Elsevier Editorial System(tm) for Fisheries Research
Manuscript Draft

Manuscript Number:

Title: Evaluating discard mortality of summer flounder (Paralichthys dentatus) in the commercial trawl fishery: Developing acoustic telemetry techniques

Article Type: Research Paper

Keywords: discard mortality; summer flounder; trawl fishery; acoustic telemetry

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Manuscript Region of Origin: USA

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August 4, 2011

Dear Dr. Rose,

Please consider the attached manuscript for publication in Fisheries Research. My contact information is above; please do not hesitate to contact me for any questions or concerns.

Sincerely,

Matthew Yergey

***Highlights**

- Commercial trawl summer flounder discards were telemetered.
- Known dead specimens served as controls.
- Live fish behaved differently from severely injured and dead fish.
- In situ latent mortality contributed substantially to total discard mortality
- An assumed 80% total discard mortality for summer flounder is supported.

Evaluating discard mortality of summer flounder (*Paralichthys dentatus*) in the commercial trawl fishery: Developing acoustic telemetry techniques

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Abstract

Fish bycatch discard mortality is one of the most significant issues influencing marine fisheries management worldwide. For summer flounder (*Paralichthys dentatus*), along the east of the United States, an 80% discard mortality is assumed but not verified. Discard mortality studies to date may be biased because they have often relied on 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. We suggest that telemetry of ultrasonically tagged fish provides an apt technique for evaluating fish bycatch discard mortality, and especially latent mortality, under natural conditions in the sea. In order to determine the mortality of these 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 on 15 September 2009 off Brigantine, New Jersey. We were able to re-detect both live and dead fish within the array during mobile tracking for approximately 24 hours before a storm. Fish of poor initial health that were re-detected after the storm together with known dead fish in a concentrated area inshore of the release site 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. Thus, 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.

Keywords: discard mortality, summer flounder, trawl fishery, acoustic telemetry

1. 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). Summer flounder, *Paralichthys dentatus,* is one of the most commercially and recreationally important fish species along the east coast of the United States. They are most abundant from Cape Cod, Massachusetts to Cape Fear, North Carolina, but are found as far north as Nova Scotia and as far south as Florida (Able and 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 estimated as loss from discards of the otter trawl and scallop dredge fisheries in 2009. These estimates are based on an estimated 80% discard mortality rate (Terceiro 2010). This estimate stems from the 2nd Amendment to the Fisheries Management Plan in 1991, where it was presented solely as an estimate (MAFMC 1991). The estimate was later supported by results in a holding pen study (Hasbrouck et al. 2008).

Discard mortality assessment for other species has relied on immediate evaluation of mortality (Davis and Schreck 2005), evaluation of delayed mortality through holding captured fish to determine survival (Davis 2005; Hasbrouck et al. 2008; Mandelman and Farrington 2007; Parker et al. 2003), and examining reflex impairment of individuals to assess likelihood of mortality (Davis 2010; Davis and Ottmar 2006). While these types of studies can provide important insights into the occurrence and quantification of immediate 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 ocean (Mandelman and 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 in-situ. Such an in-situ estimate 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 and Grothues 2007), including for summer flounder (Sackett et al. 2007; Sackett et al. 2008; Szedlmayer and Able 1993). It has also been used to assess mortality associated with catch-and-release recreational fisheries in other species (Cooke and Phillip 2004; Donaldson et al. 2008; Hightower et al. 2001; Jolley and Irby 1979). 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. 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 separate them from live individuals, (iii) preliminary telemetry study within a small estuary in order to scale expectations relevant to a more extensive and involved coastal ocean assessment, and (iv) full scale coastal ocean telemetry of fish captured by commercial otter trawl.

2.1 Tag Retention and Behavior

We tagged fish 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 previously examined for a number of fish species including paralichthyids, but the added mass and drag of a transmitter could change this. In general, external tags will be shed more easily than implanted tags (Bridger and Booth 2000) and are discouraged for longer term studies such as for migration. 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 for two trials of 4 fish each over a period of two weeks each in a 1.2 x 2.4 meter holding tank with ambient sea water (approximately 21°, 28 ppt). Fish were observed twice daily for tag retention.

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 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*). Divers have observed these scavenger species in the area of the ocean study site (Rose Petrecca, personal communication). Fish length, date and 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 Carcass Behavior in Flume

To examine the movement potential of summer flounder carcasses relative to current velocity, carcasses 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 34 ppt salt water. 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.

2.3 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 1). The bottom was a mixture of sand and silt, with populations of blue mussels (*Mytilus edulis*) and sea stars (*Asterias forbesi*), based on diver observations. 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 meters 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 for fish that moved or were transported out of the array. 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) and 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 1). Mobile tracking occurred on 7 days between July 8 and July 20, 2009 with a total effort of approximately 17 hours.

2.4 Discard Mortality Estimate

Fish for the in situ bycatch mortality assessment were captured 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 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 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 near the fixed five-hydrophone array of 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 health release conditions (Table 1). 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 immediately scored with a health index (Table 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 following standard on-deck culling procedures. 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 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).

2.5 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 (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, binned into 15-minute intervals and then 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 (Levin 2009; Wilkin 2006). Mobile tracking positions were determined on a coarse scale based on interpolation of detection time and GPS location of the boat at the time of detection.

Mortality estimates for fish captured in the trawl, tagged, and relseased 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 calcualted 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.

3. Results

3.1 Tag Retention and Behavior

In the laboratory, there was no tag loss in the live fish (n = 8) tag retention trials. In every carcass tag retention trial, the first scavenger 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. The average time for the tag to be removed, excluding trials in which the fish was removed without tag loss, was 25.1 hours.

3.2 Carcass Behavior in Flume

Transport of tagged summer flounder in the flumes occurred over a wide range of current speeds (10.1- 47.6 cm/sec) for the 71 trials conducted. The mean near-bottom speed of 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 mass ($r = 0.234$). There was a strong negative correlation between height of the leading edge of the carcass off of the sediment surface and speed of transport ($r = -0.690$). There was very little correlation between length and speed of transport ($r = -0.040$).

3.3 Observational Scaling in the Field

Three live tagged summer flounder tracked in the static estuarine array yielded intermittent movement records. 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. Live fish moved independent of flow, by contrast, tagged carcasses tended to travel with the flood and ebb tides, oscillating along the slough before leaving the array (Figure 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 (Figure 1).

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 1). Eight additional individuals were captured in a short duration tow, were of better condition and therefore were not used for deck mortality estimates, but to provide a gradient of health indices for tagging (excellent = 12.5%, good = 75.0%, poor = 12.5%, dead = 0.0%; Table 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 1). The estimated catches of other fishes (primarily skates and rays, but including some bony fishes) and invertebrates (primarily horseshoe crabs) ranged from 150-1000 lbs in three of the standard length tows (Table 2).

Most tagged fish remained in the general vicinity of their release and thus within the range of detection of the fixed array for approximately 24 hours (Figure 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 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 5). Three clear groupings emerged. The first, with the majority of individuals of all health indices, clustered at the Euclidian distance of 580, is likely due to the short duration and large number of receptions by multiple hydrophones immediately after deployment. The other two groups are relatively separated when compared to their distance to the group centered along the primary axes, with one consisting of 2 “good” condition fish and 1 “excellent” condition fish. The other consists of 5 “dead” condition fish and one “poor” condition fish, both are clustered at a distance of 870. Two “poor” and one “good” fish were clustered individually at the Euclidean distance of 580, but were relatively close in space to the group centered along the primary axis when compared to the other two clusters.

Mobile tracking efforts were also able to detect both initially live (excellent, good, and poor conditions) and dead fish during tracking (Figure 2). After the initial tracking, and the storm event at approximately 12:00 September 16th to 00:00 September 17th, 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 south west of the release site (Figure 2). This movement is consistent with bottom flow from the storm event, modeled from the Rutgers University Ocean Model. 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 fish concentrated to the southwest likely 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 being assessed as dead (Table 1).

Individuals departed the array in different directions and this was used to further differentiate live and dead fish (Figure 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%.

4. Discussion

4.1 Evaluation of Technique

The tagging techniques tested in this study allowed for quick tagging and avoided surgery, antibiotics and anesthesia. Thus, it allowed acoustic tags to be attached to individuals without adding biases from long handling time or surgical procedures. There were no mortalities as a result of tagging in preliminary work. Tag retention in live fish did not represent a problem, based on observations in the laboratory. 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 move carcasses and the fish could be misinterpreted as alive due to the continuous movement and transmission of the tag. We do not think that these field observations were compromised by scavengers because no tags stayed in the same location during the initial 24 hours thus they were not detached from the carcasses or prevented from moving.

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 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 near-shore coastline of New Jersey (4-17 cm/s mean current speed has been observed for the area (Charlesworth 1968), suggesting that currents are likely the mechanism of motion for carcasses. 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 the case, 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, detection problems associated with 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. There is also the issue of the tag malfunction, or improper handling, that resulted in 5 tags never being detected, despite being dropped into a functioning array. These limitations are something to be considered for acoustic telemetry as a means of assessing discard mortality, but there are also advantages to the approach.

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 discard mortalities than those in good condition, and no excellent condition fish were determined to be mortalities.

Due to a high number of tags that were never detected from the short duration trawl, any determination of latent effects of trawl times is not feasible due to small sample size. 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 1). This result supports some previous work that suggests shorter tow times could directly reduce mortality in flatfish (Benoit et al. 2010; Davis 2002) 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 can cause harmful abrasion in longer tows.

Observations within the array via fixed hydrophones are limited due to the short residency time, less than 24 hours. However, the excellent and good condition fish, and the poor condition and dead fish clearly differentiated in rank along at least two multivariate axes of detection patterns (Figure 5). The fish in these two divergent groups were also determined to be live or as mortalities by the other latent mortality metrics, supporting the result. This suggests that even within the initial 24 hours of observation there were distinct patterns of movement between the healthiest individuals (excellent and good condition) and the least healthy (poor condition) or dead individuals. These results support preliminary work and previous recreational catch-and-release studies that acoustic telemetry can provide a clear means to assess health, and thus mortality, in an in-situ environment (Cooke and Phillip 2004; Donaldson et al. 2008; Hightower et al. 2001; Jolley and Irby 1979). 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 and even better estimate of mortality could have been made.

The northeast storm event prevented mobile tracking. However, the resulting tag detections to the southwest of carcasses and presumed mortalities 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 (Able and Fahay 2010; Packer and Hoff 1999). The storm-derived currents caused a number of individuals to be transported in the unexpected southwest direction, which indicates drift with the current. The flume data and our preliminary work in the estuary 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 moved by the current in similar conditions, with 75% (9 of 12) of individuals moving in directions against the dominant current. Also, other tracking studies have suggested that live summer flounder do respond to storms (Sackett et al. 2007). 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: we know there are fish initially dead that 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 that would prevent movement outside of the array. However, the clear relationship of mortality with respect to initial on-deck health index suggests that this estimate is approaching an accurate value.

Our discard mortality estimate of 81.3% is essentially the same as the previous estimate (78.7-80%) based on holding tank experiments (Hasbrouck et al. 2008; Terceiro 2010), thus discard mortality rate is very high. When comparing these results to previous discard mortality studies, one goal is to provide a second means of estimation, with different biases and assumptions to add new perspective to the issue. The fact that a novel approach to determining discard mortality achieved such a high value, similar to previous estimates, seems as substantiation of this estimate. Discard mortality rates are likely highly variable and influenced by a wide variety of factors (Benoit et al. 2010; Davis 2002), as with the 33.3% estimated in section 3.3 of 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, with old and new techniques, to understand the variability and to determine on what solutions are best to reduce this waste and avoid bycatch.

In summary, while this study did not address the issues of long-term delayed mortality or directly assess the influence of predation, it did demonstrate the ability of telemetry to do so in future work because of the in-situ nature of the technique. Acoustic telemetry has been shown to be a useful tool in understanding the behavior of post trawl-captured summer flounder, and the mortality associated with commercial trawling and was formative 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 technology advances tools such as heart rate monitors and other physiological telemetry, these will provide even greater information. Moving forward, acoustic telemetry should not only be considered a viable means of assessing discard mortality, but should be considered an integral tool for understanding fishing related mortality.

Acknowledgements

We gratefully acknowledge the professionalism of Capt. Jim Lovegren and crew of the commercial trawler *FV Viking II*. Jenna Rackovan, Tom Malatesta, Jen Smith, Jim Vasslides, Steve Zeck, and Pat Filardi assisted in the field and laboratory. Thanks to Emerson Hasbrouk and the Cornell University Cooperative Extension for the on-deck health index criteria. Charlotte Fuller provided access to the IMCS flume facility and assisted with these observations. John Wilkin provided results of a flow model for the study period. Jim Hughes, Ken Roma, and John Paoli ably captained the Rutgers University vessels for mobile tracking and moored hydrophone support. Many thanks to Joe Dobarro for diving to recover a hydrophone (and its data), and to Rose Petrecca for providing insights on potential scavengers. This research was supported by a grant from the Mid-Atlantic Fisheries Management Council Research Set Aside program using donations of quota from recreational and commercial fisheries. We appreciate the efforts of the fishing vessels involved in this program. Internships were made possible by a NSF-REU grant as the Rutgers Internships in Ocean Sciences program. This paper is Rutgers University Institute of Marine and Coastal Sciences contribution No. XXX.

References

Able, K.W.; Fahay, M.P. *Paralichthys dentatus*. Ecology of Estuarine Fishes: Temperate waters of the western North Atlantic. Baltimore, MD: Johns Hopkins University Press; 2010

Able, K.W.; Grothues, T.M. An approach to understanding habitat dynamics of flatfishes: Advantages of biotelemetry. Journal of Sea Research. 58:1-7; 2007

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

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

Cooke, S.J.; Phillip, D.P. Behavior and mortality of caught-and-released bonefish (*Albula* spp.) in Bahamian waters with impliactions for sustainable recreational fishery. Biological Conservation. 118:599 - 607; 2004

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

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

Davis, M.W. Fish stress and mortality can be predicted using reflex impairment. Fish and Fisheries. 11:1-11; 2010

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

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

Donaldson, M.R.; Arlinghaus, R.A.; Hanson, K.C.; Cooke, S.J. Enhancing catch-and-release science with biotelemetry. Fish and Fisheries. 9:79-105; 2008

Grothues, T.M.; Able, K.W.; McDonnell, J.; Sisak, M.M. An estuarine observatory for real-time telemetry of migrant macrofauna: design, performance, and constraints. Limnology and Oceanography: Methods. 3:275-289; 2005

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

Hasbrouck, E.; Froehlich, T.; Gerbino, K.; Scotti, J.; Powell, E.N.; Bochenek, E.; Morson, J. Discard mortality of summer flounder in the inshore trawl fishery. in: NEFSC, ed. 47th Northeast Regional Stock Assessment Workshop. Woods Hole, Massachusetts: Northeast Fisheries Science Center; 2008

Hightower, J.E.; Jackson, J.R.; Pollock, K.H. Use of telemetry methods to estimate natural mortality and fishing mortality of striped bass in Lake Gaston, North Carolina. Transactions of the American Fisheries Society. 130:557 - 567; 2001

Jolley, J.W.; Irby, E.W. Survival of tagged and released Atlantic sailfish (*Istiophorus platypterusI*: Istiophoridae) determined with acoustical telemetry. Bulletin of Marine Science. 29:155-169; 1979

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

Levin, J. Regional Ocean Modeling System ESPRESSO model. 2009. Retrieved from: http://tashtego.marine.rutgers.edu:8080/thredds/roms/espresso/catalog.html?dataset=espresso_2009_da_averages 2010

MAFMC. Amendment 2 of the Fishery Management Plan for the Summer Flounder Fishery. 1991. Reference Document. 452

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

National Oceanic and Atmospheric Administration, O.o.C.R.M., National Estuarine Research Reserve System-wide Montioring Program. Centralized Data Management Office. 2004. Retrieved from: http://cdmo.baruch.sc.edu

Nowell, A.R.; Jumars, P.A.; Eckman, J.E. Effects of biological activity on the entrainment of marine sediments. Marine Geology. 42:133-153; 1981

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

Parker, S.J.; Rankin, P.S.; Hannah, R.W.; Schreck, C.B. Discard mortality of trawl-caught lingcod in relation to tow duration and time on deck. North American Journal of Fisheries Managment. 23:530-542; 2003

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

Sackett, D.K.; Able, K.W.; Grothues, T.M. 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; 2008

Simpfendorfer, C.A.; Heupel, M.R.; Hueter, R.E. Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. Can J Fish Aquat Sci. 59:23-32; 2002

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

Terceiro, M. Stock assessment of summer flounder for 2010. 2010. Commerce U.D.o. NFSC Reference Document. 133

Wilkin, J. ROMS Matlab tools. 2006. Retrieved from: http://romsmatlab.tiddlyspot.com/ 2010

Figure Captions:

Figure 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 were moved through the inlet.

Figure 2. The locations of individual boat tracks for detecting tagged fish and bathymetry. Also shown are the locations of tagged fish found during 3 tracking days after the storm event (approximately 12:00 September 16th to 00:00 September 17th) 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 the tracked area were of dead or poor health index on-deck.

Figure 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 mark 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 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 idicates

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 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 un-scaled because rank is relative and without units. Distance is Euclidian. Group boundaries defined by Euclidean distance are based on consensus cluster analysis.

Figure 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 with the storm currents (southwest) or in another direction, suggesting the fish is alive. 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.

Table

Table 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 Condition	**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 – 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
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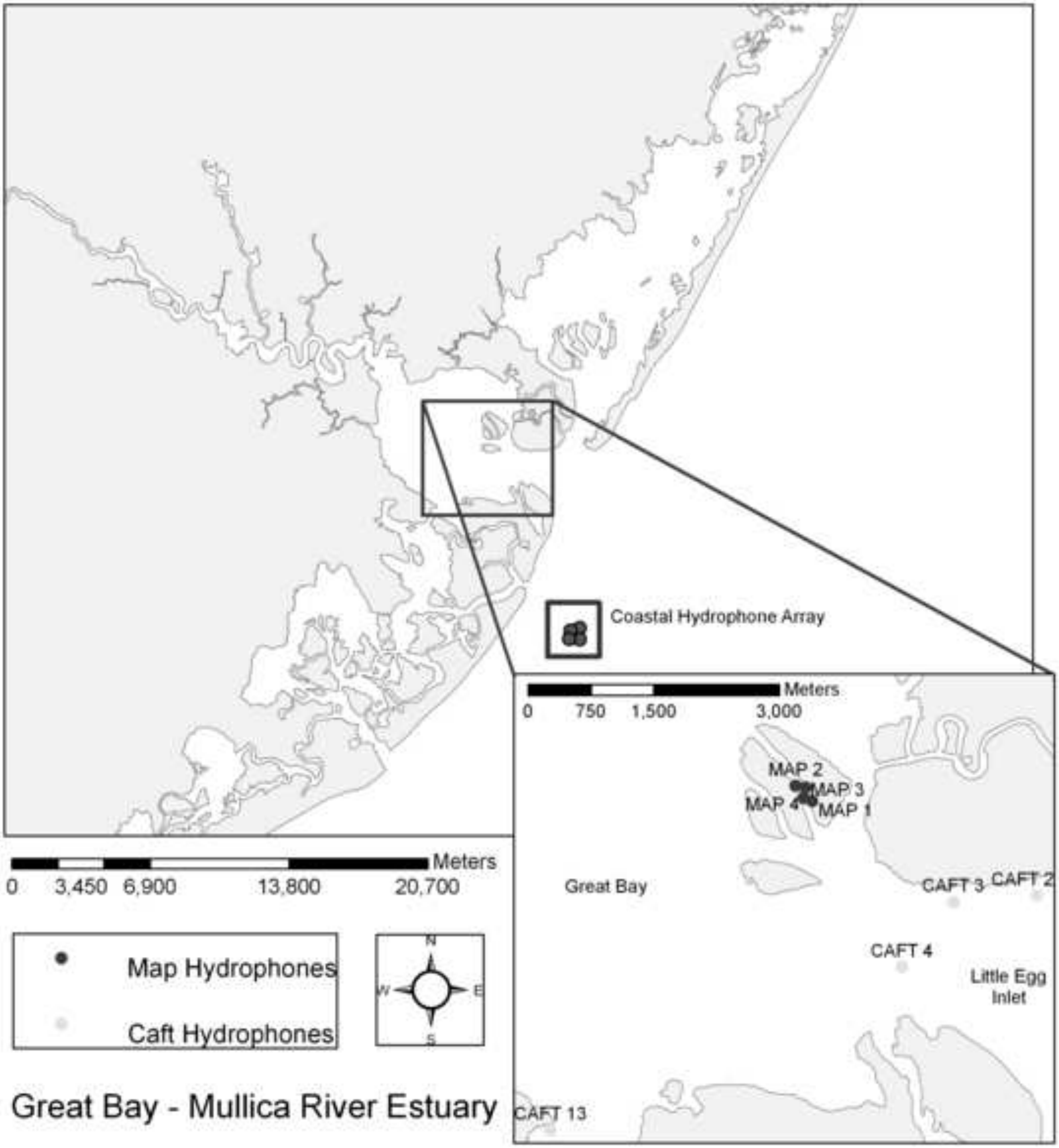

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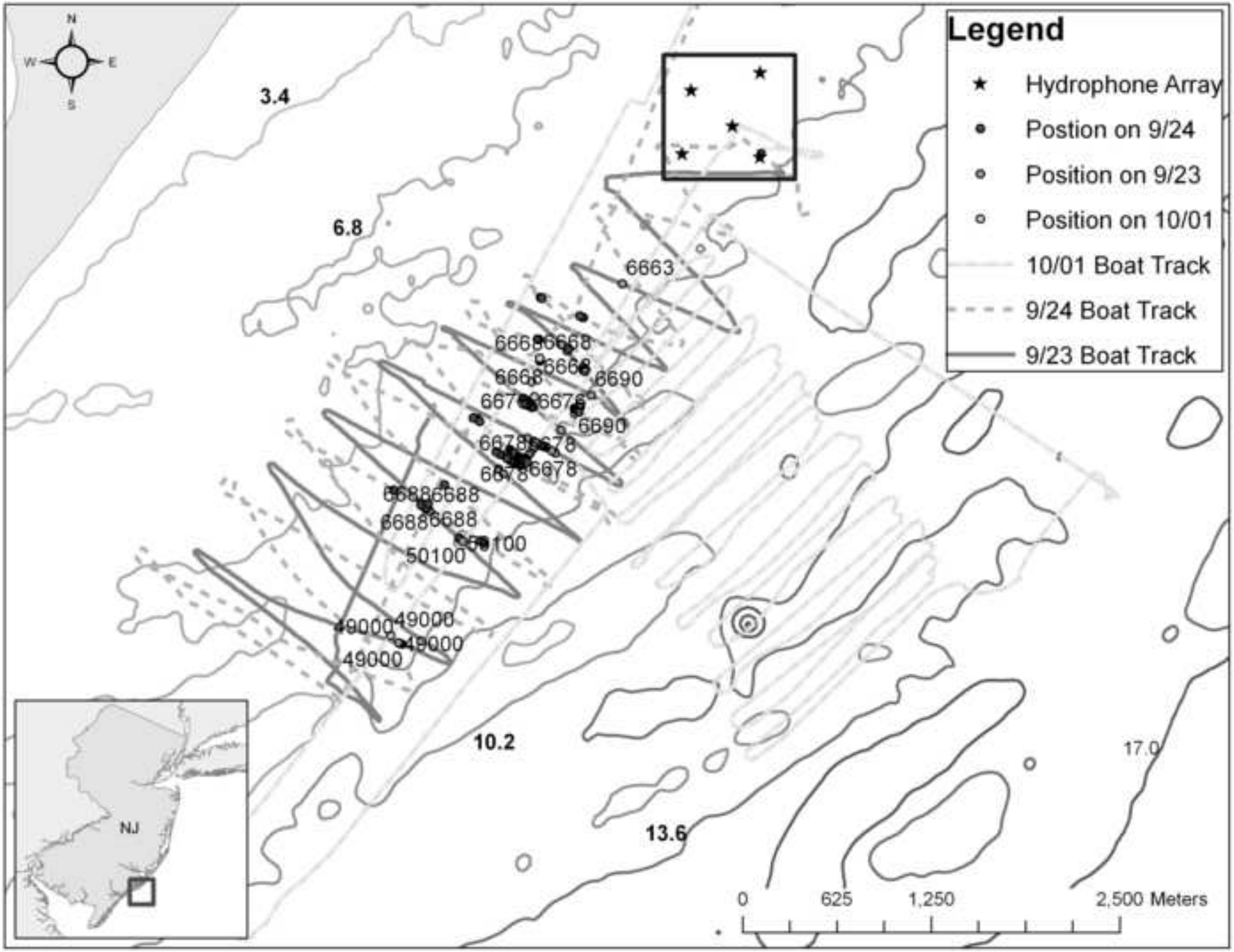

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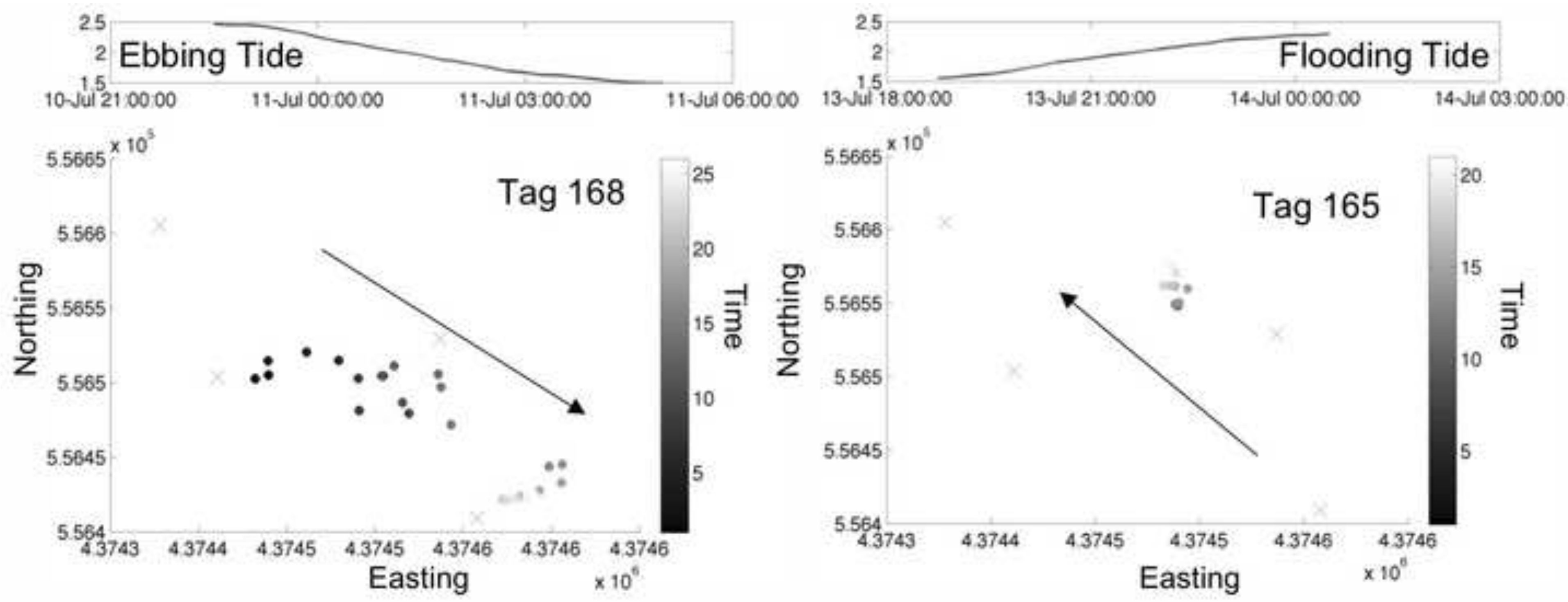

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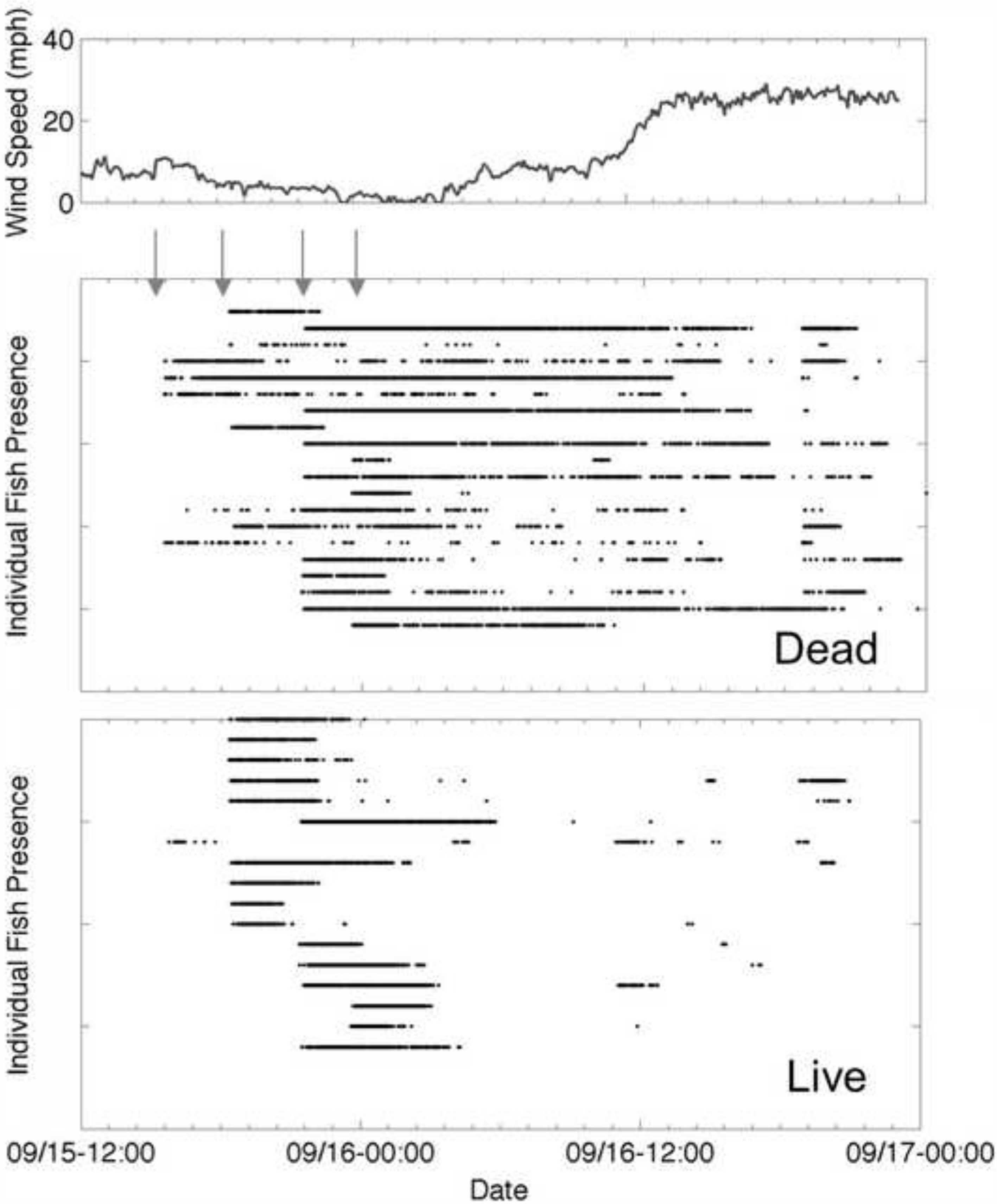

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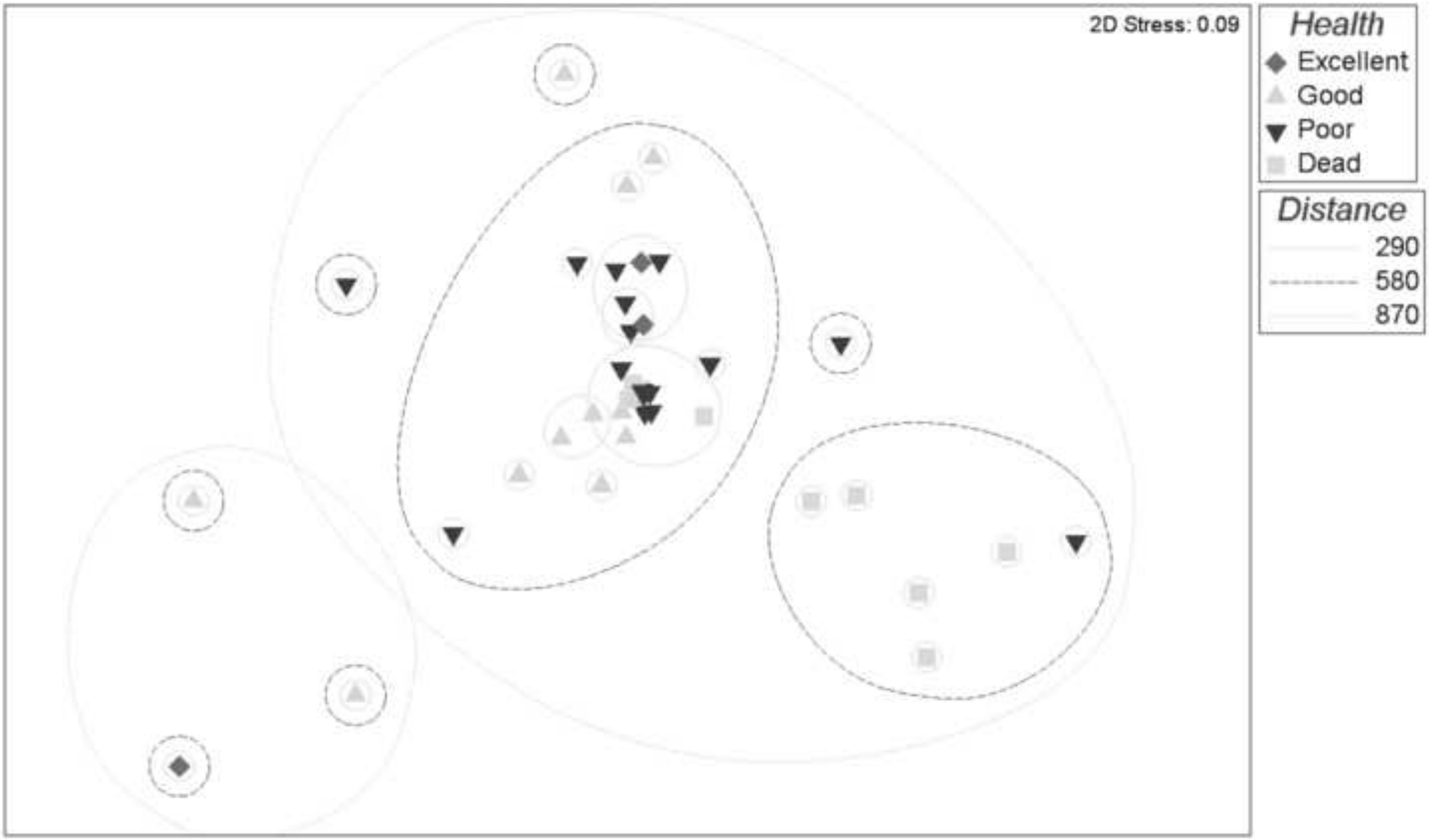

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