ABSTRACT

FRIEDL, SARAH ELIZABETH. Telemetry-based Mortality Estimates of Juvenile Spot in two North Carolina Estuarine Creeks. (Under the direction of Jeffrey A. Buckel and Joseph E. Hightower.)

Spot (*Leiostomus xanthurus*), an estuarine dependent species, are ecologically and economically important in North Carolina. No formal stock assessment has been conducted for spot due to a lack of biological and fisheries data and it has recently been recognized that additional information on mortality is a key factor in developing such an assessment. We estimated natural mortality rates (*M*) of age-1 spot (*Leiostomus xanthurus*) using a sonic telemetry approach. A total of 123 age-1 spot were surgically implanted with sonic transmitters in two North Carolina estuarine creeks in the spring of 2009 and 2010 and were tracked up to ~80 days using a stationary acoustic receiver array and manual tracking. The fates of telemetered age-1 spot were inferred using telemetry information from estimated locations and swimming speeds. Potential competitors of age-1 spot were collected using an otter trawl, while potential spot predators were collected using gill and trammel nets. The stomach contents of potential predators were collected when possible and analyzed. No natural mortalities were observed in 2009 but ten were assumed in 2010, based on 31 telemetered spot at risk for an average of 23 days in 2009 and 60 at risk for an average of 24 days in 2010. Catches of potential competitors or predators did not differ between the two years suggesting these factors were not responsible for the difference in *M*. Moreover, longnose gar, which dominated the predator catch, was found to feed almost exclusively on Atlantic menhaden (*Brevoortia tyrannus*) in both years. Our estimated 30-d *M* of 0.11 for the two years combined was higher than that predicted from Lorenzen's (1996) weight-based model. Our field-based estimate of *M* for age-1 spot in this estuarine system can assist in the

assessment and management of spot. In addition, the telemetry techniques used here provide guidelines for future telemetry work with juvenile fish in open dynamic habitat systems.

Telemetry-based Mortality Estimates of Juvenile Spot in two North Carolina Estuarine Creeks

by
Sarah Elizabeth Friedl

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Zoology

Raleigh, North Carolina

2011

APPROVED BY:

Dr. Jeffrey A. Buckel
Co-Chair of Advisory Committee

Dr. Joseph E. Hightower
Co-Chair of Advisory Committee

Dr. Frederick S. Scharf

Dr. Kenneth H. Pollock

BIOGRAPHY

Education

August 2004	Associate of Science, Washtenaw Community College, Ann Arbor, MI General Studies with High Honors
December 2007	Bachelor of Science, Eastern Michigan University, Ypsilanti, MI Biology/Conservation and Resource Use Minor
January 2011	Master of Science, North Carolina State University, Raleigh, NC Zoology/Statistics Minor

ACKNOWLEDGEMENTS

This thesis would not have been possible without the unconditional guidance, support and understanding from nothing short of a plethora of amazing people. First and foremost I would like to thank those in Michigan who donated their time, patience and knowledge and in doing so helped me successfully embark on my career as a fisheries scientist. Greg Kennedy, Jaquie Craig and Beth Stockdale showed me what it means to truly love your work. We were able to find something to laugh at every day (mostly ourselves) and I can't thank them enough for the continued support and camaraderie. Glenn Walker went above and beyond, helping me navigate the world of academia, temporarily inspiring me to love the field of cellular and molecular biology, and providing a great lunchtime listening ear.

Laura Eidietis was instrumental in kick-starting my career during my undergraduate years at Eastern Michigan University. Her endless kindness and patience in teaching me how to make posters, network at conferences and edit manuscripts are skills I will use for the rest of my time as a professional scientist. She never preached, but fully understood the value in learning and always took advantage when a teaching moment presented itself. Ulrich Reinhardt showed me the value of professional collaboration as well as provided guidance in constructing a repertoire of coursework that would send me off to graduate school well prepared. And although in Seattle, Mary Moser showed me how to think outside the box, both literally and figuratively and I thank her for opening my mind to a different way of looking at things.

My graduate committee has been the most important and influential component of my career at NC State, and I sincerely thank them for everything. Though from a distance, Fred

Scharf and Ken Pollock provided an incredible amount of knowledge, without which this thesis would not be of the caliber it is. I especially thank my co-advisors, Joe Hightower and Jeff Buckel. Both have been endlessly patient, understanding and supportive throughout the past two and a half years, and I feel very fortunate to have been under their advice. I am very proud to have earned both their professional and personal respect.

Past and present members of the Buckel and Scharf labs were at the same time essential friends and colleagues, and I thank them all: Kyle Adamski, Nate Bacheler, Melissa Brewer, Tim Ellis, Joe Facendola, Ben Kornegay, Jeff Merrill, Warren Mitchell, Jim Morley, Ray Mroch, Jen Weaver and Jon Vanderfleet. I would especially like to thank Tyler Averett, Paul Rudershausen and Cheston Peterson for never complaining or saying no, no matter how cold it was, how late it got, or how much I asked of them. Tyler and Cheston were invaluable to this project, as they collected data without compromise when I was unable to, and regardless of how busy he was Paul contributed a remarkable amount of time and energy that I can only hope to pay forward someday.

My friends and colleagues in Raleigh are like family, and I am without words for how grateful I am for their love and support. Dana and Doug Sackett, Lindsay and Bob Campbell, and Val Williams provided housing, food and love like I have never experienced, refusing to take anything in return. Through the best and worst of times they were an unconditional lifeline of kindness and friendship and I am forever grateful. I thank my fellow graduate students in DCL 258 for always providing friendship, laughter, food, and a desk for me during my many trips to Raleigh: Amanda Boury, Marybeth Brey, Zach Feiner, Bethany Galster and Steve Midway. Jim Rice and Derek Aday offered insight and compassion and never failed to make me feel welcome. I thank Shiloh Shulte and Michael Robinson for sharing their lab skills and experiences with me, and to Linda Rudd for being an incredible leader.

I thank Craig Harms and his residents and technicians, Eric Anderson, Chris Butler, Tres Clarke, Jb Minter and Betsy Stringer, for sharing their skills, knowledge, and surgical supplies, which added credibility to my research and ultimately this thesis. Craig Sullivan, Andy McGinty and Mike Hopper were kind enough to allow us to conduct research at PAFL in Aurora despite having their own work to carry out. I am especially thankful to Andy and Mike for their delicious lunches and kinds words of wisdom.

I am indebted to the wonderful Biology Department and CMAST faculty and administrative staff, especially Susan Marschalk, Meredith Henry, Harry Daniels, Dawn Newkirk, Kayde Brownlee and Dena Haughley in Raleigh, and Dave Eggleston, Marlu Bolton, Greg Bolton, Linda Dunn, Jill Miller and Ernie Yeager in Morehead City. I also thank my fellow past and present CMAST graduate students for their assistance and advice: Becky Bartel, Erika Milstein, Katie Pierson, Brandon Puckett and Ryan Rindone.

North Carolina Sea Grant provided the funding for this project, North Carolina Association of Environmental Professionals supplied additional project support, and the American Fisheries Society Student Subunit at NCSU for helped cover travel costs, all of which made this work possible.

I also thank Dewayne Fox and Lori Brown for their hospitality and generosity during meetings and otherwise. I thank Lisa McIntosh and Cindy Kleinsmith for their continued support and strength, and for teaching me how to take life one day at a time. Finally, my

network of friends and family in Michigan, North Carolina and elsewhere have provided a solid foundation for me and supported me throughout. I am the person I am because of them and I thank them for all their time, advice, inspiration, generosity and love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Natural mortality rate (*M*) is an important parameter in many stock assessment models and incorrect values can have significant effects on harvest recommendations (Clark 1999). *M* is often estimated using life history parameters such as weight (Lorenzen 1996) or maximum age (Hoenig 1983), typically as a fixed annual rate for adults, with mortality data for juvenile stages being fairly deficient (Heupel and Simpfendorfer 2002). It has been argued that these methods of determining *M* do not account for variability among ages or between years (Vetter 1988; Quinn and Deriso 1999; Hightower et al. 2001; Young and Isely 2004). As important as *M* is to stock assessments, it is difficult to estimate because natural deaths are generally not observable and are confounded by the effects of harvest (Quinn and Deriso 1999).

Spot (*Leiostomus xanthurus*), an estuarine dependent Sciaenid fish, are found along the Atlantic coast from the Gulf of Maine to the Bay of Campeche, Mexico, mostly occurring from the Chesapeake Bay to South Carolina (Phillips et al. 1989; ASMFC 2010). Adult spot spawn offshore in the Atlantic during late fall/early winter and their larvae move across the continental shelf into estuarine nursery habitats with peak abundance in December and January (Weinstein and Walters 1981; Flores-Coto and Warlen 1993; ASMFC 2010). Juvenile Sciaenids represent some of the most numerous fishes in estuarine environments, and spot represents one of the most ecologically and economically important species in North Carolina (Currin et al. 1984; Phillips et al. 1989; Flores-Coto and Warlen 1993).

Spot serve an ecologically important role by influencing benthic production and providing an important source of prey for pelagic predators (Phillips et al. 1989).

Economically, spot is consistently the number one recreational fishery in North Carolina by numbers of fish, and one of the top ten recreational fisheries by weight (www.ncfisheries.net). Though the fishery continues to be of value, the number of spot landed in the recreational fishery has recently declined; numbers caught in 2009 are 1/3 of those in 2007 and 1/2 of those in 2008. The commercial fishery is also significant, but landings have declined since 2001, except for a slight increase reported for 2009 (www.ncfisheries.net). Due to these trends, the most recent North Carolina stock status report lists spot as a species of concern.

Spot are managed through an interjurisdictional fishery management plan first adopted by the Atlantic States Marine Fisheries Commission (ASMFC) in 1987. No formal stock assessment has been conducted for spot due to a lack of biological and fisheries data. Spot are currently managed by individual states, and the ASMFC (2010) recently highlighted future research needs such as merging data from individual states, evaluating mortality by age, evaluation of size and age at maturity, and identifying stocks and coastal movements through tagging or genetic studies.

Various methods of marking or tagging animals have been employed in aquatic studies to estimate mortality. Non-telemetry tags include dyes and pigments, as well as conventional tags (e.g., bar or internal anchor tags). Telemetry studies have generally utilized passive integrated transponder (PIT) tags and radio transmitters (Winter 1996; Lucas and Baras 2000), though these methods can be hindering due to limited signal range and attenuation in saltwater (Winter 1996; Thorsteinsson 2002). Sonic transmitters work well in saltwater and have been increasingly applied in both fresh and saltwater environments (e.g., Hightower et al. 2001; Heupel et al. 2006; Bacheler et al. 2009). Data from transmitters have the advantage of not being reliant on reporting by fishers and can provide detailed spatial and temporal information about mortality (Hightower et al. 2001; Simpfendorfer et al. 2002)

A general rule regarding internal telemetry tags is that the tag weight should be no more than 2.0% of the weight of the fish in air or 1.25% of the weight of the fish in water (Winter 1996). This rule has been challenged because studies have shown that transmitters representing as high as 10 – 12% fish body weight can be surgically implanted without adverse effects on behavior, swimming performance and growth (Adams et al. 1998; Martinelli et al. 1998; Brown et al. 1999; Thorsteinsson 2002; Jepsen et al. 2005). Age-1 spot range in length from ~150 – 250 mm total length (TL) (Pacheco 1962) and ~45 – 175 g (Dawson 1965). If the 2.0% rule was strictly followed for this study, appropriate age-1 spot would be limited to a minimum of 220 mm TL (assuming a 2.9 g sonic tag) which would severely constrain the length range of the study fish as well as provide an unreliable estimate of M for age-1 spot. We therefore hypothesized that transmitters weighing between 3 – 7% fish weight would not adversely affect age-1 spot, allowing us to study the majority of the size range of age-1 spot.

The primary goal of this project was to determine the magnitude and sources of natural mortality of age-1 spot in estuarine habitats using state-of-the-art fish tracking technologies and mark-resight models. We also assessed possible covariates of age-1 spot natural mortality such as competitor and predator composition and abundance, and tested several assumptions surrounding aquatic telemetry work with small fish including elimination of transmitters consumed by predators, stationary receiver error and tag retention, and survival of small fish implanted with relatively large tags.

METHODS

Study site

The telemetry study occurred in Clubfoot and Hancock creeks, two southern tributaries of the Neuse River in eastern North Carolina (Fig. 1). Each creek is approximately 7 km long, 300 – 500 m wide and on average 1 – 3 m in depth. These tributaries were chosen because they are known nursery areas for spot (NCDMF 2008 unpublished data), and can be passively monitored with a fixed receiver array. Clubfoot and Hancock creeks are minimally influenced by tides, and changes in depth are mainly wind-driven. Both commercial and recreational fishing are permitted in Clubfoot Creek, though Hancock Creek is limited to recreational fishing only.

Transmitter implantation

Transmitters were implanted in a total of 123 age-1 spot which were captured and released in Clubfoot and Hancock creeks. Spot were captured in April and May 2009 using an otter trawl (5.0 m headrope, 20 mm mesh, 3.2 mm tail bag) and a multipanel experimental gill net (6 panels: 25.4, 50.8, 76.2, 101.6, 127.0 and 152.4 mm stretch, 7.0 m long and 2.5 m deep each), and using a multipanel gill net (3 panels: 50.8, 63.5 and 76.2 mm stretch, 15.2 m long and 2.5 m deep each) alone in April 2010.

After capture, fish were placed in a 117 L tank on-board the ~7 m research vessel. For the surgery, an individual fish was anesthetized in a 19 L tank with 100 ppm tricaine methanosulfate (MS-222). When the spot could no longer maintain equilibrium it was weighed (g) and measured for both fork and total length (mm) and placed ventral side up in a foam cushioned surgical platform fitted onto a 38 L cooler containing a re-circulating water pump. To maintain the anesthetized condition, water containing 50 ppm MS-222 was pumped continuously over the gills until the surgical procedure was complete. An incision approximately 10 mm in length was made into the peritoneal cavity and a VEMCO V9-6L ultrasonic transmitter (VEMCO Ltd., Nova Scotia, Canada; 9x21 mm, 2.9 g in air, 69 khz frequency, 60-90 s ping rate, 80 and 105 d active life) was inserted. The incision was closed with 3 to 5 simple interrupted sutures using 4.0 PDO absorbable suture material. This suture pattern was found to be superior to simple continuous sutures (see **Testing assumptions** below). The spot was then returned to a 19 L recovery tank until normal swimming behavior was observed (~2 – 5 minutes) and released. Each transmitter was verified to be functioning properly before the implanted fish was released into the creek in which it was captured.

Telemetry relocations

Telemetered spot were manually relocated at least every seven days to determine their location using a VEMCO VR100 manual receiver and omnidirectional hydrophone; searches for telemetered fish were more frequent immediately following implantation. Manual searches continued for 80 days after the final implantation in 2009 and 105 days in 2010; the length of time differed due to differing tag battery lives between years (2009 tag life = 80 d;

2010 tag life = 105 d). Listening with a manual receiver and hydrophone occurred at 33 fixed stations in each study creek which were no more than 500 m apart; water temperature, salinity, and dissolved oxygen (DO) were recorded at each station. If a telemetered spot was detected with the manual receiver at a fixed station, we continued to search for it until it was detected with a signal strength that indicated we were as close as possible to the telemetered fish. Latitude and longitude coordinates were recorded each time a telemetered fish was detected.

In order to detect spot emigration and movement, an array of submersible receivers was stationed throughout each study tributary (2009: Clubfoot n=11, Hancock n=12; 2010: Clubfoot n=13, Hancock n=15). Within our study creeks VEMCO stationary receivers (VR2 and VR2W, which will be referred to as VR2/W hereafter) detected V9-6L tags at 300 m nearly 100% of the time, and therefore were stationed in fixed positions 600 m apart from one another and within 300 m of shore (Fig. 1). In this way, we ensured that 100% of emigrating fish were observed.

Four possible fates were assigned based on the behavior of telemetered spot after release, following a logic flowchart (Fig. 2): surgery related mortality (SxM), emigration (EM), battery life end (BL) or natural mortality (NM). We limited our analysis to fish confirmed to be present and alive at least seven days after transmitter implantation to reduce the risk of misinterpreting surgery related mortalities. Therefore, if a telemetered spot permanently stopped moving within seven days of implantation it was considered to be a SxM and was consequently censored from analysis. If a fish was alive and present for at least seven days following implantation but was detected leaving the study site, it was considered an EM and was censored from any further analysis beginning the day following the emigration event. If a fish was alive and present for the entire possible battery life of the transmitter and was no longer detected after that time, it was considered at risk for all analyses to the point when the transmitter no longer functioned (BL); at that point, it was censored from the analysis.

A telemetered spot was assigned the fate of NM from three sets of criteria. The first was if the fish permanently stopped moving after at least seven days following implantation. This could occur due to a variety of factors, but the most likely explanation is predation (Lorenzen 1996). A stationary transmitter within the study area would suggest that a predator had consumed and subsequently eliminated the transmitter while still in the study creek. It was assumed that the mortality event occurred the day prior to becoming stationary. The second was if estimated latitudinal changes and/or swimming speeds were observed that were not within the "normal" ranges of age-1 spot, and was based on the assumption that we were able to differentiate moving age-1 spot from moving predators. The third was if the transmitter was not observed emigrating from the creek, but after at least seven days following implantation was no longer detected (having been relocated at least once manually or by the VR2/W array prior to the disappearance). We assumed this third circumstance to be a result of bird predation or a natural mortality where the transmitter cannot be detected (e.g., because the fish washed up onto the shore or sank into mud). Another possibility is that the fish was harvested (fishing mortality [F]).

To assign fates a series of analyses were performed. First, we summarized daily detections of all receivers for each fish in order to identify broad daily patterns of movement or a lack thereof. This summary allowed us to quickly identify dates of emigration events and censor fish that were not present for at least the first seven days after tagging.

The second step was to estimate average hourly latitudinal positions for each fish considered at risk, which were estimated solely from VR2/W detections using the method described in Simpfendorfer et al. (2002). This method uses detection data from multiple stationary receivers and generates estimates of fish position from the weighted mean receiver latitudes and longitudes where weights are the number of detections for a unique fish at each receiver during a 60-minute time period. This step provided a finer scale of movement of telemetered age-1 spot. Maximum variance in latitude for 24-hour periods was calculated for each telemetered fish and compared with all other telemetered fish to determine if outliers existed, which would warrant further examination as potential predation events. These were examined within each year since changes in VR2/W locations between years can influence our estimates of latitudinal location. Latitudinal position was adequate (i.e., we did not need longitude) for our study because the two study creeks are oriented north to south.

The third step was to estimate average hourly swimming speeds for each fish considered at risk, using the same method as above, and these were compared with average hourly latitudinal positions. Maximum swimming speeds were calculated for each telemetered fish as distance travelled in meters between two hourly weighted mean locations divided by 3600 seconds and compared with previously estimated cruising and burst swimming speeds for age-1 spot (Wyllie et al. 1976; Neumann et al. 1981; Moser 1987). Fish exhibiting an estimated swimming speed of ≥0.7 m/s were automatically considered to be predation events as this speed cannot be maintained for an hour by this size fish. These telemetered fish were categorized as NM due to predation the day the abnormally high swimming speed occurred. Additionally, we compared average observed emigration swimming speeds of assumed telemetered age-1 spot to swimming speeds of known predators such as red drum (*Sciaenops ocellatus*) and bottlenose dolphin (*Tursiops truncatus*).

For ~ 25 days in late April/early May 2010, three receivers in Clubfoot Creek did not function correctly for unknown reasons. Because these receivers did not record transmitter detections for that time, the position and swimming speeds estimated during this time period may not be as precise as with the full array.

Estimating mortality

Survival of spot was estimated using multiple relocations of internally tagged age-1 spot using manual and stationary receivers. The staggered entry Kaplan-Meier approach (Pollock et al. 1989) was used to estimate daily survival from detections of telemetered age-1 spot. This design took into account that new fish could be considered at risk and entered into the analysis on a daily basis. Survival over the study period (*S*) was estimated for 2009, 2010, and the two years combined, and converted to monthly *M*s [(-ln(*S*)/days at risk)*30]. Because of the small sample sizes and similar number of natural mortalities observed within each creek, estimates were based on pooled results from both creeks. Within each year, the study period was limited to periods when at least seven fish were at risk.

Our observed estimate of natural mortality for spot from the combined year analysis was compared to predicted estimates of *M* from a published weight-based model. Lorenzen

(1996) described natural mortality as a power function of weight using the equation $M_w=M_uW^b$, where M_w is the natural mortality rate at weight W, M_u is natural mortality at unit weight, and b is the allometric scaling factor. In addition to this comparison, our observed estimates of natural mortality and mean spot weight in our study were used to calculate a new M_u parameter value, where M_w is the observed M from this study and W is the average weight (g) of telemetered spot from both years.

Assumptions of the mark-resight data:

(1) *All marked fish present in the study area at time i (whether alive or dead) have the same probability (p_i) of being relocated.*

The tributaries were small enough to be searched thoroughly so that live and dead fish should have been found with equally high probability. On occasions when a fish was not detected during a manual relocation search, the fish was accounted for and the detection probability was treated as if it were equal to one if it was not detected emigrating the creek by the VR2/W array at the creek mouth, and was detected during the immediately prior and following manual searches or by the VR2/W array within the creek.

(2) *All marked fish alive in the study area at time i have the same survival rate to the next time i +1.*

Because we tagged fish over a relatively narrow size range, we assumed all telemetered fish had similar survival rates.

(3) *The probability of transmitter failure or of a transmitter being shed is negligible.*

Hightower et al. (2001), Heupel and Simpfendorfer (2002) and Bacheler (2008) all used VEMCO transmitters and none found evidence of transmitter failure. Of 123 transmitters we had two apparent failures, and we were able to assume failure because the transmitters were not detected either manually or by the VR2/W array immediate after release.

(4) *Marked and unmarked fish have the same survival rates.*

There were no surgery related deaths in age-1 spot implanted with similar transmitters in laboratory holding studies (see **Results** below, for ~65 g spot with sonic tag of 2.9 g in air); additionally, acute deaths (deaths within seven days of surgery) were censored as potential surgery mortalities.

(5) *Movement patterns can be used to determine whether a tagged fish remains alive or has died due to natural mortality.*

Jepsen et al. (1998), Hightower et al. (2001), Heupel and Simpfendorfer (2002), Waters et al. (2005) and Bacheler et al. (2009) used movement patterns from telemetered fish to infer the fate of individual fish.

(6) *Natural mortality occurs immediately prior to the previous relocation.*

By maintaining high relocation rates and having a stationary VR2/W array continuously monitoring the study creeks, the timing of natural mortalities was assumed to occur on the day prior to when the transmitter stopped moving.

(7) *Emigrating fish can be detected and censored from the analysis.*

Emigrating fish were detected leaving the creeks by the VR2/W array and censored from the analysis.

(8) *Telemetered spot can be distinguished from predators based on calculated swimming speeds and movement patterns.*

Swimming speed ranges and geospatial position patterns were estimated for telemetered age-1 spot. Outliers were examined and swimming speeds were compared to known predator swimming speeds to assign NM fates. Similarly, Heupel and Simpfendorfer (2002) and Bacheler (2008) inferred predation based on uncharacteristic behavior and estimated swimming speeds.

Competitor sampling

Spot and potential competitor catch data were collected in each study tributary using an otter trawl (5.0 m headrope, 20.0 mm mesh, 3.2 mm tail bag) that was towed for 4.5 minutes at a speed of approximately 4.5 k/h. Samples were sorted by species and individuals measured (fork length (FL), total length (TL), standard length (SL), carapace width (CW), disc width (DW)); species with more than 30 individuals of the same size range were subsampled. Species were considered to be potential spot competitors based on abundance, size and benthic habits. Age classes (i.e., age-0 and age-1) of spot and other potential competitors were distinguished with frequency distributions (Appendix Fig. 1) and separated for catch rate comparisons between years. Catch was averaged over the ten hauls for each sampling day and log transformed. Competitor abundance was compared between years using a two-tailed t-test using all sample days from each year. Water temperature, salinity, and DO were measured at the beginning and end points of each trawl and latitude and longitude coordinates were recorded.

Sampling was conducted on study days 4/9, 30 and 62 in 2009 (26 April/1 May, 22 May and 23 June), and study days 11, 35, 57 and 82 in 2010 (11 April, 5 May, 27 May and

21 June; except for days 4 and 9 in 2009, both creeks were sampled on the same day: day 4 represents sample 1 in Hancock Creek and day 9 represents sample 1 in Clubfoot Creek). We used systematic random sampling techniques as described in Williams et al. (2002). Each study creek was divided lengthwise by a midline transect with perpendicular widthwise transects dividing each creek into five strata of equal length. On a given sampling day, the initial start distance along the midline transect was randomly selected from a pool of three potential distances, and that distance was then used as the start point in each of the following strata. Whether the sample occurred east of, west of, or directly on the midline transect was randomly selected for each individual stratum. This procedure was applied to each study creek for each competitor sampling event.

Predator sampling

Potential predators of age-1 spot were sampled in each study creek using trammel (200 m long, 63.5 mm stretch and 60 meshes deep, and 330 mm stretch and 8 meshes deep) and gill nets (200 m long, 101.5 mm stretch and 20 meshes deep). Predator sampling was conducted on study days 3/6, 12/14, 21/22, 35 and 48/49 in 2009 (25/28 April, 4/6 May, 13/14 May, 27 May, and 9/10 June), and study days 13, 30, 44, 62, and 76 in 2010 (13 April, 30 April, 14 May, 1 June and 15 June). Systematic random sampling (see **Competitor sampling** above) was used to determine specific sample sites throughout the study creeks, and relative abundances of individual predator species and total predators were calculated. The statistical analysis of gill net catch was limited to sample days when telemetered fish were at risk for each year; therefore, a two-tailed t-test was used to compare predator CPUE from all five sample days in 2009 to the first four sample days in 2010. Catches of predators from trammel nets were not included in this comparison because trammel netting was not random with respect to strata.

Predators were measured (FL and/or TL) and when possible, stomach contents were retrieved using gastric lavage techniques (Hartleb and Moring 1995) which allowed predators to be released alive. Stomach contents from predators caught in both types of gear were used for diet analysis; contents were stored on ice and frozen prior to analysis. Prey were identified based on external morphological features and, when recovered in advanced stages of digestion, diagnostic bones (e.g., otoliths, dentary, operculum). All collected stomach contents were analyzed, though only piscivores ≥375 mm were considered potential spot predators as this size predator is theoretically large enough to consume age-1 spot ~140 – 220 mm FL based on a ~40% prey-to-predator length ratio (Scharf et al. 2000). Water temperature, salinity, DO and spatial coordinates were recorded at each sampling site.

Prey items were measured for TL or CW when direct measurements could be made. Fish and invertebrate prey items were identified using external morphology and published references (Williams 1984; Hoese and Moore 1998; FAO 2002). Excess moisture was removed from prey items by blotting with a paper towel and wet weight (g) was measured. Each predator species diet was characterized by percent weight (%W; w_i/w where w_i = wet weight of prey type *i*, w = total weight of all prey types) and percent frequency of occurrence (%O; n_i/n where n_i = number of stomachs in which a prey occurred, n = number of stomachs in which food was present; Hyslop 1980) by year.

Testing assumptions

Age-1 spot surgical implantation

A laboratory study was performed to test the hypothesis that spot of ~160 mm FL can survive being implanted with a telemetry tag and retain the tag for a relatively long period. In November 2008, sixteen age-1 spot were collected from Bogue Sound, NC using a 60 m beach seine. Eight spot (FL: mean = 156.88 ± 2.84 mm SE; weight: mean = 61.31 ± 3.49 g SE) were randomly selected and implanted with VEMCO V9-6L dummy transmitters (equal size and weight to active V9-6L transmitters) while the remaining eight served as the control group (FL: mean = 163.75 ± 4.75 mm SE; weight: mean = 68.98 ± 5.88 g SE). Age-1 spot implanted in the lab underwent the same surgical procedure as spot implanted in the field (see **Transmitter implantation** above).

Spot were randomly assigned to two experimental tanks and two control tanks for a total of four fish per tank. Though fish were randomly selected, the size of spot implanted with tags was significantly less than the control fish (FL: t=5.17, df=2, p=0.04; weight: t=6.91, df=2, p=0.02). However, this provided a more robust test of small fish survival after tag implantation. Spot incisions were closed using a simple continuous suture pattern. Although most published aquatic telemetry papers describe the use of simple interrupted sutures when implanting tags (e.g. Summerfelt and Smith 1990; Wagner et al. 2000; Bacheler 2008), we used a simple continuous suture because of the speed with which it could be done as well as to minimize drag and trauma (Summerfelt and Smith 1990; Mulcahy 2003; Harms 2005). The ratio of tag to fish weight ranged from 3.1 – 7.4%.

Spot were housed at the University of North Carolina Institute of Marine Sciences' Fisheries Research Laboratory, Morehead City, North Carolina. The four tanks each had a volume of 700 L and were flow-through with seawater from Bogue Sound, allowing for ambient temperature, salinity and DO. Because the guaranteed active V9-6L transmitter life we used in the field in 2009 was 80 days, fish were held for this same period to account for any possible adverse effects from the surgical procedure as well as from the transmitter itself. Fish were fed a ration of 2.0% total body weight twice per day, for a total daily ration of 4.0% total body weight; this ration is above their maximum daily ration at these sizes and temperatures (Baldevarona 1987). Tanks were checked during the two daily feedings for mortality and transmitter loss, and temperature, salinity and DO measurements were recorded at each feeding. Fish length and weight measurements were taken on day 0, 23, 44, 64 and 81. The sizes of control and tagged fish were examined over time using repeated measures ANOVA.

Although growth and survival of tagged fish did not differ from control fish, there was less than 100% tag retention using the simple continuous suture pattern (see **Results** below). Therefore, a second laboratory experiment was performed using simple interrupted sutures. Since growth and survival were not compromised by the tag, we did not have a control treatment for this second lab experiment. In February 2009, we surgically implanted V9-6L dummy transmitters into eight age-1 spot which were randomly assigned to two tanks for a total of four fish per tank (Tank 1: FL: mean = 171.25 ± 5.23 mm SE; weight: mean = 79.79 ± 6.71 g SE; Tank 2: FL: mean = 163.00 ± 6.92 mm SE; weight: mean = 63.23 ± 10.81 g SE). All surgical procedures were identical to the previous experiment, except that incisions were closed with 3 to 5 sutures using a simple interrupted pattern. Study length, observation and feeding methods were identical to the previous experiment except that fish length and weight measurements were taken on day 0, 21, 37, 58 and 80. Tag retention was compared between experiment 1 and 2.

Piscivore consumed transmitters

One of the assumptions of the field telemetry approach is that predators will eliminate the tags within the study area in a relatively short period of time. To test this hypothesis, we fed 11 age-1 spot (FL: mean = 174.91 ± 3.00 mm SE) implanted with V9-6L dummy transmitters to 11 striped bass (FL: mean = 654.45 ± 8.92 mm SE; weight: mean = 3.92 ± 0.20 kg SE) at the North Carolina State University Pamlico Aquaculture Field Laboratory in Aurora, NC in June 2009. After all spot were visibly confirmed to have been eaten, striped bass were moved to individual holding tanks which were checked daily for transmitter elimination (regurgitation or defecation). The time to elimination was determined for each striped bass.

Accuracy of stationary receivers

Two test tags were deployed in Hancock Creek in May 2010 to estimate transmitter location and swimming speed calculation error, which were based on VR2/W detections. The first (ID: 53197) was stationed at a fixed location for 26 days to determine if a stationary transmitter would be detected as having movement by the VR2/W receiver array, which could be erroneously created by noise or weather events (causing the transmitter to go in or out of range of individual VR2/Ws). The second (ID: 53174) was placed in four different sites throughout Hancock Creek for 2 minutes each to test the accuracy of VR2/W detection times. Latitude, longitude, start and stop time were recorded at each site and compared with stationary receiver detections. Estimated locations and speeds were determined using the same method as for telemetered spot (see **Telemetry relocations** above). The true location and timing of test tag deployments were not revealed to the personnel that conducted the manual tracking and estimated the locations/times from VR2/W data until after estimates for these variables were made.

RESULTS

Testing assumptions

Dummy transmitter implantation

In the first experiment we observed no age-1 spot mortalities due to transmitter implantation during the 80-day study period when incisions were closed with a simple continuous suture, nor were there any mortalities in control fish. However, a 75% tag retention rate was observed with this suture treatment, as one fish from each replicate expelled a tag through the incision site (at 22 d and 61 d; Fig. 3). These two fish were excluded from growth analyses. Growth was not significantly different between control and experimental groups as determined by a non-significant interaction term in the repeated measures ANOVA (FL*day: f=3.29, df=4, p=0.07; weight*day: f=2.90, df=4, p=0.09; Fig. 4A). In the simple interrupted suture experiment, both survival and tag retention were 100% and positive growth was observed for the 80-day study period (Fig. 3; Fig. 4B). Thus, the

V9-6L sonic tag does not have an adverse effect on growth or mortality in age-1 spot but requires a simple interrupted suture for 100% tag retention.

Predator elimination of consumed transmitters

A total of seven striped bass (FL: mean = 659.14 ± 12.60 mm SE; weight: mean = 4.05 ± 0.26 kg SE) consumed 11 age-1 spot implanted with dummy transmitters. Ten tags were eliminated from the piscivores and recovered from the bottom of the tanks. The eleventh tag was never eliminated and was recovered from the stomach upon necropsy on day 32. Excluding the tag that was not eliminated the average number of days it took a predator to eliminate the transmitter after ingestion was 11; however, tag elimination was observed as early as 6 days and as late as 20 days (Fig. 5).

Accuracy of stationary receivers

The fixed location test transmitter (ID: 56197) was manually relocated on three occasions and detected on all three receivers of which it was in range (receivers 6192, 4844 and 5924; Fig. 6 and 7). There were 466 VR2/W detections and estimates of location by latitude (Fig. 6) and latitude and longitude (Fig. 7) varied slightly through time due to variation in which receivers detected the transmitter each hour. This resulted in estimates of swimming speed slightly above the true value of zero (Fig. 8). The timing accuracy test transmitter (ID: 53174) that was deployed at four separate sites was detected at 3 of the 4 sites, indicating that there were VR2/W "dead zones" within the study creeks. Of the three sites where transmitter 53174 was detected, the hourly average latitudes, longitudes and times estimated from the VR2/W array matched those recorded in the field (Table 1), indicating that our method for estimating average hourly locations and speeds was accurate.

Telemetry

Ultrasonic transmitters were surgically implanted in 48 age-1 spot (FL: mean = 163 ± 1.45 mm SE; weight: mean = 71 ± 2.27 g SE) in 2009 and 75 age-1 spot (FL: mean = 167 ± 2.09 mm SE; weight: mean = 79 ± 3.22 g SE) in 2010 (see Appendix Table 1 for individual fish data). The condition (weight adjusted for differences in length) of telemetered fish at tagging was not different between the two years (Fig. 9; ANCOVA: f=1.01, df=1, 120, p=0.32). In both years all telemetered spot were relocated by VR2/W receivers. There were a total of 754,842 detections from telemetered spot on 23 VR2/W receivers in 2009, and 1,223,730 detections on 28 VR2/W receivers in 2010. Of the 48 spot implanted in 2009, 26 were manually relocated within the study creeks, while 73 of 75 were manually relocated in 2010.

In 2009, 17 fish were censored from the study due to either an assumed surgery related mortality (n=3) or an emigration event <7 days after implantation (n=14). Of the 31 fish used in the analysis, two were alive and present until the battery life of the transmitter ended, and 29 emigrated from the study system, including one emigration through the head of Clubfoot Creek. There were no assumed natural mortalities in 2009 (Table 2; Fig. 10A). In 2010, 15 fish were censored from the study due to either an assumed surgery related mortality (n=7) or an emigration event <7 days after implantation (n=8). Of the 60 fish used in the analysis, there were 10 natural mortality events and 50 emigration events, including two emigrations through the head of Clubfoot Creek (Table 2; Fig 10B). Telemetered spot used in the analysis were at risk in the study creeks an average of 23.58 days in 2009 (range 7 – 82 days) and 24.08 days in 2010 (range 7 – 67 days).

Five fish in 2009 and eight fish in 2010 temporarily emigrated (≥24 hours) from the study creek in which they were tagged but returned for at least 36 hours, allowing us to observe behavior and swimming speeds for a long enough time period to assume they were still age-1 spot and had not been consumed by a predator while out of detection range. These fish were considered at risk for the time period they returned and were censored again upon emigration. In 2010, three fish emigrated from Hancock Creek into Clubfoot Creek for at least 36 hours, allowing the same observations and assumptions as outlined above for temporary emigrants.

For 79 at-risk fish that were monitored within the two study creeks, we were able to assume they were telemetered age-1 spot and not a predator because their swimming speeds and behavior patterns were either consistent throughout the time at risk or were within the range of swimming speeds and latitudinal changes considered "normal" for age-1 spot (Fig. 11A; Appendix Fig. 2, 3, 4 and 5). For 7 of the 10 surgery related mortalities (Table 3), we were able to assume this fate because the transmitter stopped moving within seven days of implantation and was either relocated in the same location by stationary and/or manual receivers, or the transmitter detections trailed off (suggesting that the transmitter sank into the mud until it could no longer be detected; Fig. 11B; Appendix Fig. 2, 3, 4 and 5).

Of the ten assumed natural mortalities (Table 3; Fig. 12), seven were based on a combination of changes in behavior followed by a lack of movement at least seven days after implantation (IDs: 27729, 27732, 27740, 27742, 27750, 27774 and 27786; Fig. 11C; Fig. 12A, C, E, F, G, H, I), two were observed emigrating from the creek and the fate assumptions were based solely on extreme changes in latitudinal locations and swimming speeds (IDs: 27741 and 27794; Fig. 11D; Fig. 12B, J), and one was no longer detected in the creek after being present, active, and relocated multiple times following transmitter implantation (ID: 27748; Fig. 12D). Assumed natural mortalities were distributed evenly across the size range of telemetered spot in 2010, whereas the majority of assumed surgery related mortalities occurred with telemetered spot <160mm FL (Fig. 13).

Maximum latitudinal variance estimates (in squared decimal degrees) ranged from $9.23 \times 10^{-6} - 1.14 \times 10^{-4}$ in 2009 and $3.81 \times 10^{-7} - 4.54 \times 10^{-4}$ in 2010 (Fig. 14). There were no outliers in 2009 but there were two outliers in 2010 (>0.0004 decimal degrees; IDs: 27737 and 27744). Despite the high variability in latitude, these were assumed to be telemetered age-1 spot based on a lack of abnormality of other fate-determining factors (e.g. extreme swimming speed).

Maximum swimming speed estimates ranged from 0.0 – 0.50 m/s in 2009, and 0.05 – 1.14 m/s in 2010 (Fig. 15). There were no outliers in maximum swimming speed in 2009 nor were there any fish with maximum swimming speeds >0.50 m/s. However, in 2010, there were five outliers (>0.60 m/s): three of which had maximum swimming speeds >0.70 m/s (IDs: 27741, 27750 and 27794) and were assumed to be NMs due to predation, and the other two (IDs: 27727 and 27759) were assumed to be telemetered age-1 spot based on a lack of abnormality of other fate-determining factors (e.g., extreme latitudinal variation).

Emigration swimming speed averages were estimated for telemetered age-1 spot for the final 48 hours of detections as well as for the final hour alone, and ranged from 0.005 – 0.23 m/s and 0.001 – 0.23 m/s respectively (Fig. 16). The estimates for age-1 spot overlapped averages for red drum (range: 0.01 – 0.74 m/s) but the distributions were significantly different (median test: χ^2=121.13, *df*=1, *p*<0.0001). Age-1 spot estimates were also found to be significantly different (median test: χ^2=31.73, *df*=1, *p*<0.0001) from estimated average speeds of bottlenose dolphin (range: 1.1 – 2.2 m/s), and there was no overlap observed between these two groups.

Mortality

No NM events were detected in 2009. In 2010, ten assumed NM events occurred when the fish had been at risk from 9 – 59 days (Table 4). Five of the NM events occurred in Hancock Creek and five in Clubfoot Creek. All analyses were limited to time periods when there were at least seven fish at risk. For 2009, this limited the estimate from the Kaplan-Meier analysis to 23 April – 9 June, days 1 – 48 of the study. For 2010, the analysis was limited to 6 April – 23 May, days 6 – 53 of the study. For the combined years, the analysis was limited to study days 1 – 57, which represents 23 April – 18 June 2009 and 1 April – 27 May 2010. Our estimates of *M* for 30 days were 0.0 for 2009 (0 NM over 48 days; Fig. 17A), 0.17 for 2010 (10 NM over 48 days; Fig. 17B), and 0.11 for 2009 and 2010 combined (10 NM over 57 days; Fig. 18). Additionally, estimates of *M* were obtained using 9 NM (2010 *M*=0.14; combined 2009 – 2010 *M*=0.08), which assumed that the fish that disappeared from the study site (ID: 27748; Fig. 12D) was a fishing mortality and not a natural mortality.

The combined year estimate of monthly *M* (with 10 NMs) was higher than values of *M* predicted from Lorenzen's (1996) "natural system" model while the combined year monthly *M* for 9 NMs was similar to Lorenzen's predictions (Fig. 19). An M_u (mortality at unit weight, year^{-1}) of 4.62 year^{-1} would be required in order for Lorenzen's curve to predict a monthly *M* of 0.11 for a weight of 76 g, the average for age-1 spot in this study (Fig. 19).

Competitors

From the catches of 30 trawls in 2009 and 40 trawls in 2010, three species (in addition to spot) were considered potential competitors of age-1 spot. These were Atlantic croaker (*Micropogonias undulatus*), pinfish (*Lagodon rhomboides*) and *Paralichthys* spp. Neither age-0 spot nor age-0 non-spot competitor catch was significantly different between 2009 and 2010 (Fig. 20; age-0 spot: t=0.27, df=5, p=0.79; age-0 competitors: t=0.68, df=5, p=0.53). There was also no significant difference for either age-1 spot or age-1 non-spot competitor catch between 2009 and 2010 (Fig. 21; age-1 spot: t=0.79, df=5, p=0.46; age-1 competitors: t=0.66, df=5, p=0.54). Thus, it does not appear that differences in mortality between years resulted from differences in inter- or intraspecific competitor abundance.

Due to a temporary equipment malfunction in 2010, DO was only able to be collected for trawls 2, 3 and 4, though these sampling dates are comparable to those in 2009 and measurements were still able to be evaluated. Temperature, salinity and DO were similar between the two years (Fig. 22), indicating that differences in mortality were not due to differences in abiotic factors within the study creeks.

Predators

In 2009, a total of 55 gill nets and 12 trammel nets were deployed, collecting a total of 184 and 48 predators respectively. In 2010 a total of 55 gill nets and 30 trammel nets were set, catching a total of 120 and 125 predators respectively. The composition of predator species caught in gill and trammel nets was similar in 2009 and 2010 (Table 5), with predator catches dominated by longnose gar (*Lepisosteus osseus*). Gill net catch of all species combined for sample days when telemetered fish were at risk was not significantly different between 2009 and 2010 (t=0.32, df=7, p=0.76; Fig. 23). Therefore, it does not appear that differences in mortality between years resulted from differences in predator abundance.

Stomach contents from a total of 188 piscivores ≥375 mm in 2009 and 188 piscivores ≥375 mm in 2010 were analyzed. Age-1 spot were never found in the diet of any predators. In both years, diets of longnose gar (the most abundant predator) were dominated by *Clupeidae*. Other diet items in longnose gar and other predators included *Sciaenidae*, *Mugilidae* and *Ophichthidae* in 2009, and *Sciaenidae*, *Mugilidae* and *Syngnathidae* in 2010 (Table 6). The size of finfish prey items ranged from 17 – 185 mm TL, which included a portion of the range of telemetered age-1 spot (150 – 243 mm TL; Fig. 24); thus, although no age-1 spot were found, predators were able to consume fish prey of that size.

DISCUSSION

Estimation of spot mortality

We provide the first field-based estimate of natural mortality (30-d M=0.11) for age-1 spot, a relatively small estuarine fish, using a telemetry tag approach developed in a closed reservoir system (Hightower et al. 2001). Direct estimates of natural mortality rates in open dynamic systems are difficult to obtain (Vetter 1988; Quinn and Deriso 1999). Estimates of M for age-0 spot have previously been reported (Weinstein and Walters 1981; Currin et al. 1984; Weinstein et al. 1984; Ross 2003) but those estimates were based on assumed periods of residency and are potentially confounded with emigration. Here, emigrations and fate assignments were identified through the use of an acoustic receiver array and manual tracking.

Hightower et al. (2001) and Bacheler et al. (2009) used this telemetry approach on larger fish that had a relatively low risk of predation. The natural mortality rate estimates from these two studies were lower than predicted from a model based on predation risk as a function of size (Lorenzen 1996). Contrary to this, our estimate of M for age-1 spot was higher than the Lorenzen-predicted estimate. Because of this, and because the Lorenzen's curve is based on prior estimates of M, his model may be more appropriately used as a guideline to define the shape of the mortality-at-weight curve than the values themselves. Interestingly, after adjustment of this curve to match our estimates of M and spot size, the estimated M_u parameter (4.62) was higher than estimates of M_u observed in rivers (2.53), lakes (3.37), and oceans (3.69) but similar to the upper 90% confidence interval value of M_u for oceans (Lorenzen 1996).

Similar to our study, Heupel and Simpfendorfer (2002) and Bacheler et al. (2009) also estimated mortality using acoustic receivers and by documenting emigration and determining fates. Bacheler et al. (2009) placed fixed receivers at the mouths of creeks, which served as gates to detect emigration events and emigration speeds of telemetered red drum, while Simpfendorfer et al. (2002) estimated residency and movement behaviors of juvenile blacktip sharks using an array of stationary receivers across an X- and Y- coordinate system throughout an estuary. Our stationary receiver array was designed to allow coverage of as much of the study creeks as possible given a limited number of receivers. Despite the lack of complete coverage, we were able to estimate latitudinal locations and swimming speeds of spot given the orientation of the two study creeks.

We assumed that most telemetered age-1 spot would be tracked for the battery life of the tag. However, the average residency time (~23 days) of telemetered age-1 spot was considerably less than anticipated, indicating that their mobility was greater than we initially thought. Had telemetered spot remained in the study creeks for the expected time range, fish would have been at risk for longer periods of time, resulting in increased precision as noted in previous telemetry studies (Pollock et al. 1989). We analyzed two criteria for minimum fish at risk to examine possible differences in the precision of our estimate. Pollock et al. (1989) recommended a minimum of 40 – 50 animals at risk for good precision with the staggered-entry Kaplan-Meier estimator, but because of the high cost of acoustic transmitters and high emigration rate, this was not feasible for our study. Analyses for the 2009 and 2010 combined estimate were performed for both ≥7 and ≥10 fish at risk and a visual assessment of 95% confidence intervals for mortality estimates did not indicate a large difference in precision. Therefore, we concluded that a minimum number of seven fish at risk was appropriate.

Testing assumptions of the assignment of fates

There are several assumptions associated with the telemetry approach for estimating mortality, some of which were more easily violated in our study given the relatively small size of spot. Assumptions of the model were listed above (see **Methods**) and those regarding surgery related mortality, tag expulsion by telemetered age-1 spot, transmitter failure, identifying predator consumed transmitters and predator consumed tag elimination are discussed below.

The size range of spot that we could implant was constrained by the size range of tags available. Attempts were made to use a smaller tag (V7) but it had a very poor detection range within our study system. The "2% rule" (Winter 1996) has been challenged as one that does not apply to all fish species (Adams et al. 1998; Martinelli et al. 1998; Brown et al. 1999; Thorsteinsson 2002; Jepsen et al. 2005) and researchers have been encouraged to test the effects of transmitters in the lab on the species of interest before performing field studies (Bridger and Booth 2003). The transmitters we implanted in the field represented 1.7 – 6.3% of the weight of fish tagged, which is within the range of 3.1 – 7.4% of the weight of spot implanted in the lab study in which no adverse effects of either the surgery or transmitter were observed.

In contrast to our lab results, spot at the smaller end of the size range had increased surgery related mortality in the field. The possibility for surgical complications is greater when fish are tagged on site (Wagner and Cooke 2005; Moser et al. 2007) and lab results must be considered a “best case” scenario. For example, blue crabs (*Callinectes sapidus*) were abundant in both Clubfoot and Hancock creeks during our study period, and it is possible that attacks on recently tagged spot occurred, which could have resulted in severe injury or death.

The probationary period to account for surgery related mortality is generally subjective, is intended to be extremely conservative, and depends on the study system and species being tagged (Thorsteinsson 2002). Because telemetered fish emigrated so quickly from the study creeks our probationary period was not as conservative as we would have liked. We assumed that the 7-day probationary period we implemented would not bias our results based on the 100% survival rate observed in our lab study. However, because three of the assumed natural mortalities in 2010 stopped moving between 9 and 10 days after surgery, we also estimated mortality using an increased probationary period of 10 days, though this reduced the overall number of fish considered at risk because it excluded fish that emigrated between 7 and 10 days. Because of this, there was only a negligible change in mortality estimates between the 7 and 10 day probationary period analyses, and we therefore retained our original probationary period of 7 days.

In addition to surgery mortality, another possible way an erroneous NM assignment would occur was if a transmitter was expelled through the surgery incision or elsewhere through the skin (Marty and Summerfelt 1986; Baras and Westerloppe 1999). There is no consensus on which method of incision closure should be used following transmitter implantation, often due to non-reporting in the literature as well as to morphological differences between study species (Summerfelt and Smith 1990; Thorsteinsson 2002; Harms 2005; Cooke et al. 2010; Thiem et al. 2010). We were confident in assuming no tag expulsion given our laboratory findings using simple interrupted sutures.

We assumed transmitter failure would be negligible in our study. In 2010, two tags out of a total of 75 failed immediately upon release. Because these two were censored, they did not affect our mortality estimates. There was only one other tag (ID: 27748) that abruptly stopped transmitting a signal which could have been a transmitter failure, bird predation, (i.e., NM) or fishing mortality. Spot recruit to the fishery by age-1 (ASMFC 1987; Piner and Jones 2004) so it is possible that this fish was harvested. Predation by osprey was also possible, as osprey are an abundant fish predator in North Carolina, and age-1 spot fall within osprey prey size ranges (Carss and Godfrey 1996). To determine if incorrectly classifying this transmitter fate would bias our study results we considered two different estimates of 30-d M (NM n=9, F n=1; NM n=10, F n=0). The two estimates of 30-d M were 0.08 and 0.11 indicating that our Kaplan-Meier analysis was moderately sensitive to individual deaths and emphasizes the great care that needs to be taken when determining fates of telemetered fish.

We assumed that our fate assignments of telemetered age-1 spot were correct. Estimating presumed spot locations and swimming speeds was a critical component to assigning fates. Acoustic receivers recorded the correct time and general vicinity of the two test tags deployed in 2010, and estimated average hourly speeds had minimal error (swimming speed error = $\leq$0.1 m/s). However, one of the initial assumptions of our study was that emigrations by live telemetered fish would be able to be distinguished from those that had been consumed by predators. Although swimming speeds of bottlenose dolphin were clearly different than presumed age-1 spot emigration speeds, there was some overlap between spot and age-2 red drum (Bacheler 2008). Consequently, this may have influenced our ability to distinguish some predators swimming out of creek with telemetered age-1 spot in their stomach from true age-1 spot.

Another potential confounding factor for proper fate assignment was transmitter elimination (regurgitation or defecation) by a predator. To our knowledge, this is the first study to estimate time to elimination for an ingested transmitter in a piscivorous fish, and the relatively long time period from consumption to tag elimination found here has implications for future telemetry studies. It has generally been assumed that mortality can be inferred from a transmitter exhibiting non-movement (Hightower et al. 2001; Heupel and Simpfendorfer 2002; Waters et al 2005; Thompson et al 2007; Bacheler et al. 2009). Our results showed that the time before a transmitter becomes stationary due to predation may be considerable, and especially with telemetry studies of smaller fish, that natural mortalities may have to be inferred using detailed movement information. For example, we assigned two natural mortality fates (IDs: 27741 and 27794) to age-1 spot based on high within-creek swimming speeds.

Why did natural mortality differ between the two years?

Estimated mortality rates differed between the two years. There are several possibilities that may have led to this, though upon examination no factors stood out. Age-1 spot of similar size and condition were tagged in both study periods, indicating that fish from both years had an equally likely probability of surviving implantation. Only one surgeon

(S.E. Friedl) performed all surgeries and the same surgical procedure was followed in both years. The collection method was slightly different between the two years, as spot were collected in both an otter trawl and gill net in 2009 and a gill net only in 2010. However, it is not likely that this was the reason for the increased mortality in 2010, as fish were conservatively selected for implantation and only fish that had no signs of external injury and otherwise appeared in good health were used for the study. Temperature, salinity, and DO did not differ between the years, suggesting that these factors did not affect mortality rates.

Competitor catch was not different between the two years, and it is therefore unlikely that competitor abundance influenced natural mortality rates of telemetered age-1 spot. Density has been found to have an influence on age-0 spot mortality in experimental studies (Craig et al. 2007) and a difference between CPUEs for the two years would have warranted further investigation of the effects of this potential covariate. Additionally, the condition of telemetered fish in 2010 was not different from those in 2009, providing further support that competition did not differ and thus affect mortality rates.

Longnose gar dominated the catch in both years, suggesting that this was the most abundant predator species in the two creeks. However, we never observed age-1 spot remains in a longnose gar stomach and Atlantic menhaden comprised the majority of prey found in the stomach contents. This result is consistent with previous studies that have found menhaden to be the preferred prey of longnose gar, though they have also been found to prey on other juvenile fishes including spot (Goodyear 1967). Given that longnose gar feed at night and early morning and have a rapid digestion rate (within ~12 hours; Netsch 1962; Goodyear 1967), and because our sampling began ~3 hours after feeding generally ends, this could have limited the variety of prey items in the stomach contents collected later in the sampling day. Even if longnose gar did consume age-1 spot, their catch did not differ between the two years, and combined with the diet data this suggests that longnose gar were not the cause of natural mortality in 2010.

Bottlenose dolphins (*Tursiops truncatus*) are a commonly occurring predator of spot in North Carolina estuaries (Gannon and Waples 2004), and were seen in both creeks during our study, though sightings were not able to be standardized and compared between the two years. Gastric evacuation rates for bottlenose dolphin (mean initial time to evacuation: 235 ± 49 min; Kastelein et al. 2003) are such that a possible predation event and subsequent elimination of the transmitter within the same creek visit were possible, which would lead to the telemetered fish being correctly scored as a natural mortality. There was no evidence that a bottlenose dolphin emigrated from the creek with a telemetered age-1 spot in its stomach based on the large difference in estimated emigration speeds between the two species.

Predator catch did not differ between the two years and no age-1 spot were found in stomach samples, though this does not necessarily signify that age-1 spot were not being preyed upon in Clubfoot and Hancock creeks or that the suite of potential predator species was limited to those collected. Sheaves (2001) argued that a lack of catch does not necessarily indicate low predation impact. He further argues that catches of roving species will generally either be very high or zero in these dynamic systems, and that even though average site abundance may be low there may still be a considerable impact to the prey species populations in the short periods they are present.

It has been well documented that using a single gear type to sample fish communities can negatively bias abundance and occurrence estimates of populations (Hamley 1975; Millar 1992; Jackson and Harvey 1997; Sheaves 2001; Argent and Kimmel 2005). To minimize this we used the trammel net as a secondary sampling gear and a strike-net technique (i.e., up against shoreline) was employed to collect fish for both gears. Bluefish, striped bass and spotted seatrout were caught in low numbers during our study, but are schooling species that may have occurred in more open water environments. Thus, we cannot rule out the possibility that we missed spot predators in our sampling and they could have possibly differed in abundance or feeding pressure on age-1 spot between the two years.

Conclusions

Recently, there has been a call for more marine telemetry studies (Cooke et al. 2010). Telemetry studies are easier to design and perform when done with large fish in closed systems (Hightower et al. 2001; Young and Isely 2004; Thompson et al. 2007), but our results suggest that estimates of mortality can be obtained for smaller species of fish in open systems as long as great care is taken when designing the study. The effects of the transmitter on the species being studied can bias results, and researchers need to be aware of and understand assumptions of telemetry work such as surgery-related mortalities, transmitter expulsion, and predators retaining tags for long periods when determining fates of telemetered fish. For the latter bias, fine temporal and spatial scale resolution of tag locations from continuous monitoring throughout the study area is required for the most accurate assignment of fates.

Our field-based estimate of *M* for age-1 spot is important for at least two reasons. First, it allows for a direct comparison to predicted estimates of *M* based on fish weight (Lorenzen 1996), a model which has been used to provide estimates of *M* for stock assessments. Second, estimation of *M* for juvenile stages allows for a better understanding of factors that may influence recruitment variability. Spot is of significance in North Carolina both economically and ecologically and it is therefore important to develop a better understanding of their early life stages. Estuaries provide an important nursery habitat for juvenile spot (Currin et al. 1984; Stokesbury and Ross 1997; ASMFC 2010), thus, direct estimates of important demographic rates in these dynamic systems, such as natural mortality, will assist in the management of this species.

REFERENCES

Adams, N.S., D.W. Rondorf, S.D. Evans, J.E. Kelly and R.W. Perry. 1998. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences. 55(4):781 – 787.

Argent, D.G. and W.G. Kimmel. 2005. Efficiency and selectivity of gill nets for assessing fish community composition of large rivers. North American Journal of Fisheries Management. 25(4):1315 – 1320.

ASMFC (Atlantic States Marine Fisheries Commision). 1987. Fishery management plan for spot (*Leiostomus xanthurus*). Washington (DC): ASMFC. Fisheries Management Report No. 11. 81 p.

ASMFC. 2010. Spot life history report (*Leiostomus xanthurus*). Report to the ASMFC South Atlantic State/Federal Fisheries Management Board.

Bacheler, N.M. 2008. Factors influencing the mortality and distribution of subadult red drum in North Carolina. Ph.D. dissertation, Department of Zoology, North Carolina State University, Raleigh, N.C.

Bacheler, N.M., J.A. Buckel, J.E. Hightower, L.M. Paramore and K.H. Pollock. 2009. A combined telemetry – tag return approach to estimate fishing and natural mortality rates of an estuarine fish. Canadian Journal of Fisheries and Aquatic Sciences. 66(8):1230 – 1244.

Baldevarona, R.B. 1987. Effects of feeding and stocking density on growth and survival of spot, *Leiostomus xanthurus* Lacépède. Ph.D. dissertation, Marine Science Program, University of South Carolina, Columbia, SC.

Baras, E. and L. Westerloppe. 1999. Transintestinal expulsion of surgically implanted tags by African catfish *Heterobranchus longifilis* of variable size and age. Transactions of the American Fisheries Society. 128(4):737 – 746.

Bridger, C.J. and R.K. Booth. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Reviews in Fisheries Science. 11(1):13 – 34.

Brown, R.S., S.J. Cooke, W.G. Anderson and R.S. McKinley. 1999. Evidence to challenge the “2% rule” for biotelemetry. North American Journal of Fisheries Management. 19(3):867 – 871.

Carss, D.N. and J.D. Godfrey. 1996. Accuracy of estimating the species and sizes of osprey prey: a test of methods. The Journal of Raptor Research. 30(2):57 – 61.

Clark, W.G. 1999. Effects of an erroneous natural mortality rate on a simple age-structure stock assessment. Canadian Journal of Fisheries and Aquatic Sciences. 56(10):1721 – 1731.

Cooke, S.J., G.H. Niezgoda, K. Hanson, C.D. Suski and F.J.S. Phelan. 2005. Use of CDMA acoustic telemetry to document 3-D positions of fish: relevance to the design and monitoring of aquatic protected areas. Marine Technology Society Journal. 39(1):17 – 27.

Cooke, S.J., C.M. Woodley, M.B. Eppard, R.S. Brown and J.L. Nielsen. 2010. Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. Reviews in Fish Biology and Fisheries. 21(1):127-151.

Craig, J.K., J.A. Rice, L.B. Crowder and D.A. Nadeau. 2007. Density-dependent growth and mortality in an estuary-dependent fish: an experimental approach with juvenile spot *Leiostomus xanthurus*. Marine Ecology Progress Series. 343:251 – 262.

Currin, B.M., J.P. Reed and J.M. Miller. 1984. Growth, production, food consumption, and mortality of juvenile spot and croaker: a comparison of tidal and nontidal nursery areas. Estuaries. 7(4A):451 – 459.

Dawson, C.E. 1965. Length-weight relationships of some Gulf of Mexico fishes. Transactions of the American Fisheries Society. 94(33):279 – 280.

FAO. 2002. The living marine resources of the western central Atlantic. Volumes 1-3: K.E. Carpenter (ed.). Food and Agricultural Organization of the United Nations, Rome.

Flores-Coto, C. and S.M. Warlen. 1993. Spawning time, growth, and recruitment of larval spot *Leiostomus xanthurus* into a North Carolina estuary. Fishery Bulletin. 91(1):8 – 22.

Gannon, D.P. and D.M. Waples. 2004. Diets of coastal bottlenose dolphins from the U.S. mid-Atlantic coast differ by habitat. Marine Mammal Science. 20(3):527 – 545.

Goodyear, C.P. 1967. Feeding habits of three species of gars, *Lepisosteus*, along the Mississippi Gulf Coast. Transactions of the American Fisheries Society. 96(3):297 – 300.

Hamley, J.M. 1975. Review of gillnet selectivity. Journal of the Fisheries Research Board of Canada. 32(11):1943 – 1966.

Harms, C.A. 2005. Surgery in fish research: common procedures and postoperative care. Lab Animal. 34(1):28-34.

Hartleb, C.F. and J.R. Moring. 1995. An improved gastric lavage device for removing stomach contents from live fish. Fisheries Research. 24(3):261 – 265.

Heupel, M.R. and C.A. Cimpfendorfer. 2002. Estimation of mortality of juvenile blacktip sharks, *Carcharhinus limbatus*, within a nursery area using telemetry data. Canadian Journal of Fisheries and Aquatic Sciences. 59(4):624 – 632.

Heupel, M.R., C.A. Simpfendorfer, A.B. Collin and J.P. Tyminski. 2006. Residency and movement patterns of bonnethead sharks, *Sphyrna tiburo*, in a large Florida estuary. Environmental Biology of Fishes. 76(1):47 – 67.

Hightower, J.E., J.R. Jackson and K.H. Pollock. 2001. Use of telemetry methods to estimate natural and fishing mortality of striped bass in Lake Gaston, North Carolina. Transactions of the American Fisheries Society. 130(4):557 – 567.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin. 81(4):898 – 903.

Hoese, H.D. and R.H. Moore. 1998. Fishes of the Gulf of Mexico, 2nd edition. Texas A&M University Press, College Station, TX.

Hyslop, E.J. 1980. Stomach contents analysis: a review of methods and their application. Journal of Fish Biology. 17(4):411-429.

Jackson, D.A. and H.H. Harvey. 1997. Qualitative and quantitative sampling of lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences. 54(12):2807 – 2813.

Jepsen, N., K.. Aarestrup, F. Økland and G. Rasmussen. 1998. Survival of radio-tagged Atlantic salmon (*Salmo salar* L.) and trout (*Salmo trutta* L.) smolts passing a reservoir during seaward migration. Hydrobiologia. 371/372(0):347 – 353.

Jepsen, N., C. Schreck, S. Clements and E.B. Thorstad. 2005. A brief discussion on the 2% tag/bodymass rule of thumb. In: Spedicato, M.T., G. Lembo and G. Marmulla (Eds.), Aquatic Telemetry: Advances and Applications, Rome: FAO-COISPA, pp. 255 – 261.

Kastelein, R.A., C. Staal and P.R. Wiepkema. 2003. Food consumption, food passage, time, and body measurements of captive Atlantic bottlenose dolphins (*Tursiops truncatus*). Aquatic Mammals. 29(1):53 – 66.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology. 49(4):627 – 647.

Lucas, M.C. and E. Baras. 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. Fish and Fisheries. 1(4):283 – 316.

Martinelli, T.L., H.C. Hansel and R.S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling chinook salmon (*Oncorhynchus tshawytscha*). Hydrobiologia. 371/372(0):79 – 87.

Marty, G.D. and R.C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from channel catfish. Transactions of the American Fisheries Society. 115(4):577 – 589.

Millar, R.B. 1992. Estimating the size-selectivity of fishing gear by conditioning on the total catch. Journal of the American Statistical Society. 87(420):962 – 968.

Moser, M.L. 1987. Effects of salinity fluctuation on juvenile estuarine fish. Ph.D. dissertation, Department of Zoology, North Carolina State University, Raleigh, N.C.

Moser, M.L., D.A. Ogden and B.P. Sandford. 2007. Effects of surgically implanted transmitters on anquilliform fishes: lessons from lamprey. Journal of Fish Biology. 71(6):1847 – 1852.

Mulcahy, D.M. 2003. Surgical implantation of transmitters into fish. ILAR Journal. 44(4):295 – 306.

NCDMF (North Carolina Division of Marine Fisheries). 2010. Issued May, 2010. http://www.ncfisheries.net/statistics/index.html.

Netsch, Lt. N.F. and A. Witt, Jr. 1962. Contributions to the life history of the longnose gar, (*Lepisosteus osseus*) in Missouri. Transactions of the American Fisheries Society. 91(3):251 – 262.

Neumann, D.A., J.M. O'Connor and J.A. Sherk, Jr. 1981. Oxygen consumption of white perch (*Morone americana*), striped bass (*M. saxatilis*) and spot (*Leiostomus xanthurus*). Comparative Biochemistry and Physiology. 69A(3):467 – 478.

Pacheco, A.L. 1962. Age and growth of spot in lower Chesapeake Bay, with notes on distribution and abundance of juveniles in the York River system. Chesapeake Science. 3(1):18 – 28.

Phillips, J.M., M.T. Huish, J.H. Kerby and D.P. Moran. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic) – spot. U.S. Fish and Wildlife Service Biological Report 82(11.98). U.S. Army Corps of Engineers, TR EL-82-4. 13 p.

Piner, K.R. and C.M. Jones. 2004. Age, growth and the potential for growth overfishing of spot (*Leiostomus xanthurus*) from the Chesapeake Bay, eastern USA. Marine and Freshwater Research. 55(6):553 – 560.

Pollock, K.H., S.R. Winterstein, C.M. Bunck and P.D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management. 53(1):7 – 15.

Quinn, T.J. II and R.B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York, New York.

Ross, S.W. 2003. The relative value of different estuarine nursery areas in North Carolina for transient juvenile marine fishes. Fishery Bulletin. 101(2):384 – 404.

Scharf, F.S., F. Juanes and R.A. Rountree. 2000. Predator size – prey size relationships of marine fish predators: interspecific variation and effects of ontogeny and body size on trophic-niche breadth. Marine Ecology Progress Series. 208:229 – 248.

Sheaves, M. 2001. Are there really few piscivorous fishes in shallow estuarine habitats? Marine Ecology Progress Series. 222:279 – 290.

Simpfendorfer, C.A., M.R. Heupel and R.E. Hueter. 2002. Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. Canadian Journal of Fisheries and Aquatic Sciences. 59(1):23 – 32.

Stokesbury, K.D.and S.W. Ross. 1997. Spatial distribution and an absolute density estimate of juvenile spot *Leiostomus xanthurus* in the tidal fringe bordering a North Carolina salt marsh. Marine Ecology Progress Series. 149:289 – 294.

Summerfelt, R.C. and Smith, L.C. 1990. Anesthesia, surgery, and related techniques. In: Schreck, C.B. and P.B. Moyle (Eds.), Methods for fish biology. American Fisheries Society, Bethesda, Maryland, USA, pp. 213 – 272.

Thiem, J.D., M.K. Taylor, S.H. McConnachie, T.R. Binder and S.J. Cooke. 2010. Trends in the reporting of tagging procedures for fish telemetry studies that have used surgical implantation of transmitters: a call for more complete reporting. Reviews of Fish Biology and Fisheries. DOI: 10.1007/s11160-010-9194-2.

Thompson, J.S., D.S. Waters, J.A. Rice and J.E. Hightower. 2007. Seasonal natural and fishing mortality of striped bass in a southeastern reservoir. North American Journal of Fisheries Management. 27:681 – 694.

Thorsteinsson, V. 2002. Tagging methods for stock assessment and research in fisheries. Report of concerted action FAIR CT.96.1394 (CATAG). Reykjavik. Marine Research Institute Technical Report (79). 179 p.

Wagner, G.N., E.D. Stevens and P. Byrne. 2000. Effects of suture type and patterns on surgical wound healing in rainbow trout. Transactions of the American Fisheries Society. 129(5): 1196–1205.

Wagner, G.N. and S.J. Cooke. 2005. Methodological approaches and opinions of researchers involved in the surgical implantation of telemetry transmitters in fish. Journal of Aquatic Animal Health. 17(2):160 – 169.

Waters, D.S., R.L. Noble and J.E. Hightower. 2005. Fishing and natural mortality of adult largemouth bass in a tropical reservoir. Transactions of the American Fisheries Society. 134(3):563 – 571.

Weinstein, M.P. and M.P. Walters. 1981. Growth, survival and production in young-of-year populations of *Leiostomus xanthurus* Lacépède residing in tidal creeks. Estuaries. 4(3):185 – 197.

Weinstein, M.P., L. Scott, S.P. O'Neil, R.C. Siegfried II and S.T. Szedlmayer. 1984. Population dynamics of spot, *Leiostomus xanthurus*, in polyhaline tidal creeks of the York River Estuary, Virginia. Estuaries. 7(4A):444 – 450.

Williams, A.B. 1984. Shrimps, lobsters, and crabs of the Atlantic coast of the eastern United States, Maine to Florida. Smithsonian Institution Press, Washington, D.C.

Williams, B.K., J.D. Nichols and M.J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Diego, California.

Winter, J.D. 1996. Advances in underwater biotelemetry. In: Murphy, B.R. and D.W. Willis (Eds.), Fisheries Techniques 2nd Edition. American Fisheries Society, Bethesda, Maryland, USA, pp. 555 – 590.

Wyllie, M.C., E.R. Holmstrom and R.K. Wallace. 1976. Temperature preference, avoidance, shock, and swim speed studies with marine and estuarine organisms from New Jersey. Bulletin #15, Ichthyological Associates, Inc., Ithaca, N.Y.

Vetter, E.F. 1988. Estimation of natural mortality in fish stocks: a review. Fishery Bulletin. 86(1):25 – 43.

Table 1. Actual and estimated times and locations of deployment of test transmitter 53174. Estimated values = VR2/W weighted averages, actual values = field recorded data. No VR2/W data were recorded at Site 1. Analyst was blind to time and location of tag deployments.

	Start time		Stop time		Average latitude		Average longitude	
Site	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual
1	N/A	7:47	N/A	7:48	N/A	34.928	N/A	-76.852
2	7:58:47	8:00	8:00:28	8:02	34.936	34.936	-76.856	-76.855
3	8:12:32	8:13	8:14:05	8:15	34.937	34.938	-76.856	-76.857
4	8:32:55	8:34	8:34:12	8:36	34.918	34.919	-76.855	-76.854

Table 2. Summary of fates for telemetered age-1 spot in 2009 and 2010. Number of each assumed fate by year is listed followed by its proportion of the total for that year.

	2009		2010	
Tagged	48		75	
Fate (%)				
Surgery mortality	3	(0.06)	7	(0.09)
Transmitter failure	0	(0.00)	2	(0.03)
Emigration <7d	14	(0.29)	6	(0.08)
Natural mortality	0	(0.00)	10	(0.13)
Battery life end	2	(0.04)	0	(0.00)
Emigration ≥7d	29	(0.60)	50	(0.67)

Table 3. Detailed descriptions of fate assignment for the ten assumed natural mortalities in 2010.

Transmitter #	Creek	Lack of movement	Fast swimming speed	Extreme latitude changes	Other comments
27740	Clubfoot	X			VR2/W detections indicate nighttime movement into receiver array; manual tracking relocations indicate daytime residency away from receiver array
27741	Clubfoot		X	X	Assumed predation event on ~day 14; estimated swimming speeds are extreme accompanied by extreme latitude changes - predator eventually emigrates with transmitter still ingested
27742	Clubfoot	X			Stationary position is out of range of VR2/W array, only relocated by manual tracking after that
27748	Clubfoot				Fish disappears from creek; possible bird predation, *F*
27750	Clubfoot	X	X	X	Transmitter has very fast speed then becomes stationary and signal fades out quickly; tag is assumed to be sinking into substrate after being eliminated from a predator
27729	Hancock	X			Hourly VR2/W detections indicate good movement for ≥7d; becomes stationary and though swimming speeds >0 were estimated after a period of nonmovement it appears to be due to error
27732	Hancock	X			Lack of movement begins ~day 26; lack of VR2/W "grid" is misleading - creates small movement error after this time
27774	Hancock	X			Transmitter becomes stationary and signal fades out over ~10d
27786	Hancock	X			VR2/W detections indicate good movement for ≥7d; transmitter becomes stationary, VR2/W detections end on ~day 76 but tag is manually relocated in same site after that
27794	Hancock		X	X	Assumed predation event on ~day 27; estimated swimming speeds are extreme accompanied by extreme latitude changes - predator eventually emigrates with transmitter still ingested

Table 4. Summary of days at risk for 2010 telemetered age-1 spot natural mortality events.

Transmitter #	Creek	Date Implanted	Fate Date	No. Days At Risk	FL (mm)	Weight (g)
27729	Hancock	4/1/2010	4/9/2010	9	176	80
27732	Hancock	4/2/2010	4/26/2010	25	155	56
27740	Clubfoot	4/6/2010	4/19/2010	14	195	120
27741	Clubfoot	4/6/2010	4/19/2010	14	179	63
27742	Clubfoot	4/6/2010	4/15/2010	10	159	59
27748	Clubfoot	4/7/2010	5/16/2010	36	164	75
27750	Clubfoot	4/7/2010	4/17/2010	11	197	115
27774	Hancock	4/19/2010	4/27/2010	9	145	47
27786	Hancock	4/22/2010	6/22/2010	59	163	74
27794	Hancock	4/19/2010	5/14/2010	26	172	99

Table 5. Predator species caught in gill and trammel nets in 2009 and 2010.

	2009		2010	
Species	Gill net	Trammel net	Gill net	Trammel net
Black drum (*Pogonias cromis*)	X	X		
Bluefish (*Pomatomus saltatrix*)		X	X	
Bullhead catfish (*Ameiurus* spp.)				X
Chain pickerel (*Esox niger*)				X
Largemouth bass (*Micropterus salmoides*)	X			
Longnose gar (*Lepisosteus osseus*)	X	X	X	X
Red drum (*Sciaenops ocellatus*)	X	X	X	X
Southern flounder (*Paralichthys lethostigma*)	X		X	
Spotted seatrout (*Cynoscion nebulosus*)	X	X	X	X
Striped bass (*Morone saxatilis*)	X	X	X	
White catfish (*Ameiurus catus*)	X			X
Yellow perch (*Perca flavescens*)	X			

Table 6A. Percent frequency and weight of stomach contents of predators lavaged in 2009. Size ranges and mean of predators lavaged.

	2009 Predator species													
	Black drum		Largemouth bass		Longnose gar		Red drum		Spotted seatrout		Striped bass		White catfish	
2009 Prey taxa	%O	%W	%O	%W	%O	%W	%O	%W	%O	%W	%O	%W	%O	%W
Fishes														
Brevoortia tyrannus			100.0	20.5	77.4	80.5	45.8	53.6	77.8	61.9	50.0	80.4	11.1	1.2
Clupeidae					3.8	0.5								
Ophichthidae							4.2	9.0						
Mugil spp.			100.0	79.5										
Sciaenidae														
Micropogonias undulatus					1.9	0.3			11.1	24.6				
Syngnathidae							4.2	0.6						
Unknown Fish					62.3	18.4	58.3	6.4	44.4	10.6	100.0	19.3	22.2	7.7
Invertebrates														
Bivalvia														
Macoma spp.	25.0	45.7											11.1	0.6
Bivalvia	75.0	54.3					4.2	0.5						
Penaeidae														
Penaeus aztecus							12.5	2.5	11.1	0.5				
Penaeus spp.									11.1	0.2			33.3	1.9
Portunidae														
Callinectes sapidus							25.0	6.6						
Xanthidae														
Xanthidae							25.0	17.7	11.1	0.1				
Vegetation														
SAV					5.7	0.3	37.5	3.0	11.1	2.2	50.0	0.3	100.0	88.6
Other														
Total stomachs analyzed	4		1		130		28		10		2		13	
Number containing prey	4		1		53		24		9		2		9	
Mean TL (cm) (SE)	413 (17)		370 (-)		787 (5)		432 (5)		435 (26)		455 (25)		396 (7)	
TL range (cm)	385-460		-		620-975		388-545		302-560		430-480		340-445	

Table 6B. Percent frequency and weight of stomach contents of predators lavaged in 2010. Size ranges and mean of predators lavaged.

	2010 Predator species									
	Bluefish		Bullhead catfish		Longnose gar		Red drum		Spotted seatrout	
2010 Prey taxa	%O	%W	%O	%W	%O	%W	%O	%W	%O	%W
<u>Fishes</u>										
Clupeidae										
Brevoortia tyrannus	100.0	100.0			50.0	94.1	20.0	8.9		
Sciaenidae										
Leiostomus xanthurus					2.1	0.3				
Sciaenidae					2.1	<0.1			100.0	98.0
Syngnathidae										
Syngnathidae					10.4	0.6				
Unknown Fish					47.9	4.7	20.0	8.0	50.0	2.0
<u>Invertebrates</u>										
Amphipoda							10.0	0.8		
Decapoda					2.1	<0.1				
Isopoda					2.1	0.1				
Penaeidae										
Penaeus aztecus							20.0	8.9		
Xanthidae										
Xanthidae					6.3	0.2	70.0	73.5		
<u>Vegetation</u>										
SAV			100.0	100.0						
<u>Other</u>										
Total stomachs analyzed	1		1		171		13		2	
Number containing prey	1		1		48		10		2	
Mean TL (mm) (SE)	665 (-)		380 (-)		761 (7)		438 (26)		288 (4)	
TL range (mm)	-		-		510-960		350-660		284-292	

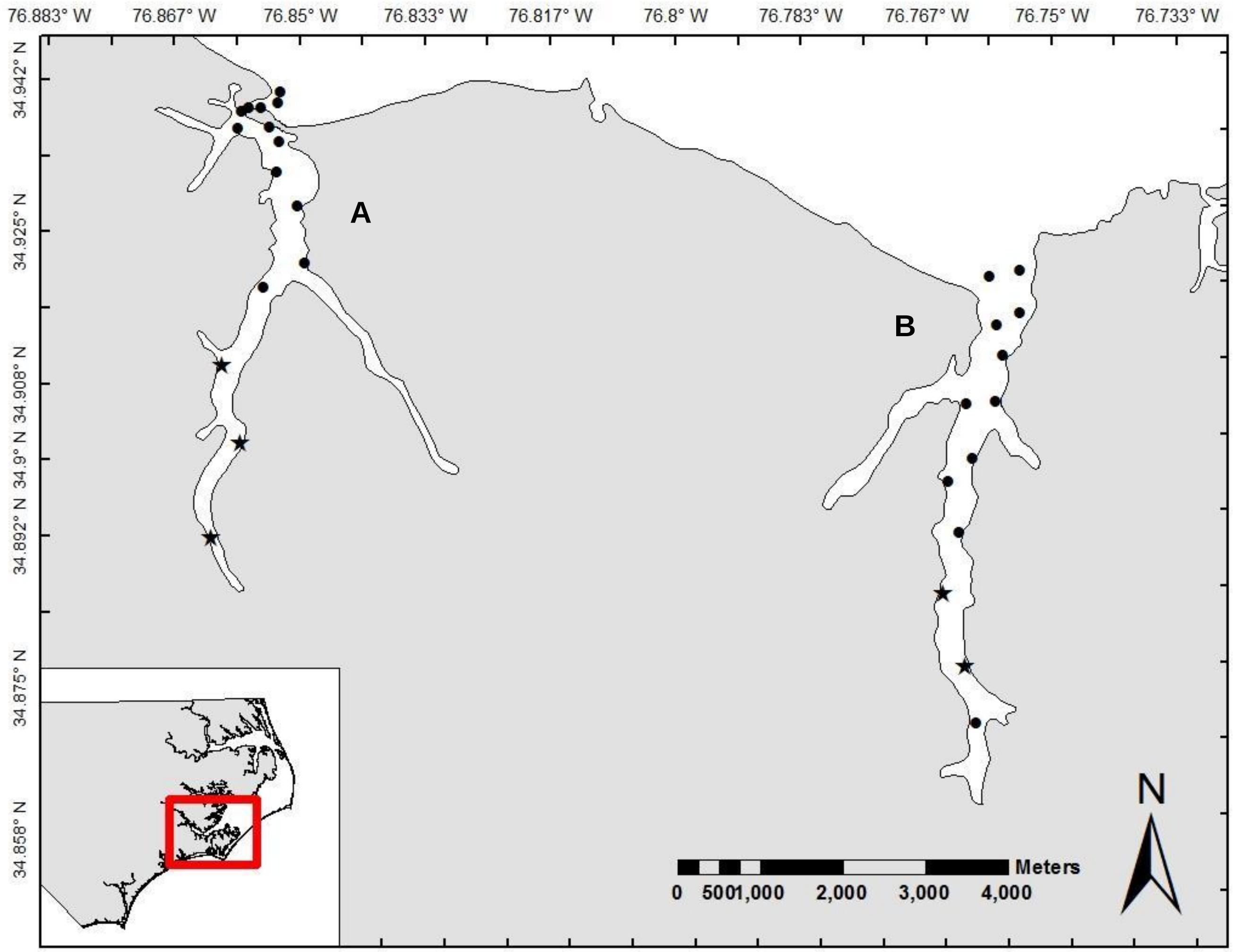


Figure 1. Study site; A: Hancock Creek B: Clubfoot Creek. Circles are 2009 and 2010 receivers, stars are additional receivers used in 2010.

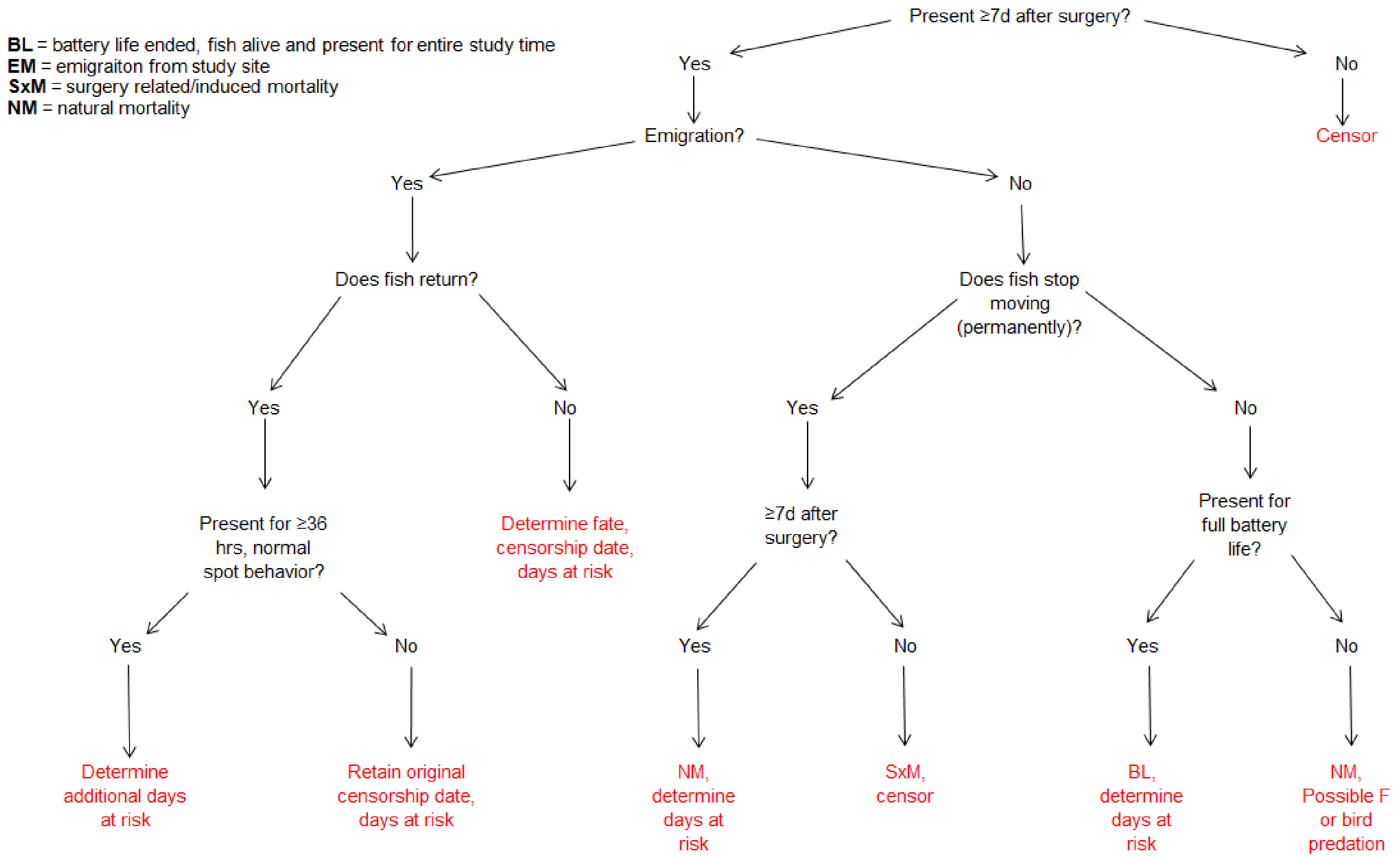


Figure 2. Fate assignments for telemetered age-1 spot. One of four possible fates was assigned: emigration (EM), surgery related mortality (SxM), natural mortality (NM) or battery life end (BL).

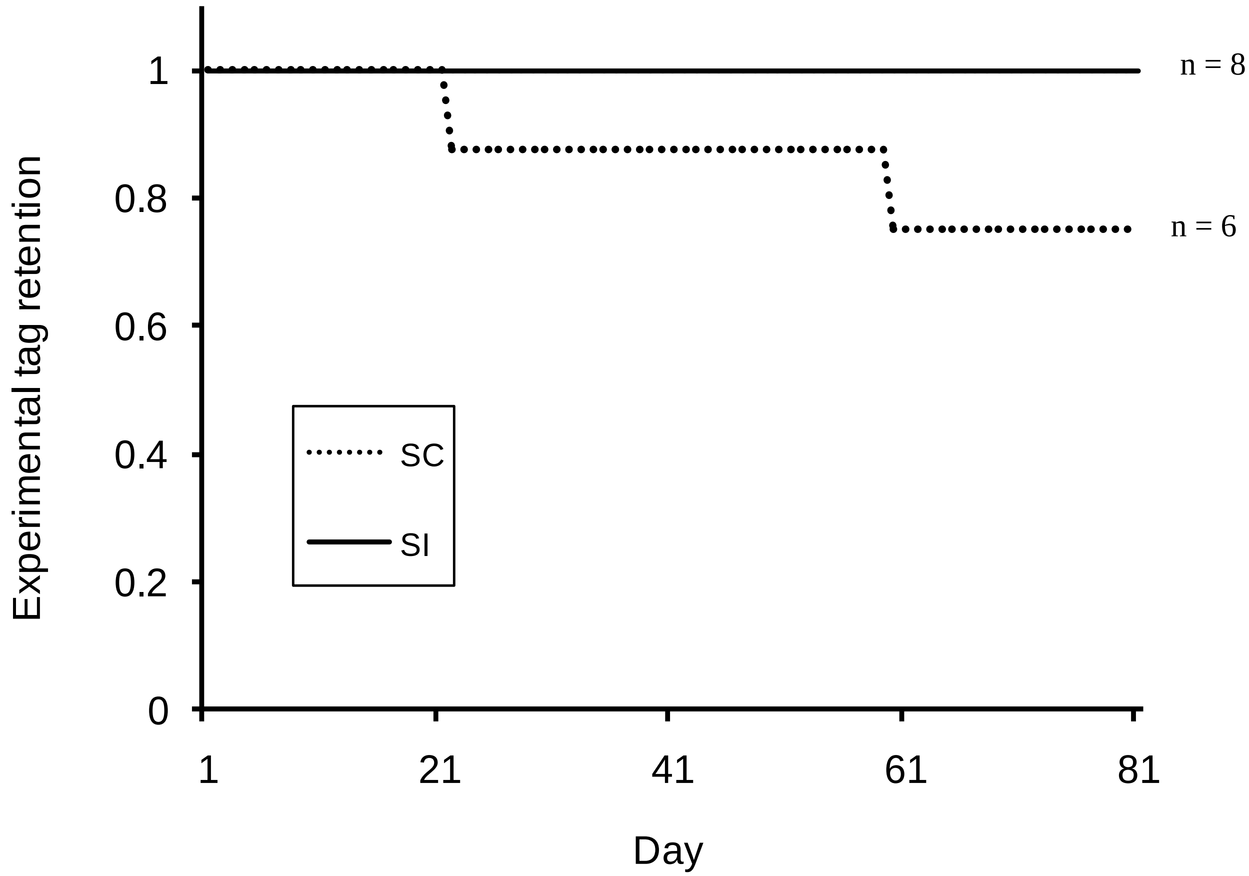


Figure 3. Proportion of tags retained over time for laboratory age-1 spot implanted with V9-6L dummy transmitters, simple continuous (SC) and simple interrupted (SI) sutures. Initial sample size for each suture type was n=8.

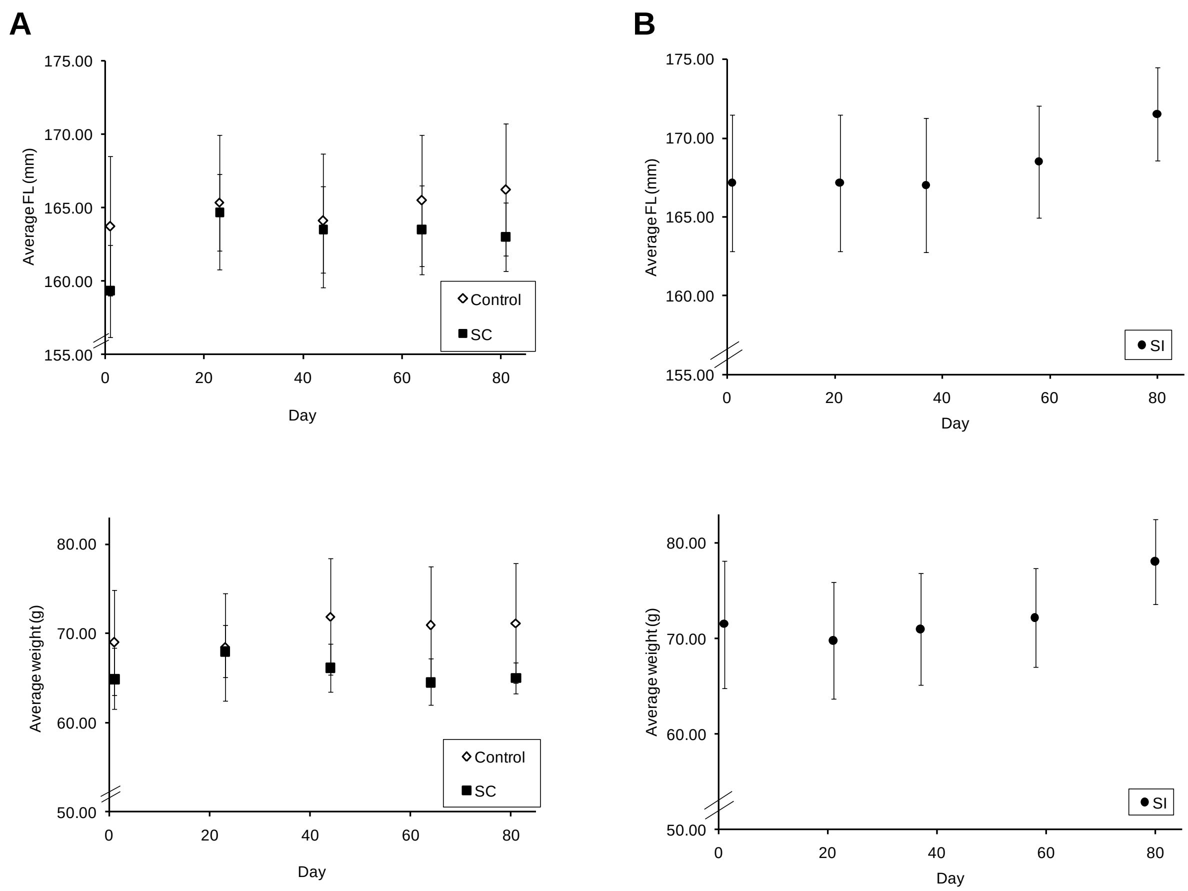


Figure 4. Growth in length (FL; top row) and weight (g, bottom row) for age-1 spot implanted with dummy V9-6L transmitters and incisions closed with **A**. simple continuous (SC) sutures and **B**. simple interrupted (SI) sutures. Only fish that retained transmitters for entire experiment are shown. Open diamonds represent control fish and filled symbols represent tagged fish.

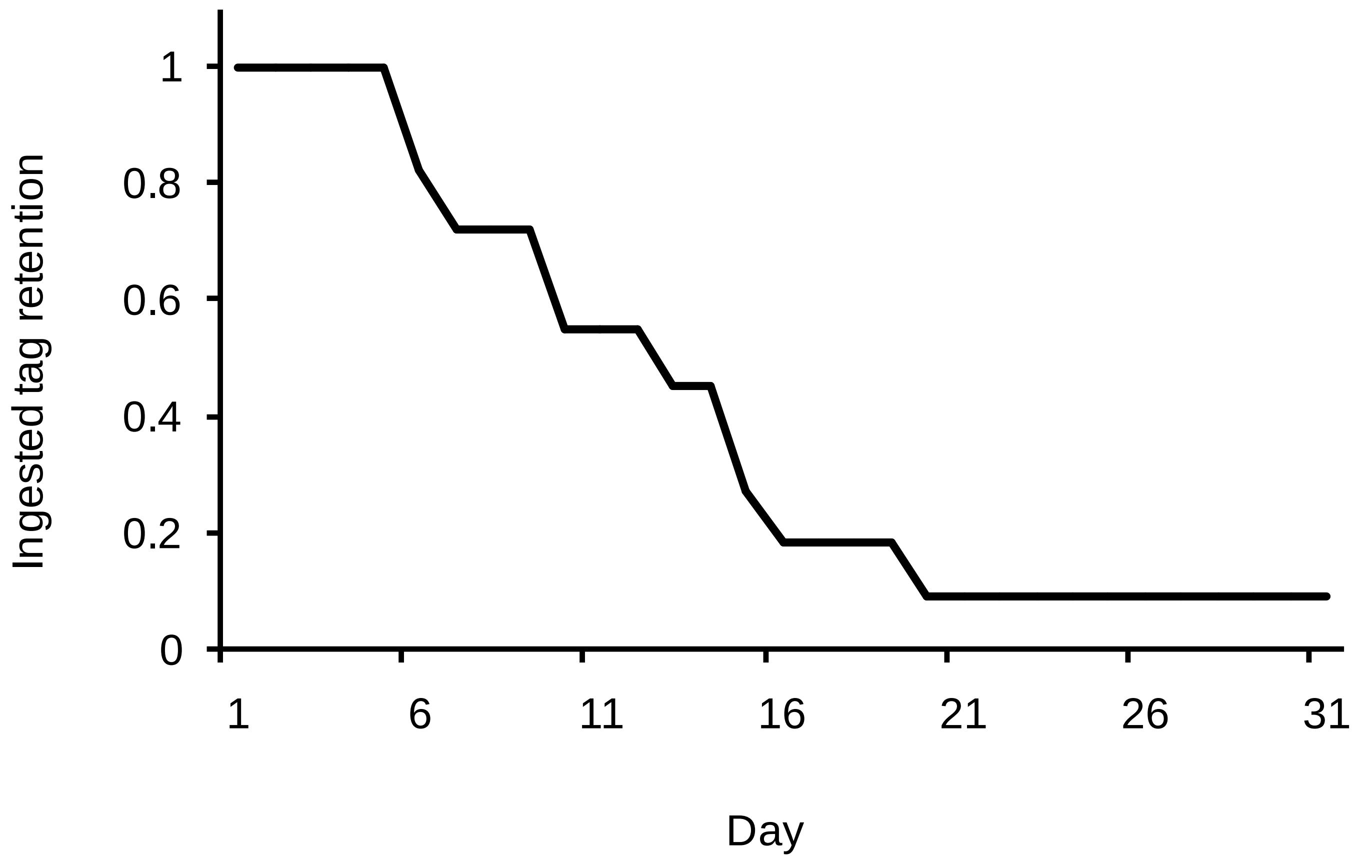


Figure 5. Proportion of transmitters retained over time in striped bass predators that ingested age-1 spot containing V9-6L dummy transmitters. Ten tags were eliminated (regurgitated or defecated) from the predators through the 31-day study, the remaining one was recovered upon necropsy at the end of the study on day 32.

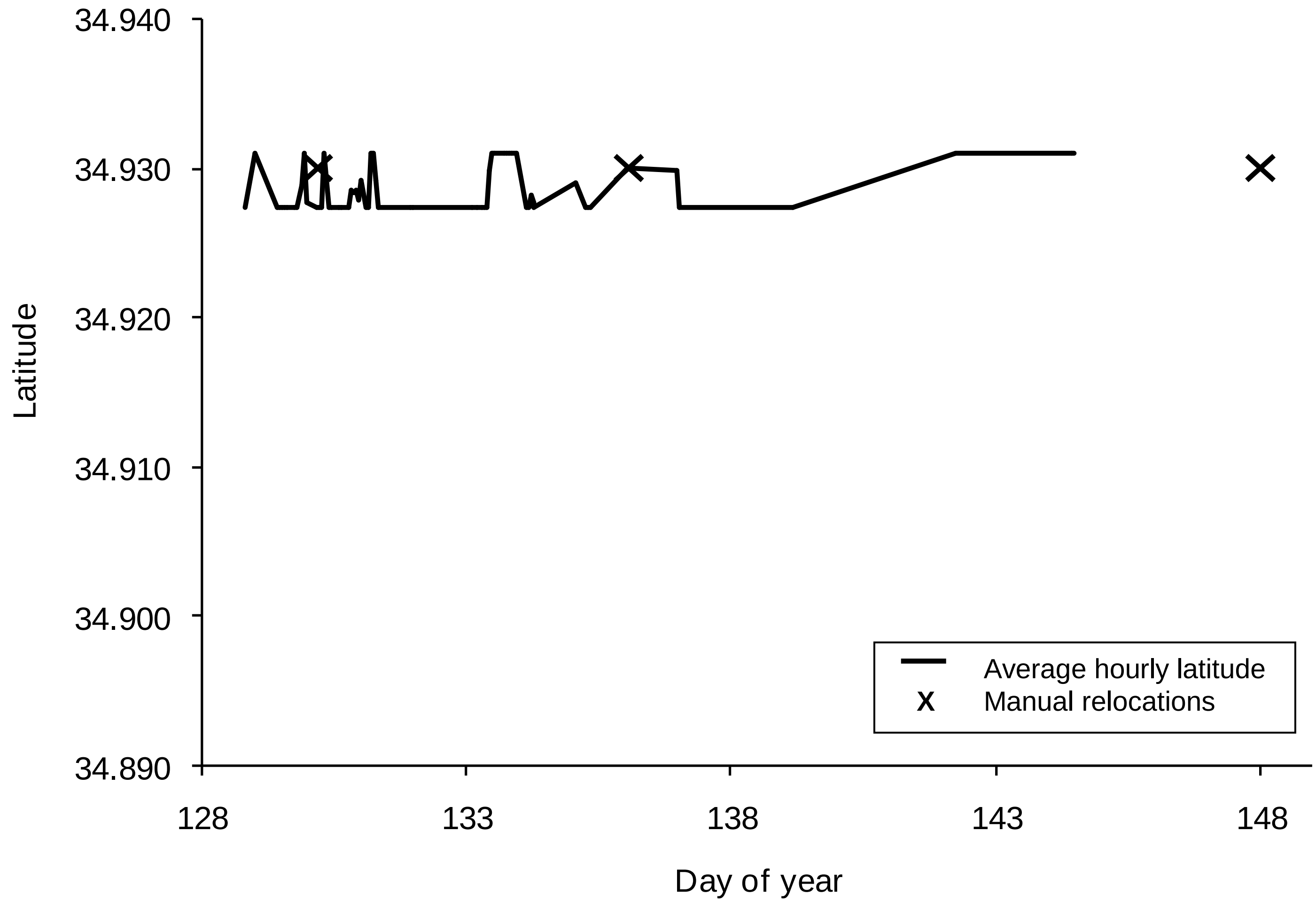


Figure 6. Average hourly latitude and manual tracking relocations of stationary test transmitter 56197 over time.

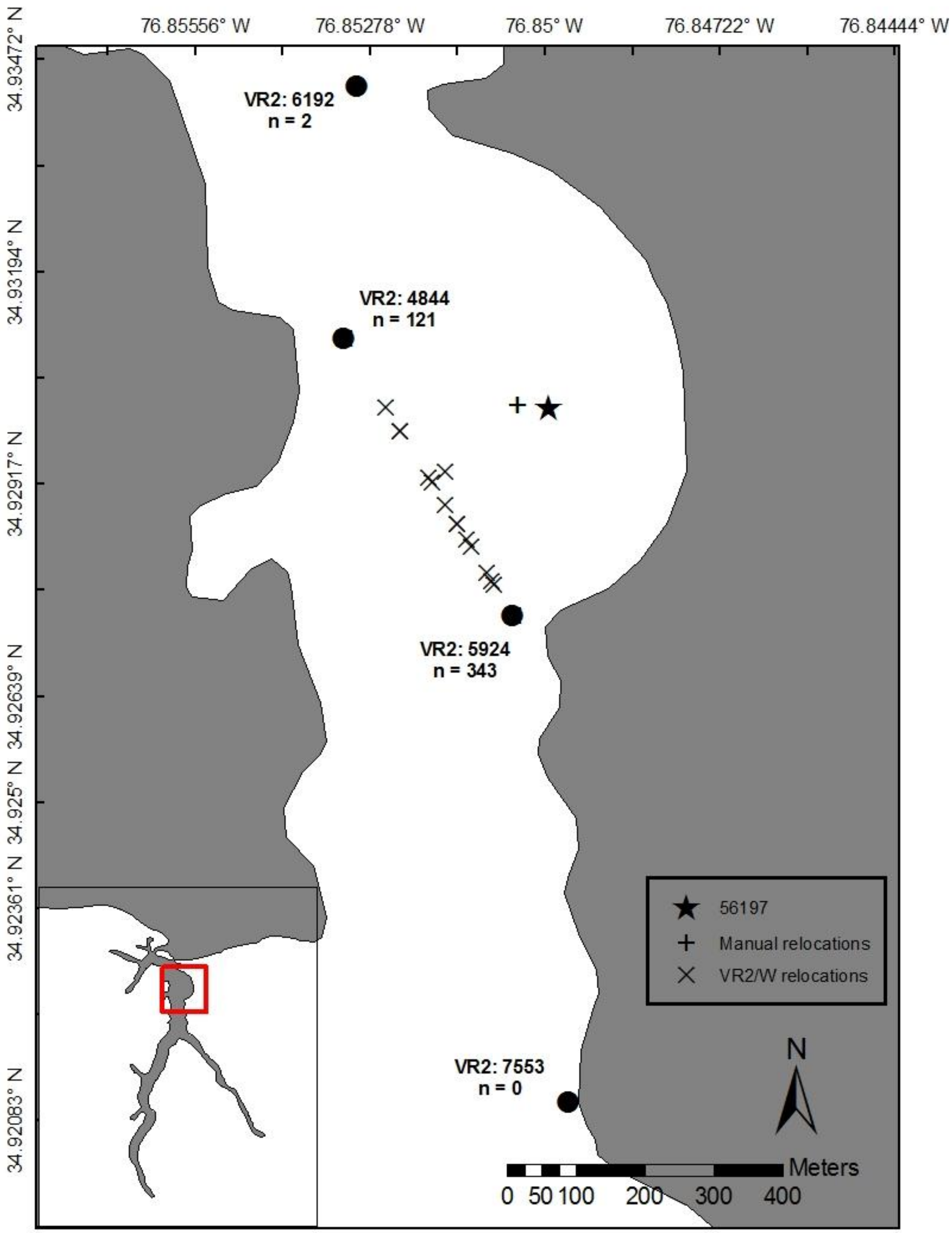


Figure 7. Hourly estimated average positions from VR2/W receivers and manual relocations (3 in the same location) for stationary test transmitter 56197. Time and location of tag deployment were unknown to field crew and analyst. Filled circles represent VR2/Ws and sample sizes are number of detections per VR2/W receiver.

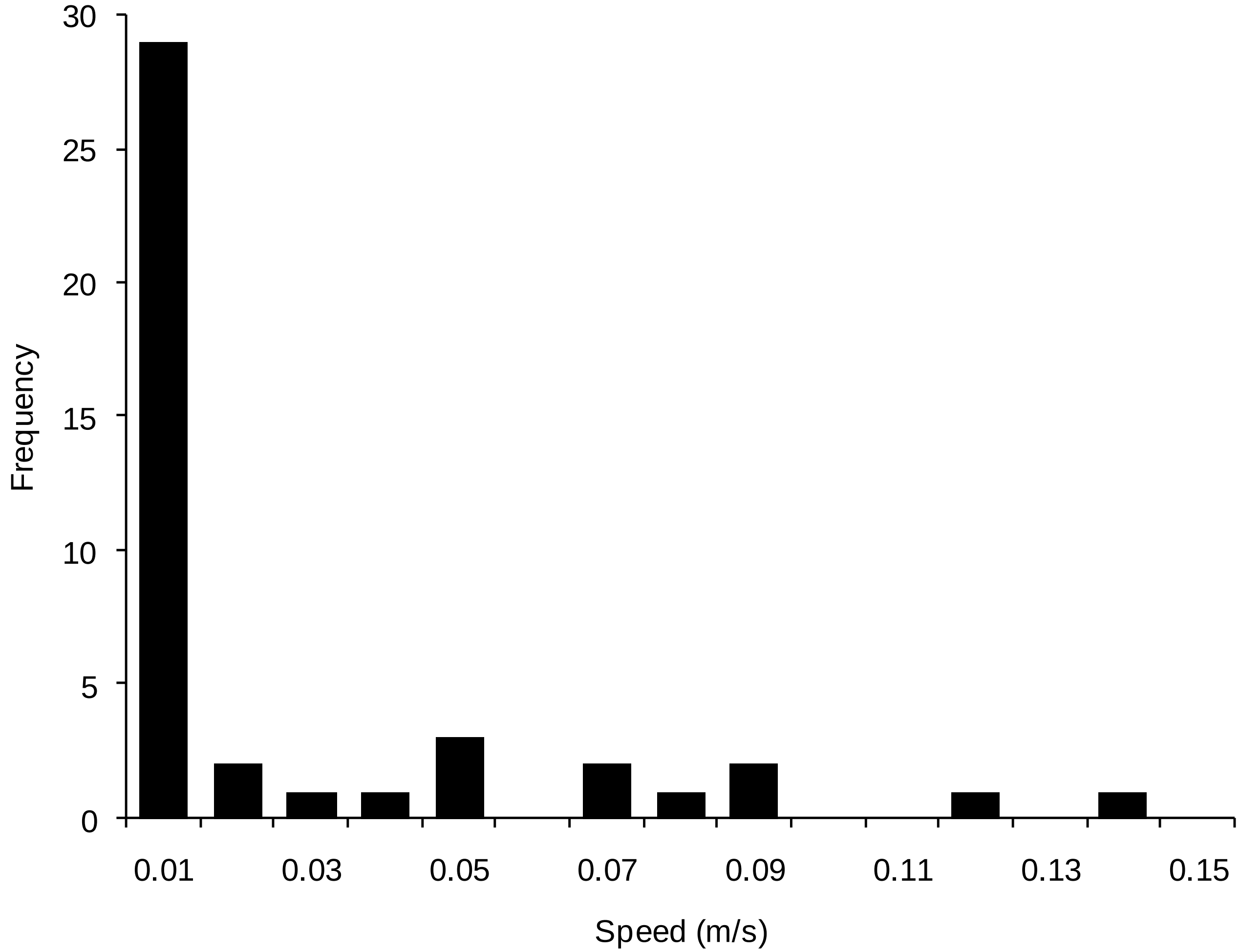


Figure 8. Frequency of estimated speeds (m/s) for stationary test transmitter 56197 based on hourly average VR2/W detections.

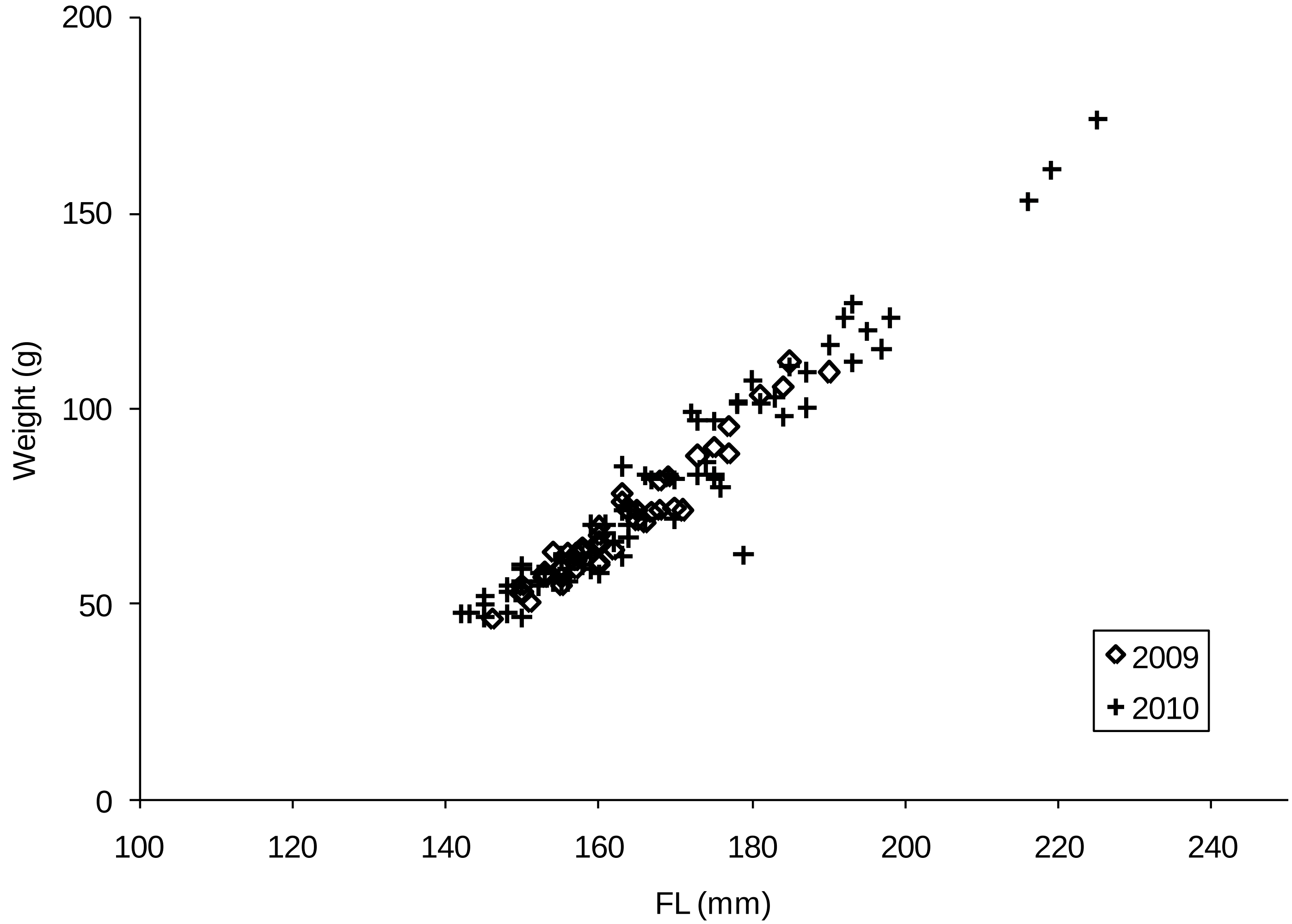


Figure 9. Weight versus length of telemetered age-1 spot in 2009 and 2010.

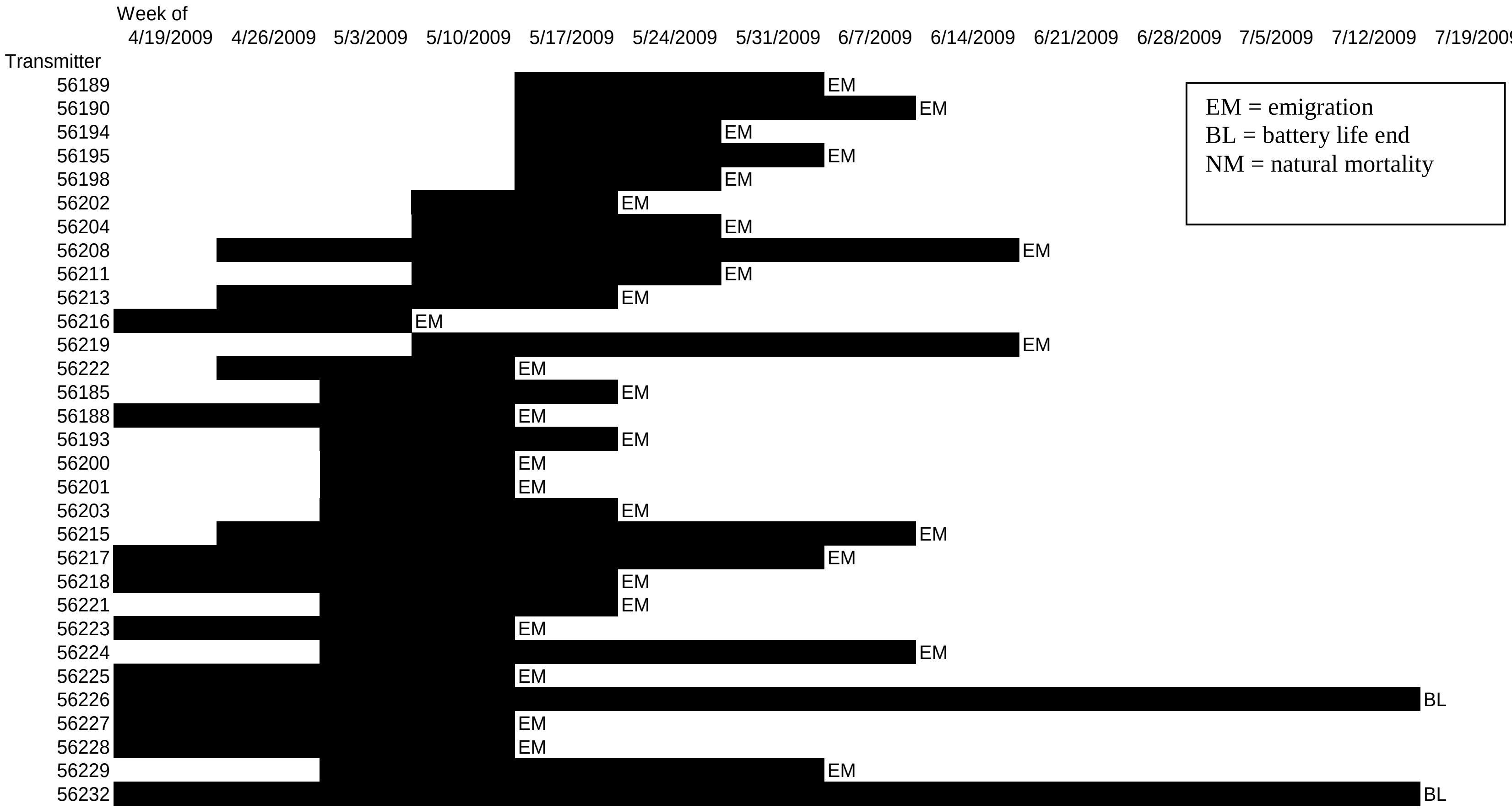


Figure 10A. Relocation histories for 31 telemetered age-1spot in 2009; relocations include only fish considered at risk for the study. Letters indicate the fate of each telemetered fish as an emigration (EM) or battery life end (BL); no natural mortality (NM) events were detected in 2009.

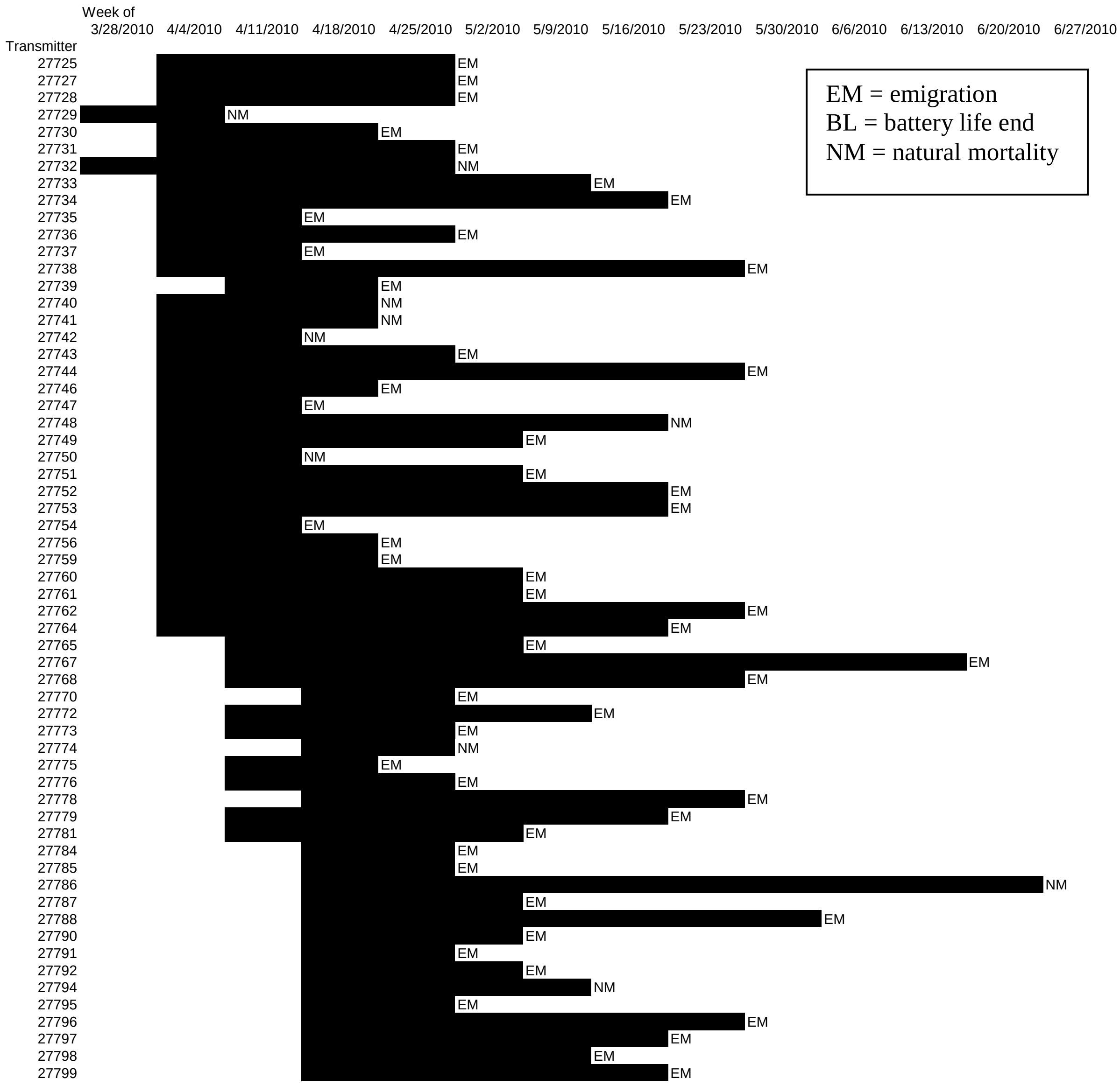


Figure 10B. Relocation histories for 60 telemetered age-1spot in 2010; relocations include only fish considered at risk for the study. Letters indicate the fate of each telemetered fish as an emigration (EM), battery life end (BL), or natural mortality (NM).

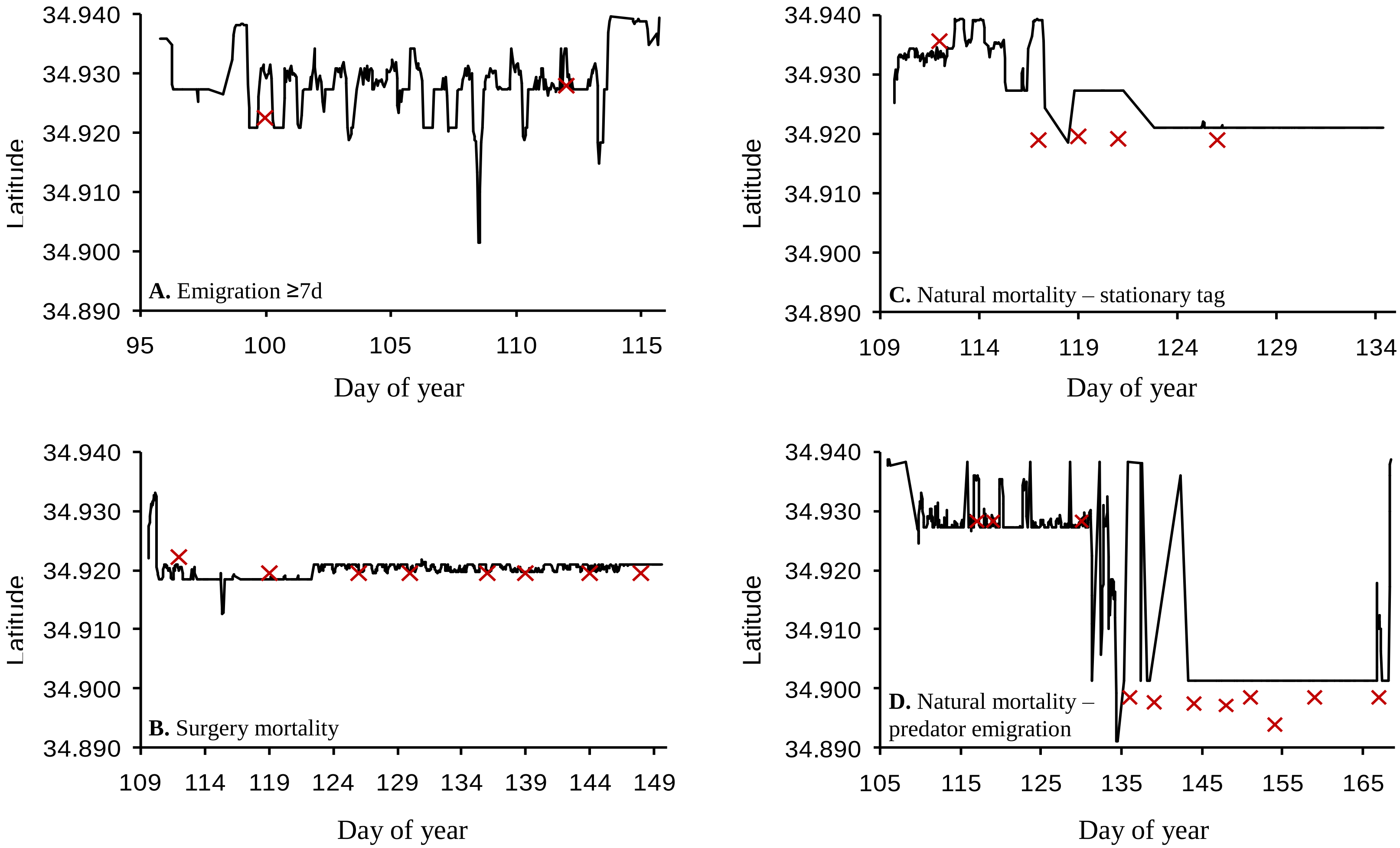
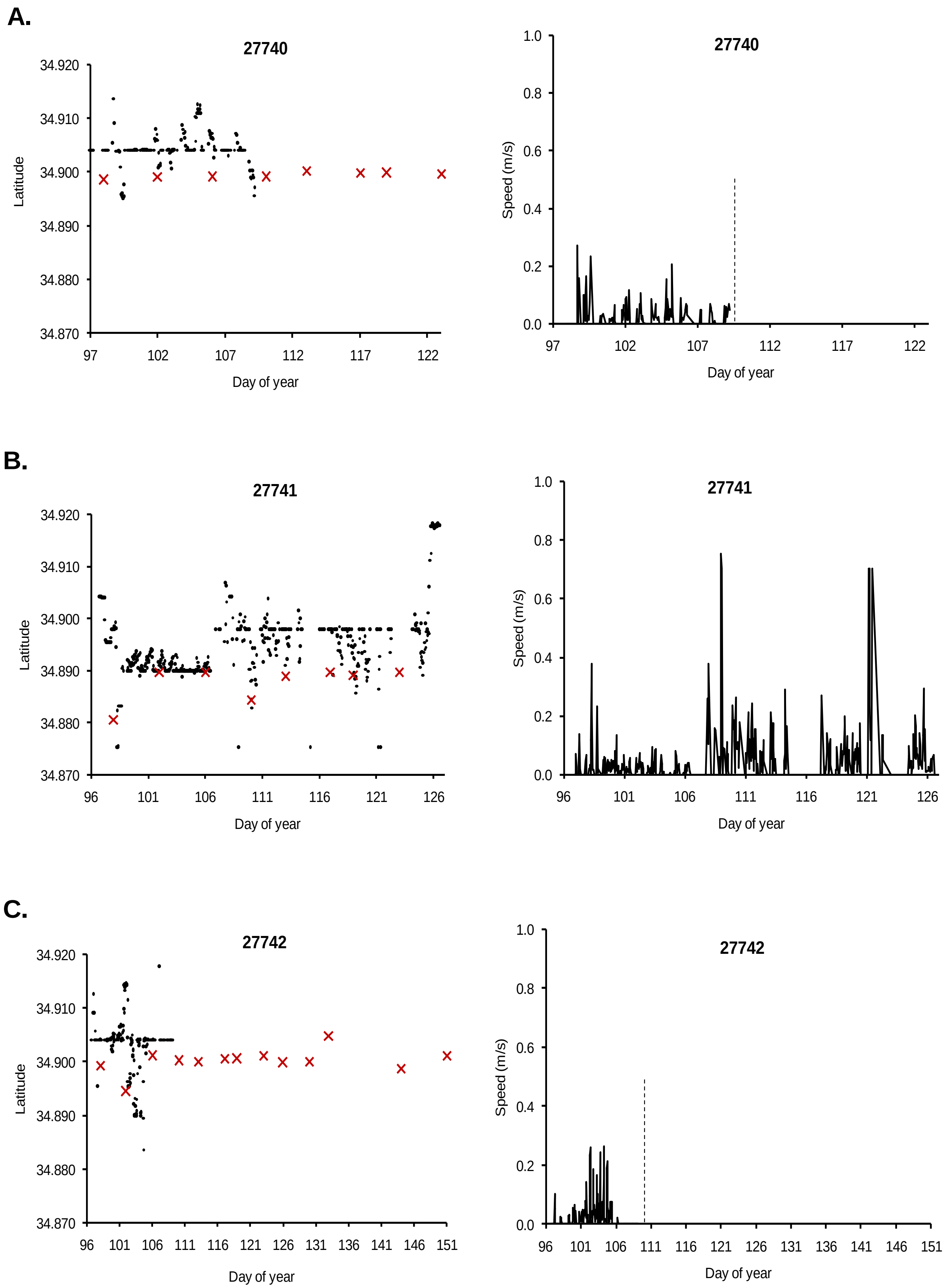
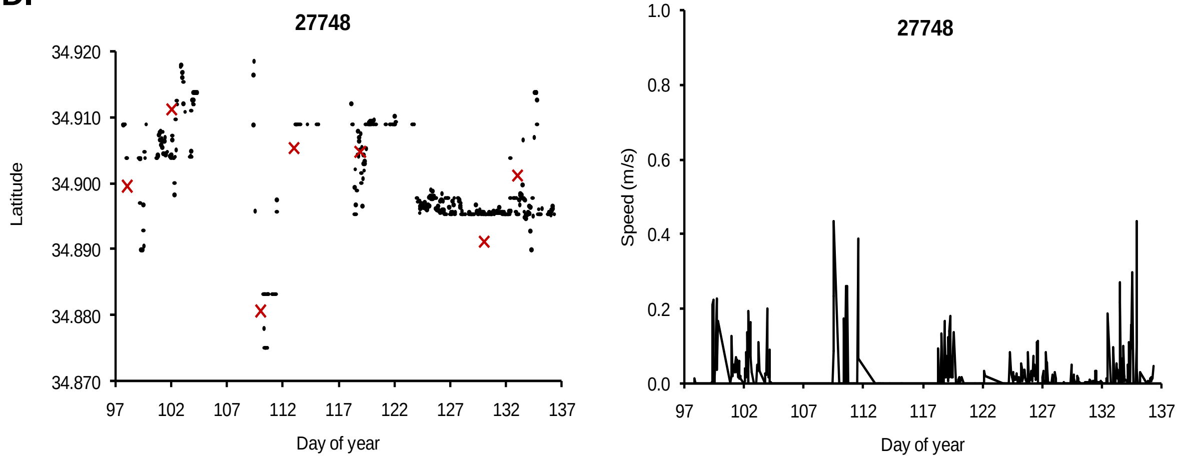


Figure 11. Assumed fate examples from VR2/W estimated average hourly positions (black line) and manual tracking relocations (**X**): **A.** Emigration ≥7 days; **B.** Surgery related mortality; **C.** Natural mortality (e.g. if tag was eliminated from predator); **D.** Natural mortality where predator emigrates with tag still ingested.

Figure 12. Estimated average hourly latitudinal positions (dots), manual tracking relocations (**X**), and swimming speeds (m/s) of the ten assumed natural mortalities of telemetered age-1 spot in 2010. Vertical dashed lines indicate when VR2/W data were no longer available to estimate swimming speeds. Clubfoot Creek fish: 27740, 27741, 27742, 27748 and 27750; Hancock Creek fish: 27729, 27732, 27774, 27786 and 27794.

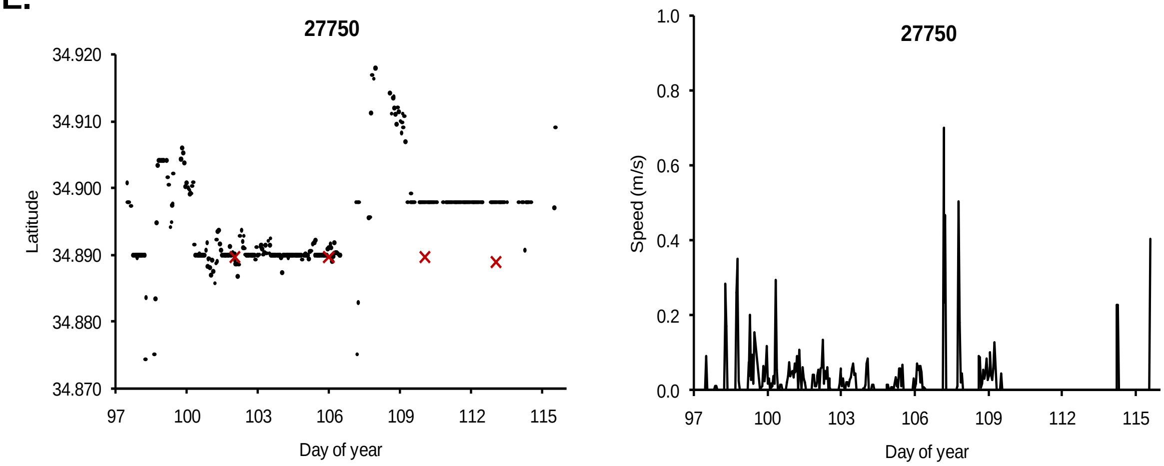

A.
27740
Latitude
34.920
34.910
34.900
34.890
34.880
34.870
97
102
107
112
117
122
Day of year
27740
Speed (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
97
102
107
112
117
122
Day of year
B.
27741
Latitude
34.920
34.910
34.900
34.890
34.880
34.870
96
101
106
111
116
121
126
Day of year
27741
Speed (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
96
101
106
111
116
121
126
Day of year
C.
27742
Latitude
34.920
34.910
34.900
34.890
34.880
34.870
96
101
106
111
116
121
126
131
136
141
146
151
Day of year
27742
Speed (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
96
101
106
111
116
121
126
131
136
141
146
151
Day of year

D.



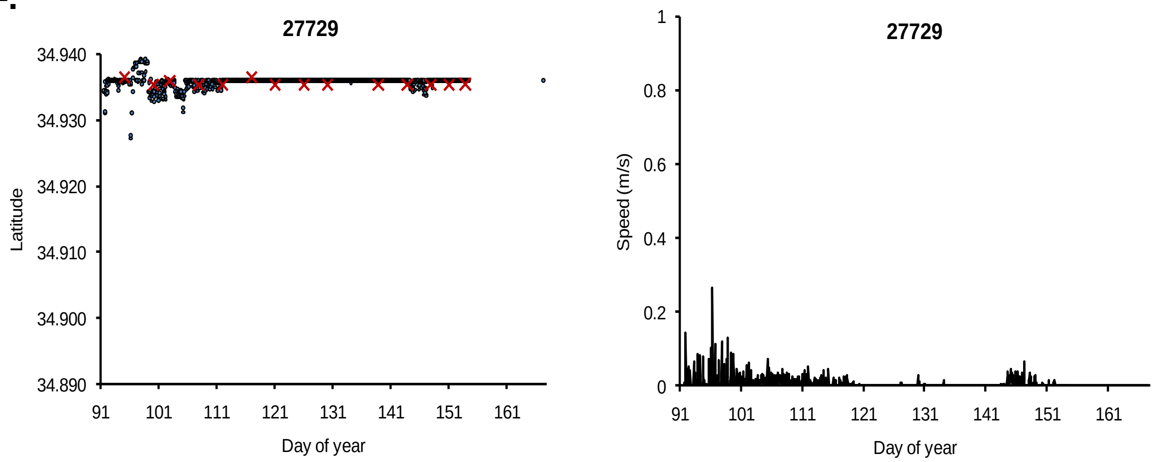
27748
Latitude
34.920
34.910
34.900
34.890
34.880
34.870
97
102
107
112
117
122
127
132
137
Day of year
27748
Speed (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
97
102
107
112
117
122
127
132
137
Day of year

E.

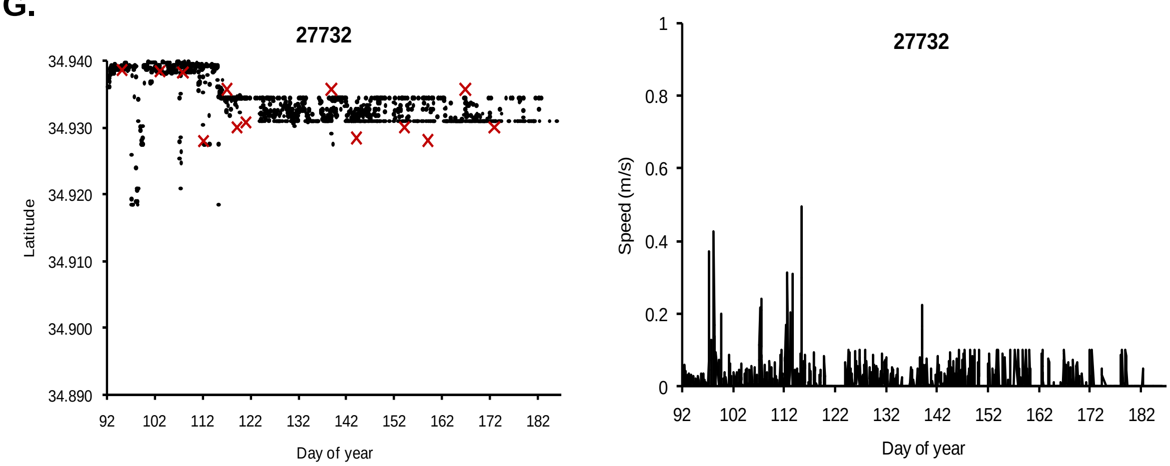


27750
Latitude
34.920
34.910
34.900
34.890
34.880
34.870
97
100
103
106
109
112
115
Day of year
27750
Speed (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
97
100
103
106
109
112
115
Day of year

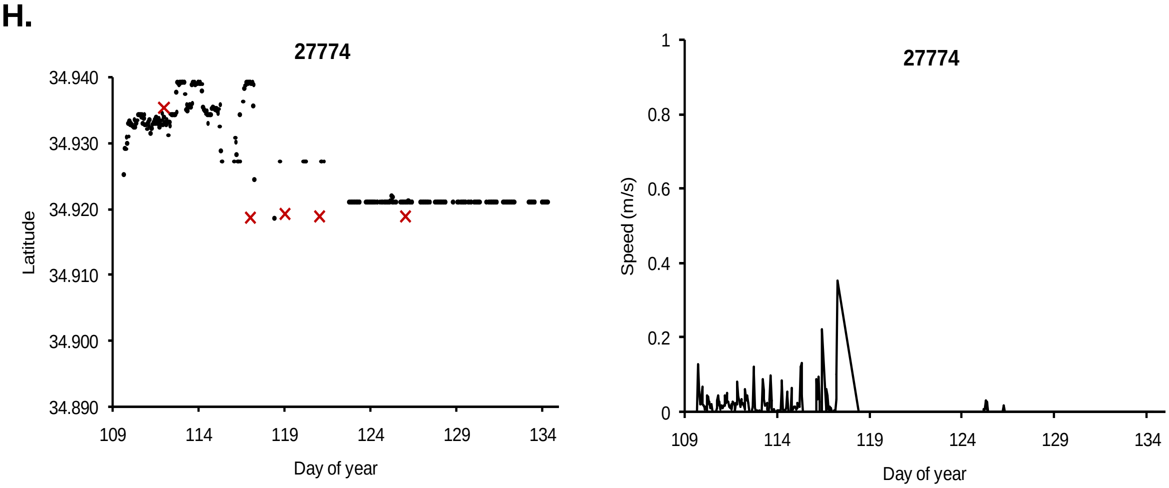
F.


27729
Latitude
34.940
34.930
34.920
34.910
34.900
34.890
91 101 111 121 131 141 151 161
Day of year
27729
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
91 101 111 121 131 141 151 161
Day of year

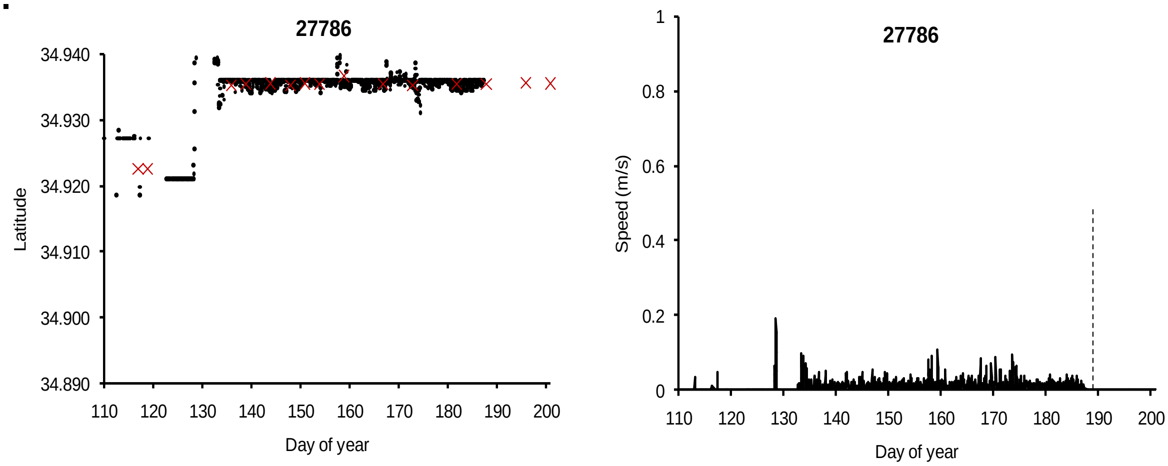
G.


27732
Latitude
34.940
34.930
34.920
34.910
34.900
34.890
92 102 112 122 132 142 152 162 172 182
Day of year
27732
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
92 102 112 122 132 142 152 162 172 182
Day of year

H.

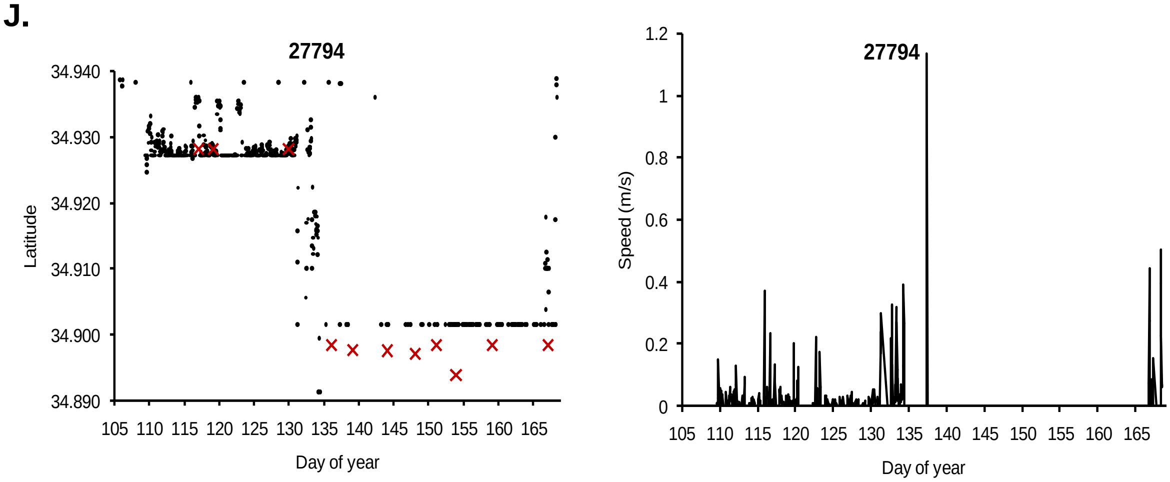

27774
Latitude
34.940
34.930
34.920
34.910
34.900
34.890
109 114 119 124 129 134
Day of year
27774
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
109 114 119 124 129 134
Day of year

I.



27786
Latitude
34.940
34.930
34.920
34.910
34.900
34.890
110
120
130
140
150
160
170
180
190
200
Day of year
27786
Speed (m/s)
1
0.8
0.6
0.4
0.2
0
Day of year

J.



27794
Latitude
34.940
34.930
34.920
34.910
34.900
34.890
105
110
115
120
125
130
135
140
145
150
155
160
165
Day of year
27794
Speed (m/s)
1.2
1
0.8
0.6
0.4
0.2
0
Day of year

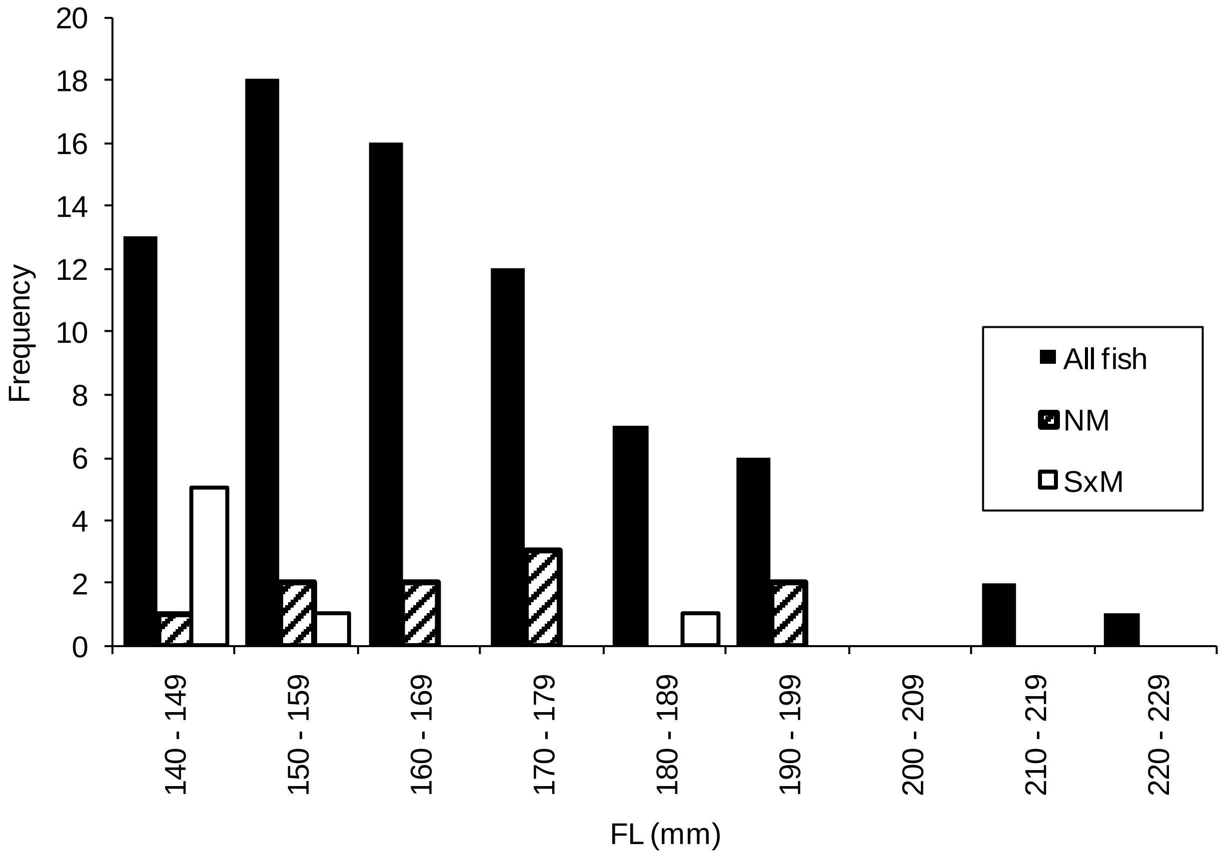
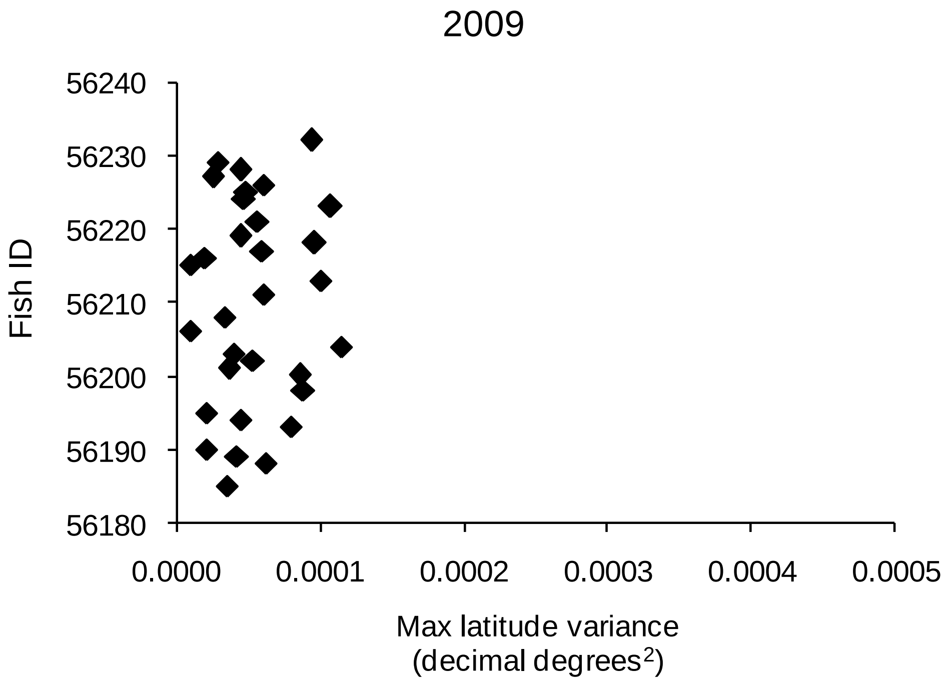


Figure 13. Length frequency of telemetered age-1 spot for 2010. Natural mortalities were evenly distributed across the size range of telemetered fish, surgery related mortalities occurred mostly with fish <160mm (FL).



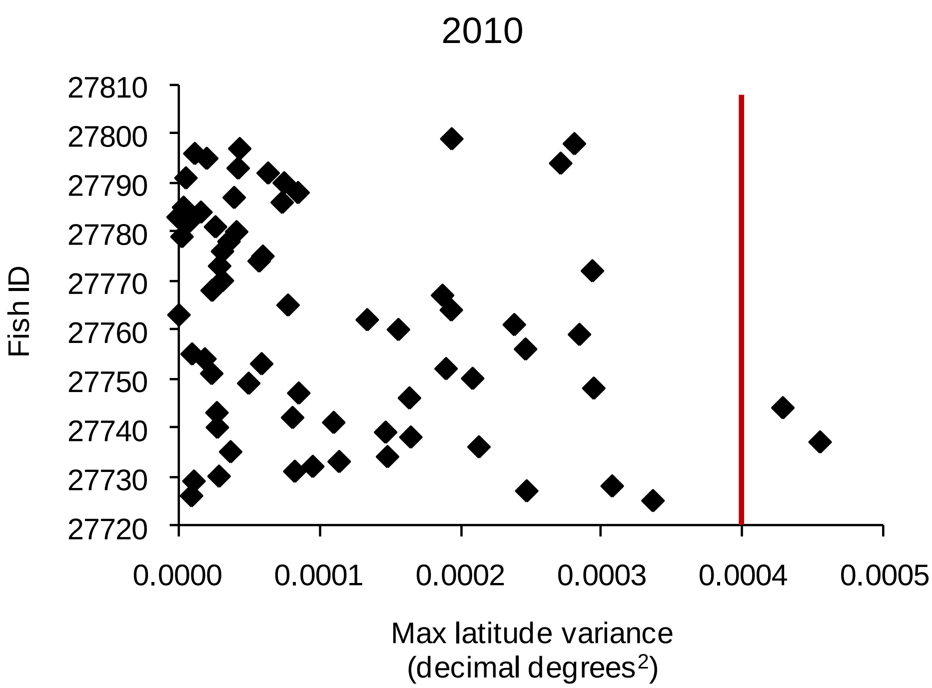


Figure 14. Maximum latitudinal variance (squared decimal degrees) for telemetered age-1 spot in 2009 and 2010. Outliers occurred in 2010 at >0.0004 squared decimal degrees (red line).

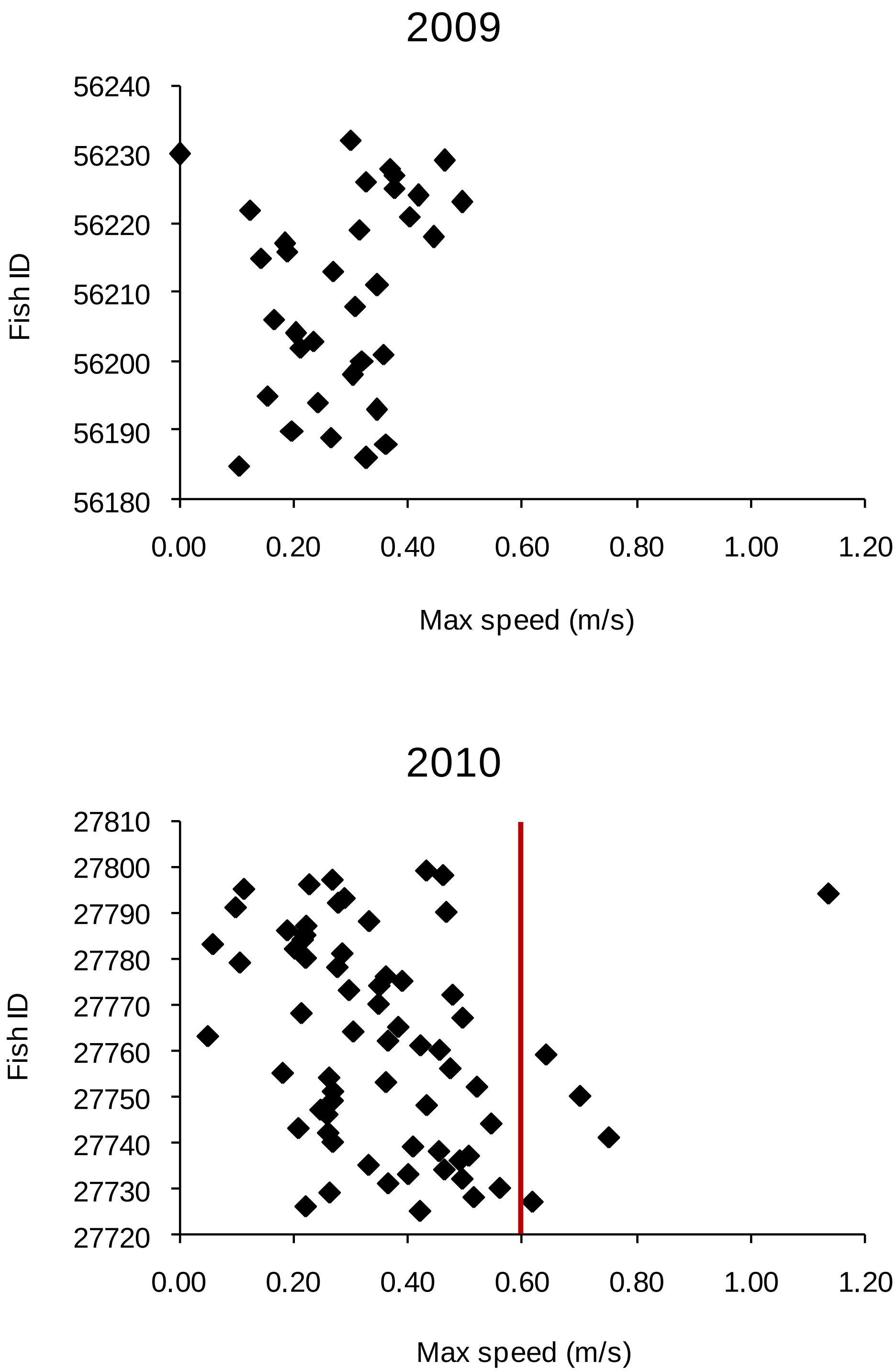


Figure 15. Maximum speed (m/s) for telemetered age-1 spot in 2009 and 2010. Outliers occurred in 2010 at >0.60 m/s (red line).

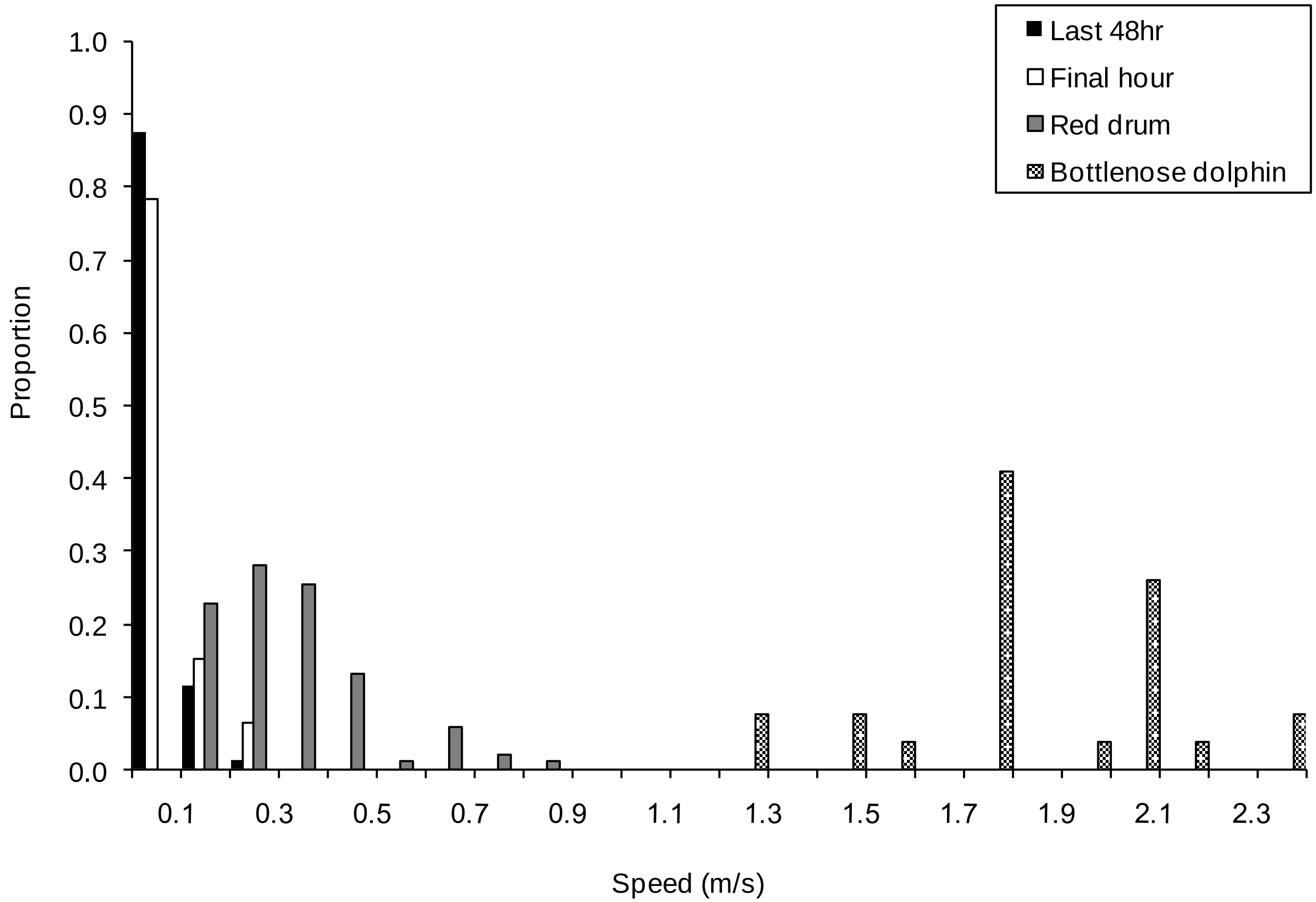


Figure 16. Estimated average emigration swimming speeds for telemetered age-1 spot, compared to estimates from the same study creeks for red drum and bottlenose dolphin (Bacheler 2008). Two different estimated averages for age-1 spot are shown: an average of the last 48 hours of detections (including emigration) and the final estimated hourly average swimming speed.

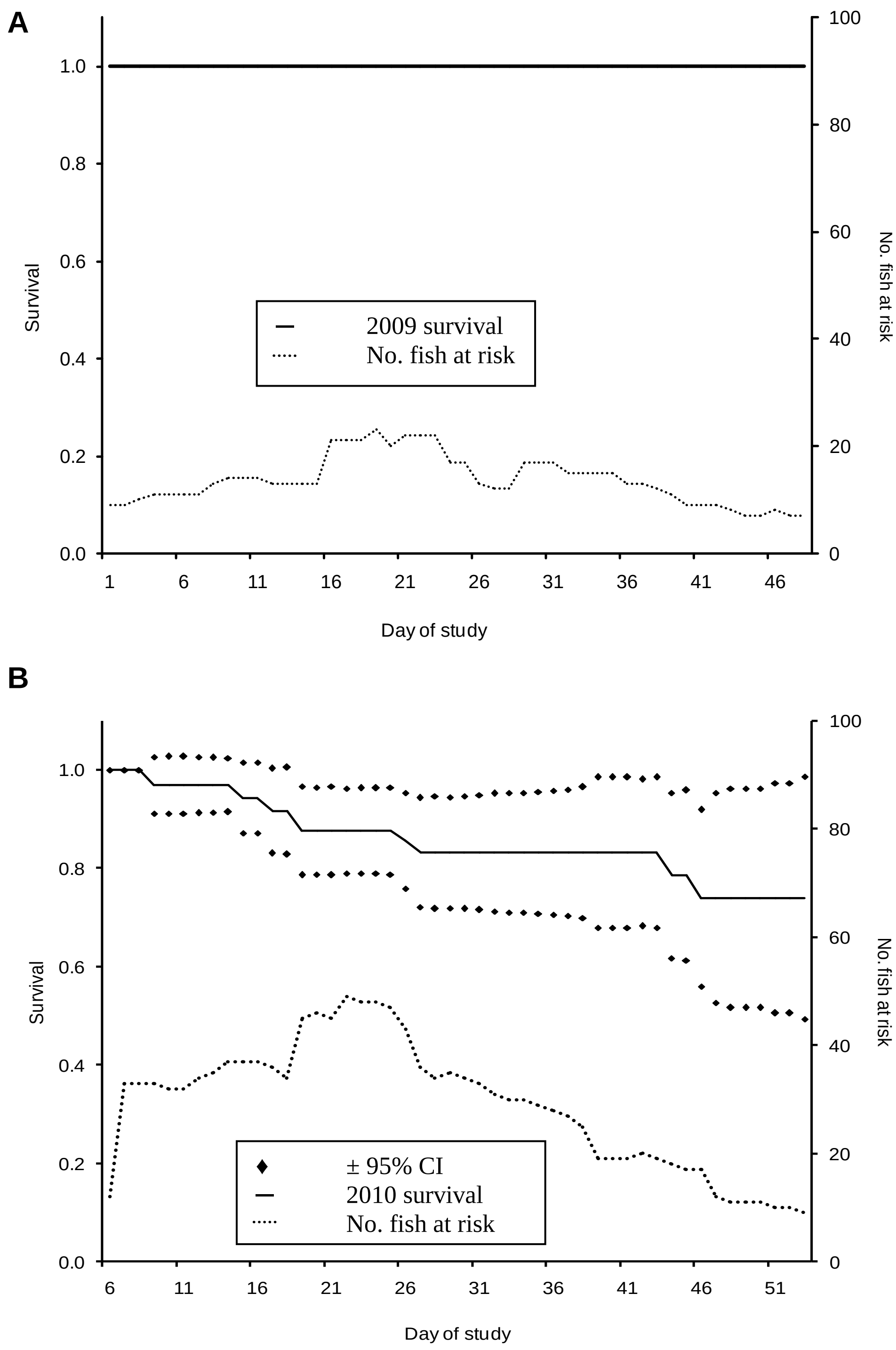


Figure 17. A. 2009 estimated daily survival (solid line) and numbers of fish at risk (dotted line) for telemetered age-1spot; **B.** 2010 estimated daily survival for telemetered age-1 spot and number of fish at risk. Diamonds indicate 95% upper and lower confidence intervals of survival.

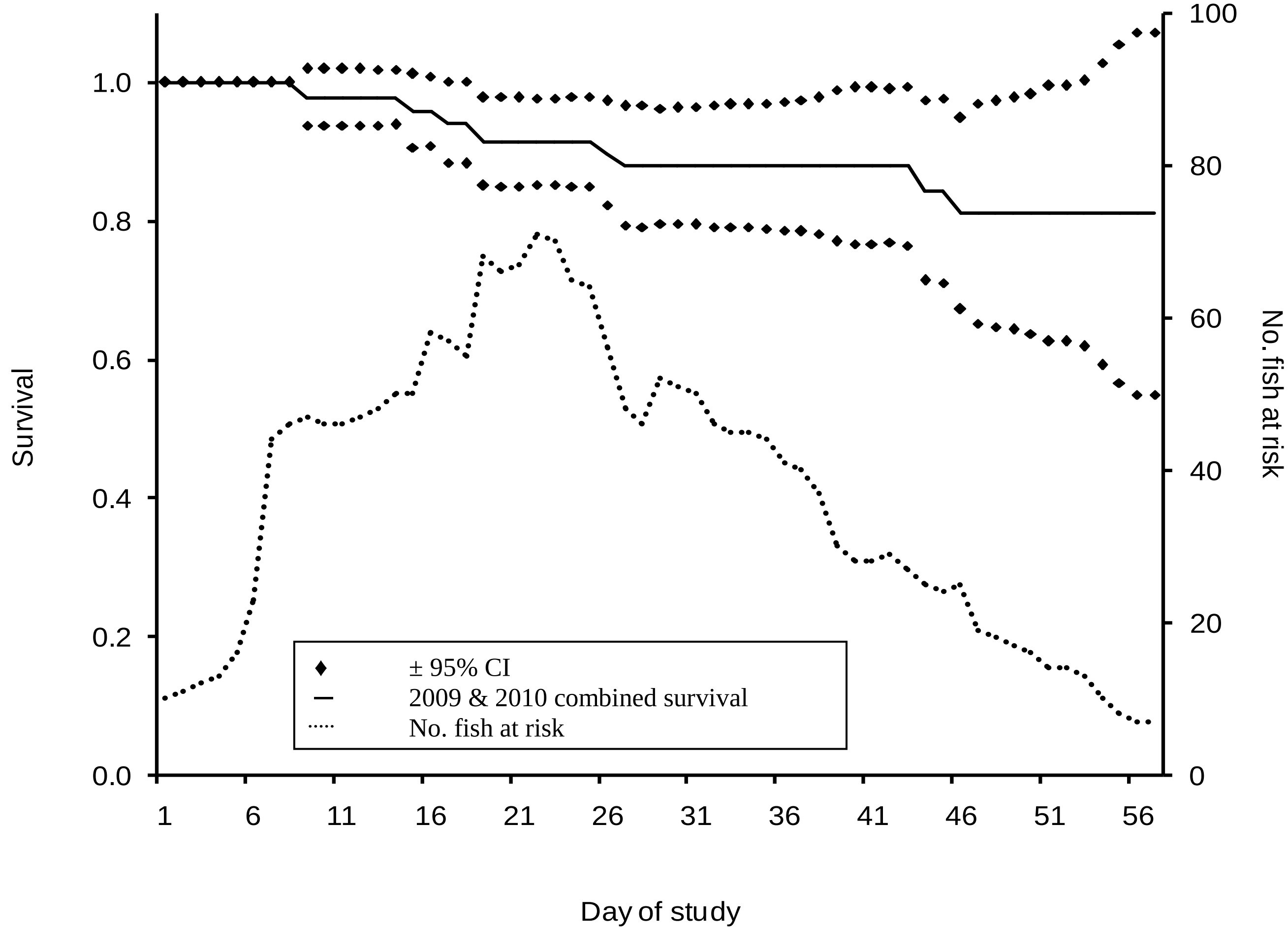


Figure 18. Estimated daily survival (solid line) and numbers of fish at risk (dotted line) for 2009 – 2010 (combined) telemetered age-1 spot. Diamonds indicate 95% upper and lower confidence intervals of survival.

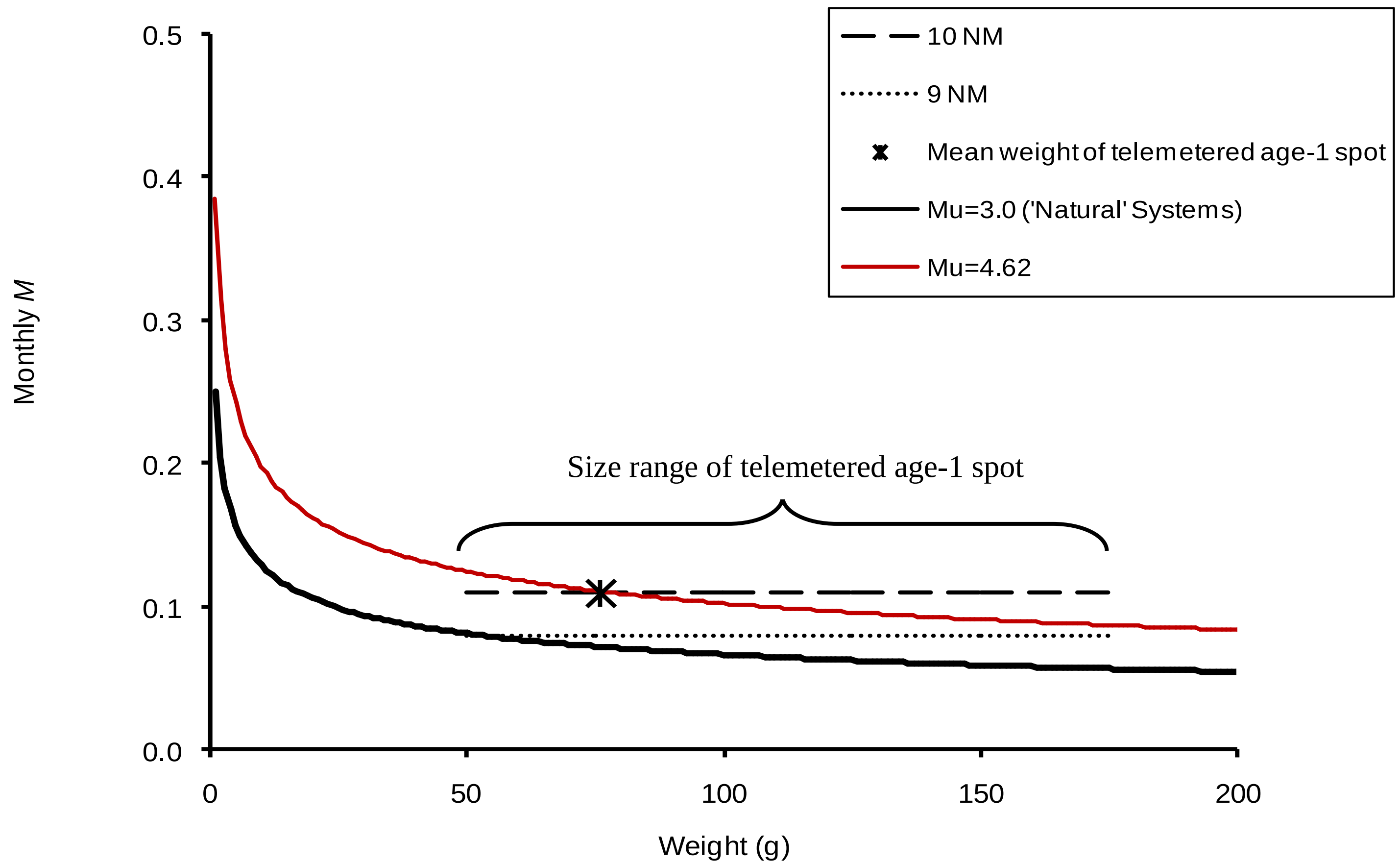


Figure 19. Observed (horizontal lines) and predicted (black curve; Lorenzen 1996) 30-d *M*s by weight for age-1 spot; observed monthly *M* is a combined Kaplan-Meier estimate for 2009 and 2010 telemetered fish, estimated for 9 (dotted line) and 10 (dashed line) natural mortalities. The red curve represents the Lorenzen (1996) function adjusted to match the mean weight and mortality rate (10 NM, combined year estimate).

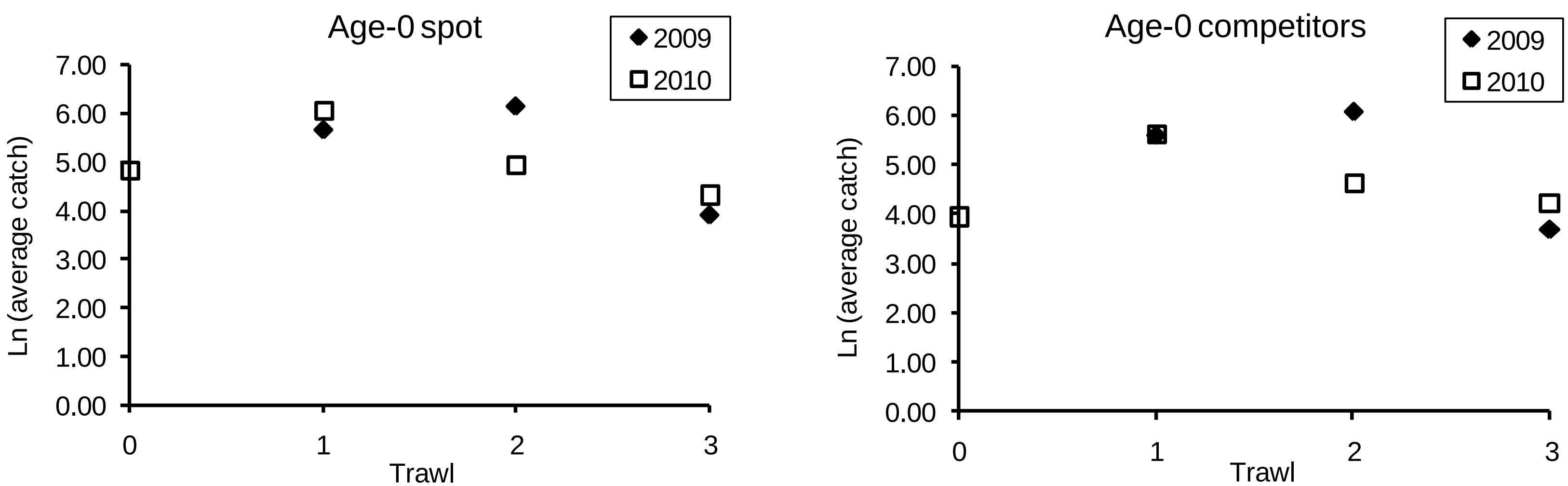


Figure 20. Age-0 spot and potential competitor trawl CPUE for 2009 and 2010. Potential competitors include Atlantic croaker (*Micropogonias undulatus*), pinfish (*Lagodon rhomboides*) and *Paralichthys* spp.

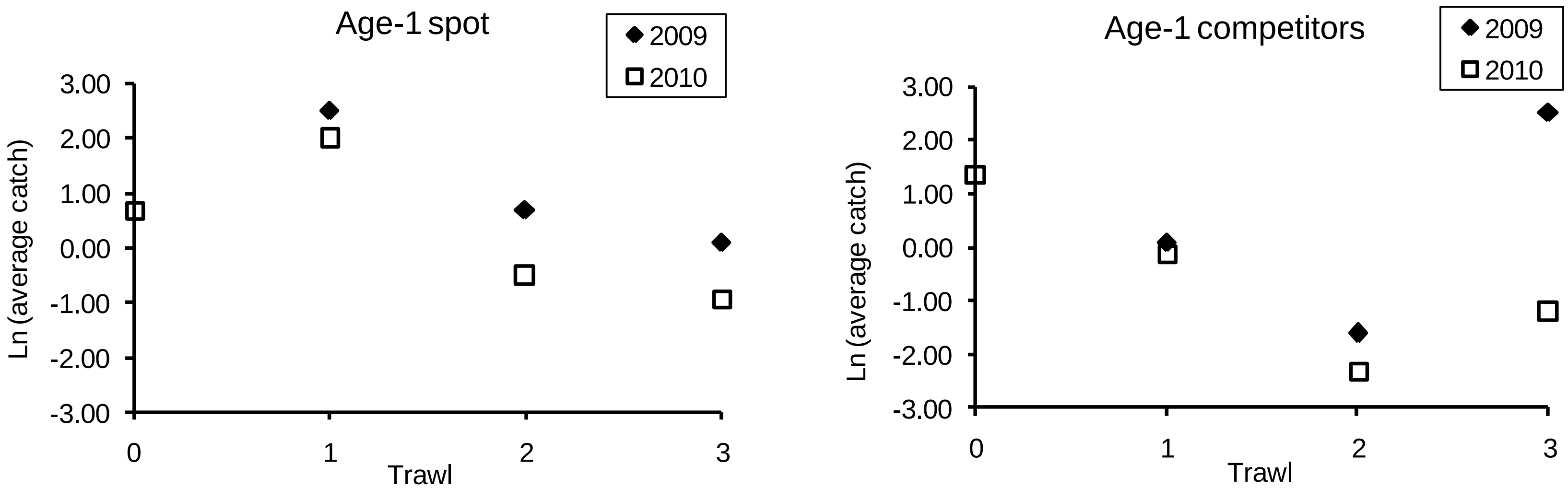


Figure 21. Age-1 spot and potential competitor trawl CPUE for 2009 and 2010. Potential competitors include Atlantic croaker (*Micropogonias undulatus*), pinfish (*Lagodon rhomboides*) and *Paralichthys* spp.

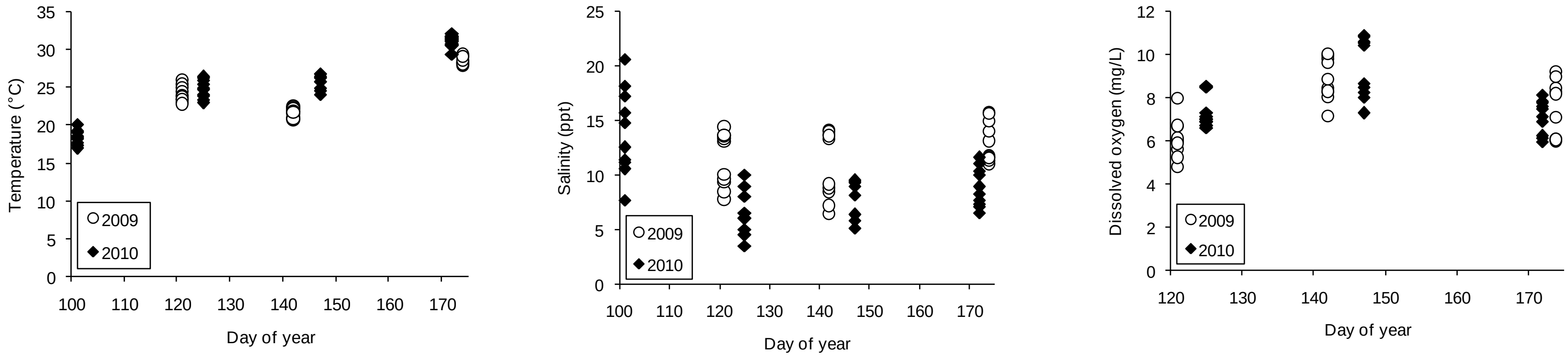


Figure 22. Temperature (°C), salinity (ppt), and dissolved oxygen (mg/L) in 2009 and 2010.

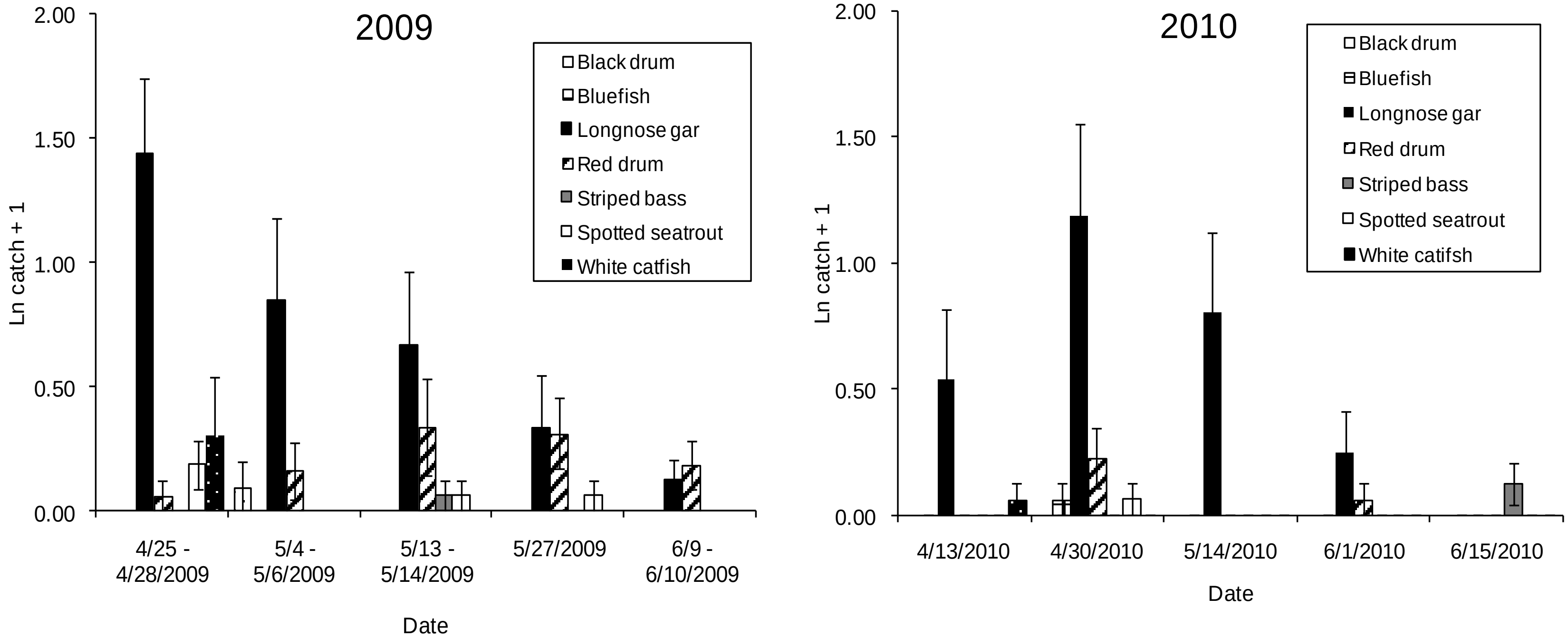


Figure 23. Daily gill net CPUE for predators ≥375mm TL in 2009 and 2010.

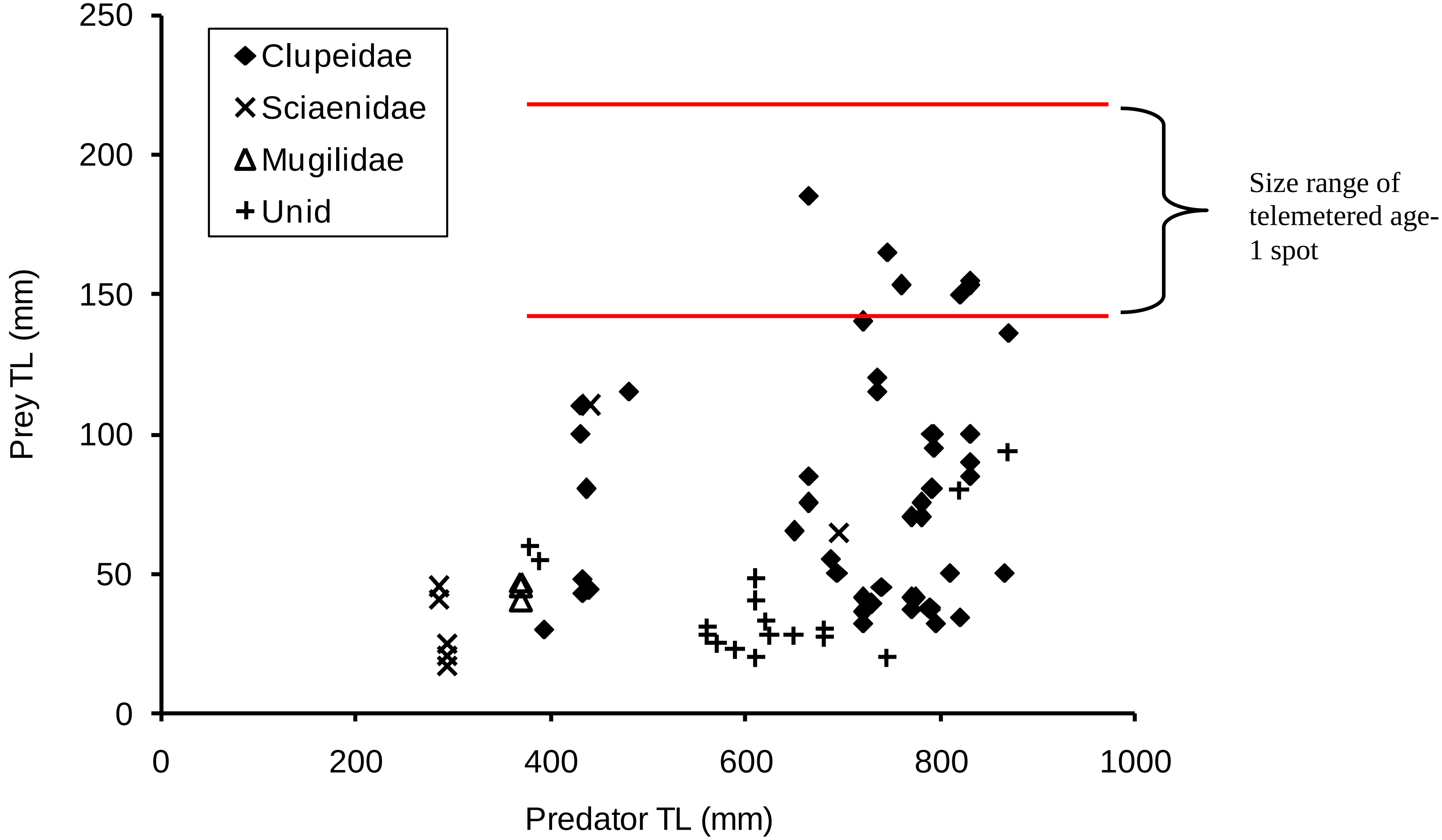


Figure 24. Finfish and unidentified prey sizes from all lavaged predators in 2009 and 2010. Range includes size range of telemetered age-1 spot.

APPENDICES

Appendix Table 1. A. Age-1 spot surgically implanted with V9-6L sonic transmitters 23 April – 21 May 2009. **B.** Age-1 spot surgically implanted with V9-6L sonic transmitters 1 – 22 April 2010. Gray lines indicate fish excluded from analyses due to surgery related mortality, emigration from the study site <7 d after implantation, or transmitter failure.

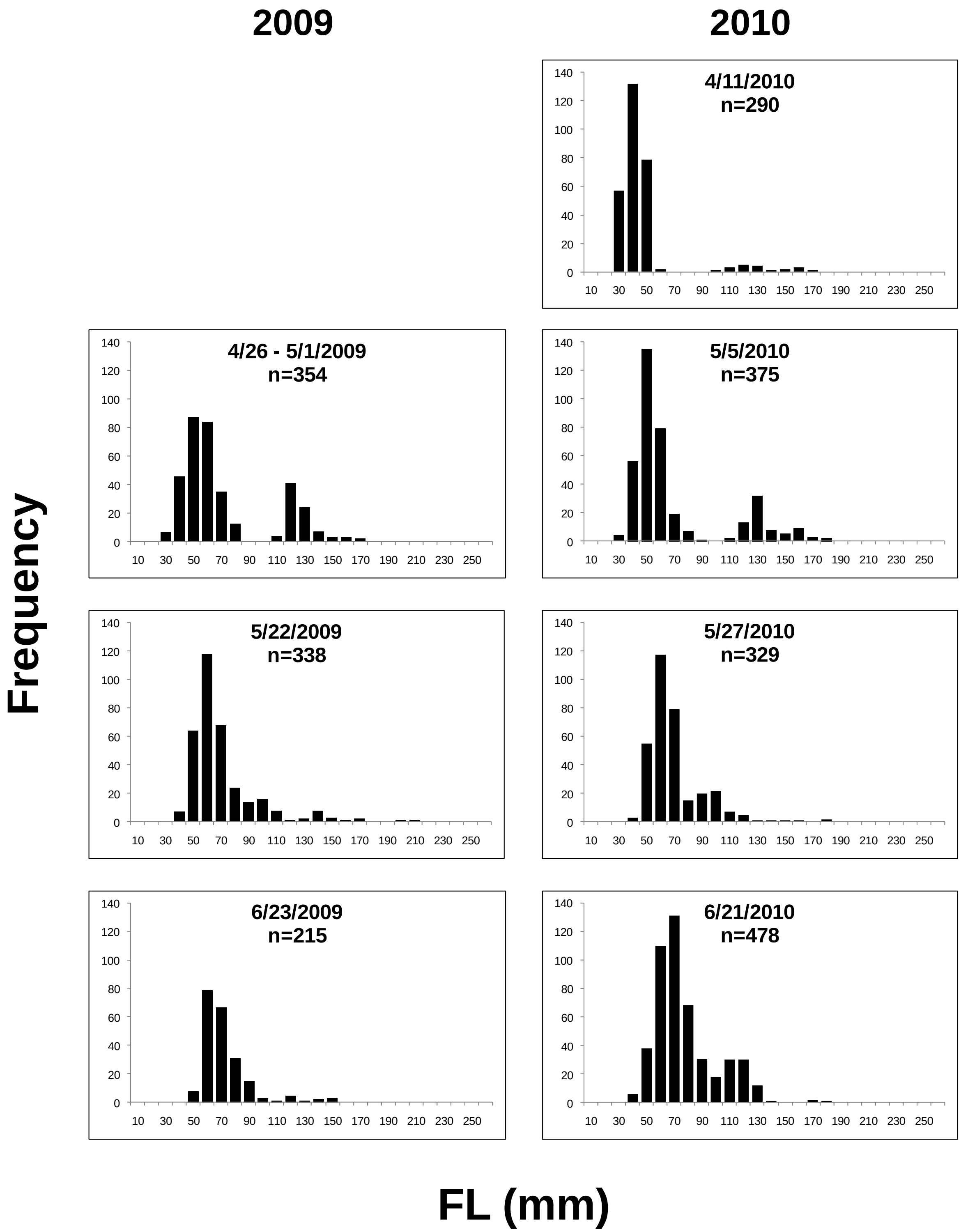
Transmitter #	Date Activated	Date Implanted	Fate Date	No. Days At Risk	Fate	Creek	Weight (g)	FL (mm)	TL (mm)
56185	5/6/2009	5/8/2009	5/17/2009	9	EM	Hancock	76.2	163	171
56186	5/11/2009	5/21/2009	5/25/2009	0	SM	Clubfoot	71.5	165	177
56187	5/11/2009	5/21/2009	5/24/2009	4	EM	Clubfoot	87.7	173	185
56188	4/20/2009	4/23/2009	5/15/2009	23	EM	Hancock	60.0	160	170
56189	5/11/2009	5/21/2009	6/2/2009	13	EM	Clubfoot	88.5	177	190
56190	5/11/2009	5/21/2009	6/9/2009	20	EM	Clubfoot	74.1	165	180
56191	5/11/2009	5/21/2009	5/23/2009	3	EM	Clubfoot	73.5	167	180
56192	5/11/2009	5/21/2009	5/24/2009	4	EM	Clubfoot	90	175	189
56193	5/6/2009	5/8/2009	5/23/2009	16	EM	Hancock	63.5	154	164
56194	5/11/2009	5/21/2009	5/29/2009	9	EM	Clubfoot	70.8	166	178
56195	5/11/2009	5/21/2009	5/31/2009	11	EM	Clubfoot	55	150	160
56196	5/6/2009	5/8/2009	5/12/2009	5	EM	Hancock	82.6	169	180
56198	5/11/2009	5/21/2009	5/27/2009	7	EM	Clubfoot	69.5	160	170
56199	5/6/2009	5/8/2009	5/12/2009	5	EM	Hancock	65.1	160	170
56200	5/6/2009	5/8/2009	5/14/2009	7	EM	Hancock	74.2	164	175
56201	5/6/2009	5/8/2009	5/15/2009	8	EM	Hancock	62.5	156	165
56202	5/6/2009	5/11/2009	5/23/2009	13	EM	Clubfoot	78.5	163	175
56203	5/6/2009	5/8/2009	5/17/2009	10	EM	Hancock	62.6	157	167
56204	5/6/2009	5/11/2009	5/30/2009	20	EM	Clubfoot	59.7	155	167
56205	5/6/2009	5/8/2009	5/11/2009	4	EM	Hancock	81.5	168	178
56206	4/24/2009	4/30/2009	5/6/2009	0	SM	Clubfoot	57	155	165
56207	4/24/2009	5/8/2009	5/13/2009	6	EM	Hancock	105.5	184	206
56208	4/24/2009	4/30/2009	6/15/2009	47	EM	Clubfoot	59	157	167
56209	5/6/2009	5/12/2009	5/15/2009	4	EM	Clubfoot	57	153	163
56210	5/6/2009	5/12/2009	5/15/2009	4	EM	Clubfoot	67.8	160	170
56211	5/6/2009	5/12/2009	5/27/2009	16	EM	Clubfoot	58.8	155	166
56212	5/6/2009	5/21/2009	5/24/2009	4	EM	Clubfoot	95.5	177	190
56213	4/20/2009	5/1/2009	5/17/2009	16	EM	Clubfoot	65	160	170
56214	4/20/2009	5/1/2009	5/4/2009	4	EM	Clubfoot	50.6	151	161
56215	4/20/2009	4/26/2009	6/10/2009	43	EM	Hancock	74.5	170	180
56216	4/20/2009	4/25/2009	5/3/2009	9	EM	Clubfoot	53.3	150	160
56217	4/20/2009	4/23/2009	6/4/2009	43	EM	Hancock	90.0	175	185
56218	4/20/2009	4/23/2009	5/17/2009	25	EM	Hancock	74.1	168	178
56219	5/6/2009	5/11/2009	6/15/2009	36	EM	Clubfoot	54.7	155	167
56220	4/20/2009	4/30/2009	5/3/2009	4	EM	Clubfoot	57.7	153	163
56221	4/20/2009	5/8/2009	5/18/2009	8	EM	Hancock	111.8	185	200
56222	4/20/2009	4/30/2009	5/13/2009	14	EM	Clubfoot	73.8	171	182
56223	4/20/2009	4/23/2009	5/15/2009	22	EM	Hancock	61.3	157	169
56224	4/20/2009	5/8/2009	6/11/2009	35	EM	Hancock	65.0	160	170
56225	4/20/2009	4/23/2009	5/15/2009	22	EM	Hancock	63.5	158	169
56226	4/20/2009	4/23/2009	7/13/2009	82	BL	Hancock	46.3	146	156
56227	4/20/2009	4/23/2009	5/15/2009	23	EM	Hancock	64.4	158	168
56228	4/20/2009	4/23/2009	5/10/2009	18	EM	Hancock	60.6	160	172
56229	4/20/2009	5/8/2009	6/7/2009	31	EM	Hancock	103.5	181	195
56230	4/20/2009	5/1/2009	5/1/2009	0	SM	Clubfoot	52.6	150	160
56231	4/20/2009	4/26/2009	4/27/2009	2	EM	Hancock	66.1	160	170
56232	4/20/2009	4/23/2009	7/13/2009	82	BL	Hancock	63.8	162	171
56234	5/6/2009	5/8/2009	5/10/2009	3	EM	Hancock	109.1	190	203

Appendix Table 1B.

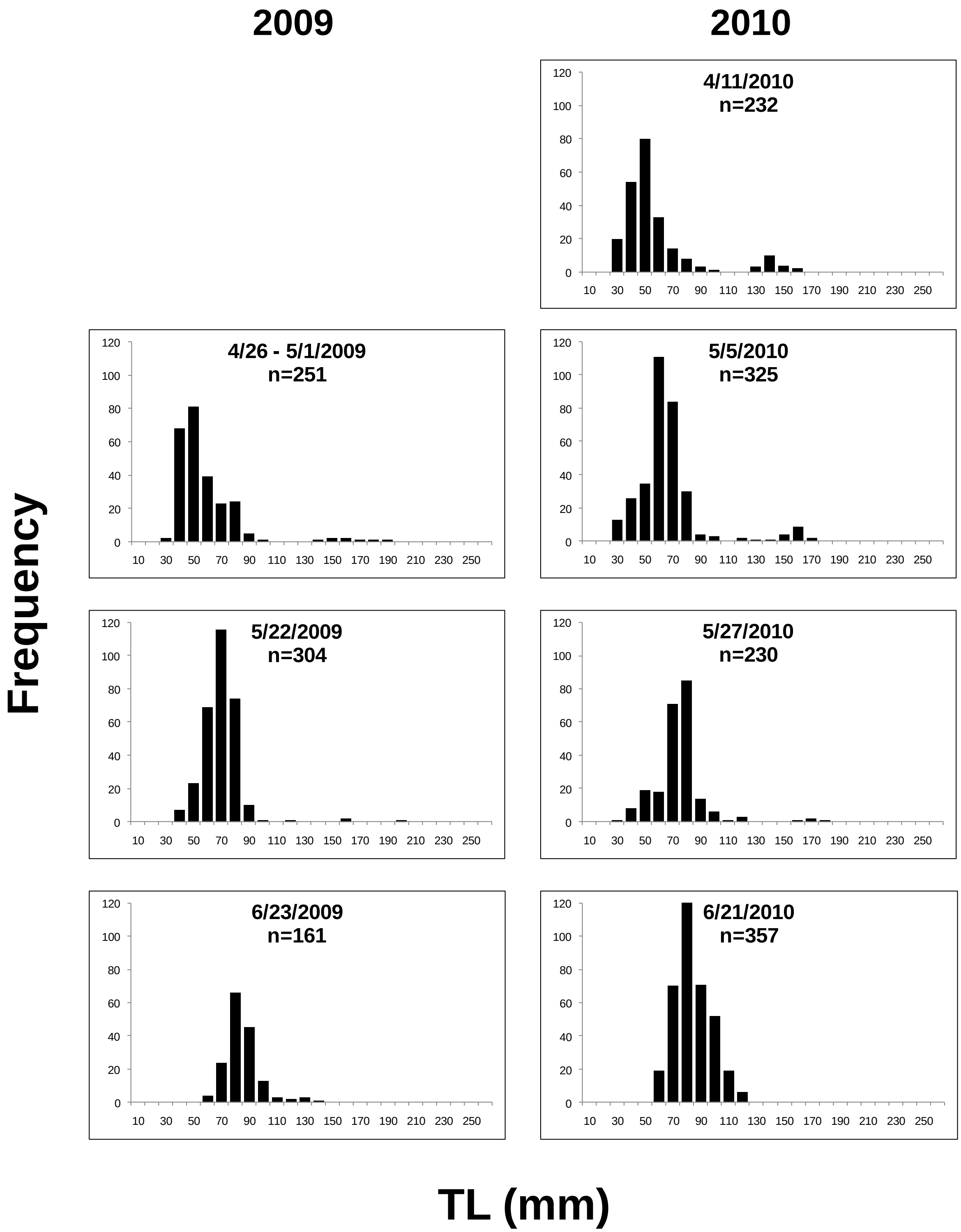
Transmitter #	Date Activated	Date Implanted	Fate Date	No. Days At Risk	Fate	Creek	Weight (g)	FL (mm)	TL (mm)
27725	3/29/2010	4/6/2010	4/29/2010	24	EM	Clubfoot	56	156	167
27726	3/29/2010	4/5/2010	4/5/2010	0	SM	Hancock	98	184	198
27727	3/29/2010	4/6/2010	5/1/2010	26	EM	Clubfoot	63	159	170
27728	3/29/2010	4/7/2010	4/27/2010	16	EM	Clubfoot	72	170	182
27729	3/29/2010	4/1/2010	4/9/2010	9	NM	Hancock	80	176	189
27730	3/29/2010	4/6/2010	4/24/2010	19	EM	Clubfoot	62	163	179
27731	3/29/2010	4/5/2010	4/25/2010	21	EM	Hancock	100	187	201
27732	3/29/2010	4/2/2010	4/26/2010	25	NM	Hancock	56	155	165
27733	3/29/2010	4/5/2010	5/13/2010	39	EM	Hancock	161	219	237
27734	3/29/2010	4/6/2010	5/16/2010	41	EM	Clubfoot	68	161	172
27735	3/29/2010	4/7/2010	4/16/2010	10	EM	Clubfoot	83	173	185
27736	3/29/2010	4/5/2010	4/26/2010	22	EM	Hancock	174	225	243
27737	4/6/2010	4/7/2010	4/13/2010	7	EM	Clubfoot	63	159	170
27738	4/6/2010	4/7/2010	5/23/2010	47	EM	Clubfoot	112	193	205
27739	4/6/2010	4/12/2010	4/21/2010	10	EM	Hancock	82	170	184
27740	3/29/2010	4/6/2010	4/19/2010	14	NM	Clubfoot	120	195	209
27741	3/29/2010	4/6/2010	4/19/2010	14	NM	Clubfoot	63	179	193
27742	3/29/2010	4/6/2010	4/15/2010	10	NM	Clubfoot	59	159	172
27743	4/6/2010	4/7/2010	4/25/2010	19	EM	Clubfoot	83	175	188
27744	4/6/2010	4/7/2010	5/25/2010	47	EM	Clubfoot	47	150	161
27745	4/6/2010	4/7/2010	4/12/2010	6	EM	Clubfoot	86	174	189
27746	4/6/2010	4/7/2010	4/18/2010	12	EM	Clubfoot	62	155	166
27747	4/6/2010	4/7/2010	4/14/2010	8	EM	Clubfoot	70	164	175
27748	4/6/2010	4/7/2010	5/16/2010	36	NM	Clubfoot	75	164	176
27749	4/6/2010	4/7/2010	5/7/2010	31	EM	Clubfoot	59	156	168
27750	4/6/2010	4/7/2010	4/17/2010	11	NM	Clubfoot	115	197	212
27751	4/6/2010	4/7/2010	5/8/2010	31	EM	Clubfoot	58	160	167
27752	4/6/2010	4/7/2010	5/16/2010	40	EM	Clubfoot	58	152	163
27753	4/6/2010	4/7/2010	5/16/2010	35	EM	Clubfoot	67	164	177
27754	4/6/2010	4/7/2010	4/13/2010	7	EM	Clubfoot	58	153	165
27755	4/6/2010	4/7/2010	4/7/2010	0	SM	Clubfoot	55	148	160
27756	4/6/2010	4/7/2010	4/21/2010	15	EM	Clubfoot	123	198	212
27757	4/6/2010	4/7/2010	4/7/2010	0	TF	Clubfoot	153	216	232
27758	4/6/2010	4/7/2010	4/12/2010	6	EM	Clubfoot	70	161	173
27759	4/6/2010	4/7/2010	4/20/2010	14	EM	Clubfoot	48	148	158
27760	4/6/2010	4/7/2010	5/6/2010	30	EM	Clubfoot	63	155	166
27761	4/6/2010	4/7/2010	5/2/2010	26	EM	Clubfoot	55	152	154
27762	4/6/2010	4/7/2010	5/23/2010	46	EM	Clubfoot	72	166	179
27763	4/6/2010	4/7/2010	4/7/2010	0	SM	Clubfoot	63	158	171
27764	4/6/2010	4/7/2010	5/17/2010	41	EM	Clubfoot	82	175	189
27765	4/11/2010	4/12/2010	5/4/2010	23	EM	Hancock	56	154	163
27766	4/11/2010	4/12/2010	4/13/2010	2	EM	Hancock	60	158	170
27767	4/11/2010	4/12/2010	6/18/2010	67	EM	Hancock	53	149	160
27768	4/11/2010	4/14/2010	5/23/2010	40	EM	Clubfoot	50	145	158
27769	4/11/2010	4/15/2010	4/15/2010	0	TF	Hancock	59	150	161
27770	4/11/2010	4/19/2010	4/26/2010	8	EM	Hancock	97	173	186
27771	4/11/2010	4/14/2010	4/17/2010	4	EM	Clubfoot	66	162	174
27772	4/11/2010	4/14/2010	5/13/2010	30	EM	Clubfoot	97	175	188
27773	4/11/2010	4/15/2010	4/26/2010	12	EM	Hancock	82	167	180
27774	4/11/2010	4/19/2010	4/27/2010	9	NM	Hancock	47	145	158
27775	4/11/2010	4/14/2010	4/22/2010	9	EM	Clubfoot	56	152	162
27776	4/11/2010	4/14/2010	5/1/2010	18	EM	Clubfoot	103	183	198
27777	4/11/2010	4/15/2010	4/15/2010	0	EM	Hancock	62	155	167
27778	4/11/2010	4/19/2010	5/27/2010	39	EM	Hancock	74	165	177
27779	4/11/2010	4/15/2010	5/22/2010	38	EM	Hancock	127	193	209
27780	4/11/2010	4/19/2010	4/19/2010	0	SM	Hancock	53	148	160
27781	4/11/2010	4/15/2010	5/5/2010	21	EM	Hancock	116	190	204
27782	4/11/2010	4/15/2010	4/15/2010	0	SM	Hancock	56	150	160
27783	4/11/2010	4/15/2010	4/15/2010	0	SM	Hancock	52	145	156
27784	4/11/2010	4/19/2010	4/26/2010	8	EM	Hancock	111	185	199
27785	4/13/2010	4/22/2010	4/30/2010	9	EM	Hancock	102	178	191
27786	4/13/2010	4/22/2010	6/22/2010	59	NM	Hancock	74	163	170
27787	4/13/2010	4/19/2010	5/4/2010	16	EM	Hancock	101	178	190
27788	4/13/2010	4/19/2010	6/1/2010	44	EM	Hancock	109	187	199
27789	4/13/2010	4/19/2010	4/19/2010	0	EM	Hancock	85	163	176
27790	4/13/2010	4/22/2010	5/8/2010	17	EM	Hancock	83	169	180
27791	4/13/2010	4/19/2010	4/25/2010	7	EM	Hancock	123	192	206
27792	4/13/2010	4/19/2010	5/8/2010	20	EM	Hancock	60	150	160
27793	4/13/2010	4/19/2010	4/19/2010	0	SM	Hancock	48	142	150
27794	4/13/2010	4/19/2010	5/14/2010	26	NM	Hancock	99	172	184
27795	4/13/2010	4/19/2010	4/25/2010	7	EM	Hancock	101	181	195
27796	4/13/2010	4/22/2010	5/28/2010	37	EM	Hancock	83	166	178
27797	4/13/2010	4/19/2010	5/20/2010	32	EM	Hancock	107	180	193
27798	4/13/2010	4/22/2010	5/12/2010	21	EM	Hancock	70	159	170
27799	4/13/2010	4/22/2010	5/16/2010	25	EM	Hancock	48	143	151

Appendix Figure 1. Size-frequency distributions for spot and potential competitors (Atlantic croaker, pinfish and *Paralichthys* spp).

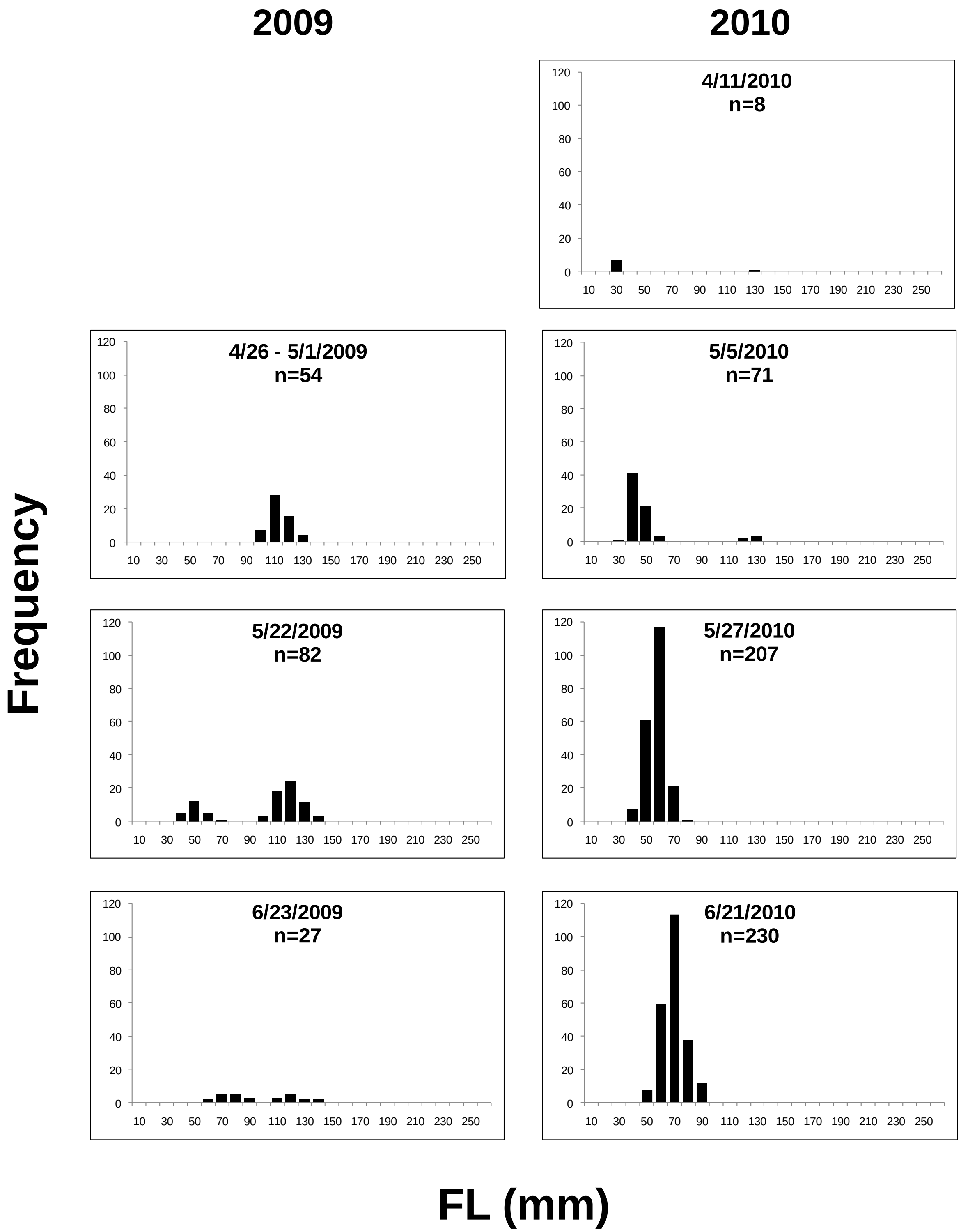
Spot frequency by FL



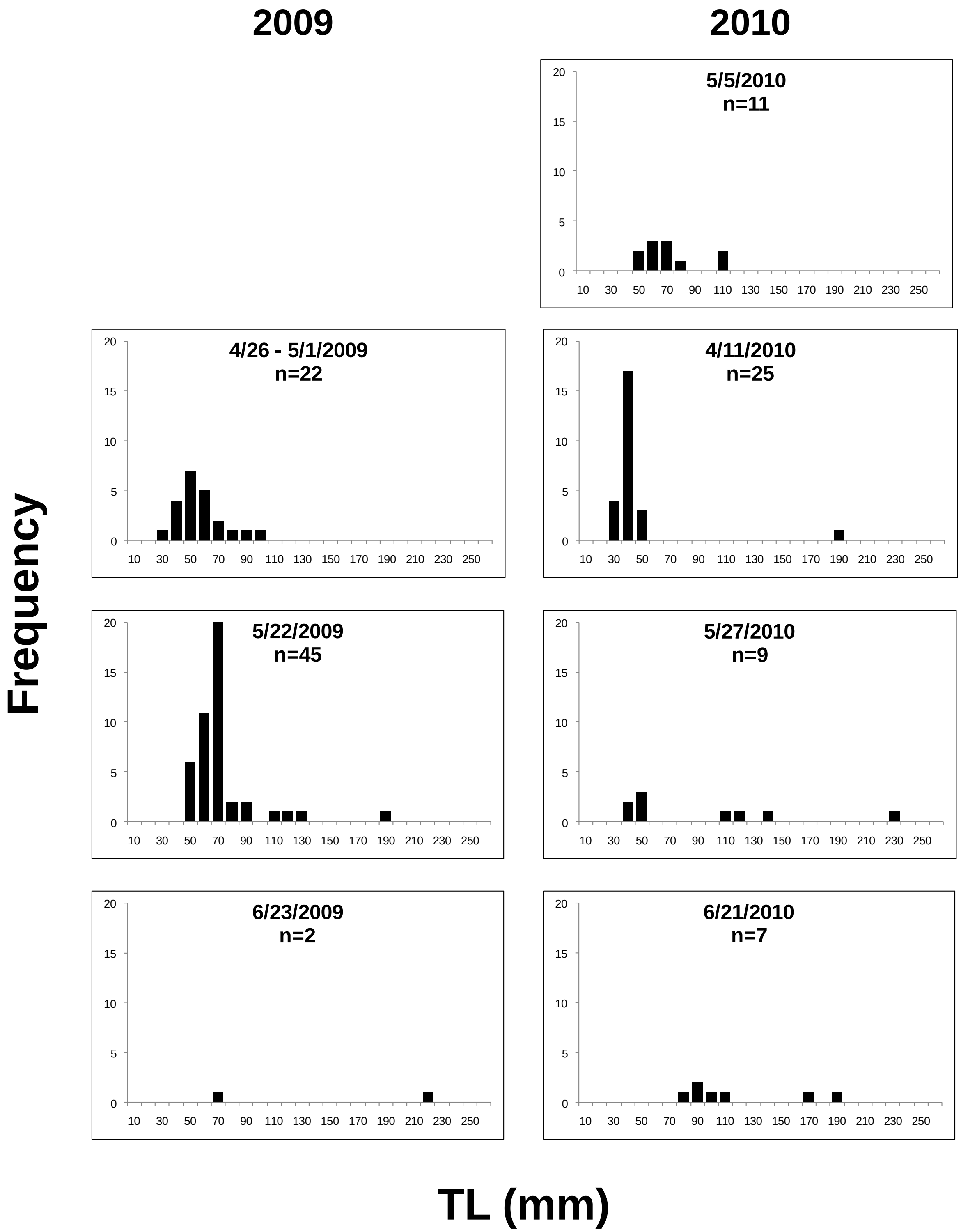
Atlantic croaker frequency by TL



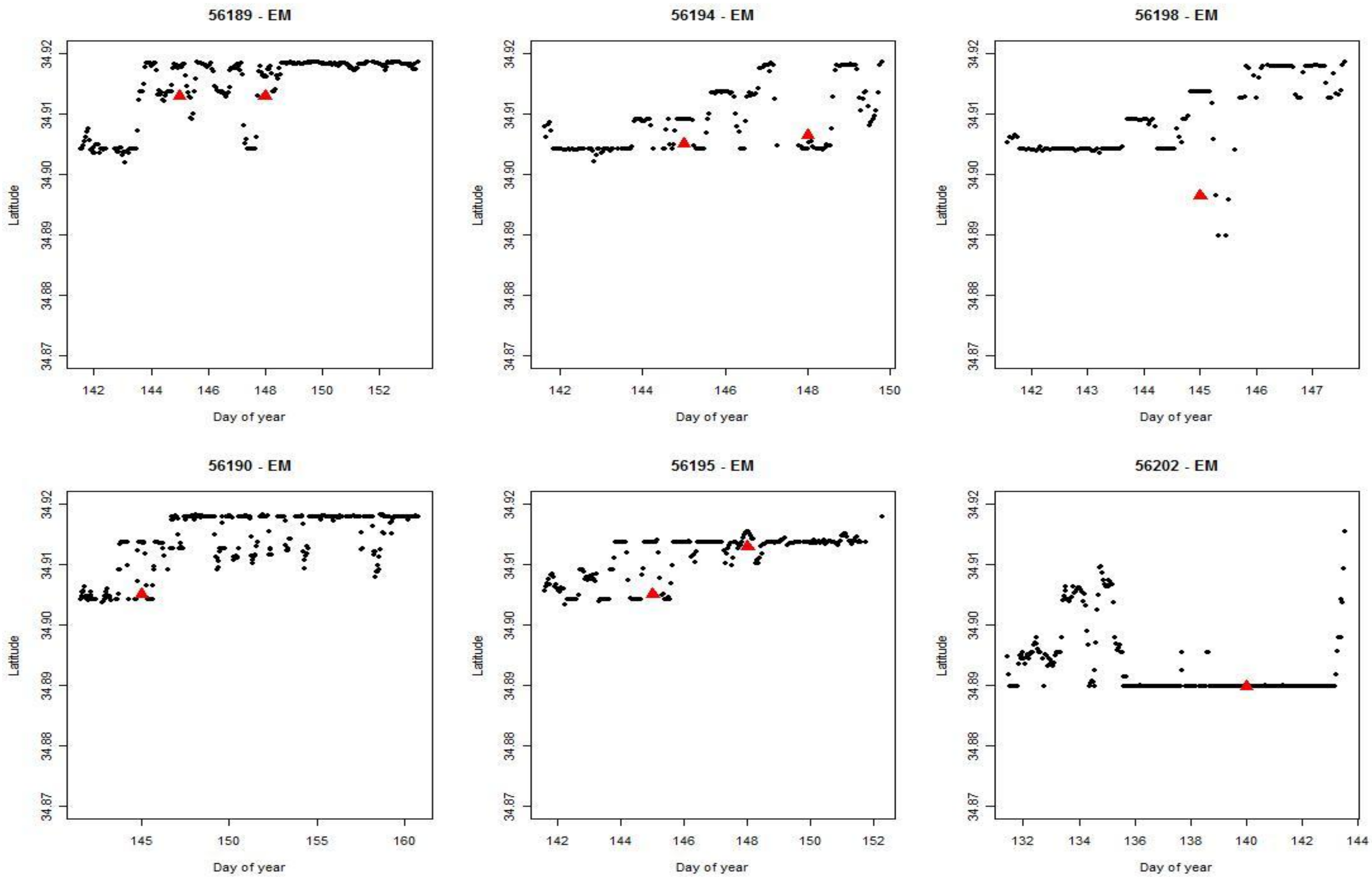
Pinfish frequency by FL

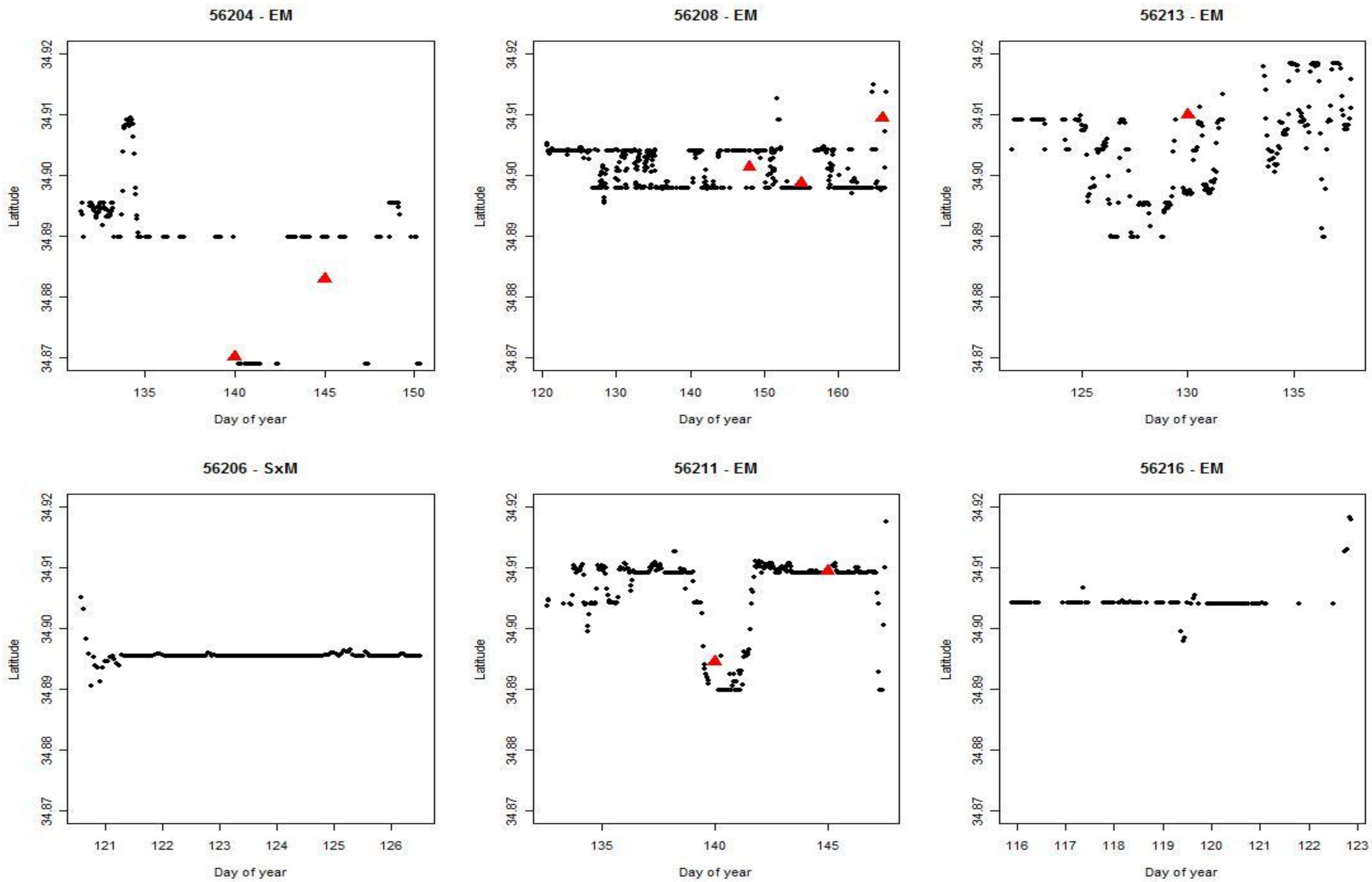


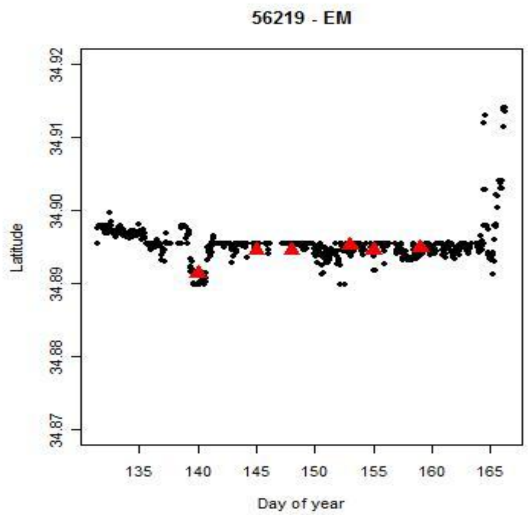
***Paralichthys* spp. frequency by TL**

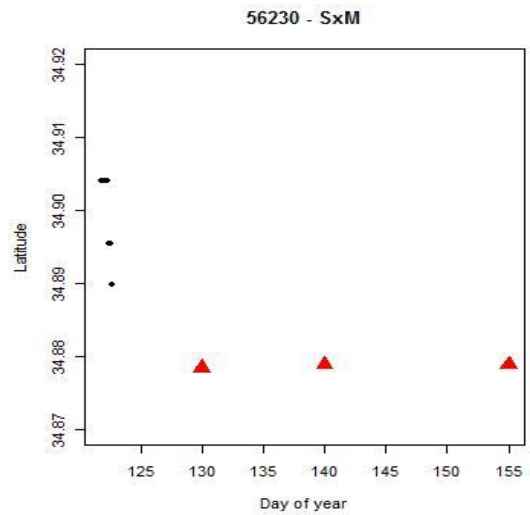


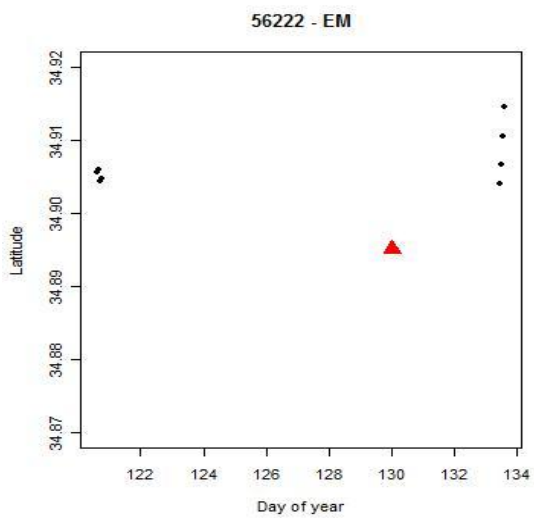
Appendix Figure 2. Estimated average hourly latitudes and manual tracking relocations for all at risk telemetered age-1 spot in 2009. Black dots are VR2/W detections, red triangles indicate manual tracking relocations. Fate assignments are: emigration (EM), surgery related mortality (SxM), natural mortality (NM) and battery life end (BL).

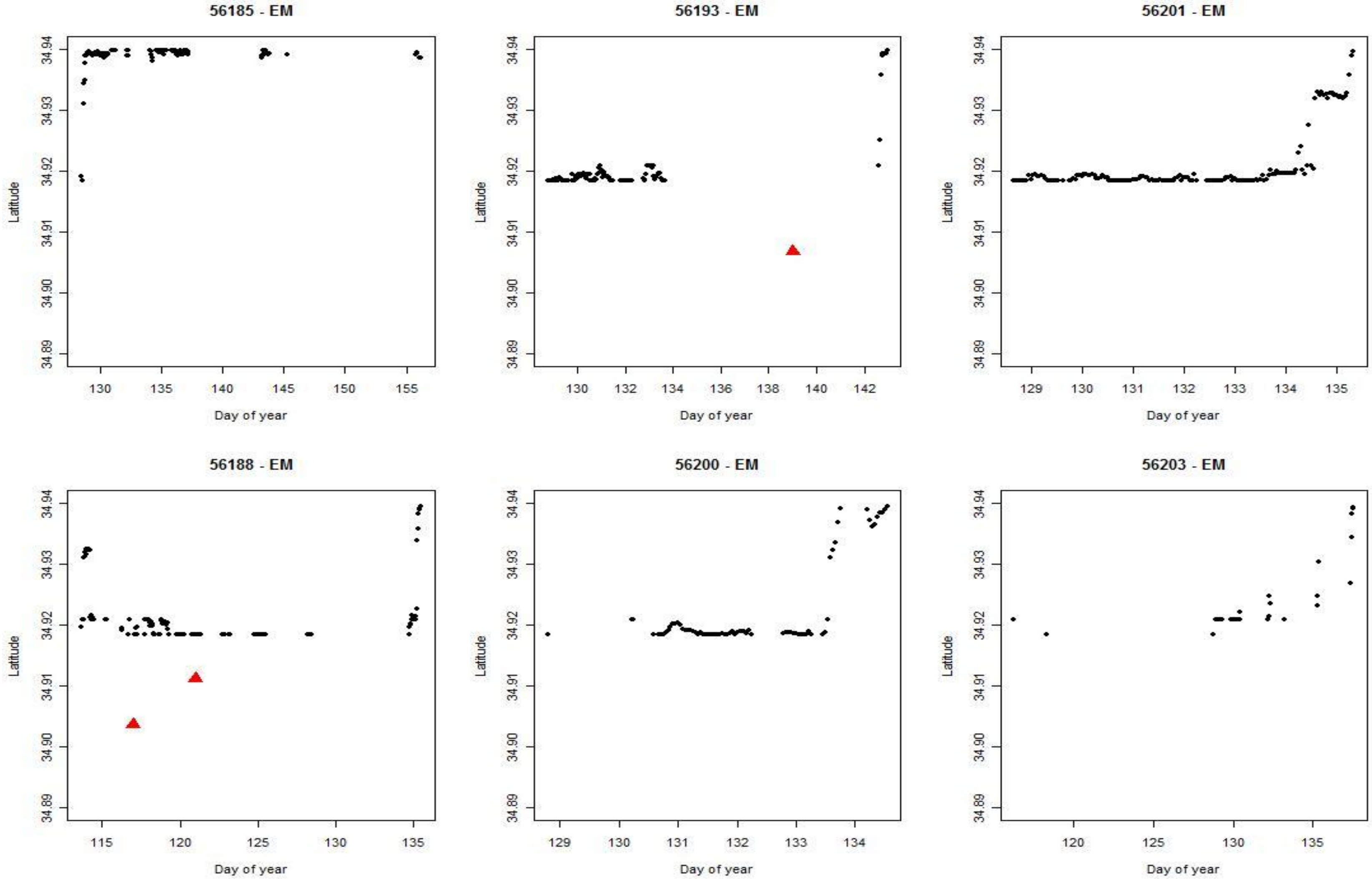

56189 - EM
56194 - EM
56198 - EM
56190 - EM
56195 - EM
56202 - EM
Latitude
Day of year
34.87
34.88
34.89
34.90
34.91
34.92

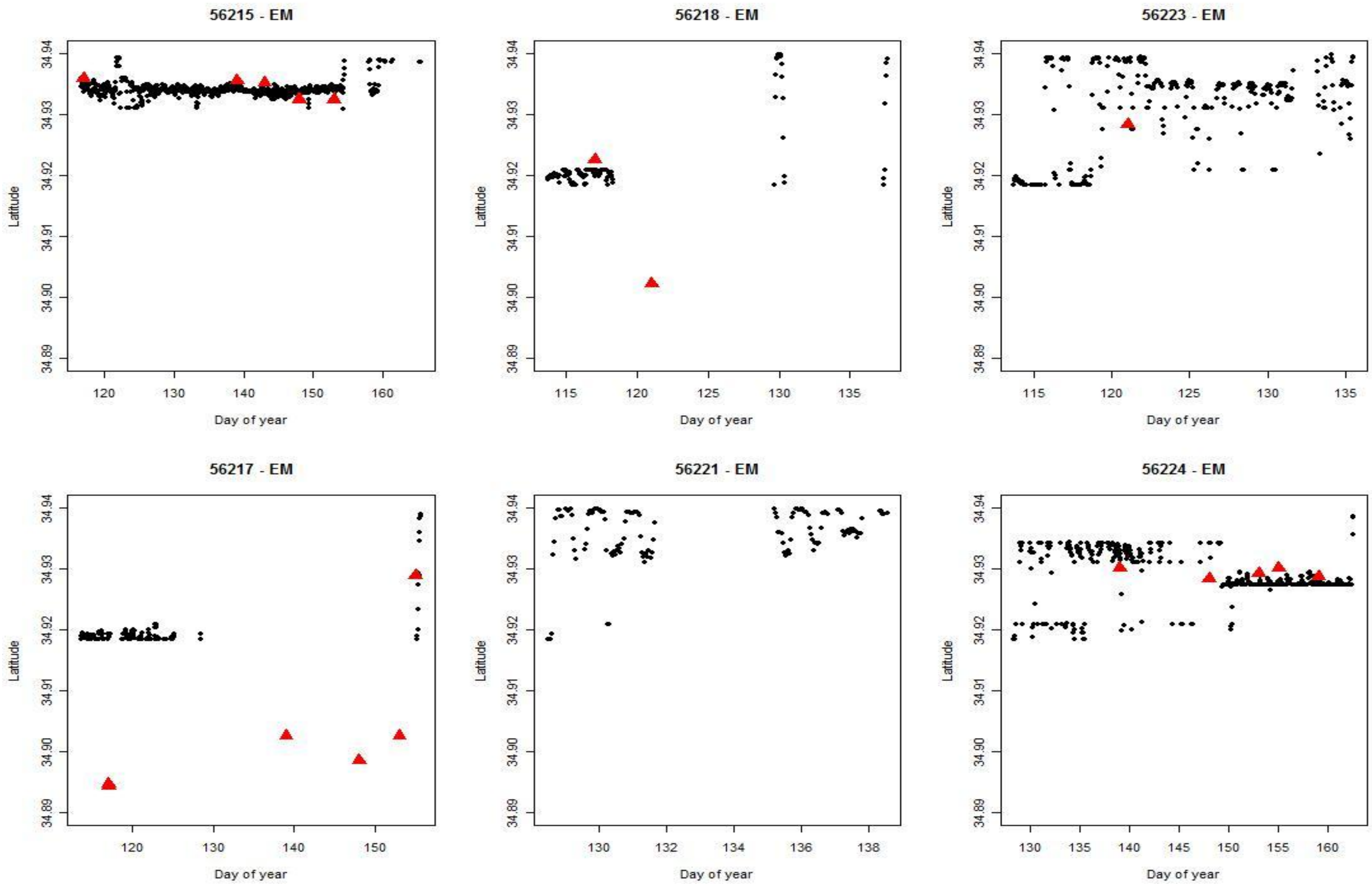

56204 - EM
56208 - EM
56213 - EM
56206 - SxM
56211 - EM
56216 - EM
Latitude
Day of year
34.87
34.88
34.89
34.90
34.91
34.92

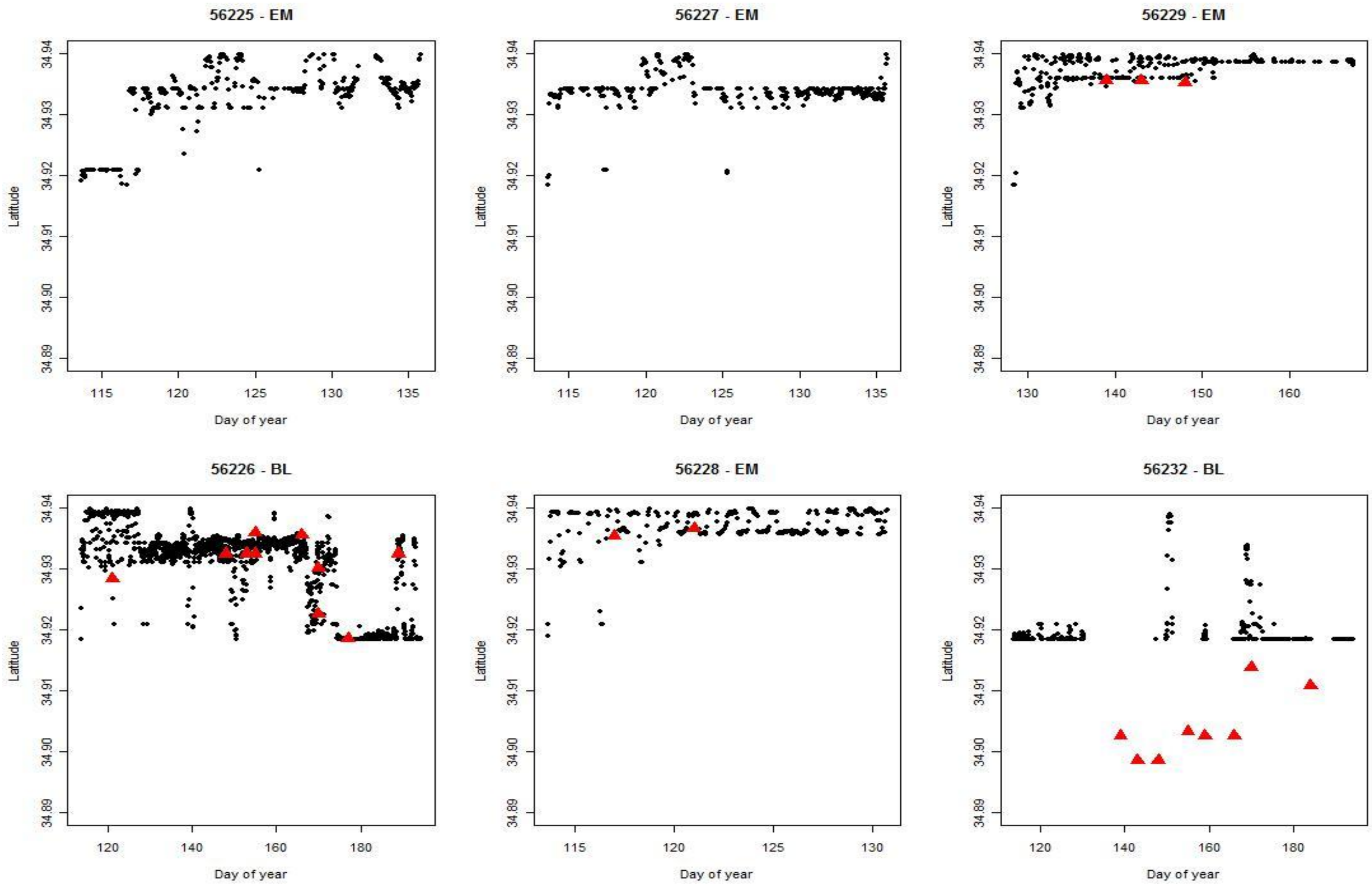

56219 - EM
Latitude
Day of year


56230 - SxM
Latitude
Day of year

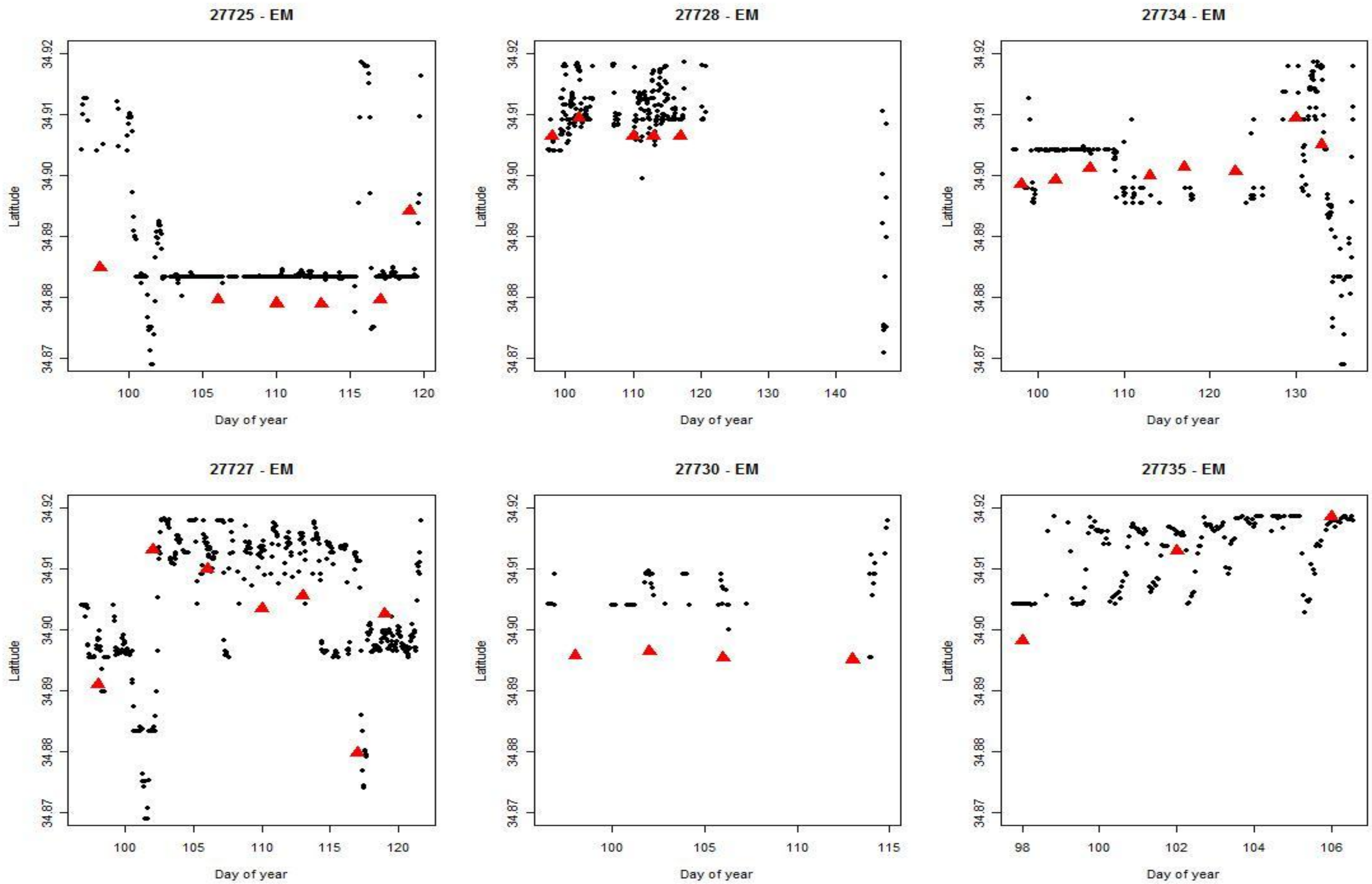

56222 - EM
Latitude
Day of year


56185 - EM
56193 - EM
56201 - EM
56188 - EM
56200 - EM
56203 - EM
Latitude
34.89
34.90
34.91
34.92
34.93
34.94
Day of year
130
135
140
145
150
155
132
134
136
138
142
129
131
133
115
120
125

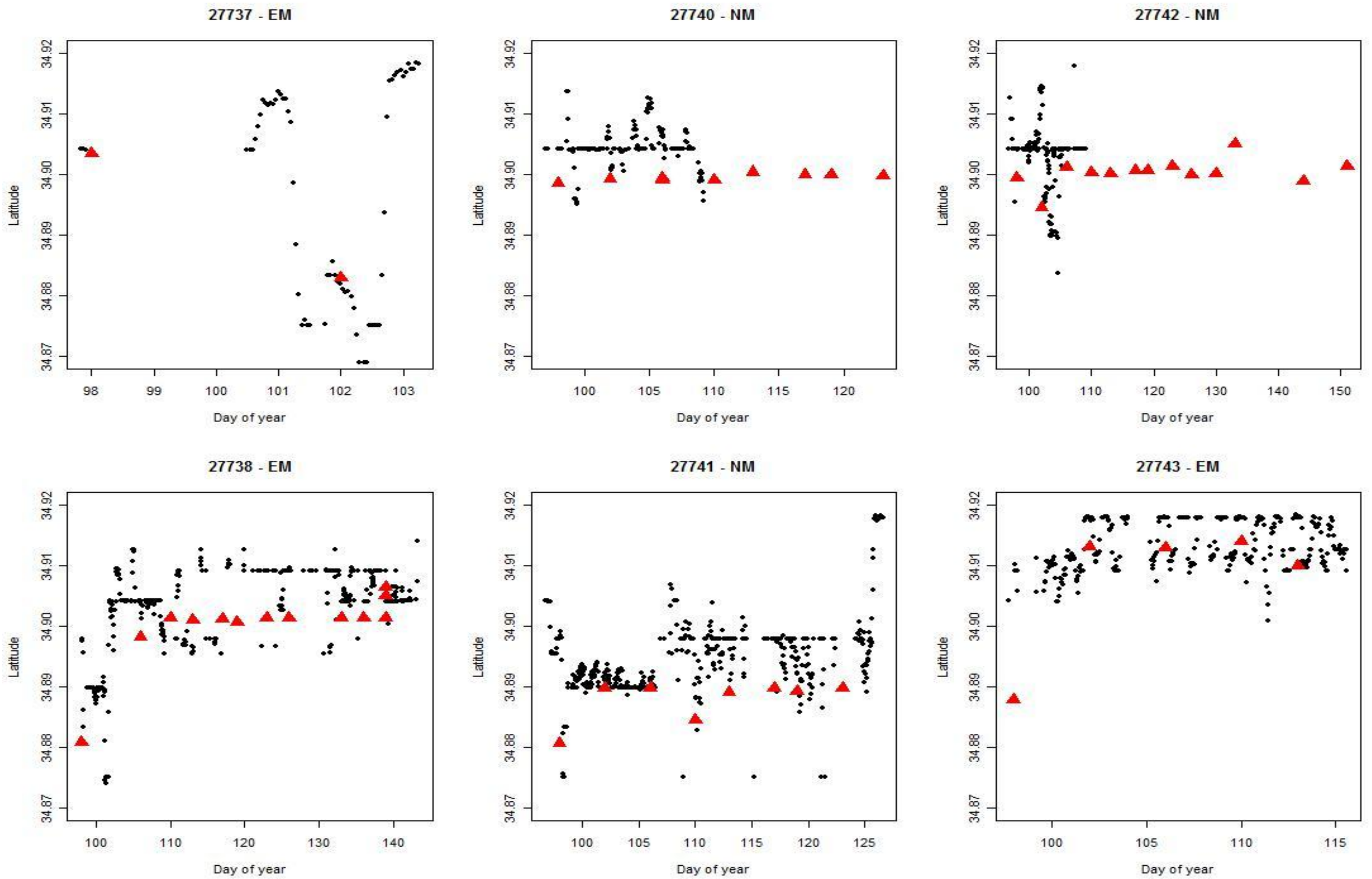

56215 - EM
56218 - EM
56223 - EM
56217 - EM
56221 - EM
56224 - EM
Latitude
34.89
34.90
34.91
34.92
34.93
34.94
Day of year
120 130 140 150 160
115 120 125 130 135
115 120 125 130 135
120 130 140 150
130 132 134 136 138
130 135 140 145 150 155 160

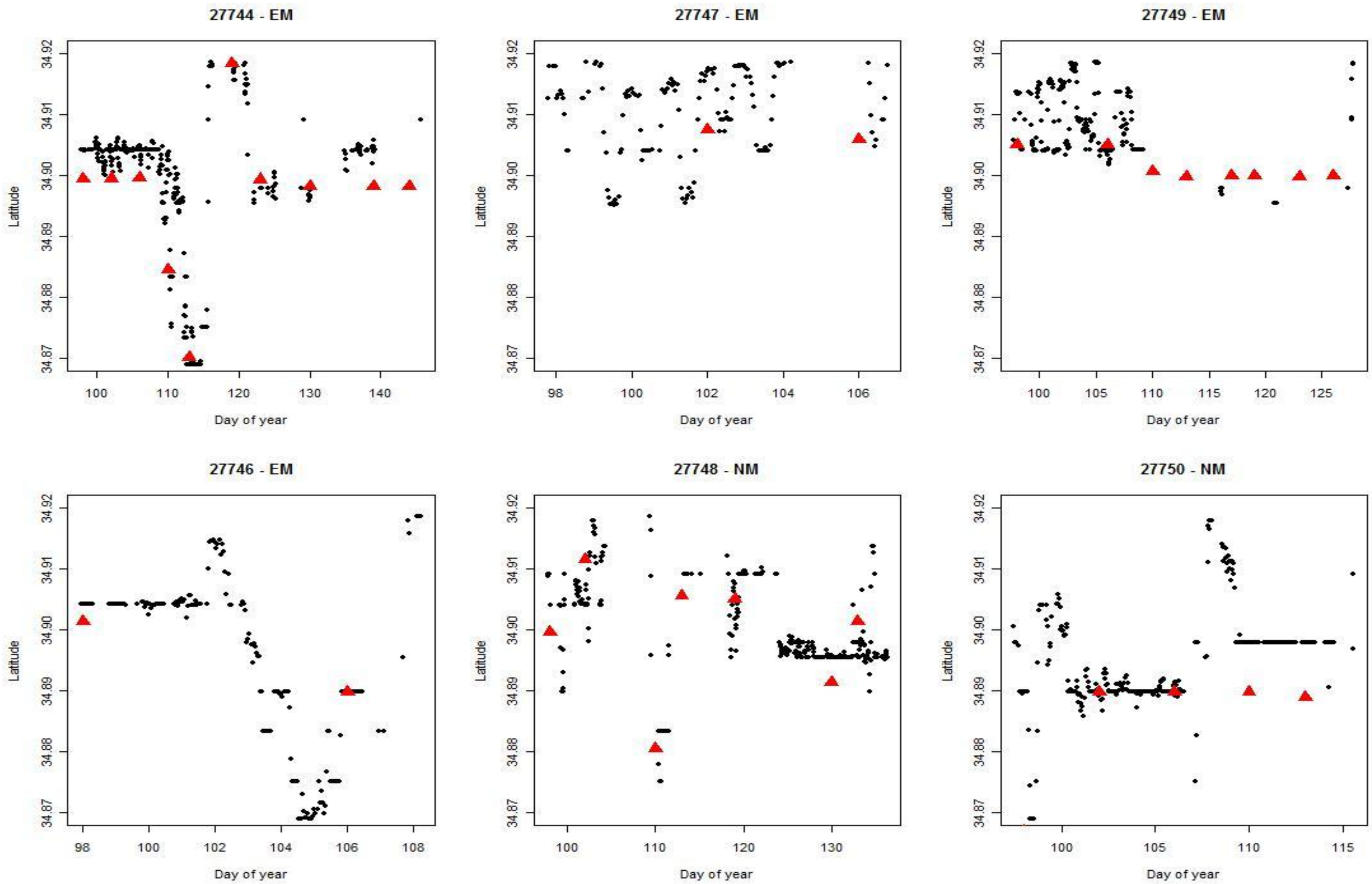

56225 - EM
56227 - EM
56229 - EM
56226 - BL
56228 - EM
56232 - BL
Latitude
Day of year
34.89
34.90
34.91
34.92
34.93
34.94
115
120
125
130
135
140
150
160
180

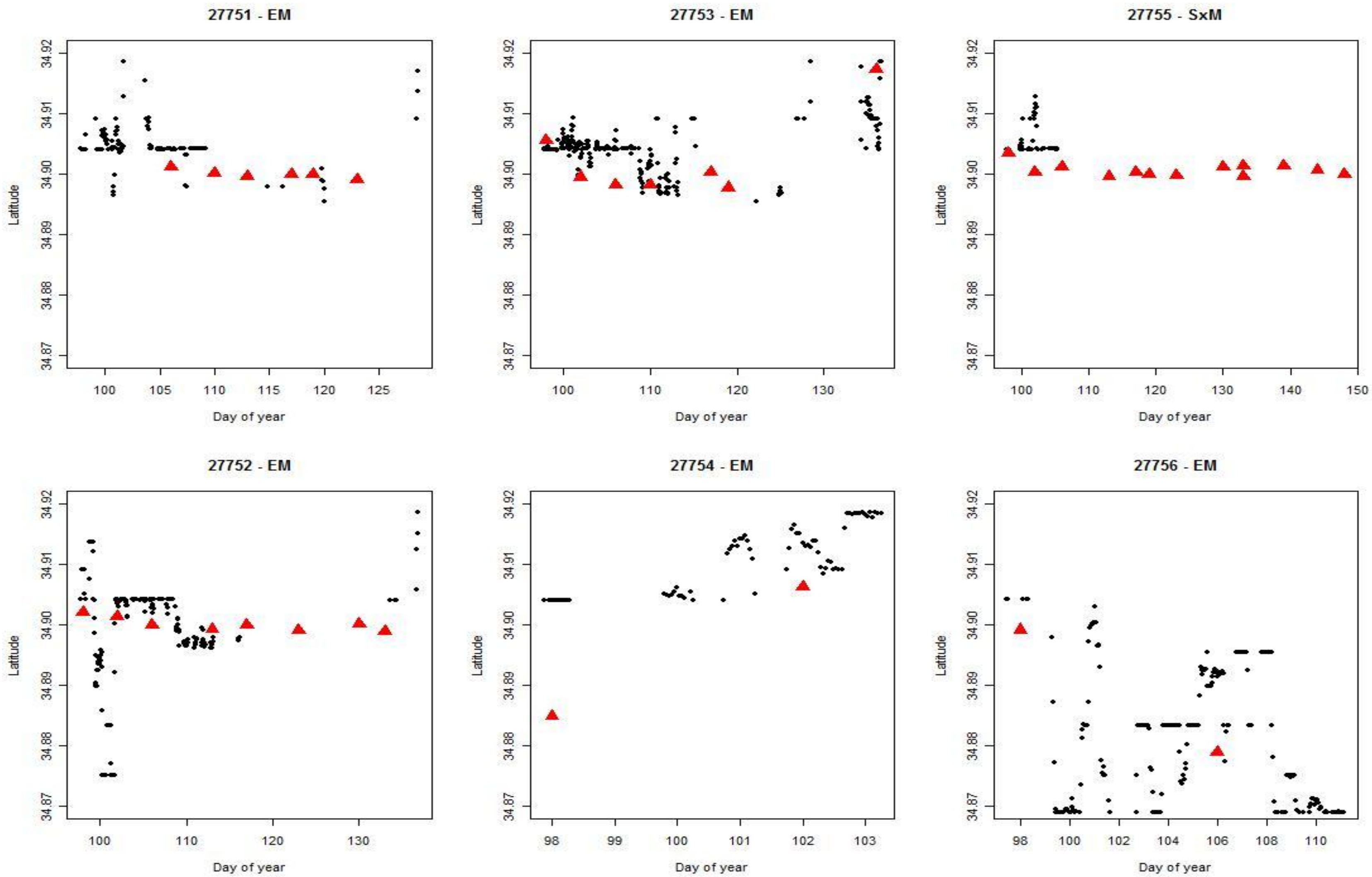
Appendix Figure 3. Estimated average hourly latitudes and manual tracking relocations for all at risk telemetered age-1 spot in 2010. Black dots are VR2/W detections, red triangles indicate manual tracking relocations. Fate assignments are: emigration (EM), surgery related mortality (SxM), natural mortality (NM) and battery life end (BL).

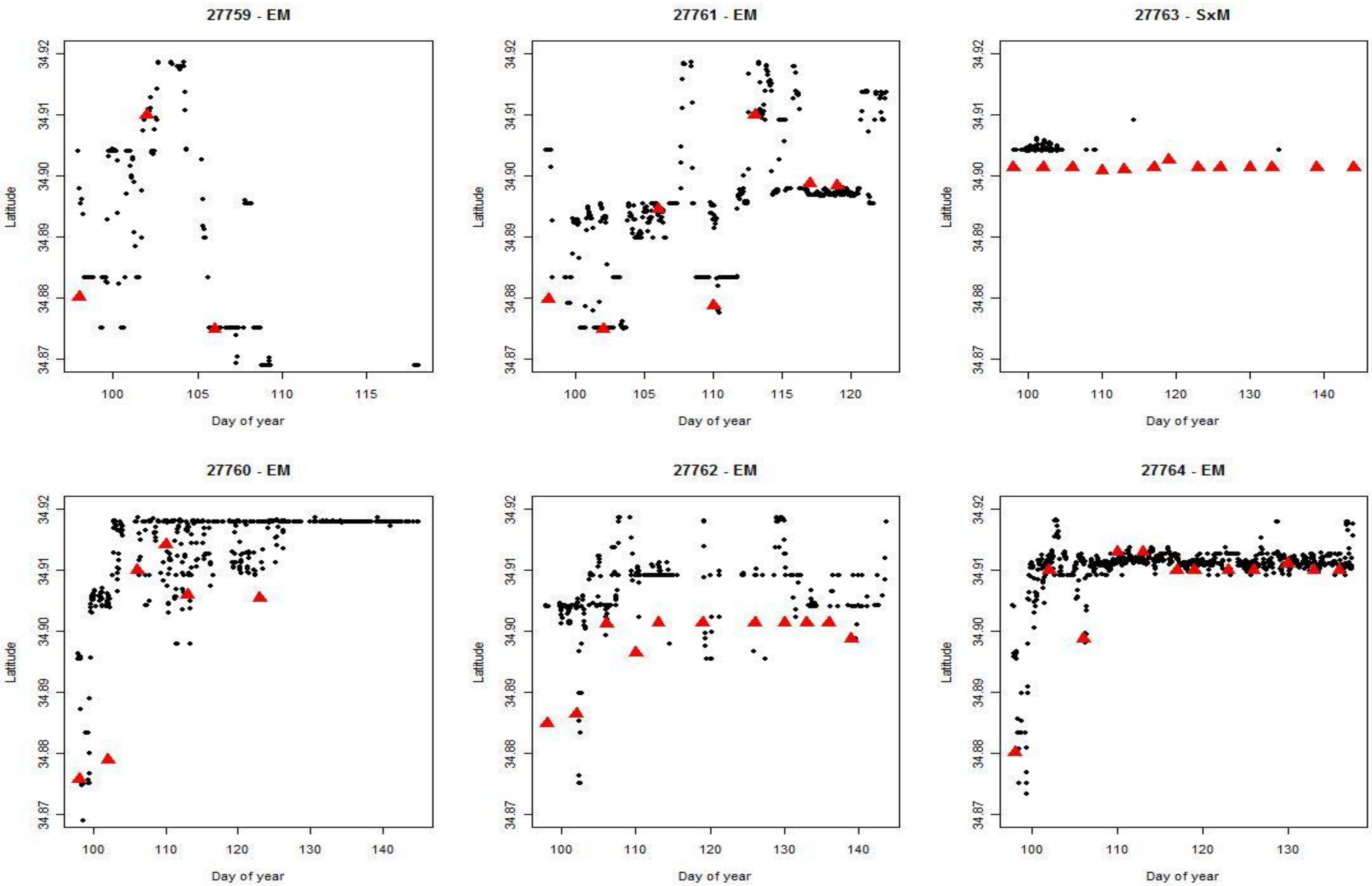


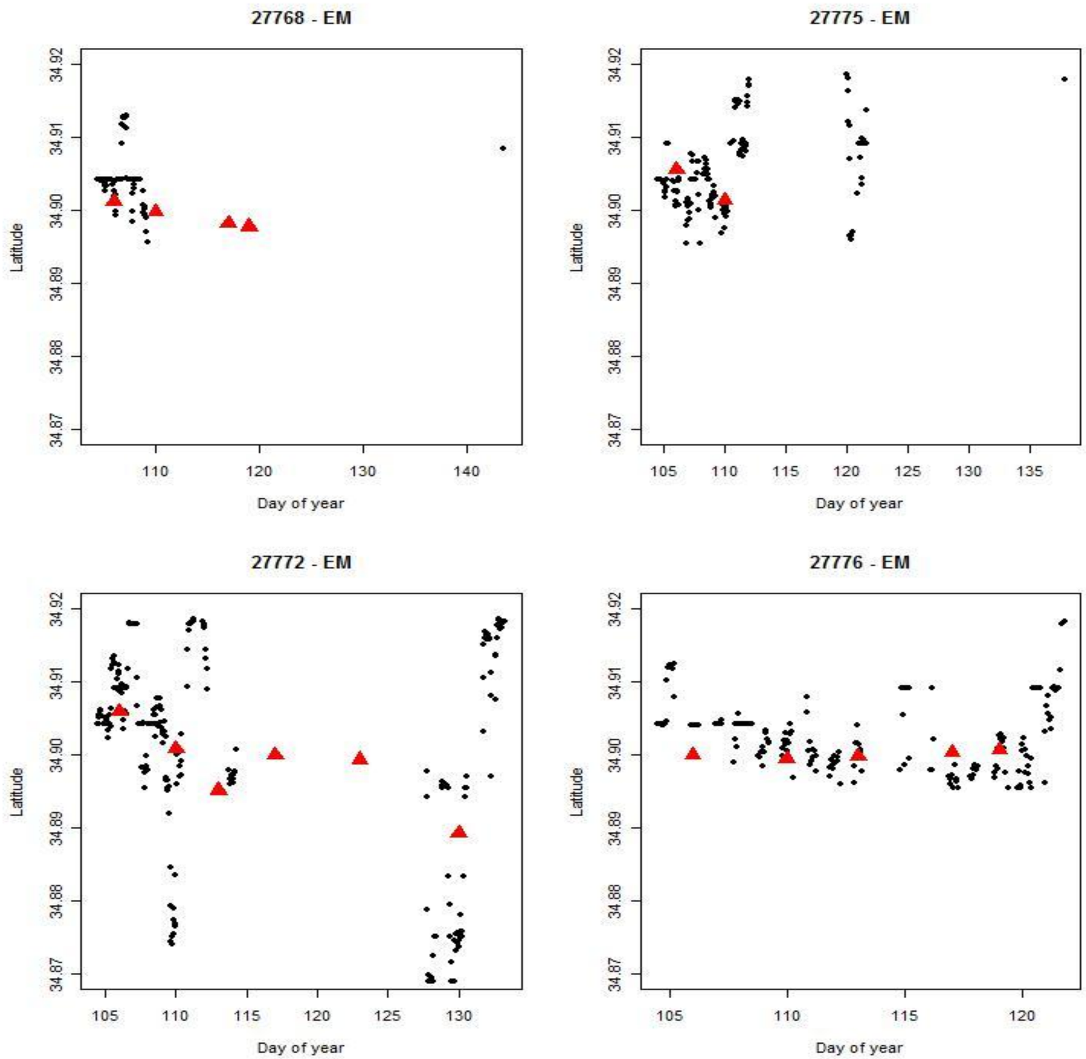
27725 - EM
27728 - EM
27734 - EM
27727 - EM
27730 - EM
27735 - EM
Latitude
Day of year


27737 - EM
27740 - NM
27742 - NM
27738 - EM
27741 - NM
27743 - EM
Latitude
Day of year

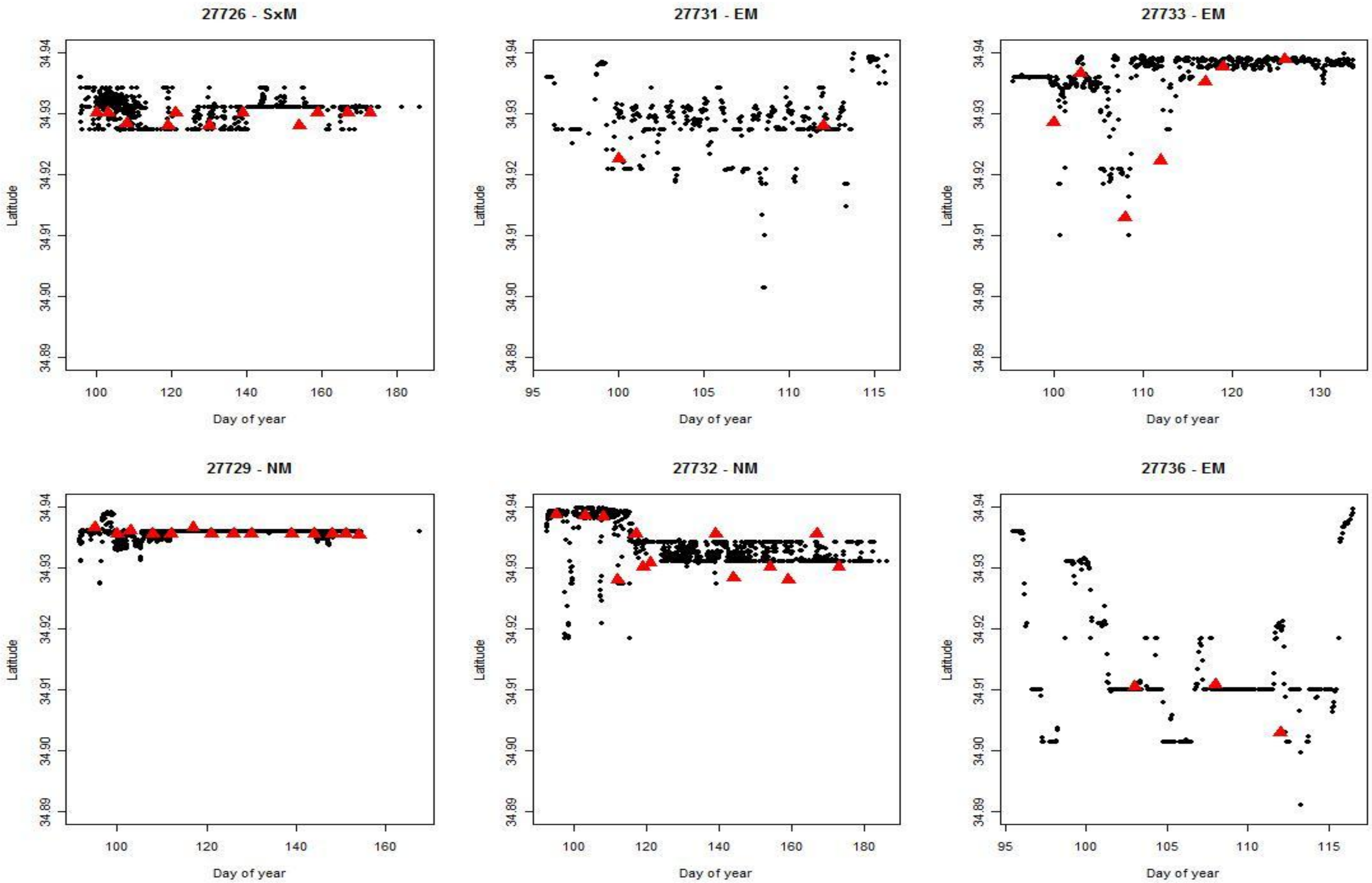

27744 - EM
27747 - EM
27749 - EM
27746 - EM
27748 - NM
27750 - NM
Latitude
34.87
34.88
34.89
34.90
34.91
34.92
Day of year

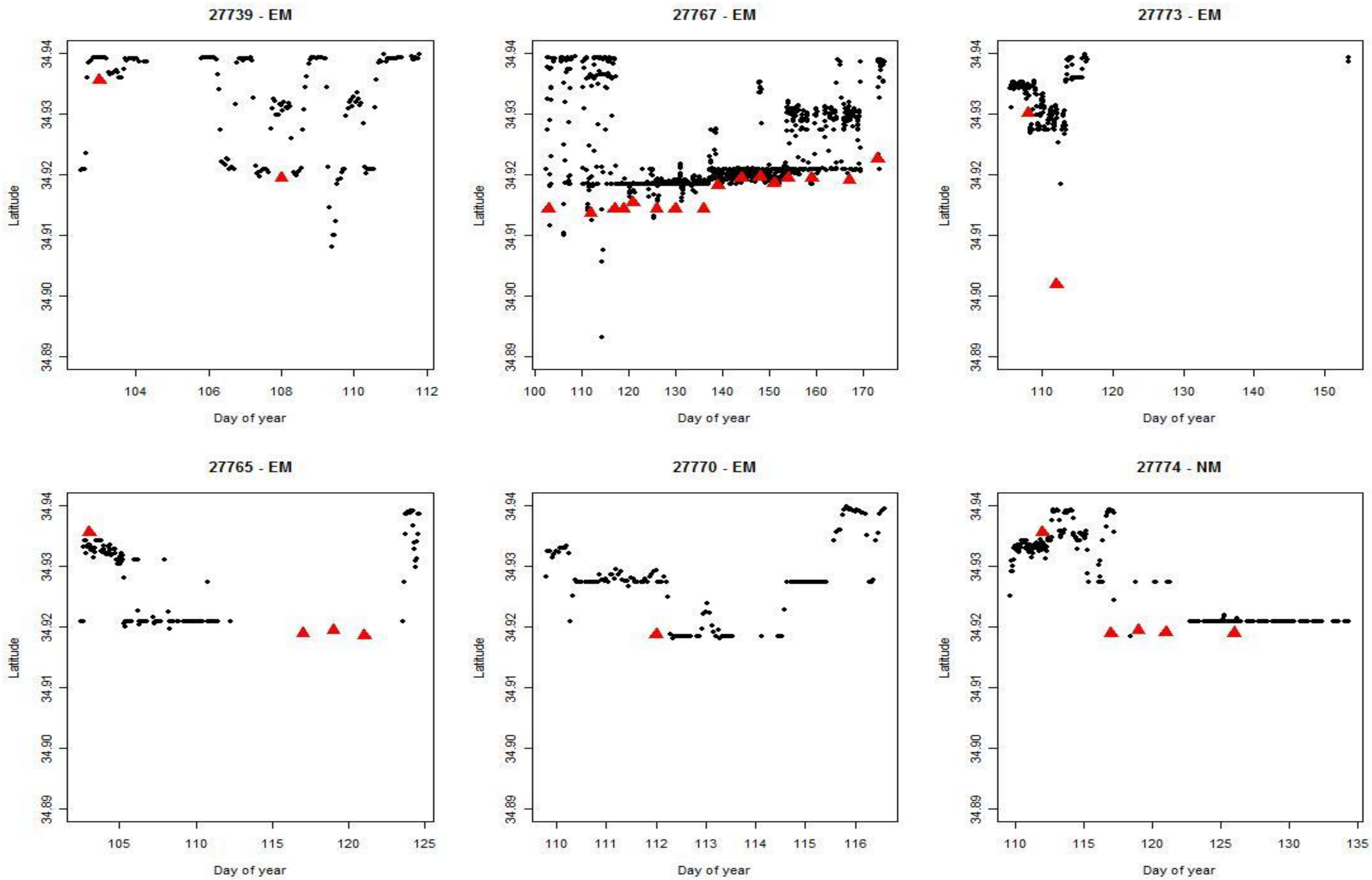

27751 - EM
27753 - EM
27755 - SxM
27752 - EM
27754 - EM
27756 - EM
Latitude
Day of year

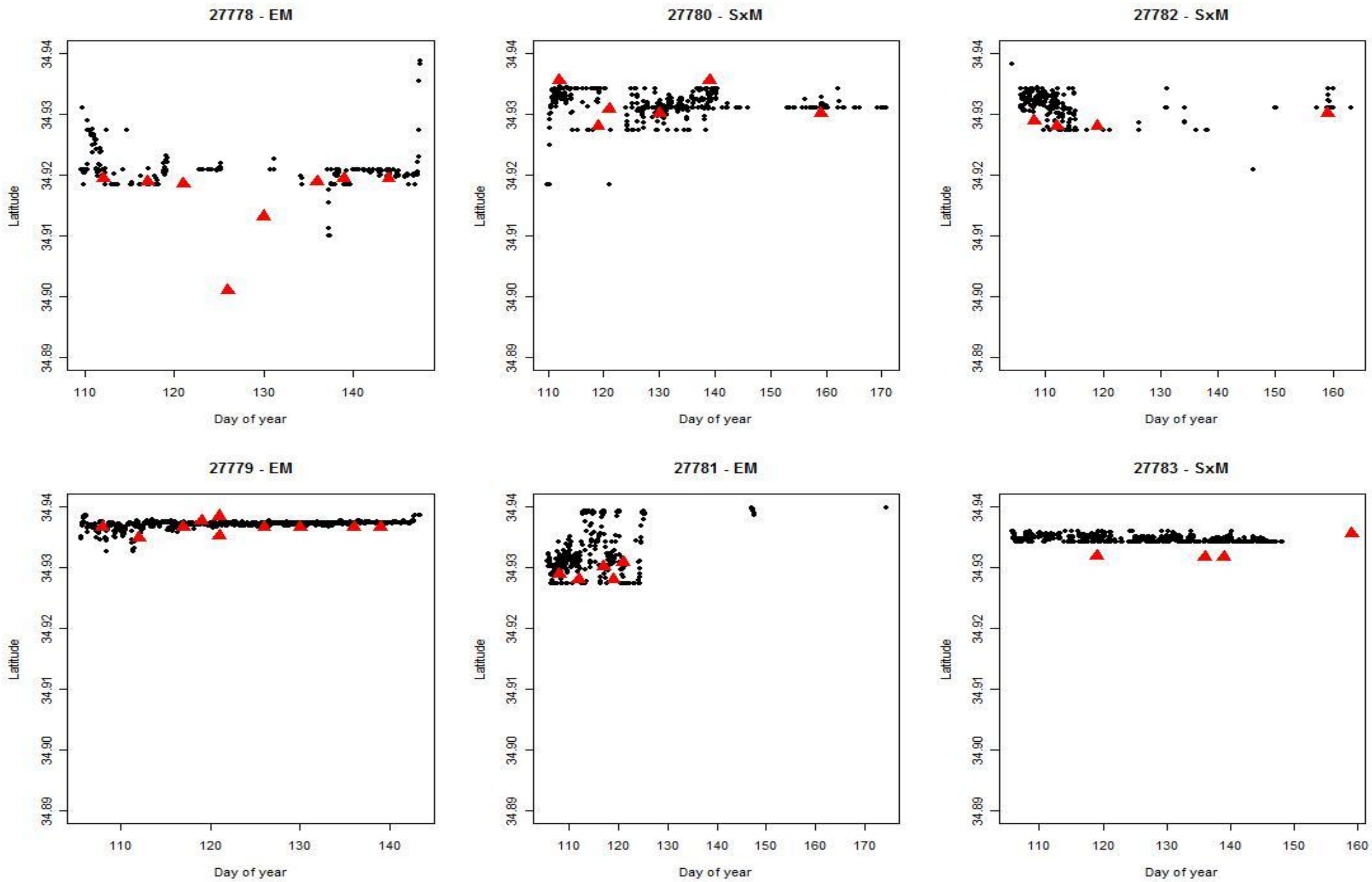

27759 - EM
27761 - EM
27763 - SxM
27760 - EM
27762 - EM
27764 - EM
Latitude
Day of year
34.87
34.88
34.89
34.90
34.91
34.92
100
105
110
115
120
130
140

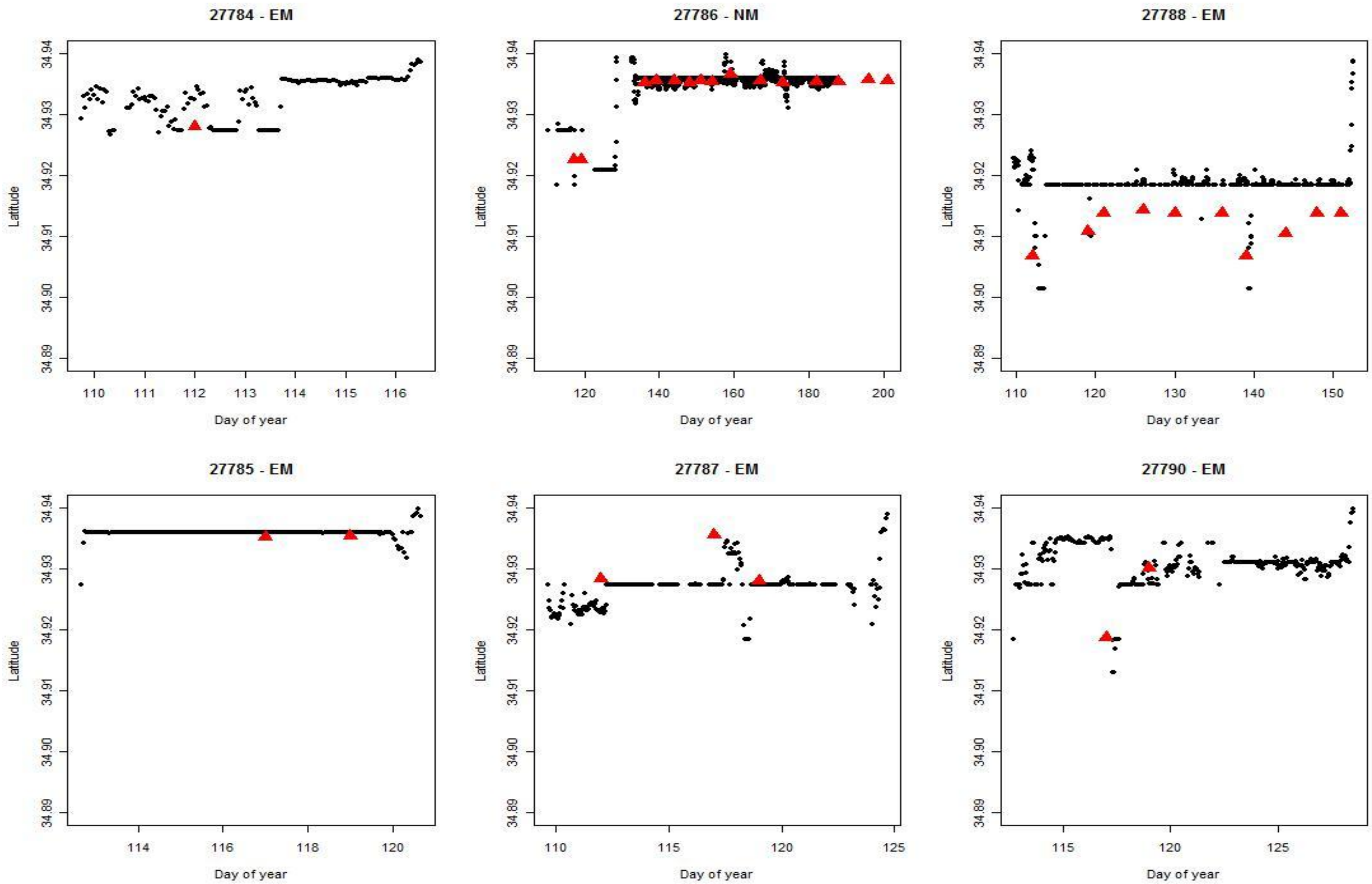


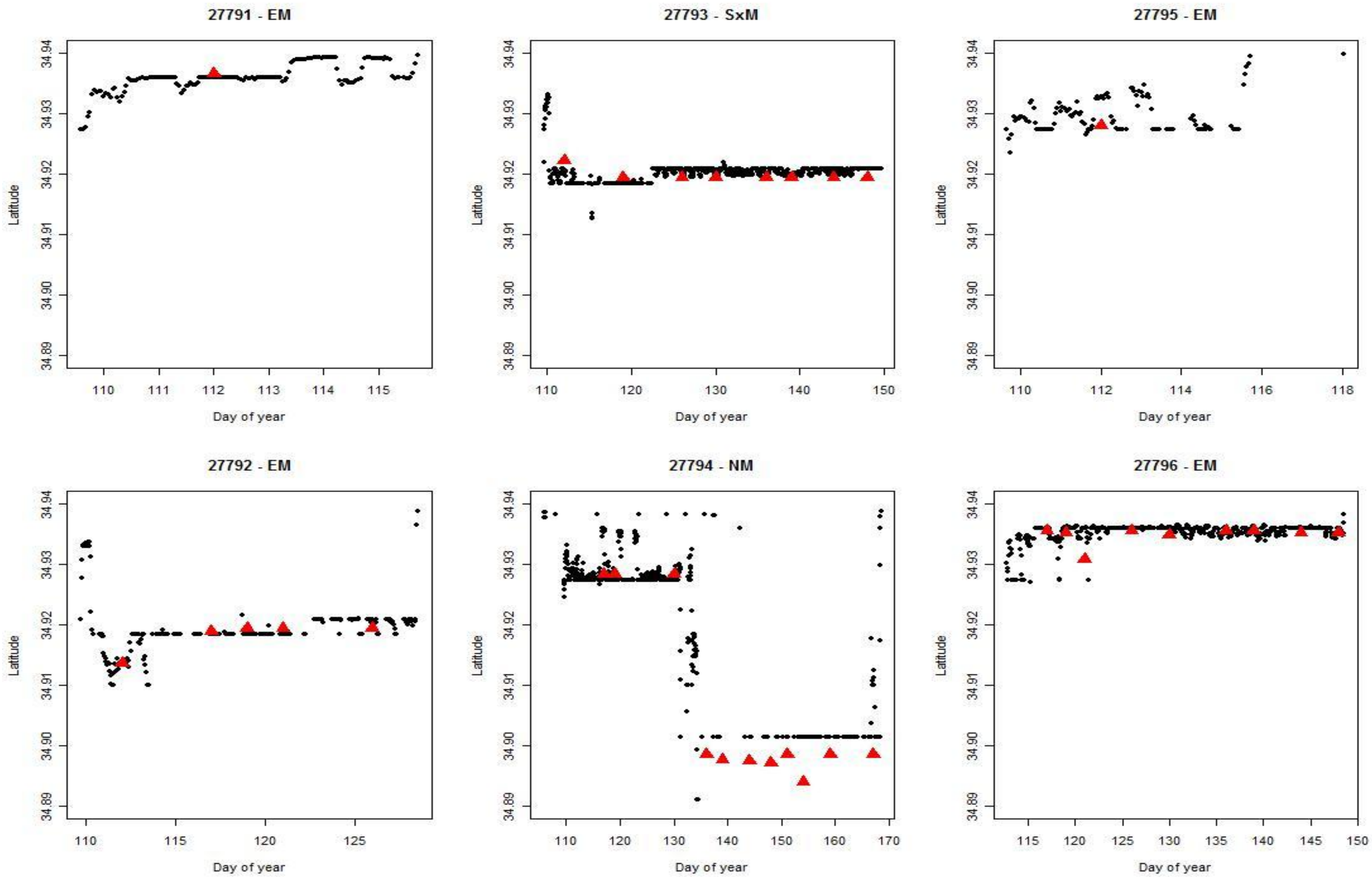
27768 - EM
27775 - EM
27772 - EM
27776 - EM
Latitude
Day of year
34.87
34.88
34.89
34.90
34.91
34.92
105
110
115
120
125
130
135
140

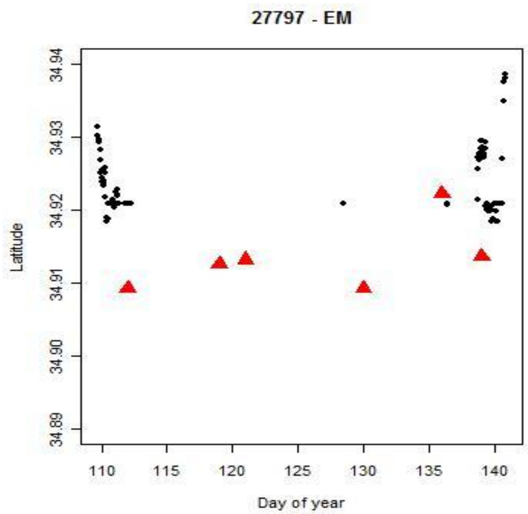

27726 - SxM
27731 - EM
27733 - EM
27729 - NM
27732 - NM
27736 - EM
Latitude
34.89
34.90
34.91
34.92
34.93
34.94
Day of year

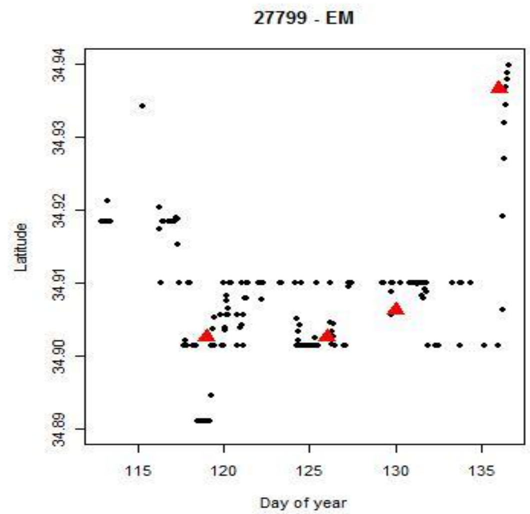

27739 - EM
27767 - EM
27773 - EM
27765 - EM
27770 - EM
27774 - NM
Latitude
Day of year
34.89
34.90
34.91
34.92
34.93
34.94

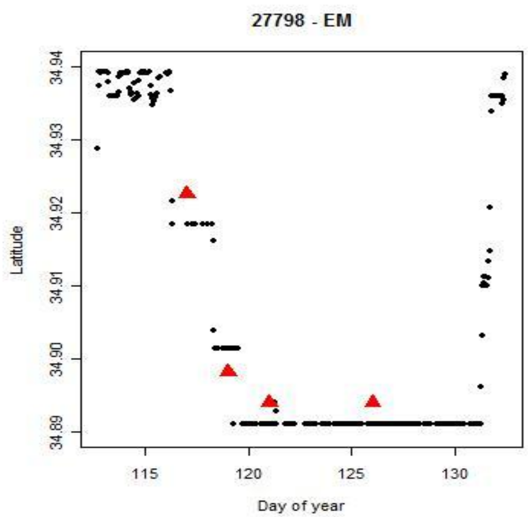

27778 - EM
27780 - SxM
27782 - SxM
27779 - EM
27781 - EM
27783 - SxM
Latitude
Day of year


27784 - EM
27786 - NM
27788 - EM
27785 - EM
27787 - EM
27790 - EM
Latitude
Day of year
34.89
34.90
34.91
34.92
34.93
34.94

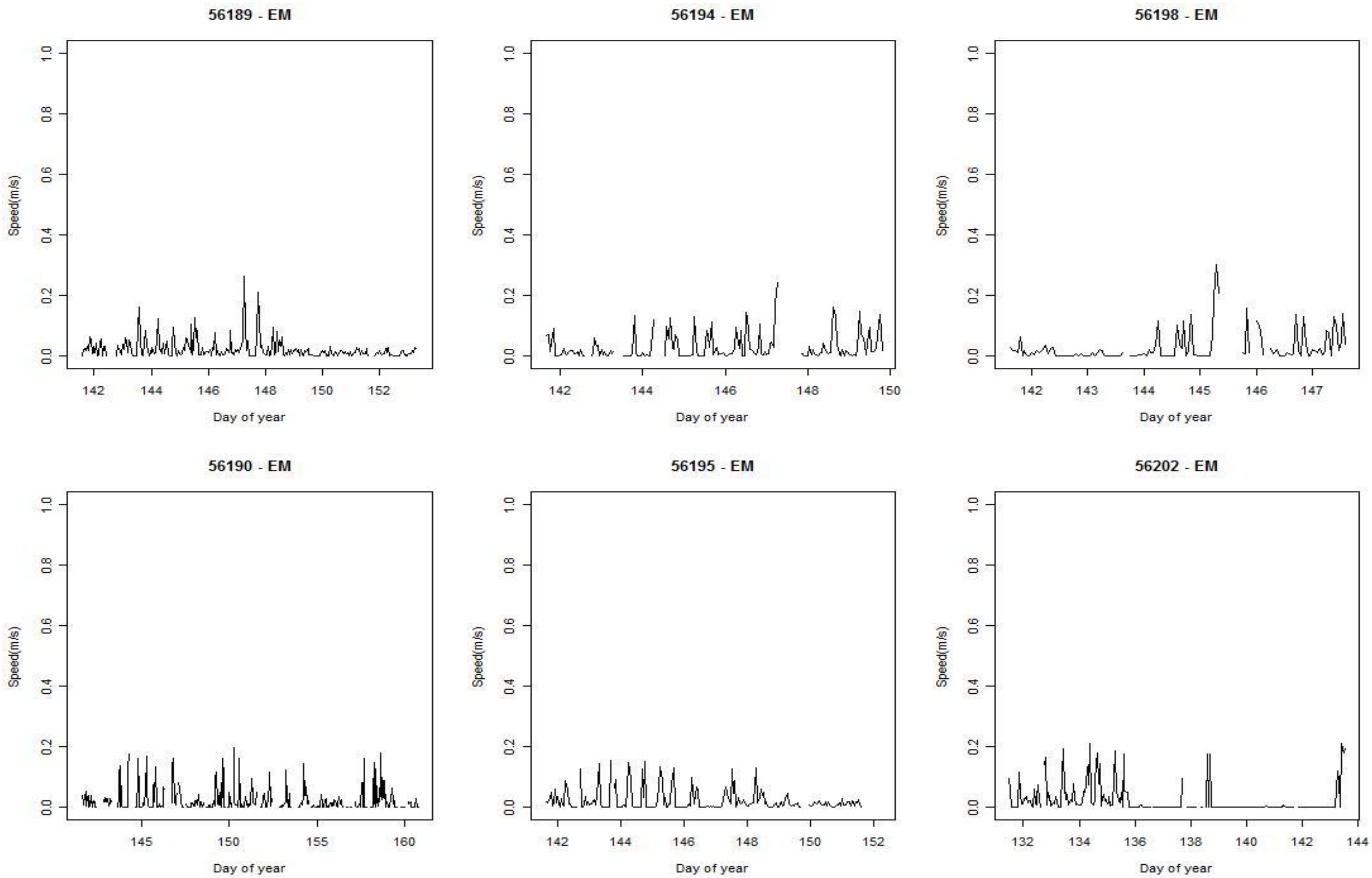

27791 - EM
27793 - SxM
27795 - EM
27792 - EM
27794 - NM
27796 - EM
Latitude
Day of year

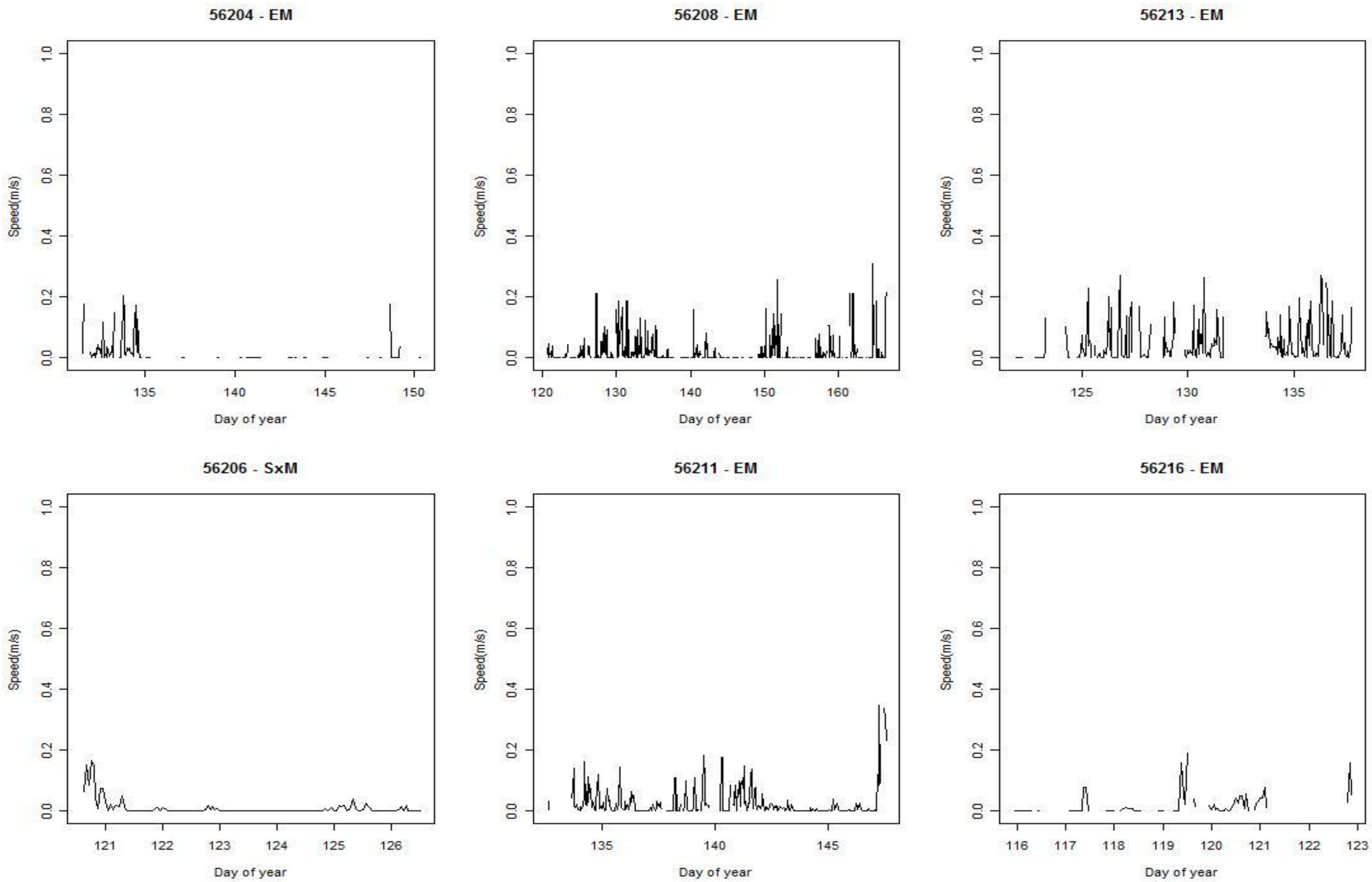

27797 - EM
Latitude
34.89
34.90
34.91
34.92
34.93
34.94
110
115
120
125
130
135
140
Day of year

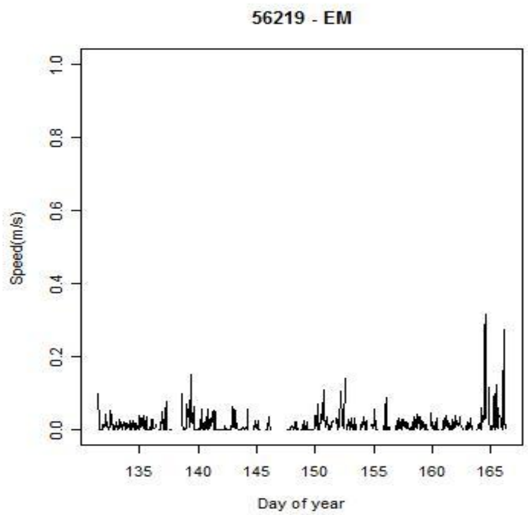

27799 - EM
Latitude
34.89
34.90
34.91
34.92
34.93
34.94
115
120
125
130
135
Day of year

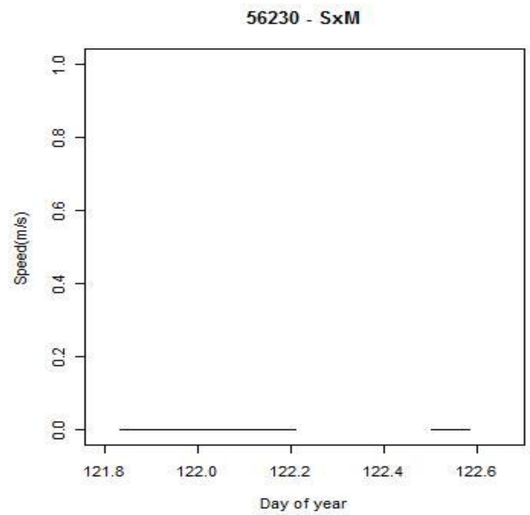

27798 - EM
Latitude
34.89
34.90
34.91
34.92
34.93
34.94
115
120
125
130
Day of year

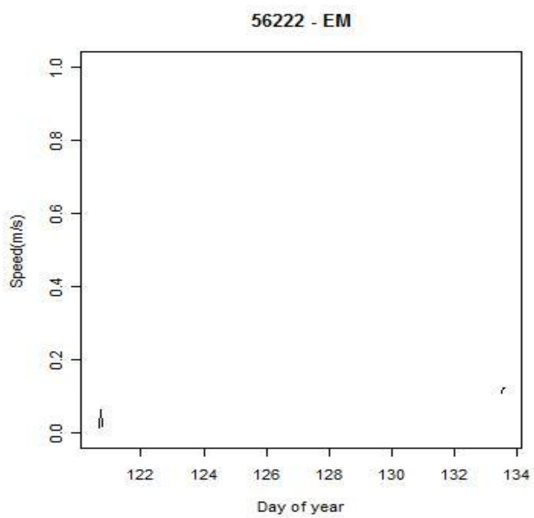
Appendix Figure 4. Estimated average hourly swimming speeds (m/s) for all at risk telemetered age-1 spot in 2009. Fate assignments are: emigration (EM), surgery related mortality (SxM), natural mortality (NM) and battery life end (BL).

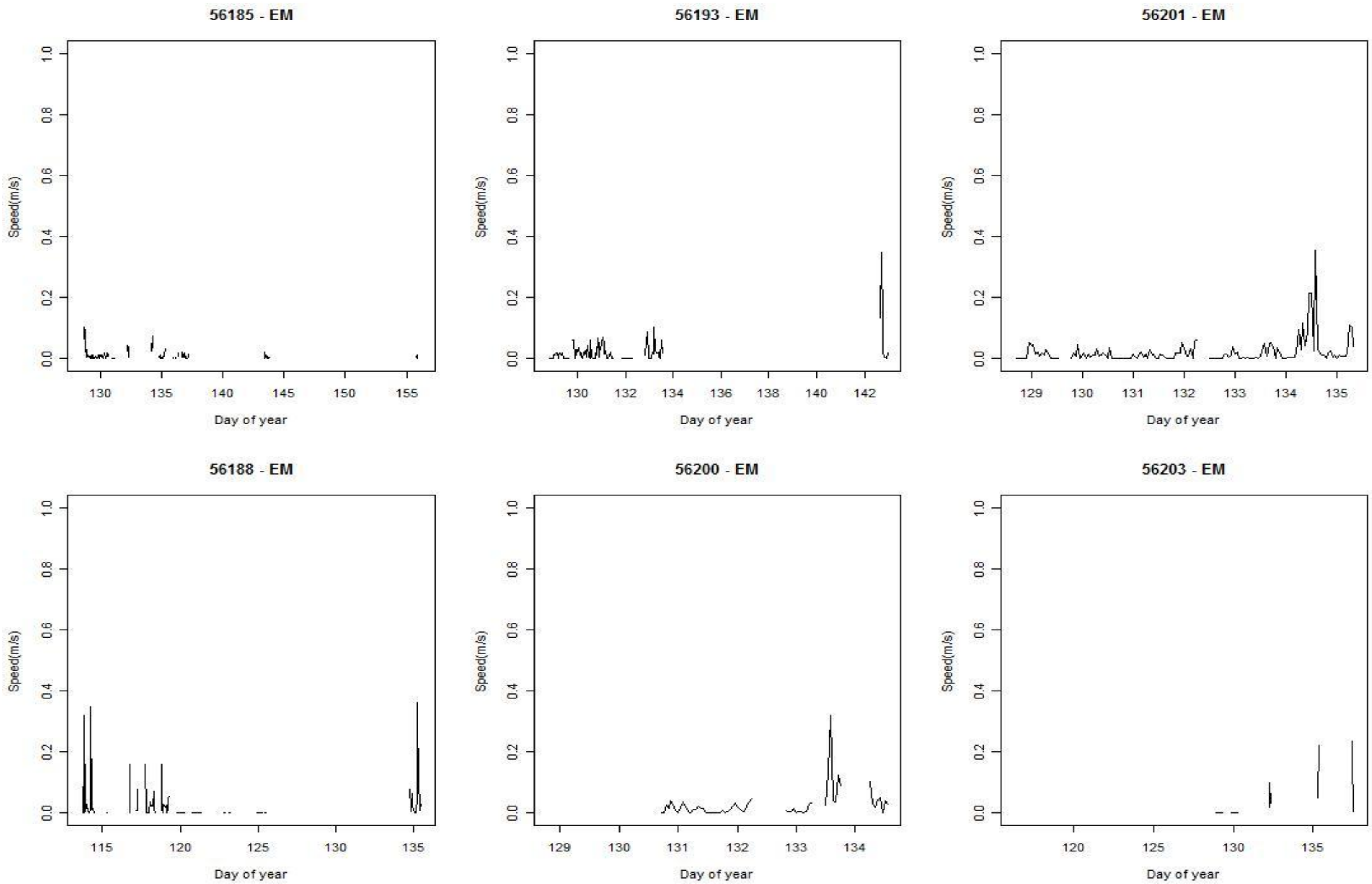

56189 - EM
56194 - EM
56198 - EM
56190 - EM
56195 - EM
56202 - EM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0


56204 - EM
56208 - EM
56213 - EM
56206 - SxM
56211 - EM
56216 - EM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0
135
140
145
150
120
130
140
150
160
125
130
135
121
122
123
124
125
126
135
140
145
116
117
118
119
120
121
122
123

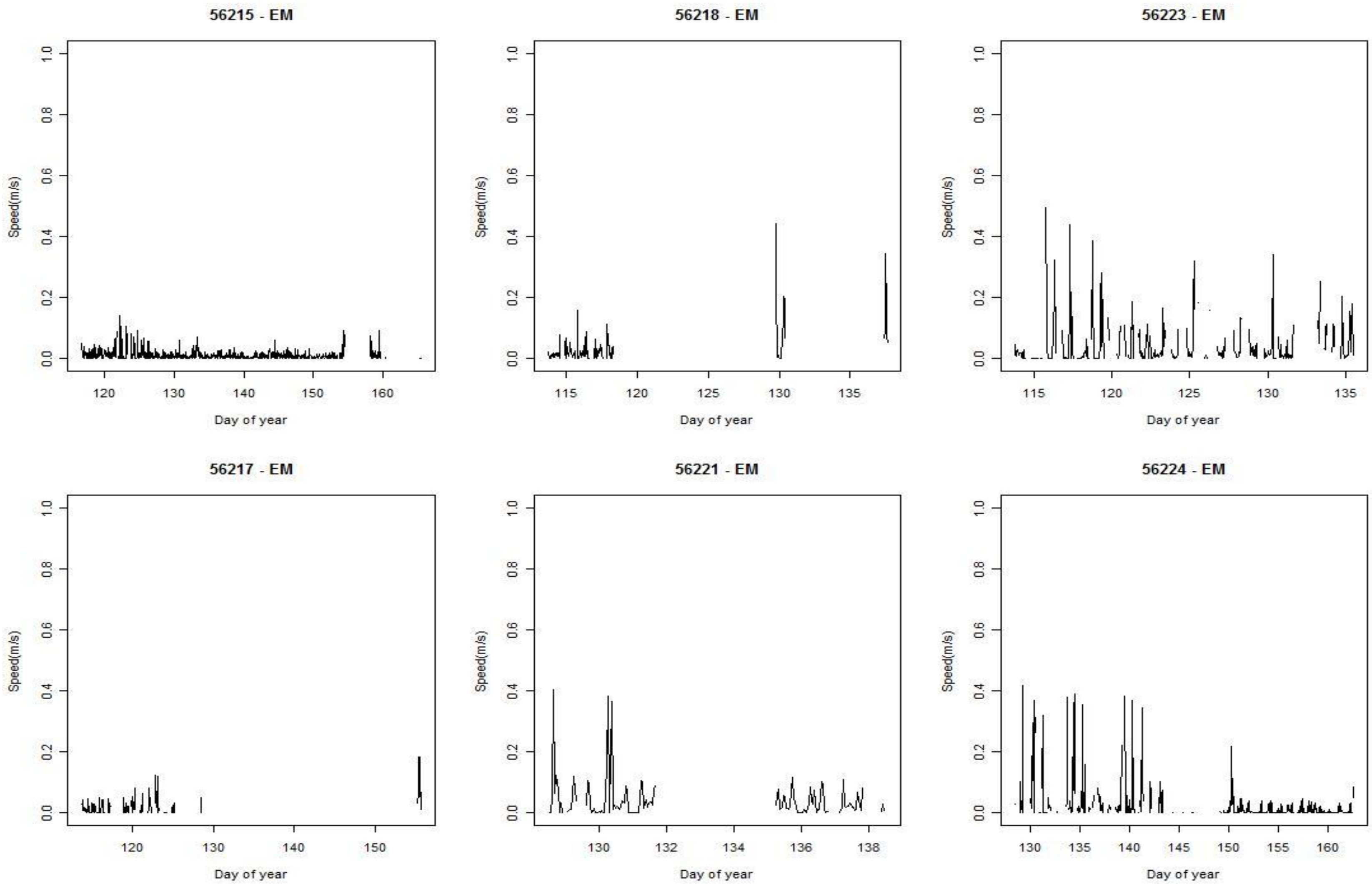

56219 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
135
140
145
150
155
160
165
Day of year

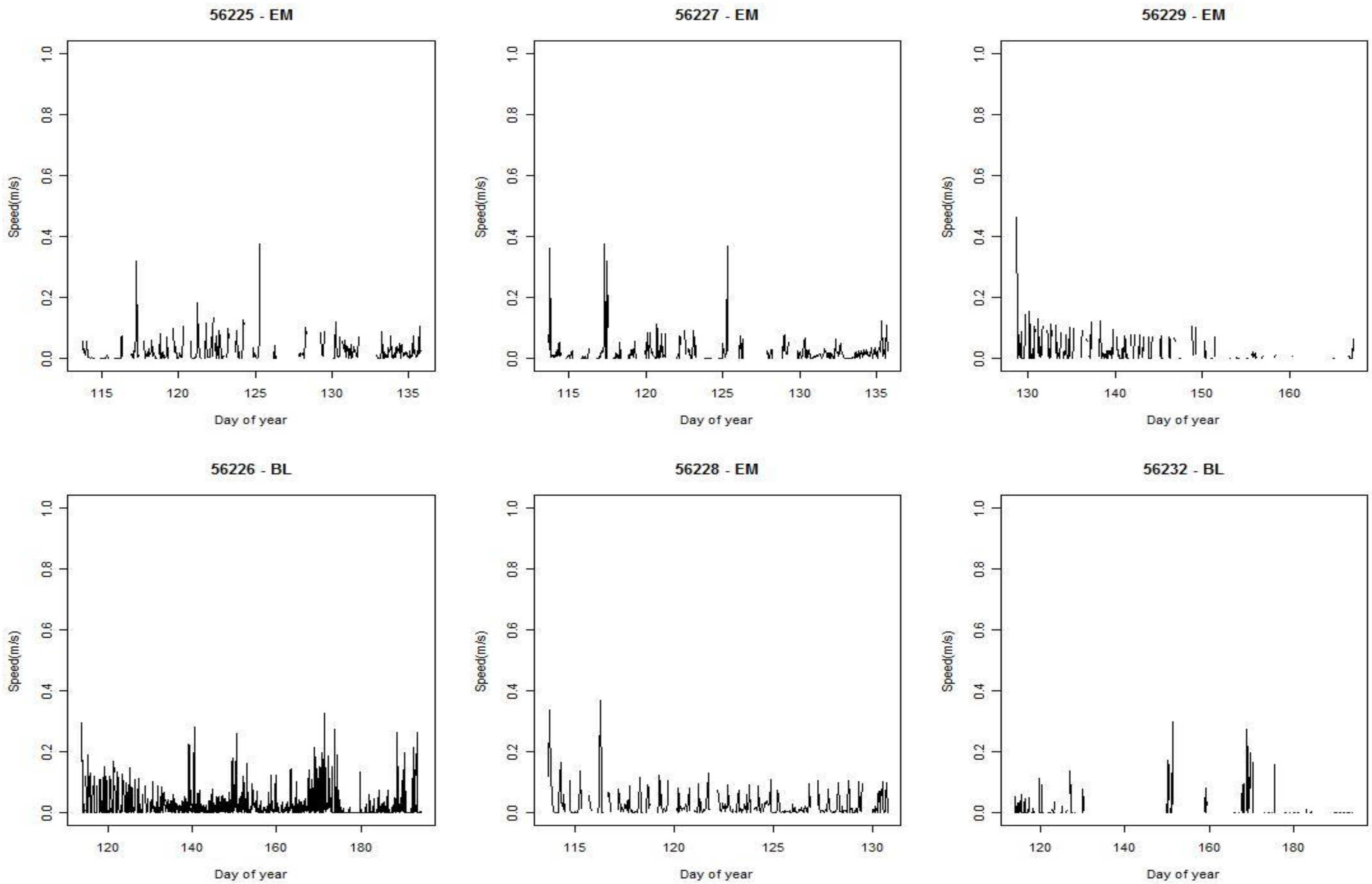

56230 - SxM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
121.8
122.0
122.2
122.4
122.6
Day of year


56222 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
122
124
126
128
130
132
134
Day of year

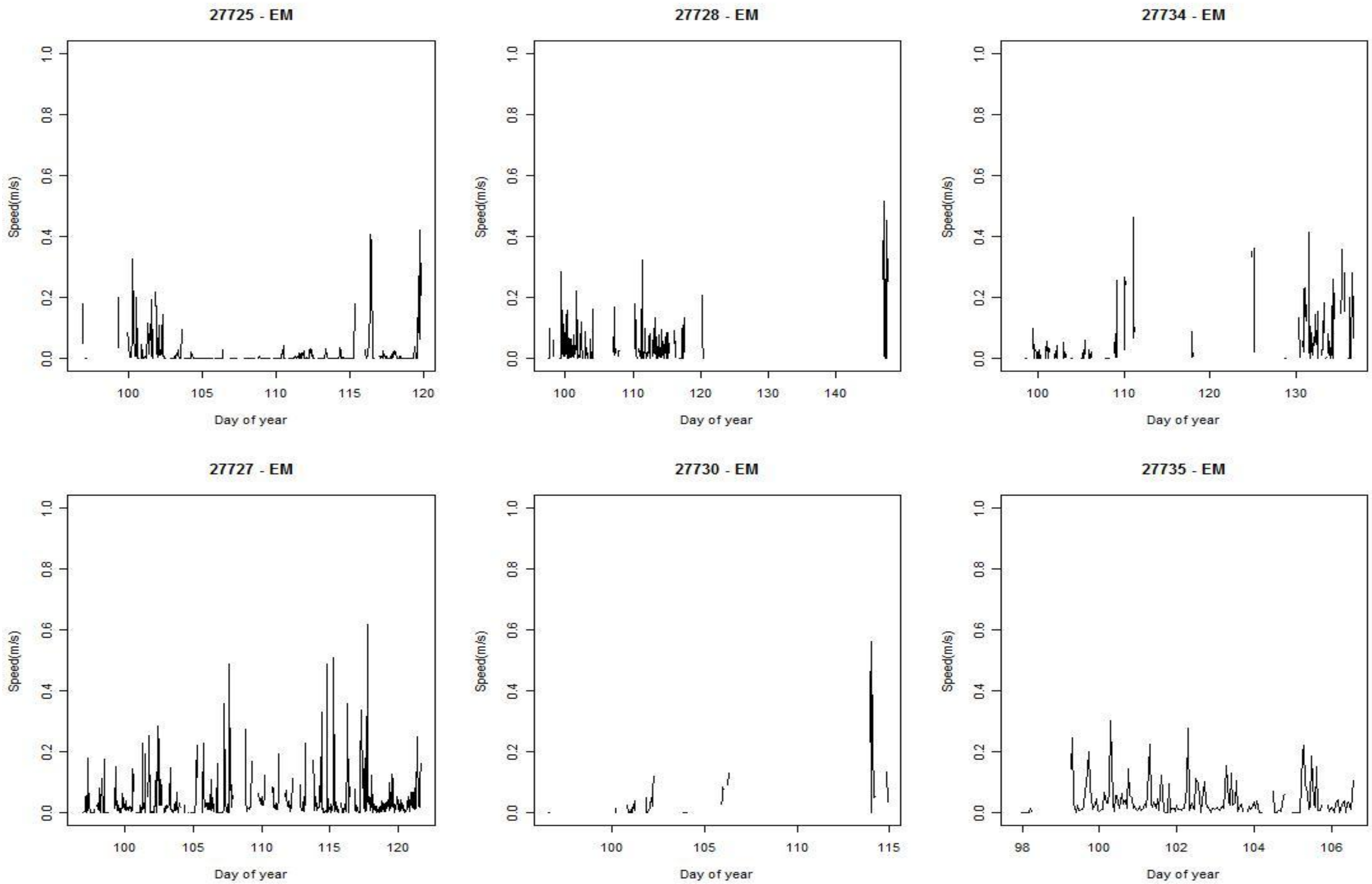


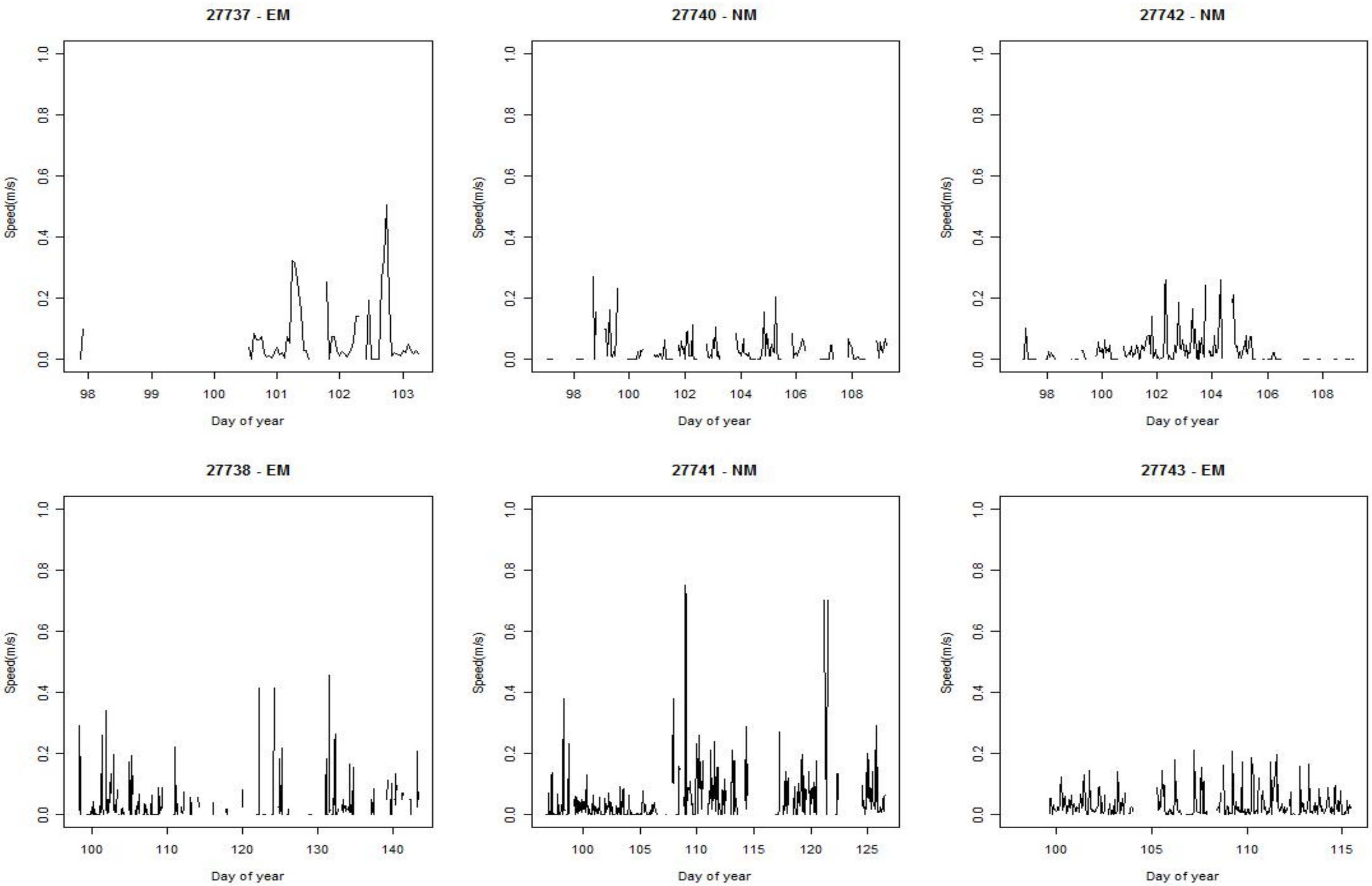
56185 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
130
135
140
145
150
155
Day of year
56193 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
130
132
134
136
138
140
142
Day of year
56201 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
129
130
131
132
133
134
135
Day of year
56188 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
115
120
125
130
135
Day of year
56200 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
129
130
131
132
133
134
Day of year
56203 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
120
125
130
135
Day of year

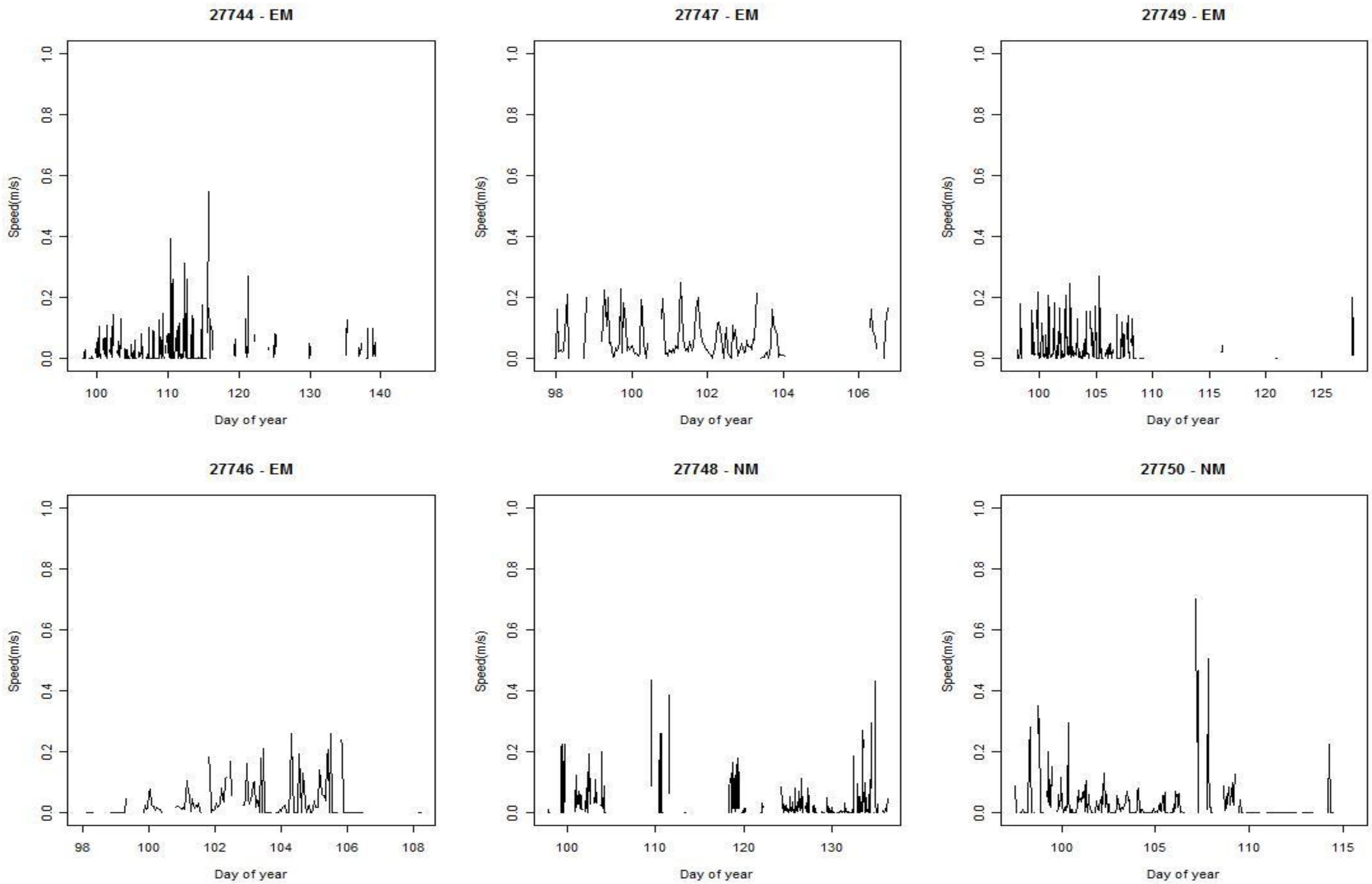

56215 - EM
Speed(m/s)
Day of year
56218 - EM
Speed(m/s)
Day of year
56223 - EM
Speed(m/s)
Day of year
56217 - EM
Speed(m/s)
Day of year
56221 - EM
Speed(m/s)
Day of year
56224 - EM
Speed(m/s)
Day of year

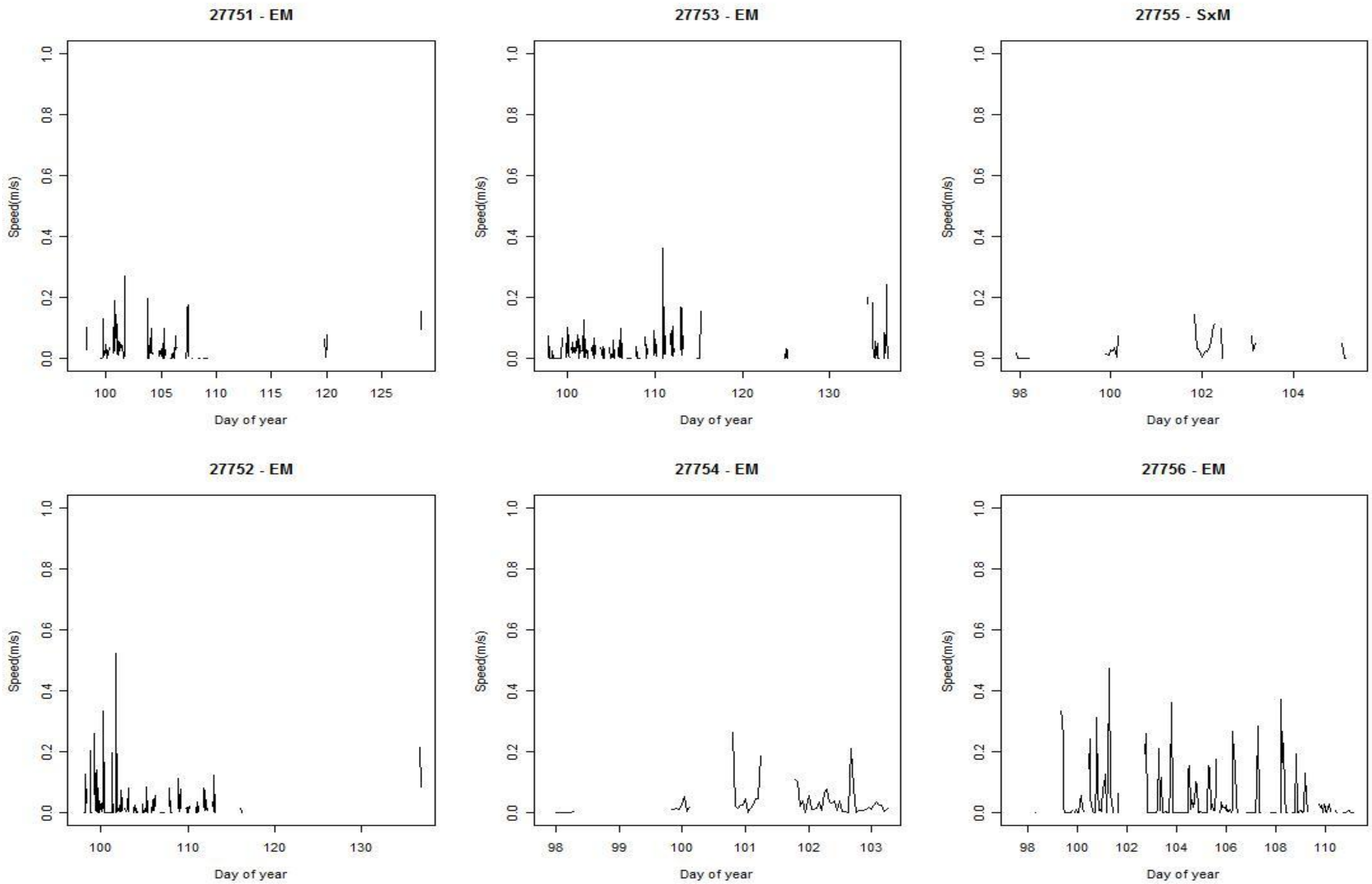

56225 - EM
56227 - EM
56229 - EM
56226 - BL
56228 - EM
56232 - BL
Speed(m/s)
Day of year
0.0 0.2 0.4 0.6 0.8 1.0
115 120 125 130 135
130 140 150 160
120 140 160 180
115 120 125 130

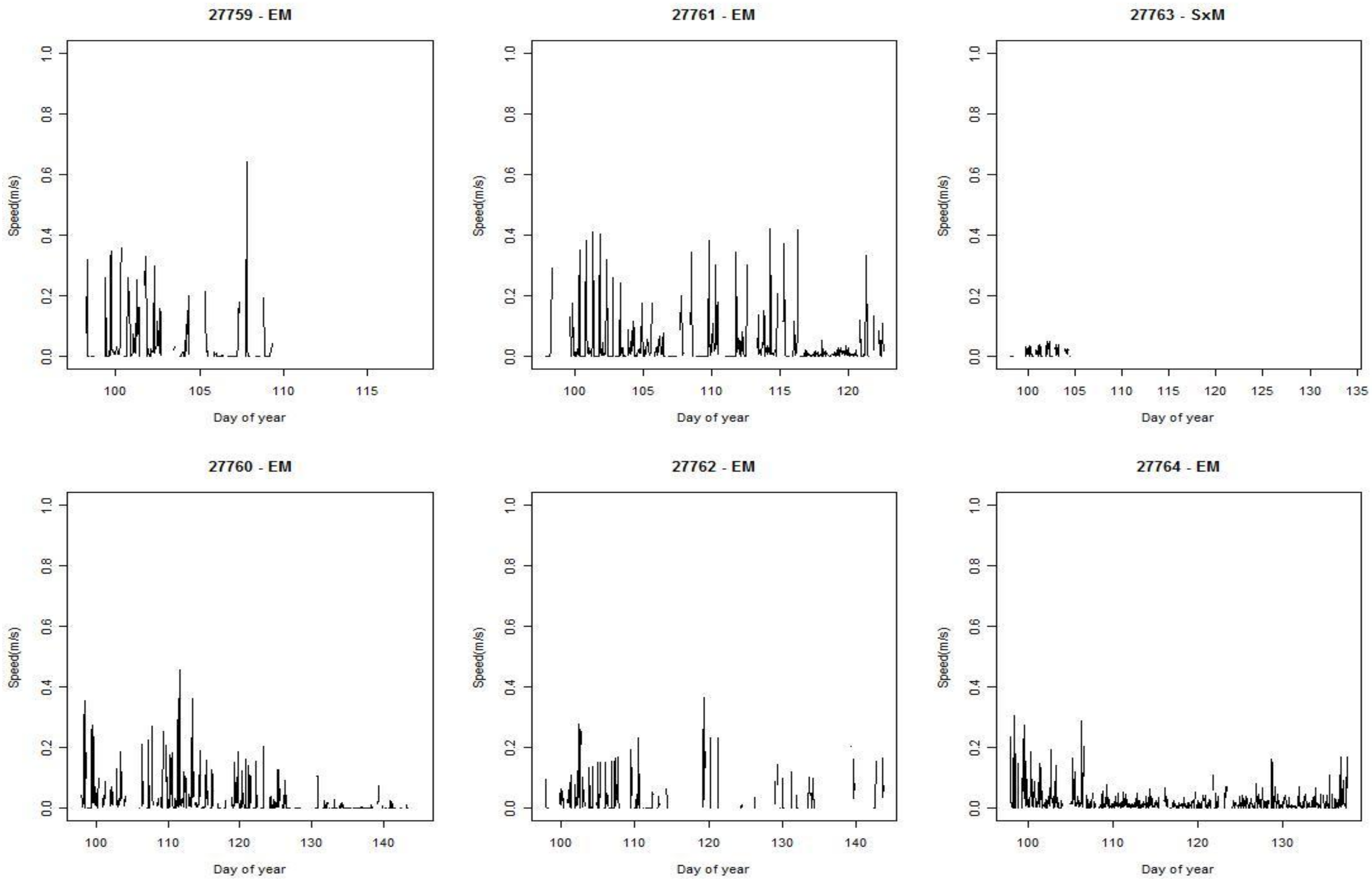
Appendix Figure 5. Estimated average hourly swimming speeds (m/s) for all at risk telemetered age-1 spot in 2010. Fate assignments are: emigration (EM), surgery related mortality (SxM), natural mortality (NM) and battery life end (BL).

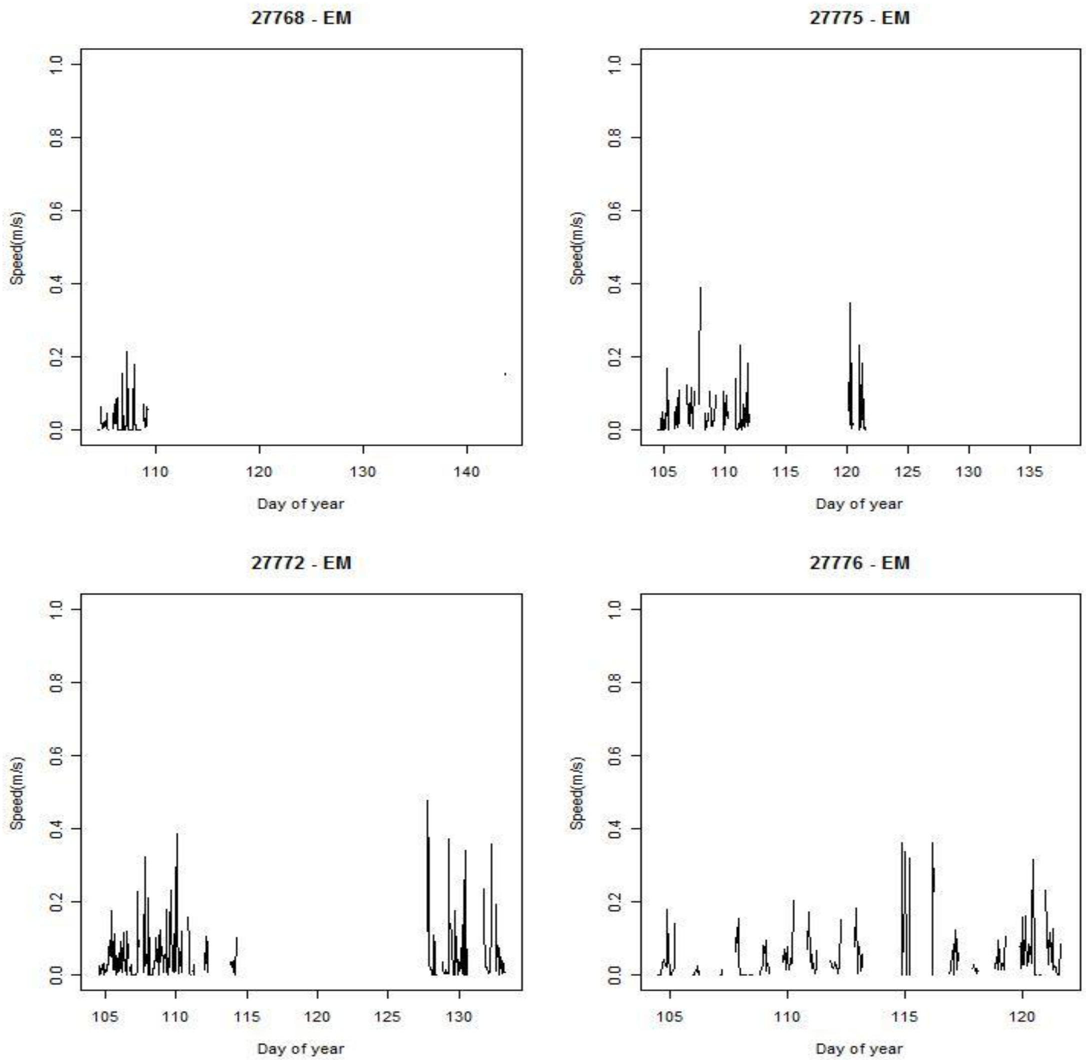

27725 - EM
27728 - EM
27734 - EM
27727 - EM
27730 - EM
27735 - EM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0
100
105
110
115
120
130
140
98
102
104
106

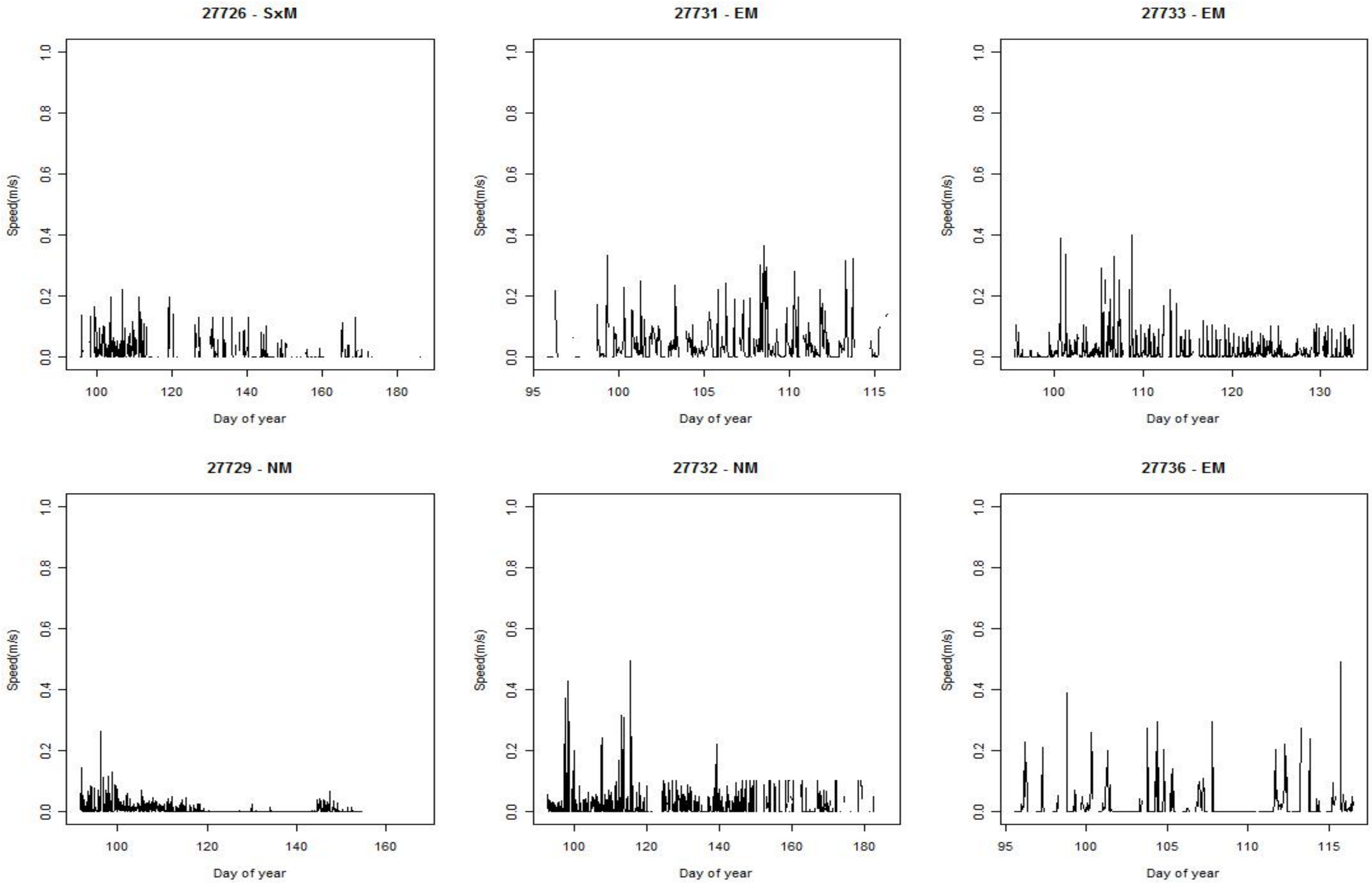

27737 - EM
27740 - NM
27742 - NM
27738 - EM
27741 - NM
27743 - EM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0
98
99
100
101
102
103
104
105
106
108
110
115
120
125
130
140

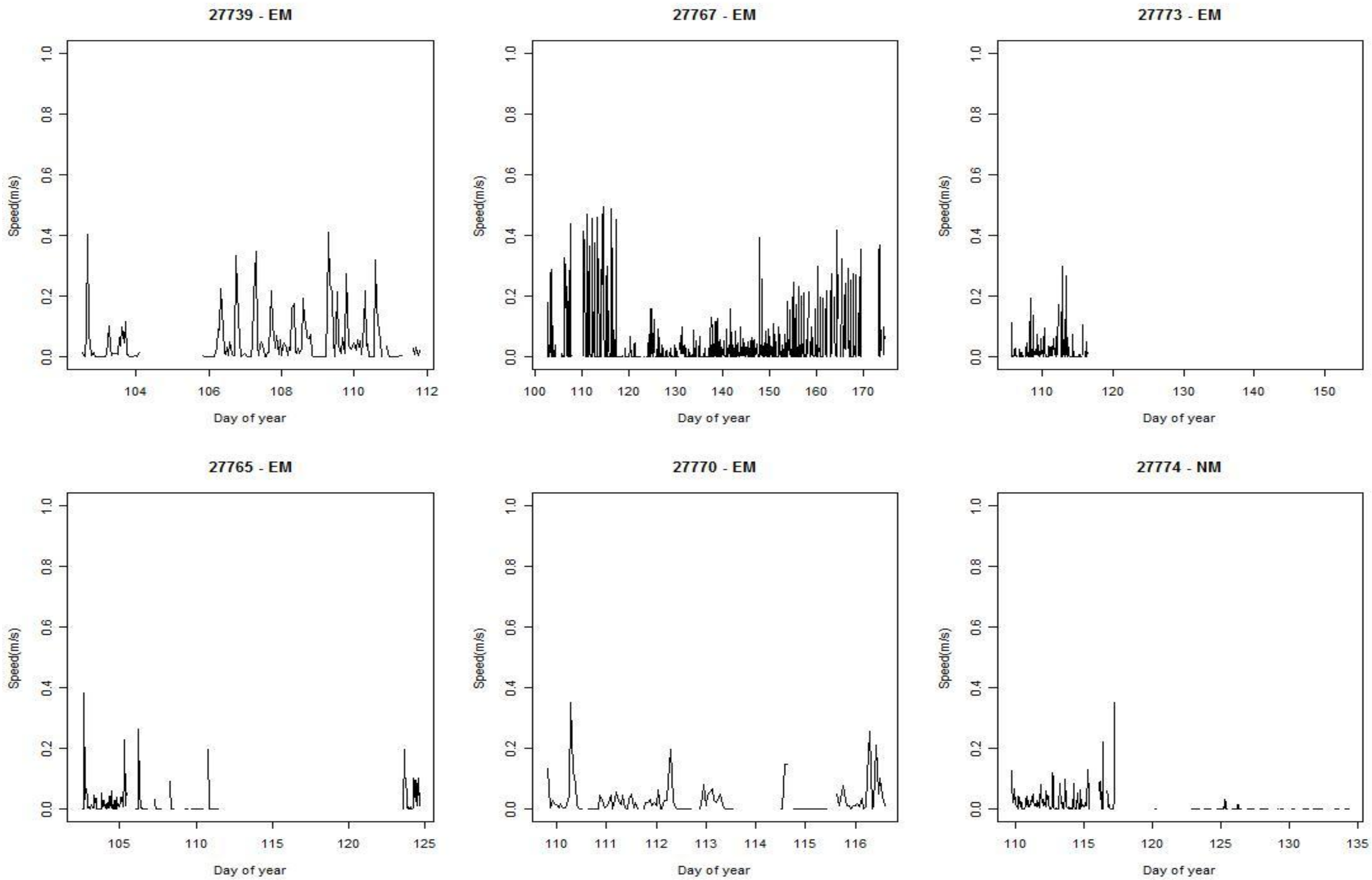

27744 - EM
27747 - EM
27749 - EM
27746 - EM
27748 - NM
27750 - NM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0

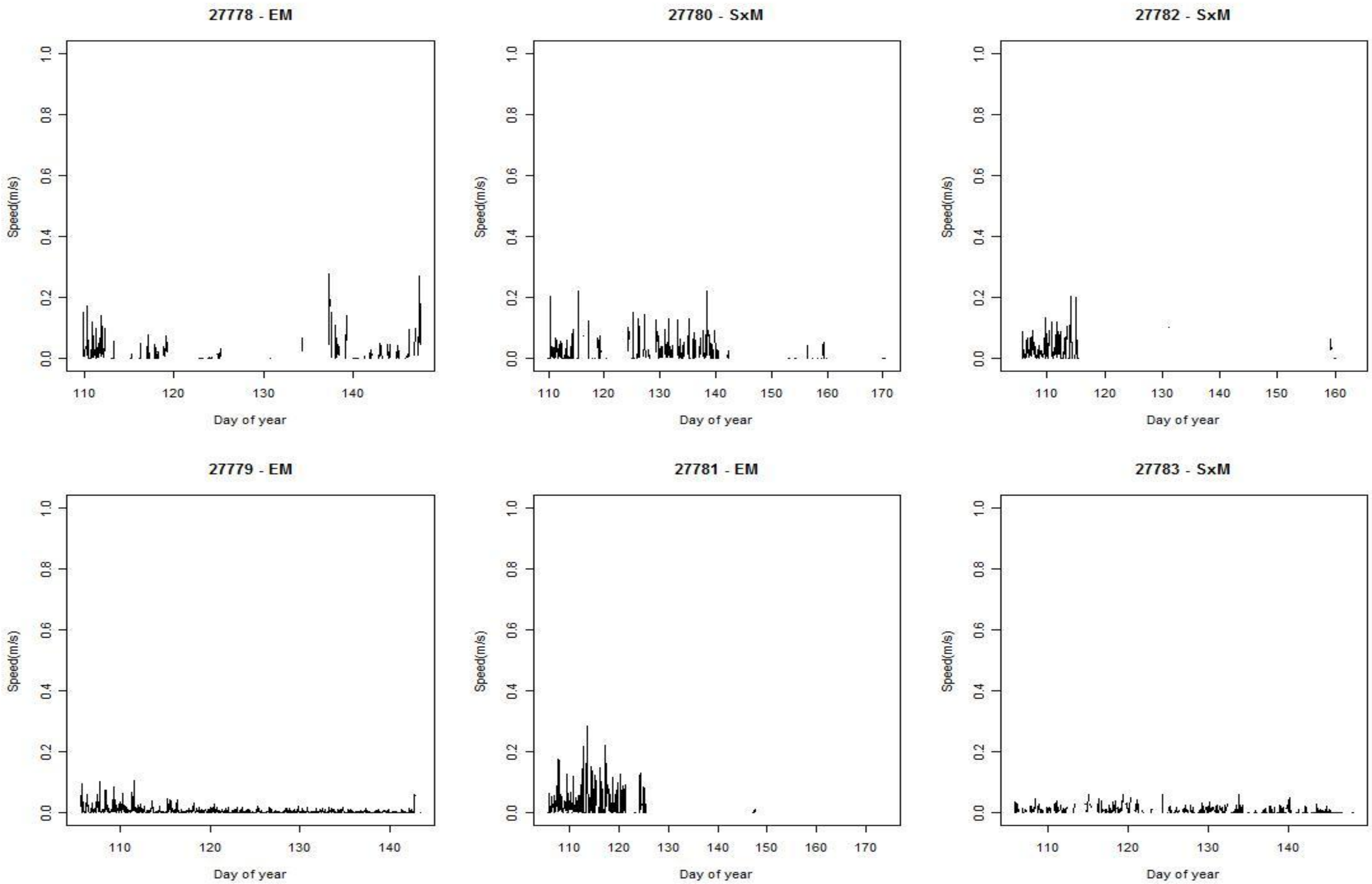

27751 - EM
27753 - EM
27755 - SxM
27752 - EM
27754 - EM
27756 - EM
Speed(m/s)
Day of year

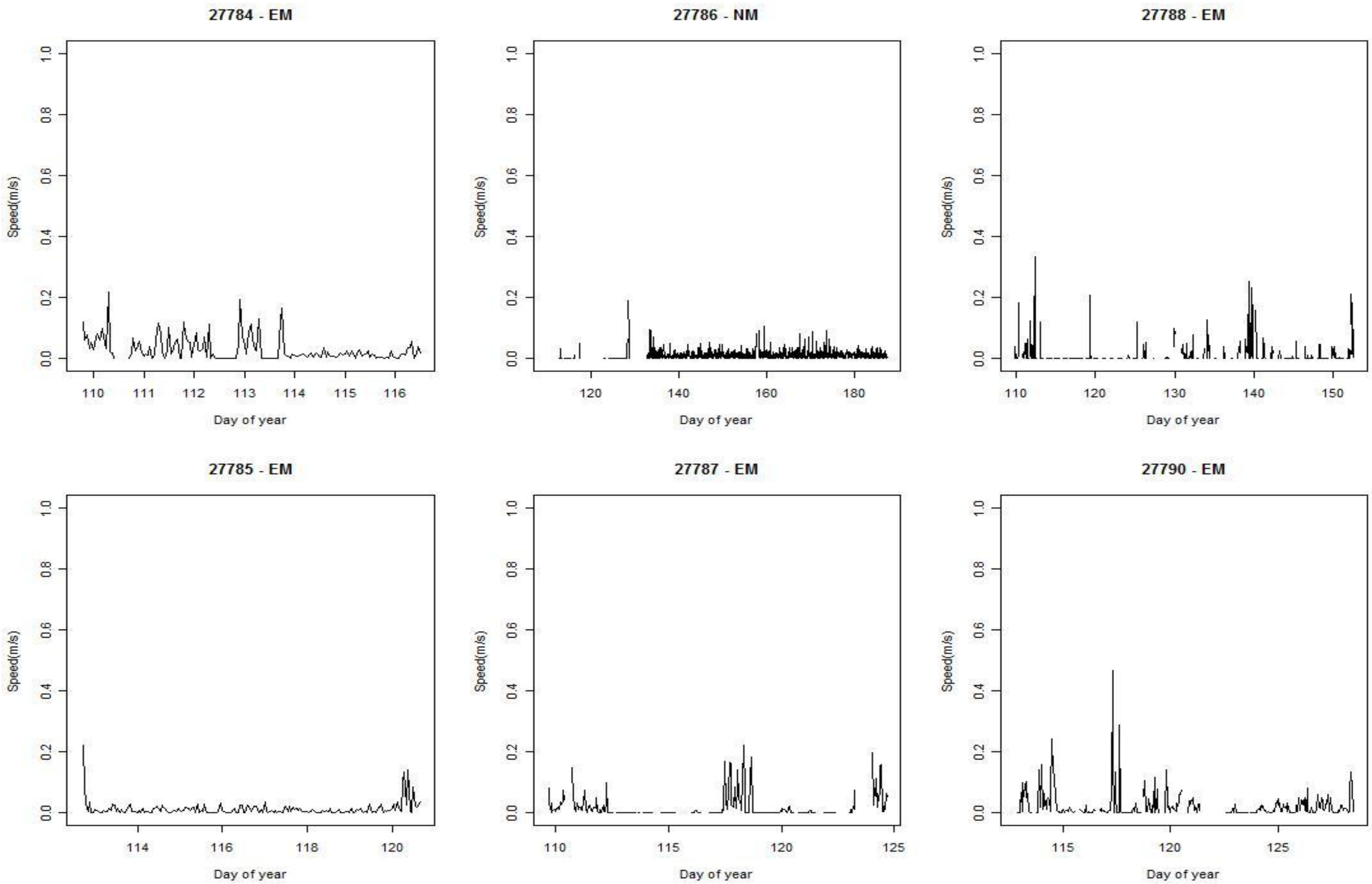

27759 - EM
27761 - EM
27763 - SxM
27760 - EM
27762 - EM
27764 - EM
Speed(m/s)
Day of year

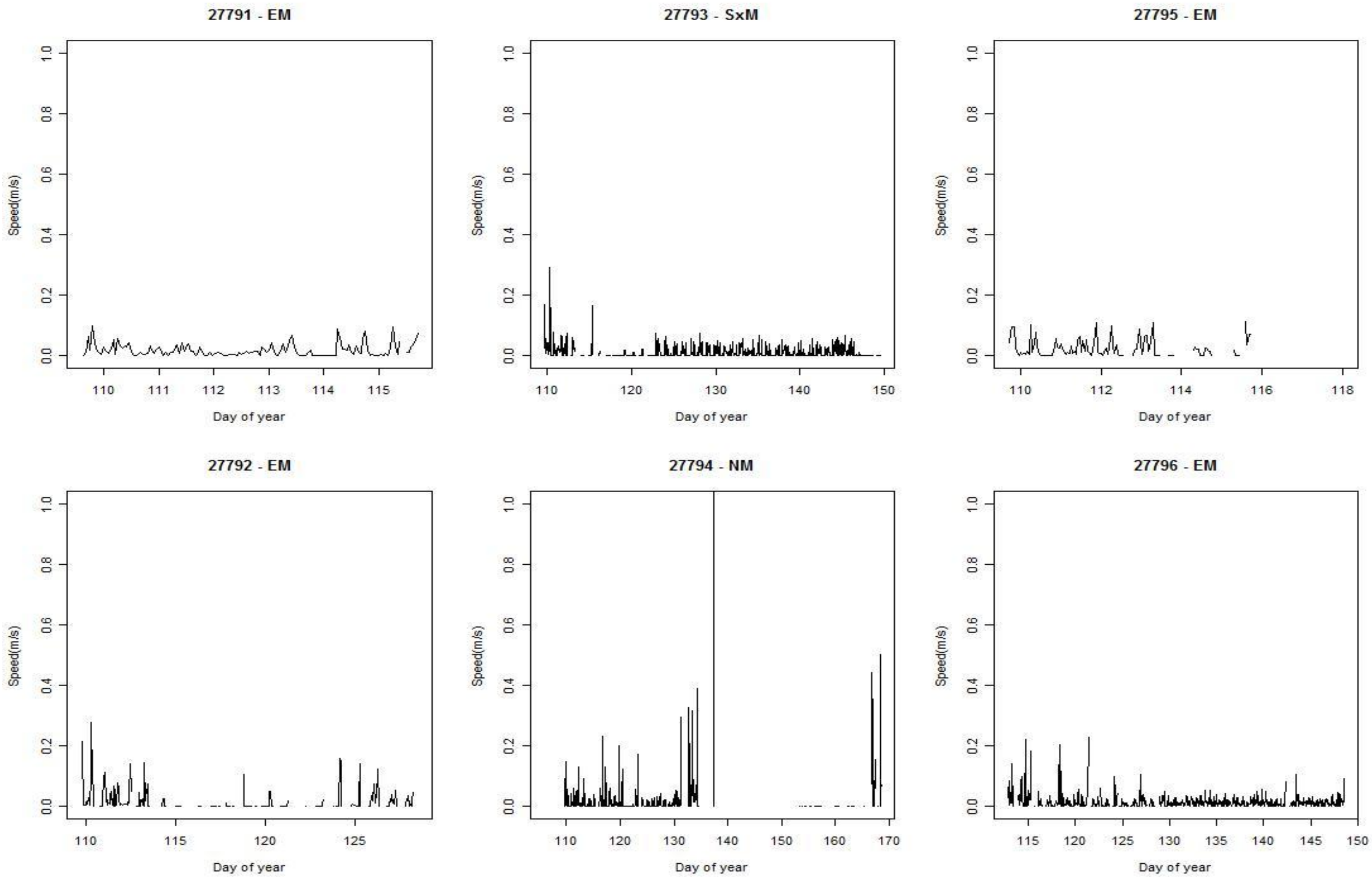

27768 - EM
27775 - EM
27772 - EM
27776 - EM
Speed(m/s)
Day of year

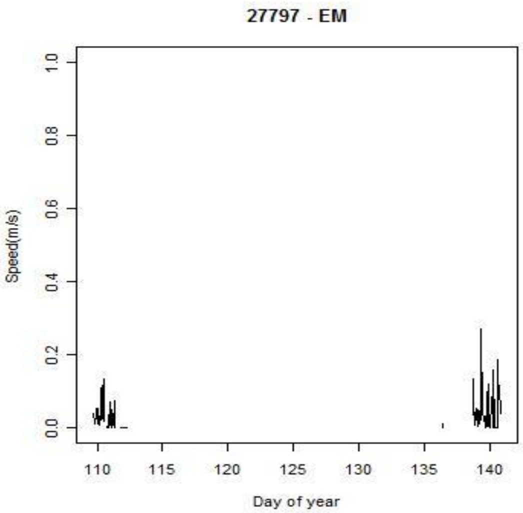

27726 - SxM
27731 - EM
27733 - EM
27729 - NM
27732 - NM
27736 - EM
Speed(m/s)
Day of year

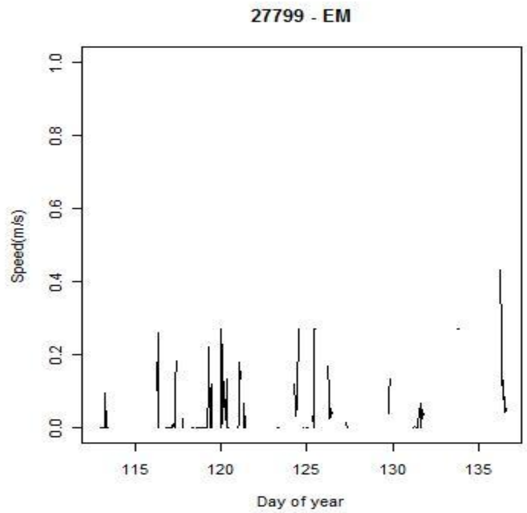

27739 - EM
27767 - EM
27773 - EM
27765 - EM
27770 - EM
27774 - NM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
Day of year
104
106
108
110
112
100
110
120
130
140
150
160
170
105
115
125
111
113
114
116
135

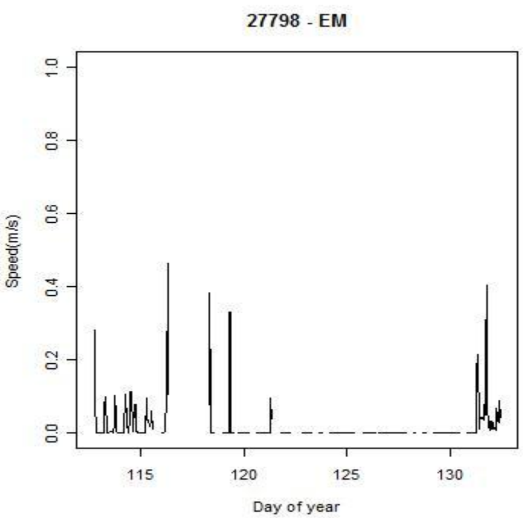

27778 - EM
27780 - SxM
27782 - SxM
27779 - EM
27781 - EM
27783 - SxM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0
110
120
130
140
150
160
170


27784 - EM
27786 - NM
27788 - EM
27785 - EM
27787 - EM
27790 - EM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0
110
111
112
113
114
115
116
120
140
160
180
130
150
118
125


27791 - EM
27793 - SxM
27795 - EM
27792 - EM
27794 - NM
27796 - EM
Speed(m/s)
Day of year
0.0
0.2
0.4
0.6
0.8
1.0


27797 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
110
115
120
125
130
135
140
Day of year


27799 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
115
120
125
130
135
Day of year


27798 - EM
Speed(m/s)
0.0
0.2
0.4
0.6
0.8
1.0
115
120
125
130
Day of year