PROJECT TITLE: **Discard Mortality in the Summer Flounder Fishery: A New Approach to Evaluation**

FINAL REPORT

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Executive Summary

Fish bycatch discard mortality is one of the most significant issues influencing marine fisheries management in the world and this applies, perhaps especially so, in the U.S. For summer flounder (*Paralichthys dentatus*), it is assumed that there is an 80% discard mortality from the commercial fishery. Discard mortality studies to date have often relied on immediate evaluation of mortality or reflex impairment, and evaluation of delayed mortality through holding captured fish for varying lengths of time to determine survival and condition. Because of inability of laboratory or holding experiments to replicate the natural environment, the mortality rates derived from these experiments may be biased. We suggest that telemetry of ultrasonically tagged fish presents an improved technique for evaluating fish bycatch discard mortality, and especially latent mortality, under natural conditions in the sea. Our goal was to determine the discard mortality for summer flounder in the otter trawl fishery in the Mid-Atlantic Bight.

A new method of tag attachment was developed and tested for this study. In the laboratory, summer flounder tagged with these tags behaved similar to control fish. This tagging technique also allowed for quick tagging and did not require any surgery or sedatives. The effectiveness of motion sensitive tags in determining discard mortality was also tested in the laboratory, estuary, and ocean. The laboratory trials suggest that a six-hour delay is much greater than the periodicity of summer flounder movements, and should therefore be appropriate for use in determining mortality. Thus, motion sensitive tags provide another means through which to interpret mortality in tagged discards. Vertical movement has also shown to be potentially useful when determining mortality of a fish using acoustic telemetry over both field studies in 2009 and 2010.

In order to test the assumption that we could distinguish between live and dead tagged fish using telemetry, we tracked fish in a preliminary effort in an estuary and evaluated their behavior in the laboratory. These studies showed that dead summer flounder (carcasses) can move substantial distances, and did so in synchrony with tidal currents. Dead fish in laboratory flumes were lifted off the bottom and transported over a wide range of current speeds, thus further supporting the field observations. Live fish were much less mobile and more directed in their movements.

In order to determine the mortality of these discarded fish, both live and dead summer flounder were tagged and released in a fixed hydrophone array on 15 September 2009 at a location off Brigantine, New Jersey. Initial results from commercial fishery length tows showed most fish in a poor to intermediate health condition. The initial on deck mortality was 32.7%. Mobile tracking efforts were able to re-detect both initially live and dead fish during tracking, and within the array for approximately 24 hours before a northeast storm event. Fish of poor initial health re-detected after the storm were found in a relatively concentrated area about 8 km south west of the release site, while live fish excited the array as they moved offshore as typical of the fall migration. These movement patterns provide a latent mortality estimate of 50.0%. The final discard mortality estimate, combining on deck mortality and latent mortality, is 82.7%. These observations suggest that discard mortality is on the same order of magnitude as current estimates. Further, the findings of this project suggest that acoustic telemetry is a viable means

to assess discard mortality in summer flounder and other species.

Introduction

Fish bycatch discard mortality is one of the most significant issues influencing marine fisheries management in the world (Davis 2002, Kennelly and Broadhurst 2002) and this applies, perhaps especially so, in the U.S. (Harrington et al. 2005). It is generally assumed that a very high proportion of the discarded fishes die when returned to the sea, although significant rates of survival may occur in some fisheries including flatfishes (see Mesnil 1996). For summer flounder (*Paralichthys dentatus*), it is assumed that there is an 80% discard mortality from the commercial fishery, most of which comes from trawl fisheries (Terceiro 2010) but efforts that have confirmed this value have been complicated by bias (Davis, 2002), and much lower values are estimated for recreational fisheries (6 - 11%, Lucy and Holton 1998, Malchoff et al. 2002). An erroneous estimate will result in unnecessary closures or reductions in the allowable catch. This is an especially important issue in the Mid - Atlantic Bight because summer flounder is one of the most important species in terms of total numbers and landings by weight in both commercial and recreational fisheries (Packer and Hoff 1999, Terceiro 2010). At the same time, while the management of this species has rebuilt the stock (Terceiro, 2010, Able et al. 2011), erroneous estimates of discard mortality on potentially relaxed quotas may have a greater impact than in the past.

Discard mortality studies to date have often relied on immediate evaluation of mortality or reflex impairment, and evaluation of delayed mortality through holding captured fish for varying lengths of time to determine survival and condition (Chopin and Arimoto 1995, Davis 2005, Davis and Schreck 2005, Davis and Ottmar 2006). In fact, such a study of delayed mortality occurred with Research Set Aside funding in 2007 and 2008 (Hasbrouck et al. pers. comm.). While these types of studies can provide important insights into the occurrence and qualification of survival, it is difficult to assess the longer term, latent effects of capture as bycatch and to be able to separate holding tank effects from those encountered in the sea (Mandelman and Farrington, in press). Factors such as predation and natural feeding habits are not easily replicated in holding experiments, and only slightly easier is quantifying the variability of physical correlates to mortality such as temperature and dissolved oxygen levels(Benoit et al. 2010). Because of the inability of laboratory or holding experiments to replicate the natural environment, the mortality rates derived from these experiments may be biased.

We show that telemetry of ultrasonically tagged fish presents a viable and improved technique for evaluating fish bycatch discard, including latent, mortality under natural conditions in the sea. The general development of telemetry in the last few decades (Lucas and Baras 2000, Cooke et al. 2004) and especially electronic tags and receivers (Sibert and Nielsen 2001, Arnold and Dewar 2001, Bain 2005, Grothues 2009) has radically changed the way in which we can study fishes and the effects of fishing. Many of these applications have focused on flatfishes (Able and Grothues 2007a). Our own studies have demonstrated the utility of telemetry techniques to the study of habitat use and site fidelity for other economically important species such as striped bass (Able and Grothues 2007b, Ng et al. 2007) and bluefish (Grothues and Able 2007). More

specifically, we have previously successfully tagged and tracked summer flounder over two years and gained insights into their migration dynamics, site fidelity and habitat use in estuaries (Sackett et al. 2007, 2008).

Goals and Objectives

As a result of the above, our goal was to determine the discard mortality for summer flounder in the otter trawl fishery in the Mid-Atlantic Bight, a specific priority for the 2008 MAFMC Research Set - Aside Program. The specific objectives were to develop telemetry techniques to help to determine the rate of discard mortality as it varies with 1) length, age, and reproductive status and 2) relative to predation. In the process, we developed new laboratory and field approaches to evaluate telemetry techniques and how to measure discard mortality for summer flounder and other species.

Methods

Evaluation of Techniques

Tag Attachment - A new method of tag attachment was developed and tested for this study. Surgical tag attachment is known to be secure but surgery could further influence the behavior and mortality of survivors. In response to this concern we developed a method of attaching transmitters to dart (Floy) tags, and tagging fish in a matter of seconds without the use of incision, suture, anesthesia, or antibiotics. For this purpose, dummy transmitters were glued to Floy tags with cayanoacrylate and then further secured by shrink-wrapping onto the tag. The transmitters were toggled in place on the fish by inserting the needle of a tagging gun (Northwest Technology Inc.) from the eyed side of the fish, below the dorsal fin, and angled slightly downward, towards the head. This left the tag dangling from the eyed side near the dorsal margin.

Behavior of summer flounder (n=32, 273-454 mm TL) with dangling tags was examined on healthy captive summer flounder in laboratory tanks (1.2 x 2.4 m) in the flow-through seawater laboratory at the Rutgers University Marine Field Station (RUMFS) to determine tag effect on behavior, if any. Tag size (11x40 2.0 g, 11x46 4.2 g, 11x61 5.6 g) was scaled to the size of fish as would happen during the actual study, where larger fish would carry larger, tags with sensors and smaller fish would carry smaller and lower duration tags without sensors. Two pilot studies were conducted with summer flounder, 8 of which were tagged and were distributed evenly across two holding tanks (23.4 cm deep, 27.2°C, 29.9 ppt) with 4 tagged and 4 untagged flounder in each. The experiment was repeated with long and short tag anchor lengths. Trials lasted two weeks. Fish were observed for 1 hr twice daily. Individuals were scored on metrics of behavior; eating, dorsal fin fluttering, turning, growth, and tag retention.

Tag Retention - Premature detachment of transmitters from a fish during a tracking experiment would provide an inaccurate movement record. We analyzed tag retention in both live and dead (carcasses) summer flounder in order to evaluate the timing and cause of tag loss. Carcasses were

tagged with dummy transmitters, (model MA-11-18 Lotek Inc.) attached to Floy T-Bar tags as before. The tagged carcasses (n=11, 275-386 mm total length from Great Bay and Little Egg Inlet, New Jersey) were placed in a 1.2 x 2.4 meter holding tank also containing invertebrate scavengers with flow-through filtered seawater (ambient temperature) at RUMFS. Water temperature during these trials (17 June – 22 July, 2009) ranged from 17-21 ^{o}C. Potential scavengers on the carcasses 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*). Fish length, date and time of deployment, and water temperature were recorded to determine factors, besides scavengers, that might contribute to tag loss. Observations of invertebrate response were taken 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 for these individuals.

Flume Observations – To examine the movement potential of summer flounder carcasses under differing flow, carcasses were placed in a flume to determine the current speed at which the carcass might be transported. Fish (236-402 mm total length) used in this experiment were collected from Great Bay and Little Egg Inlet, New Jersey using hook and line. The fish were euthanized via blunt trauma, with care taken to not disturb the surface of the fish. The fish were stored frozen and transported to the flume facility at the Rutgers University Institute of Marine and Coastal Sciences (IMCS), then thawed and tagged with a dummy MAP transmitter, (model MA-11-18 Lotek Inc.) attached using the t-bar method above. Once tagged, the fish were introduced into the flume. The flume used in this experiment was modeled after the University of Washington's Friday Harbor Laboratory racetrack flume, with a working channel length of 620 cm and width of 70 cm (C. Fuller, pers. comm.). There was approximately 1 cm of coarse sand from Great Bay spread evenly along the bottom of the flume. Water depth was 20 cm. Carcasses were placed both eyed side up and blind side up for 3 trials in each orientation. In most trials fish were oriented such that the head was toward the oncoming flow. For a subset, the fish was placed perpendicular to the flow, as well as tail towards the flow. The flume flow rate was manually adjusted and set to 7 different speeds: 10, 15, 17, 20, 25, 30, and 35 cm/s. The speed settings were surface flow rates; near bottom flow rates were later measured using a laser Doppler velocimeter. At each speed the fish was observed and any transport was noted. After some initial movement was observed the water speed was slowly increased until transport of the tagged carcass was achieved and the surface flow rate was recorded. The fish was then allowed to move until either settling back on the sand or until it traveled over 3 meters at which time it was considered to not have re-settled. There were two separate days of testing in the flumes on 11 fish during 71 individual trials. On the second testing day the height of the head (or forward most part of the fish) above the sand was recorded for each trial, whereas it was only occasionally observed during the first day of testing.

Evaluation of Motion Tags and Settings

The effectiveness and ideal settings of motion sensitive tag (Lotek 11x48mm MA Series Acoustic Sensor Transmitters; MA-PM11-12: 76KHz, 8.5g in air, 4.5g in water) in determining

discard mortality were tested in the laboratory, the estuary and the ocean. In the laboratory three summer flounder (445, 326, 467 mm) were caught by hook and line and transferred to a holding tank at Rutgers University Marine Field Station for observation of movement patterns on June 18, 21, 23 and 24, 2010. The fish were individually placed in an experimental tank (100 cm x 66 cm; water depth 30 cm) and observed for an 8-hour period to provide baseline of activity levels. Infrared lights and digital video were used to record fish activity at intervals throughout the diel cycle to provide day-night comparison. The video images were reviewed to quantify the time the fish spent in motion versus stationary to determine an appropriate reset-delay period for the motion sensor tags. Duration of motion was defined as the time (in seconds) from the fish's first movement until the fish resettled. One fish was tagged with the motion sensor transmitter and tag receptions were recorded with a submerged hydrophone in the tank to determine the sensitivity of the tags to the fish's movements. The tags used were Lotek 11x48mm MA Series Acoustic Sensor Transmitters (MA-PM11-12: 76KHz, 8.5g in air, 4.5g in water). Transmitters were motion and pressure sensitive with signal repeat rate of 5 seconds. Tags had a motion-reset delay period of six hours and were the second most of five sensitivity settings (corresponding to 8 changes of state in 1 minute to yield "motion state"). Pressure sensors are sensitive to 34 meters over 50 intervals (0.68 meters).

In order to track fish with motion tags in the estuary, two summer flounder (543 and 435 mm) were caught by hook and line in Little Sheepshead Creek in Great Bay. These were tagged with motion tags using t-bar attachment method and released in their catch locations on 12 and 20 July 2010. Each fish was tracked upon release for the following 24 to 48 hours using stereo hydrophones towed at a depth of approximately 1 meter. GPS recorded the boat's position for the duration of the tracking period. A submerged hydrophone was also placed in the study site where both fish were released. A third transmitter was attached to a flat steel weight (30 x 30 x 5.1 cm) and placed near the submerged hydrophone for 24 hours to evaluate ambient flow influences on motion as detected with the tags.

In order to track fish with motion tags in the ocean, 13 summer flounder (378 – 511 mm) were collected throughout the Mullica River- Great Bay Estuary via hook and line, 2-minute otter trawl, and as bycatch in crab pots, from the 6 August through 2 September 2010 for use in motion assessment in the ocean (Table 1). Two fish were euthanized and acted as baseline for carcass behavior. All fish were tagged with pressure/motion tags attached in the method described above. Two motion settings were used, both with a sensitivity of 4, one with a delay of 6 hours and one with a delay of 10 minutes. One fish was tagged with both six-hour and ten-minute motion-delay tags in order to provide a direct comparison of the two settings and assess precision of the pressure tags (Table 1). The fish were released in a location along the same contour (~12 meters depth) as the previous year's study, but slightly further north (Figure 1). There were 5 WHS 3050 wireless hydrophones (Lotek Wireless, Inc., St. Johns Canada) deployed in a pentagon formation with approximately 300 meters separation, providing clear direction of departure of these fish. The tagged fish were released into the center of the array; the initial deployment was of 4 fish with six-hour motion delay tags, followed by another dead fish with a six-hour delay. 24 hours after the initial deployment, 8 more fish were deployed with ten-minute motion delay tags, one of which was double tagged with both six-hour and ten-minute

tags. The fish were tracked immediately following release using the stereo hydrophone system as used before. Tracking was semi-continuous (8 hour shifts on a single vessel with 1 hour delay between shifts due to travel time to and from the study location) for a 50-hour period following the initial release.

Preliminary Tracking of Live and Dead Fish (Carcasses) in the Estuary

In order to test the assumption that we could distinguish between live and dead (carcasses) tagged fish, we tracked both types of summer flounder in a preliminary effort in an estuary. An unnamed slough located near Newman's Therefore and Seven Islands, in the Great Bay estuary, New Jersey was the primary study site (Figure 2). The slough was approximately 125 meters wide and ranged to 4 meters deep. The bottom was a mixture of sand and silt and had a high population of mussels and sea stars, based on diver observations. During the study the surface temperature ranged from 19-23°C.

Fish Tagging – Three fish were caught by hook and line within the study location for tagging and subsequent tracking. All were tagged with Lotek MA-11-18 series acoustic transmitters in the dorsal-anterior epaxial muscle area in a manner similar to that of Sackett et al. (2007). The tags dimensions were 11x51 mm, weighing 4.5 g in water, and had a frequency of 76.8 kHz with a 5 sec signal repeat rate. For tagging, the fish were pressed blind side down onto a measuring board with two hollow needles mounted at a fixed width to penetrate the fish's musculature posterior to the operculum. Bridle wires from the transmitter were lopped through the holes and closed together on the blind side with a surgeon's knot. No anesthetic was used, as it might inhibit the fish's immediate natural behavior. Fish were released in the middle of the tracking array. Fish with tag 59 (356mm) and 60 (357mm) were tagged and released on 8 July 2009. Tag 54 (471 mm) was caught and released on 14 July 2009.

In addition to the live fish, carcasses (n=4, 316-370 mm) were tagged in a similar manner with acoustic transmitters broadcasting in two code series (dual mode MAP and CAFT, Lotek Wireless Inc.). One code mode was used to follow movements on the fine scale through an array capable of trilatering position to meter-scale resolution within a 1 x 0.125 km array within the release slough (Figure 2). The other code mode was used to follow tagged summer flounder through a larger existing gated array in the Great Bay estuary (see Grothues et al., 2005) after exit from the fine scale array. The tagged carcasses were released in the same manner as the live transmitter tagged fish. The tag numbers and release dates were tag 56 on 7 July 2009, tag 168 on 10 July 2009, and tags 165 and 166 on 13 July 2009.

Passive Acoustic Tracking – A small array of acoustic hydrophones was used to passively track the live fish and carcasses. Four WHS_3050 76Khz Wireless Hydrophones (Lotek Wireless, Inc., St. Johns Canada) were deployed within the slough in a polygon, each ~ 250 meters away from it's nearest neighbor (Figure 2). Data was recorded in the trilateration array over 188.62 hours from July 8, 2009 at 15:37 to July 16, 2009 at 11:00.

Active Acoustic Tracking - Mobile acoustic tracking of the above tagged fish was accomplished

using stereo hydrophones (Lotek LHP_1) and a Lotek MAP 600 RTA Receiver deployed from a small 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). Signal identity was recorded along with the power, coordinates, time, and bearing to help determine the position of tagged fish. Most tracking efforts consisted of a zigzag pattern up and down the slough. These data were used to supplement that from passive tracking for fish that may have left the array and into Great Bay. Tracking occurred on 7 days between July 8, 2009 and July 20, 2009 with a total effort of approximately 17 hours.

Data Analysis – We used Asynchronous Logging Positioning System (ALPS) software to trilaterate the positions of the live fish and carcasses from difference in time-of-arrival for a given transmitter signal between multiple hydrophones in the slough. Logger clock drifts were back calculated to synchronization in post-processing using signals from a special synchronizing tag at a known position that is audible to all loggers. Fish position was plotted within the array for 24 hours after each initial deployment. For active tracking, trackers recorded latitude, longitude, time, bearing, tag number, and signal strength in order to track fish movement outside of the array. In order to see if movement was related to tides or diel periodicity, movement periodicity was compared to tidal charts, which included times of sunrise and sunset.

Evaluation of Discard Mortality in the Ocean

Both live (n=43) and dead (n=17) summer flounder were tagged on 15 September 2009 at a location off Brigantine, New Jersey (Figure 1, Table 2). The fish were captured with a commercial otter trawl fished from the Viking II (Capt. Jim Lovegren). The net was a "flat" double with a 5.5 inch-between-knot mesh with 80-foot sweep using a 60-foot top line. The ground rig utilized a 20 fathom bridle with 4 inch cookies on the lower leg. A tickler chain was set near the center of the sweep. The net was fished with a 150 m tow rope in approximately 7-8 m of water. Tow times ranged from 76 to 129 minutes. Trawls (n=5) were performed as a series of loops originating and ending at a central site. This site was within a fixed hydrophone array of five synchronized MAP hydrophones. Most trawl times were from 111 – 129 min but a final trawl was shorter (76 min) in an effort to capture several less seriously damaged fish in order to establish a gradient of release conditions. After each tow the catch was dumped on the deck of the fishing vessel and the times to cull the catch and remove the summer flounder were recorded. Each summer flounder was scored with a health index 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).

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To determine the latent mortality of these discarded fish, fish of all categories were tagged with acoustic tags in the t-bar method previously developed (see above). 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 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. The submerged data logging hydrophone array was recovered when mobile tracking, conducted between 15 September and 11 October 2009 (Figure 3, Table 3), indicated that most fish had left the area.

Data Analysis - The pattern of detection in the fixed hydrophone array was analyzed using non-metric Multidimensional scaling (Primer E software, Plymouth, UK) and position estimates based on hydrophone affinity via contacts and power (adapted from the activity cell method of Simpfendorfer et al. 2002).

Results

Evaluation of Techniques

Tag Attachment and Retention - In the laboratory, juvenile and adult summer flounder tagged with dummy transmitters behaved similar to similar sized control fish and actively pursued prey. Growth occurred and was not statistically different between tagged and untagged fish. Tags normally rested on top of the fish both during active swimming and while the fish rested on the substrate. However, long anchors on tags sometimes dangled over the dorsal margins and could cut the dorsal fin membrane, which also pulled on the tag anchor; therefore, shorter anchors were chosen for further experiments and should be used in the future.

In every laboratory retention trial, the first invertebrate species 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. These often kept the other crab species from the carcass. Once these crabs began to leave the carcass, some individual green crabs and blue crabs began to feed at the fins and where the spider crabs had opened the carcass. The blue crab specimens were rarely observed scavenging on the carcass when other species were already feeding.

Scavengers have the ability to separate the tag from a carcass, but the timing of the separation can vary 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. In these trials, the fish was removed with the tag because the decaying fish was fouling the water in the experimental tank. The duration of tag attachment varied greatly, the quickest tag removal happened in 0.6 h and the longest trial in which the tag was removed by the scavengers lasted 51 h. The average time for the tag to be removed, excluding trials in which the fish was removed before the tag was lost, was 25.1 hours. In one trial, the tag was cut at the T-bar, dislodging it without having the skin around the attachment site eaten away.

The presence of scavenges may influence the ability of the carcass to be transported by currents, and may also limit signal transmission by the tag. Early in each trial, regardless of the size of the fish the smaller crabs of all three species would begin feeding at the fins while the larger crabs began at the fish's gills and mouth. Once large areas of the carcass were open, the crabs would feed on all parts of the body. In 7 of the 11 trials, crabs (both green and spider crabs) were observed using the tag attachment site to get into the flesh under the skin of the carcass. The

crabs would follow the tag to the base and begin to feed at the hole made by the tagging gun. Channeled whelks and moon snails were never observed feeding on the carcass early in the trial, but were seen on the carcasses by 3 hours after the trial began. When these mollusks fed on the carcasses, they often remained in the same place on the carcass for multiple observation periods, while the crabs still fed and would move around the snails. Regardless of the type of scavenger, their presence would influence the mobility of the carcass.

Flume Observations – Somewhat surprisingly, transport of tagged juvenile and adult fish in the flumes occurred over a wide range of current speeds. The mean speed of transport was 27.3 cm/sec (10.1- 47.6 cm/sec). Those individuals with their head above the sediment surface initially, due to stiffening of the body after death, were more likely to be transported at lower speeds (mean 26.4 ± 4.6 cm/sec) when compared to the mean of those with heads resting flat on the sediment surface (mean 35.8 ± 5.8 cm/sec).

Evaluation of Motion Tags and Settings

The laboratory trials suggest that a six-hour delay is much greater than the periodicity of summer flounder movements, and should therefore be appropriate for use in determining mortality assuming movement does not occur after mortality (see above). A mean from all trials for 'time in motion' was found to be 59 seconds, and mean 'stationary time' was 216 seconds (Figure 4). Field deployment of motion tags with six-hour delay showed different motion characteristics between live summer flounder and fixed attachments. The stationary weighted tag gave a "motion" signal for an additional 3:19 hours after the six-hour delay (9:15 hours total time in "motion") suggesting the tag was initially sensitive to currents. Over the remainder of the study, the tag never returned to a "motion" signal (Figure 5). There was no evidence of fouling or burial of the plate in the sediment to reduce current movements. Transmitters attached to live fish never gave a "no-motion" signal for the duration of the study. These results, combined with the laboratory experiments suggest that long delay (~ 6 hours or longer) tags may be useful for periodic tracking mortality assessment, while shorter motion delay (~10 minutes) may provide movement detail for continuous analysis of behavior, again, assuming that dead fish do not move (see above).

Tracking motion tags in the ocean - Both live and dead fish remained within the fixed hydrophone array area for up to 25 days following their release in 2010, despite some storm events (Figure 6). The percentage of "motion" receptions was higher in the six-hour tags than in the ten-minute tags, as would be expected (Table 4). The percentages of "motion" receptions of the dead fish were not significantly different from the live fish in either motion delay setting. In the six-hour delay tags, the dead fish did have less motion than the mean, but there was a single fish that had only 14 percent of receptions as "motion", which skewed the results. In the ten-minute delay tags, the dead fish had the highest percentage of motion receptions, but the wide range of percentages (28-95%) kept this from being significant, while in the six-hour tags there was one live fish with very low motion percentage compared to the dead fish. This result suggests that the motion tags used may not have had the ideal settings for use in the turbulent coastal ocean.

Preliminary Tracking of Live Fish and Carcasses in the Estuary

Tracking of three live summer flounder in the static estuarine array yielded intermittent movement records most likely owing to burial. Residency within the array ranged from 47.2-178.0 hours. Initially, hydrophones did not detect any of the summer flounder with tags until 5-6 hours after release, suggesting burial, which decreases the likelihood of tag detection (Grothues and Able, unpublished data). From 6-72 hours, transmitter tagged fish showed little movement from the release point. After about 48 hours (tag 59) and 72 hours (tag 60) two fish began to move northward in the slough (Figure 2). Tag 60 left the slough northward into Great Bay between 01:26 on July 12 and the next tracking period of July 14. Mobile tracking indicated that tag 59 was still resident up to July 20, which was the last day of tracking. Its signal was detected 600 meters from the northern end of the slough. Mobile tracking also showed tag 54 moving to the southern end of the slough up to the final day of tracking. It was last located about 250 meters from the southern end of the slough. Once transmitter-tagged fish left the slough, their signals were not found during mobile tracking in the bay.

Movement of live tagged individuals and tagged carcasses differed. Movement of all live tagged fish within the array in the slough was independent of tides and diel periodicity. By comparing movement of transmitter-tagged fish to hydrophone data and tidal charts, we determined that movement occurred at all stages of the tide and was thus independent of tidal influence. On the meter scale, fish often moved randomly at various tidal and day-night cycles, without apparent patterns. Movement of transmitter tagged summer flounder carcasses occurred in the field as observed in the flume. However, carcass movement was clearly different from that of live transmitter-tagged fish. Carcasses tended to travel with the incoming and outgoing tides, oscillating along the slough before leaving the array. Of the four carcasses deployed, only tag 56 did not move with the tide, perhaps because scavengers immobilized it while they were feeding on the carcass. Tag 56 was detected within the slough on July 7, at which time it left the array at the southern end of the slough, during the predicted ebbing tide. The carcass with tag165 moved with the tides on July 13 and 14, travelling with the ebbing tide and then leaving the slough at the north end on the flooding tide. The carcass with tag 166 traveled with the tide on July 13 but was not detected again until July 16 when it travelled with the tide again, leaving the array at the southern end. Carcass with tag 168 moved with the tide on July 10 and 11, and then was not detected until July 15. It left the array at the northern end at the time of the predicted high tide.

Tagged carcasses moved much greater distances that expected. Outside of the slough, the three carcasses tagged with dual frequency transmitters (Tags 165, 166, and 168) were detected with the CAFT hydrophone system in Great Bay and Little Egg Inlet (Table 2, Figure 2). Tag 165 was detected at hydrophones No. 3 and No. 2 on July 14, No. 4, No. 3, and No. 2 on July 15 and then not detected again in this array. Tag 166 was heard at hydrophones No. 3 and No. 2 on July 15, moved between No. 2 and No. 3 on July 16, then No. 4 and up to No. 13 until moving out of the range of the hydrophones (Figure 2). Carcass with tag 168 was moving out Main Marsh Thoroughfare on July 14 and not found again. These carcasses were not detected during the July

22 and 23 mobile tracking of Great Bay, Little Egg Inlet, and the Mullica River, however, the fish with tags 166 and 168 were detected in the vicinity of grassy channel (CAFT hydrophone No. 13, Figure 2) on the mobile distribution tracking on August 14.

Evaluation of Discard Mortality in the Ocean

Mortality estimates immediately after trawl retrieval yielded fish ranging from excellent condition to dead individuals (Table 5). Overall the health index, based on observations of 52 individuals from commercial length trawls, the initial on deck mortality was 32.7%. There were 8 individuals used to assess latent mortality of better conditioned fish captured in a short duration tow that is not indicative of commercial trawling and were thus not used for deck mortality estimates. The length of live (excellent, good, poor health index) and dead fish overlapped at sizes below 600 mm but more live fish were >600 mm (Figure 7). The estimated catches of fishes (primarily skates and rays, but including some bony fishes) and invertebrates (primarily horseshoe crabs) ranged from 150-1000 lbs. The condition of fish on deck appeared to vary with tow times and relative to bycatch of other species. Subsequent tracking in 2009 and 2010 helped to clarify latent mortality in the poor, good and excellent condition fish (see above).

Tracking of live fish and carcasses provided estimates of latent mortality and of fish and carcass behavior. Most fish remained in the general vicinity of their release and thus within the range of detection for the fixed array for approximately 24 hours. Five fish that were tagged were never heard by any receiver, and 4 tagging records were found to have recording error, these fish were not used in any future analysis. The subsequent departure of live and dead fish coincided with a Northeast storm event (Figure 8). Patterns of detections in the fixed hydrophone array differed between fish dependent on condition at release, as displayed by non-metric multidimensional scaling (nMDS) ordination (Figure 9). The nMDS shows clear groupings of mostly dead and poor condition fish, as well as a grouping of good and excellent condition fish, suggesting that a fish's initial condition is related to its movement within the array. There was also a large cluster of fish due to the short duration since release. Additionally, depth data collected by these hydrophones for the fish that were tagged with pressure sensitive tags (n=17) showed distinct differences in use of the water column following release and helped to differentiate live and dead fish. There were several fish (n=7) that showed distinct vertical movement behavior, with substantial movement up and down in the water column in 2009 (Figure 10). The movement characteristics varied by individual including highly periodic oscillations to mid-water depths, long slow ascents to the surface followed with a slow return to the bottom, or few short deviations from the bottom. The dead fish in 2009 had little vertical deviation from the bottom, and showed only the tidal fluctuations (Figure 10). Conversely, the two dead fish in 2010 both had repeated, large (greater than 5 m) deviations from the bottom, in short bursts (less than 10 minutes) over 4 days (Figure 11). The live fish, like those in 2009, showed substantial vertical movement into the water column, but no clear pattern among individuals emerges (Figure 12). The mean depth of detection in 2009 was also above the mean water depth for the array location, again suggesting that the fish were vertically active (Figure 13). The fish tagged with multiple tags in 2010 have almost identical vertical profiles for both tags, supporting the precision of the tags (Figure 14).

Mobile tracking efforts during 2009 were able to re-detect both initially live and dead fish during tracking. After the initial tracking, and the storm event, fish of dead and poor conditions dominated the detections, with few good and no excellent condition fish presumably because they swam out of the area of detection of the array and mobile tracking (Table 6). To further investigate the potential of current driven movement, the direction of exit from the array was determined for fish by using an activity cell method adapted from Simpendorfer et al. (2002), creating position estimates based on hydrophone affinity via number of contacts and reception power (decibels). The plots were created for the final 5 hours of each fish's residence within the array, binned into 15 minute intervals, the trend in direction can than be related to the currents during the time of departure (Figure 14).

Fish, presumably those dead on deck or subsequently dying, were re-detected after the storm series were found in a relatively concentrated area about 8 km south west of the release site (Figure 15). This indicates movement (drift) during the storm parallel to the beach and isobaths, followed by settling, possibly with tag detachment, carcass decay, or entrapment by benthic scavengers. This movement is consistent with modeled flow from the Rutgers University Ocean Model provided by John Wilkin (Figure 16). When compared to boat tracks and locations from the 3 days after the storm in which fish were found (Table 6) a clear area of residence emerges (Figure 15). 22 fish were detected in this area, of those 10 were dead on deck of the trawler, 10 were in poor condition on board, and 2 were in good condition. This suggests that the fish in this area are likely dead and have been moved by the strong currents of the storm event. Despite further storms, the position of these tags did not change noticeably after a week, potentially because of scavengers or carcass degeneration reducing currents effect on movement.

The northeast storm event prevented mobile tracking, yet the resulting south-west current direction yielded a distinctly different pattern from the expected direction of travel towards the shelf break normally exhibited by migrating summer flounder (Packer and Hoff, 1999). When mobile tracking continued after the storm, a clear grouping of fish, likely moved by the storm currents, were located down to the southwest of the array, the direction of currents during the storm (Figure 15). The initial health conditions of these fish, mostly dead or poor condition, further suggest that currents moved these fish to the "graveyard" cluster of dead fish. If we assume the "graveyard" holds all of the mortalities, both initial and latent, from the trawls, there can be a second estimate of mortality made. The latent mortality, without initially dead fish, is 33.3%, with 52.6% "poor" fish, 14.3% "good" fish, and 0% "excellent" fish being assessed as dead. This assumption requires a caveat: we know there are fish initially dead that did not end up in the graveyard, yet the clear pattern of more fish in poorer conditions suggests there is validity to this estimate. Using this as an initial platform to work off we can develop some other metrics to incorporate into a more holistic mortality estimate. By using the assumption that current direction is the mechanism of movement for dead fish and the offshore direction of movement is indicative of life fish, we can look at individual fish direction of departure from the array to determine if they were moving in the southwest direction with currents, or towards the shelf break. A healthy fish would likely be moving into deeper water as part of the seasonal migration

(Packer and Hoff, 1999), and fish following the southwest current is more likely a dead fish than a live. The Simpendorfer center of activity analysis provided that information, showing direction of departure as an additional metric for a discard mortality estimate. The calculation of latent mortality, excluding initially dead fish, is then 50.0%, with 68.4% "poor" fish, 35.7% "good" fish, and 0% "excellent" fish being evaluated as dead. By combining our initial on-deck mortality with this latent mortality estimate we obtain a total discard mortality of 82.7% (Table 7). By taking the number of dead fish that would be accounted for as dead in our latent mortality estimate, we have a rough estimate of error associated with this estimate. Fourteen dead fish would be accounted for as dead using our metrics, thus 87.5% of the dead fish were properly categorized as dead, or an error of 12.5%.

Discussion

Evaluation of Techniques

The new tagging techniques developed in this study allowed for quick tagging and did not require any surgery or antibiotics or sedatives. Further, this technique allowed acoustic tags to be attached to individuals without adding biases from long handling time or surgical procedures. The speed also allows the tagging procedure to happen in the same timeframe as standard culling procedures aboard trawling vessels. Tag retention in live fish did not represent a problem, based on observations in the laboratory, while scavengers may complicate the issue in fish that are dead.

Motion sensitive tags provide another means through which to interpret mortality in tagged discards. Our results suggest that the six-hour delay would be the more effective motion delay, yet the sensitivity used may not be ideal. There was some difference in the dead fish motion with a six-hour delay, but this was largely accounted for by an individual who's percentage of motion was by far the least of any fish. The range in the ten-minute delay suggests these may be useful to examine more fine scale behavior, including vertical movement.

Vertical movement is useful when determining mortality of a fish using acoustic telemetry. Pressure sensitive tags allowed the monitoring of vertical behaviors of tagged fish, providing another form of movement with which to assess mortality. Healthy summer flounder exhibit vertical movement, and there is data supporting their use of tidal stream transport (Szedlmayer and Able, 1993). By quantifying healthy vertical movement behavior, deviations from this can be attributed to stress and even mortality. Our results show substantial vertical movement by healthy fish in both years, but no clear pattern of behavior was observed. The concept of tidal stream transport does seem to be supported, with many of the fish that exhibited vertical movements showing upward movement before departing the array. Many of the fish discarded dead in 2009 showed a very distinctive, and flat, vertical profile, but this did not hold true in 2010, where large peaks were present. It is unlikely that currents were able to move the carcasses such great depths with such speed, and therefore predators are likely to be the cause.

Preliminary Tracking of Live Fish and Carcasses in the Estuary

Our preliminary work in the estuary showed that summer flounder carcasses can move substantial distances, and did so in synchrony with the tidal currents, suggesting that the currents were the mechanism responsible for movement. These results are supported by the flume examination of current speeds required to move a summer flounder carcass, where the threshold speed was as low as 10 cm/s. These current speeds are commonly seen in the natural environment (4-17 cm/s mean current speed has been observed for the area; Charlesworth, 1968), suggesting that currents are likely to be the mechanism of motion for carcasses. Scavengers also likely play a role in the availability of carcasses to be moved by currents. One of the areas to focus on for future work is coupling of tracking efforts and physical oceanography to better understand the movements of carcasses and discards that have died.

Evaluation of Discard Mortality in the Ocean

Full-scale assessment of discard mortality with acoustic tags in the ocean was complicated by a storm, but yielded promising results towards determining a discard mortality rate. Initial on-deck assessment of the trawl-induced mortality was relatively low, at 30.0%, but the number of fish of intermediate health was high, demonstrating the need for quality assessment of delayed mortality. Another result of note is the apparent size refuge from immediate mortality, with fish greater than 600 mm not having any initial mortality. This lower mortality of larger fish was not skewed by the shorter trawl, which had lower mortality but a wide range of fish sizes (295-665). The potential for a size refuge is interesting, perhaps preventing fish from being gilled in the mesh, and should be incorporated into future discard mortality estimates.

Several unexpected hurdles influenced the project, providing some lessons for future research. One complication was related to our attempts to trilaterate tags within the array deployed in the ocean, which would provide meter-scale resolution movement while the tag was being detected by at least 3 hydrophones simultaneously. This was achieved in previous studies and in the preliminary work in the estuary, but the ambient noise in the coastal ocean reduced the signal reception distance greater than expected. In future work, assuming a smaller reception range would be helpful in obtaining trilateration. Another setback resulted from the storm that kept us from tracking directly after release of the fish in the first year of study.

Our final estimate of discard mortality, including initial and latent mortality, is 82.7%, which agrees closely with prior studies and the current management value of 80%. The findings of this project also suggest that acoustic telemetry is a viable means to assess discard mortality in summer flounder, and potentially in other commercially important species. We were not able to achieve our goal of discerning discard mortality as it varies with length, age, or reproductive status, but have laid the groundwork for future work using acoustic techniques to provide answers to these pressing questions.

Outreach

Yergey, M. E., K. W. Able, and T. M. Grothues. 2010. Preliminary evidence for vertical

movement behavior of summer flounder (*Paralichthys dentatus*) based on ultrasonic telemetry. Oral Presentation, Tidewater Chapter American Fisheries Society, March 19, Annapolis, MD.

Yergey, M. E., K. W. Able, T. M. Grothues, C. Crawford, K. DeCristofer. 2010. A pilot study for acoustic telemetry-based estimate of summer flounder commercial discard mortality: laboratory studies and field observations. Poster Presentation, American Fisheries Society Mid-Atlantic Chapter Meeting, November 18, Lewes, DE.

Yergey, M. E., K. W. Able, T. M. Grothues, K. DeChristofer, and C. Crawford. 2010. The use of acoustic telemetry as a means of assessing discard mortality in the summer flounder (*Paralichthys dentatus*) commercial fishery: A first look. Oral Presentation, 12th Flatfish Biology Conference, December 1, Westbrook, CT.

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Literature Cited

Able, K.W. and T.M. Grothues. 2007a. Approaches to understanding habitat dynamics of flatfishes: advantages of biotelemetry. Journal of Sea Research. 58:1-7.

Able, K.W. and T.M. Grothues. 2007b. Diversity of estuarine movements of striped bass (*Morone saxatilis*): a synoptic examination of an estuarine system in southern New Jersey. Fishery Bulletin 105:426-435.

Able, K. W., M. C. Sullivan, J. A. Hare, G. Bath-Martin, J. C. Taylor, and R. Hagan. 2011. Larval abundance of summer flounder (Paralichthys dentatus) as a measure of recruitment and stock status. Fish. Bull. 110:68-78.

Arnold, G. P. and H. Dewar. 2001. Electronic tags in marine fisheries research: a 30 year perspective. In: Siebert, J. R., Nielsel, J. L (Eds.) Electronic Tagging and Tracking in Marine Fisheries. Kluwer, Dordrecht, pp. 7-64.

Bain, M. B. 2005. Electronic tags . In: Cadrin, S. X., Friedland, K. D., Waldman, J. R. (Eds.) Stock Identification Methods: Applications in Fishery Science. Elsevier Academic Press. Burlington, MA., pp. 235-226.

Benoit, H.P., T. Hurlbut, J. Chassé. 2010. Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. Fisheries Research 106: 436-447.

Charlesworth, L. J. 1968. Study of bay, inlet, and nearshore marine sedimentation. PhD Dissertation, State University of New Jersey, Trenton NJ.

Chopin, F. S. and T. Arimoto. 1995. The condition of fish escaping from fishing gears – a review. Fisheries Research 21: 315-327.

Cooke, S. J., S. G. Hinch, M. Wikelski, R. D. Andres, L. J. Kuchel, T. G. Wolcott, and P. J. Butler. 2004. Biotelemetry: a mechanistic approach to ecology. Trends Ecol. Evol. 19: 334-343.

Davis, M. W. 2002. Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci. 59: 1834-1843.

Davis, M. W. 2005. Behaviour impairment in captured and released sablefish: ecological consequences and possible substitute measures for delayed discard mortality. Journal of Fish Biology 66: 254-265.

Davis, M. W. and M. L. Ottmar. 2006. Wounding and reflex impairment may be predictors for mortality in discarded or escaped fish. Fisheries Research 82: 1-6.

Davis, M. W. and C. B. Schreck. 2005. Responses by Pacific halibut to air exposure: lack of correspondence among plasma constituents and mortality. Transactions of the American Fisheries Society 134: 991-998.

Grothues, T. M. 2009. A review of acoustic telemetry technology and a perspective on its diversification relative to coastal tracking arrays. pp77-90 In J. L. L. Neielsen et al. (eds.) Tagging and Tracking of Marine Animals with Electronic Devices. Reviews; Methods and Technologies in Fish Biology and Fisheries 9.

Grothues, T. M., K.W. Able, J. McDonnell, and M. M. Sisak. An estuarine observatory for real-time telemetry of migrant macrofauna: Design, performance, and constraints. Limnology and Oceanography: Methods 3: 275:289.

Grothues, T. M. and K. W. Able. 2007. Scaling acoustic telemetry of bluefish *Pomatomus saltatrix* in an estuarine observatory: detection and habitat use patterns. Transactions of

the American Fisheries Society 136:1511-1519.

Harrington, J. M., R. A. Myers and A. A. Rosenberg. 2005. Wasted fishery resources: discarded by-catch in the U.S.A. Fish and Fisheries 6: 350-361.

Kennelly, S. J. and M. K. Broadhurst. 2002. By-catch begone: changes in the philosophy of fishing technology. Fish and Fisheries 3: 340-355.

Lucas M. C. and E. Baras. 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. Fish and Fisheries 1: 283-316.

Lucy, J. A. and T. D. Holton. 1998. Release mortality in Virginia's recreational fishery for summer flounder, *Paralichthys dentatus*. Final contract report to the Virginia Marine Resource Commission. Virginia Marine Resource Report Number 97-8.

Malchoff, M. H., J. Gearhart, J. Lucy and P. J. Sullivan. 2002. The influence of hook type, hook wound location, and other variables associated with post catch-and-release mortality in the U.S. summer flounder recreational fishery. pp. 101-105 In: Catch and Release in Marine Recreational Fisheries, J. A. Lucy and A. L. Studholme (eds), American Fisheries Society Symposium 30, Bethesda, MD.

Mandelman, J. W. and M. A. Farrington. 2007. The estimated short-term discard mortality of a trawled elasmobranch, the spiny dogfish (*Squalus acanthis*). Fisheries Research 83: 238-245.

Mesnil, B. 1996. When discards survive: accounting for survival of discards in fisheries assessments. Aquat. Living Resour. 9: 209-215.

NEFSC. 2000. Report of the 31st Northeast Regional Stock Assessment Workshop (31st SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent. Ref. Doc. 00-15, 400 p.

Ng, C., K. W. Able and T. M. Grothues. 2007. Habitat use, site fidelity and movement of adult striped bass in a southern New Jersey estuary based on acoustic telemetry. Transactions of the American Fisheries Society 136:1344-1355.

Packer, D.B. and T. Hoff. 1999. Life history, habitat parameters, and essential habitat of mid-Atlantic summer flounder. American Fisheries Society Symposium 22:76-92.

Sackett, D.K., K.W. Able and T.M. Grothues. 2007. Dynamics of summer flounder, *Paralichthys dentatus*, seasonal migrations based on ultrasonic telemetry. Estuarine Coastal and Shelf Sciences 74:119-130.

Sackett, D.K., K.W. Able and T.M. Grothues. 2008. Habitat dynamics of summer flounder, *Paralichthys dentatus*, within a shallow USA estuary, based on multiple approaches using acoustic telemetry. Marine Ecology Progress Series 364:199-212.

Sibert, J. R. and J. L. Nielsen (Eds.) 2001. Electronic Tagging and Tracking in Marine Fisheries. Kluwer Academic Publishers, Dordrecht.

Simpfendorfer, C. A., M. R. Heupel and R. E. Heuter. 2002. Estimation of short-term centers of activity from an array of omni-directional hydrophones and its use in studying animal movements. Canadian Journal of Fisheries and Aquatic Sciences. 59:23-32

Szedlmayer, S.T., K.W. Able. 1993. Ultrasonic telemetry of age-0 summer flounder, *Paralichthys dentatus*, movements in a southern New Jersey estuary. Copeia 3: 728-736.

Terceiro M. 2010. Stock assessment of summer flounder for 2010. US Dept Commer, NFSC Reference Document. 10-14; 133 p.

Table 1. Summary of collection and tagging information for 2010 ocean tracking. The motion delay setting is shown for each fish, the sensitivity was at a setting of "4" which with yield a motion signal if 8 changes of state occur in 1 minute period.

Tag ID	Length	Date Collected	Method of Collection	Date Released	Health	Motion Delay
55332	390	31 August 2010	Hook and Line	15 September 2010	A	10 min.
55384	378	31 August 2010	Hook and Line	15 September 2010	A	10 min.
55020 55436*	511	31 August 2010	2 Minute Otter Trawl	15 September 2010	A	Both
55592	403	31 August 2010	Hook and Line	15 September 2010	A	10 min.
55488	476	31 August 2010	Hook and Line	15 September 2010	A	10 min.
55596	417	31 August 2010	Hook and Line	15 September 2010	A	10 min.
55644	462	2 September 2010	2 Minute Otter Trawl	15 September 2010	A	10 min.
55540	463	16 August 2010	Crab Pot (Bycatch)	15 September 2010	D	10 min.
54968	399	19 August 2010	Hook and Line	14 September 2010	A	6hr.
54500	363	27 August 2010	Hook and Line	14 September 2010	A	6hr.
54916	394	27 August 2010	Hook and Line	14 September 2010	A	6hr.
55124	366	27 August 2010	Hook and Line	14 September 2010	A	6hr.
55280	430	6 August 2010	Hook and Line	14 September 2010	D	6hr.

Table 2 – Summary tow and catch information for fish tagged onboard the FV Viking II on 15 September 2009. Total number of fish tagged during the cruise was 60. 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 #1 four live fish were landed, and along with an unknown number of dead fish were placed in a cooler. A random subsample 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 #3 to reach the total number of fish.

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

Table 3. Mobile tracking efforts conducted offshore of Brigantine, NJ after tagging on 15 September 2009 and a second concentrated tracking period in September 2010. All tracking conducted with Lotek MAP-RT system. See Figure 16 for ocean study area including hydrophone array at release site.

Date	Tracking Operations	Duration (hrs)	Number of Fish Detected
September 15, 2009	Mobile tracking within the array	9	11 (11 deployed)
September 16, 2009	Mobile tracking within the array	4.5	34
September 18, 2009	Mobile tracking within the array	4.6	2
September 20, 2009	Mobile tracking east of the array	5.3	2
September 21, 2009	Mobile tracking southeast of the array	6.3	--
September 22, 2009	Mobile tracking southeast of the array	5.7	1
September 23, 2009	Mobile tracking southwest of the array	4.7	11
September 24, 2009	Mobile tracking southwest of the array	3.3	16
September 28, 2009	Mobile tracking east of the array	3.25	0
September 30, 2009	Mobile tracking east of the array (≈7 nm offshore)	6.5	0
October 1, 2009	Mobile tracking east of the array	5.3	8
October 4, 2009	Mobile tracking east of the array (≈10 nm offshore)	4.5	0
October 5, 2009	Mobile tracking east of the array	5.4	0
October 11, 2009	Mobile tracking east of the array (≈12 nm offshore)	4.8	0
Total		73.15 hrs	85 detections
September 14, 2010	Deployment and Tracking within the array	13	5 (5 deployed)
September 15, 2010	Deployment and Tracking within the array	24	13 (13 deployed)
September 16, 2010	Tracking in the array	13	12 (13 deployed)
Total		50 hrs	30 detections

Table 4. Breakdown of motion and non-motion detections and percentage of detections in motion for 14 fish tagged with motion sensitive tags, those with a * represent tags with a six-hour motion delay, while those without have a ten-minute motion delay. The two tags in italics were attached to the same fish for time-delay comparison. The grey highlight indicates dead fish.

Tag ID	**Number of Motion Detections**	**Number of Non-Motion Detections**	**Percentage of Motion Detections**
54500*	186	1181	13.61%
54916*	482	0	100.00%
54968*	892	0	100.00%
55124*	618	24	96.26%
55280*	406	269	60.15%
*55020**	*1019*	*0*	*100.00%*
55436	*681*	*329*	*67.43%*
55384	272	226	54.62%
55332	133	343	27.94%
55488	6914	2560	72.98%
55540	1171	62	94.97%
55592	566	50	91.88%
55644	674	892	43.04%
55696	501	192	72.29%

Table 5. The on deck condition assessment of 52 individual summer flounder from 4 standard commercial otter trawl tows, conducted off the coast of Brigantine, NJ, September 15, 2009.

Health Condition	**Number of Individuals**	**Percent of Total Catch**
Excellent	3	5.8%
Good	9	23.1%
Poor	20	38.5%
Dead	16	32.7%

Table 6. Tagged summer flounder discards re-detected by mobile tracking efforts between September 15 and October 5, 2009

Tag ID No.	Health	9/15/2009	9/16/2009	9/23/2009	9/24/2009	10/1/2009	10/5/2009	Total Days Found
6661	B		X					1
6663	C		X					1
6664	C		X		X			2
6665	D		X	X				2
6666	B		X					1
6668	D		X			X		2
6670	C		X	X		X		3
6673	C		X	X	X			3
6675	C		X		X			2
6676	D		X	X	X	X		4
6678	D		X	X	X	X		4
6680	B		X					1
6682	D		X			X		2
6685	D	X	X					2
6688	C		X	X	X			3
6689	D		X					1
6690	D		X	X	X	X		4
6691	D	X	X					2
6692	D		X		X			2
6693	D		X		X			2
6695	B				X			1
6696	D		X	X		X		3
6697	C			X	X			2
6698	B		X					1
6699	D		X					1
6701	C	X	X					2
6703	D		X		X			2
6704	D	X	X					2
49000	B	X	X	X		X		4
49100	C	X	X		X			3
49300	D		X					1
49400	C		X					1
49500	C	X			X			2
49600	C	X	X					2
49700	C	X	X		X			3
49800	C		X					1
49900	B	X						1
50000			X					1
50100	C			X				1
50200	D		X					1
50900							X	1
Tags found		10	35	11	15	8	1	

Table 7. Summary table of all mortality estimates, initial, both latent estimates, and the final discard mortality estimate.

Mortality Estimate	Percent Mortality
On-Deck Mortality	32.7%
Latent Mortality from “Graveyard”	33.3%
Latent Mortality w/ “Direction of Departure”	50.0%
Total Discard Mortality	82.7%

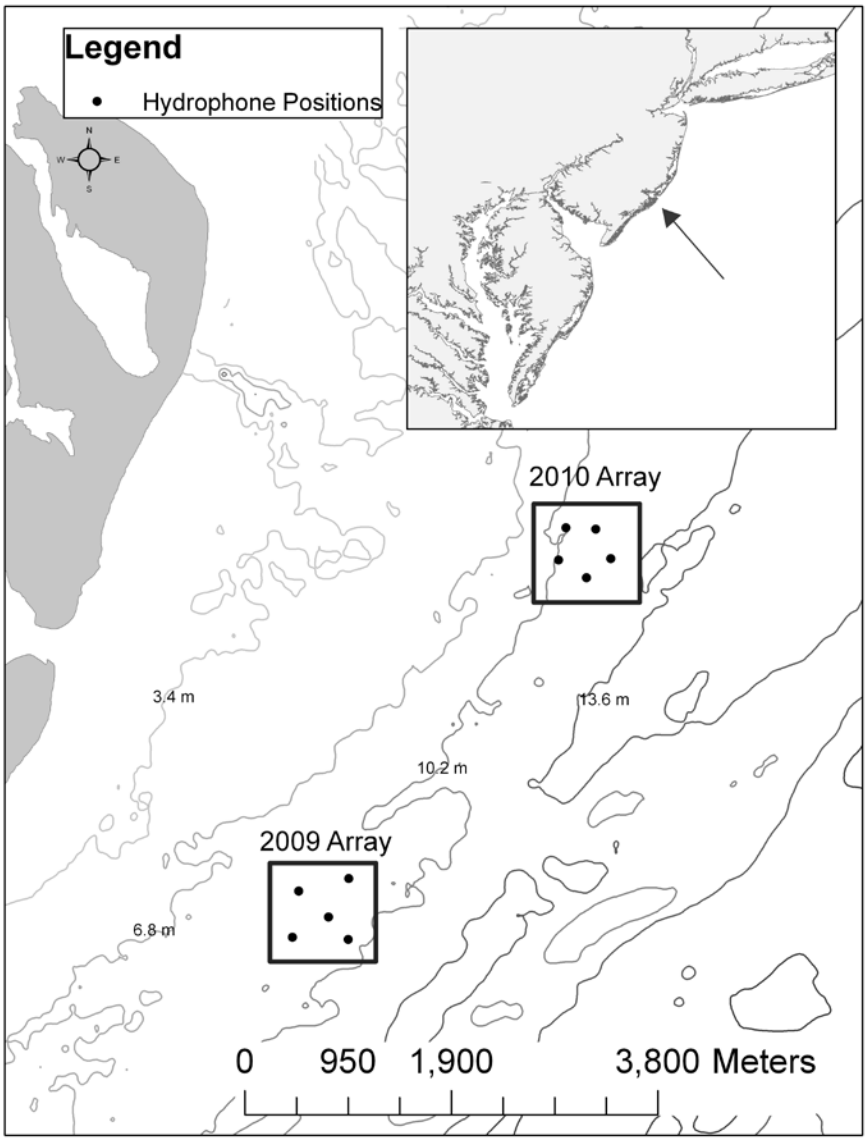

Figure 1. The ocean study sites from September 2009 and September 2010 off the coast of Brigantine, New Jersey. Both sites at roughly the same depth (~12 m).

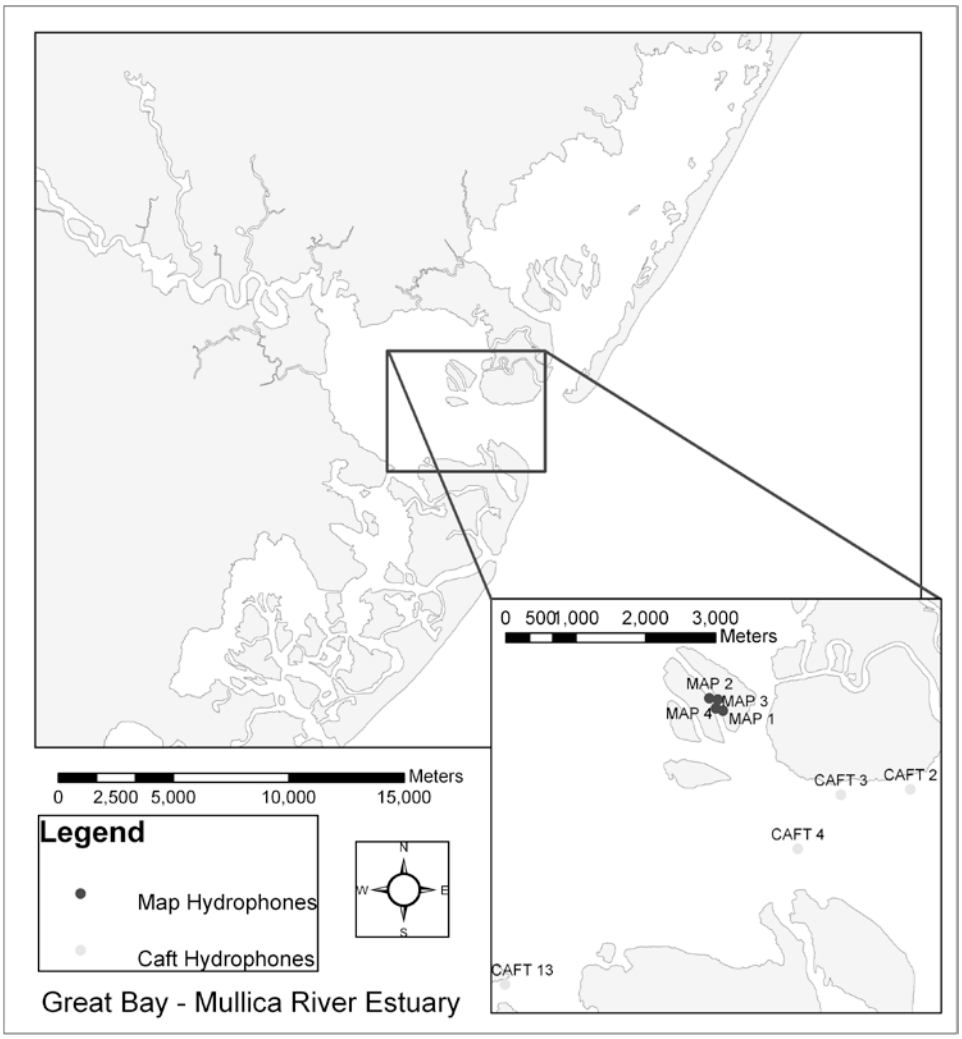

Figure 2. Hydrophone location within the Great Bay – Mullica River estuary. The MAP hydrophones were deployed within the slough for preliminary assesment of live and dead fish movement. The CAFT hydrophones were deployed as a part of a large scale array throughout the estuary, but had infrequent receptions when several of the dead fish were moved out of the inlet.

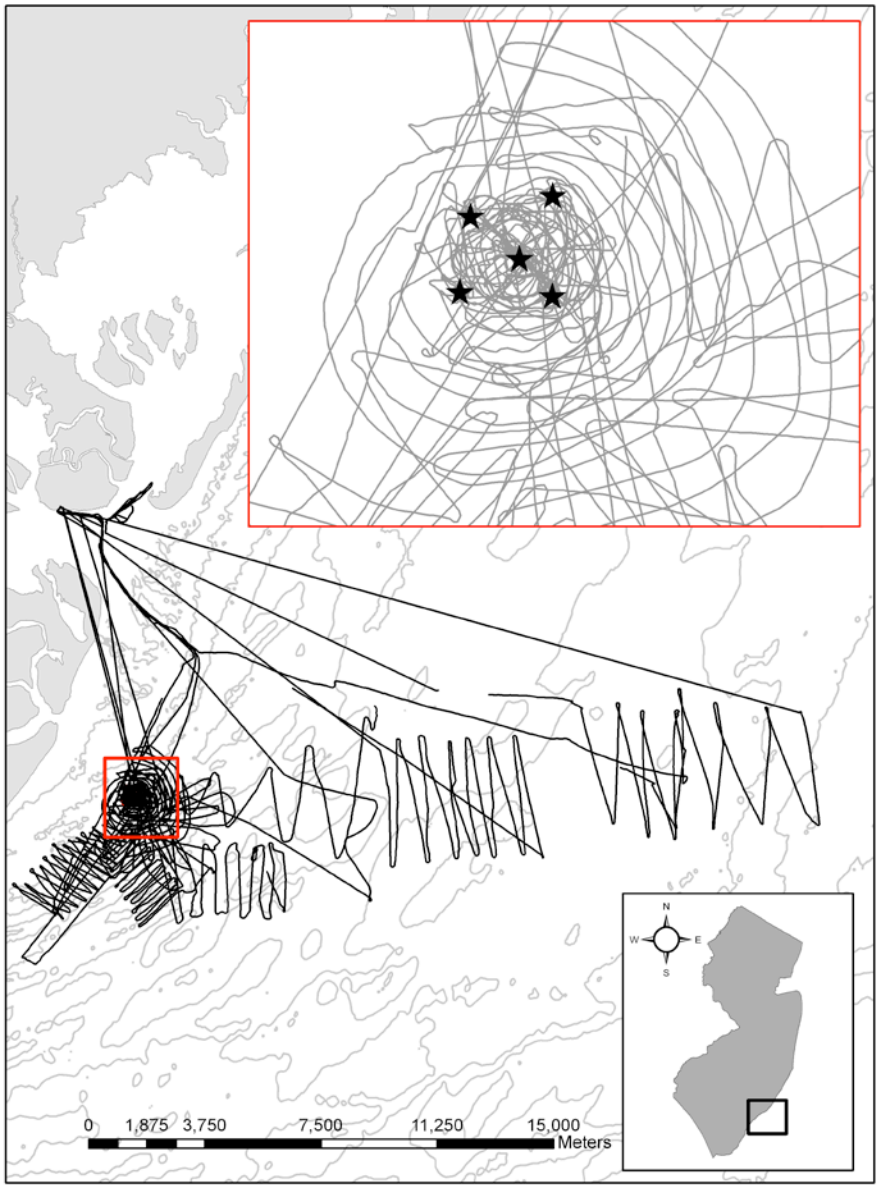

Figure 3. Location of mobile tracking efforts conducted offshore of Brigantine, New Jersey, after tagging on 15 September 2009. Stars in inset indicate the hydrophone positions. See Table 2 for additional details.

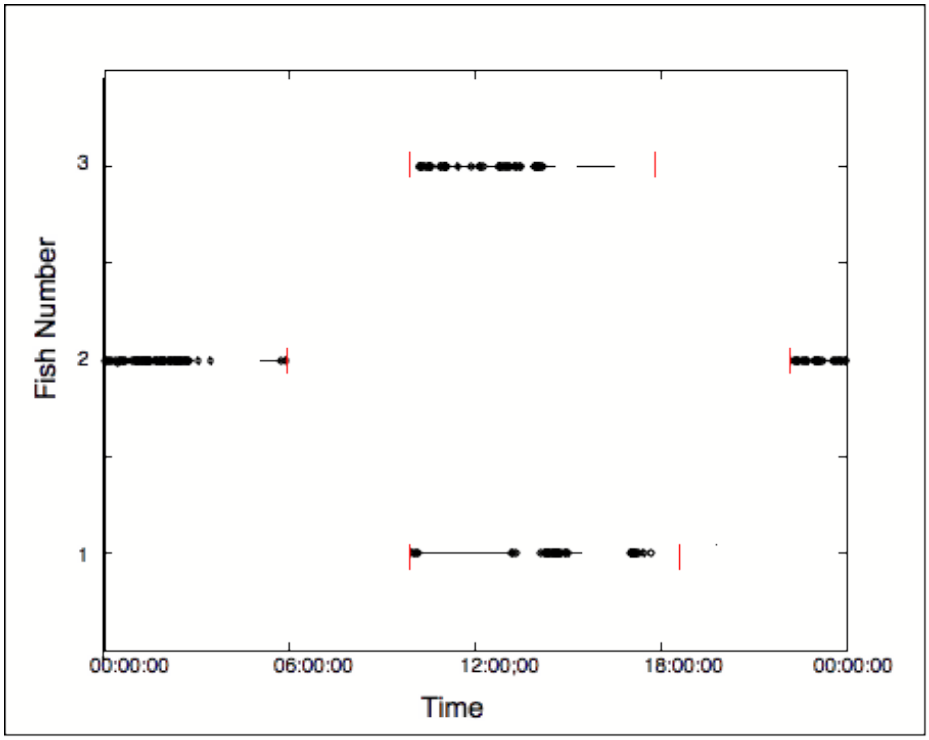

Figure 4. Motion of observed summer flounder in laboratory observations via infrared camera. Lines indicate period of motion, with dots representing start and end points of motion. Time axis represents a 24-hour day, observations were taken over several days and compiled for comparison. Mean time in motion 59 seconds, mean time stationary 216 seconds.

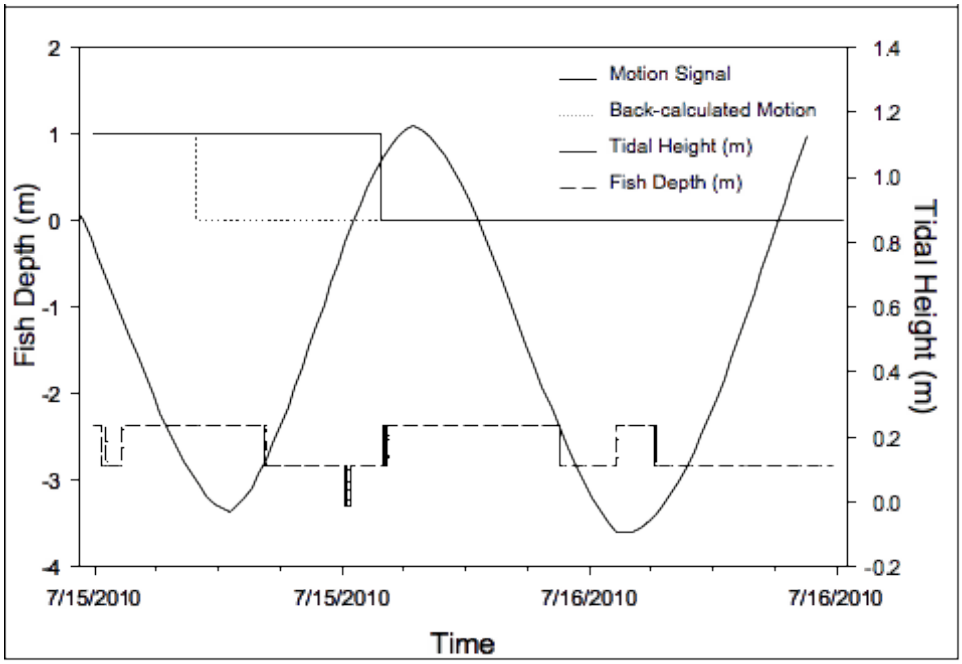

Figure 5. The depth and motion of a tag attached to a stationary steel plate in an estuary to evaluate if current alone could cause a motion signal. The depth is representative of the tide as expected, with the motion state of the tag being longer than the expected six-hour programmed delay. The back calculated motion shows the time of rest, 3:19 hours after deployment.

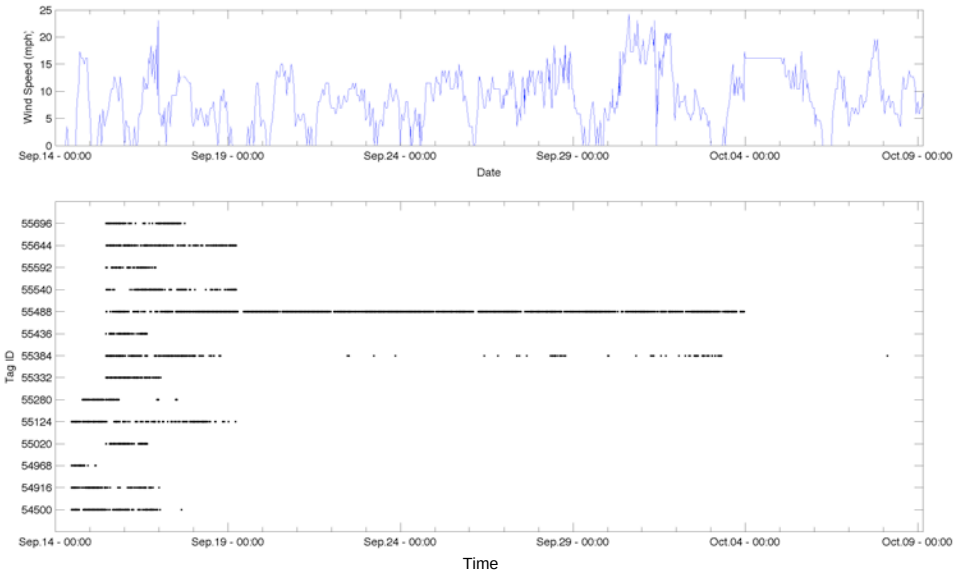

Figure 6. Timeline of fish presence within the array 2010 deployment, in conjunction with wind speed data from Atlantic City NOAA weather station. Despite several periods of high winds the fish stayed within the area.

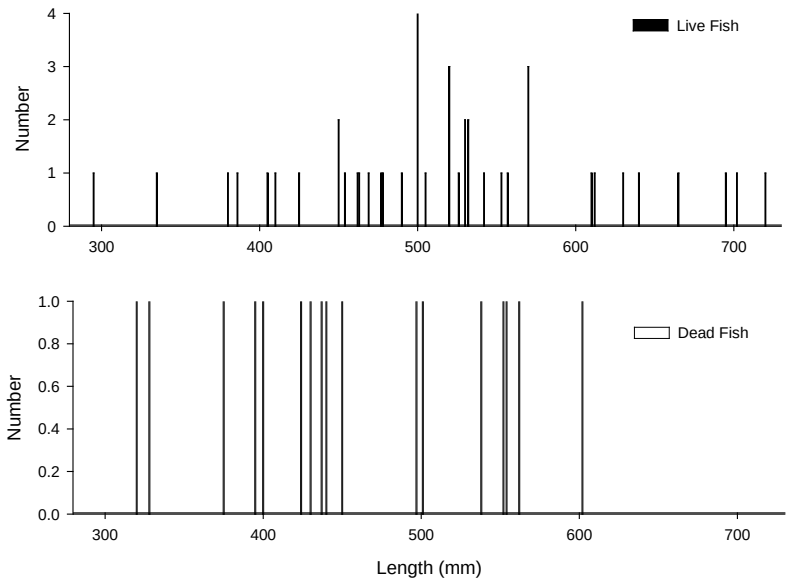

Figure 7. Length frequency distribution for live and dead summer flounder captured with a commercial otter trawl on 15 September 2009.

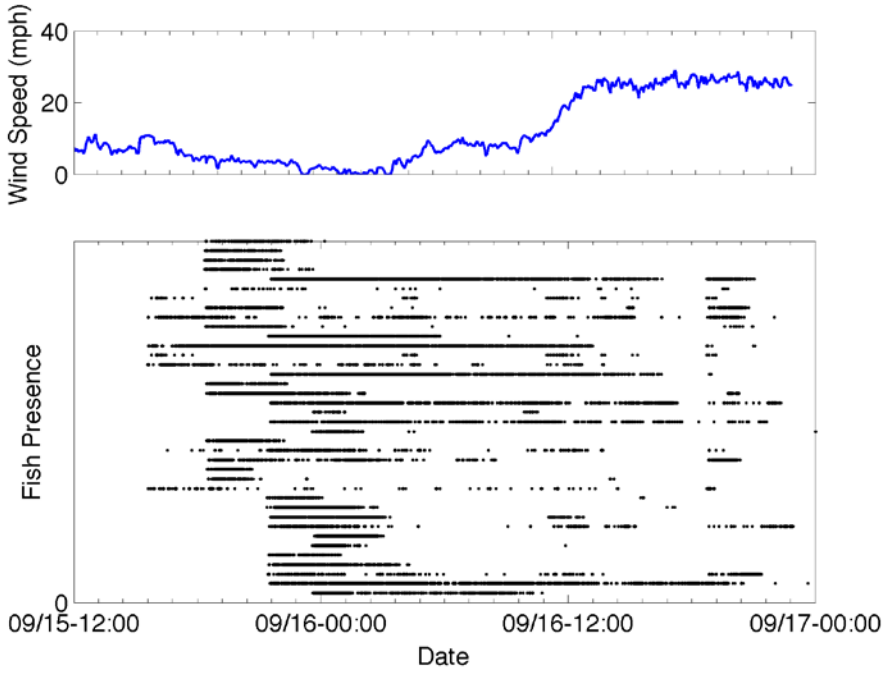

Figure 8. Presence of ultrasonically tagged summer flounder discards in the coastal ocean hydrophone array during September 2009. Top panel shows wind speeds from Atlantic City NOAA weather station associated with a North East storm event in synch to fish departure from the array.

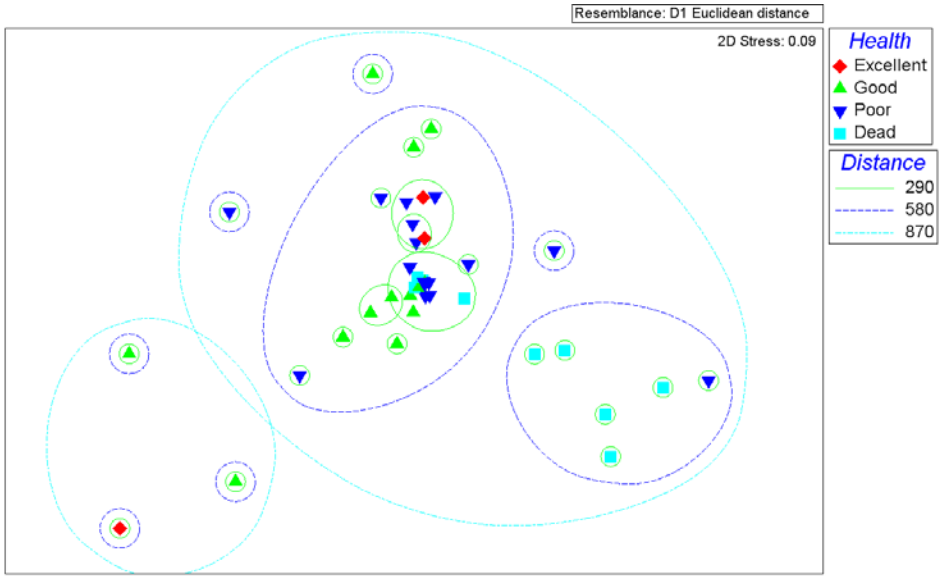

Figure 9. Multidimensional Scaling plot of ranked similarity among all ultrasonically tagged summer flounder discards over 24 hours during September 2009. Symbols represent the health condition-at-release, with a being the best and d being dead. The similarity is calculated on the basis of detection patterns at each of five hydrophones. Axes represent the first two major trends in the multidimensional space and are un-scaled, because rank is relative and without units.

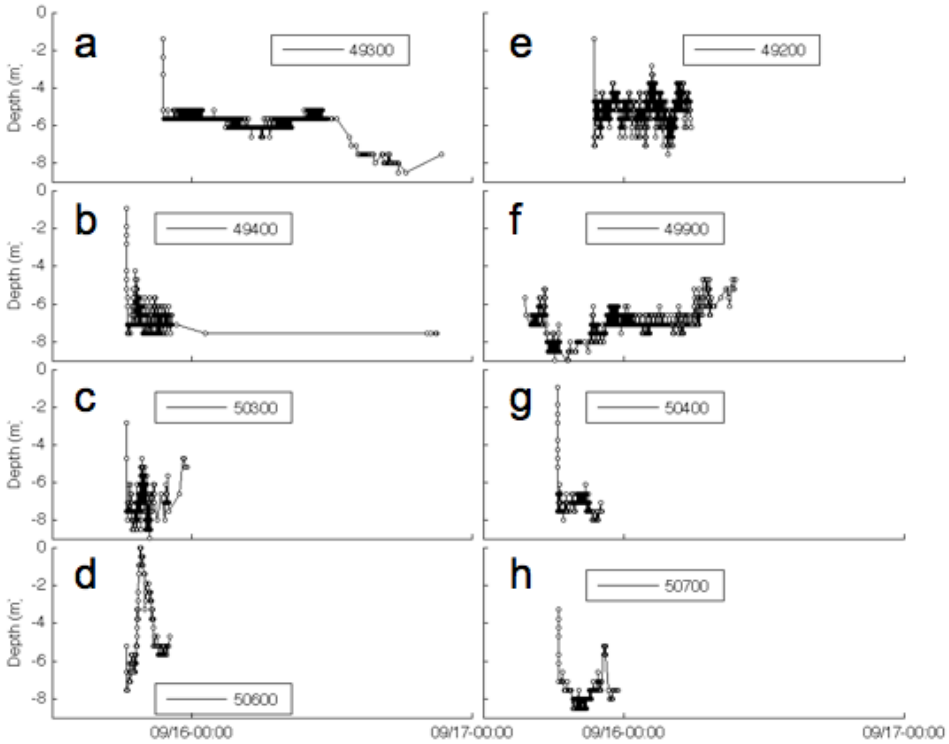

Figure 10. Vertical movement of summer flounder from pressure sensing ultrasonic tags in an array of 5 stationary submerged data logging hydrophones approximately 3km offshore of Brigantine, NJ from September 15th to the 17th, 2009. Tags are sensitive to 0.2 m depth, with 10-second transmission interval. Both dead (n=2) and live (n=15) fish of varying degrees of health were tagged. Both dead and live fish were detected within the array, with the dead fish having a longer residence time. Certain live fish (b – h) showed significant movement into the water column but did so asynchronously and to varying degrees. The dead fish (example in panel a) did not show signs of entering the water column, suggesting the movement of live fish was not a result of currents or tides.

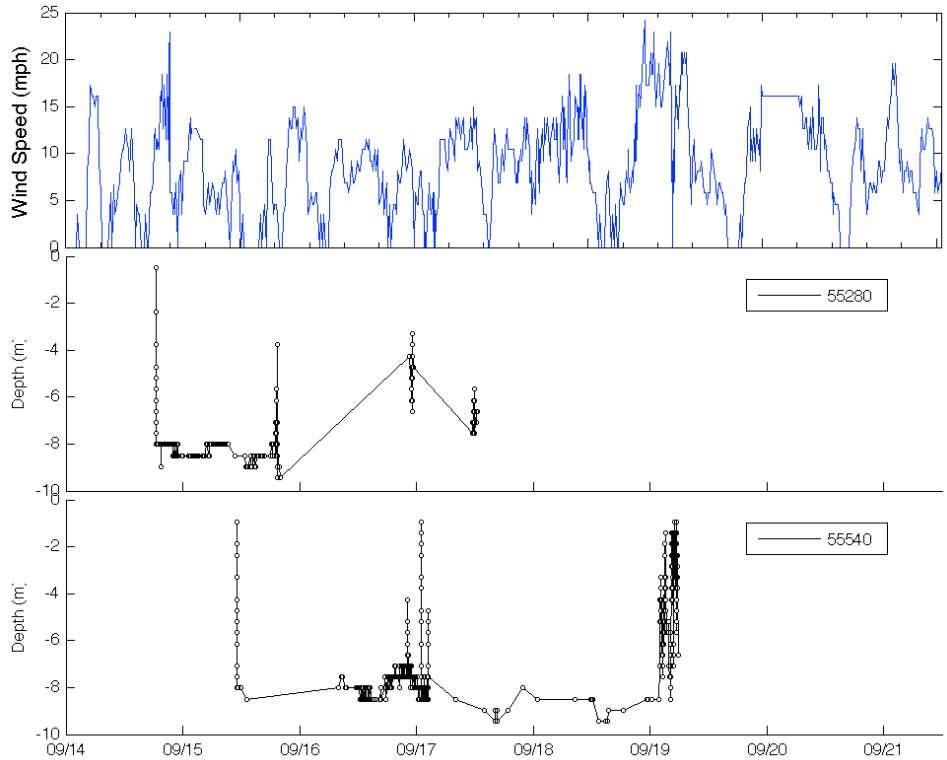

Figure 11. Vertical movement of two dead summer flounder from pressure sensing ultrasonic tags in an array of 5 stationary submerged data logging hydrophones approximately 3km offshore of Brigantine, NJ from 14 September to 21 September 2010. Top frame displays wind speeds from Atlantic City NOAA weather station. Tags are sensitive to 0.2 m depth, with 10-second transmission interval. The high extent of vertical movement differs greatly from the dead fish in 2009. There is not a clear pattern associated with the vertical movement and wind speed, suggesting perhaps predators are moving the tags and not wind driven currents.

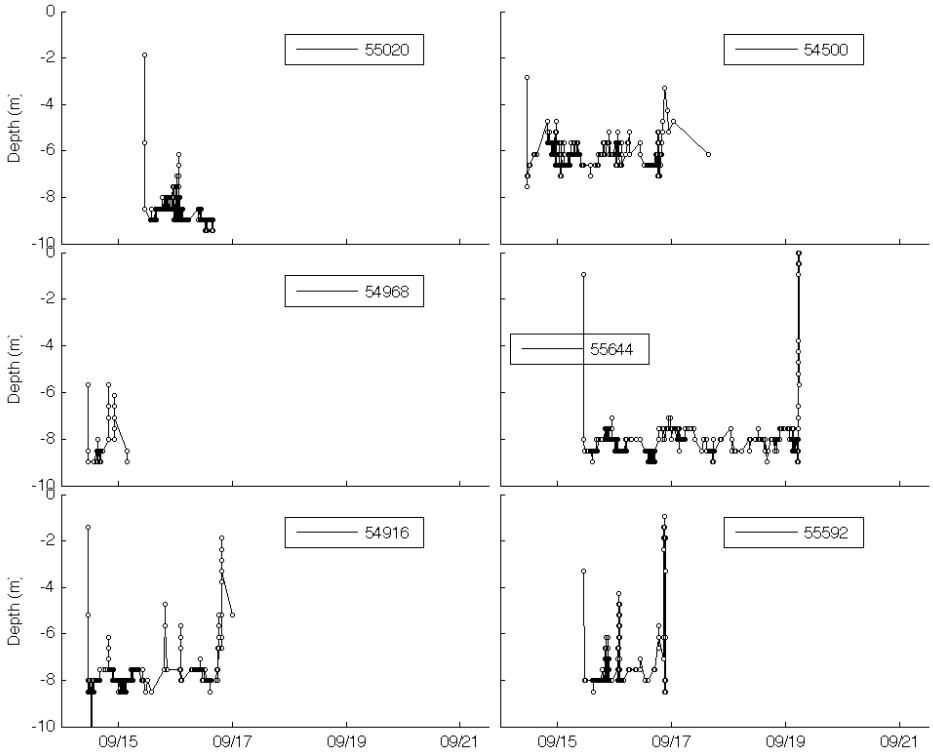

Figure 12. Vertical movement of six summer flounder from pressure sensing ultrasonic tags in an array of 5 stationary submerged data logging hydrophones approximately 3km offshore of Brigantine, NJ from 14 - 21 September 2010. Tags are sensitive to 0.2 m depth, with 10-second transmission interval. Each fish exhibited substantial movement into the water column, but there were no consistent patterns among fish.

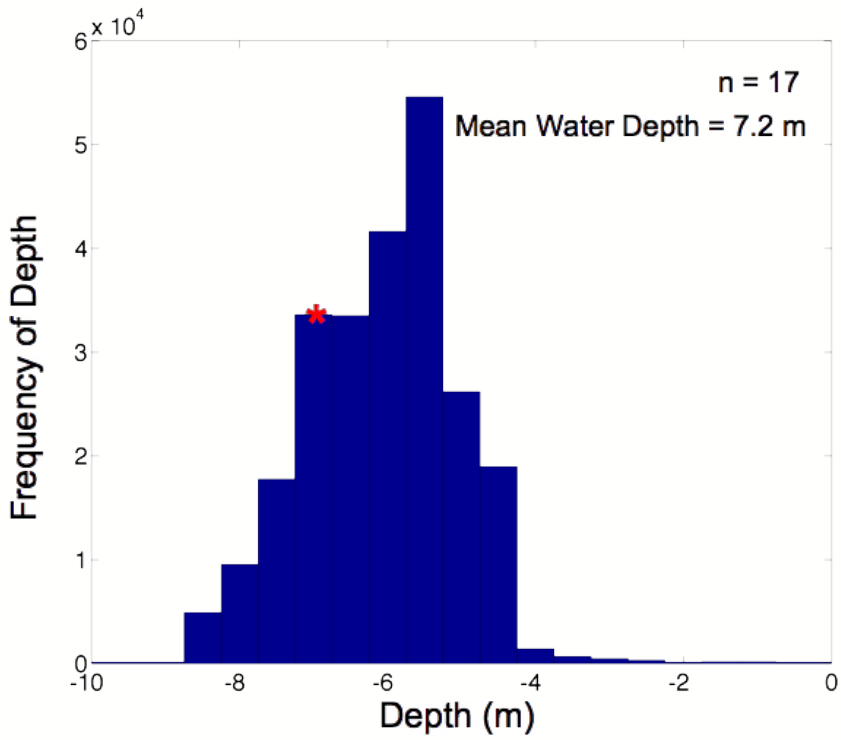

Figure 13. Distribution of the depth of signal detections within the fixed array for the 17 fish with pressure sensitive tags in September 2009. Mean water depth, marked with a star, was 7.2 meters and the peak of the depths was above this mean depth, indicating the fish were spending more time in the water column than might be expected for a demersal species.

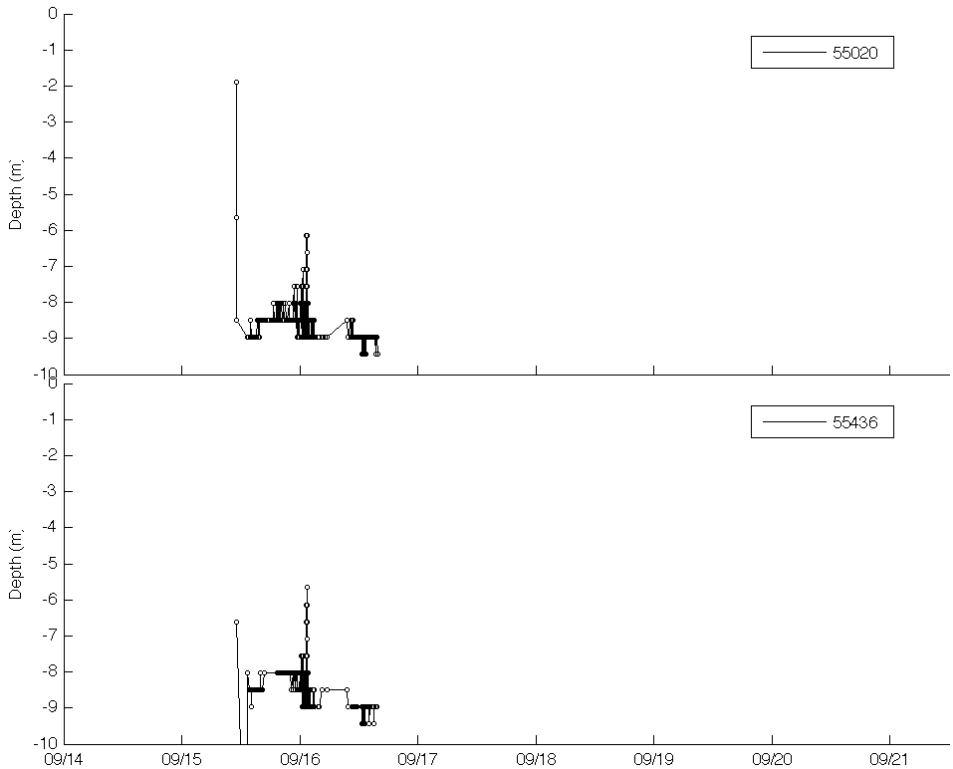

Figure 14. Vertical movement from 2 different pressure sensing ultrasonic tags on a single summer flounder in an array of 5 stationary submerged data logging hydrophones approximately 3km offshore of Brigantine, NJ from 14 - 21 September 2010. Tags are sensitive to 0.2 m depth, with 10-second transmission interval. The similarity between profiles supports the precision of the tags.

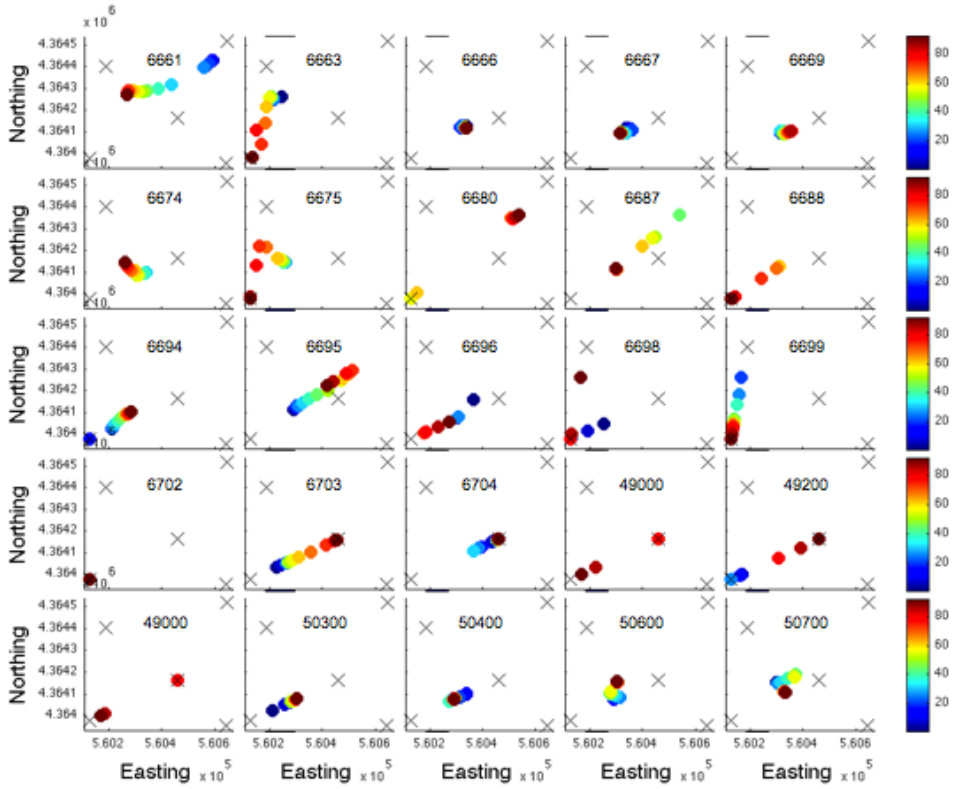

Figure 15. Center of activity plots (technique adapted from Simpendorfer et al. 2002) for summer flounder using 15-minute intervals for the last 5 hours each individual was within the array listening area. The direction of departure from the array indicates if the fish traveled with the storm currents (south west) or in another direction. Not moving with the storm currents would suggest the fish is alive, thus allowing the direction of departure as an additional metric in assessing discard mortality. 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.

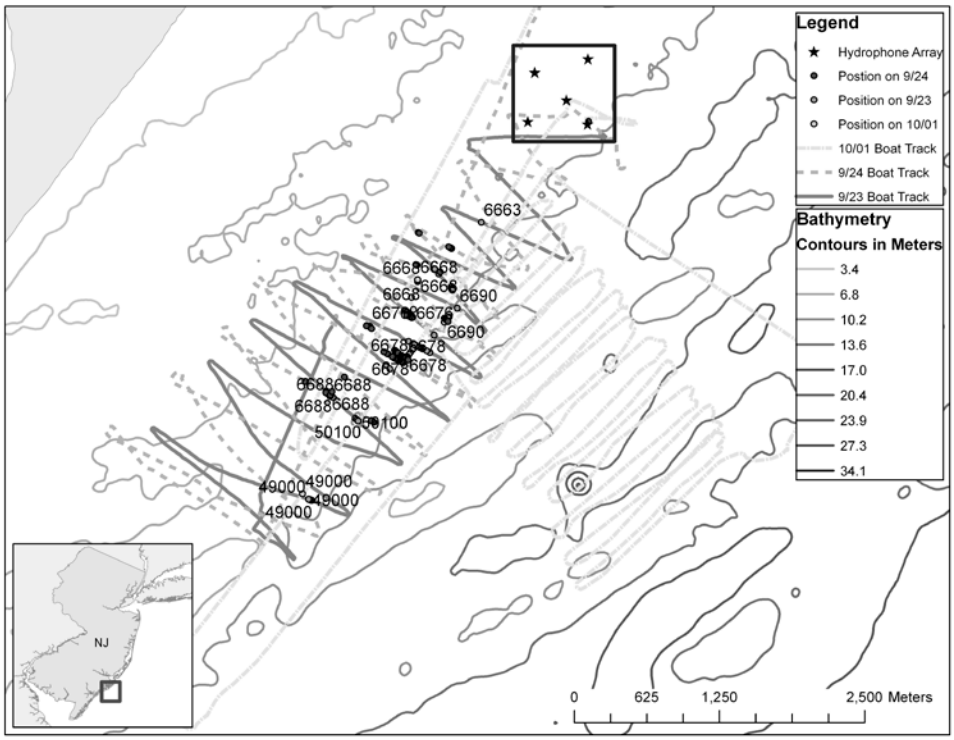

Figure 16. The positions of location of fish found during 3 tracking days after the storm event moved them out of the array area (box) during 2009. Most fish were in the same location all three days, indicating a lack of movement during that time. A large proportion of the fish located in this area were dead or poor condition fish on deck (See Table 3).

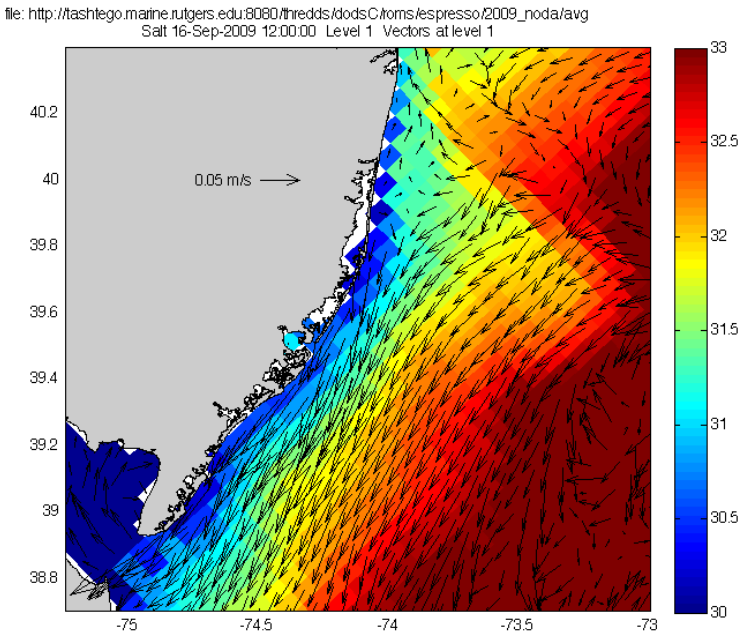

Figure 17. Modeled bottom flow in the study area for 16 September 2009, the time of the storm event that coincided with tagged fish departure form the array. The color bar represents salinity, and the reference arrow is 0.05 m/s.