard rate was presented solely as an estimate (MAFMC 1991), but later supported by results in a holding pen study (Hasbrouck et al. 2008).

Discard mortality assessment has relied on immediate evaluation of mortality (Davis & Schreck 2005), evaluation of delayed mortality through holding captured fish to determine survival (Parker et al. 2003, Davis 2005, Mandelman & Farrington 2007, Hasbrouck et al. 2008), and examining reflex impairment of individuals to assess likelihood of mortality (Davis & Ottmar 2006, Davis 2010). While these types of studies can provide important insights into immediate survival, it is difficult to assess the longer term, latent effects of capture and to be able to separate holding tank effects from those encountered in the ocean (Mandelman & Farrington 2007). Natural factors such as predation and ability to feed are not easily replicated in holding tank experiments, and only slightly easier is quantifying and replicating the variability of physical correlates to mortality such as temperature and dissolved oxygen levels (Benoit et al. 2010). Thus, the mortality rates derived from these experiments may be biased.

Acoustic telemetry provides a novel approach for assessing discard mortality in fishes. Movement of tagged discards may provide a means to discern latent mortality. Such an in-situ assessment allows for natural variability, feeding behavior and predation, and avoids the biases associated with on-deck and holding assessments. The use of biotelemetry for flatfish has been effective for determining fine scale movements (Able & Grothues 2007), including for summer flounder (Szedlmayer & Able 1993, Sackett et al. 2007, 2008). It has also been used to assess mortality associated with catch-and-release recreational fisheries in other species (Jolley & Irby 1979, Hightower et al. 2001, Cooke & Phillip 2004, Donaldson et al. 2008). In this paper we evaluate laboratory and field techniques for using acoustic telemetry to assess mortality in summer flounder, and apply these techniques to estimate the discard mortality, both initial and latent, in commercial trawl catches.

2.2. Methods

This study was conducted in the laboratory and along the coast of southern New Jersey between June and October 2009. Four phases consisted of (i) testing a quick and low impact tagging technique, (ii) a flume examination of current speeds required to move dead summer flounder and thus potentially discern them from live individuals in field observations, (iii) preliminary telemetry study within a small estuary to scale expectations for a more extensive and involved coastal ocean assessment, and (iv) full scale coastal ocean telemetry of fish captured by commercial otter trawl.

2.2.1 Tag Retention and Behavior

We tagged summer flounder externally to decrease handling time and avoid surgery and anesthesia as potential confounding effects. Acoustic transmitters were attached to Floy t-bar tags with cyanoacrylate glue and shrink wrap. The tags were then inserted into the epaxial musculature using tagging guns (Mark III Pistol Grip Tag Fast Swiftach Tool, No. 08958, Avery Dennision, Fitchburg MA). T-bar tag retention has been examined for a number of fish species including paralichthyids, but the added mass and drag of a transmitter could change this. We analyzed tag retention in both live and dead (carcasses) summer flounder in order to evaluate the timing and cause of tag loss. Live fish (n=8, 273-454 mm TL) were tagged with dummy transmitters, (model MA-11-18 Lotek Wireless, 11 x 51 mm, 4.5 g in sea water, Inc., St. Johns, Newfoundland). Tag retention was monitored twice daily during two trials of four fish each over a period of two weeks in a 1.2 x 2.4 meter holding tank with ambient sea water (approximately 21° C, 28 ppt).

Tag retention trials were conducted on carcasses because different mechanisms of detachment, such as scavenging and decay, were likely compared to live fish. Tagged carcasses (n=11, 275-386 mm TL) were placed in a 1.2 x 2.4 meter holding tank with flow-through seawater (ambient temperature and salinity, approximately 21°C, 28 ppt) that also contained invertebrate scavengers. Potential scavengers included, 30-40 mud snails (*Nassarius spp.*), 12-15 spider crabs (*Libinia emarginata*), 3-5 blue crabs

(*Callinectes sapidus*), 2-4 green crabs (*Carcinus maenas*), 3 channeled whelks (*Busycon canaliculatum*), 5 hermit crabs (*Pagurus spp.*), and 4 moon snails (*Lunatia heros*). Divers have observed these scavenger species in the area of the ocean study site (Rose Petrecca, personal communication). Fish length, date, time, and water temperature were recorded at deployment. Observations of invertebrate response were made immediately after introduction of the carcass into the tank followed by hourly observations. The condition of the carcass, the activity of the scavengers, and the timing of tag detachment were noted. Observations were terminated after tags were removed or after near-complete decay of the carcass.

2.2.2 Carcass Behavior in Flume

To examine the movement potential of summer flounder carcasses relative to current velocity, they were subjected to controlled currents in a racetrack flume (Nowell et al. 1981). The flume (working channel length of 620 cm, width of 70 cm, depth 20 cm) had approximately 10 mm of coarse sand spread evenly along the bottom and was filled with water (34 ppt). The water velocity (10, 15, 17, 20, 25, 30, and 35 cm/s surface velocity) was manually adjusted using a rheostat dial. Near-bottom velocities were subsequently measured using a laser Doppler velocimeter. Fish (236-402 mm total length) were euthanized via blunt trauma, with care taken to not disturb the surface of the fish. Carcasses were placed in a variety of orientations on the sediment surface on the flume bottom, and the distance of the leading edge above the sediment surface was measured before flow was initiated. The speed was increased incrementally until the carcass was lifted from the sediment surface. The time and current speed at which the carcass lifted were recorded.

2.2.3 Observational Scaling in the Field

In order to test the assumption that we could distinguish between live and dead acoustically-tagged summer flounder, and understand the temporal and spatial scale needed to do so, we tracked both in a preliminary effort in an estuary. The test area was an unnamed slough (approximately 125 meters wide, 4 meters deep) located in Great Bay estuary, New Jersey (Figure 2.1). An array of four post-synchronized trilaterating hydrophones (WHS_3050, Lotek Wireless, Inc) passively tracked the live fish and carcasses from July 8 to July 23, 2009. The hydrophones were moored within the slough in a polygon, each ~ 250 m away from its nearest neighbor. Additionally, mobile acoustic tracking of the tagged fish utilized stereo hydrophones (Lotek LHP_1) and a Lotek MAP 600 RTA Receiver and global positioning system (GPS) on a small boat. Signal identity was recorded along with the power, coordinates, time, and bearing to help determine the position of tagged fish. These data were used to supplement that from passive tracking. Tide data for the area was obtained from NOAA National Estuarine Research Reserve Centralized Data Management Office (2004).

Three live summer flounder (356 – 471 mm) were caught by hook and line within the study location. All were tagged with acoustic transmitters (Lotek MA-11-18 series) in the dorsal-anterior epaxial muscle area in a manner similar to that of Sackett et al. (2007). In addition to the live fish, carcasses of this species (n=4, 316-370 mm) were tagged with transmitters (Lotek MS-16-25) that broadcast in two code series (dual mode

MAP and CAFT, Lotek Wireless Inc.). One code mode (MAP) was used to follow movements on the fine scale trilatering array (to meter-scale resolution) within the estuary. The other code mode (CAFT) was used to follow tagged summer flounder through a larger existing gated array in the Great Bay estuary (Grothues et al. 2005) after exit from the fine scale array (Figure 2.1). Mobile tracking occurred on 7 days between July 8 and July 20, 2009 with a total effort of approximately 17 hours.

2.2.4 Discard Mortality Estimate

Fish for the in-situ discard mortality assessment were captured with a commercial otter trawl from the *F/V Viking II* (26.5 meters, Capt. Jim Lovegren) on 15 September 2009 in the coastal ocean off Brigantine, New Jersey (Figure 2.1). The net was a "flat" double with a 140 mm-between-knot mesh with 24.4-meter sweep using an 18.3-meter top line. The ground rig utilized a 36.6-meter bridle with 102-mm cookies on the lower leg. A tickler chain was set near the center of the sweep. The net was fished with a 150 m towrope in approximately 7-8 m of water. Trawl tows (n=5) were performed as a series of loops originating and ending at a central site near the fixed five-hydrophone array of MAP hydrophones. Trawl times were from 111 – 129 min except for the final trawl (76 min) in an effort to capture several less-seriously damaged fish to establish a gradient of health indices at release (Table 2.1). After each tow the catch was dumped on the deck and the times to cull the catch and remove summer flounder were recorded. Each summer flounder was immediately scored with a health index (Table 2.1) following a prior study (E. Hasbrouck, pers. comm.) as Excellent (minor scratches, no visible signs of mucus damage, minor scale loss); Good (moderate damage, moderate scratches, visible damage to mucus layer); Poor (significant scratches, scale loss, mucus layer severely affected, lethargic but still capable of arching the body); and Dead (fish does not arch). All summer flounder were treated as bycatch discards and returned to the water in a manner consistent with fishing vessel operations. This meant that specimens were allowed to lay on-deck during sorting and most were diverted only long enough for measurement, dart tagging, and condition assessment before being returned to the water. Exceptions were to make sure that control carcasses were actually dead by removing the gills.

To determine the latent mortality of these discarded fish, both live (n=43) and dead (n=17) summer flounder were tagged as previously described and released into the array. The study location had a mean depth of 8.8 meters, and mean temperature and salinity of 21.2 °C and 29.6 ppt, respectively. Submerged data logging hydrophones were positioned as corners of a square with sides of approximately 500 m and a fifth hydrophone at the center (Figure 2.1). Thus, the total listening range extended to a square of approximately 2.25 km^2, although the area for fine scale positioning (determined by overlapping listening range) was considerably smaller (~500 m^2). The submerged data logging hydrophone array was recovered and downloaded when mobile tracking, conducted between 15 September and 11 October 2009, indicated that most fish had left the area. Three tags had erroneous tagging data, therefore initial health and size data cannot be related to telemetry data; neither these fish nor the records were used in any future analysis.

Mobile tracking of tagged fish was accomplished using stereo hydrophones (Lotek LHP_1) and a Lotek MAP 600 RTA Receiver deployed from the stern of a boat. Tracking data were recorded and viewed in real time using a laptop computer connected to the receiver running Maphost V4.5 (Lotek Wireless Inc). Initial tracking patterns focused on the area of deployment, and subsequently spiraled outwards, covering an area of roughly 300 km^2. After it was apparent that fish had left the area of deployment, tracking efforts were directed south and east in a series of nearly parrallel lines (Figure 2.2).

2.2.5 Data Analysis

We discriminated between live and dead discards from the commercial trawler based on two methods. First, the similarity of their detection in time and among hydrophones was calculated on Euclidean distance and projected using non-metric multidimensional scaling (nMDS; Primer E software, Plymouth, UK). Individual fish detections were binned at 15-minute intervals for each fixed hydrophone and the similarity matrix was calculated from the number of receptions at each hydrophone for each individual. The differences in detection were used to infer differences in behavior and location between live and dead discards. Second, the direction of exit from the array was determined for each fish by using a sound-pressure (decibels) weighted activity cell method adapted from Simpfendorfer et al. (2002), the assumption being that the direction of departure will differ between live and dead fish. Positions were determined for each 15-minute interval using equations 1 and 2 (below) for X and Y coordinates respectively,

$$\overline{X}_{\Delta t} = \frac{\sum_{i=1}^{n} R_i P_i X_i}{\sum_{i=1}^{n} R_i P_i} \quad (1) \qquad \overline{Y}_{\Delta t} = \frac{\sum_{i=1}^{n} R_i P_i Y_i}{\sum_{i=1}^{n} R_i P_i} \quad (2)$$

where R_i is the number of receptions at hydrophone i, P_i is the power of receptions at hydrophone i, and X_i and Y_i are the x and y coordinates of hydrophone i. The plots were created for the final 5 hours of each fish's residence within the array and the trend in direction was determined and compared to the currents during the time of departure. Bottom current data was retrieved from the output from the Regional Ocean Modeling System (ROMS) ESPRESSO model and plotted using RomsPlot Matlab tools (Wilkin 2006, Levin 2009). Mobile tracking positions were determined on a coarse scale based on interpolation of detection time and GPS location of the boat.

Mortality estimates for fish captured in the trawl, tagged, and released were calculated as percentages. On-deck mortality precentage was the number of individuals assessed as dead on-deck divided by the total catch. Latent mortalities were calculated by dividing the number of individuals determined to be mortalities by the number of individuals assessed as live (poor through excellent condition) on-deck, excluding those fish never detected (n=5). Individuals determined to be mortalities by multiple estimates were only included in one estimate so as to not compound mortality percentages. All mortality percentages (on deck and latent) were added to create the final discard mortality estimate.

2.3. Results

2.3.1 Tag Retention and Behavior

There was no tag loss in the live fish (n = 8) tag retention trials. In every carcass tag retention trial, the first scavengers to approach the summer flounder carcass were spider crabs, and often in a group of about 4-6, usually within the first few minutes after the carcass was added to the tank. Some scavengers demonstrated the ability to separate the tag from a carcass, but the timing of the separation varied greatly. The tags were removed from the carcass in 7 of the 11 trials (63%); in the other 4 trials, the tag was still attached to a layer of skin after most of the fish had been consumed or decayed. The quickest tag removal happened in 0.6 h and the longest trial in which the tag was removed by the scavengers lasted 51.0 h (average = 25.1 hours).

2.3.2 Carcass Behavior in Flume

Transport of tagged summer flounder in the flume occurred over a wide range of current speeds (10.1- 47.6 cm/sec) in the 71 trials. The mean near-bottom speed at transport was 27.3 cm/sec. The most common response was for the carcasses to slowly lift up off the bottom, leading edge first, until it was fully off the bottom and transported down-current. There was a moderate positive Pearson correlation between speed of transport and weight (r = 0.234). There was a strong negative correlation between height of the leading edge of the carcass off of the sediment surface and speed at transport (r = -0.690). There was very little correlation between length and speed at transport (r = -0.040).

2.3.3 Observational Scaling in the Field

Three live tagged summer flounder tracked in the static estuarine array yielded intermittent movement records independent of flow. Hydrophones did not detect any of the live summer flounder until 5-6 hours after release. Residency of live fish within the array ranged from 47.2 hours for one fish and the duration of the study (20 days) for the other two. In contrast, tagged carcasses traveled with the tidal flow, oscillating along the slough before leaving the array (Figure 2.3). Mean carcass residence time was 43.6 hours ± 49.2. Three carcasses tagged with dual frequency transmitters (Tags 165, 166, and 168) were detected outside of the slough array with the CAFT hydrophone system (hydrophones 2, 3, 4, and 13) in Great Bay and Little Egg Inlet, at distances greater than 5 km from the slough indicating long distance transport was possible (Figure 2.1).

2.3.4 Discard Mortality Estimate

Fish caught in the commercial trawl (n = 49) ranged from excellent condition to dead individuals on-deck (excellent = 6.1%, good = 20.4%, poor = 40.8%, dead = 32.7%; Table 2.1). Eight additional individuals captured in a short duration tow were in better condition and therefore were not used for deck mortality estimates, but provided a gradient of health indices for tagging (excellent = 12.5%, good = 75.0%, poor = 12.5%, dead = 0.0%; Table 2.1). The length of live (335-730 mm) and dead (328-602 mm) fish overlapped at sizes below 602 mm, but all fish greater than 602 mm (n = 8) were live on-deck (Table 2.1). The estimated catches of other fishes (primarily skates and rays, but including some bony fishes) and invertebrates (primarily horseshoe crabs) ranged from 68-454 kg in three of the standard length tows (Table 2.2).

Most tagged fish remained in the general vicinity of their release and thus within the range of the fixed array for approximately 24 hours (Figure 2.4). During this time the fixed array recorded 40,969 fish detections. Five tagged fish were never detected by any of the receivers, including one dead fish. Subsequent departure of live and dead fish from the array coincided with a Northeast storm event (Figure 2.4). Despite the relatively short period of detection, there were patterns with respect to a fish's initial health index via ordination and cluster analysis (Figure 2.5). Four clear groupings emerged at the Euclidean distance of 870. The first included two sub-groups at a distance of 580, one with a majority of individuals of all health indices, likely due to the short duration and large number of receptions by multiple hydrophones immediately after deployment. The second sub-group consisted of five dead individuals and one "poor" individual. The second group is relatively close in distance to the first, with 2 "good" condition fish and 1 "excellent" condition fish. The last two groupings at the distance 870 were individual dead fish. The sub-group of dead individuals within the largest first group, in addition to the two dead individual groups highly separated in space demonstrates that the dead and dying fish had different movement patterns.

Mobile tracking efforts were also able to detect both initially live (excellent, good, and poor conditions) and dead fish during tracking (Figure 2.2). After the initial tracking, and the storm event at approximately 12:00 September 16 to 00:00 September 17, fish of dead (n=9) and poor (n=11) conditions dominated the detections, with few good (n = 2) and no excellent condition fish. Those fish re-detected after the storm were found in a relatively concentrated area about 8 km southwest of the release site (Figure 2.2). This movement is consistent with bottom flow from the storm event, modeled from the Regional Ocean Modeling System. Thus, both the fish and model prediction indicate movement in a southwest direction from the array. The concentrated area of detections contained 22 fish (38.6% of those tagged). Assuming that fish concentrated to the southwest represent passive movement of mortalities, this yields a latent mortality percentage of 35.1%. The breakdown of these latent mortalities based on initial condition is 57.9% of all "poor" individuals, 13.3% of all "good" individuals, and 0% of all "excellent" individuals assessed as dead (Table 2.1).

Individuals departed the array in different directions and this was used to further differentiate live and dead fish (Figure 2.6). Based on oceanic bottom current models, those individuals following the southwest current were considered mortalities, while others were considered live. Live fish tended to move eastward into deeper water, with a few fish moving northward. Those already considered in the mobile tracking area of concentration were not included in these results. This analysis yields an additional latent mortality percentage of 13.5%, based on the occurrence of 4 "good" individuals, 1 "poor" individual, and 1 "dead" individual. Combining the direction of departure estimate of latent mortality with that of the mobile tracking data brings the total latent mortality to 48.6%. On-deck mortality was combined with latent mortality to obtain a total discard mortality of 81.3%. This yields a gradient of discard mortality based on initial health index as follows: 63.2% of all "poor" individuals, 40.0% of all "good" individuals, and 0% of the "excellent" individuals evaluated as dead. The deviation in mortality estimates from on-deck estimates provides a measure of error. Ten dead fish would be accounted for as dead using our metrics, thus 66.7% of the dead fish were properly categorized as dead, or a potential error of 33.3%. Thus, our best estimate of total (on-deck and latent) mortality is 81.3% but could be within the range from 48.0% to 100%.

2.4. Discussion

2.4.1 Evaluation of Technique

The tagging techniques tested in this study allowed for quick tagging and avoided surgery, antibiotics and anesthesia, allowing acoustic tags to be attached without adding biases from long handling time or surgical procedures without mortalities. Tag retention in live fish did not represent a problem, however, scavengers may complicate tag retention in fish that are dead. The presence of scavengers on top of a carcass may influence the ability of the carcass to be transported by currents, and may limit signal transmission. In addition, larger scavengers, such as sharks, could consume and move carcasses and the fish could be misinterpreted as alive. It seems possible that scavengers effected several carcasses' movements, and this may be the reason for the classification errors in latent mortality.

The 5-6 hour delay in reception of live fish in the preliminary trials in the estuary suggests immediate burial, which decreases the likelihood of tag detection (Grothues and Able, unpublished data). Summer flounder carcasses in-situ in the estuary were shown to move substantial distances in synchrony with the tidal currents, suggesting currents were the mechanism responsible for movement. These results are supported by the flume work, where the threshold speed to move a carcass was as low as 10 cm/s. These current speeds are commonly seen in the near-shore coastline of New Jersey (4-17 cm/s mean current speed has been observed for the area (Charlesworth 1968). In the ocean, carcasses also moved long distances and thus the premise that movement or no-movement could easily differentiate live and dead fish is not supported, at least for this flatfish.

The acoustic telemetry approach, while novel and potentially very informative, does have some limitations for estimating discard mortality. First and foremost, the methods for determining mortality are estimates based on behavior, and will never be as clear-cut as observing mortality directly. There are also the limitations associated with acoustic tracking in general, like observation effort, tag malfunction or retention, signal loss from fish burial, and cost. The issue of tracking effort was notable in this study, as the time and cost of tracking a large number of fish on the continental shelf is substantial. Tag malfunction, or improper handling, resulted in 5 tags never being detected despite being deployed into a functioning array.

2.4.2 Discard Mortality Estimate

The initial on-deck mortality was relatively low at 32.7%, compared to our final estimate of mortality of 81.3%. On-deck assessment of a health index also yielded a large number of "good" and "poor" condition fish. These results further support the need for accurate latent mortality estimates to be included in estimates of discard mortality. In addition, the initial health index of fish show a good agreement with our mortality assessments, with those in the poor condition having higher percentage of latent mortality than those in good condition, and no excellent condition fish were determined to be mortalities.

The failure to detect a number of tags from the short duration trawl caused a small sample size that made any determination of latent effects of trawl times unfeasible. The initial conditions of the fish in the short duration trawl, however does yield an interesting result, with the majority of fish being in the "good" condition and no fish being dead on-deck (Table 2.1). This result supports previous work that suggests shorter tow times could directly reduce mortality in flatfish (Davis 2002, Benoit et al. 2010) and specifically summer flounder (Hasbrouck et al. 2008). Other advantages of shorter tow times include smaller total catch, which could reduce crushing effects in the trawl and time on deck due to reduced sorting times (Davis 2002). The large number of hard-shelled horseshoe crabs in the trawls in this study is a clear example of bycatch that could cause harmful abrasion in longer tows.

Observations within the array via fixed hydrophone are limited to less than 24 hours due to the short residency time. However, the excellent and good condition fish differentiated from the poor condition and dead fish in detection pattern along at least two multivariate axes. This differentiation was also supported by the other latent mortality metrics. These results are consistent with previous recreational catch-and-release studies that acoustic telemetry can provide a clear means to assess health, and thus mortality in-situ (Jolley & Irby 1979, Hightower et al. 2001, Cooke & Phillip 2004, Donaldson et al. 2008). It would be reasonable to assume that if the storm had not occurred and thus fish had remained resident within the array longer, that more fish would have separated from the larger grouping and a more confident estimate of mortality could have been made.

The northeast storm event prevented initial mobile tracking. However, the resulting transport of tagged carcasses and presumed mortalities to the southwest yielded a distinctly different pattern from the expected direction of travel into deeper water and towards the edge of the continental shelf normally exhibited by migrating summer flounder during the fall of each year (Packer & Hoff 1999, Able & Fahay 2010). The storm-derived currents caused a number of individuals to be transported in the unexpected southwest direction, which indicates drift with the current. This is consistent with the flume data and our preliminary work in the estuary, which indicated that dead fish can be moved by bottom currents. Additionally, subsequent work in the fall of 2010 in the same general area on the continental shelf (unpublished data) suggests that excellent condition fish are not likely to be passively moved by the current, with 75% (9 of 12) of individuals moving in directions different than the dominant current. Thus, these composite observations of live and dead fish support our interpretation that those fish found concentrated to the southwest, and those leaving the array in a southwestward direction should be considered to be mortalities. This assertion requires a caveat: some known dead fish (control) initially were not detected in the concentration to the southwest of the array, nor were they observed to depart the array in the southwest direction; therefore not all mortality can be accounted for in this type of drift analysis. Possibly some of the lack of movement by some carcasses could be the result of scavengers on the carcasses, as observed in the tank experiments. We believe scavengers likely influenced the miss-classified dead fish in this way.

Our discard mortality estimate of 81.3% is essentially the same as the previous arbitrary estimate (80%; Terceiro 2010) and that based on pen observations (78.7%; Hasbrouck et al. 2008), thus discard mortality rate in the summer flounder commercial fishery can be very high. The fact that a novel approach to determining discard mortality achieved such a high value, similar to previous estimates, seems to substantiate these estimates. Discard mortality rates are likely highly variable and influenced by a wide variety of factors (Davis 2002, Benoit et al. 2010), as with the 33.3% estimated error rate in this study. This variability and the high rate of mortality make it important to continue to pursue the question of fisheries related impacts on mortality, to understand the variability, and to determine best practices for reducing bycatch.

In summary, while this study did not address the issues of in-situ long-term delayed mortality or directly assess the influence of predation, it did demonstrate that acoustic telemetry is a useful tool in understanding the behavior of post trawl-captured summer flounder. Further, this study was informative in developing useful metrics for observing latent mortality. The ability to observe individuals in-situ provides a distinct advantages over holding and laboratory experiments, and as telemetry technology advances tools, such as motion sensors, heart rate monitors, and other physiological sensors, these will provide additional insights.

Tables

Table 2.1. The on-deck health index assessment and final fate of individual summer flounder (n = 57) from (A) four standard commercial otter trawl tows (mean tow length 120 minutes) and (B) one short commercial otter trawl (tow length 78 minutes), conducted off the coast of Brigantine, NJ, September 15, 2009. Health index as follows: Excellent (minor scratches, no visible signs of mucus damage, minor scale loss); Good (moderate damage, moderate scratches, visible damage to mucus layer); Poor (significant scratches, scale loss, mucus layer severely affected, lethargic but still capable of arching the body); and Dead (fish does not arch). Percentages for final fate (mortality, undetected or live) are based on the total number of fish in each health condition. Percentages for on-deck and total for each fate category are based on the total number of fish tagged.

A)

Health Index	**Mean Length (Range, mm)**	**Number On-Deck (%)**	**Final Fate**		
			Undetected (%)	**Latent Mortality (%)**	**Assumed Live (%)**
Excellent	580 (500-720)	3 (6.1%)	0 (0.0%)	0 (0.0%)	3 (100%)
Good	504 (430-570)	10 (20.4%)	0 (0.0%)	3 (30.0%)	7 (70.0%)
Poor	514 (335-702)	20 (40.8%)	1 (5.0%)	12 (60.0%)	7 (35.0%)
Dead	474 (328-602)	16 (32.7%)	1 (6.3%)	10 (62.5%)	*5[1] (31.3%)*
Total		49	2 (4.1%)	24 (49.0%)	*22[2] (44.9%)*

[1]These fish are known to be dead and are included in the on-deck mortality, but our latent mortality estimates would not have classified them as mortalities.

[2]Total does includes known dead fish (see above)

B)

Health Index	**Mean Length (Range, mm)**	**Number On-Deck (%)**	**Final Fate**		
			Undetected (%)	**Latent Mortality (%)**	**Assumed Live (%)**
Excellent	295	1 (12.5%)	1 (100%)	0 (0.0%)	0 (0.0%)
Good	573 (410-695)	6 (75.0%)	1 (16.7%)	3 (50.0%)	2 (33.3%)
Poor	478	1 (12.5%)	1 (100%)	0 (0.0%)	0 (0.0%)
Dead	-	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total		8	3 (37.5%)	3 (37.5 %)	2 (25.0%)

Table 2.2 – Summary tow and catch information for summer flounder tagged on 15 September 2009. Cull time was the amount of time a fish was on the deck and handled before being returned to the water. For the Health Index a value of A=excellent, a B=good, a C=Poor, and a D=dead. In tow number 1 four live fish were landed, and along with an unknown number of dead fish were held separately. A random sub-sample of these fish, as well as an unknown number of fish collected in a trial tow, were combined with the dead fish collected in tow number 3 to reach the total number of fish (n = 60).

Tow Number	Tow Time (min)	Estimated Total Catch in kg (lbs)	Average Depth in meters (fathoms)	Range of Cull Times (m:ss)	Health Index proportions
1	111	68 (150)	17 (9.3)	*	*
2	122	454 (1000)	10 (5.5)	9:30-26:40	A-0 B-2 C-6 D-3
3	126	454 (1000)	14.6 (8.0)	1:02-18:30	A-2 B-4 C-7 D-*
4	129	Not recorded	18.2 (10.0)	0:18-16:00	A-1 B-6 C-7 D- 5
5	76	Not recorded	12.8 (7.0)	0:30-7:50	A-1 B-6 C-1 D-0

Figure Captions:

Figure 2.1. Hydrophone locations within the Great Bay – Mullica River estuary. The MAP hydrophones were deployed within a slough for preliminary assesment of live and dead fish movement. The CAFT hydrophones were deployed as a part of a large scale array throughout the estuary but had infrequent receptions when several of the dead fish moved through the inlet.

Figure 2.2. The locations of individual boat tracks for detecting tagged fish and bathymetry in the coastal hydrophone array (see Figure 1). Also shown are the locations of tagged fish found during three tracking days after the storm event (approximately 12:00 September 16 to 00:00 September 17) moved them out of the coastal hydrophone array during 2009. Most fish were in the same location all three days, indicating a lack of movement during that time. A large proportion of the fish located in the tracked area were of dead or poor health index on-deck.

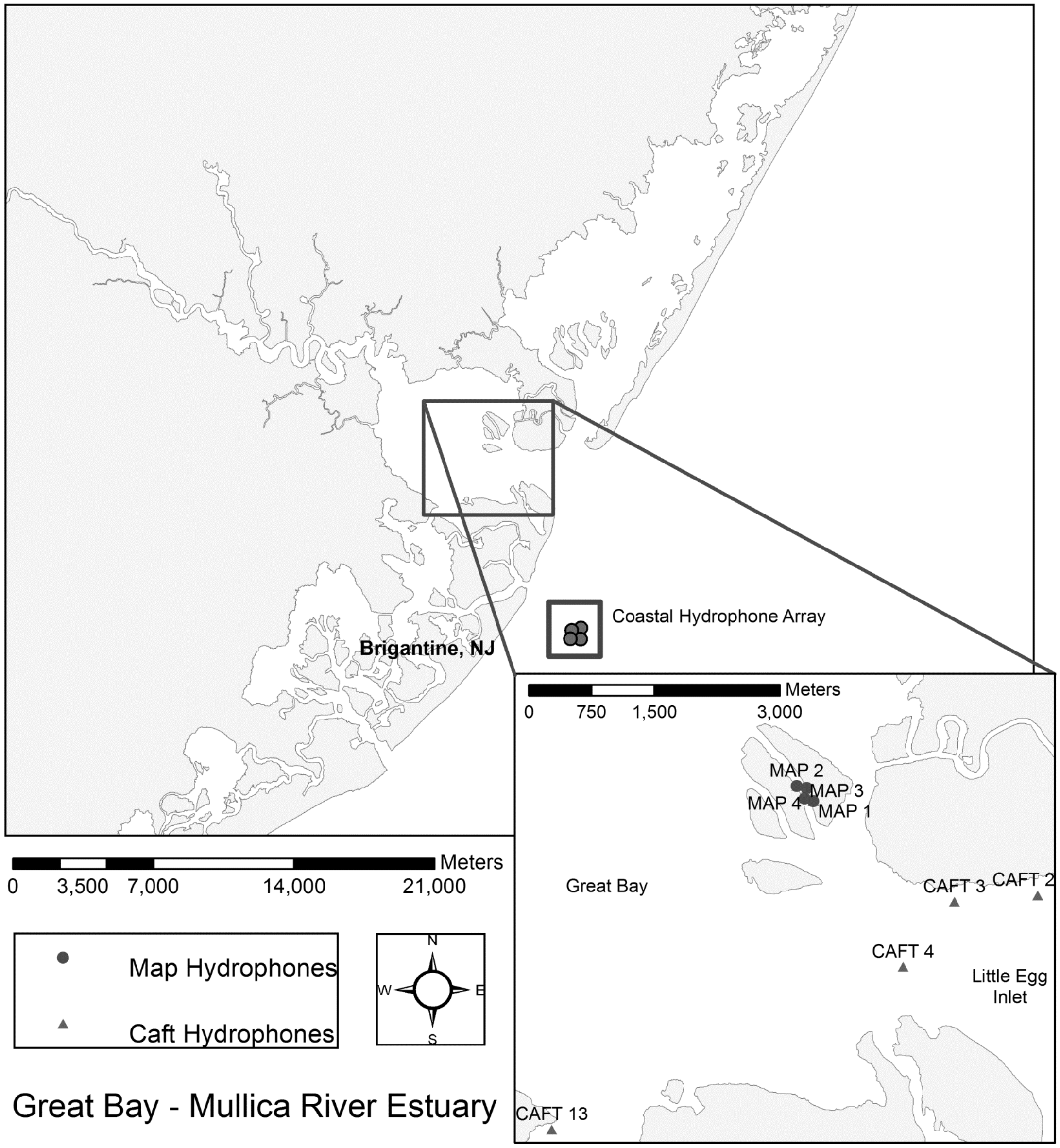
Figure 2.3. Movement of summer flounder carcasses tagged with acoustic transmitters (tags number 168 and 165) in a small, unnamed slough in Great Bay, NJ relative to tidal stage. The X marks the locations of the stationary hydrophones used to collect the telemetry data. The carcass positions are during the timeframe of the tide stage data and the darkness of the dot indicates time, with darkest being earliest and lightest representing latest. Two separate carcasses are moving in synchrony with tidal currents in both ebbing and flooding tides.

Figure 2.4. Presence of ultrasonically tagged individual live and dead summer flounder discards in the coastal ocean hydrophone array (see Figure 2) during September 2009. Top panel indicates wind speeds from Atlantic City NOAA weather station associated with a northeast storm event in synchrony with fish departure from the array. The bottom two panels show those determined to be dead, via the metrics of this study, and those determined to be live, respectively. The arrows indicate the approximate time of fish release.

Figure 2.5. Multidimensional scaling plot of ranked similarity among all ultrasonically tagged summer flounder discards over 24 hours after tagging during September 2009. Symbols represent the health index at release. The similarity is calculated on the basis of detection patterns at each of five hydrophones. Axes represent the first two major trends in the multidimensional space and are not scaled because rank is relative and without units. Distance is Euclidian. Group boundaries defined by Euclidean distance are based on consensus cluster analysis. Group A1 is a mix of all four health indices, while A2 is mostly dead individuals with one poor individual. Group B is two good and one excellent individual, while groups C and D are both comprised of a single dead individual. Groups B, C and D are separated in space, suggesting differences in movement behavior.

Figure 2.6. Center of activity plots (technique adapted from Simpfendorfer et al. 2002 and described in Materials and Methods) for tagged summer flounder using 15-minute

intervals for the last 5 hours each individual was within the listening array. The direction of departure from the array indicates if the fish traveled possibly with the storm currents (southwest), suggesting the fish were dead, or in another direction, suggesting the fish were alive. Those fish that were determined to be mortalities are marked as "dead." Several fish with few centers (due to low number of detections) were not included in this plot but were included in the discard mortality assessment.



Coastal Hydrophone Array
Brigantine, NJ
Meters
0 3,500 7,000 14,000 21,000
Map Hydrophones
Caft Hydrophones
N
W
E
S
Great Bay - Mullica River Estuary
Meters
0 750 1,500 3,000
MAP 2
MAP 3
MAP 4
MAP 1
Great Bay
CAFT 3
CAFT 2
CAFT 4
Little Egg Inlet
CAFT 13

Figure 2.1

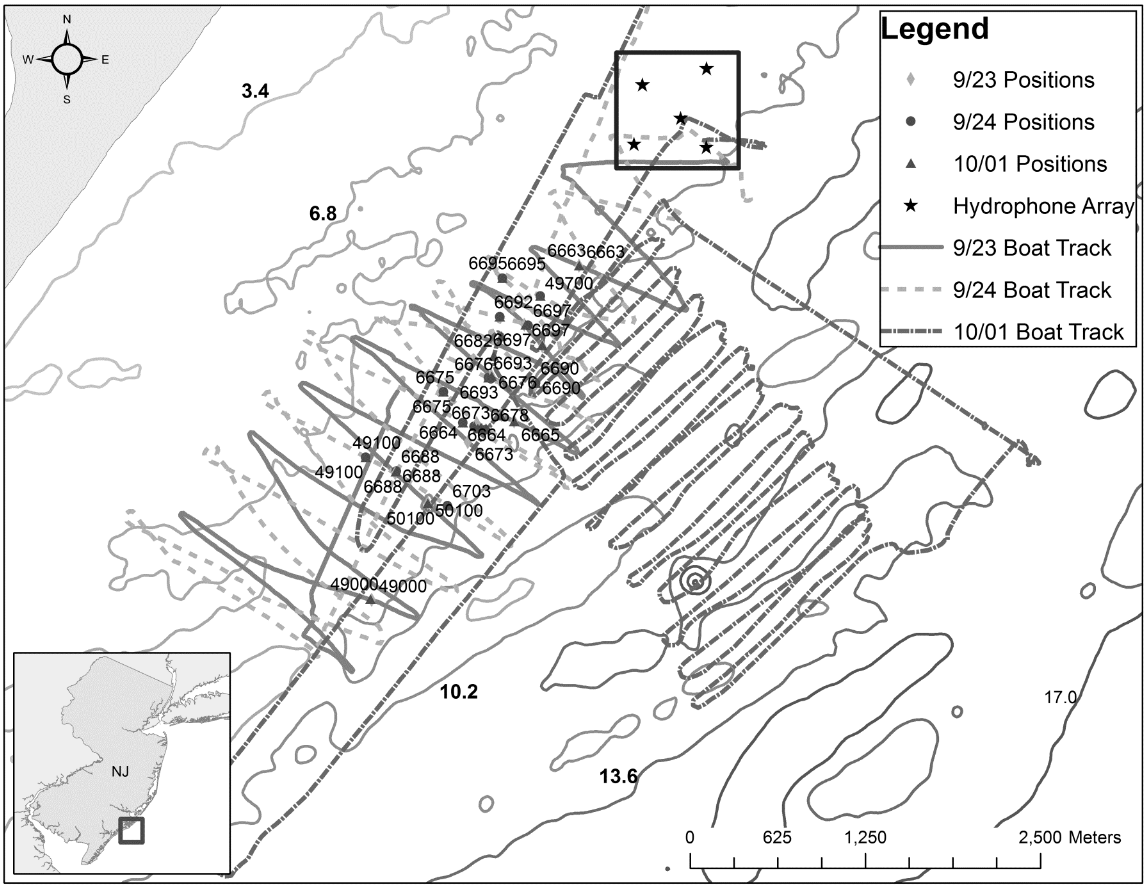

Legend
9/23 Positions
9/24 Positions
10/01 Positions
Hydrophone Array
9/23 Boat Track
9/24 Boat Track
10/01 Boat Track
N
S
E
W
3.4
6.8
10.2
13.6
17.0
NJ
0
625
1,250
2,500 Meters

Figure 2.2

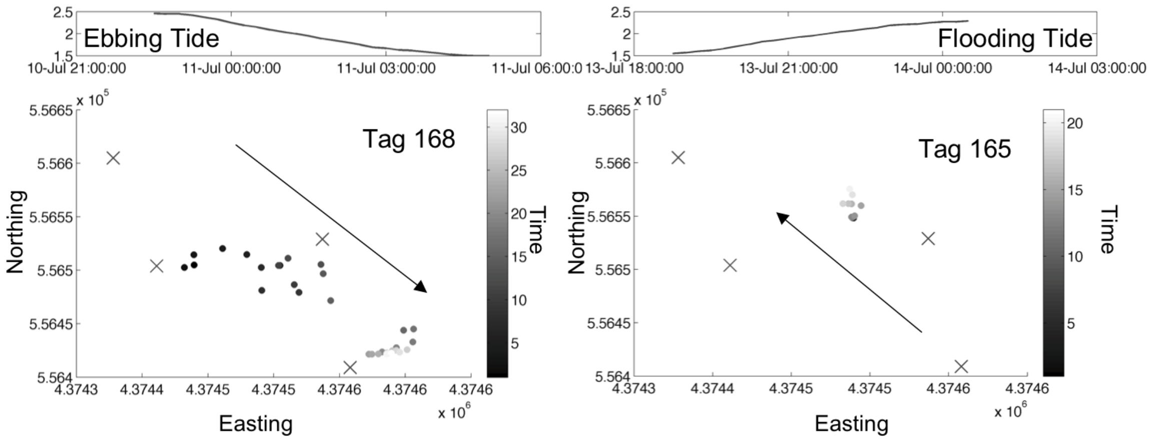

Ebbing Tide
Flooding Tide
10-Jul 21:00:00
11-Jul 00:00:00
11-Jul 03:00:00
11-Jul 06:00:0
13-Jul 18:00:00
13-Jul 21:00:00
14-Jul 00:00:00
14-Jul 03:00:00
Tag 168
Tag 165
Northing
Easting
Time

Figure 2.3

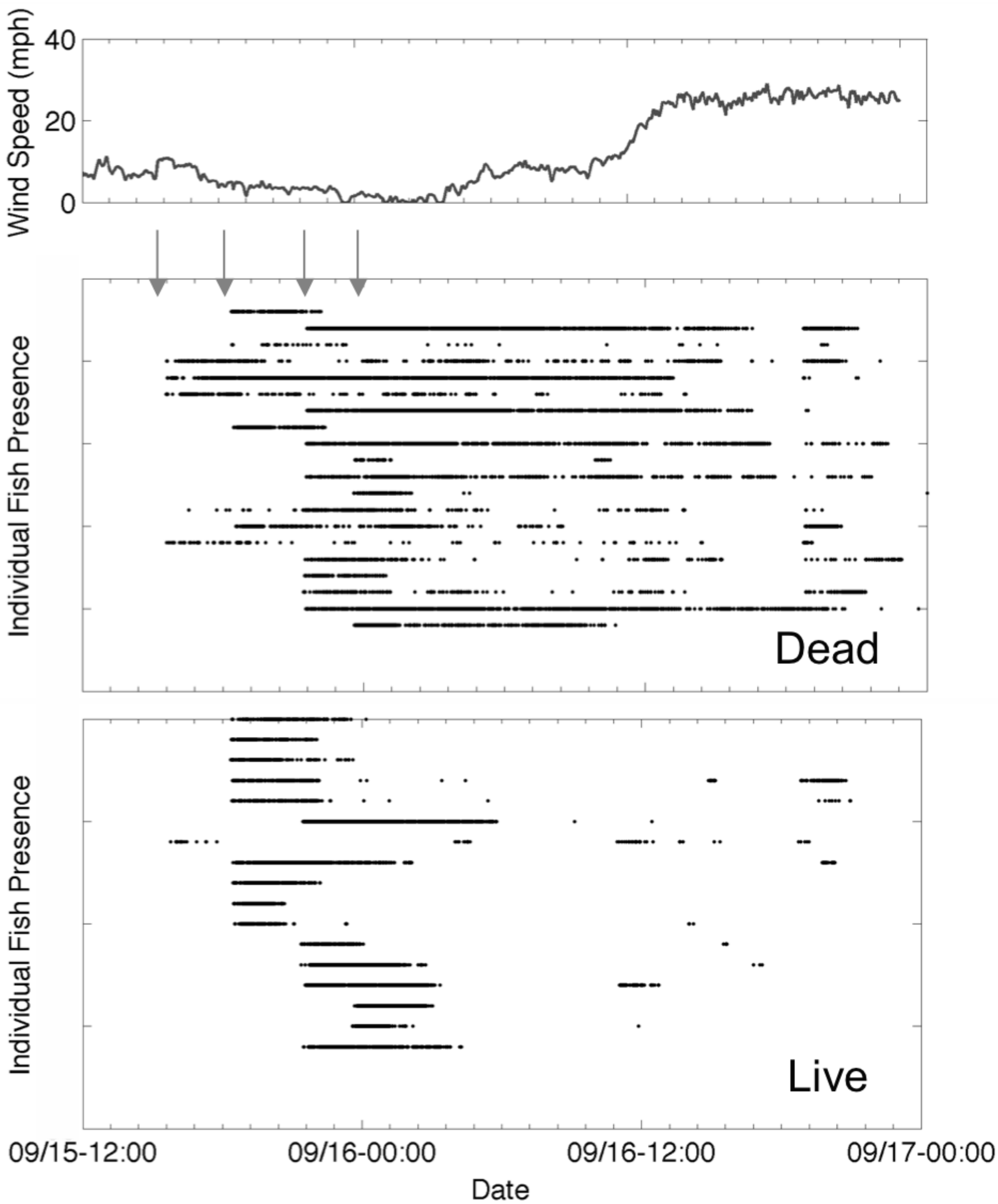

Wind Speed (mph)
40
20
0
Individual Fish Presence
Dead
Individual Fish Presence
Live
09/15-12:00
09/16-00:00
09/16-12:00
09/17-00:00
Date

Figure 2.4

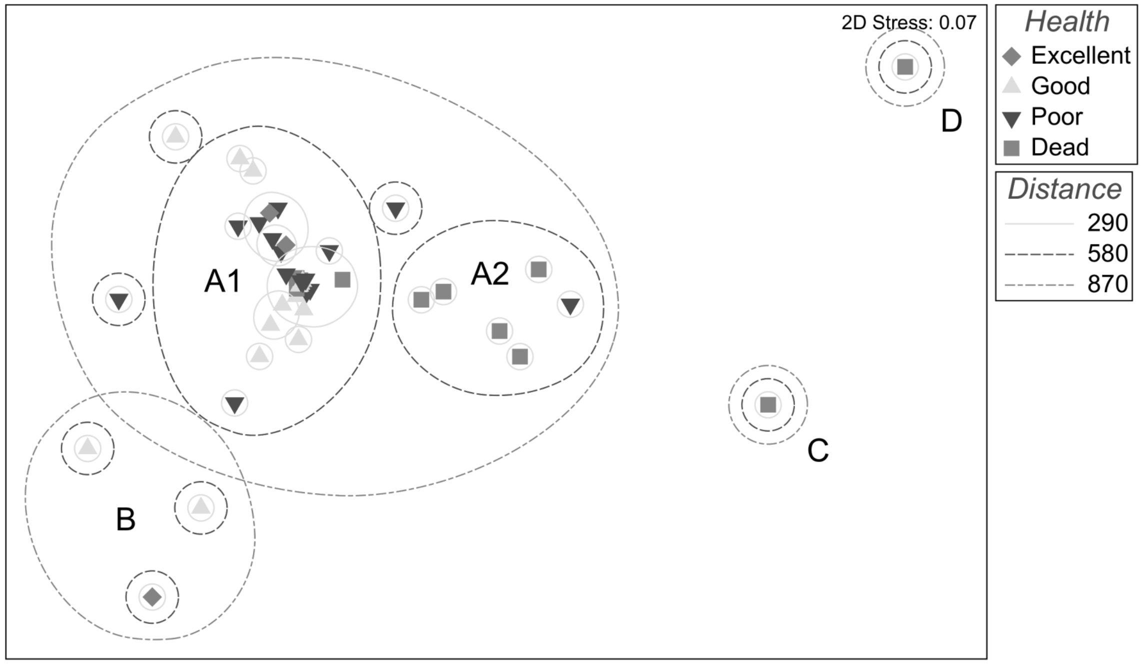

2D Stress: 0.07
A1
A2
B
C
D
Health
Excellent
Good
Poor
Dead
Distance
290
580
870

Figure 2.5

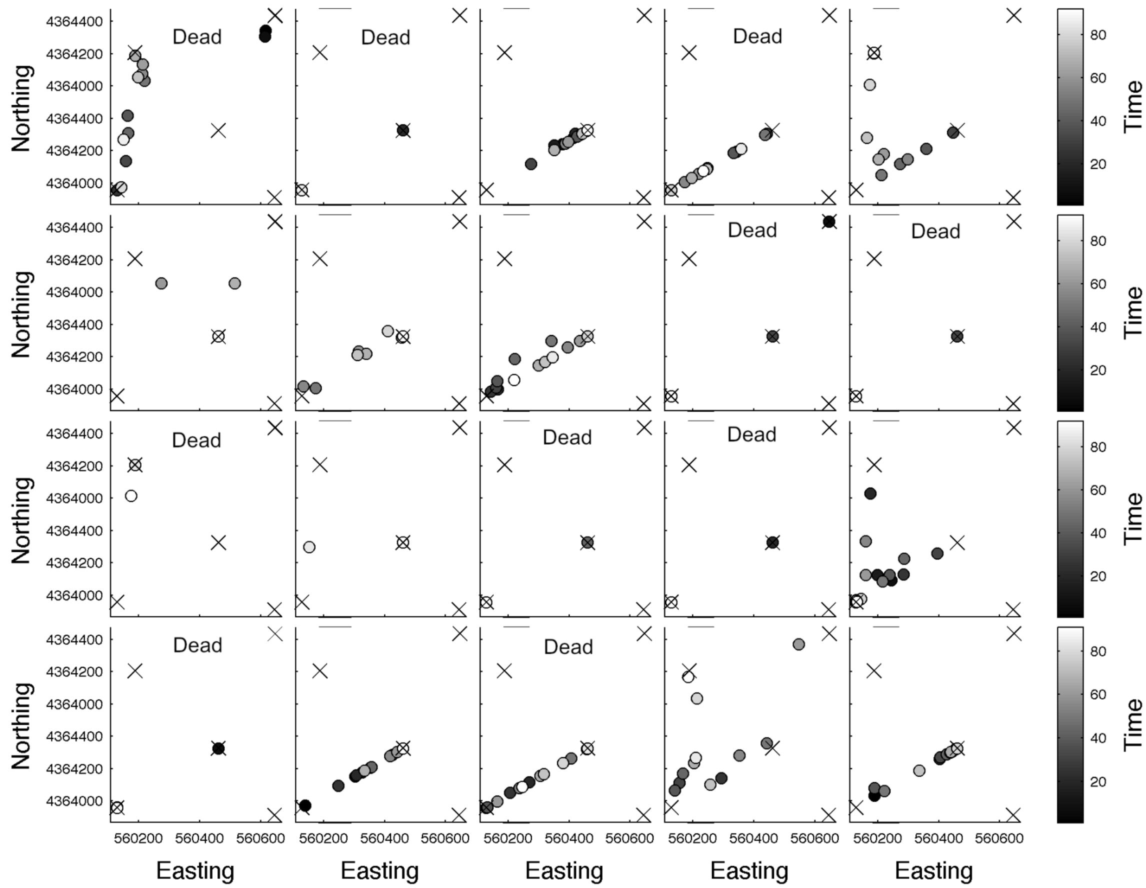

Dead
Northing
Easting
Time
4364400
4364200
4364000
560200
560400
560600
20
40
60
80

Figure 2.6

- CHAPTER 3 –

SUMMER FLOUNDER VERTICAL MOVEMENT: OBSERVATIONS OF PELAGIC BEHAVIOR IN A PRESUMED DEMERSAL SPECIES

Abstract

Flatfish are generally considered to be demersal. However, there is a growing body of literature on flatfish species exhibiting pelagic behaviors for various essential functions. Summer flounder are economically important flatfish commercially harvested with bottom trawl along the east cost of the United States. Captive summer flounder use "stroke and glide" behavior in the water column and they can feed actively there. We applied sensored acoustic telemetry techniques to determine if adult summer flounder (363 – 720 mm) demonstrate vertical movements during the fall migration period. Pressure sensing tags recorded depth of individual tagged fish at a resolution of 0.68 meters. Generally, signal values indicating depths two meters or greater above an individual's greatest depth were considered to be pelagic in nature. The individual depth profiles show clear patterns of active pelagic behavior in 6 out of 14 live fish in 2009 and 6 out of 11 live fish in 2010. The mean percent of time above this floor was 16.8% with a standard deviation of 24.4% in 2009, and 1.2%, with a standard deviation of 3.0% in 2010. This behavior occurred more frequently (86.0%) during nighttime, but there were no other clear environmental correlates, among those tested (wind speed, wind direction, and barometric pressure)

3.2 Introduction:

Flatfish are generally considered to be demersal. The flattened body of flatfish lends itself to resting on the substrate. Yet the assumption that flatfish are mostly demersal may need re-evaluation. The flat body type, which with appropriate coloration provides camouflage while resting on the sediment, is also idealized for gliding long distances in the water column (Takagi et al. 2010). Historically, there had only been data on the vertical movements of two flatfish species, sole (*Lepidopsetta polyxystra*) and plaice (*Pleuronectes platessa*), with both exhibiting vertical movements to expediate tidal stream transport during migrations (De Veen 1978, Arnold & Metcalfe 1995, Gibson 1997, Hunter et al. 2004). However, there is a growing body of literature showing that flatfish species exhibit pelagic behaviors for various essential functions, including feeding (Yasuda et al. 2010), migration (Kawabe et al. 2004, Walsh & Morgan 2004, Yasuda et al. 2010) and reproduction (Seitz et al. 2003). The flatfish species characterized as having substantial vertical movement to date include four Pleuronectidae (sole, plaice, Pacific halibut *Hippoglossus stenolepis*, yellowtail flounder *Limanda ferruginea*) and one Paralichthidae (Japanese flounder *Paralichthys olivacious*).

Summer flounder (*Paralichthys dentatus*) are an important recreational and commercial fishery along the east cost of the United States. There has been some evidence of tidal stream transport in marsh creeks (Szedlmayer & Able 1993), which may be facilitated by pelagic behavior. If summer flounder use the water column for migration as for other flatfish, it may also be important to reproduction, as this species reproduces during the seasonal fall migration offshore (Packer & Hoff 1999, Able & Fahay 2010). Behavioral observations in tanks have shown that summer flounder are day-active visual feeders, and they have been observed to use "stroke and glide" behavior in the water column (Olla et al. 1972, Staudinger & Juanes 2010). Such behavior occurs when an individual swims upward followed by pointing their head downward and flattening the body, resulting in a glide downwards and forwards (Olla et al. 1972). There has also been evidence in tank feeding experiments that summer flounder feed actively, swimming or gliding in the water column in pursuit of prey (Staudinger & Juanes 2010). These tank observations, as well as the growing body of literature on other flatfish vertical movement, emphasize the need to better understand these movements in the natural environment.

Recent technological innovations allow for observation of individual fish in the wild with greater detail than previously available. One such innovation is the incorporation of sensors into acoustic tags. These provide a more holistic view of individual habitat use and behavior including swim depth, temperature, salinity, and even heart rate (Block et al. 1992, Dewar et al. 1999). The use of pressure sensitive acoustic tags allows for observation of depth through time. These in-situ pelagic behavior observations may improve our understanding of migrations, feeding, and spawning. We applied depth-sensored acoustic telemetry techniques in two different years to determine if adult summer flounder demonstrate vertical movements during the fall migration period off the coast of southern New Jersey.

3.2 Methods:

3.2.1 Study Site

This study was conducted along the coast of southern New Jersey between September and October 2009 and between August and October 2010. The study locations in 2009 and 2010 were in close proximity, and had a mean depth of 8.8 meters (range: 7.3 – 10.4 meters) and 11.3 meters (range: 8.8 – 12.8 meters), mean temperatures of 21.2 °C (range: 19.8 – 21.8 °C) and 20.2 °C (range: 19.3 – 21.3 °C) and mean salinity of 29.6 (range: 28.5 – 31.3) and 31.1 (range: 21.1 - 31.6), respectively (Figure 3.1). Hydrophone arrays were deployed in the study sites and fish were released directly into the arrays (see below).

3.2.2 Fish Collection

Summer flounder were captured in 2009 with a commercial otter trawl fished from the *F/V Viking II* (26.5 meters, Capt. Jim Lovegren) on 15 September 2009 in the coastal ocean off Brigantine, New Jersey (Figure 3.1). These adults (live n=15, 380 – 720 mm; dead n=1, 552 mm) were part of an in-situ bycatch mortality assessment(Yergey et al. 2012). Fish health was assessed on a 4 point scale from excellent to dead, tagged, and fish were release following standard commercial culling procedures and into the center of the acoustic array (Table 3.1). Dead fish were intended to provide a baseline for non-directed movement.

To remove the effects of trawling, there was a second effort to examine healthier individuals. In 2010, 13 adult summer flounder (378 – 511 mm) were collected throughout the Mullica River- Great Bay estuary with a variety of gears, from 6 August - 2 September 2010 and maintained and fed in the laboratory until deployment (Table 3.2). Two fish were euthanized to provide a baseline. The tagged fish were released into the center of the acoustic array. The initial release was of 5 fish on September 14, followed 24 hours later by a second release of 8 more fish.

3.2.3 Acoustic Telemetry

Acoustic transmitters (76.8 kHz, Lotek 11x48mm MA Series Acoustic Sensor Transmitters; MA-PM11-12: 76KHz, 8.5g in air, 4.5g in water, 5 s repeat rate) were attached to Floy t-bar tags with cyanoacrylate glue and shrink wrap. Tags were then inserted into the epaxial musculature using tagging guns (Mark III Pistol Grip Tag Fast Swiftach Tool, No. 08958, Avery Dennision, Fitchburg MA) without anesthetics or antibiotics, in order to not affect fish behavior. In 2010, one individual was tagged with two transmitters to evaluate inter-tag error of the pressure sensors in evaluating fish movements.

In 2009, submerged data logging hydrophones were positioned as corners of a square with sides of approximately 500 m and a fifth hydrophone at the center (Figure 3.1). In 2010 the array shape was modified based on data from the first year, and hydrophones were deployed in a pentagon formation with approximately 300 meters separation, thus providing more detailed location for individual fish (Figure 3.1). The total listening range extended to an area of approximately 2.25 km^2 in 2009, and 1.8 km^2 in 2010.

3.2.4 Data Analysis

Recorded pressure signal values were converted to depth using the conversion factor of -0.694 psi to 1 meter in salt water. Depth was recorded at a resolution of 0.68 meters, with a maximum depth of 34 meters. The initial descent from the surface was removed prior to analysis of pelagic behavior but retained on plots of depth for each individual. Water temperature was recorded in 2009 from sensors in tags, and from CTD casts in 2010 (YSI – Yellow Spring Instruments, Ohio). Depth values two meters or more above an individual's greatest depth were considered to be pelagic in nature. This 2-meter floor was used so as to not miss any pelagic behavior, while preventing any potential pressure changes due to tides from confounding the results. This is based on the assumption that the greatest depth an individual experienced was the sediment surface. There was one exception to this assumption that was problematic, and will be discussed later. The duration of individual pelagic events were determined for each fish, as was the total time spent above 2 meters. The percent of time spent in the water column was also determined to allow for comparison between fish with different total detection times. The rate of ascent and descent through the water column were determined by taking the change in depth and time between each depth reception. These values should be considered as rough indicators of ascent and descent rates, as any non-linear change in depth would not be accounted for. Individual depth profiles were created using the calculated depth to examine vertical behavior through time. These profiles can be used to determine the characteristics of vertical movement (periodicity, frequency, depth in the water column, etc.), in addition to validating the pelagic time estimates.

The frequency of all vertical movements was binned into 10-minute intervals for analysis. This time series was used to create a rank similarity matrix using Euclidean distance and compared to fish size for both years via Mantel coefficients. Analysis of similarity (ANOSIM; analogue of ANOVA) compared the 2009 rank similarity matrix in vertical movement to the health indices of the fish. The time series data was also categorized as day or night and the two groups were evaluated using a Mann-Whitney rank sum test. The potential physical correlates – wind speed, wind direction and barometric pressure – were examined using data from a WeatherFlow weather station located in Tuckerton, NJ (WeatherFlow 2011). These data were also binned into 10-minute intervals for comparison to the percent of available fish (those still present in the array) up in the water column using a Spearman's rank correlation. The double-tagged fish receptions were compared using a pairwise Spearman's rank correlation of mean depths for 10-minute intervals.

3.3 Results:

3.3.1 Residency in the Array

In 2009, 16 live and dead fish were detected in the array; of these 12 fish remained in the general vicinity of the fixed array for approximately 24 hours and the other four left in less than 12 hours. The mean residence time was 1153 minutes ± 647 minutes (3.6 – 30.4 hours; Figure 3.2). During this time the fixed array recorded 172,614 fish detections. Subsequent departure of live and dead fish from the array coincided with a Northeast storm event (Figure 3.2). In 2010, both live and dead fish remained within the fixed hydrophone array area for varying durations up to 25 days following their release, with a mean residence time of 7234 minutes ± 9705 minutes (16.8 – 543.8 hours; Figure 3.3). This is represented by 204,785 fish detections.

3.3.2 Evidence of Pelagic Swimming

The differences in the movements of live fish and carcasses were critical to the interpretation of pelagic swimming. The two carcasses in 2009 had a high percent of time in the water column (mean = 66.6%, standard deviation = 2.39), and showed similar vertical profiles. Both had a large increase in depth at the final few hours of detection, potentially as the fish were moved into deeper waters (Figure 3.4). Due to the knowledge that these are not directed movements, it was determined that the high percent of time in the water column may be an artifact of how bottom depth was assessed for these particular fish.

In 2010, both dead fish exhibited sharp and significant vertical movement (Figure 3.5). This movement occurred over multiple days and at different times of day without any significant correlation between the physical parameters of wind speed or barometric pressure. There was a slightly significant correlation (rho = 0.08, $p = 0.04$) to wind direction, but the rho near zero indicates there is no clear pattern. The median of overall vertical deviation rates (both ascent and descent) was significantly different ($p < 0.001$) between live (n=12) and dead (n=2) fish in 2010 according a Mann-Whitney test when zeros were removed from the data. Dead fish had a faster ascent and descent rate than live fish (Figure 3.6). There was no such relationship in ascent or descent rates for live and dead fish in 2009. As such, the results from these carcasses in both years were not considered to be pelagic behavior and were not considered in subsequent analysis.

There were five initially live fish in 2009 that were later characterized as dead in a latent discard mortality study(Yergey et al. 2012). There was no significant difference in the number and timing of pelagic events in 10 minute intervals between these latent mortalities and other live fish (ANOSIM, $p = 0.99$), meaning these results can be interpreted together without bias.

The pelagic movement exhibited by live fish was variable in both years, and from year to year. The individual depth profiles show clear patterns of active pelagic behavior in 6 of the live fish (43.0%) in 2009 and 6 (54.5%) in 2010 (Figures 3.4, 3.7). Four of the six fish exhibiting vertical movements did so in a highly periodic nature (repeated vertical deviations in relatively short duration) in 2009, while episodic pelagic events (single vertical deviations) were more common (3 of 6 fish) in 2010. Fish 50600 in 2009 displayed a different behavior, with a slow ascent up to the surface, followed by a long slow descent, the total time of this behavior was approximately 156 minutes (Figure 3.4).

The two transmitters attached to the same fish in 2010 showed very similar vertical profiles, and also had no statistical difference for percentage of time in the water column or ascent rates (Figures 3.6, 3.7). The 10-minute mean depth comparison yielded a positive correlation near 1 (rho = 0.86, $p < 0.001$), confirming these tags are similar in depth determination. The differences relate to the particulars of when and which individual tag signals were detected from each of the tags, not from differences in the measurements by the sensors.

The mean time of pelagic swimming events of live individuals in 2009 was 3.9 minutes with a standard deviation of 16.9 minutes. The longest pelagic swimming event was 179.0 minutes. The mean percent of time spent above 2 meters was 16.8% with a standard deviation of 24.4% (Table 3.3). In 2010, the mean time of pelagic swimming was 6.6 minutes, with a standard deviation of 33.6 minutes. The maximum time in the water column was 259.2 minutes. The mean percent of time spent above 2 meters was 1.2%, with a standard deviation of 3.0% (Table 3.3). Five live individuals spent greater than 10% of observed time above the 2 m depth threshold in 2009, yet in 2010 none of the 14 fish spent more than 10% above this limit, and only one live fish spent more than 5% of its time there (Table 3.3).

The mean rate of ascent in 2009 was 1.9 meters per minute, with a standard deviation of 1.3 meters per minute (range: 7.7×10^{-4} – 11.3 meters per minute; Figure 3.6). In 2010 the mean rate of ascent was 1.6 meters per minute, with a standard deviation of 1.8 meters per minute (range: 7.4×10^{-5} – 25.5 meters per minute; Figure 3.6).

There was no correlation between fish size and vertical movements in either year (2009 $p = 0.57$, 2010 $p = 0.80$). Comparing the health index of these 2009 fish with vertical movements the ANOSIM of health index to rank similarity of pelagic detections showed clear global differences between groups ($R = 0.71$, $p = 0.002$), while only one pairwise test, between poor and excellent conditions, showed significant differences ($R = 0.87$, $p = 0.005$). In both years there was a highly significant difference between the number of vertical deviations during the day and night ($p < 0.001$ in both years). Most detections of vertical movement over the 24-hour cycle were at nighttime (Figure 3.8). The physical correlates of wind speed, wind direction, and barometric pressure had no significant correlation to percent of available live fish in the water column in 2010. In 2009, however, both barometric pressure and wind speed (correlates of the northeast storm event) had highly significant, negative correlation (rho = -0.72 and rho = -0.26, respectively; both $p < 0.001$) with respect to percent of available fish in the water column.

3.4 Discussion

3.4.1 Limitations of the Study

The timing, duration, and degree of vertical movements were variable and difficult to generalize. Some individuals did not exhibit any vertical movements (44.8% of total), and others only did so briefly (10.3% of total), i.e. spending less than a minute above the two-meter threshold. The duration of vertical movements was also extremely variable, with a standard deviation greater than five times the mean in both years. The variation was also seen from year to year, with the 2010 group of fish showing less total time in the water column. These inter-year comparisons should be done with caution though, as the total duration of the studies differed, and the fish in 2009 experienced commercial trawling.

The clear global differentiation between health groups in pelagic behavior, along with the excellent condition fish having higher percent of time in the water column, suggests that pelagic behavior was reduced by trawling effects on the fish in poorer condition. This is supported by the pairwise differences between excellent and poor health groupings.

The vertical movement of the dead fish (14.0% of total) in both years is interesting, but does not likely result from similar mechanisms. In 2009, the profiles show similar, fairly consistent, depth, with a clear tidal signal in the depth profile as expected for a carcass lying on the bottom. This changes at the end of the timeline, because the depth of the carcasses increased suddenly. Thus the 2-meter threshold appears to be deeper in the water column (Figure 3.5). This deepening of the 2-meter threshold causes the earlier consistent depths to be miss-classified as pelagic in the analysis. There are plausible explanations for this. First, these fish were moved to a steeper bathymetric contour at the edge of the array by storm currents, as we know occurred in summer flounder carcasses (Yergey et al. 2012). A second possibility is that the northeast storm event that occurred during this time created a storm surge at the study site, i.e. deeper water depth, that was not observed at the tidal station in Atlantic City (National Oceanic and Atmospheric Asociation CO-OPS 2011).

In 2010, there was no clear relationship between physical parameters (including wind speed, wind direction, and barometric pressure) and the movements of the carcasses. We believe the vertical movements are related to biotic influences, likely a scavenger carrying the fish or tag, thus causing the movements. This is supported by the ascent speeds observed in these dead fish, statistically greater than those observed in live summer flounder. In both years the vertical movement observed in the dead fish did not provide the expected baseline of no vertical movement, but the characteristics of their movements were different from those observed in live fish. Therefore, I feel confident that the pelagic behaviors described for live fish are not associated with the potentially confounding factors associated with the dead fish.

3.4.2 Evidence for Pelagic Swimming

This study shows clear evidence that summer flounder exhibit substantial pelagic behavior, with 48% of all individuals exhibiting some degree of this behavior. In addition, this behavior was observed in both years. Further, four live individuals spent more than 25% of their time up in the water column. Of these, two spent greater than 60% of the time observed two meters or greater above the bottom. The evidence for flatfish spending time in the water column is not new; tidal transport has been recognized and studied in flatfish for decades (De Veen 1978, Arnold & Metcalfe 1995, Gibson 1997, Kawabe et al. 2004, Kawabe et al. 2009, Takagi et al. 2010). To date five species of flatfish have exhibited pelagic swimming, sole (Nichol & Somerton 2009), plaice (De Veen 1978, Arnold & Metcalfe 1995), Pacific halibut *Hippoglossus stenolepis* (Seitz et al. 2003), yellowtail flounder *Limanda ferruginea* (Walsh & Morgan 2004), and one Paralichthidae (Japanese flounder *Paralichthys olivacious*) (Kawabe et al. 2004, Kawabe et al. 2009, Takagi et al. 2010). Even a "round fish", bluefish (*Pomotomous saltatrix*) has been observed to turn on its laterally compressed side to glide as an energetically efficient means of transport (Stehlik 2009). With this in mind, our results should not be surprising, yet substantial pelagic behavior represents a novel idea in our understanding of summer flounder.

Examination of the time series of vertical deviations with a variety of biotic and abiotic factors shows several relationships. First, pelagic movements occurred more often during nighttime. Summer flounder are thought to be day-active (Olla et al. 1972), so extensive nighttime pelagic swimming is counter-intuitive and thus may be an important factor in the behavior. The relationship between the pelagic behavior and wind speed and barometric pressure in 2009 is potentially confounded by two factors, tag reception strength which may be reduced at high wind speeds (unpublished data), and the storm surge associated with the building northeast winds. Without clear data on reception range or storm surge, this relationship cannot be associated directly with the behavior of summer flounder. The lack of any correlation to physical parameters in the live fish in 2010 suggests there is no mechanistic link between behavior and wind speed or barometric pressure, but rather one or both of the potentially confounding factors. Overall there were several significant trends in the time series data, but none that elucidate any potential behavioral cues for pelagic swimming.

3.4.3 Implications

There may be significant seasonal variation in the pelagic swimming if this behavior is correlated with seasonal migrations. This general pattern is suggested for representative temperate species (Figure 9.2 in Able & Fahay 2010). If this is accurate, it suggests that pelagic swimming occurs mostly in the spring during migration offshore from the edge of the shelf, and in the fall during their return. Further, the otter trawl fishery for summer flounder is oriented for a demersal species, and thus substantial pelagic swimming may cause poor selectivity and the associated problems of increased bycatch and reduced efficiency. As an example, estimates of distribution and abundance of summer flounder during the migration periods should perhaps be limited to daytime tows because they are more likely to be on the bottom at this time. This gear selectivity could also influence fisheries-independent scientific surveys, which also use bottom oriented trawl gear (Clark 1979, Terceiro 2010). Thus population estimates based on these trawl data may be biased.

It is important to determine the reason behind pelagic behavior. Using data-logging tags with multiple sensors such as temperature and heart rate monitors could help determine more about the factors associated with these behaviors (Kawabe et al. 2004, Kawabe et al. 2009). In addition, accurate, fine scale current data in the area of the fish during the time of pelagic behavior could potentially provide clear evidence of use of tidal stream transport (Kawabe et al. 2004, Kawabe et al. 2009). A study examining this phenomenon should also have a large spatial and temporal scale to evaluate the occurrence on scales relevant to management. With a firm understanding of the factors involved in this pelagic behavior, stock assessment scientists may be able to keep fishing surveys restricted to times and areas where gear selectivity will be optimized.

There are numerous reasons to suggest that substantial pelagic behavior is important in many flatfish species. Summer flounder are thought, like many fish species, to use tidal stream transport in the larval stage to enter estuaries to exploit the nursery habitats therein (Hare et al. 2005, Able & Fahay 2010). If this behavior is used in the larval stage, then it seems likely that it can also be used in the juvenile and adult stages. Even flatfish coloration may indicate a pelagic lifestyle, as the light underside, relative to the dorsally pigmented upper surface, provides these fish with counter coloration commonly observed in pelagic species. As technologies become even more widespread it seems likely we will discover that other flatfishes exhibit similar pelagic behaviors.

Table 3.1. Length and health condition of fish collected via commercial otter trawl off the coast of Brigantine, New Jersey on September 15, 2009.

Tag ID	Length (mm)	Health Condition On-Deck
49000	505	Good
49100	610	Poor
49200	500	Excellent
49300	440	Dead
49400	462	Poor
49500	520	Poor
49600	380	Poor
49700	500	Poor
49800	532	Poor
49900	570	Good
50100	386	Poor
50200	552	Dead
50300	720	Excellent
50400	454	Poor
50500	477	Poor
50600	520	Excellent
50700	500	Poor

Table 3.2. Summary of collection and tagging information for fish collected and tagged for 2010 ocean tracking. Note the individual with two tags for both tag retention confirmation and pressure sensitivity validation. * indicates dead individuals.

Tag ID	**Length**	**Date Collected**	**Method of Collection**	**Days Held in Lab**
55332	390	31 August 2010	Hook and Line	15
55384	378	31 August 2010	Hook and Line	15
55020 55436	511	31 August 2010	2 Minute Otter Trawl	15
55592	403	31 August 2010	Hook and Line	15
55488	476	31 August 2010	Hook and Line	15
55596	417	31 August 2010	Hook and Line	15
55644	462	2 September 2010	2 Minute Otter Trawl	13
55540*	463	16 August 2010	Crab Pot (Bycatch)	29
54968	399	19 August 2010	Hook and Line	25
54500	363	27 August 2010	Hook and Line	17
54916	394	27 August 2010	Hook and Line	17
55124	366	27 August 2010	Hook and Line	17
55280*	430	6 August 2010	Hook and Line	38

Table 3.3 Time spent by summer flounder in the water column (two meters or more above the bottom) along with the total time of receptions and the ratio of pelagic swimming to total time for observations of acoustically tagged individuals off the coast of Brigantine, New Jersey in 2009 and 2010. * Indicates individual was dead upon release. † Indicates double tagged individual's tags.

2009

Tag ID	Total Pelagic Time (min)	Total Time Tracked (min)	Percent Time Pelagic
49000	73.0	1539.2	4.7%
49100	0.0	1751.6	0.0%
49200	285.6	406.2	70.3%
49300*	884.0	1361.2	64.9%
49400	4.2	1586.1	0.3%
49500	282.1	1462.9	19.3%
49600	70.8	1321.6	5.4%
49700	0.0	628.0	0.0%
49800	0.0	1200.2	0.0%
49900	265.1	919.7	28.8%
50100	0.0	1433.6	0.0%
50200*	917.2	1342.4	68.3%
50300	69.8	180.5	38.7%
50400	0.0	221.5	0.0%
50600	119.2	188.7	63.2%
50700	11.3	270.5	4.2%

2010

Tag ID	Total Pelagic Time (min)	Total Time Tracked (min)	Percent Time Pelagic
54500	86.4	3427.2	2.5%
54916	345.6	3499.2	9.9%
54968	0.0	648.0	0.0%
55020†	0.0	1713.6	0.0%
55124	0.0	3456.0	0.0%
55280*	100.8	1569.6	6.4%
55332	0.0	2174.4	0.0%
55384	0.0	31766.4	0.0%
55436†	0.0	1569.6	0.0%
55488	0.0	26308.8	0.0%
55540*	216.0	4838.4	4.5%
55592	14.4	1742.4	0.8%
55644	28.8	5356.8	0.5%
55696	0.0	6580.8	0.0%

Figure Captions:

Figure 3.1. Study sites off the coast of Brigantine, New Jersey during September 2009 and September 2010. Filled circles indicate location of individual hydrophones in each array. Both sites are at roughly the same depth (7.3-12.8 meters).

Figure 3.2. Pattern of occurrence of ultrasonically tagged summer flounder (A) within a coastal ocean hydrophone array during September 2009, in conjunction with wind speed (B), barometric pressure (C), and wind direction (D) in Tuckerton New Jersey, and the number of fish remaining in the array (E). Barometric pressure and increased wind speed associated with a northeast storm event are synchronous with fish departure from the array.

Figure 3.3. Pattern of occurrence of ultrasonically tagged summer flounder (A) within a coastal ocean hydrophone array during September and October 2010, in conjunction with wind speed (B), barometric pressure (C), and wind direction (D) in Tuckerton New Jersey, and the number of fish remaining in the array (E).

Figure 3.4. Vertical movement of individual summer flounder (see Table 1) by tag number from pressure sensing ultrasonic tags in an array of five stationary submerged data logging hydrophones approximately 3 km offshore of Brigantine, NJ from September 15 -17, 2009. Both dead (n=2) and live (n=14) fish of varying degrees of health were tagged. Tidal data retrieved from NOAA CO-OPS Atlantic City station (station ID 8534720).

Figure 3.5. Vertical movement of two dead summer flounder from pressure sensing ultrasonic tags in an array of 5 stationary submerged data logging hydrophones approximately 3km offshore of Brigantine, NJ from 14 September to 21 September 2010. Top frame displays wind speeds in Tuckerton NJ.

Figure 3.6. Ascent rates (meters per minute) by tag number from pressure sensing ultrasonically tagged summer flounder approximately 3 km offshore of Brigantine, NJ from 2009 and 2010. Error bars are 1 standard deviation.

Figure 3.7. Vertical movement of individual live summer flounder (see Table 2) by tag number from pressure sensing ultrasonic tags in an array of 5 stationary submerged data logging hydrophones approximately 3 km offshore of Brigantine, NJ from September 14 to October 9, 2010. Both dead (n=2) and live (n=11) fish were tagged. Tidal data retrieved from NOAA CO-OPS Atlantic City station (station ID 8534720).

Figure 3.8. Box plot of all depth receptions above 2-meter from the sediment surface for all tagged fish in each year, compiled in hour intervals over the 24 cycle. The grey areas indicate night times (± 20 minutes based on daylight changes during observation period). Note the large number of zeros in the data account for the large number of outliers, as indicated by the crosses, yet these data are still of interest in this study.

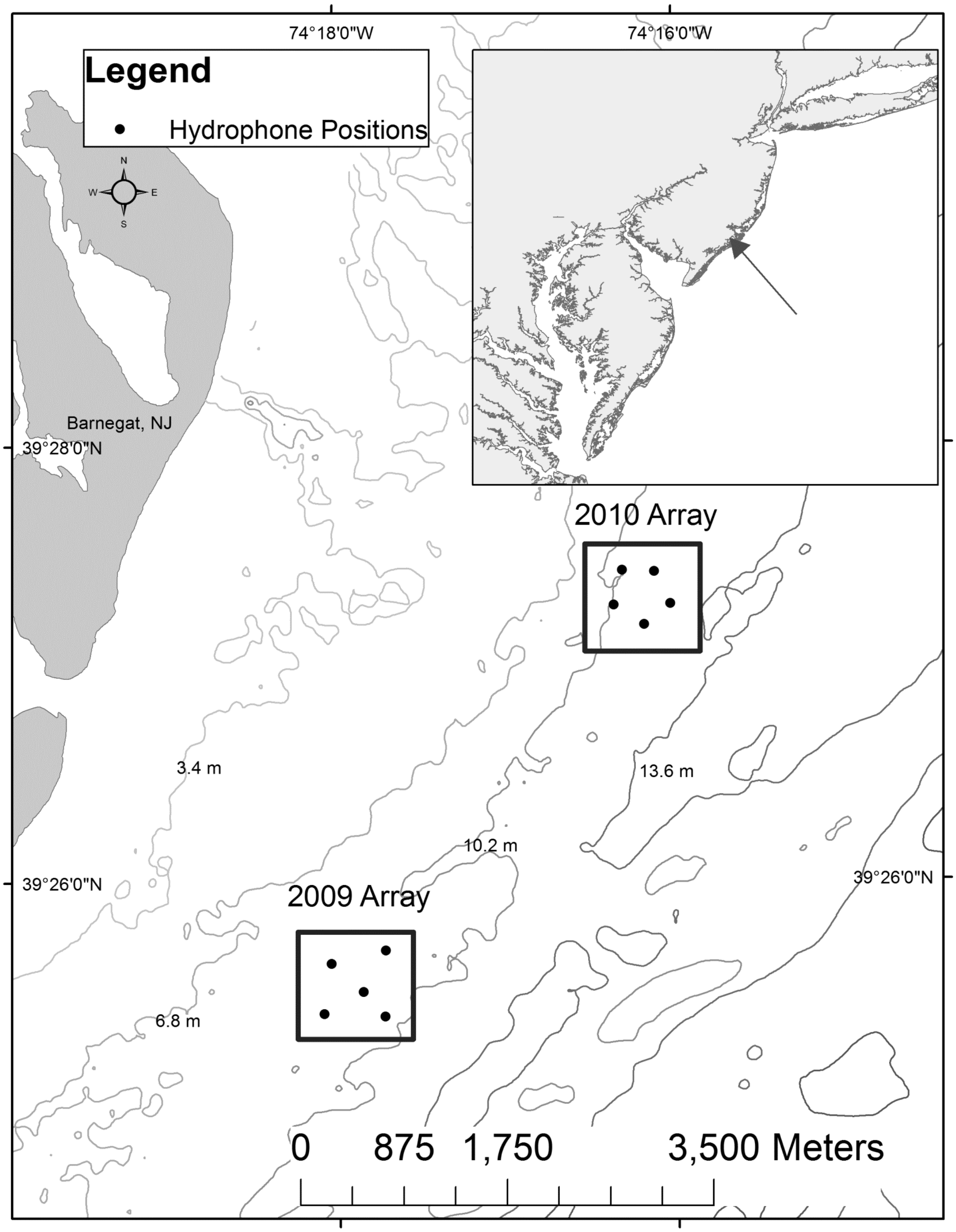

74°18'0"W
74°16'0"W
Legend
Hydrophone Positions
N
W
E
S
Barnegat, NJ
39°28'0"N
2010 Array
3.4 m
13.6 m
10.2 m
39°26'0"N
39°26'0"N
2009 Array
6.8 m
0 875 1,750 3,500 Meters

Figure 3.1

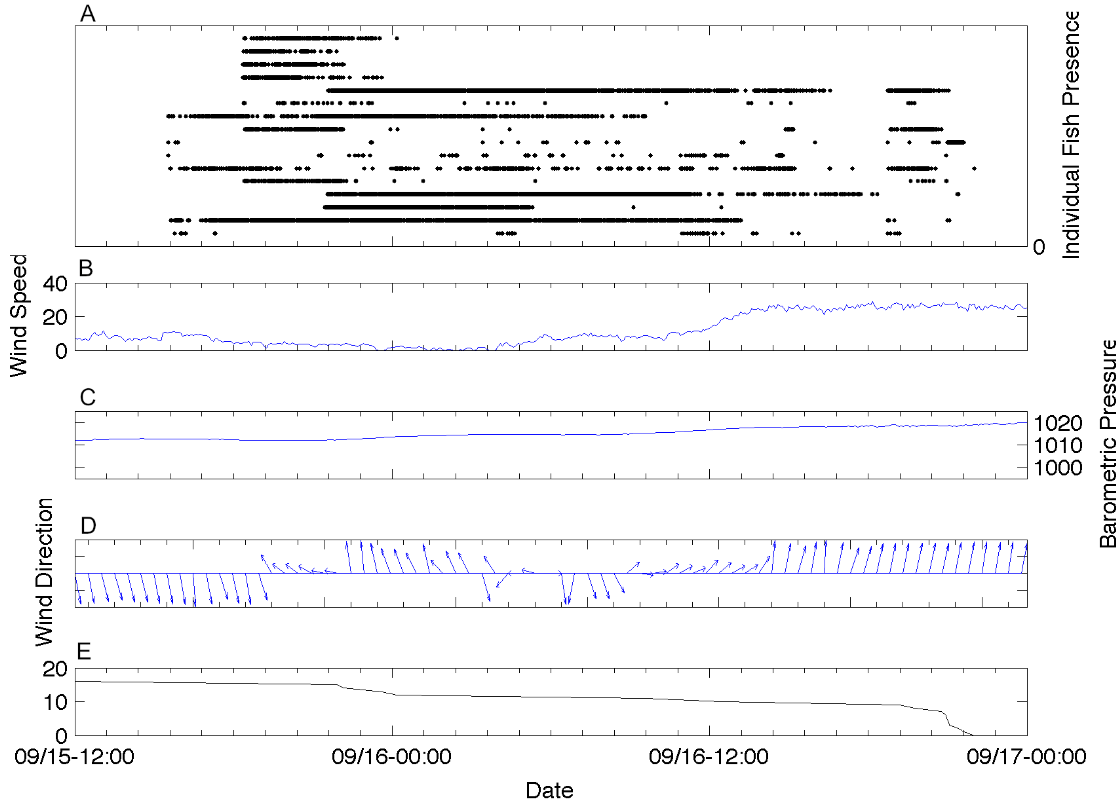

A
Individual Fish Presence
0
B
Wind Speed
40
20
0
C
1020
1010
1000
Barometric Pressure
D
Wind Direction
E
20
10
0
09/15-12:00
09/16-00:00
09/16-12:00
09/17-00:00
Date

Figure 3.2

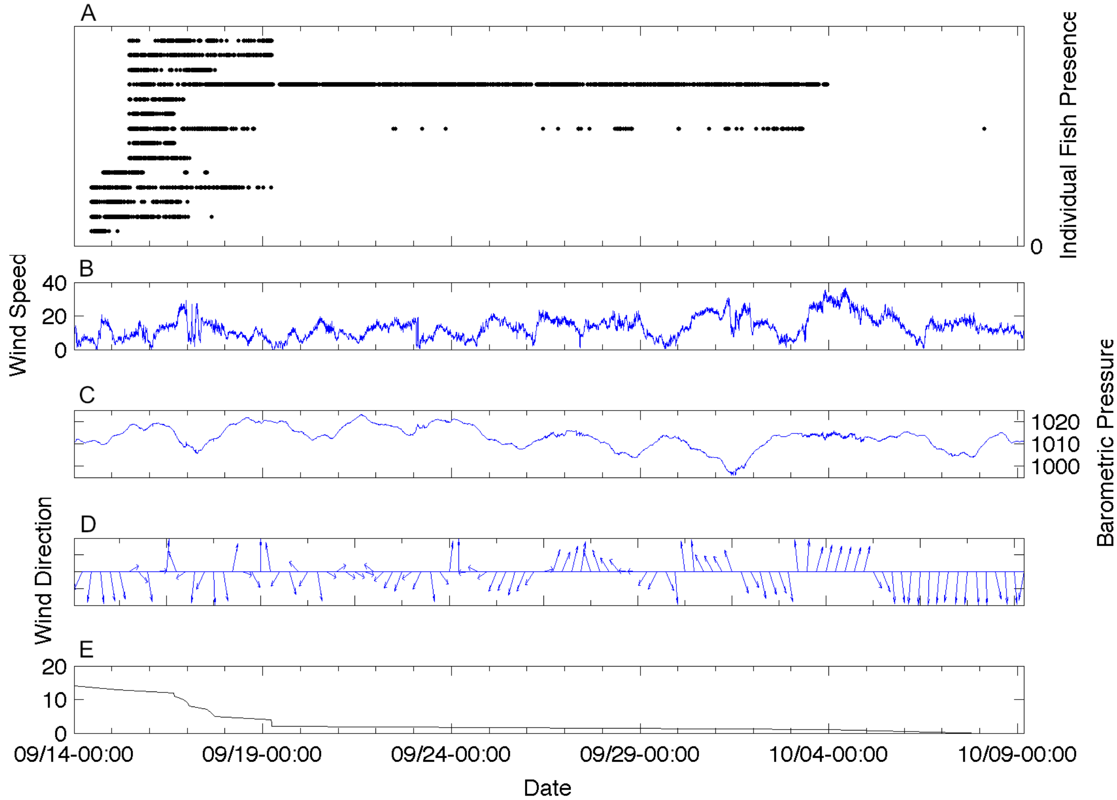
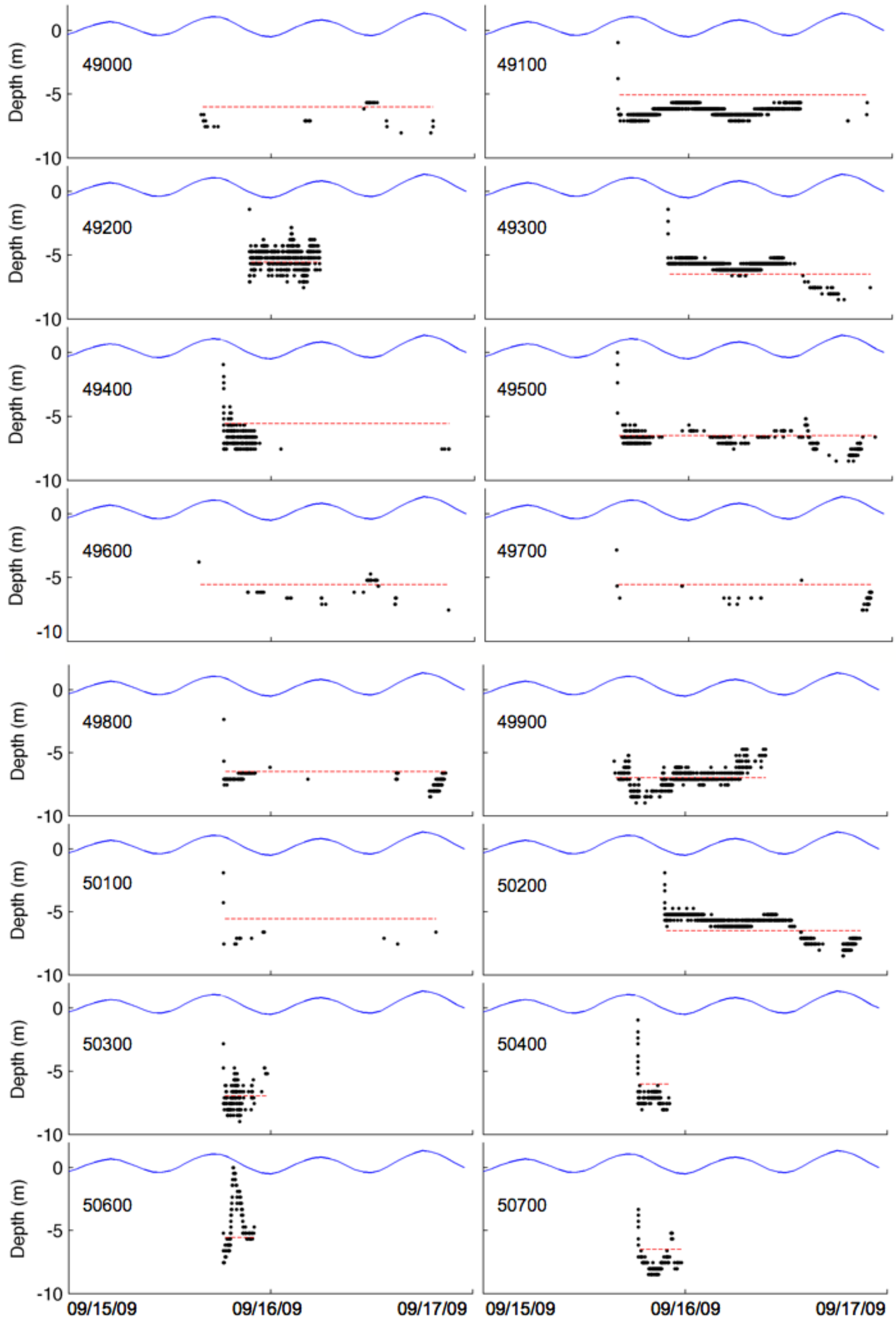

A
B
C
D
E
Individual Fish Presence
0
Wind Speed
40
20
0
1020
1010
1000
Barometric Pressure
Wind Direction
20
10
0
09/14-00:00
09/19-00:00
09/24-00:00
09/29-00:00
10/04-00:00
10/09-00:00
Date

Figure 3.3



Depth (m)
0
-5
-10
49000
49100
49200
49300
49400
49500
49600
49700
49800
49900
50100
50200
50300
50400
50600
50700
09/15/09
09/16/09
09/17/09

Figure 3.4

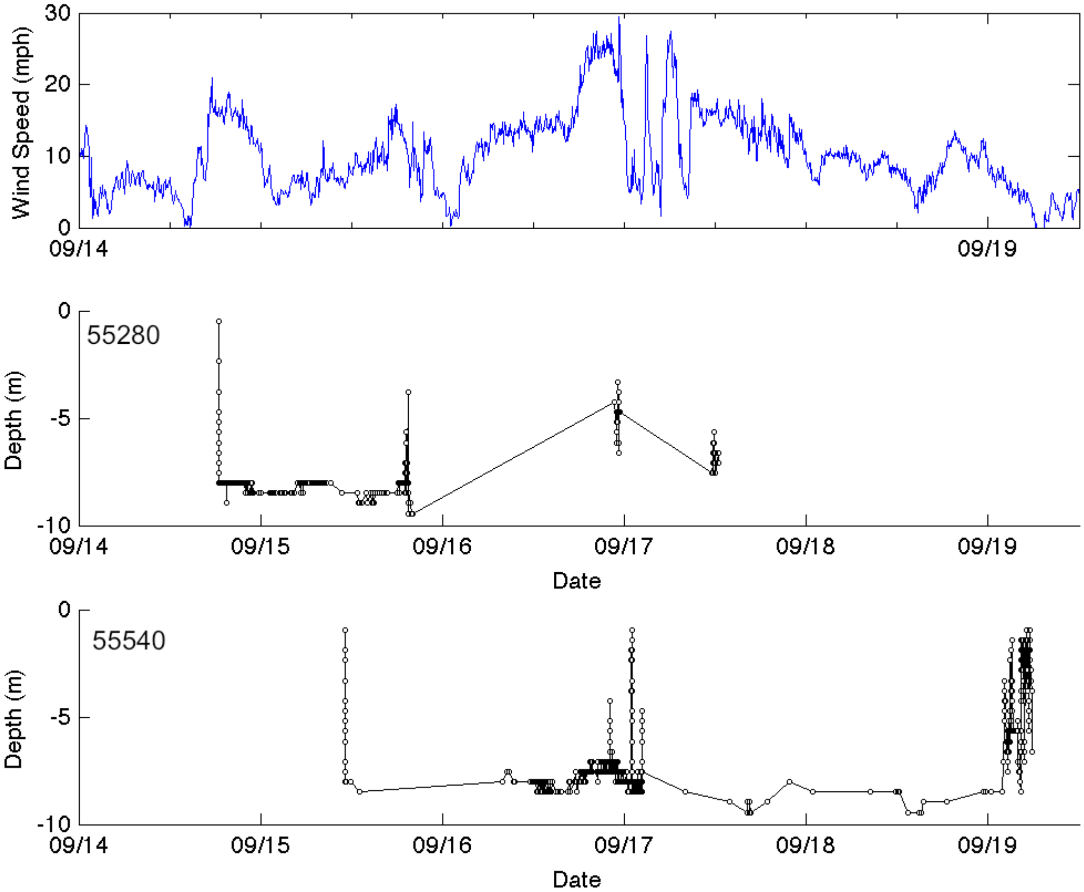

Wind Speed (mph)
30
20
10
0
09/14
09/19
55280
Depth (m)
0
-5
-10
09/14
09/15
09/16
09/17
09/18
09/19
Date
55540
Depth (m)
0
-5
-10
09/14
09/15
09/16
09/17
09/18
09/19
Date

Figure 3.7

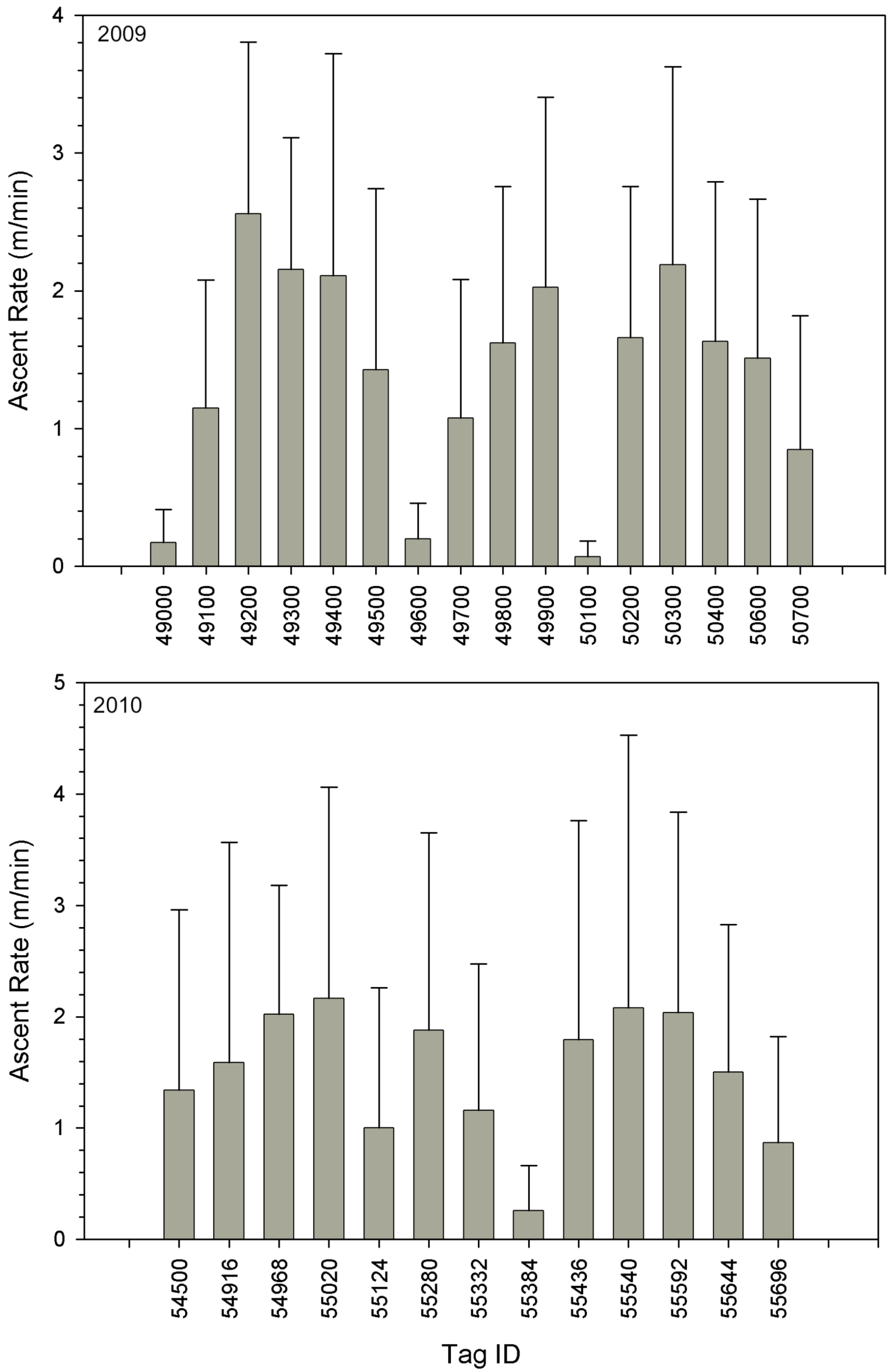

2009
Ascent Rate (m/min)
0
1
2
3
4
49000
49100
49200
49300
49400
49500
49600
49700
49800
49900
50100
50200
50300
50400
50600
50700
2010
Ascent Rate (m/min)
0
1
2
3
4
5
54500
54916
54968
55020
55124
55280
55332
55384
55436
55540
55592
55644
55696
Tag ID

Figure 3.6

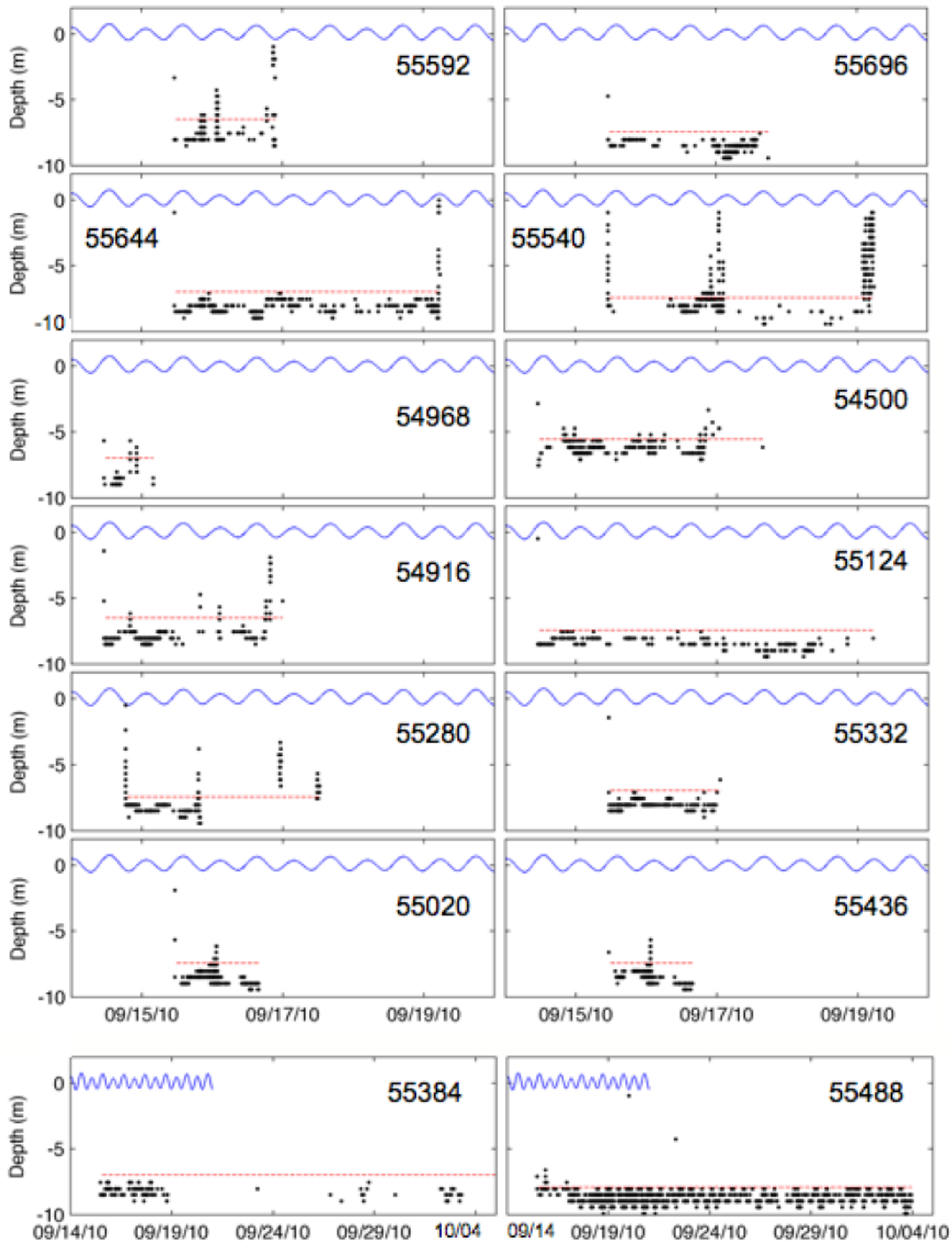

55592
55696
55644
55540
54968
54500
54916
55124
55280
55332
55020
55436
55384
55488
Depth (m)
0
-5
-10
09/15/10
09/17/10
09/19/10
09/14/10
09/19/10
09/24/10
09/29/10
10/04
09/14
10/04/10

Figure 3.7

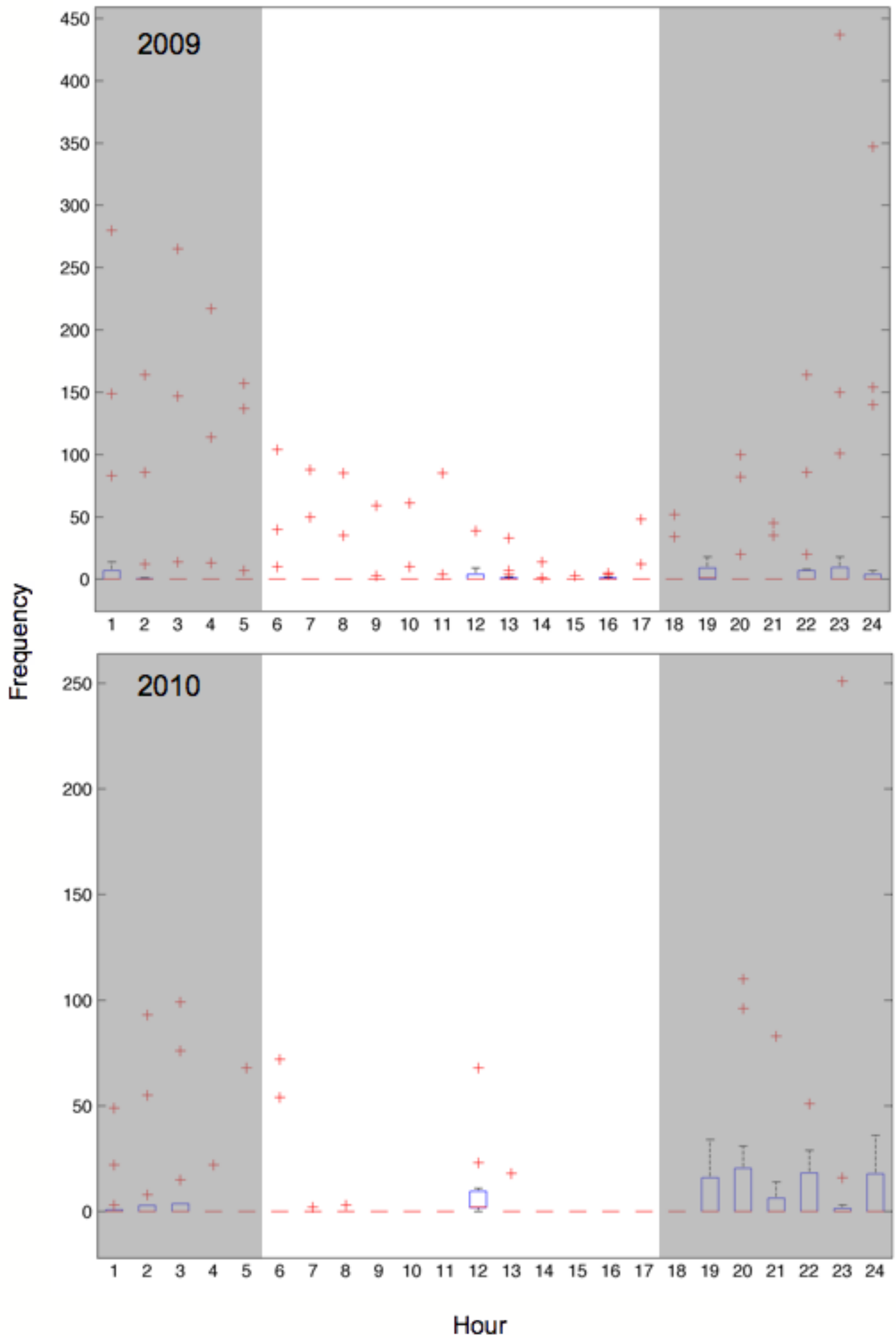

2009
2010
Frequency
Hour
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 3.8

- CHAPTER 4 -

GENERAL CONCLUSIONS

These findings provide novel insights into summer flounder ecology and management. By using acoustic telemetry in new ways this study has filled important data gaps in our understanding of this important species. Specifically this study (1) quantified discard mortality in the commercial trawl fishery using a novel approach, and (2) determined that summer flounder actively swim in the water column for substantial periods of time, a previously unanticipated behavior for this species.

The value quantitatively determined for summer flounder discard mortality in situ (81.3%) was very close to previous work (80% assumed, 78.7% in Hasbrouck et al. 2008) yet within our studies and others there is a high degree of variability. This variability likely stems from a variety of factors, including but not limited to the relative health of the individuals during capture, other bycatch species associated with the trawl, length of the trawl, and time on deck. All of the listed factors can be compounded in longer tows. Longer tows will have a greater chance to exhaust summer flounder and thus likely reduce their post-trawl survival. Long trawls also have a higher chance of containing harmful bycatch (like the hard shelled horseshoe crabs in this study), as well as an overall increase in catch that relates to longer time on deck (Davis 2002). Looking towards a more sustainable fishery, improving our understanding of tow times to discard mortality should be of top priority.

The results of this study can influence the summer flounder stock assessment, and thus our management of the species. Foremost, we need to determine with more specificity the extent and timing of pelagic movements, and adjust scientific surveys accordingly. Secondly, the confirmation of the discard mortality rate can reduce our uncertainty of current stock estimates if this pelagic behavior is taken into consideration. Improving assessments allows managers to feel more confident about the regulations and allows decisions to be made preemptively instead of reactively.

This study revealed only a nocturnal trend for pelagic behavior. It is possible this behavior is developed from the diel vertical movement patterns of larvae, which are also up in the water column at night. It may also be to avoid larger predators that may otherwise take advantage of the more exposed movements during the daytime. Since summer flounder are thought to be visual feeders, this may indicate that the behavior is not feeding related, or that summer flounder visualization of prey is somehow increased at night (Staudinger & Juanes 2010). Clearly, more work needs to be done on this subject.

This study exposes the need to further pursue studies of summer flounder fine scale movements. By using telemetry techniques we can determine factors most detrimental to summer flounder discard mortality, and thus make progress to reduce the waste associated with it. Telemetry techniques will also play a critical role in furthering our understanding of pelagic behaviors in summer flounder, in particular the cues or causes behind the behavior. The telemetry techniques used in this study can also be applied to other species. As the cost of equipment goes down and the size of tags is reduced, these techniques become more accessible and the preceding work can provide insights into their use for both mortality studies and for examining aspects of fish behavior.

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