Incorporating Migration and Local Movement Patterns into Management Strategies for Spiny Dogfish (*Squalus acanthias*)

by

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ABSTRACT OF DISSERTATION

The overall purpose of this dissertation is to increase understanding of migration and movement behaviors associated with a highly migratory elasmobranch species. In particular, I seek to determine whether sufficient evidence exists to warrant the separation of the northwest Atlantic Spiny Dogfish (*Squalus acanthias*) into separate management units. These management units are not genetically distinct, but rather would be based on unique behaviors adopted by hypothesized groups of dogfish that connect reproductive, feeding, and overwintering grounds ("contingents"). This dissertation includes an introductory chapter that introduces the reader to the Spiny Dogfish resource and recent management actions undertaken, followed by a chapter that provides technical and design recommendations based on a meta-analysis and a case study, which address the challenges of conducting behavioral research in dynamic environments through the use of acoustic telemtry. Approximately 30 percent of papers reviewed had no details on design specifications. Meta-analyses suggest that more fish were redetected when more acoustic equipment was deployed for longer periods of time, exemplifying the need for

robust equipment that can withstand the rigors of an offshore, dynamic environment. In particular, we found that a heavy anchor, a subsurface float holding a mooring line, and a highflier-float system produced the best results in our case study. New behavioral information, derived from an analysis of data collected through a long-term conventional mark-recapture program and a multi-year acoustic tagging program, suggest that spiny dogfish tagged off North Carolina in overwintering grounds routinely make seasonal migrations to summer feeding habitats off southern New England (specifically, Massachusetts), but do not necessarily follow the same pathway each year. Sharks were often not detected on acoustic receivers for lengthy periods of time, and mark-recapture data indicated extremely lengthy times at liberty (1,000+ days). Spiny Dogfish were also noted to be locally abundant but exhibit short residency times on the Hatteras Bight acoustic array. An evaluation of potential environmental drivers of localized behavior in the southern extent of the Spiny Dogfish range noted that certain factors (i.e., water temperature and weather) had an effect on the presence and absence of dogfish in the Hatteras Bight. Finally, the dissertation discusses the Spiny Dogfish Contingent Hypothesis, which suggests that the northwestern Atlantic stock could comprise as many as five behaviorally distinct groups of Spiny Dogfish. The work presented in this dissertation identifies predictable behavioral patterns undertaken by individual Spiny Dogfish and inferred from recapture data, which can be used in context with future studies to further evaluate and refine the Spiny Dogfish Contingent Hypothesis. Despite many examples in the literature where Contingent Theory has been applied to describe spatially complex behavior in fish stocks, it is rarely applied in management plans. The current management structure in place for Spiny Dogfish is complex, has evolved to respond to fishery needs over the past 16 years, and involves multiple state and federal agencies, councils and commissions. Future research would likely need to quantify contingent “vital rates” and/or contribution to overall spawning stock biomass or fisheries to fully justify the development of a new management framework.

Incorporating Migration and Local Movement Patterns into Management Strategies

for Spiny Dogfish (*Squalus acanthias)*

A Dissertation

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by

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DEDICATION

I dedicate this project, and all of the associated blood, sweat, tears, shark bites, sunburns, and sea-sickness, to my family and friends. And to my sister, because she asked me to do so.

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CHAPTER 1: CHALLENGES OF MANAGING ELASMOBRANCH FISHERIES AT THE APPROPRIATE UNIT STOCK – THE CASE OF THE SPINY DOGFISH (*SQUALUS ACANTHIAS*)

Introduction

Highly migratory fishes, including elasmobranchs, present unique challenges for fisheries management. Oftentimes, these species may have ranges that extend beyond the geographic or bathymetric scope of fisheries and fishery independent surveys. Scientists in turn have difficulty in simply identifying the extent of the unit stock, which translates to uncertainty in the evaluation of population parameters that are essential in predicting the volume of harvest that may be taken sustainably in a given year. Fisheries managers are often asked to account for factors and behaviors in these species that are beyond their control, knowledge, and/or jurisdiction. In addition, the expense of collecting enough basic biological information for a wide-ranging species to support or contest management strategies can be prohibitive. How then, can effective management strategies be developed for a migratory species? Science must look past assumed paradigms, and periodically question the assumptions concerning behavior and life history of migratory species to ensure that management practices best reflect the life history of the stock.

Unique Challenges in Managing Elasmobranch Fisheries

Elasmobranch Stock Identification. Stock identification for elasmobranchs can be challenging because these species are often data-poor, which makes it difficult to identify the biological and geographic extent of a management unit. Extensive migration has been noted in many species of elasmobranchs, including catsharks (*Scyliorhinus canicula*, Sims et al. 2001), Lemon sharks (*Negaprion brevirostris,* Feldham et al. 2002), Sandbar sharks (*Carcharhinus plumbeus*, J. Musick and Pratt, personal communications in Hueter et al. 2005), Blacknose sharks (*Carcharhinus acronotus*, Hueter et al. 2005), and Blacktip sharks (*Carcharhinus limbatus*, Keeney et al. 2003; Hueter et al. 2005). These studies noted homing, or the repeated return of individuals to a particular area, for reproductive, foraging and refuge habitats. In some cases, large numbers of sharks were concentrated in a small spatial area (either in a school, or bottle-necked by physical features). Migrating fish that undergo extensive migrations are often forced in great numbers into a small area; this provides an opportunity for hunters of these fish to harvest large numbers with minimal effort. Fish may also concentrate in small areas without any sort of physical constraint, where water quality conditions and/or prey concentrations attract them. This also results in aggregations of fish that a vulnerable to fishermen. It is reasonable to suspect that the same conditions that allow for massive exploitation of migrating fish that home to specific habitats may also apply to sharks. Localized stock depletion of sharks may be masked until a notable reduction in harvest or surveyed stock is recognized. Hueter et al. (2005) noted:

> *"Depending on the degree and nature of philopatry, a shark stock that may otherwise be viewed as a single population because of overlapping ranges and congruent migratory routes may in fact constitute a metapopulation of genetically heterogeneous components."*

Localized stock depletion could account for the apparent worldwide decline in large shark stocks (Baum et al. 2003), and suggests a strong need to understand the multiple scales across which migration may occur in different species of sharks. Reducing management uncertainty through improved understanding of life history is critical for elasmobranchs that are the target of high-volume shark fisheries; many of these species may have high local abundance, but do not exhibit a high resilience to the effects of fishing (Smith et al. 1998). With some exceptions, most elasmobranch species are long-lived, slow growing, late to mature, and tend to have small broods with long gestation times (Smith et al. 1998), all of which reduce resiliency.

Shifts in distribution and localized abundance are very common for many species sampled through fishery independent surveys, such as those completed by the National Marine Fisheries Service (NMFS). Winter Skate (*Leucoraja ocellata)* underwent an apparent disappearance and recovery on George's Bank between 1980 and 2000. Originally thought to be due to changing population dynamics, it was later hypothesized that the entire population underwent a transient northern shift in distribution (Frisk et al. 2008). The NMFS bottom trawl surveys are primary fishery independent data sources used to assess Spiny Dogfish stocks; however, assessments may be unduly influenced by unusual changes in distribution that may result in unrealistic or unexplainable changes in estimated biomass (Sargarese et al. 2014). For these reasons, it is critical that the identification of a unit stock, and the geographic boundaries containing the stock, are appropriately defined such that any fluctuations in distribution or abundance through time are recognized and incorporated into the assessment of a stock.

Without knowledge of the spatial and temporal extent of migration, the rate of migration, and important habitats included in the migration, it is difficult to identify the full range and extent of a management unit. In turn, this uncertainty makes the prediction of population level responses (i.e., recruitment) to fishery practices a very difficult undertaking. Thus, understanding migration, and collecting data on fish stocks that fully encompasses these behaviors, is essential in the successful management and protection of migratory fishery resources.

High Volume Elasmobranch Shark Fisheries. Holden (1973, 1974) explored the question of whether elasmobranch fisheries could be sustainably harvested, given certain aspects of elasmobranch life history. Holden and others (Stevens et al. 1997; Walker 1998; Simpfendorfer 1999; Prince 2005) prescribe caution, suggesting that the level of exploitation should reflect the productivity of a stock and/or include selective targeting of sharks that are not large, mature, spawning females. Some shark stocks (i.e., Blue sharks (*Prionace glauca*), Spiny Dogfish (*Squalus acanthias*), and School shark (*Galeorhinus galeus*)) exhibit complex stock structuring by size, age, sex, and reproduction. Assessments of these stocks should be done with spatially structured population models using spatially disaggregated data (Walker 1998). School sharks are often targeted when they aggregate for feeding or reproductive purposes (Prince 2005). However, there is evidence that suggests females exhibit philopatry for certain pupping grounds; therefore, any targeted fishing on those pupping grounds would have a concentrated effect on the reproductive stock versus targeted fishing on feeding aggregations (which would include subadults, males, and reproductive females from multiple breeding grounds). In contrast, Prince (2005) noted that Gummy sharks (*Mustelus antarcticus*) are comparatively unspecialized and have no specialized pupping grounds; 90 percent of the catches in this fishery come from aggregations of subadults. Prince concludes that a small subset of shark fisheries may be robust to fishing pressure; however, elasmobranch fisheries are still highly susceptible to over-exploitation. Walker (1998) suggests that only small proportions of shark stocks can be taken sustainably, and the maximum sustainable yield is highly dependent on the productivity of stocks. Some sharks, such as Atlantic Sharpnose (*Rhizoprionodon terraenovae*), Smooth

Dogfish (*Mustelus canis,* also referred to in management as part of the “Smoothhound” stock complex which also includes Florida Smoothhound, *M. norrisi*, and Gulf Smoothhound, *M. sinusmexicanus*), and Bonnethead (*Sphyrna tiburo*) are highly productive and are able to support high volume, robust shark fisheries. The National Marine Fisheries Service’s (NMFS) Highly Migratory Species (HMS) Management Division manages highly migratory sharks through a combination of species-specific and species complex quotas (NMFS 2006; NMFS 2013). The highest quotas currently are assigned to the small coastal shark complex, which includes Atlantic Sharpnose, Bonnethead, and Finetooth sharks, and the Blacktip shark fishery. West coast shark fisheries are, by comparison, much smaller in terms of scope (number of species managed). In 2011, 117 metric tons of sharks (Blue, Thresher, and Shortfin Mako) included under the Pacific Highly Migratory Species Fishery Management Plan were landed. Landings of Pacific HMS sharks are comparable to landings for Atlantic Blue, Thresher, and Shortfin Mako. Additionally, NMFS is in the process of developing quotas and a management plan to support a high volume fishery for Atlantic Smooth Dogfish. Landings for Smooth Dogfish reached 2.2 million pounds in 2011. Under Amendment 3 to the 2006 Consolidated Highly Migratory Species Fishery Management Plan (FMP), NMFS delayed implementation of a preliminary quota of 715.5 metric tons for Smooth Dogfish (the highest of any shark species or complex managed under the HMS FMP). Smooth Dogfish measures will be finalized under Amendment 9 to the 2006 Consolidated HMS FMP. The proposed rule, published in August 2014, includes a Smoothhound complex quota of 1,739.9 metric tons dressed weight (approximately 3.8 million pounds) based on the maximum landings from the 10 most recent years of data plus two standard deviations (NMFS 2014).

The Spiny Dogfish fishery, which is jointly managed by the Mid-Atlantic Fishery Management Council,the New England Fishery Management Council, and the Atlantic States Marine Fisheries Commission (ASMFC), has by far the highest quotas established for any of the U.S. east coast shark fisheries and is one of a small number of high-volume elasmobranch fisheries. However, the species exhibits many life history traits that would seemingly make it susceptible to overexploitation (Smith et al. 1998; Cortes 2002; Fordham 2004). Rago and Sosebee (2009) suggest that sustainable exploitation rates of Spiny Dogfish are likely to be quite low. The species is known to live at least 35-40 years in the northwest Atlantic (Nammack et al. 1985). Age at maturity has been estimated to be 12 years for Spiny Dogfish (*S. acanthias*) in the Atlantic (Burgess 2002; Castro 2011). Average length at maturity (L_{50}) tends to vary from 77.9 to 79 cm for the Northwest Atlantic (Nammack et al. 1985; Sosebee 2005). Smith et al. (1998) evaluated intrinsic rebound potentials of 26 shark species, including both Atlantic and Pacific Spiny Dogfish (*S. suckleyi)*. Pacific Spiny Dogfish were noted to have the lowest intrinsic rebound potential, although Atlantic Spiny Dogfish were also grouped with the least resilient sharks. Pacific Spiny Dogfish exhibit different life history characteristics than Atlantic Spiny Dogfish, and were recently differentiated back into a separate species (Verissimo et al. 2010; Ebert et al. 2010) making it more difficult to infer life history traits and strategies for Atlantic Spiny Dogfish from Pacific Spiny Dogfish (e.g., Pacific Spiny Dogfish live 80 or more years, and age at maturation is estimated to be 25-35 years (Saunders and MacFarlane 1993; Vega et al. 2009). These sharks warrant special consideration with respect to the development and management of fisheries, in particular the protection of breeding stocks to ensure that spawning stock biomass is not compromised for short-term economic gain of fishery participants.

Atlantic Spiny Dogfish Fisheries

Atlantic Spiny Dogfish fisheries in the United States and Canada tend to harvest mature females due to their large size (which proved the most economically viable for markets overseas), and availability and proximity of large schools of female sharks that aggregate close to shore (Rago 1998; Wallace et al. 2009). Dogfish are typically captured with gillnet, longline and trawl gear (Grulich and DuPaul 1986; Hickman et al. 2000). The timing of the fishery in a given year reflects the temporal and spatial distribution of the species (Rago and Sosebee 2009). In the southern half of the range, dogfish are susceptible to commercial fisheries between November and April in a typical year; in the northern half of the range, dogfish are available year-round to commercial fisheries (Hickman 2000; MAFMC 1999; ASMFC 2002).

Spiny Dogfish on both the Atlantic and Pacific coasts have undergone exploitation at various times over the past century to meet demands for oil, liver (Vitamin A), meat, and fins. At various times, management entities on the Pacific and Atlantic costs offered a bounty for dogfish in support of an eradication program due to concerns about damage to fishing gear, effective loss of viable fishing grounds due to dogfish bycatch, and predation effects (Ketchen 1986; Bargmann 2009). Landings of Spiny Dogfish are shown in Figure 1. Blue bars indicate data presented in the original Fishery Management Plan (FMP) for Spiny Dogfish (MAFMC 1999), while red bars indicate data provided in the draft Environmental Assessment for Amendment 3 to the FMP (MAFMC 2014). Data in the earlier time series (blue) includes landings from Russia and other countries. Foreign landings decreased from over 52 million pounds in 1972 to between 50,000 to 1,500,000 lbs/year between 1978 and 1992; after 1992, landings by fleets from outside the United States and Canada were 0 lbs/year. Data from the later time series (1998 through 2012) includes landings only from the United States and Canadian fleets. Most of the landings through the 1960s and late 1970s were from foreign vessels, prior to the implementation of the Magnuson-Stevens Act and the gradual implementation of 200 nautical mile Exclusive Economic Zones (EEZ) via the United Nations' Convention on the Law of the Sea in 1982.

This fishery was considered by U.S. fishermen to be economically viable only as a volume fishery (Register et al. 2007; NCDMF 2008); however, trip limits have varied with the status of the fishery. Prior to the development of a fishery management plan, there were no retention limits for Spiny Dogfish. The fishery was considered a lucrative and stable wintertime option for North Carolina fishermen through the 1990s (Hickman et al. 2000). Price per pound of Spiny Dogfish ranged from $0.07/pound to $0.15/pound between 1988 and 1997 (with the exception of 1995-1996 when price/pound was just under $0.20/pound. From 2000 through 2012, prices tended to stabilize around $0.20/pound, on average (fin prices were probably higher).

Biomass of Spiny Dogfish generally increased after the 1970s in the Northwest Atlantic, possibly due to increases in growth rates (Silva 1993; Rago and Sosebee 2009). Between 1976 and 1996, Atlantic Spiny Dogfish were considered an "under-utilized" species, and both state and federal management entities encouraged the exploitation of Spiny Dogfish as an alternative to declining cod and other groundfish fisheries (Hutchings and Myers 1994; Rago et al. 1998; Rulifson et al. 2002). Spiny Dogfish meat is eaten in Europe, Australia, New Zealand, South America and Japan (Fordham 2005). U.S. industry groups attempted to create more domestic demand by relabeling Spiny Dogfish as "cape shark" and "northern shark"; however, a domestic market never fully solidified to support the volume of landings (Fordham 2004). NMFS developed and distributed guidance in the 1980s and 1990s to the fishing industry on how to handle, process, and market dogfish, in particular through the Sea Grant College Program (Delaware Sea Grant, handling and processing, Hicks 1985; Virginia Sea Grant, high volume processing, DuPaul and Grulich 1985; Virginia Sea Grant, development, costs and returns of a Spiny Dogfish fishery, Grulich and DuPaul 1986). Furthermore, international demand for Northwest Atlantic Spiny Dogfish increased as stocks in the Northeast Atlantic collapsed due to heavy fishing pressure (Waters 2010). Estimated U.S. east coast landings peaked in 1996, at over 60 million pounds of dogfish captured. The tremendous increase in exploitation through the 1990s alarmed scientists for a number of reasons: concentrated mortality on the spawning stock biomass; trends in average size from fishery independent and fishery dependent sources were consistent with increased fishing mortality; decreases in minimum biomass estimates for female sharks greater than 80 cm total length in trawl surveys; and increased estimated mortality on female sharks; considerable uncertainty regarding data and parameters used for stock assessment, stock structure, and role in the ecosystem. Estimated discards from other fisheries was known to be high. Rago et al. (1998) suggested that in some years, discards may have mirrored the magnitude of landings. Furthermore, Rago et al. (1998) cautioned against continued increases in exploitation and advocated for the development of an appropriate management plan for the species.

Spiny Dogfish Stock Assessments Imply A Stock Collapse and Rebuilding. Atlantic Spiny Dogfish provide an example of a species that has undergone an unexplainably rapid stock decline and rebuilding. NMFS determined in 1994 that dogfish were "near full exploitation" in the 18th Northeast Stock Assessment Report (SAW), and estimated exploitable and total biomass at 258,000 mt and 649,000 mt, respectively (NEFSC 1994). However, the report also predicted declines in biomass given the then-current levels of exploitation, and noted some potentially troubling indicators for the stock (declining mean lengths in fishery independent and dependent data; no increases to the spawning portion of total biomass; total catches that may have been as much as 2/3 higher than reported catches due to unreported discards; potential negative replacement of the breeding stock, etc). The female SSB was deemed overfished with overfishing occurring by the National Marine Fisheries Service (NMFS) in 1998, per results from a 1997 stock assessment (NEFSC 1997). At the 26th Northeast Stock Assessment Workshop, Spiny Dogfish were determined to be over-exploited (NEFSC 1998). Stock assessment biologists noted that stock rebuilding could, due to the life history of Spiny Dogfish, take decades (NEFSC 1998).

Spiny Dogfish were next assessed at the 43rd Northeast Stock Assessment Workshop in 2006 (NEFSC 2006). Biomass estimates indicated that the stock was no longer overfished. However, there was some question regarding the determination of whether overfishing was occurring. Under previous biological reference points, overfishing would have been occurring; however, the 26th SAW increased the overfishing threshold. Based on the new threshold, the stock status was considered improved. Projections from the stock assessment suggested continued increases in spawning stock biomass as sharks from the sizable, non-fished age classes matured. Estimated stock sizes of mature females increased by nearly two-fold between 2005 and 2006. NMFS scientists noted in the 43rd SAW that this increase was implausible given the slow growth rate of the species, and suggested that the elevated indices could be a function of changing distribution and availability of dogfish to the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey. In other words, the distribution of dogfish along the continental shelf shifted into large strata with higher weighting factors in the overall estimation of abundance in this year. Scientists saw the changes in status as a technicality based on caveats within the models and implausible survey data in 2006; and recommended conservative management measures for Spiny Dogfish fisheries. In 2007 the ASMFC Spiny Dogfish Technical Committee recommended that directed fishing on dogfish should not be permitted until the stock was considered rebuilt (ASMFC 2007). In 2008, the ASMFC Spiny Dogfish Technical Committee continued to note concerns about the determination of rebuilt status, including: size frequency distributions that did not include extremely large fish or immature fish below 70 cm TL; low numbers of juveniles; poor recruitment over the previous ten years that could influence future spawning stock biomass; pup survival rates and assumptions concerning pup survival; and skewed sex ratios (ASMFC 2008b).

The 2010 benchmark Transboundary Resources Assessment Committee (TRAC) report did not reach a consensus stock assessment for Spiny Dogfish because of the degree of uncertainty inherent in the two models developed (TRAC 2010). One model assumed a single unit stock, while the other model assumed a resident northern component and a southern component comprising both resident and migratory dogfish. The TRAC determined that the methodologies incorporated into the 43rd SAW were appropriate for determination of stock status for U.S. management purposes. Data from the 2010 TRAC (and subsequent status reviews by NMFS) indicated the potential for low spawning stock biomass between 2011 and 2017 as a result of the low numbers of recruits between 1997 and 2003 (TRAC 2010). The 2010 TRAC projection models suggest potential oscillations in total stock abundance as a result of a scarcity of recruits.

NOAA Fisheries determined that the federal Spiny Dogfish stock was rebuilt in 2010, after the NEFSC revised biological reference points for Spiny Dogfish that were used in stock assessment models (Rago and Sosebee 2010). Since 2010, Spiny Dogfish status has continued to be evaluated annually; the species has remained in a rebuilt status, with the stock deemed not overfished and overfishing not occurring. An analysis of biomass data presented in the NMFS 2013 Status Report and Projections for Spiny Dogfish shows interesting trends and considerable variation in interannual estimates of dogfish abundance from survey data (Rago and Sosebee 2009; Rago and Sosebee 2013; Figure 2; Figure 3). Between 1983 and 1993, biomass estimates of mature females over 80 cm total length (TL) generally increased with large interannual fluctuations every 2 to 3 years (Figure 3). These fluctuations are still observable in the data when the biomass estimates of females over 80 cm TL were depressed from the late 1990s through the mid-2000s. Biomass estimates of subadult sharks (36 cm to 79 cm TL) were noted to be large and increasing from 1986 through 1997 (MAFMC 1999; Figure 3). Estimated biomass of subadult females tended to be higher than biomass of adult females from 1994 through 2005. Fluctuations in biomass of subadult females are also evident in the time series. Biomass of very young sharks (male and female combined, less than 35 cm TL) fluctuated between 1980 and 1988, remained fairly constant between 1988 and 1993, peaked in 1994, and then remained low until 2009. After 2009, the biomass of very young sharks increased rapidly, with 2013 being a record year for estimated biomass of this size class. NMFS' pup index displayed near decadal (8-12 year) fluctuations between the late 1960s and late 1990s (shaded in alternating cycles (Figure 2). Pup index was extremely low between 1997 and 2003, but increased thereafter to record levels (Rago and Sosebee 2013).

The projected weak cohorts have not materialized in the data, although biomass estimates after 2006 are quite variable (Figure 3). Rago and Sosebee (2013) note that increased, recent recruitment with the recovery of the Spiny Dogfish population has resulted in increased abundance of small fish (<60 cm TL) (Figure 3). These numbers of subadult Spiny Dogfish have reduced the likelihood of the previously predicted sharp decrease in female spawning stock biomass. However, stock status updates in 2011 and 2012 have cautioned against the potential for stock biomass fluctuations or declines as result of poor recruitment in earlier years (MAFMC 2011; Rago and Sosebee 2012).

Management Measures Adopted in Response to Spiny Dogfish Stock Assessment Results. In response to the determination that Spiny Dogfish spawning stock biomass (SSB) was overfished, NMFS initiated development of a joint fishery management plan (FMP) with the Mid-Atlantic Fishery Management Council (lead council) and the New England Fishery Management Council to manage the fishery in federal waters (3 to 200 nautical miles from shore). It took several years for the management plan to be implemented due to delays and continued Council requests for additional analyses and scientific review (Fordham 2004). The federal fishery management plan allowed for a one-year exit fishery with a 22 million pound quota; in subsequent years the quotas were established to meet maximum fishing mortality goals of F = 0.2 (first year) and subsequently, F = 0.03. Implementation of the federal fishery management plan began in May 2000, at the start of the 2000-2001 fishing year with a 4 million pound quota. The Atlantic States Marine Fisheries Commission (ASMFC) completed development and implementation of an interstate fishery management plan (FMP) by the start of the 2003-2004 fishing year. ASMFC did not incorporate federal landings under its quota measures. However, the federal management plan defined a total allowable catch (TAC) that included state landings. During the years between implementation of a federal management plan and implementation of the ASMFC FMP, the majority of landings occurred in state waters (MAFMC 2014; Figure 4). For example, at the implementation of the federal FMP in 2000, the federal quota was set at 4 million pounds. The fishery in state waters, which was unrestricted, landed more than 21 million pounds in the same year (Fordham 2004).

Furthermore, there have been periodic changes to the structure of both management plans. The fishery management plans (FMPs) were initially designed to reflect seasonal availability to the fishery. NMFS created two fishing periods, May 1 through October 31 and November 1 through April 30. Semi-annual quotas (along with trip limits) in the federal FMP were designed to allow fishermen throughout the range to be able to take advantage of the fishery. The assignment of quota to each semi-annual period in both ASMFC and federal FMPs was based on historical landings data. However, due to the species distribution and availability to fisheries the entire federal quota was taken within three months in the first year of federal implementation (ASMFC 2002).

There have been some adjustments to the federal FMP since implementation. Framework I to the FMP was enacted in 2006 to allow for the specification of multi-year management measures (MAFMC 2005). Amendment 1 to the federal FMP constituted part of an Omnibus Amendment designed to address the Magnuson Stevens Act requirement that all of the MAFMC and NEFMC's FMPs include standardized bycatch reporting methodology (MAFMC and NEFMC 2007). The goal of Framework 2 of the Spiny Dogfish federal FMP was to build flexibility into processes that are used to define and update status determination criteria (74 FR 30012). This framework adjustment was designed to allow for faster incorporation of new management measures that may result from scientific reviews by defining acceptable levels of peer review and providing guidance on how the council can engage its Scientific and Statistical Committee (SSC). It also redefined stock status criteria for Spiny Dogfish, in general terms. Amendment 2 to the Spiny Dogfish federal FMP was also part of an Omnibus amendment developed in response to new National Standard 1 guidelines (74 FR 3178; January 16, 2009) that required new Allowable Catch Limits (ACLs) and Accountability Measures (AMs). In particular, this Amendment specified an ACL that was equal to the Allowable Biological Catch (ABC); implemented an allowable catch threshold (ACT) to buffer the ACL; and implemented accountability measures that, in the event of a quota overage, would reduce the following year's quota by the weight of the overage. In July 2014, NMFS finalized Amendment 3 to the federal Spiny Dogfish FMP, in which NMFS eliminated allocation of the federal commercial quota by period or by region. NMFS justified the removal of allocation periods by noting that this action would make federal management more consistent with ASMFC's interstate fishery management plan (79 FR 16753; March 26, 2014). The federal fishery management plans, therefore, were relatively simple in terms of the spatial and temporal scope of management strategies compared to the interstate fishery management plan.

The ASMFC fishery management plan was developed and implemented by the 2003-2004 fishing year. A separate Total Allowable Catch (TAC) was established under the ASMFC interstate fishery management plan for Spiny Dogfish resources in state waters annually. The ASMFC plan initially mirrored the federal plan through the allocation of the coast-wide quota by time periods: 57.9 percent of the coast-wide quota to Period I (May 1 to October 31), and 42.1 percent to Period II (November 1 to April 30). However, the interstate FMP was soon adjusted to better reflect the concerns of state fisheries and fishermen. States at the extreme southern end of the Spiny Dogfish range felt that they were not provided fair opportunity to harvest a portion of the quota. Spiny Dogfish were available year round to fishermen off southern New England; however, mid-Atlantic fishermen (in particular those from North Carolina and Virginia) had much less time to participate in the fishery and had to compete with fishermen up through Maine (ASMFC 2011). Addendum II was implemented by ASMFC in 2008 to divide the interstate quota up between management regions so that each received a percentage share (ASMFC 2008). While this was an improvement, there was still contention that states in the northern part of the southern region were able to access and harvest the full quota before dogfish became available to fishermen in Virginia and North Carolina. Therefore, the management structure changed again in 2011, when ASMFC implemented Addendum III to dissolve the southern region and allocate percentages of the quota to states based on historical landings in order to preserve access (ASMFC 2011). The northern region allocation remained the same (58 percent), but the southern quota was split as follows: 2.707 percent to New York, 7.644 percent to New Jersey, 0.896 percent to Delaware, 5.920 percent to Maryland, 10.795 percent to Virginia, and 14.036 percent to North Carolina.

In general the interstate fishery management plans attempted to provide complementary actions to ensure that state fisheries would not undermine federal fisheries, and vice versa. However, there were many points over the previous fifteen years of management where inconsistent measures were adopted for Spiny Dogfish by NMFS and ASMFC (Table 1). For example, in the 2003-2004 Fishing Year, NMFS had instituted a 4,000,000 pound quota for Spiny Dogfish, and daily trip limits of 600 and 300 pounds for Period I and Period II, respectively. However, ASMFC instituted a quota of 8,800,000 pounds and allowed states to set their own trip limits (some used the federal trip limits, some established trip limits much higher).

Inconsistencies between interstate and federal management from the 2006 through 2008 fishing years occurred after NMFS finalized a benchmark stock assessment in 2006. Following the 43rd NEFSC Stock Assessment Workshop (SAW), NMFS implemented the same quotas for the 2006, 2007, and 2008 fishing years; however, the ASMFC chose to increase quotas in response to the federal determination that the stock was no longer overfished, and overfishing was not occurring. NMFS and ASMFC deviated again in the quota implemented for the 2014 and 2015 fishing years, with the federal quota being set more conservatively than the interstate quota. A federal 600 pound daily trip limit was enforced through the rebuilding period, and gradually increased to 4,000 pounds per trip for both state and federal entities as the fishery recovered (MAFMC 1999; Hickman et al. 2000; ASMFC 2002; Rago and Sosebee 2013).

Rapid Rebuilding of the Spiny Dogfish Stock. Science has not yet conclusively explained how a stock of a long-lived, late maturing shark in such poor shape, as evidenced through sampling efforts and subsequent stock assessments in the late 1990s through 2005, could rebuild so quickly. NMFS biologists have, though the dissemination of stock status reviews, displayed a lack of confidence in the plausibility of data used in identifying stock status of Spiny Dogfish (particularly between 2005 and 2006, and again in 2012). Furthermore, the stocks exhibited characteristics of overfished stocks for several years after stocks were determined to no longer be overfished. NMFS noted that total standing biomass of sharks remained relatively high, and in particular there have been moderate numbers of sub-adults and consistent numbers of males in the water column. However the proportion of the stock that "counted" for stock assessment purposes, the mature females targeted by the fishery, became much reduced. Due to the slow growth rates of Spiny Dogfish and delayed maturation, it is unlikely that large numbers of sub-adult sharks were able to suddenly account for the rapid re-development of the female spawning stock biomass that occurred between 2006 and 2010 (i.e., they likely could not have grown fast enough to replace the overfished females). Sex ratios of mature males to mature females in NEFSC bottom trawl surveys have shifted from 7:1 at the height of the collapse of female spawning stock biomass to between 3:1 to 4:1 (Rago and Sosebee 2013).

Where then, did these female sharks come from to rebuild the population so quickly? Perhaps the entire population of sharks was not susceptible to sampling gear, therefore resulting in an underestimation of total standing stock biomass. Beamish and McFarlane (2009) note the presence of substantial numbers of juvenile Spiny Dogfish in pelagic, mid-water habitats. Presumably, sharks in the middle of the water column would not be sampled and included in population estimates based on data collected by a bottom-trawl survey. Or, perhaps the female spawning stock biomass was replenished.

Fahy (1989, as noted by Stevens 2000) determined that rapid rebuilding of Spiny Dogfish stocks off southeastern Ireland was related to immigration and re-colonization from less-depleted areas rather than through changes in fecundity, mortality, or growth rates. If a niche suddenly opened up, sharks from adjacent, un-sampled regions (e.g., off the continental shelf) could easily move in and take advantage of available resources. It is also possible that coastal populations were replenished by sharks from deepwater areas off the continental shelf, or that coastal populations regularly move on and off the continental shelf. Sharks tagged in mark-recapture experiments off North Carolina have been recaptured off the continental shelf (R. Rulifson, East Carolina University, Department of Biology, personal communication; *this dissertation*). Spiny Dogfish have been previously noted to make onshore-offshore migrations (Shepherd et al. 2002; Campana et al. 2008; TRAC 2010). Carlson et al. (2014) deployed 20 pop-up satellite archival

X-tags on Spiny Dogfish off the coast of North Carolina. These sharks tended to disperse either along the continental shelf, or eastward into deep waters off the continental shelf, sometimes beyond the extent of the U.S. Exclusive Economic Zone.

Any of these hypotheses could explain the periodic “plagues” of dogfish that fishermen have reported at times when the female spawning stock biomass was considered to be low. Quotas have increased by nearly 45 million pounds since interstate fisheries management programs were initiated. There is clearly a need for more basic biological information to explain the population dynamics of Spiny Dogfish and how this species was able to rebuild so quickly in order to determine appropriate levels of exploitation for a sustainable fishery, as well as appropriate target population levels to address a more ecosystem-based management approach.

Research Objective

The Spiny Dogfish fishery is currently managed as a single unit stock, in part because dogfish sampled from different locations throughout the northwestern Atlantic are not genetically distinct (Verissimo et al. 2010). However, recent tagging evidence has emerged suggesting that the population structure could be more complex due to observable distinct behavior patterns undertaken by groups of dogfish.

Campana et al. (2008) evaluated spiny dogfish tagging data as part of a 5-year research program to improve understanding of stock structure, migration, and observable trends in the fishery for management purposes and to guide joint U.S.-Canadian management discussions. Spiny dogfish were hypothesized to exhibit complex metapopulation characteristics in Canadian waters, with some dogfish aggregations exhibiting migratory behaviors into and out of Canadian waters at periodic, multi-year intervals, while others were considered residents. The Canadian groups were hypothesized to be largely independent of each other, and a "sink" population in the southern Gulf of St. Lawrence was proposed due to an overall increase in age and size and decrease in numbers. The Gulf of Maine was proposed to constitute a mixing ground between dogfish residing in U.S. waters and dogfish residing in Canadian waters. Analysis of tag data implied a mixing rate of 10-20 percent, otherwise suggesting that dogfish released in U.S. waters primarily remain in U.S. waters and dogfish released in Canada primarily remain in Canadian waters. Seasonal migrations in Canadian waters were found to be primarily onshore-offshore, and changes in abundance of dogfish were linked to potential increases in seasonal catchability of sharks by survey gear driven by distribution across depth strata and the extent of the survey instead of immigration or emigration between U.S. and Canadian stocks. The southern populations of dogfish were proposed to undertake migrations between the Mid-Atlantic and the Gulf of Maine to remain in a "preferred" temperature range.

In 2010 the Transboundary Resource Assessment Committee, a group which "reviews stock assessments and projections necessary to support management activities for shared resources across the USA Canada boundary in the northwestern Atlantic" (TRAC 2010), developed the Spiny Dogfish Contingent Hypothesis. This new behavioral paradigm for Spiny Dogfish suggested that the northwestern Atlantic stock could be comprised of multiple behavioral contingents (Campana et al. 2008; Figure 5, TRAC 2010). The independent Canadian residential groups proposed in Campana et al. (2008) were carried forward; however, the new hypothesis separated U.S. dogfish into migratory groups that moved between the Mid-Atlantic and Cape Cod (the "Mid-Atlantic" migratory contingent) and in a gyre-like pattern around the Gulf of Maine which moved onshore in the summer and offshore in the winter (the "Gulf of Maine" migratory contingent). Clarke (1968) described contingents as a unique group of fish that "*engage(s) in a common pattern of seasonal migration between feeding areas, wintering areas, and spawning areas"*, and, once established, *"maintain its integrity by engaging in a distinct pattern of seasonal migration not shared by fish of other contingents."* Contingents may be defined based on broad behavioral descriptions, such as whether the groups of fish in question are resident or migratory (Elsdon and Gillanders 2006), or from more specific classifications of behavior (Clark 1968). Although most of the recent contingent theory is based on divergent observable patterns in behavior , membership within a contingent can be fluid for some examples noted in the literature, and may vary through the lifespan of a member (e.g., Secor et al. 1999 noted in a review of contingent maintenance mechanisms that arctic char may exhibit reversible migration tactics). The TRAC noted that there was some uncertainty regarding migration rates, and exchange between proposed Spiny Dogfish contingents. Subsequent deployments of a limited number of satellite tags by Carlson et al. (2014) suggested that there may be at least two groups of dogfish; however this supposition is based on small numbers of tagged sharks, and there is uncertainty regarding the proportion of the Spiny Dogfish stock undertaking seasonal movements (TRAC 2010; Sargarese et al. 2014).

The overall purpose of this dissertation is to increase understanding of migration and movement behaviors unique to one highly migratory elasmobranch species. In particular, I seek to determine whether sufficient evidence exists to warrant separation of the northwest Atlantic Spiny Dogfish population into separate management units as proposed in the Spiny Dogfish contingent hypothesis (Figure 5; TRAC 2010). It should be noted that proposed structures in both A and B (Figure 5) may appear to depict Cape Hatteras as a southern boundary of the stock; however these figures are only intended to generalize concepts. Spiny Dogfish schools routinely venture south of Cape Hatteras (e.g., Newman et al. 2000), and have been noted off South

Carolina (B. Frazier, South Carolina Department of Natural Resources, unpublished data) and even anecdotally in deep waters off the continental shelf of Florida (D. Hemilright, commercial fisherman, F/V Tar Baby, Manteo NC, personal communication). This dissertation will also establish the northern and southern extent of the proposed Mid-Atlantic migratory contingent (#1).

This dissertation is partitioned into subsequent chapters that review available methodologies for studying migration and provide recommendations on establishing a behavioral research program for Spiny Dogfish (Chapter 2); present new fishery independent behavioral data on Spiny Dogfish (Chapter 3); elucidate local drivers of behavior of Spiny Dogfish that overwinter off the coast of North Carolina (Chapter 4); and evaluate the feasibility of creating distinct management units based on the Spiny Dogfish contingent hypothesis (Chapter 5). Finally, this dissertation will also include a map appendix depicting the site of all acoustic detections of sharks that were tagged off North Carolina.

Dissertation Chapters

Preface/Introduction (Chapter 1): Challenges of Managing Elasmobranch Fisheries at the Appropriate Unit Stock - The Case of the Spiny Dogfish (*Squalus acanthias*).

Elasmobranches like Spiny Dogfish are particularly difficult to manage, as they are often data poor, exhibit complicated migration patterns, and have widely varying distribution patterns. This chapter introduces the dissertation with a discussion on the challenges of elasmobranch management and stock identification, a thorough review of the Spiny Dogfish resource, including the fishery, recent changes in biomass (and stock status), and resulting federal and interstate management initiatives taken in response to the decline in stock status through the

1990s. The purpose of the dissertation, which is to increase understanding of migration and movement behaviors and explore whether sufficient evidence exists to substantiate a new hypothesis on Spiny Dogfish stock structure, is discussed in context of the unpredicted, exceptionally rapid recovery of the species.

Chapter 2: Design Considerations for Offshore Acoustic Arrays to Support Behavioral Research. This chapter discusses the challenges in obtaining data on long-term, long-distance migration of animals for purposes of clarifying units for stock assessment or management purposes. One of the challenges in studying migration patterns of highly migratory elasmobranches, such as Spiny Dogfish, are the limited opportunities to collect fishery independent data in a way that is truly reflective of the behavior of individual fishes. We present a methodological discussion on approaches to behavioral research on fishes, and provide recommendations on the development of an acoustic tagging program which balances data output against cost and manpower limitations.

Chapter 3: Migration and Local Movement Patterns of Spiny Dogfish Overwintering in the Southern Mid-Atlantic Bight and off Cape Hatteras, North Carolina. This chapter presents results of acoustic and mark-recapture tagging studies on Spiny Dogfish that overwinter in coastal North Carolina waters from November to April. These Spiny Dogfish are hypothesized to be part of the proposed Mid-Atlantic migratory contingent that moves between overwintering habitats in the Mid-Atlantic to summer habitats off New England. However, there is uncertainty with regard to how much this proposed contingent overlaps spatially with the proposed Gulf of

Maine contingent, whether it mixes with the proposed Gulf of Maine contingent behaviorally (i.e., do individuals adopt into more than one contingent?), and the extent to which it migrates into the South Atlantic Bight. Previous research has identified the Cape Cod region could serve as a mixing ground between two hypothesized contingents of sharks (Rulifson et al. 2012). In order to refine or verify the definition and existence of contingents it is important to evaluate behavior and movement patterns both of sharks that are located within the mixing grounds and sharks that are located in areas that are clearly attributable to one contingent (in other words, studying fish in overwintering grounds of the southern Mid Atlantic Bight). This chapter identifies the seasonal, regional, spatial and yearly movement patterns of sharks that overwinter in the Mid Atlantic and South Atlantic Bights, and touches on previous research completed off Cape Cod, Massachusetts that question whether this region is an area of spatial overlap or behavioral mixing for groups of Spiny Dogfish in the northwestern Atlantic Ocean. The chapter includes an analysis of acoustic and mark-recapture data to analyze localized movements, and synthesizes large scale migration patterns and address the question of where these sharks go on a broad scale.

Chapter 4: Influence of Environmental Conditions on Overwintering Spiny Dogfish in the Hatteras Bight, North Carolina. Because Spiny Dogfish are known to exhibit considerable variability in seasonal distribution and abundance, it is also important to understand the drivers of localized movement and migratory behavior. This chapter will include a comparison of Spiny Dogfish acoustic data (Chapter 2) to environmental data to characterize the variables that best predict localized presence and absence.

Chapter 5: The Spiny Dogfish Contingent Hypothesis – Proposed Delineation of Mid-Atlantic and Gulf of Maine Migratory Contingents. This chapter will present a theoretical grounding of the contingent hypothesis and other related behavioral theories (partial migration and meta-population), and provide an overview of the Spiny Dogfish Contingent Hypothesis. I also include all data associated with the East Carolina University Spiny Dogfish research program (survey, mark-recapture data, and acoustic data) with published literature to delineate northern and southern extents of the Mid-Atlantic migratory contingent of Spiny Dogfish. This chapter also includes a discussion on management of fisheries contingents, drawing upon examples from other fisheries. I also reflect on previous and current management strategies for Spiny Dogfish, and discuss the implications of a change in management that reflects the behavior patterns identified in this dissertation.

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List of Tables and Figures

percent of the harvest; and green areas constitute less than 1 percent of the harvest. VTR data predominantly come from vessels participating in northeast permitted fisheries that are conducted north of Cape Hatteras, North Carolina. Therefore VTR data may underestimate the landings of dogfish in the southern part of the range from fishermen that participate in other southern fisheries (e.g., snapper grouper, croaker, weakfish, etc) occurring south of Cape Hatteras. Source: Environmental Assessment of Amendment 3 to the Federal FMP, MAFMC 2014).

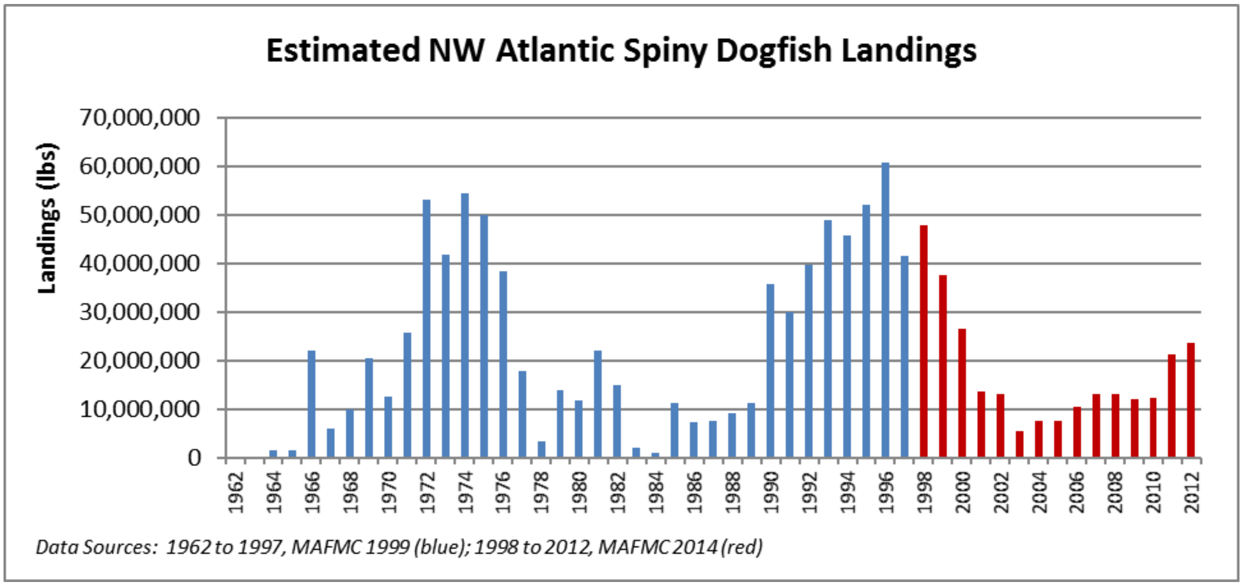
Figure 5. The single stock structure for Spiny Dogfish (A), which assumed a single mass movement of sharks between summer and winter habitats, compared to the new proposed multi-contingent structure (B) with two major contingents (identified as #1 and 2) and three resident / satellite contingents that do not receive immigrants from the major contingents (#3-5). Source: TRAC 2010.

Tables and Figures

Table 1.

Fishing Year	Federal Management Measures		Federal Status			ASMFC Management Measures	
	Quota	Trip Limits	Overfished?	Overfishing Occurring?	Rebuilt?	Quota	Period II Trip Limits
2000-2001	4,000,000	600 / 300	Y	Y	N	none	n/a
2001-2002	4,000,000	600 / 300	Y	Y	N	none	n/a
2002-2003	4,000,000	600 / 300	Y	Y	N	none	n/a
2003-2004	4,000,000	600 / 300	Y	N	N	8,800,000	up to 7,000 (NC 4,000)
2004-2005	4,000,000	600 / 300	Y	N	N	4,000,000	300
2005-2006	4,000,000	600 / 300	Y	N	N	4,000,000	300
2006-2007	4,000,000	600	N	N	N	6,000,000	States Allowed to Set Own Trip Limit
2007-2008	4,000,000	600	N	N	N	6,000,000	(300 - 4,000)
2008-2009	4,000,000	600	N	N	N	8,000,000	3,000
2009-2010	12,000,000	3,000	N	N	N	12,000,000	3,000
2010-2011	15,000,000	3,000	N	N	Y	15,000,000	3,000
2011-2012	20,000,000	3,000	N	N	Y	20,000,000	3,000
2012-2013	35,700,000	3,000	N	N	Y	35,600,000	3,000
2013-2014	40,842,000	4,000	N	N	Y	40,800,000	4,000
2014-2015	41,784,000	4,000	N	N	Y	49,370,000	4,000
2015-2016	41,578,000	4,000	N	N	Y	50,612,000	4,000

Figure 1.



Estimated NW Atlantic Spiny Dogfish Landings
Landings (lbs)
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
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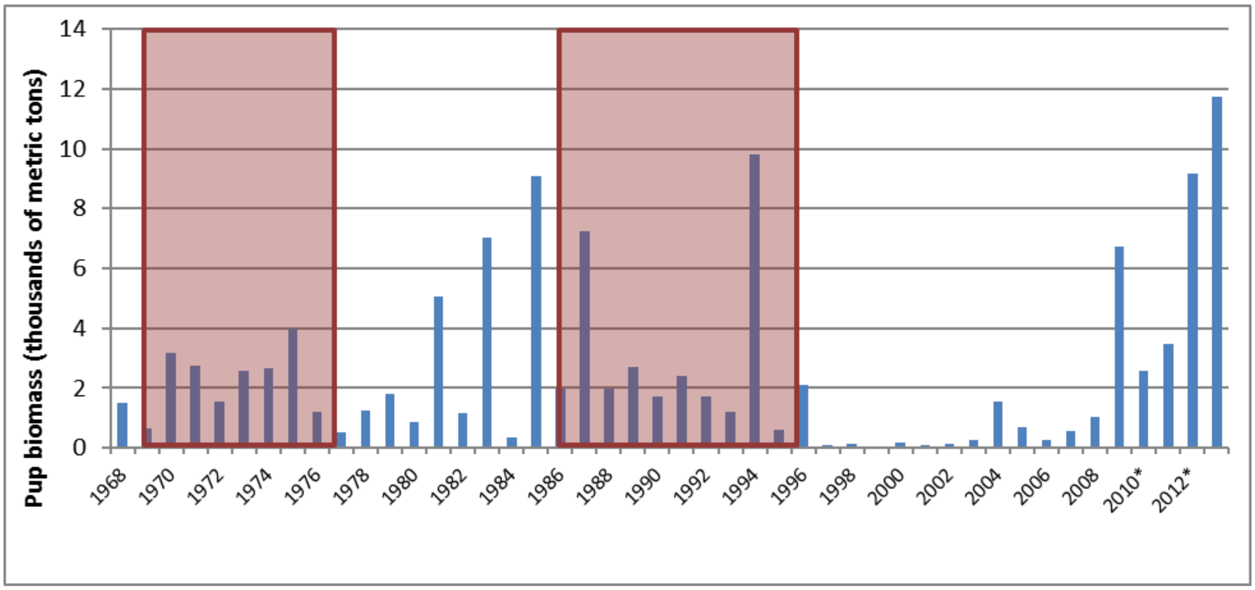
2002
2004
2006
2008
2010
2012
Data Sources: 1962 to 1997, MAFMC 1999 (blue); 1998 to 2012, MAFMC 2014 (red)

Figure 2.



Pup biomass (thousands of metric tons)
14
12
10
8
6
4
2
0
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010*
2012*

Figure 3.

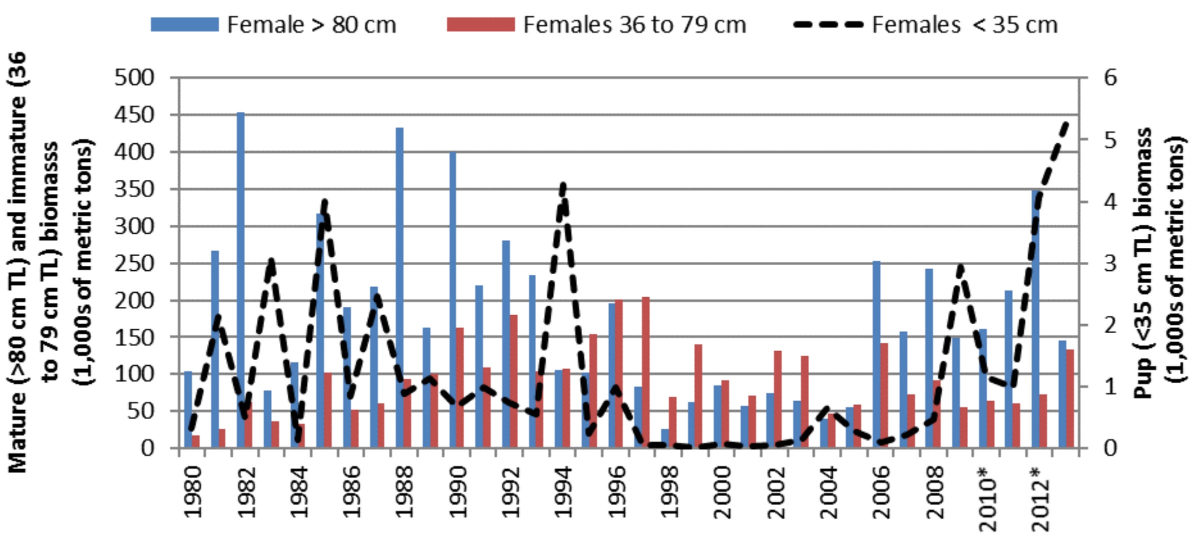

Female > 80 cm
Females 36 to 79 cm
Females < 35 cm
Mature (>80 cm TL) and immature (36 to 79 cm TL) biomass (1,000s of metric tons)
Pup (<35 cm TL) biomass (1,000s of metric tons)
500
450
400
350
300
250
200
150
100
50
0
6
5
4
3
2
1
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010*
2012*

Figure 4.

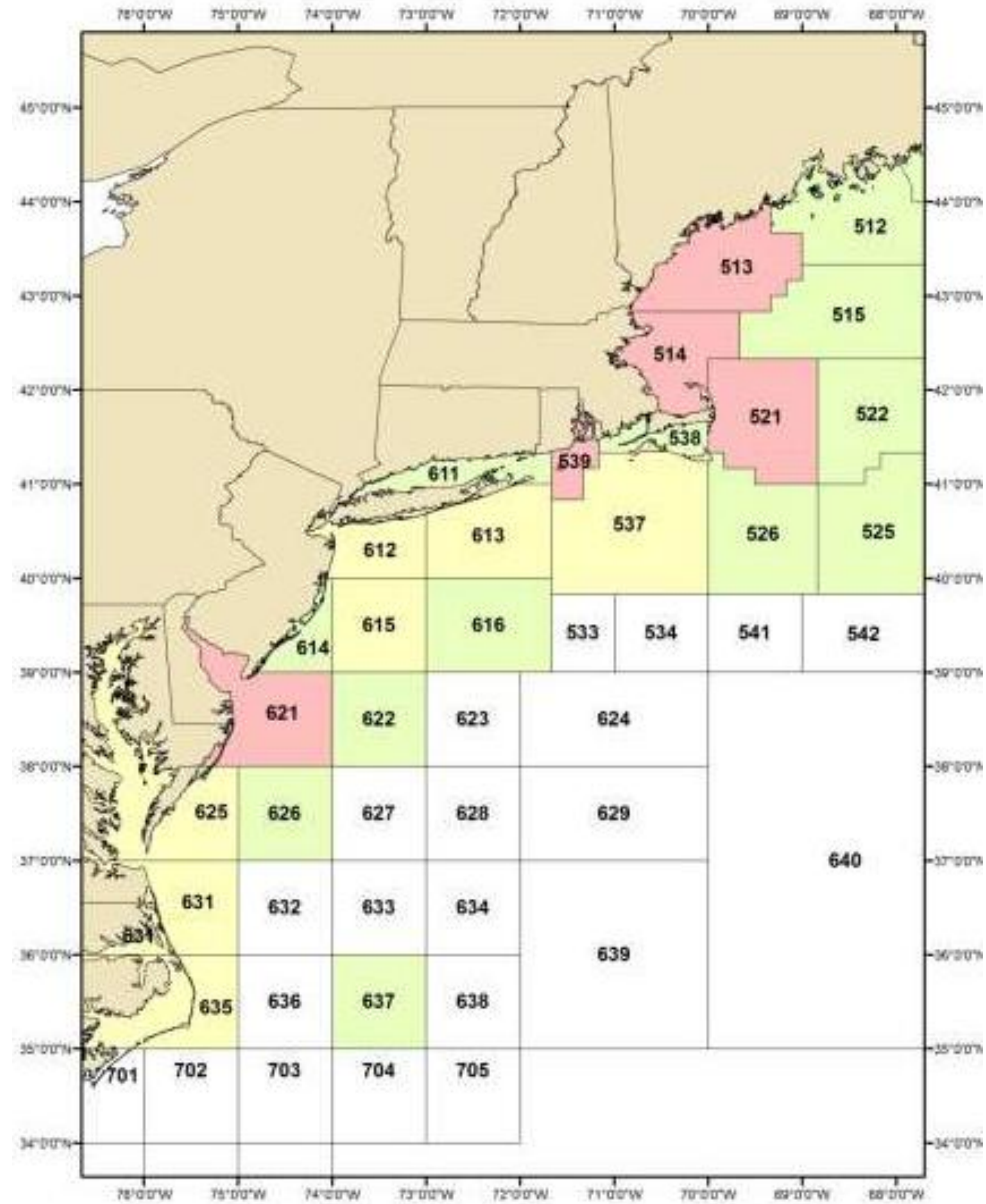


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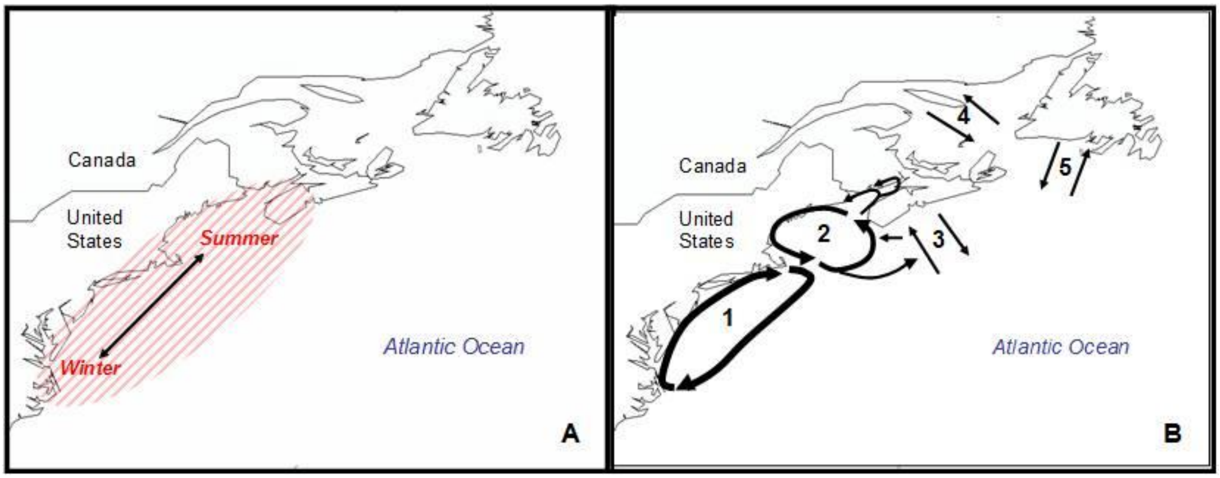
Figure 5.



Canada
United States
Summer
Winter
Atlantic Ocean
A
Canada
United States
1
2
3
4
5
Atlantic Ocean
B

CHAPTER 2: DESIGN CONSIDERATIONS FOR OFFSHORE ACOUSTIC ARRAYS TO SUPPORT BEHAVIORAL RESEARCH.

Abstract

The number of manuscripts published using acoustic telemetry has increased dramatically between 1986 and 2012 (Kessel et al. 2014), yet it can be difficult to identify the most appropriate strategy for conducting acoustic fisheries research in challenging field environments. Much of the current acoustic literature focuses on research with species in fundamentally different environments such as lakes, rivers, estuaries, coral reefs, and atolls, and does not offer adequate advice on appropriate deployment methodology for challenging coastal, high energy environments. This chapter therefore addresses the question of how to deploy acoustic receivers in an open ocean environment through 1) an analysis of the type of information available through biological research articles and the identification of patterns in acoustic array design elements; 2) a case study describing the Hatteras Acoustic Array off the Outer Banks of North Carolina; and 3) a summary of the technical recommendations provided in “design” type publications by authors experienced in the deployment of acoustic telemetry infrastructure. Most articles reviewed in the meta-analysis offered little or no description of the anchoring mechanisms, or simply noted that receivers were “moored” or “anchored” to the bottom. In instances where the anchoring mechanism was noted, authors seemed to most often use either blocks of cement or concrete, or some type of boat anchor that either locks, screws, or digs into the substrate. Research success (based on the number of redetections) was not specifically linked to a certain design element, but was related to the number of transmitters, number of receivers, the degree of overlap between receivers, and the length of time receivers were deployed. In general,

researchers looking to conduct this type of work in offshore coastal environments are encouraged to account for long-term exposure to a variety of challenging environmental factors (e.g., biofouling, severe weather, salt corrosion) and should tend gear regularly.

Introduction: Methodological Approaches to Elucidate Behavior of Marine Fishes and Elasmobranches

Behavioral research on migratory fish stocks has been enhanced through the development of new technological approaches to the conventional mark-recapture research program. Tagging studies are an important tool for researchers because they provide important clues to localized behavior, migration, habitat use, and population structure of fish stocks. Discrete data from tagged individuals can be combined and used to infer population-level movement patterns at a finer scale than what might be apparent from a broad-scale survey.

The choice of methodology is often a compromise between practical limitations (i.e., cost, manpower) and the resolution of data needed to answer the research question. Coarse scale movement and range extent can be assessed from conventional mark-recapture programs using low-cost external tags or marks (Rogers and White 2007). Conventional mark-recapture methods using external tags (e.g., spaghetti or button tags) or marks (e.g., fin clips) are usually inexpensive, are not labor intensive when conducted in conjunction with a directed fishery, and allow a large number of animals to be tagged (Heupel and Webber 2012). However, conventional mark-recapture tag studies often provide only two points of data for a particular animal consistent with the release and recapture event (in studies where angler catch-release rates are high, tagged animals may be recaptured multiple times); information on behavior between these two (or more) points in time is unavailable. Recapture rates are sometimes low for mark-recapture studies (i.e., 5 percent or less), especially those conducted within open marine or coastal systems (e.g., R. Rulifson *unpub.;* Parker 1990; McFarlane and King 2003; Register 2006; Landa et al. 2008; Tallack 2009). Recapture events are often dependent on the behavior of commercial or recreational fisheries and fishermen. High return rates are not uncommon for high profile or high effort fisheries (e.g., 27 percent for red snapper in Gulf of Mexico artificial reefs, Patterson et al. 2001; 21 percent return rate for striped bass tagged off New Brunswick, Williamson 1974 and Dadswell 1976; 16.6 percent for striped bass tagged in the Bay of Fundy, Rulifson et al. 2008). However, data are not available on animals that move beyond the regions normally accessible to the fishery or animals that are otherwise not captured. At the other end of the spectrum of available tagging methods, archival pop-up satellite tags (PSATs) or Smart Position and Temperature (SPOT) tags are extremely expensive (US $5,000 or more per individual for the tag and data support via satellite), but are less labor intensive and offer long-tracking, high resolution data (Heupel and Webber 2012). The tagging method considered for this research, acoustic tagging and telemetry, falls in the middle of this spectrum.

Acoustic Tagging. Recent advances in acoustic technology have allowed for cost-effective, longer-term tracking studies of individual animals using acoustic telemetry, which provide high resolution, fishery-independent data when compared to conventional mark-recapture programs (Heupel et al. 2006). Acoustic telemetry studies are dependent upon two types of equipment: a transmitter and a receiver. Acoustic transmitters are small tags that are programmed to emit a series of ultrasonic pings (a “pulse train”) containing identification codes and possibly environmental data (e.g., water temperature or pressure), and error checking information (Webber 2009). Researchers often select between transmitters that continuously emit pings, which are often used to continuously track individual fish over long periods of time, and coded transmitters, which emit the pings and pulse trains across specific time intervals. Transmitters are programmed such that the time between pulse trains will vary between tags, allowing multiple transmitters to be detected by receivers simultaneously (which may be important if the tagged species exhibits site fidelity, territoriality, and/or schooling behavior). Modern acoustic receivers are submersible single-channel receivers capable of logging and storing large amounts of data.

The type of receiver and deployment strategy used in a study may vary depending on the available resources and the goals of the study. Given the additional expense of acoustic tags, researchers must carefully consider research strategies and the acoustic environment prior to deployment. Most acoustic telemetry researchers typically choose between receivers designed to accommodate active (e.g., actively looking for transmitters along a survey path) or passive (e.g., receivers deployed and left in aquatic environments to collect data on animals that swim within range) acoustic sampling methods. Active acoustic telemetry usually consists of tracking individual animals with a mobile receiver (Campos et al. 2009; Heupel and Webber 2012). Active tracking is often used for direct tracking of individually tagged animals to learn about short-term movement patterns; however, active tracking of animals can be extremely labor intensive (Trefethen et al. 1957; Holland et al. 1985). Passive acoustic telemetry allows researchers to identify and track behavior without disturbance; animals are not captured, are free to engage in normal behavior, and are not subjected to any unusual environmental conditions consistent with an active research program (*i.e.*, boat noise) that might influence behavior (Nielsen 1992; Heupel et al. 2006). Receivers might be arranged in complex arrays that allow triangulation and location in two-dimensional or three-dimensional space (e.g., Steig 2000;

Klimley et al. 2001; Cooke et al. 2005; Ubeda et al. 2009). Scientists rely on the positioning of acoustic arrays that record presence and absence or to address issues such as immigration or emigration from selected habitats (Heupel et al. 2006).

Passive acoustic telemetry systems have been used successfully to study the migration patterns of multiple species of fishes in riverine and estuarine systems (e.g., sturgeon, Collins et al. 2000; striped bass, Ng et al. 2007; razorback suckers, Zelasko et al. 2010; Australian bass, Walsh et al. 2012). The use of acoustic curtains and arrays to study the migration patterns of marine fish moving through open ocean habitats has become more practical with the development of regional and international data-sharing networks, such as the Ocean Tracking Network (OTN) (O'Dor and Stokesbury 2009), the Atlantic Cooperative Telemetry Network (ACT) (http://theactnetwork.com/; Fox et al. 2009), regional integrated ocean observing systems (e.g, the Gulf of Maine Ocean Observing System, or GoMOOS), and the Pacific Ocean Shelf Tracking Project (POST) (Jackson 2011). The United States Navy has also developed an array in the southeastern part of Chesapeake Bay (and adjacent coastal areas) and at bombing test sites in North Carolina to monitor ecological effects of training exercises (C. Watterson, United States Navy, Newport News, VA, pers comm). These collaborative networks have effectively allowed researchers to extend the research footprint to large scale geographic regions such as continental coastlines (ACT), and even entire ocean basins. The ACT network, within which the Cape Hatteras array maintained by East Carolina University discussed in this manuscript was situated, provided comprehensive coverage of many coastal habitats along the east coast of the United States. The ACT network was started as a mechanism to study the behavior and dispersion of diadromous fish from particular river systems (e.g., Atlantic sturgeon). Despite the recent increase in acoustic coverage in these environments, there is a notable lack of offshore acoustic arrays in the mid-Atlantic region.

Objective

The number of manuscripts published using acoustic telemetry has increased dramatically between 1986 and 2012 (Kessel et al. 2014), yet it can be difficult to identify the most appropriate strategy for conducting acoustic fisheries research in challenging field environments. Much of the current acoustic literature focuses on research with species in freshwater (rivers or lakes), partially or wholly contained (lagoons, or estuaries), or isolated environments (atolls or coral reefs), and does not offer adequate advice on appropriate deployment methodology for challenging offshore, high energy environments. This chapter therefore addresses the question of how to deploy acoustic receivers in an open ocean environment through 1) an analysis of the type of information available through biological research articles and the identification of patterns in acoustic array design elements; 2) a case study describing the Hatteras Acoustic Array off the Outer Banks of North Carolina; and 3) a summary of the technical recommendations provided in “design” type publications by authors experienced in the deployment of acoustic telemetry infrastructure. The objective of the meta-analysis is to characterize and quantify gear schematics utilized by scientific researchers conducting acoustic telemetry research. The case study highlights research on the migration and local movement patterns of Spiny Dogfish (*Squalus acanthias*) overwintering off the coast of North Carolina. The meta-analysis and case study are compared to hard recommendations provided in the literature to develop a suite of guidelines for deployment of acoustic receivers in remote, offshore, open ocean environments.

Methods

Examination of the literature on acoustic telemetry suggests that there are two common classes of articles available for reference: those that seem to focus on design, performance, and methodological approaches (i.e., a "design paper"), and articles that are more focused on presenting biological research with variable amounts of detail on deployment schematics (i.e., a "biological research paper"). Arguably, a scientific researcher initiating a field program should consult both types of papers. The former tend to provide grounding in highly technical aspects of design and acoustic theory, and may offer research design recommendations. The latter apply the theory and intense analysis of design specifications towards fisheries research objectives, with the purpose of evaluating a biological or fishery problem. Successful designs can be inferred from high detection rates, and repeated uses of schematics across multiple research programs. However, these fisheries acoustics research articles tend to (rightly) focus less on the methods of deployment, and more on the data analyses and modeling efforts, and interpretation of data for biological or management purposes.

Articles were queried using the East Carolina University Joyner Library "One Search", a powerful search engine that queries the entire library catalog and all online resources accessible by East Carolina University library patrons. Two types of literature searches were undertaken for articles that: 1) featured acoustic telemetry research for elasmobranchs (Keywords: "shark" and "acoustic telemetry"; and 2) featured acoustic telemetry research on non-elasmobranch, teleost fish (Keywords: "fish" and "acoustic telemetry"). Search parameters were restricted to journal articles and dissertations only, but otherwise no additional restrictions were incorporated. Results of the literature query were screened for target species, and the utilization of passive acoustic telemetry (i.e., deployed receivers in a fixed location). Initial searches included only projects conducted in open ocean environments, but results did not produce enough applicable articles for analysis; therefore, the search was repeated to include acoustic telemetry research conducted in many different types of aquatic and marine environments. Many of the elasmobranch articles were published by authors researching the same system; therefore, manuscripts by the same authors that featured the exact same methodological design were represented by only one manuscript to reduce inherent biases in the analysis. Out of over 200 articles that were screened, 46 unique elasmobranch manuscripts and 51 unique teleost fish manuscripts were retained for additional analysis.

Each article was reviewed for the attributes listed in Table 2 and logged in separate databases for each analysis group (elasmobranchs and non-elasmobranch target species). Data were summarized in Microsoft Excel to describe general trends, and imported into SAS JMP (Version 9) for statistical analysis. The purpose of the study was characterized from the goal or objective statements provided in the introduction to the manuscript and the abstract. Numerical variables from each dataset were analyzed with tests of normality to indicate whether data transformations were appropriate (numerical and nominal variables identified with asterisks in Table 2). In particular, the Number of Fish Redetected and the Single Redetection Rate (simple percentage of total tagged fish) were explored as dependent variables. Continuous (numerical) dependent variables and categorical dependent variables are labeled in Table 2.

Shapiro-Wilk Goodness-of-fit tests were run on numerical data extracted from the sampled elasmobranch and non-elasmobranch articles (and a combined pool of all articles) to determine which dependent variable (Number of Fish Redetected or Single Redetection Rate) should be used in statistical analyses. Furthermore, Shapiro-Wilk Goodness of fit tests also were used to determine whether independent variables extracted from sampled elasmobranch and non-elasmobranch articles (and a pooled sample of all articles reviewed) needed to be transformed. Log-transformed, continuous independent variables were compared by type of paper (elasmobranch and non-elasmobranch) using ANOVAs. Number of Fish Redetected (cube root transformed) was compared to log-transformed numerical variables that exhibited normal distributions in either the non-elasmobranch sample of articles, the elasmobranch sample of articles, or both groups of articles pooled (e.g., Maximum Battery Life, Maximum Deployment Length, Maximum Time Interval Between Downloads, Number Receivers, Number Transmitters, and Maximum Range) using regression analysis. Number of Fish Redetected (cube root transformed) was compared to ordinal variables using ANOVA (system containment, type of array, receiver attachment surface, type of anchor, type of habitat, and receiver overlap) to determine whether there were any statistically significant differences between categories within these variables in either the non-elasmobranch sample of articles, the elasmobranch sample of articles, or both groups of articles pooled. Results of the meta-analysis were compared to the information provided in acoustic telemetry and array “design” articles, and to the results of our case study detailing research on Spiny Dogfish to provide guidelines for the long-term deployment of acoustic receivers in offshore, dynamic environments.

Results: Meta-Analysis

Articles analyzed for the meta-analysis are listed in Appendix 1. A total of 46 research articles that presented passive acoustic telemetry research on 34 species of elasmobranchs were analyzed. Nine of these elasmobranch articles reviewed tagging efforts on more than one species. Most species were only referenced in one paper (n = 20 species); however seven species were researched in two articles, three species in four articles, and one species in six separate articles. Approximately 66 percent of the elasmobranch articles referenced Carcharhinid species (Table 3; Figure 6). A total of 51 articles that discussed research on 59 non-elasmobranch species were evaluated. Most of these articles tended to target one species per paper, and covered a broad variety of genera (most prevalent Genus was *Oncorhynchus* spp.) (Figure 7). Six non-elasmobranch articles researched more than one species at a time.

The purposes of elasmobranch and teleost fish research articles screened for the meta-analysis were compared (Figure 8). The identification of spatial and temporal movement patterns, habitat utilization, and residency were common objectives among all research articles. Site fidelity was a more common objective for elasmobranch research, while mortality (natural mortality rates and analyses of post release mortality) studies were more common in teleost fish research. In both cases, there were a large number of articles oriented to discussing specific fishery management problems. Home range, diel movements, and analyses of presence/absence with environmental associations were also common goals for several elasmobranch and teleost fish research articles.

Of the sample of articles analyzed, 67 percent of those featuring research on elasmobranchs and 73 percent of those featuring research on non-elasmobranchs were found to contain some detail regarding deployment schematics or methodologies (Table 4). Fifteen percent of the sampled elasmobranch articles, and eight percent of the non-elasmobranch articles, incorporated a description of methodologies by referencing another paper.

The majority of elasmobranch and non-elasmobranch articles included the use of Vemco transmitters and receivers (http://vemco.com/about/) in chosen methodologies. Vemco receivers were used in ninety-six percent of elasmobranch articles and 76 percent of non-elasmobranch articles. Several authors cited benefits from the common use of Vemco equipment by receiving tag information from other researchers. A broad mix of Vemco acoustic transmitters were used in some studies. Model type varied by size, and researchers tended to follow recommended limits on tag:fish mass (2 to 10 percent, depending on species). Studies that used more than one kind of Vemco transmitter were studying a range of size classes or species.

In most articles, acoustic receivers were attached to rope, bar, or a cable that was suspended in the water column (Table 4), and attached to an anchoring mechanism (Table 5). Most articles offered little or no description of the anchoring mechanisms, or simply noted that receivers were "moored" or "anchored" to the bottom. In instances where the anchoring mechanism was noted, authors seemed to most often use either blocks of cement or concrete, or some type of boat anchor that either locks, screws, or digs into the substrate. Reported detection ranges of receivers varied slightly ($\chi^2 = 5.9743$, df = 2, p = 0.05), with higher average detection ranges noted for brackish and freshwater environments (e.g., lakes and reservoirs) than for marine environments (Figure 9).

Most articles did not have details on every parameter analyzed in the meta-analysis. A majority of elasmobranch and non-elasmobranch articles failed to present details on the spatial area of receiver arrays, spacing of receivers, length of time between data downloads, details on how receivers were deployed and retrieved, whether biofouling affected the receiver arrays, receiver loss, and factors attributed to receiver loss (Table 6). Furthermore, design specifications such as anchor dimensions or substance, or the mechanics of receiver attachment were typically not mentioned. Most articles mentioned whether range testing was undertaken and whether an estimate of the maximum or average detection range of receivers under a limited set of conditions was calculated. Also, I assessed whether there was enough description of the sites to determine whether arrays were positioned around geophysical features or if the deployment site was open or exposed (e.g., a seamount or an open coastal region), partially open (e.g., an estuary), or fully enclosed (e.g., a lake or reservoir). In some cases where maps were scaled and detection ranges provided (or graphically depicted), it was possible to identify whether receivers likely overlapped in detectable range.

Shapiro-Wilk Goodness-of-fit tests on numerical data extracted from the sampled elasmobranch and non-elasmobranch articles (and a pooled dataset based on elasmobranch and non-elasmobranch articles) indicated that most numerical, independent variables were likely not normally distributed. Null hypotheses under these tests are that the data are likely part of a normal distribution, with small p-values (in this case, < 0.05) rejecting the null hypothesis. As an example, Table 8 shows goodness of fit test results for numerical variables extracted from the sample of non-elasmobranch acoustic telemetry articles. Interestingly, test results for several variables were indicative of the normal distribution when elasmobranch and non-elasmobranch articles were analyzed separately (e.g., elasmobranch articles, Log(Max Estimated Battery Life), $W = 0.971036$, $p = 0.51$; non-elasmobranch articles, Log(Max Estimated Battery Life), $W = 0.974707$, $p = 0.73$). However, in some cases those same variables were not normally distributed when pooled across both samples of literature and then analyzed (e.g., Log (MaxEstimatedBatteryLife), $W = 0.941608$, $p = 0.0064$, data not shown). Table 9 shows Shapiro-Wilk goodness of fit test results for transformed dependent variables. The cube root transformation was the only transformation that resulted in successful normalization of the dependent variables tested, and results suggest that the transformation normalized the data in both the separate datasets (elasmobranch and non-elasmobranch articles) and when the datasets were pooled.

Statistical analyses also noted some differences between types of articles. When comparing the elasmobranch and non-elasmobranch articles, there was not a statistically significant difference in the cube-root transformed number of fish redetected ($F = 2.182$, $df = 74$, $p > 0.05$); however, there were differences between the two types of articles with respect to the log-transformed length of receiver deployment ($F = 10.8756$, $df = 75$, $p < 0.05$) and the log-transformed number of transmitters ($F = 5.41$, $df = 85$, $P < 0.05$). The number of transmitters tended to be higher and the receivers tended to be deployed for longer periods of time in non-elasmobranch articles (Figure 10; Figure 11).

Some statistically significant relationships were noted between the number of fish redetected and some continuous dependent variables. For the sampled non- elasmobranch articles, statistically significant linear relationships were modeled between the Number of Fish Redetected, and the Maximum Deployment Length ($R^2 = 0.1678$; $F = 5.6474$, $df = 29$, $p < 0.05$) and the Number of Receivers ($R^2 = 0.1299$; $F = 4.6267$, $df = 32$, $P < 0.05$). For the sampled elasmobranch articles, statistically significant linear relationships were modeled for the Number of Transmitters ($R^2 = 0.1733$; $F = 6.9191$, $df = 34$, $p < 0.05$). The linear regression was strengthened when the data were fit to a 6^{th} order polynomial line instead of a linear line of best fit ($R^2 = 0.3658$; $F = 2.6915$, $df = 34$, $p < 0.05$). For a pooled sample of data from both elasmobranch and non-elasmobranch articles, a statistically significant relationship was also modeled for the Number of Transmitters ($R^2 = 0.3015$; $F = 28.9201$, $df = 68$, $p<0.05$). The linear regression was also strengthened when the data were fit to a 6th order polynomial line instead of a linear line of best fit ($R^2 = 0.4516$; $F = 8.510$, $df = 68$, $p < 0.05$).

No statistically significant relationships were noted between categorical independent variables and the transformed number of fish redetected when elasmobranch and non-elasmobranch articles were analyzed separately. However, in the analysis of pooled elasmobranch and non-elasmobranch articles, statistically significant differences were noted between the number of fish redetected and the degree of receiver overlap (i.e., are receivers placed so that estimated detection ranges fully overlap, partially overlap, do not overlap, have varying degrees of overlap?; $F = 3.34$, $df = 73$, $p<0.05$). Therefore, authors that utilized varying degrees of overlap in receiver deployment had higher numbers of fish redetected than those that consistently spaced receivers apart such that detection ranges always overlapped fully, partially, or not at all (Figure 12).

Case Study: An Example of A Successful Offshore Array – The Hatteras Bight Acoustic Array

Deployment Location. The study area includes coastal regions of the Outer Banks and Cape Hatteras, North Carolina. Cape Hatteras is a highly productive environment through which many species of fish transit during migration cycles. The continental shelf narrows from roughly 100 kilometers to less than 50 kilometers around Cape Hatteras (Werner et al. 1999) (Figure 13). In addition, shallow shoals and hard bottom reefs extend from Cape Hatteras nearly three-quarters of the distance from shore to shelf, and are interspersed with several channels through which animals and vessels may transit. The physical oceanography (e.g., Bumpus 1974, Beardsley et al. 1976, Atkinson et al. 1985, Pietrafesa et al. 1985, Bane 1994, Rhoades and Hecker 1994, Berger et. al 1995, Churchill and Berger 1998, Werner et al. 1999), and the biological oceanography (Weston 1988, Gabriel 1992, Werner et al. 1999, and Sedberry 2001, among others) are thoroughly reviewed elsewhere and are thus not discussed in great detail here. The Gulf Stream is often positioned between the 40 meter and 70 meter isobaths (Werner et al. 1999), and follows the edge of the continental shelf until it reaches Cape Hatteras, where it is deflected offshore. The Labrador Current moves southward immediately along the North American coast; this wedge of colder, fresher water can force the western edge of the Gulf Stream away from the coastline in winter months (Schollaert et al. 2004) (Figure 14). In addition, brackish waters exiting Chesapeake Bay to the south can have significant influence on temperature, salinity, and distribution of biota.

Animals following these respective currents (e.g., Bluefin Tuna *Thunnus thynnus*, Swordfish *Xiphias gladius*, Dolphinfish *Coryphaena hippurus*), or those following preferential thermal clines (e.g., Spiny Dogfish are known to follow the 8.3ºC / 47º F isotherm) are channeled into narrow warm and cold water regions along the continental shelf. The combination of physical factors and unique oceanographic conditions establishes a region whereby animals tracking certain conditions through migration (e.g., ocean currents, continental shelf break, or the coastline) are effectively funneled through a smaller area that is conducive for the deployment of an acoustic array of receivers.

The array site was located within the Hatteras Bight of Raleigh Bay, a coastal embayment that is bordered by Diamond Shoals (Cape Hatteras) to the north and Lookout Shoals (Cape

Lookout) to the south (Figure 14). The bathymetry of the coastal embayments south of Cape Hatteras is relatively smooth except for the aforementioned reef and shoals (Werner et al. 1999). The orientation of the shoals and the islands of the Outer Banks effectively protect the area from weather and sea conditions in three directions. According to local commercial fishermen, this makes the region an important temporary shelter for commercially important fish stocks that reside along the North Carolina Outer Banks in the wintertime. North Carolina coastal waters are subject to extreme wintertime weather systems including periodic storm fronts and nor'easters, which can generate sea conditions comparable to those encountered during the summertime hurricane season. Anchor systems deployed in the Hatteras Bight study area had to be able to withstand strong along-shore currents, tidal inlet processes, swash, boat traffic, periodic storm events and sedimentation.

The site of the array was selected in consultation with local commercial fishermen. A number of factors were considered in selecting the array deployment location, including ease of access and distance from the home port of Hatteras, NC; minimization of acoustic interference due to waves breaking and swash along Hatteras Shoals; safety concerns about deploying and working in and around Hatteras Shoals; and the identification by commercial fishermen of locations with the narrowest sections of continental shelf to ensure maximum coverage.

Array Configurations for Dynamic Environments. The objectives surrounding the deployment of the Cape Hatteras acoustic array were to develop a system that could be deployed in a rapid, safe, and cost-effective manner. Figure 15 and Figure 16 show schematics for anchor and float systems used in three consecutive years (Figure 15A in 2009, Figure 15B in 2010, Figure 16 in 2011).

Research Year 1 (November 2008 – April 2009)

Deployment schematic. Anchor systems consisted of eighteen-wheeler tractor tire hubs purchased from local junkyards (Figure 15A). A length of chain was bolted across the top of the hub, and was connected to a 4.57 meter (15-foot) length of 1.9 centimeter (0.75 inch) twisted polypropylene line. A harness for the VR2W was constructed out of 300 pound nylon monofilament (location indicated by a yellow line in Figure 15A, see harness in Figure 16). The VR2Ws were attached to the harness with zip ties, and longline clips on the VR2W harness were attached to loops that were woven into the polypropylene line. A hard trawl float (20.3 cm / 8 inches in diameter) kept the VR2W line upright in the water column. A 51 kHz Vemco V16 pinger tag in a durable PVC shark case was attached to the line with zip ties; this tag was programmed to emit pings at random 30 to 90 second intervals during wintertime daylight hours (roughly eight hours per day, although programmed times did change due to daylight savings time). The float line (1.9 centimeter or 0.75 inch twisted polypropylene line) and float system were connected to the subsurface float line with a marine mammal breakaway. The breakaway allows the disengagement of the mainline from the anchor system and acoustic receiver in the event that the line is severed by a passing boat or marine mammals, or by rope deterioration. The float line was connected to two standard sized crab pot floats at the surface to mark the location of the gear and indicate the direction of surface water movement.

Testing of Array Design. The anchor and float system was tested in inshore waters near Beaufort, NC, in November 2008 with divers to ensure that the VR2W would be held upright in the water column. The array units were deployed two months prior to deployment of acoustic transmitters to assess the durability of the system and conduct range tests.

Range test results (conducted throughout the study) suggested that the Hatteras Bight was an extremely noisy environment. Detection efficiencies implied a maximum system efficiency of 60 percent at a distance of 100 meters from the receiver in nearshore conditions of the Hatteras Bight (approximately 1.6 kilometers, or 1 mile, from the beach); however, system efficiencies were noted to change with environmental conditions. For example, receivers deployed in calm sea conditions had a much higher detection range than those deployed in seas with 0.9 – 1.5 meter (3 to 5 feet) waves. Subsequent range testing in deeper water at locations between 4.8 to 9.6 kilometers (3 to 6 miles) offshore suggested that the VEMCO estimate of 800 meters was viable in certain conditions (calm sea conditions, little temperature stratification in the water column, deep water, and increased distances from nearshore swash zones); however, the detection efficiency at this distance from the receiver tended to be low.

Receiver Unit Spacing. Range tests indicated that receivers needed to be deployed much closer together to ensure acoustic "coverage" by receivers. However, the objectives of the study were to deploy receivers as far from shore as possible. We accounted for increased water movement through the shoreline swash zone, and deployed our first receiver at least 1.6 kilometer from the beach. The first nine receivers in the array were spaced approximately 600 meters apart based on range testing within the nearshore environment. Offshore receivers (the last three) were spaced 1000 meters apart to extend the line out as far as possible with minimal coverage gaps. Results from 2009 implied that target species encountered on one receiver were also detected on adjacent receivers when the receivers were spaced further apart.

Deployment and Retrieval. Array units (anchor, VR2W harness, and float system) were pushed overboard once assembled onboard. Divers then ensured that the anchors landed on the bottom in an upright position, and clipped the VR2Ws into a harness as depicted in Figure 15A. Retrieval consisted of attempting to relocate the crab pot buoys that marked the location of the array. During array servicing and attempts at relocating the VR2W, a portable receiver system (VEMCO VR 100) was used to interface with the 51 kHz locator pingers if surface markers were found to be missing at the receiver site. Divers had to be deployed to retrieve receivers due to the inability to raise the anchor to the surface.

Receivers Shifted Offsite and/or Lost. One offshore receiver deployed approximately 8.8 kilometers offshore in 2009 was moved over 4.8 kilometers from its initial location due to an encounter with a commercial fishing vessel. One VR2W receiver also went missing in 2009 due to corrosion on the hardware that connected it to the polypropylene line. Two other receivers were moved offsite, likely through encounters with commercial fishing operations.

Biofouling Organisms. Physical biotic interference with the acoustic receiver was noted in our study. Growth was common on receivers deployed for over a month. More growth was observed in offshore sites than at nearshore sites, possibly due to scouring and strong currents closer to shore. There was significantly more growth on receivers deployed without some sort of protective coating. Desitin ®, a diaper rash cream that contains zinc oxide, was found to be very effective in controlling the attachment and growth of biofouling organisms (see Figure 17 for examples of receivers that did not receive a coating of Desitin, A and C, and receivers that did receive a coating of Desitin, B and D). The most common biofouling organisms included bryozoans, algae, and barnacles. Divers sent to collect acoustic receivers noted that the subsurface float lines holding receivers that were covered with biofouling organisms did not remain perpendicular to the water column, likely due to the weight and increased friction of the fouling organisms relative to the buoyancy of the subsurface floats. Therefore, it is recommended that offshore arrays be retrieved and cleaned once each month to minimize potential interference to the acoustic field.

Lessons Learned in 2009:

- The hubs were not recoverable due to being covered up by sand from sedimentation processes after the five month deployment period.
- The diver-based system was not practical for wintertime field work off the coast of North Carolina. Divers were limited to a set number of dives per day due to the difficult diving conditions (also a safety concern), which extended the amount of time needed to deploy and retrieve gear. Weather conditions off the coast of North Carolina are highly dynamic, and the weather windows that afforded good sea conditions were often only 1-2 days in length. In addition, extending the array further offshore would increase the depth of the dives (which would reduce the number that individual divers could complete in a day).
- All hardware must be stainless steel. We initially used longline clips with brass swivels that experienced some corrosion due to sea water.
- Gear movement and loss was attributed to interactions with fishing gear (e.g., trawlers); modifications should raise visibility and increase avoidance of gear.
- Most tagged animals were detected on more than one receiver. We therefore felt that the concerns about "detection gaps" between receivers did not outweigh the benefits of extending the array as far seaward as possible.

- Biofouling necessitated cleaning and replacement of lines every 1-2 months during warm months, and every 2-3 months in colder months.

Research Year 2 (December 2009 – July 2010)

Deployment Schematic. Due to the problems with a diver-based retrieval (and encounters with fishing vessels in 2009), a new anchor-and-float system was developed for the 2010 field season (Figure 15B). The 2010 anchor system used 1.27 centimeter (0.5 inch) galvanized chain and a 6.35 kilogram (18-pound) Danforth anchor as a base. The same type of subsurface float line as used in 2009 was attached to the chain using stainless steel shackles at a point where, when the line was folded down against the anchor, the VR2W would lie behind the anchor and not rub or bump against it during retrieval (Figure 15 is not drawn to scale to depict this specification). At the end of the chain, a 2.54 centimeter (1 inch) twisted polypropylene line was used to connect the anchor unit to the surface float system. The float system was designed to increase visibility to commercial fishing vessels, both visually and by radar; it consisted of a "highflier" connected to the mainline, which was kept at the surface with large (15.24 centimeter x 35.56 centimeter; 6 inch x 14 inch) crab pot floats. Highfliers consisted of an aluminum radar reflector and a flag printed with "research in progress" and contact information mounted on an aluminum pole with an appropriate counterweight.

Testing of Array Design. This anchor configuration was tested between July 2, 2009, and September 15, 2009, off Atlantic Beach, North Carolina. The anchor-highflier system did not move despite heavy vessel traffic (commercial fishing vessels, shipping vessels, and recreational vessels), several frontal systems, and one tropical system (Hurricane Bill) that affected North Carolina coastal sea conditions during the deployment period.

Receiver Unit Spacing. In 2010, the receivers were spaced 1600 meters (1 mile) apart to obtain the maximum amount of coverage possible within the Hatteras Bight.

Deployment and Retrieval. VR2Ws were clipped onto the anchor system and deployed without divers by playing out the anchor line with the boat in idle speed, securing the anchor in sediment, and then a rapid (but gentle) lowering of the harnessed VR2W, subsurface float, and lines used to connect the anchor to the highflier. The entire line (12 receivers and anchor-float systems) was deployed in one day; subsequent retrievals (requiring a winch) took one to one and a half days due to limited amount of deck space on the vessel.

In 2010 and 2011, acoustic receivers were deployed and retrieved using a 12-volt winch (Powerwinch Capstan 1000 Windlass, 453 kilogram pull for a line up to 1.58 centimeters (0.625 inches) in diameter) and boom system mounted to the rear port gunnel of a 7.6 meter TomCat power boat (Figure 18). A manual winch (basic boat trailer winch, roughly 1,134 kilograms pull) was also used to allow for increased control over the anchor system at the end of retrieval (Figure 18). The boom was constructed to allow the anchor system to be retrieved in a way that minimized contact with the side of the vessel; the boom pivoted to allow the anchor system to be deposited in the back of the boat. Maintenance was conducted as necessary to replace fouled lines, broken or damaged parts, and to remove biofouling organisms. Receivers were removed and cleaned, data were downloaded, and the receiver was redeployed.

Receivers Shifted Offsite and/or Lost. Nine of ten receivers deployed in January 2010 were recovered in May 2010. One missing receiver from the 2010 deployment was never recovered.

Lessons Learned in 2010:

- During the 2010 deployment, we observed that the chains used to help weight down the anchor system tended to wrap around the anchor; while this provided additional weight to the system, it also allowed the anchor system to roll during weather events or periods of strong current movement.
- Lines need to be replaced every 1-2 months in spring 2010 due to accumulation of fouling organisms.
- Partnering with the fishing industry ensured that a large number of people monitored the array for us in between trips. This type of cooperation is essential to the success of projects depending on gear deployed in heavily fished areas.

Research Year 3 (December 2010 – November 2011)

Deployment Schematic. Modifications to the 2010 VR2W anchor-float system were made after the entire array was shifted offsite due to a tropical storm (Figure 16). A circular cement block weighing approximately 45.36 kilograms (100 pounds) was added to the system to provide a more stable anchoring platform. A 5.9 kilogram (13 pound) Danforth anchor was connected to the top of the cement block with a 1.9 centimeter (0.75 inch) diameter, 4.3 meter (14 foot) long galvanized chain. A sub-surface float system was also connected to the top of the cement block via a 1.83 meter (6 foot) long, 0.48 centimeter (0.1875 inch) diameter stainless steel cable (instead of polypropylene line). The receiver line was suspended in the water column with a hard trawl float (20.32 centimeters / 8 inches). The VR2W was secured to a harness constructed from 136 kilogram (300 pound) test monofilament line and shackled to stainless steel cable loops to improve durability (the monofilament harness was long enough to discourage acoustic interference from the stainless steel loops). Surface floats and a highflier were also deployed in 2011 to maintain visibility to passing fishing vessels.

Testing of Array Design. No additional testing of the acoustic array was conducted in 2011.

Receiver Unit Spacing. In 2011, the receivers were spaced 1600 meters (1 mile) apart to obtain the maximum amount of coverage possible within the Hatteras Bight.

Deployment and Retrieval. The extra weight from this receiver anchoring system necessitated the use of a hydraulic winch bolted onto a boom for retrieval. Retrieval methods were identical to those in 2010 (see description under Year 2).

Receivers Shifted Offsite and/or Lost. Hurricane Irene significantly affected the receiver array. All receivers were pushed offsite approximately 3200 meters (2 miles) to the northeast. After modifications were made to the acoustic array, only one acoustic receiver was missing at the end of the deployment period.

Lessons Learned in 2011

- Adaptations to the system were necessary after Hurricane Irene made landfall in coastal North Carolina on August 27, 2011. 45.4 kg (100 pound) blocks of concrete were added to the anchor systems and stainless steel cables were used to connect the subsurface float to the anchoring system to improve overall system durability.

Synthesis and Discussion

This chapter provides a comprehensive synthesis of recommendations from two types of articles commonly found in the literature ("biological research" and "design" articles) and from our own experiences in conducting acoustic telemetry research off the coast of North Carolina. Given the limitations, and in some cases lack of information, from these sources, this synthesis allows recommendations on site analysis, range testing, deployment and retrieval of equipment, anchoring mechanisms, receiver attachment, and maintenance.

Site Analysis, Range Testing and Deployment. An understanding of site specific factors that affect how the transmitter and receiver communicate is essential to successful collection and evaluation of data. Therefore researchers need to catalog and account for potential physical and oceanographic variables that could reduce the likelihood of success. While most "biological research articles" presented information on the site, and many discussed the detection range of receivers, these articles tended to not focus on the identification and discussion of factors that may have influenced detectability of transmitters. Many of these articles incorporated discussion of factors that affect receiver detections by reference (especially when the author was able to cite previous work completed in the study location), or simply relied on the advice provided by the manufacturer (i.e., factory and field testing completed under more carefully controlled settings). However, many of the "design" articles did discuss site selection and factors influencing the acoustic field of receivers and detection of transmitters (Table 11).

After careful analysis of our study location, and consideration of logistics and costs, we determined that we needed a durable system that could be deployed for several months at a time with minimal tending. We accounted for many of the factors presented in Table 11 when developing the Hatteras Bight Acoustic Array, and even held a workshop in 2007 to discuss study design and logistics in 2007 (Rulifson and Hemilright 2008). The biggest concerns with the Hatteras Bight Acoustic Array were based on oceanographic conditions and heavy fishing activity in the area. In response, we experimented with multiple types of anchors to identify the best option that was durable and resistant to extreme weather and sea conditions, and heavy activity from fishing vessels. Furthermore, due to the remote location and infrequent (1-3 months or more) site visits, the array had to be durable enough to withstand these stressors.

The meta-analysis of biological research articles and a review of design articles indicate that many researchers are concerned with how the environment affects the detection range of receivers. Detection range was one of the most commonly reported design aspects in the "biological research" articles. Guidelines and suggestions from authors of "design" articles are presented in Table 12. In particular, Kessel et al. (2014) provided an extremely thorough literary analysis of over 300 articles and provides recommendations on important variables to consider in study design, site analysis, and range testing. Analysis of biological research articles indicated that detection range of sampled articles tended to be lower in marine environments (however, this is inclusive of *all* marine environments and spans coral reef, open ocean, and deep submarine canyons).

Design and development of the Hatteras Bight Acoustic Array was initially based on manufacturer advice concerning detection range and spacing of acoustic receivers; we were therefore surprised and concerned when range testing indicated receivers needed to be spaced more closely together. The final deployment in Year 1 of the Hatteras Bight Acoustic Array balanced conflicting needs to have complete coverage down the acoustic line yet extend the array as far offshore as possible.

The initial grant that funded the Hatteras Bight Acoustic Array did not include enough money (in part due to our own inexperience with budgeting for this type of project) for thorough range testing to be completed across multiple days, times of day, and seasons. Although recommended by multiple authors of the “design” articles, we did not have enough money for sentinel tags that would have enabled us to better evaluate the causes in variability of acoustic detections. We would therefore strongly recommend that researchers completing acoustic telemetry research in similar environments plan to run continuous sentinel tags, to range test as often as possible while arrays are in the water, and even consider a preliminary pilot project based on range testing to assess the study site and develop a deployment plan that maximizes the likelihood of achieving research objectives.

The actual deployment and retrieval of acoustic receivers can provide a significant logistical challenge, especially in deeper waters. Recommendations on deployment and retrieval from “design” articles are presented in Table 13. The ease and speed with which receivers can be deployed and retrieved should factor into design considerations (Lacroix and Voegeli 2000; Heupel et al. 2006), especially if receivers are deployed in high traffic areas or if weather or sea conditions pose logistical challenges to deployment and retrieval with divers (the latter being the case off the Outer Banks of North Carolina). We attempted deployment and retrieval with divers in the first year the Hatteras Acoustic Array was deployed, and quickly found that conditions were unsafe due to cold water and required work in air temperatures less than 4º C (40º F). Divers were limited in the number of dives they could do in a day, and the work could often not be completed in the extremely short windows of calm wintertime weather off the Outer Banks.

Researchers seem split on whether it is best to use surface tag lines to ease deployments or whether it is better to “hide” the receiver on the bottom and either use grappling lines, divers, or acoustic releases to retrieve gear. Most authors that chose to hide equipment and also identified a retrieval mechanism either relied on divers (see the following references in Appendix 1: Garla et al. 2006; Kerwatch et al. 2008; Papastamatious et al. 2010; Lee et al. 2011; da Silva et al. 2013; Hawthorne 2013; Kock et al. 2013; Lefevre et al. 2013; Reyier et al. 2014), snagging or grappling a line or loop on the anchor system (see the following references in Appendix 1: Castagna 2010; Halfyard et al. 2012; Smith 2013), or on deepwater acoustic release mechanisms (see the following references in Appendix 1: Welch et al. 2004; Dawson and Starr 2009; McMichael et al. 2010; Wolfe 2013; Alfonso et al. 2014; Daley et al. 2014). Given the logistical challenges of deployment and retrieval, it was discouraging that a number of the “biological research” articles glossed over or did not mention how equipment was deployed and retrieved.

If rapid deployment is desired, we recommend a system whereby receivers can be pushed overboard already attached to equipment. Because of the sedimentation risks caused by prevailing alongshore currents, and gear movement from extreme weather and encounters with fishing gear, the Hatteras Acoustic Array was eventually deployed with large floats and a radar reflector on the tagline to aid in relocating the equipment. We successfully relied on collaborative working relationships with the local fishing community to gain assistance in day-to-day monitoring (and avoidance) of the acoustic equipment. Cooperative commercial fishermen were willing to locate our buoys while working in the area and report back on whether they were still at the deployment site, to share information about the experiment, and to assist in outreach regarding the project. With respect to retrieval, it is easiest to find gear that is marked at the surface; however, if exceptionally precise location information is recorded via a ship GPS unit then equipment may be grappled (e.g., Domeier 2005). For a variety of reasons, it may be desirable to not mark location of underwater equipment; in this instance, we recommend that researchers conducting research in offshore environments consider deployment of cabled acoustic equipment that communicate data with vessels via a modem versus driving a vessel in circles attempting to grapple lines that may be subject to unknown currents (and thus in a different orientation to gear than expected) or buried in sediment.

Anchoring Mechanisms. An appropriate anchor system is a key factor in deployment success (Heupel et al. 2006). Anchor system recommendations from “design” articles are presented in Table 14. Choice of anchor is largely dependent on the substrate and environmental forces that will act against the system. In energetic environments such as swash zones or inlets, or if extended deployments of acoustic Doppler current profilers are planned, we recommend a hybrid system that permits sediment to move underneath the frame or trawl shield to minimize the risk of gear burial.

Many acoustic receiver arrays along the U.S. east coast are opportunistically deployed on navigational markers, often requiring the use of divers to affix and retrieve receivers. Navigation buoys are safe and durable anchors, and mariners are prohibited by law from harassing navigation markers, making them attractive options for long-term deployment situations. However, acoustic receiver manufacturers often advise against their deployment on navigation buoys, which expose the receivers to increased environmental noise due to proximity of shipping and navigation channels. Boat traffic, noise, and wake can interfere with the acoustic field and possibly trigger false detections (Simmonds and MacLennan 2005; Heupel et al. 2006). Because mariners are prevented from harassing navigation buoys by state and federal law, and navigation buoys tend to be well marked, researchers should consider whether the potential loss of acoustic detection range is offset by the likelihood of gear loss. Finally, depending on the goals of the project, researchers may have to invest in alternative anchoring mechanisms if acoustic sampling is required in regions where navigation buoys are not present. In short, the acoustic array should be designed to meet the needs of the research project, and receiver locations should not be restricted to current navigational infrastructure.

Receiver Attachment. Recommendations presented by authors in "design" articles are itemized in Table 15. Receivers are often attached to metal chains that connect the buoy to an anchor; however, mounting acoustic receivers on metal can detrimentally affect detection efficiencies (Clements et al. 2005). Clements et al. (2005) compared the effects of different mounting platforms on an acoustic receiver in a freshwater reservoir. Detection ranges tended to be between 200-400 meters, but when a metal mounting bar was used the acoustic detection range was minimal at distances greater than 100-200 meters from the receiver. Unfortunately the most stable and durable mounting platforms, especially in highly dynamic environments such as fast-moving rivers or coastal environments, tend to be made out of metal. The most common means of attachment mentioned in both the "biological research" articles and the "design" articles was direct attachment of the receiver to a rope or line; we found this to be an easy and effective solution for the Hatteras Acoustic Array. This approach is also commonly recommended by Vemco Ltd.

Maintenance. Recommendations from "design" articles (e.g., Fitzgerald et al. 1947; Clare 1998; Afsar et al. 2003; Domeier 2005; Heupel et al. 2008; Table 16) and our case study concur on the importance of regular cleaning and maintenance to maintain receiver performance; however, maintenance was rarely discussed in the "biological research" articles. Normal wear and tear will occur over the life of the research study, but physical abrasion from extreme currents or tides or corrosion due to exposure will degrade anchor systems (Titzler et al. 2010; Cudney, *this study*). Similar to the results noted in this study, Titzler et al. (2010) found multiple weak points in the ropes, receiver bridle, surface buoys, and taglines that comprised their anchor systems, and ended up replacing many degradable parts with stainless steel shackles, pins, and cable to increase durability. Titzler et al. (2010) deployed many acoustic receivers in a riverine, high flow environment, and noted success after a polyurethane fin was added to the receiver to stabilize it in the water column and reduce drag. Maintenance and upkeep (e.g., replacing lines and degradable parts) also mitigates the effects of biofouling organisms on receiver orientation in the water column. There is strong support in the literature, and from our case study and field experiences, for the use of anti-fouling paint on underwater equipment. We also found success in coating receivers with Desitin ® (zinc oxide) and then wrapping them in saran wrap (use duct tape, electrical tape, or zip ties to hold saran wrap in place).

Conclusions

Aside from the recommendations contained in the Synthesis and Discussion section, we offer a few final recommendations for researchers wishing to deploy acoustic receivers in offshore environments:

1) Researchers should take the time to fully analyze the deployment location with respect to environmental factors that may affect the outcome of the study concurrently with the development of a project budget. Discussions with coastal and offshore fishermen may yield clues on whether current patterns, sea condition, tides, temperature, salinity, or other factors need to be factored into research design.

2) Conduct range testing as often as possible, in as many conditions as possible. Deploy sentinel tags. Determine whether your study requires full, partial, or no overlap between receivers in advance to meet research objectives and space them accordingly.
3) Open ocean deployments are often conducted in remote locations, requiring considerable time and expense for upkeep. Investments of time and resources to make the system more durable at the beginning of a study may save money in the long term by reducing the number of visits to replace equipment and adapting the system to forcing agents within the environment.
4) Develop a realistic plan for maintenance. How often can receiver anchor units be retrieved for data downloads and cleaning? Deployments in coastal photic zones may necessitate removal of algal growth, whereas deployments at any depth will have to mitigate attachment of bryozoans, limpets, and barnacles. Have appropriate biofouling mitigative techniques been adopted? Visit the array as often as possible to ensure it is in good working order. Frequent retrieval, cleaning, and deployment is logistically difficult in offshore environments. Include as much money in the budget for maintenance as possible – it always takes longer and costs more to do offshore research.
5) Conduct long-term tests of anchor systems before deploying acoustic receivers during the same time of year that equipment will be deployed. Many researchers have found success in using concrete anchors, but there are many alternatives that are available depending on the type of substrate in study locations.
6) If no tag lines are to be used, be as precise as possible in recording deployment location. If tag lines are to be used, develop collaborative working relationships with individuals that frequently work in the area and can keep an eye on equipment on your behalf. If

deployments with tag lines occur in an area with heavy vessel traffic, deploy radar reflectors on equipment.

7) If studying migratory species, it is recommended that researchers collaborate in region-wide telemetry networks. Networks can provide expanded coverage at little to no additional cost to the researcher or home institution, and reduce the risk of deploying equipment without redetecting animals (Welch et al. 2013).
8) Publish the results of your range test, and the conditions under which they were conducted, so that others might benefit from your findings.

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(respectively), that failed to provide details on aspects of passive acoustic receiver deployment schematics, study design, receiver loss, or range testing.

Table 8. Goodness-of-Fit tests run on independent numerical variables derived from a meta-analysis of non-elasmobranch acoustic telemetry articles. Variables that were deemed more likely to have a normal distribution are shown in bold font.

Table 9. Shapiro-Wilks Goodness of Fit tests on dependent variables used in statistical analyses. Cube root transformation of the number of fish detected is shown for three different datasets analyzed (data only from elasmobranch articles, data only from non-elasmobranch articles, and a dataset consisting of both elasmobranch and non-elasmobranch articles).

Table 10. VR2W range test results from Cape Hatteras, North Carolina. Tests were conducted during November, 2008, in nearshore wintertime weather conditions (0.6 – 1.5 meter waves, 4º C air temperature, 8ºC water temperature with some stratification through the water column, 10.7 – 12.2 meter depth, and strong alongshore currentvertical profiling/layering of horizontal currents).

Table 11. Abiotic, biotic and anthropomorphic factors that are known to detrimentally affect detection range of acoustic receivers.

Table 12. Summary of recommendations concerning range testing from a sample of "design" focused acoustic telemetry articles.

Table 13. "Design" paper recommendations for the deployment and retrieval of acoustic equipment.

Table 14. Recommendations for the consideration of different types of anchors from "design" articles.

Table 15. Recommendations by "design" paper authors on attachment of the acoustic receiver to the anchor system.

Table 16. Recommendations from "design" articles concerning regular maintenance and upkeep of acoustic receiver arrays deployed in aquatic and marine environments.

Figure 6. Genera of elasmobranch species studied in a sample of 46 passive acoustic telemetry articles.

Figure 7. Genera of non-elasmobranch species studied in a sample of 51 passive acoustic telemetry manuscripts.

Figure 8. Objective keywords identified in elasmobranch and teleost fish passive acoustic telemetry research articles screened for meta-analysis.

Figure 9. Boxplots showing the average detection range noted in research articles occurring in brackish, freshwater, and marine habitats.

Figure 10. Comparison in the log-transformed length of receiver deployment between non-elasmobranch ("other") articles and elasmobranch ("SHK") articles indicates longer deployment times in studies not focused on elasmobranchs. Boxes describe the median (line in box) and the 25 and 75 percent quartiles (top and bottom edges of boxes). Whiskers describe the range of points.

Figure 11. Comparison in the log-transformed number of transmitters deployed between non-elasmobranch ("other") articles and elasmobranch ("SHK") articles indicates fewer transmitters tend to be deployed in elasmobranch research than in studies not focused on elasmobranchs. See Figure 5 for a description of box plots.

Figure 12. Comparison of the transformed number of fish detected by the amount of detection range overlap between receivers, as indicated by authors based on range testing or reported estimated detection ranges.

Figure 13. Bathymetric map of U.S. east coast. The study area is highlighted with a red box. Source: Google Maps.

Figure 14. Sea surface temperature satellite composite map showing surface temperature conditions on February 21, 2010, and Raleigh Bay / Hatteras Bight. North Carolina is a unique mixing ground of two major current systems plus outflow from the Chesapeake Bay watershed. Source: Rutgers University Coastal Ocean Observing Lab.

Figure 15. Anchor system schematics for 2009 (A) and 2010 (B). In 2009, 1.9 centimeter (0.75 inch) polypropylene line was attached directly to the subsurface float, and connected to a single standard sized crab pot float. In 2010, the surface float line was connected to the end of an anchor chain. 2010 surface marker included a high flier connected to the surface float line via a 3.05 meter (10 foot) long, “Y”-shaped rope bridle.

Figure 16. 2011 deployment schematic for the Hatteras Bight acoustic array anchor and float systems.

Figure 17. Biofouling of VR2W acoustic receivers when the receiver was deployed without an anti-foulant (A, C) versus when receivers were deployed with Desitin (zinc oxide; B, D).

Figure 18. Winch and boom system used to retrieve anchors, lines, and the acoustic receivers.

Tables and Figures

Table 2.

Citation	**Deployment Details**
Purpose	Spatial area of array
Species of interest	Receiver spacing
	Receiver detection range overlap?** (Full, partial or none)
Equipment Specifications	Overall length of deployment*
# Receivers*	Deployment intervals* – how often are data downloaded from receivers?
# Transmitters*	Deployment / retrieval process
Transmitter specifications – pulse train, battery life*, frequency	Biofouling / preventative measures
Transmitter location – internal or external attachment to study specimen	Depth of deployment
	Receiver location in water column
Redetections	Receiver loss (number)
# of fish*	Factors attributed to receiver loss
Single redetection rate*	
Multiple redetection rate	**Receiver deployment schematics**
	Type of anchor
Study Site	Weight of anchor (kg)
Network or isolated array	Size of anchor (dimensions)
Location	Anchor substance
Physical and oceanographic features	Receiver orientation (up or down)
Containment of system** – full, partial, or open	Receiver attachment surface
Type of array – grid, curtain, strategic site selection, high resolution, 3-D positioning array, etc.	Type of lines used
Range Testing? (Y/N)**	**Other notes on study design**
Maximum detection range (meters)*	
Detection rate	

Table 3.

Elasmobranch Study Species (Scientific & Common Names)			
Rhizoprionodon terraenovae	Atlantic Sharpnose Shark	*Ginglymostoma cirratum*	Nurse Shark
Carcharhinus tilstoni	Australian Backtip Shark	*Carcharhinus amboinensis*	Pigeye Shark
Carcharhinus melanopterus	Blacktip reef Shark	*Echinorhinus cookei*	Prickly Shark
Carcharhinus limbatus	Blacktip Shark	*Carcharhinus plumbeus*	Sandbar Shark
Triaenodon obesus	Whitetip Reef Shark	*Sphyrna lewini*	Scalloped Hammerhead Shark
Sphyrna tiburo	Bonnethead Shark	*Rhinobatos productus*	Shovelnose Guitarfish
Notorynchus cepedianus	Broadnose Sevengill Shark	*Negaprion acutidens*	Sicklefin Lemon Shark
Carcharhinus leucas	Bull Shark	*Carcharhinus albimarginatus*	Silvertip Shark
Carcharhinus perezi	Caribbean Reef Shark	*Hexanchus griseus*	Sixgill Shark
Cephaloscyllium laticeps	Australian SwellShark; Draughtboard Shark	*Pristis pectinata*	Smalltooth Sawfish
Manta birostris	Giant Manta ray	*Mustelus canis*	Smooth Dogfish
Mustelus californicus	Gray Smoothhound Shark	*Mustelus mustelus*	Smoothhound Shark
Somniosus microcephalus	Greenland Shark	*Centrophorus zeehaani*	Southern dogfish
Carcharhinus amblyrhynchos	Grey Reef Shark	*Carcharhinus sorrah*	Spottail Shark
Mustelus antarcticus	Gummy Shark	*Galeocerdo cuvier*	Tiger Shark
Negaprion brevirostris	Lemon Shark	*Carcharodon carcharias*	White Shark
Triakis semifasciate	Leopard Shark		

Non-Elasmobranch Study Species (Scientific & Common Name)			
Thunnus albacares	Yellowfin Tuna	*Ophiodon elongatus*	Lingcod
Acipenser medirostris	Green Sturgeon	*Pagellus bogaraveo*	Blackspot Seabream
Albula vulpes	Bonefish	*Pangasianodon gigas*	Mekong Giant Catfish
Anguilla anguilla	European eel	*Paralichthys dentatus*	Summer Flounder
Argyrosomus japonicus	Mulloway	*Perca fluviatilis*	Yellow Perch
Branchiostegus japonicus	Red Tilefish	*Pomadasys commersonnii*	Spotted Grunter
Centropristis striata	Black Sea Bass	*Pomatomus saltatrix*	Bluefish
Cheilinus undulatus	Humphead Wrasse	*Rhabdosargus globiceps*	White Stumpnose
Chelonia mydas	Green Sea Turtle	*Salmo salar*	Atlantic Salmon
Choerodon schoenleinii	Black-Spot Tuskfish	*Salvelinus alpinus*	Arctic Char
Gadus morhua	Atlantic Cod	*Scarus psittacus*	Palenose Parrotfish
Genyonemus lineatus	White Croaker	*Scarus rubroviolaceus*	Ember Parrotfish
Katsuwonus pelamis	Skipjack Tuna	*Sciaenops ocellatus*	Red Drum
Labrus bergylta	Ballan Wrasse	*Sebastes caurinus*	Copper Rockfish
Lthrinus nebulosus	Spangled Emperor	*Selar crumenophthalmus*	Bigeye Scad
Lutjanus campechanus	Red Snapper	*Serranus cabrilla*	Comber
Morone saxatilis	Striped Bass	*Serranus scriba*	Painted Comber
Mycteroperca microlepis	Gag	*Sphyraena barracuda*	Great Barracuda
Mycteroperca phenax	Scamp	*Stenodus leucichthys*	Inconnu
Naso unicornis	Bluespine Unicornfish	*Thymallus thymallus*	European Grayling
Naso lituratus	Orangespine Unicornfish	*Trachinotus falcatus*	Permit
Oncorhynchus kisutch	Coho Salmon	*Xyrauchen texanus*	Razorback Sucker
Oncorhynchus mykiss	Steelhead Trout	*Zebrasoma flavescens*	Yellow Tang
Oncorhynchus tshawytscha	Chinook Salmon		

Table 4.

Any Details on Deployment?	Elasmobranch		Non-Elasmobranch	
	Number of Articles	**Percent of Articles**	**Number of Articles**	**Percent of Articles**
Yes	31	0.67	37	0.73
No	15	0.33	14	0.27
Total	46	-----	51	-----
Incorporation by Reference (Inclusive of Y/N)	7	0.15	4	0.08

Table 5.

Elasmobranch Articles		Non-Elasmobranch Articles	
Attachment Surface	**# Articles**	**Attachment Surface**	**# Articles**
No Information Provided	27	No Information Provided	28
unspecified rope or line	8	unspecified rope or line	9
metal pole / rebar	3	metal pole / rebar	2
chain / galvanized chain	2	galvanized chain /steel cable	2
steel cable (thin)	2	PVC pipe	2
nylon rope	2	rebar / steel cable	1
PVC pipe	1	nylon rope	1
rubber	1	polypropelene line	1
sand screw	1	screw anchor / auger	1
stainless steel threaded rod	1	stainless steel anchor	1
		FAD mooring line	1
		ground line	1
		navigation buoy	1

Table 6.

Elasmobranch Articles		Non-Elasmobranch Articles	
Type of Anchor	**# Articles**	**Type of Anchor**	**# Articles**
No Information Provided	22	No Information Provided	20
concrete	7	Concrete block	7
cement block	3	"Anchor"	6
sand screws	2	"Moored"	3
"Moored"	2	Pyramid Anchor	3
dock pilings and channel markers	2	Screw Anchor / Auger	3
steel clump weight	1	Cast Iron Heating Element	1
star pickets, cable ties, stainless steel wire	1	Steel Pipe	1
screws or sandbags	1	Bruce Anchor/Chain	1
sandbags	1	Car Tire (filled w/ concrete)	1
pyramid anchor	1	FAD	1
Concrete filled tires	1	Ground Line	1
chains	1	Pilings and Navigation Buoys	2
CART	1	Sandbags	1

Table 7.

Descriptive Parameter	Elasmobranch Articles		Non-Elasmobranch Articles	
	# Articles	Percent of Articles	# Articles	Percent of Articles
*Physical features	4	9	3	6
*Oceanographic features	33	72	39	76
*Containment (Full, Partial, Open)	1	2	0	0
*Type of Array	2	4	1	2
Spatial Area of Array	39	85	36	71
Spacing of Receivers	32	70	27	53
Receiver Overlap	17	37	4	8
Length of Deployment (Months)	5	11	15	29
How Often Data Downloaded	26	57	32	63
How are receivers deployed/retrieved?	35	76	36	71
Biofouling Comments / How Mitigated	40	87	43	84
Type Anchor	22	48	20	39
Weight Anchor	39	85	42	82
Size Anchor	45	98	48	94
Anchor substance	31	67	32	63
Depth of Deployment (meters)	22	48	32	63
Location in water column	25	54	14	27
Receiver Orientation	30	65	23	45
Attachment surface	27	59	28	55
Type Lines Used	36	78	40	78
Receiver Loss (number)	38	83	44	86
Receiver Loss Cause	40	87	46	90
Range Testing?	6	13	4	8
Maximum detection range (meters)	9	20	18	35
Percentage at maximum detection range	36	78	42	82

Table 8.

Variable	W-score (Shapiro Wilk GofF)	p<W? (small p-value rejects null, p<0.05)	Possibly a Normal Distribution?
Max Estimated Battery Life	0.897756	0.0119	No
Log (Max Estimated Battery Life)	**0.974707**	**0.7286**	**Yes**
Log (Number of Fish Redetected)	**0.957195**	**0.1342**	**Yes**
Max Length Deployment (months)	0.897177	0.0016	No
Log (Max Length Deployment (months))	**0.956445**	**0.1265**	**Yes**
Log (Max Interval Between Downloads)	**0.923773**	**0.1710**	**Yes**
Max Interval Between Downloads	**0.917401**	**0.1335**	**Yes**
Maximum Detection Range (meters)	0.928983	0.0208	No
Log (Max Detection Range)	0.854460	0.0002*	No
Number Receivers	0.888184	0.0006*	No
Log(Number Receivers)	**0.987299**	**0.9036**	**Yes**
Number Transmitters	0.630170	<0.0001*	No
Log (Number Transmitters)	0.930186	0.0118*	No

Table 9.

Variable	**W-score (Shapiro Wilk GofF)**	**p<W? (small p-value rejects null, p<0.05)**	**Possibly a Normal Distribution?**
Cube Root Transformation (# Fish Redetected) – Elasmobranch Articles	**0.988260**	**0.9653**	**Yes**
Cube Root Transformation (# Fish Redetected) – Non Elasmobranch Articles	**0.961368**	**0.1865**	**Yes**
Cube Root Transformation (# Fish Redetected) – All Articles	**0.977889**	**0.2204**	**Yes**

Table 10.

Distance from Receiver (m)	Pings Detected	Pings Sent by Transmitter	System Efficiency
100	1089	1812	60.1
200	153	264	58
300	112	204	54.9
400	138	264	52.3
500	111	204	54.4
600	47	180	26.1
700	2	204	1
800	4	252	1.6

Table 11.

Author	Design Subject	Notes
Pincock et al. 2010; Singh et al. 2013; Welsh et al. 2012	Physical Barriers	Underwater signal distortion and acoustic propagation loss happen in complex environments (e.g., reefs), in stratified environments, or near water-air and water-substrate barriers.
Clements et al. 2005; Cudney, J.L. (*this study*)	Vessels / Vessel Traffic/Fishing Activity	Physical or proximate encounters with vessels generate acoustic interference and are a primary cause of receiver loss or damage.
Voegeli and Pincock 1996; Winter 1996; Thorstad et al. 2000; How and de Lestang 2012	Oceanographic / Environmental Conditions	Sea state, air entrapment, cavitation, currents, changing water velocities, eddies, salinity, temperature, depth, suspended matter. Receivers deployed near the water column surface pick up vessel noise, wave action, and air bubbles.
Whitecraft et al. 2007	Mangroves	Mangrove swamps are obstruction rich environments. Detrital litter on bottom can decrease detectability of tags, and mangrove prop roots induce attenuation due to small air bubbles present on roots.
Voegeli and Pincock 1996; Klimley et al. 1998; Voegeli et al. 1998; Finstad et al. 2005	Biotic Noise	Receivers often pick up noise from benthic animals (e.g., shrimp, oysters, barnacles, etc).
Singh et al. 2013; Cudney, J.L. (*this study*)	Wind and Weather	Wind can decrease detection range of receivers either due to waves or to the introduction of air bubbles into surface layers.
Clements et al. 2005	Biofouling	Cause of biotic noise and can disrupt receiver orientation in water column.

Table 12.

Author	Design Subject	Notes
Heupel et al. 2006	Type of Tags	Do not use too many tags. Do not use tags with short ping intervals. Use tags similar to those that will be deployed in test subjects (specifications).
Moser et al. 2006	Periodicity of Range Testing	Daily or hourly calibration produces the most accurate results in high noise or high interference environments.
Pincock et al. 2010	Extreme Conditions	Do range testing in the worst acoustic conditions at your site.
Pincock et al. 2010	Depth	Range testing should be done at a variety of depths.
Singh et al. 2013	Detection range	Detection ranges vary tremendously by environment, and don't usually conform to factory specifications.
Payne et al. 2010; Kessel et al. 2014	Sentinel tags	Sentinel tags should be deployed to monitor variability in detection range through time and ground truth fluctuations in animal detections against the environment.

Table 13.

Author	Design Subject	Notes
Castagna 2006; Heupel et al. 2006; Send et al. 2013	Cost	Expensive boat and dive operations make acoustic uploading desirable (e.g., VR4 or cabled/acoustic modem systems).
Clements et al. 2005	Fast recovery	Trawl anchors resulted in faster recovery than heavy concrete anchors that require a hydraulic boom for deployment and retrieval.
Welch et al. 2003; Heupel et al. 2006	Deployment on bottom without surface tag lines	Keeps receivers hidden from the public and reduces the likelihood of damage or loss.
Domeier 2005; Heupel et al. 2006; Cudney, J.L. (*this study*)	Divers	Divers are depth limited and can be a bottleneck for deployment/retrieval operations. Divers can be used to ensure that gear pushed overboard is oriented properly on the bottom. Sand screw anchors require the use of divers.
Welch et al. 2003; Loher et al. 2010	Acoustic Releases	Acoustic releases can be used to retrieve gear on the bottom, but may also be subject to failure. Risks are greater with lengthy deployments.
Domeier 2005	Precision of Data Collection Leads to Easy Recovery	Ease of recovering hydrophones is related to the precision used to deploy stations and record position.

Table 14.

Author	**Design Subject**	**Notes**
Clements et al. 2005; Cudney, J.L.(*this study*)	Concrete Blocks	Suitable for lengthy deployments or deployments in areas subject to heavy currents.
Clements et al. 2005; Cudney, (*this study*)	Danforth Anchors	If there is a need for rapid retrieval and deployment at the study site.
Lacroix and Voegeli 2000; Clements et al. 2005	Ketch anchor	Ketch anchors are more resistant to dragging and are good in fast current environments.
Heupel and Hueter 2001; Domeier 2005; Heupel et al. 2006	Sand screw anchors	In shallow water locations that have soft substrate, screw-type anchors offer a secure anchor system that can be attached to a mooring system via chain or mooring line. Requires divers.
Domeier 2005	Sandbags	Sandbags (15-20 kg) are good anchors for hard substrate.
Casto-Yerty and Bettoli 2009	Bridge pilings	Acoustic shadows and additional environmental noise may occur due to turbulence and air entrapment as water flows around bridge pilings.
Bettoli et al. 2014	SUR anchors	Durable anchors in high energy/current velocity environment (tested in rivers).
Heupel et al. 2006	Mooring Platforms Commonly Utilized by Researchers	Construction sites, piers, wharves, pilings, islands, marina entrances, port entrances, natural bottlenecks, along submerged channels, tidal creeks, shelf-wide fence and array deployments, known aggregation hotspots, hard bottom reefs, edges of submarine canyon.
Welch et al. 2004; Heupel et al. 2006;	Floats	Creates an "acoustic shadow", need to be sufficient distance away from floats
Simmonds and MacLennan 2005; Heupel et al. 2006	Navigation buoys as anchors	Anchoring a receiver to a navigation buoy exposes the receiver to increased environmental noise; boat traffic, noise, and wake can interfere with the acoustic field and possibly trigger false detections

Table 15.

Author	Design Subject	Notes
Clements et al. 2005	Mounting bars	The transducer end should be clear of mooring cables, lines, or poles, which can reduce detection range by nearly 100 percent at distances of 100-200 meter when these elements are in the acoustic field.
Welch et al. 2003; Domeier 2005; Send et al. 2013	Seafloor moorings	Receivers should sit directly on the seabed and not include surface floats vulnerable to vessel traffic or fishing activities. Deepwater deployments are better protected and can remain deployed for longer periods of time.
Clements et al. 2005; Domeier 2005; Heupel et al. 2006	Transducer orientation	Receivers are most sensitive in the horizontal plane around the transducer and least sensitive to the vertical plane (directly above and below). At the bottom or off bottom, they should be oriented upwards. At the surface, they should be oriented downwards. Mid-water deployments should be based on biology of target species.
Titzler et al. 2010; Cudney, *current study*	Receiver loss due to failure of mooring system	Receivers were lost due to physical abrasion and corrosion from extreme river flows/tides.

Table 16.

Author	Design Subject	Notes
Clare 1998; Afsar et al. 2003; Heupel et al. 2008	Biofouling	Deterring marine growth is important to maintain full functionality of marine equipment.
Fitzgerald et al. 1947	Effects on Acoustic properties	Within 3-5 months, oceanographic equipment can be rendered inoperative due to biofouling.
Domeier 2005	Preventative maintenance	Researchers should remove or replace lines every 18 months to 2 years. Thimbles and shackles should be replaced every 18 months. Replace anchors as needed.
Domeier 2005; Heupel et al. 2008	Anti-fouling paint	Use of anti-fouling paint is recommended, decreases fouling and results in higher performance.

Figure 6.

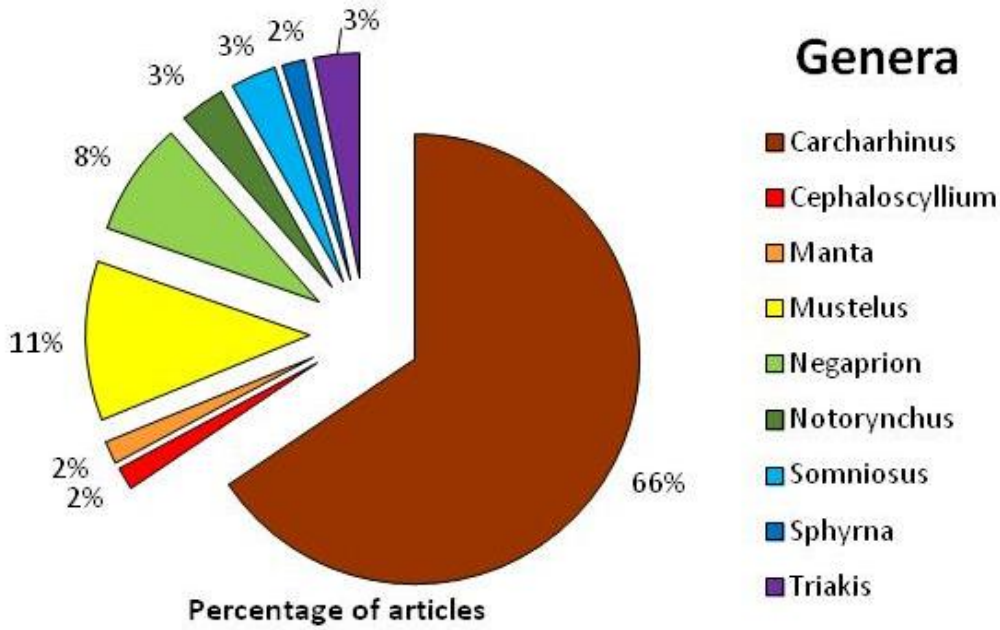

Genera
Carcharhinus
Cephaloscyllium
Manta
Mustelus
Negaprion
Notorynchus
Somniosus
Sphyrna
Triakis
66%
2%
2%
11%
8%
3%
3%
2%
3%
Percentage of articles

Figure 7.

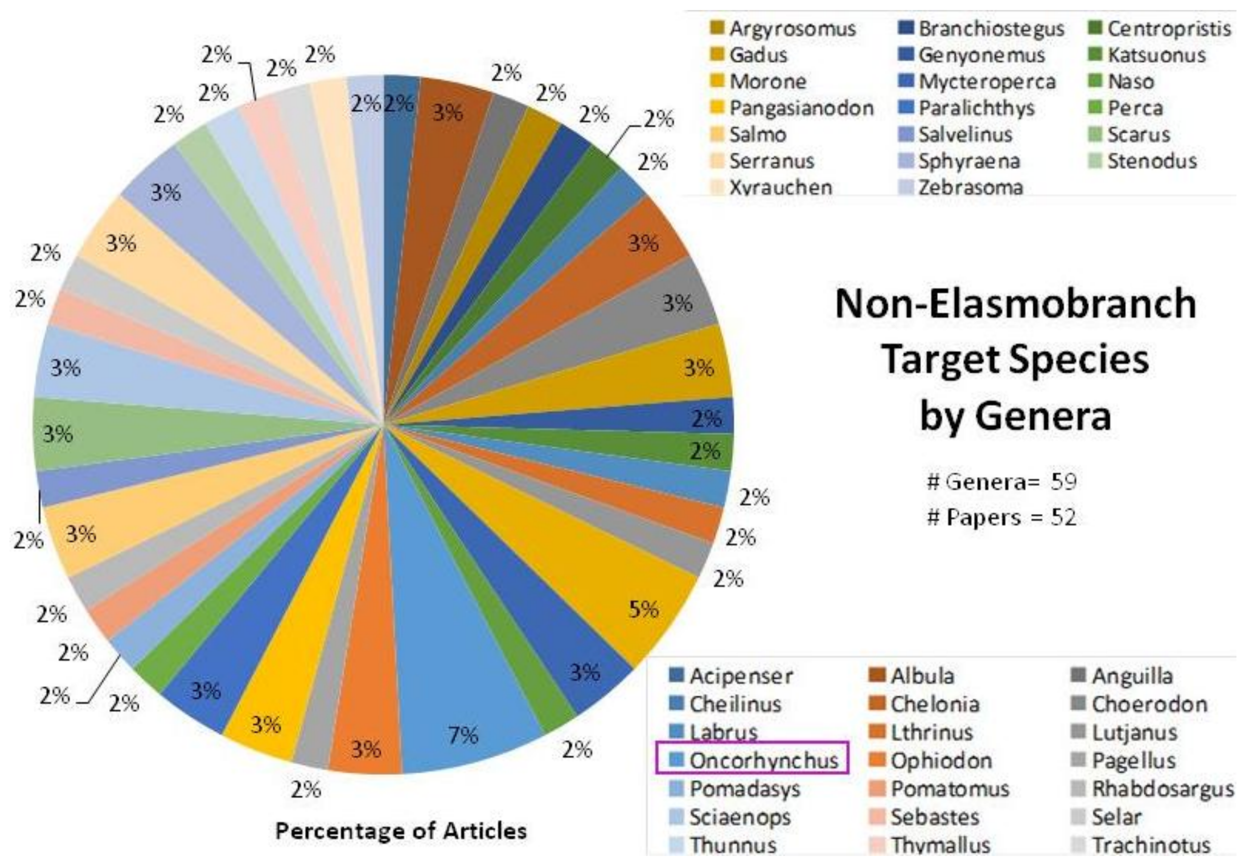

Non-Elasmobranch Target Species by Genera
Genera= 59
Papers = 52
Percentage of Articles
Argyrosomus
Branchiostegus
Centropristis
Gadus
Genyonemus
Katsuonus
Morone
Mycteroperca
Naso
Pangasianodon
Paralichthys
Perca
Salmo
Salvelinus
Scarus
Serranus
Sphyraena
Stenodus
Xyrauchen
Zebrasoma
Acipenser
Albula
Anguilla
Cheilinus
Chelonia
Choerodon
Labrus
Lthrinus
Lutjanus
Oncorhynchus
Ophiodon
Pagellus
Pomadasys
Pomatomus
Rhabdosargus
Sciaenops
Sebastes
Selar
Thunnus
Thymallus
Trachinotus

Figure 8.

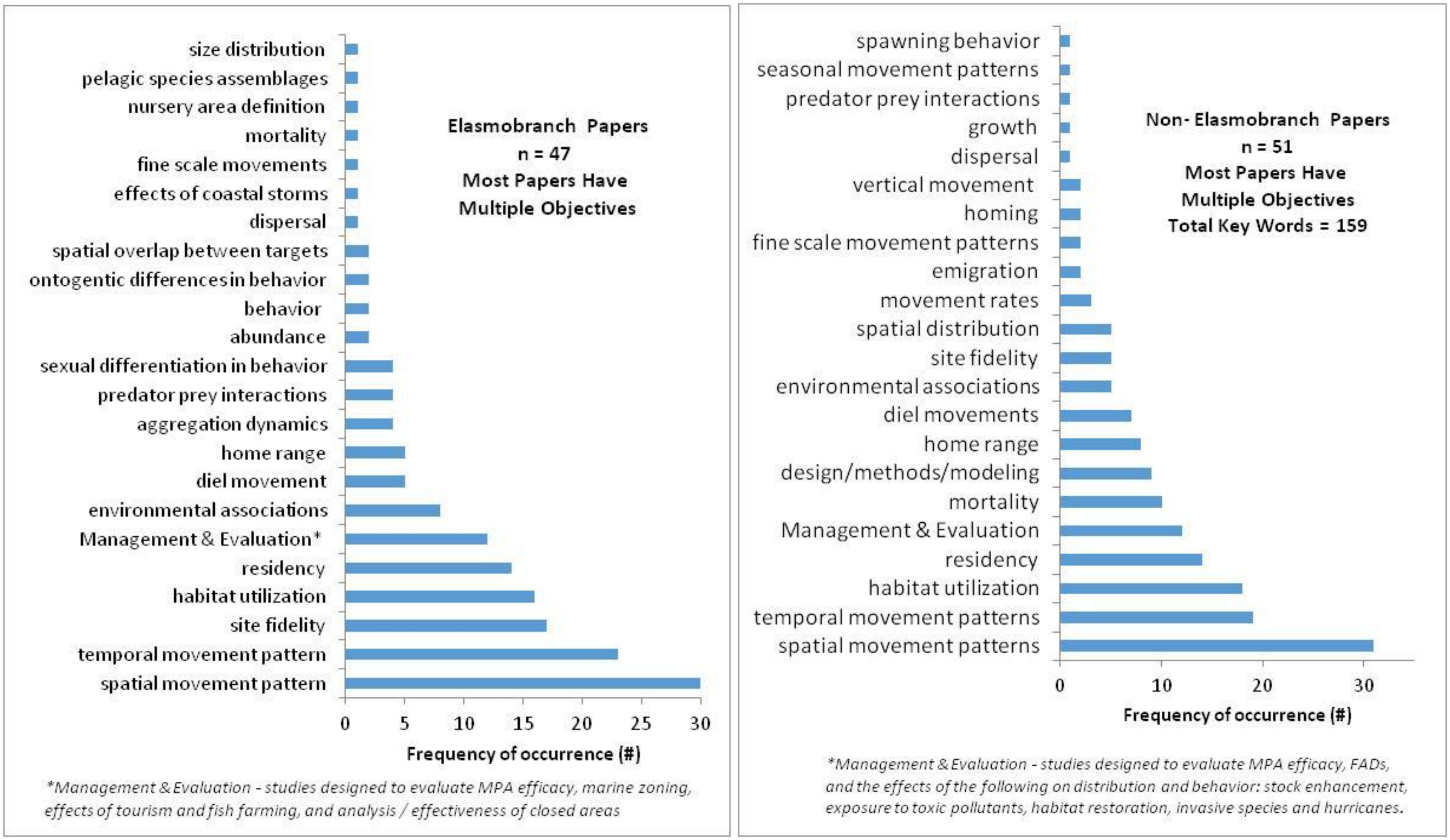
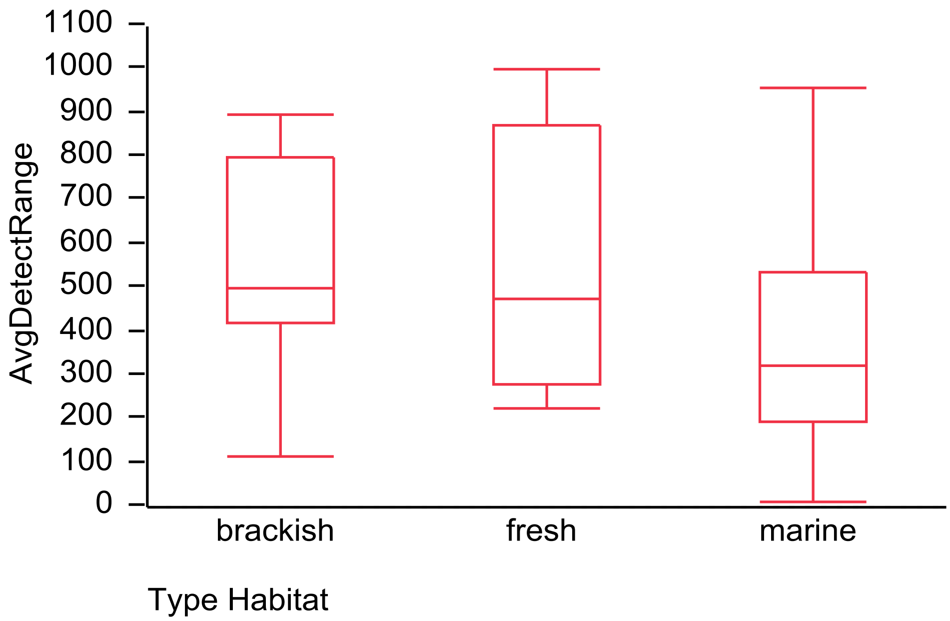

size distribution
pelagic species assemblages
nursery area definition
mortality
fine scale movements
effects of coastal storms
dispersal
spatial overlap between targets
ontogentic differences in behavior
behavior
abundance
sexual differentiation in behavior
predator prey interactions
aggregation dynamics
home range
diel movement
environmental associations
Management & Evaluation*
residency
habitat utilization
site fidelity
temporal movement pattern
spatial movement pattern
0 5 10 15 20 25 30
Frequency of occurrence (#)
Elasmobranch Papers
n = 47
Most Papers Have
Multiple Objectives
*Management & Evaluation - studies designed to evaluate MPA efficacy, marine zoning, effects of tourism and fish farming, and analysis / effectiveness of closed areas
spawning behavior
seasonal movement patterns
predator prey interactions
growth
dispersal
vertical movement
homing
fine scale movement patterns
emigration
movement rates
spatial distribution
site fidelity
environmental associations
diel movements
home range
design/methods/modeling
mortality
Management & Evaluation
residency
habitat utilization
temporal movement patterns
spatial movement patterns
0 10 20 30
Frequency of occurrence (#)
Non- Elasmobranch Papers
n = 51
Most Papers Have
Multiple Objectives
Total Key Words = 159
*Management & Evaluation - studies designed to evaluate MPA efficacy, FADs, and the effects of the following on distribution and behavior: stock enhancement, exposure to toxic pollutants, habitat restoration, invasive species and hurricanes.

Figure 9.



1100
1000
900
800
700
600
500
400
300
200
100
0
AvgDetectRange
brackish
fresh
marine
Type Habitat

Figure 10.

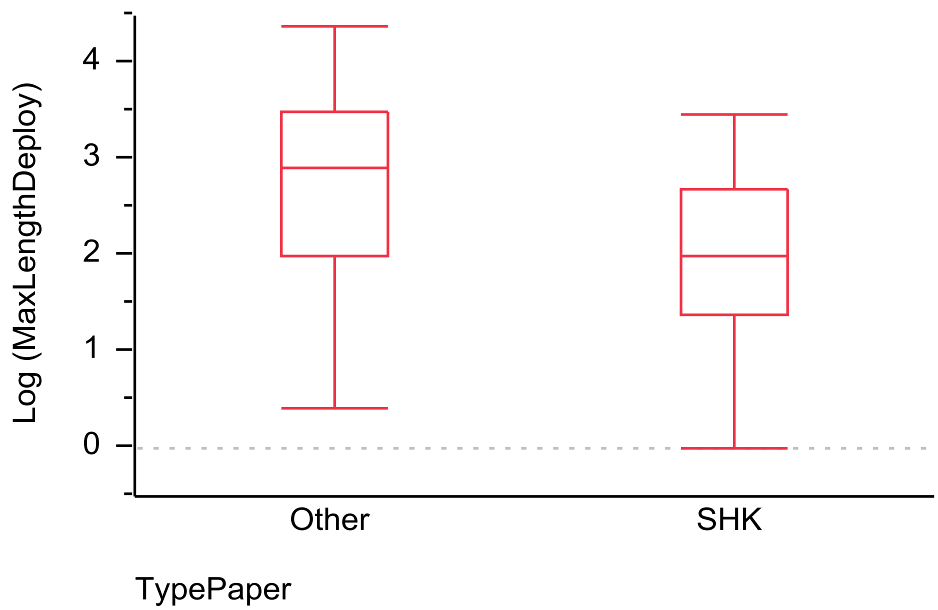


Figure 11,

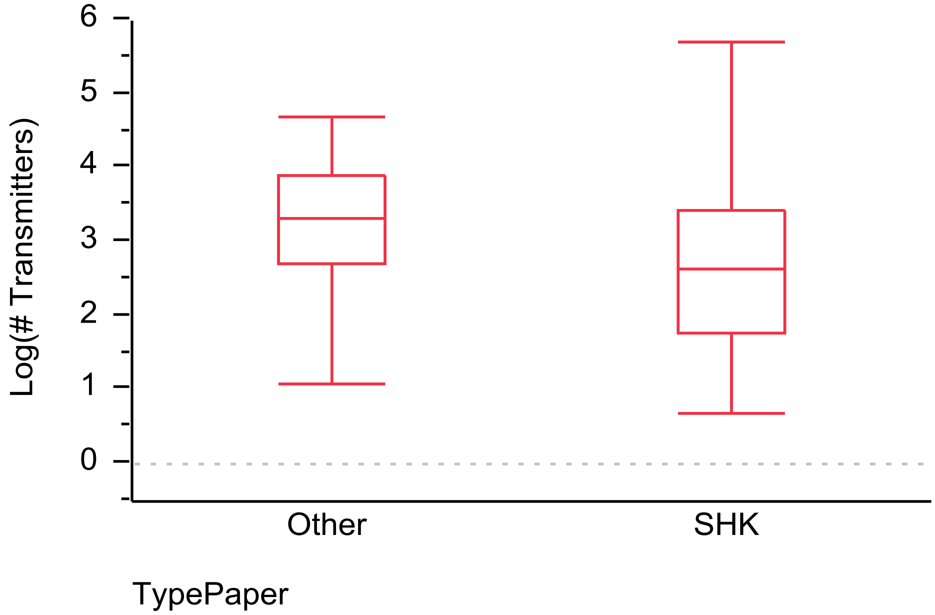


Figure 12.

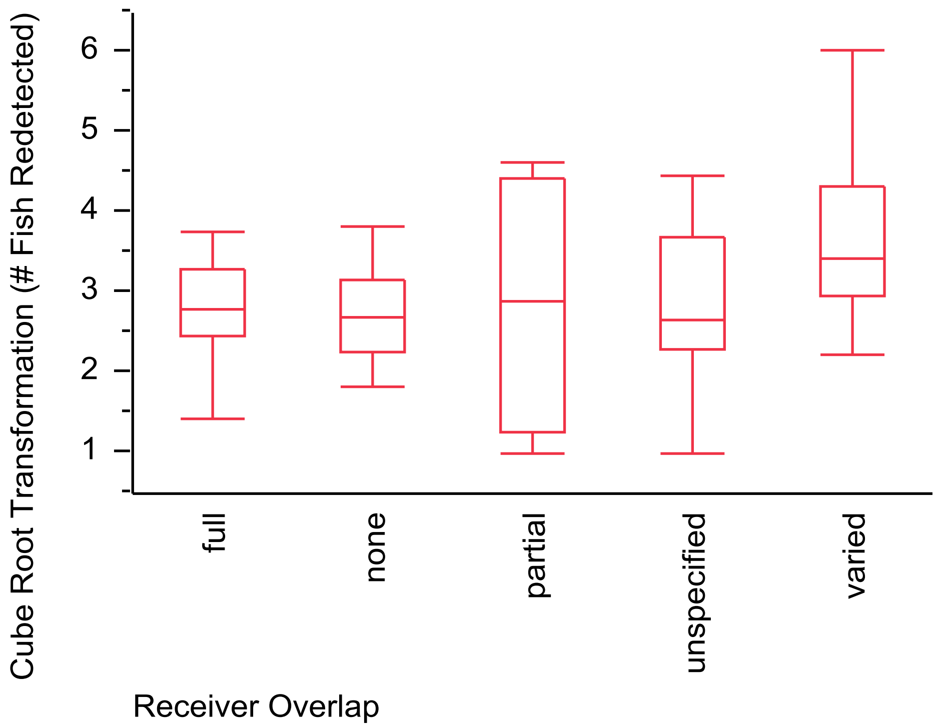

Cube Root Transformation (# Fish Redetected)
6
5
4
3
2
1
full
none
partial
unspecified
varied
Receiver Overlap

Figure 13.

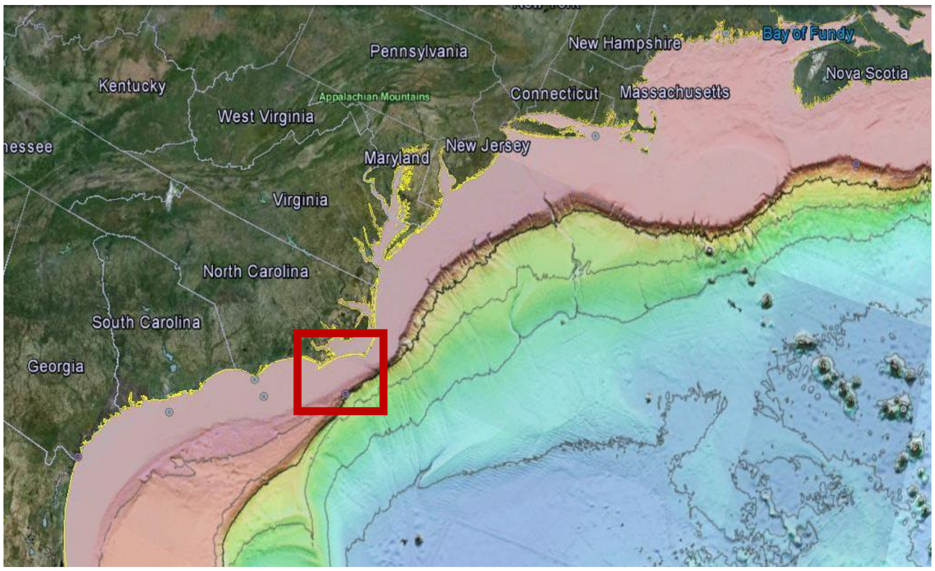
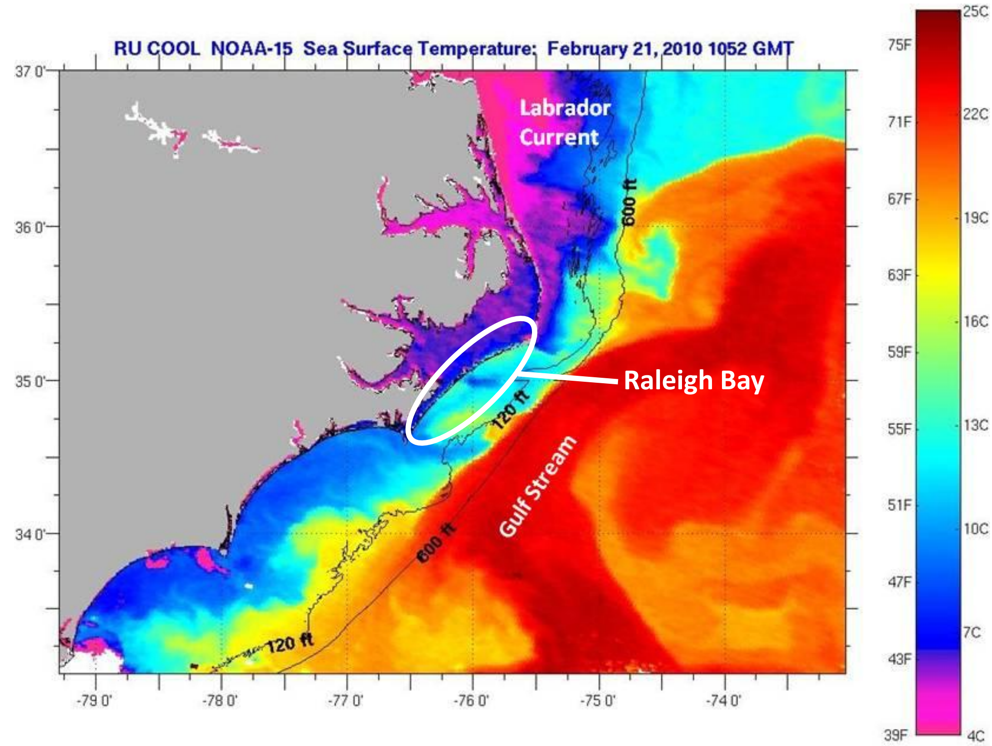
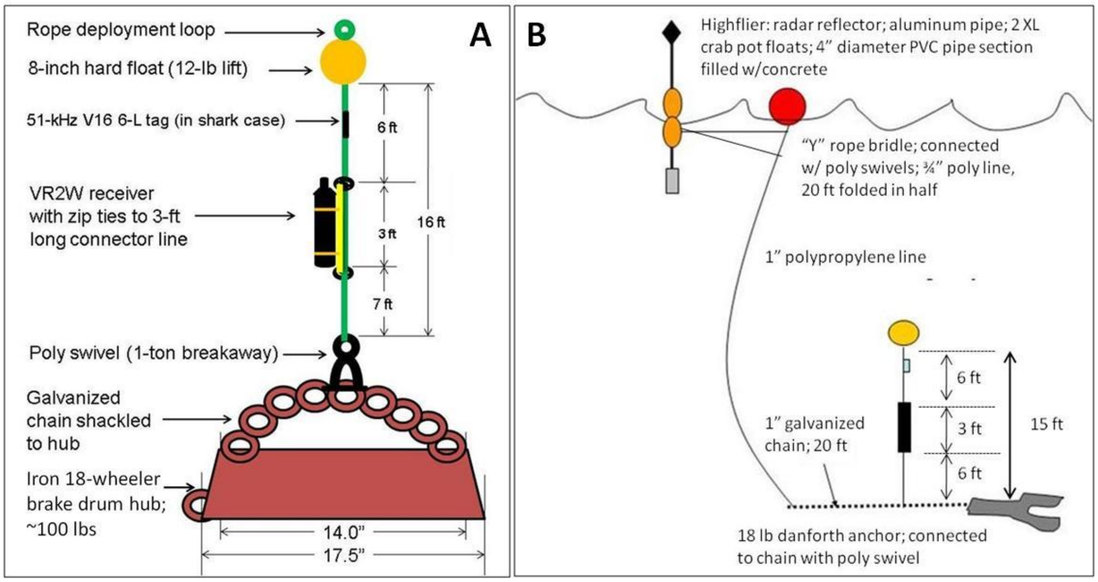

Pennsylvania
New Hampshire
Bay of Fundy
Nova Scotia
Kentucky
Appalachian Mountains
Connecticut
Massachusetts
West Virginia
essee
Maryland
New Jersey
Virginia
North Carolina
South Carolina
Georgia

Figure 14.



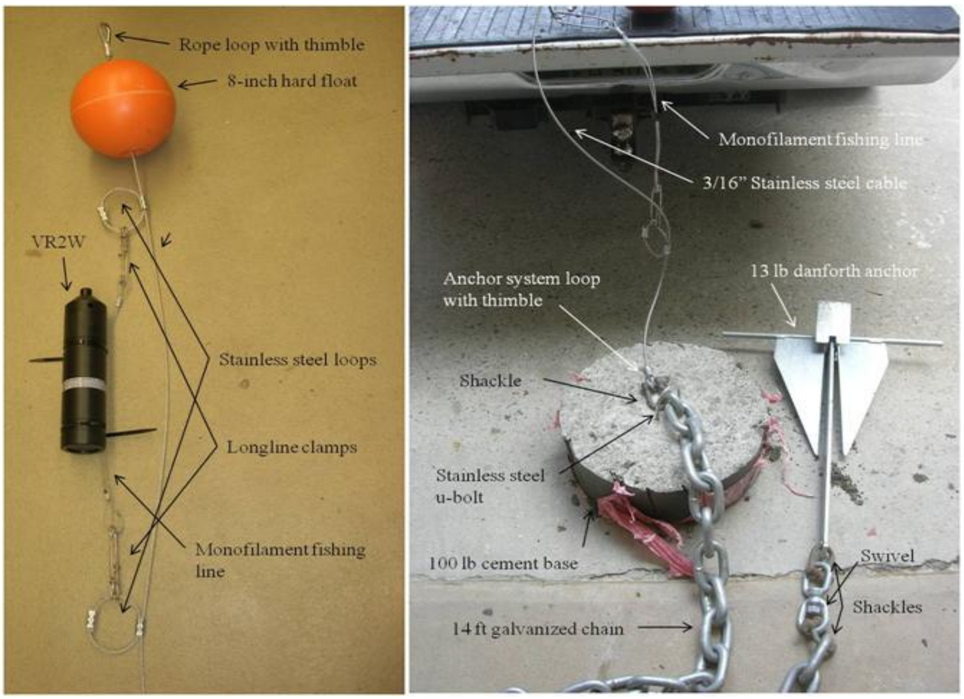
RU COOL NOAA-15 Sea Surface Temperature: February 21, 2010 1052 GMT
Labrador Current
Raleigh Bay
Gulf Stream
600 ft
120 ft
600 ft
120 ft
37 0'
36 0'
35 0'
34 0'
-79 0'
-78 0'
-77 0'
-76 0'
-75 0'
-74 0'
75F
71F
67F
63F
59F
55F
51F
47F
43F
39F
25C
22C
19C
16C
13C
10C
7C
4C

Figure 15.



Rope deployment loop
8-inch hard float (12-lb lift)
51-kHz V16 6-L tag (in shark case)
VR2W receiver with zip ties to 3-ft long connector line
6 ft
3 ft
7 ft
16 ft
Poly swivel (1-ton breakaway)
Galvanized chain shackled to hub
Iron 18-wheeler brake drum hub; ~100 lbs
14.0"
17.5"
A
B
Highflier: radar reflector; aluminum pipe; 2 XL crab pot floats; 4" diameter PVC pipe section filled w/concrete
"Y" rope bridle; connected w/ poly swivels; ¾" poly line, 20 ft folded in half
1" polypropylene line
6 ft
3 ft
6 ft
15 ft
1" galvanized chain; 20 ft
18 lb danforth anchor; connected to chain with poly swivel

Figure 16.



Rope loop with thimble
8-inch hard float
VR2W
Stainless steel loops
Longline clamps
Monofilament fishing line
Monofilament fishing line
3/16" Stainless steel cable
Anchor system loop with thimble
13 lb danforth anchor
Shackle
Stainless steel u-bolt
100 lb cement base
Swivel
Shackles
14 ft galvanized chain

Figure 17.

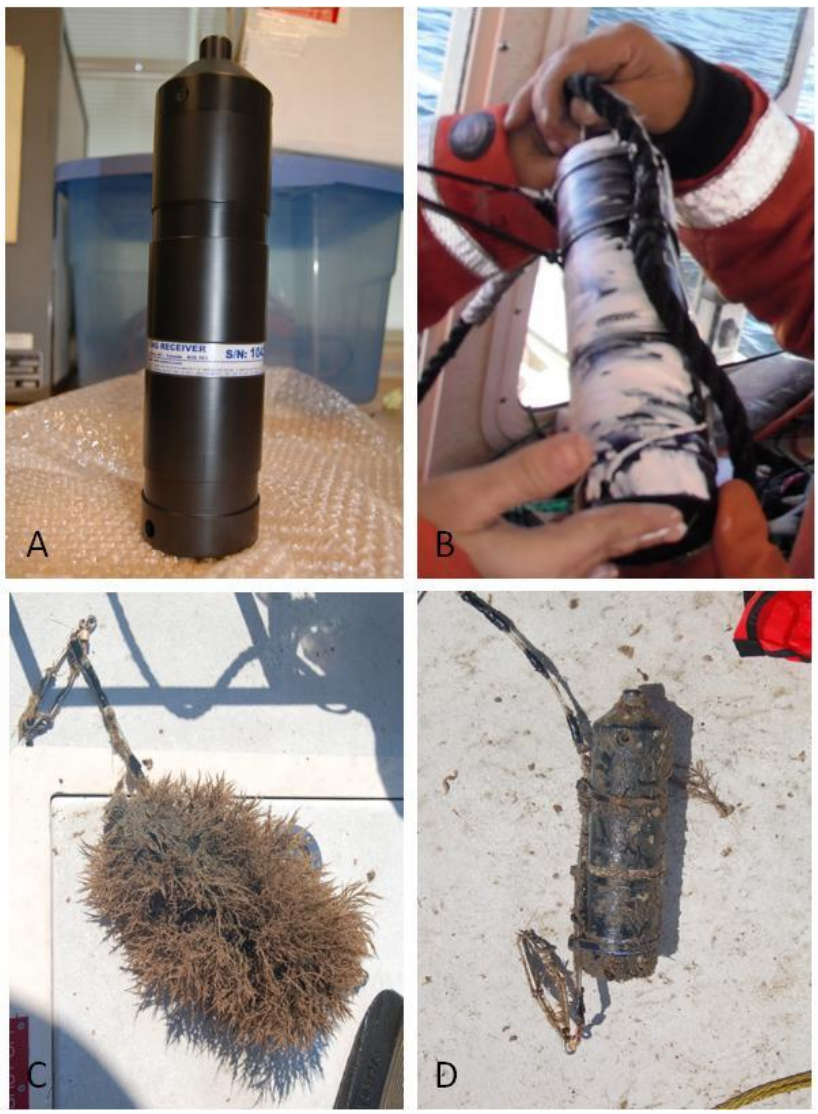


Figure 18.

CHAPTER 3: MIGRATION AND LOCAL MOVEMENT PATTERNS OF SPINY DOGFISH OVERWINTERING IN THE SOUTHERN MID-ATLANTIC BIGHT AND OFF CAPE HATTERAS, NORTH CAROLINA

Abstract

Spiny Dogfish is an abundant, temperate, small coastal shark that was assumed until recently to comprise a single unit stock. This chapter discusses results from two research programs conducted between 1997 and 2012 aimed at better understanding the stock structure of this species: a long-term mark-recapture program utilizing external dart tags, and acoustic telemetry research conducted on sharks that encountered compatible receiver arrays between North Carolina and the Gulf of Maine. The research presented herein fills a critical knowledge gap and reflects the only finalized tagging study to date that has focused principally on dogfish at the southern extent of the range. I summarize and speculate on the migration and movement patterns of a particular group of Spiny Dogfish, the purpoted Mid-Atlantic migratory contingent, and identify a clear predictable seasonal migration of Spiny Dogfish sharks between spatially discrete areas off the coast of North Carolina and southern New England. Results from tagging studies completed by our laboratory off Cape Cod, and from previous studies in the northern half of the range, provide further clarification on the northern extent of this hypothesized contingent and the behavior of other hypothesized contingents in the northwest Atlantic.

Introduction

Identification and delineation of appropriate stock units are essential for understanding the true state of a fish stock, and for the creation of effective and sound fishery management measures (Stephenson 1999). Many migratory species such as Atlantic Cod (*Gadus morhua*), Atlantic Herring (*Clupea harengus*) and Atlantic Salmon (*Salmo salar*), to name a few, were initially managed as single-stock fisheries until population declines forced managers to alternatives (Merriman 1941; Wise 1963; Sinclair 1988; Sinclair and Iles 1988; Serchuk and Wigley 1993; Myers et al. 1997; Stephenson 1999). Recent fishery disasters, such as the collapse of Gulf of Maine Atlantic Cod fishery, can be partially attributed to a lack of assessment and management at a scale appropriate for a complex stock structure (Wise 1963; Serchuk and Wigley 1993; Myers et al. 1997; Dobbs 2000; Ames 2003). As demonstrated by the history of these fisheries, science must look past assumed paradigms and periodically question the assumptions concerning behavior and life history of migratory species to ensure that management practices best reflect the life history of the stock.

The Spiny Dogfish (*Squalus acanthias*) is an abundant, slow-growing, late maturing, schooling shark commonly found in temperate waters. Despite a recent crash in coastal female spawning stock biomass, populations in the northwest Atlantic support a high-volume shark fishery. Coastal spawning stock biomass was considered rebuilt after 2008, much sooner than expected after interstate and federal management plans were implemented in the 2000s (ASMFC 2002; MAFMC 1999; 65 FR 1557, January 10, 2000). Despite a rebuilt management status of "not overfished / overfishing not occurring", there is considerable uncertainty regarding how the coastal Spiny Dogfish stock was capable of rebuilding so fast. Stock assessment models completed over the last decade suggested subsequent declines due to low pup production that have not yet materialized in the fishery (MAFMC 1999; ASFMC 2002; ASMFC 2013; Rago and Sosebee 2013). There is a strong need for research that better elucidates the behavior and stock structure of Spiny Dogfish, in part to explain the reason for such rapid recovery of the species through the 2000s and to reduce management uncertainty.

Fishery dependent, mark-recapture research on segments of the Spiny Dogfish population has been conducted since the 1960s in Atlantic Canada and off New England (Jensen 1961, 1966, 1969; Templeman 1963 and 1984; Shafer 1970; Hickman et al. 2000; Rulifson et al. 2002; Moore 1995, unpublished data; Campana et al. 2008). After consideration of all tagging studies to date, Campana et al (2008) noted evidence of spatial structuring within the northwest Atlantic Spiny Dogfish stock. Specifically, a new dogfish behavioral paradigm was hypothesized that identified separate groups, or "contingents", of Spiny Dogfish populations that exhibit similar migratory behaviors (TRAC 2010).

Spatial structuring also has been observed in other closely related dogfish species. Although not specifically referenced as a behavioral contingent, research by Wood et al. (1979), McFarlane and King (2003), and Taylor et al. (2009) suggest, using different terminology, that northwest Pacific Spiny Dogfish (the previous taxonomic classification, *Squalus suckleyi (Girard 1855),* was recently resurrected by Ebert et al. 2010) may exhibit different migration and life history strategies by location. For example, Pacific Spiny Dogfish in inland coastal waters tend to be recaptured in inland coastal waters, whereas there were a greater number of instances of Pacific Spiny Dogfish released in open waters that were recaptured in open coastal waters of other states or countries (McFarlane and King 2003; Taylor et al. 2009). In addition, Taylor et al. 2009 noted that the distribution pattern of recaptures in historical tagging studies of Puget Sound support modeling Pacific Spiny Dogfish in Puget Sound as a metapopulation as opposed to separate stocks.

The contingent hypothesis of intrapopulation migratory groups was first presented by Clark (1968), and was further evaluated by Secor (1999, 2005) through consideration of behaviorally distinct "contingents" of striped bass that were part of the same genetic stock. Contingents were defined by Secor (1999, 2005) as a useful management unit that is based upon divergent migration behaviors or habitat use within a unit stock. This potential new paradigm of dogfish behavior in the northwest Atlantic proposes that there are two primary migratory contingents of dogfish (Figure 19). One large group of dogfish is hypothesized to cycle between overwinter habitats in North Carolina (and possibly further southward into the South Atlantic Bight) and summer habitats in the southern Gulf of Maine ("mid-Atlantic contingent", Figure 19, Panel B, #1). Another large group of dogfish is suspected to make a gyre-like migration around the Gulf of Maine, moving offshore in the winter and onshore in the summer ("Gulf of Maine contingent", Figure 19, Panel B, #2). There are also a number of discrete satellite groups of dogfish in Atlantic Canada that exhibit a small degree of intermixing with the Gulf of Maine gyre-contingent (Figure 19, Panel B, #3-5). Discrete studies on individual contingents are therefore needed to evaluate the timing, spatial extent, and migration pathways undertaken by each proposed contingent.

Most of the previous tagging studies on northwest Atlantic Spiny Dogfish have been conducted in northern parts of the range; therefore, we focused our research efforts on Spiny Dogfish that are clearly part of the hypothesized Mid-Atlantic migratory contingent. This manuscript discusses two research programs conducted between 1997 and 2012: a long-term mark-recapture program utilizing external dart tags, and acoustic telemetry research conducted on sharks that encountered compatible receiver arrays between North Carolina and the Gulf of Maine. Data from the two studies are combined and presented collectively to provide a more comprehensive and robust discussion on the behavior of the presumptive Mid-Atlantic migratory contingent. The research presented herein fills a critical knowledge gap and reflects the only finalized tagging study to date that has focused principally on dogfish at the southern extent of the range. Therefore an objective of this manuscript is to summarize and speculate on the migration and movement patterns of Spiny Dogfish sharks that could be part of the hypothesized Mid-Atlantic Contingent. The primary null hypothesis explored in this research questioned the presence of a clear identifiable and predictable seasonal migration of Spiny Dogfish sharks moving between spatially discrete areas off the coast of North Carolina and southern New England. However, we also conducted tagging at what we suspect to be an area of spatial overlap, and possible behavioral mixing ground, between between the proposed Mid-Atlantic and Gulf of Maine migratory contingents in order to clarify the rate of mixing (Rulifson et al. 2012). Tagging studies from Nova Scotia are also incorporated into this larger study as a compliment to tagging efforts at the northern end of the range (Moore 2009). The geographic northern and southern extents of migration for Spiny Dogfish which overwinter off the coast of North Carolina are inferred from two types of tagging studies and supplemental evidence.

Methods

Acoustic Tagging of Spiny Dogfish. The study was conducted using VEMCO V16-4H acoustic tags (A69-1303, R64K 320/20; VEMCO Ltd, Shad Bay, Nova Scotia). Tags operated on a 69 kHz frequency, and had an estimated battery life of 510-820 days. Acoustic pings were programmed to emit at random 30 to 90- second intervals; this random transmission interval minimized errors that occur when multiple pings are detected at the same time by acoustic receivers. Fifty Spiny Dogfish sharks were surgically implanted with acoustic tags January 29 – 31, 2009 onboard the *R/V Cape Hatteras* during the annual Cooperative Winter

Tagging Cruise (CWTC), between Cape Hatteras and the NC/VA line (Figure 20). Length (mm TL) and weight (g) of sharks were noted to ensure that the water weight of the tag did not surpass 2 percent of the body mass of the shark. Sharks were initially monitored for 12 hours to gauge short-term survival and tag expulsion (100 percent survival, 0 percent expulsion after 12 hours). Most sharks were noted to adopt normal swimming behavior within 10 minutes of release into the recovery tank; all sharks were observed exhibiting normal behaviors within an hour of surgery. In 2010, adult Spiny Dogfish were collected by commercial gillnet and by angling (Figure 21), surgically implanted with acoustic tags, and released (n = 30 sharks: 15 south and 15 north of Cape Hatteras, NC). In addition, 10 sharks were captured, tagged, released and immediately tracked using a Vemco VFIN towable unit (5 south and 5 north of Cape Hatteras, NC). No sharks were tagged in 2011; however, the tags surgically implanted in 2009 and 2010 were still detectable according to battery life projections provided by Vemco, LTD.

Passive Acoustic Detection of Tagged Spiny Dogfish. A Vemco VR2W acoustic receiver array was created to track Spiny Dogfish movements in the Hatteras Bight. Although typical battery life for a VR2W is 15 months, they were retrieved more often to download data, and to conduct maintenance and repairs on the moorings, lines and floats used to maintain the VR2W in the water column. Array schematics were modified between 2009 and 2012 as needed in order to maximize the probability of successful deployment and retrieval of the array (see Chapter 2 for details).

Twelve receivers were deployed within the Hatteras Bight in 2009 (Figure 22). The first receiver was situated 750 meters from the beach to avoid swash zone conditions. The first nine receivers in the array were spaced approximately 600 meters apart based on range testing within the nearshore environment. Offshore receivers (the last three) were spaced 1000 meters apart to extend the line out as far as possible with minimal coverage gaps. Results from 2009 supported spacing the receivers farther apart, thereby extending the line further offshore. In 2010, 10 VR2Ws were deployed approximately 1600 meters (1 mile) apart from each other, in roughly the same line that was used in 2009. The receivers were deployed from January 2010 to May 2010, and sites were visited periodically throughout the sampling season to check on equipment. All sites were accounted for through April 1, 2010. Only one unit was moved offsite (it was not found), suggesting that the use of radar reflectors minimizes the risk of destructive encounters with vessels. See Chapter 2 for a complete description of mooring systems.

Many institutions and agencies between Florida and Newfoundland use VEMCO acoustic receivers and transmitters in research activities (Figure 23). Our receiver array detected a number of acoustically tagged fish implanted by other investigators. Similarly, our transmitters were detected by other researchers on their acoustic arrays. These data provided valuable information on the timing of migration, and the movement patterns of overwintering North Carolina Spiny Dogfish. Data sharing occurred primarily through the Atlantic Cooperative Telemetry (ACT) network. This network is organized and maintained by Dr. Dewayne Fox (Delaware State University) and Tom Savoy (Connecticut Department of Environmental Protection). Semi-annual updates to a tagging database, which contains tag and owner information, are distributed to members of the network. Members provide data to one another as receivers are uploaded.

Active Tracking of Tagged Spiny Dogfish. Active tracking of acoustically tagged dogfish was completed after tags were detected by a VEMCO VR-28 VFin deployed during acoustic surveys (Figure 24A and Figure 24B). When a fish surgically implanted with an acoustic transmitter came within range of the hydrophones, the signal was transferred through the towed unit to a receiver unit (blue and silver box, Figure 24C). The receiver unit integrated the acoustic signals with a GPS unit and created a text file that contained the ID number, a date/time stamp, the signal strength, direction of the signal, and sensor data (if applicable). Survey tracks were recorded using the compatible GPS software program "Chart Navigator Pro" (Figure 24D). Mobile surveys were conducted in February and March of 2009 and 2010 over the gray-shaded region in Figure 25. Active acoustic tracking was conducted in February and March of 2009 and 2010 (n = 16 days/season, eight days north of Cape Hatteras and eight days south of Cape Hatteras over the two-month study period). Sampling routes (e.g., Figure 24D) were selected after consideration of fishing reports, weather conditions, recommendations from fishing captains (including the co-PI), and from satellite sea surface temperature maps obtained from Rutger's University Coastal Oceans Observing Lab (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0&product=sst). When a transmitter was detected, we circled the boat around the initial detection point to determine if the tagged fish was moving. We attempted to remain onsite to obtain a minimum number of detections (n = 10, or five minutes). If the transmitter was moving, we attempted to track the shark for a short period of time to determine directionality of movement.

External Mark-Recapture Tag Program (1997-2012). Between 1996 and 2012, East Carolina University researchers deployed over 47,000 tags in Spiny Dogfish (Table 17). Depending on the research project, Spiny Dogfish were either captured via hook and line (n = 15), handline (n = 744), longline (n = 5,564), gillnet (n = 13,141), or trawl (n = 27,487). Sharks were measured for total length, sexed, and tagged with a Floy single barb dart tag (Floy SS-94)

(Figure 26A, Figure 26B). Tags were printed with a return mailing address and web address, a serial tag number, and a reward amount. The website (not in operation after the end of 2013) provided information about the tagging program and a form that could be filled out by fishermen regarding the recapture event. Fishermen were asked to provide information regarding the recapture event, including the location and date of capture, capture method, gear specifications, weather and sea conditions, and sex and approximate total length of the shark.

Data Analysis – Acoustic Data

Passive and active detection data (geographic location coordinates, date and time of detection, transmitter ID number) from the Cape Hatteras Acoustic Array and arrays maintained by collaborative partners were downloaded, summarized, and plotted in ArcGIS, EXCEL, and JMP 9 and JMP 10 (statistical analysis). Detection data were analyzed to fully evaluate the spatial and temporal distribution of acoustic detections on the Cape Hatteras Acoustic Array and other arrays operated by partner institutions.

In evaluating the temporal trends in detection data, unique independent detection events were identified as those that occurred discretely in time and space. Since we were interested in periodicity of detection events, and observed that sharks tended to remain in the area of the acoustic array and were detected many times over short intervals, we identified a unique event as those that either were separated by at least 12 hours, or were from separate transmitter IDs. The 12 hour window was selected as a starting point for this analysis, but future analyses should consider whether results would vary due to biotic or abiotic cycles of different time durations (e.g., tidal cycles are approximately every 6 hours). Detections that occurred within a short span of each other on receivers deployed in close proximity were considered to be part of the same detection event. The following were calculated for each independent detection event: amount of time spanning each detection event, days at large, number of detections, number of stations, description of movement along the array (onshore, offshore, or remaining in one area), and a description of the event timing (sustained in array for less than an hour, sustained in array for less than 12 hours, and multiple visits within a 12 hour period). Minimum rates of movement (km/day) were calculated by dividing straight line distance (km) as measured in ArcGIS 9.3 and time elapsed (days) between detection points for individual sharks. Movement rates by region (coastal North Carolina, Massachusetts, Gulf of Maine and Delaware) were analyzed using a Kruskal Wallis test in JMP (Version 9); nonparametric multiple comparisons were made using the Steel-Dwass All Pairs test (similar to the Tukey HSD post-hoc test for parametric data).

Data Analysis – Mark-Recapture Data.

Recapture data were examined in ArcGIS, EXCEL, JMP 9, and JMP 10 to further develop hypotheses regarding patterns in spatial and temporal distribution of Spiny Dogfish. Timing of recaptures was analyzed to determine whether sharks from specific release years constituted greater proportions of recapture events, and whether certain years had more recapture events. Days-at-large (DAL), or the number of days between release and recapture events, were analyzed by location of release, release year, and recapture year. Long-term periodicity of recapture events was determined by comparing DAL to latitude and to the distance between release and recapture events. Shifts in latitudinal distribution of all recapture events were analyzed by standardizing all recapture events to calendar day. Because sharks were tagged and released at different times of year, an analysis that just considers DAL could obscure seasonal latitudinal recapture patterns.

Given particular interest in the Massachusetts region as potential behavioral mixing (or spatially overlapping) grounds between the hypothesized Mid-Atlantic migratory contingent and the hypothesized Gulf of Maine migratory contingent, part of the research program consisted of a study whereby sharks were tagged with both mark-recapture and acoustic tags, and released on either side of Cape Cod, Massachusetts. Further discussion of this research project may be found in Rulifson et al. (2012).

Given that dogfish migrations are thought to be cyclic in nature, North Carolina-tagged shark data were analyzed to determine whether sharks were recaptured in similar locations at similar times of year (based on the distance between the original release location and the recapture location). An annual increment was defined as a period spanning the annual anniversary of the tagging and release of a shark (plus/minus three weeks to account for natural inter-annual variability in the timing of migration). The location of recapture for sharks at annual increments was compared between years, and to short-term increments (0-30 days, 31-60 days, and 0-60 days) to determine how close recaptures were at similar times of year. If sharks were completing a regular circuit between Massachusetts and North Carolina and arriving at the overwintering grounds at roughly the same time each year, then the distances between release and recapture at the annual increments should be similar. Complete geographic information was provided for 400 North Carolina-tagged Spiny Dogfish. Distance between release and recapture location was found to not be normally distributed; hence the data were log-transformed for statistical analysis.

Results – Acoustic Telemetry Experiment

Maps depicting the redetections of these sharks between 2009 and 2011 are shown in Appendix 2 and Appendix 3 of this dissertation. The locations of all acoustic tag detections (both in North Carolina and other locations) are shown in Figure 27. Spiny Dogfish were not detected on acoustic arrays south of the Hatteras Acoustic Array. Although the North Carolina Hatteras Acoustic Array was deployed in 2012, no Spiny Dogfish were redetected on the array that year. Of the 53 sharks tagged in 2009, 17 sharks were redetected on the Hatteras Acoustic Array for an array redetection rate of 32 percent over the expected duration of battery life for the tags (Table 18). The years with the greatest number of detections included 2009 and 2011; in 2010 only 5 animals tagged in 2009 were redetected on the Hatteras array. Annual detection rates of these sharks (assuming the 53 2009-tagged sharks were at large and available to interact with the array in a given year) were 15.09, 9.43, and 16.98 percent in 2009, 2010, and 2011, respectively. Five of the sharks were detected on the array in multiple years; of these, four were redetected in subsequent years, implying annual return migrations to the area.

A total of 26 of the 40 sharks surgically implanted in 2010 were redetected on the Hatteras Acoustic Array, for an array redetection rate of 65 percent (Table 19). Annual detection rates of these sharks (assuming all 40 of the 2010-tagged sharks were at large and available to interact with the array in a given year) were 50 and 45 percent in 2010 and 2011. Twelve of these sharks were detected both in 2011 and 2012 on the Hatteras Acoustic Array.

Spatial Distribution of Detections. When considering all of the detection data provided to the team by scientists from other institutions, 39 of the 53 tags deployed off NC in 2009 (73.5 percent) were redetected off the coast of North Carolina, in Delaware Bay, in Long Island Sound, off the coast of Massachusetts, and in the Gulf of Maine (Table 20). After the initial tagging season, the largest numbers of 2009-tagged sharks were redetected in Delaware Bay (fall and spring) and off the coast of Massachusetts (summer). Nineteen of the sharks tagged in 2009 were detected in coastal North Carolina in 2009, 2010, or 2011 by passive (VR2W acoustic array) or active (VFIN) acoustic sampling off the coast of North Carolina. One shark (#54065) was redetected off the coast of North Carolina three years in a row. Four 2009-tagged sharks were redetected off the coast of North Carolina in consecutive years, and seven sharks were only redetected in the third detection year off the coast of North Carolina. Several of these sharks were detected in locations outside of North Carolina at other times of the year.

After tagging and redetection in the winter and early spring of 2009, the tagged sharks dispersed northward and a few (n = 3) were redetected in Delaware Bay in April and May 2009. A few of the sharks were redetected in various locations between New York and the northern Gulf of Maine in summer 2009, but it was not until the fall of 2009 that a larger number (N = 11) of sharks were redetected in close proximity within a relatively short time span in Delaware Bay. A number of these sharks were redetected in winter and early spring of 2010 on the Hatteras Acoustic Array (n = 8). The largest number of sharks detected within an aggregated spatio-temporal timeframe occurred in the summer of 2010, when 18 sharks were tracked off the coast of Massachusetts.

Of the 40 sharks tagged off NC in 2010, 35 (87.5 percent) were redetected off the coast of North Carolina, in Delaware Bay (“Del Bay11”), off the coast of Massachusetts (“Mass10”, “PlymouthBay10”, and “Mass11”), and in the Gulf of Maine (“GoMOOS10”) (Table 21). Twenty-seven sharks were redetected by the Hatteras Bight acoustic array and via active VFIN sampling of coastal habitats; 12 of these sharks were redetected in consecutive years. Most of the sharks redetected on the Hatteras acoustic array were tagged and released south of Cape Hatteras. However, the five sharks tagged and tracked off Wimble Shoals were all redetected by the Hatteras array at least once, and three of the Wimble Shoals sharks were detected in both 2010 and 2011. Five sharks tagged off Oregon Inlet were redetected in the Hatteras Bight in 2010 and 2011.

After tagging and release off the coast of North Carolina in the late winter and early spring, over half of the 2010-tagged sharks (n = 23, 58 percent) were redetected off the coast of Massachusetts in summer 2010. A large number (n = 16, 40 percent) of 2010-tagged sharks were redetected off the coast of the Outer Banks between December 2010 and March 2011. A small number of sharks were sparsely detected between Delaware Bay and the Gulf of Maine between spring and fall of 2011. A notable number (n = 10, 25 percent) of 2010-tagged sharks next showed up off the coast of New Jersey and New York from January to May 2012 (but were not detected off the coast of North Carolina).

Results for active acoustic surveys for tagged Spiny Dogfish were not as robust as results for passive acoustic deployments. Active acoustic survey yielded location data for six 2009-tagged sharks in 2009 and four 2009-tagged sharks in 2010. Active acoustic surveys were more successful in 2010, with 19 animals being redetected using the VFIN towable receiver; four of these sharks had been tagged in 2009 and 15 were tagged in 2010 (Figure 28).

Most of the sharks detected with active acoustic tracking were also detected on the passive acoustic array. A small proportion of the sharks tagged and released north of Cape Hatteras were detected only via acoustic surveys. Two 2009-tagged sharks were detected each year of the study only through the VFIN acoustic surveys. One of these sharks was detected again in 2010 and 2011 in North Carolina; the other shark was detected in 2010 in the Gulf of Maine and in 2011 back in North Carolina. Two of the 2010-tagged sharks detected with the VFIN were not detected on the Hatteras array.

Most detections of sharks occurred on the same side of Cape Hatteras in which they were tagged, but some movement around Cape Hatteras was documented (Table 22). Most of the 2010-tagged sharks that were detected in regions south and west of Cape Hatteras had been tagged either in the Hatteras Bight or Cape Lookout. Only one 2010-tagged shark that was released south of Cape Hatteras was redetected with the VFIN well north of the shoals fringing Cape Hatteras. Sharks detected in 2009 and 2010 also tended to be relocated near complex bathymetric features. Many of the sharks were detected in sloughs, or channels, that run through the shoals off Cape Hatteras, Oregon Inlet, and the Outer Banks. Two sharks (one tagged in 2009 and one tagged in 2010) were detected off the continental shelf break in waters close to 100 meters in depth. South of Cape Hatteras, most of the detections of tagged sharks happened either within a few km of the beach along sandy bottom, along the south side of Diamond Shoals, or further offshore closer to the shelf break.

Temporal Distribution of Detections. Sharks tagged in 2009 and 2010 appeared on the Cape Hatteras Acoustic Array within a few weeks of each other, typically from January through March or early April (Figure 29, Figure 30). Sharks were detected multiple times within a season (Figure 29, Figure 30). Figure 31 shows the number of times that tagged Spiny Dogfish returned to the acoustic array deployed within the Hatteras Bight in each wintertime sampling season. These “returns” constituted independent detection events, whereby the detection events were separated by at least 12 hours from each other. While a large number of sharks were only detected one time each season (i.e., only one detection event was noted for 23 sharks), there were a number of tagged sharks that exhibited multiple independent detection events. In 2010 and 2011 (the years with the largest numbers of detections), the average number of independent detection events recorded for each tagged shark on the Hatteras Acoustic Array was 3 and 3.5 times, respectively. Figure 32 shows the timing of detections in 2009, 2010, and 2011 by week. In 2009 and 2010, the number of detections on the Cape Hatteras Acoustic Array peaked between early February and early March. In 2011, a definitive peak in the number of detections was noted the first week of February; however detections occurred across a broader time range (somewhat attributable to when gear was deployed). In 2009 and 2010, detections of tagged sharks dropped off after the last week of March; in 2011 the last sharks were detected the first week of April on the Hatteras Acoustic Array (Figure 32).

A total of 184 individual detection events from 43 different Spiny Dogfish were observed on the Hatteras Acoustic Array, ranging from less than a minute to over 24 hours (Table 23; Figure 33). Nine of these detection events consisted of a single detection (meaning that these data are suspect due to the risk of false detections). Fifty fish were not detected on the acoustic array and therefore had no independent detection events considered in this analysis; some of these animals were detected on other arrays and these independent detection events will be considered in future analyses. Overall, most detection events lasted between 15 minutes and 2 hours. Figure 34 shows the frequency distribution of individual detection event duration by year. The majority of detection events in 2009 lasted between 45 minutes and 2 hours. The majority of detection events in 2010 were between 16 and 45 minutes in duration. In 2011, the time interval with the greatest number of detection events was 1-2 hours; however, many detection events also occurred between 16 and 45 minutes. There were no statistically significant differences in the log-transformed duration of detection events (total time in minutes) by detection year ($F = 0.2159$, $df = 182$, $p>0.05$). The greatest number of detection events started between midnight and 1:00am (Figure 35).

Temporal Aspects of Detections Beyond North Carolina. Aggregated acoustic tagging data standardized to calendar day of detection is suggestive of a cyclic north-south migration based on the timing of detections and the latitude of occurrence (Figure 36). While sharks were periodically detected on buoys that were part of the Gulf of Maine Ocean Observing System (one of which was in the central Gulf of Maine), most detections in the northern half of the range occurred off coastal Massachusetts during the summer and fall of 2010 (Figure 37). Four peaks were observable in the data, suggesting that some environmental factor may be driving dogfish at periodic intervals into habitats sampled.

Analysis of straight-line distance between detection points and time elapsed between detections (i.e., movement rates) indicate that sharks can move very quickly within short periods of time. Sharks were noted to move up to 32 kilometers in the same day, with an average movement rate of sharks between two points on the same day of 4.92 km/day (± 6.90 km/day). Sharks were also noted to make extensive movements within a day , as evidenced by Shark #63952, which moved from deepwater continental shelf break habitat approximately 55 kilometers (35 miles) off the coast of Rodanthe, NC (near a physical feature known as “the point” to local fishermen) to a detection site just off the beach near Hatteras Inlet. The distance between these two locations was measured to be approximately 106 kilometers (66 miles). Unusually fast rates of travel could be reflective of a predation event and the tag’s presence inside a predator; however, without additional information such as external temperature sensors this would be hard to prove. Additional analyses should be undertaken to evaluate local movement and between-array movement rates to determine if this rate of travel is realistic for spiny dogfish.

The average travel rate of sharks detected within a 24 hour period was estimated to be 19.58 kilometers/day (± 18.51 kilometers/day). Average movement rate between detection points was different by arrival region (North Carolina, Massachusetts, and Delaware, Gulf of Maine; Kruskal Wallis / Chi Square, $\chi^2 = 17.21$, df = 3, $p < 0.05$), with a particular leg assigned based on the arrival location. Comparison using a Steel-Dwass Multiple Comparisons analysis (non-parametric version of a Tukey HSD test; e.g., Neuhauser and Bretz 2001) indicated significant differences in movement rates (kilometers/day) between detection points between North Carolina and Delaware (Z = -2.79, p = 0.03), North Carolina and Massachusetts (Z = -3.22, p = 0.007) and North Carolina and the Gulf of Maine (Z = -3.04, p = 0.013) (see Figure 38 for box plots of log-transformed travel rates by region). Travel rates are hypothesized to be slightly slower for legs that arrived in or were wholly contained in coastal North Carolina than in other areas. This analysis did not differentiate between local movements and long-range movements; future analyses should account for the differences between these two types of movements.

Results: Mark-Recapture Experiment

Spatial Extent of Recaptures. As of December 31, 2014, a total of 619 conventional dart tags were returned to East Carolina University, which equates to a 1.32 percent return rate for the project (Table 24). Recapture rates for Massachusetts-tagged sharks and North Carolina-tagged sharks were roughly 1.64 and 1.12 percent, respectively. Recapture rate for Nova Scotian-tagged sharks was higher (2.94 percent), and 75 percent of these sharks were recaptured and returned from Canada. Approximately 4.7 percent (n = 26) of the sharks released in the United States were recaptured in Canada (Table 24); 6.0 percent of the North Carolina-tagged sharks were recaptured in Canada. Despite repeated attempts to communicate with fishermen, we were unable to obtain exact recapture location information for 14 tags. Locations of recapture were approximated from qualitative descriptions from fishermen, or based on the return address or postmark from mailings.

Most of the sharks released off of North Carolina (typically in late winter) were recaptured in North Carolina (usually within 1-3 months of release) or Massachusetts (usually within 4 – 7 months of release). Most of the tag returns from sharks released off coastal Massachusetts were recaptured in the same area, but recaptures occurred year round.

Recapture location of Massachusetts-tagged sharks is of particular interest because Massachusetts is suspected to be a mixing ground (or an area of spatial overlap) for sharks in the Gulf of Maine and Mid-Atlantic hypothetical behavioral contingents. Ninety-one sharks that were released north of the 42º N Latitude line were recaptured; of these, 70 sharks were recaptured north of Cape Cod and 21 were recaptured south of Cape Cod (Figure 39). Forty-seven of the sharks released south of the 42º N Latitude line were recaptured. Some of these sharks, released along Cape Cod just south of the 42º N Latitude line, were caught in almost equal numbers north and south of the 42º N Latitude line. Sharks that were released well to the south of Cape Cod (off Rhode Island) tended to be recaptured south of Cape Cod.

Mark-recapture data provided additional insight on the peripheral distribution of tagged Spiny Dogfish (albeit limited by the distribution of fisheries that encounter tagged Spiny Dogfish). Northern recapture locations of all North Carolina-tagged sharks are shown in Figure 40. North Carolina-tagged sharks were recaptured in the two circled locations through a majority of the year (spring through fall). Northward movements between the two areas along the shoreline of Cape Cod were identified from recapture data in June (Figure 41); however a number of recapture events also happened during this time out in the Gulf of Maine. Southward movements along Cape Cod were observed in October (Figure 42). North Carolina-tagged Spiny Dogfish were only recaptured within Cape Cod Bay in late summer.

Geographic recapture data were provided to ECU researchers for 64 tagged sharks that were recaptured south of Cape Hatteras, North Carolina (see Figure 43). Most of the recaptures occurred in between Cape Hatteras and Cape Lookout, North Carolina, and reflected the seasonal availability of the species to the local fishery. Sharks were recaptured south of Cape Hatteras as early as November and as late as June in a given fishing year. Overall, the greatest number of recaptures south of Cape Hatteras occurred in March (data not shown).

Timing of Recaptures. Release and recapture years were provided by industry participants for 403 North Carolina-tagged Spiny Dogfish (Table 25), 142 Massachusetts-tagged Spiny Dogfish, and 51 Nova Scotia-tagged Spiny Dogfish (data from Massachusetts and Nova Scotia not shown to maintain a reasonable scope and size for this chapter). For North Carolina-tagged Spiny Dogfish, the release year with the greatest number of recaptures was 2006 (n = 121 tags); this was the same year with the largest number of tags released (n = 10,713 tags). The majority of tagged sharks were recaptured within 1-2 years of the release event, especially in the early years of the tagging program (i.e., roughly 96 percent of the tags deployed on sharks in 1997 and 1998 were returned either in the same year or the consecutive year, whereas between 2000 and 2006, on average 59 percent of the tags were returned within 2 years of deployment). The most recaptures occurred in 2007 (n = 78 tags) (Table 25).

Days-at-large (DAL) were the number of days between the release and recapture events. The overall median DAL for all tag recaptures (across all release locations) was 340 days. Median DAL for North Carolina-tagged sharks, Massachusetts-tagged sharks, and Nova Scotian-tagged sharks were 313 days, 403 days, and 338 days, respectively. Figure 44 shows boxplots depicting the median DAL by release year of North Carolina-tagged Spiny Dogfish sharks, which provides an indication of how long sharks from a given year tended to be "at liberty" before they were recaptured. Years with robust fisheries (late 1990s and after 2010) tended to have smaller DALs than the years encompassing the rebuilding period for Spiny Dogfish (2000 to 2008). The greatest median DAL occurred in 2004; the year with the greatest variability in DAL was 2005. It is also worth noting that DAL by recapture year has increased dramatically since 2007; this could be a result of stricter management measures in the directed fishery (i.e., lower quotas), a reduction in interactions with incidental fisheries, or more sharks adopting behaviors that make them less susceptible to capture from either directed or incidental fisheries (Figure 45).

A number of recapture events with DALs greater than 1,000 days in primary recapture areas (North Carolina, Virginia, and Massachusetts) were noted in the study (Figure 46). Most of these long-term recapture events in the southern mid-Atlantic Bight had timeframes of two to five years at liberty. Long-term recapture events off southern New England varied between three to ten years, while long term recapture events in the Gulf of Maine varied between three to seven years. When the distance between release and recapture locations was compared to days-at-large, a clear cyclic pattern over multiple years was observable for North Carolina-tagged fish (Figure 47). When the recaptures were standardized by calendar day and compared to latitude, there was clear indications that North Carolina tagged dogfish undertake extensive migrations between latitudes of 34ºN and 45ºN, whereas sharks tagged off Massachusetts and Nova Scotia tend to be recaptured at latitudes closer to the latitude of release (Figure 48).

A number of tag returns occurred close to anniversaries of tagging events (i.e., those that occurred within the timeframe of an "annual increment"). Tag returns from 35 sharks were considered to occur within an annual increment of the release event, and there were 49 tag returns that occurred within a short time (<60 days) of release. Many of these tag recaptures occurred within a relatively short distance of the tag and release location (Table 26).

Discussion

Behavioral data, no matter how they are collected, are limited by the inherent biases associated with the methodologies. Utilizing both acoustic and mark-recapture data provide a more robust description of movement patterns than either approach might on its own. For example, acoustic tagging methods collects fishery independent data on individual fish and can provide irrefutable evidence of cyclic migrations between North Carolina and Massachusetts as individuals are sequentially detected on arrays along the coast. Data collections are limited to locations where acoustic receivers are deployed and are subject to the "detectability" of tags within the environment. However, it is possible to receive hundreds of data points for an individually tagged fish while the batteries are active. Conversely, mark-recapture data may provide expanded spatial coverage since returns are based on the extent (and behavior) of fisheries that might interact with tagged sharks. Tagged Spiny Dogfish were captured with seine, handline, rod and reel, gillnet, pelagic and bottom longline, trawl, trap and pot gears deployed in multiple fisheries between South Carolina and Iceland. Since conventional tag mark-recapture data most often only feature two data points (rarely more if animals are released with tag still in place) for each animal (release and recapture locations), behavior patterns are inferred from collective analysis of all mark-recapture data. Conventional, external tags are not, however, limited in terms of battery life (a problem with acoustic tags), and conventional tags have been returned a decade or more after the release event. This project demonstrates that the two types of approaches can collectively provide a more comprehensive picture of Spiny Dogfish behavior than either approach by itself.

Annual redetection rates of acoustically tagged spiny dogfish within the Hatteras Bight ranged between 10 and 15 percent in 2009 and 40 to 50 percent in 2010. These rates were somewhat low compared to single redetection rates from acoustic tagging projects completed on other species reported in manuscripts utilized in Chapter 2 for the meta-analysis. For example, Andrews et al. (2007) noted single redetection rates of 100 percent for Sixgill Sharks in Puget Sound; Dewar et al. (2008) detected 85 percent of tagged Giant Manta in Komodo Marine Park, Indonesia; 100 percent of Gray Smoothhound in a California estuary were redetected by Espinoza (2010); Smith (2012) redetected 84 percent for Bonnethead Shark tagged and released in a Georgia estuary; Filmalter et al. (2013) relocated 86 percent of Sicklefin Lemon Shark tracked at an Indian Ocean atoll; and 100 percent for White Sharks in False Bay, South Africa tagged by Kock et al. (2013) were redetected. In drawing comparisons between our study and these studies, it is important to remember that several of these systems were either partially enclosed (thereby constraining tagged animals within an area that has active receivers, which should increase the probability of detection), or the acoustic receivers were deployed in habitat oasises (e.g., Indian Ocean atoll) whereby the tagged animals would be incentivized to remain due to availability of food sources. Understanding an animal's behavior can assist in strategizing the deployment of acoustic receivers. For example, white sharks are known to patrol specific hunting grounds, so the deployment of acoustic receivers in areas close to beaches frequented by seals (e.g., Kock et al. 2013) might increase the likelihood of detection in those areas.

Our acoustic array was deployed in an area that may serve as a migratory bottleneck for some species traveling along the continental shelf. High detection rates for other animals in the Mid-Atlantic Bight (i.e., Atlantic sturgeon) may be due to the tendency of these animals to be "shoreline huggers" (R.W. Laney, U.S. Fish and Wildlife Service, personal communication). However, dogfish are known to make rapid on- and off-shelf movements; there was no physical barrier preventing these sharks from swimming around the array or off the continental shelf. Furthermore, these animals are not known to be shoreline huggers; rather, they are classically referred to as a deepwater shark that often distributes across the continental shelf (e.g., Burgess 2002). Although not a firm rule, there are examples in the literature of acoustic tagging studies conducted in open ocean environments that experienced lower single redetection rates (e.g., 49 percent redetection rate of Steelhead Trout *Oncorhynchus mykiss* in a study evaluating marine movements (Welch et al. 2004); 54 percent redetection rate for Green Sturgeon completing marine migrations (Lindley et al. 2008); 55 percent redetection rates for Tiger Sharks tracked across the Coral Sea (Werry et al. 2014)). Furthermore, we noted that dogfish were detected in a variety of habitats, and therefore may not be behaviorally constrained in the same way as are animals that are dependent on specific food sources or constrained to particular habitats.

Our recapture rates of Spiny Dogfish tagged in mark-recapture experiments were either slightly lower or consistent with results from other tagging studies completed on Spiny Dogfish. Templeman (1954, 1984) tagged 2,657 sharks between 1942 and 1965 off southern Newfoundland (Canada), and had a recapture rate of 8.7 percent (n = 232 individuals). Myklevoll (1993; as reported in Campana et al. 2008) tagged 500 sharks in Georges Bank between 1956 and 1961, and obtained recapture data on 14 individuals (2.5 percent). Jensen (1961, 1966, 1969) tagged 999 Spiny Dogfish in 1968 between Cape Cod, Maine, and Brown Banks (Canada), and obtained recapture data from 25 sharks (2.8 percent). Shafer (1970) tagged and released 3,583 Spiny Dogfish at various locations throughout the Mid-Atlantic Bight and New England, and reported a recapture rate of 1.67 percent, which is close to the results obtained in our tagging program. McFarlane and King (2003) tagged over 71,000 Pacific Spiny Dogfish (*S. suckleyi*) between 1978 and 2000, and received recapture information on 2,940 indivuals (4.1 percent). Our mark-recapture results therefore do not appear to be inconsistent or unusual when compared to other tag studies on Spiny Dogfish.

Distribution of Spiny Dogfish on either U.S. coast has long been known to reflect a northward distribution in the summer and a southward distribution in the winter (Brodeur et al. 2009; e.g., McMillan and Morse 1999 and Campana et al. 2009 in the Atlantic, and Bonham et al. 1949 and Holland 1957 in the Pacific). Jensen et al. (1961) noted that dogfish are spring and autumn transients in the southern part of the range (NY to NC), and in the Cape Cod area are mostly transients moving to the north in the spring and the south in the fall. Templeman (1984) found southward migrations in late autumn and winter of sharks tagged off Newfoundland to waters off the U.S. for overwintering and liberation of young; northward return feeding migrations to regions off Newfoundland occurred in late spring and early summer. Acoustic data and mark-recapture external tag data from this research indicate that an identifiable component of the Northwest Atlantic stock makes seasonal migrations between North Carolina and Massachusetts. There is also evidence that dogfish remain available to coastal New England fisheries for much of the year; indeed, year round fisheries in these areas are not uncommon (ASMFC 2002; see annual reviews of the Interstate Fishery Management Plan for detailed landings by state). We note that dogfish tagged at the extreme northern end of the range tended to not be recaptured beyond southern New England; however this could be a function of sample size since the number of sharks tagged by Moore (1999) and Register (2007) were relatively small compared to the number of sharks tagged off of North Carolina by Rulifson (Hickman et al. 2000; Rulifson et al. 2002). Comparison of recapture latitudes with calendar day from both mark-recapture and acoustic data suggest that the North Carolina-tagged Spiny Dogfish (as part of the hypothesized mid-Atlantic migratory contingent) make regular, cyclic migrations between mid-Atlantic wintertime and southwestern Gulf of Maine or southern New England summer habitats (Figure 49). This is further corroborated by the repeat detection of individually tagged Spiny Dogfish multiple years in a row on either (or both) the Cape Hatteras and Massachusetts coastal arrays.

Mark-recapture external tag data and acoustic data suggest that Spiny Dogfish arrive in coastal North Carolina in December (or even November) of a given year, and may stay well until April or May of a given year (depending on water temperature and other environmental factors, see Chapter 3). In wintertime, many Spiny Dogfish were recaptured (mark-recapture external tag) or redetected (acoustic tags) south of Cape Hatteras, which traditionally has been recognized as a southern extent of the Spiny Dogfish range for management purposes by the Mid-Atlantic and New England Fishery Management Councils, and NOAA Fisheries. Our data corroborate with other research that has noted the presence of dogfish south of Cape Hatteras. Some recaptures occurred south of Cape Hatteras (a small number from South Carolina fishermen). Large dogfish aggregations have been observed in the Hatteras Bight and Onslow Bay (Figure 50; Newman et al. 2000, Rulifson and Moore 2009), and there are reports of these sharks venturing much further south. Spiny Dogfish are found in numbers large enough to support an annual wintertime tournament held in Wrightsville Beach, North Carolina (east of Wilmington, NC) (A. Baird, Mercer Pier Dogfish Tournament organizer, personal communication). Spiny Dogfish are periodically encountered in surveys conducted off Charleston, SC (*pers comm.,* B. Frazier, South Carolina Department of Natural Resources, Marine Resources Division, Charleston). In addition, numerous fishermen between North Carolina and Florida have reported Spiny Dogfish in exceptionally deep waters off the continental shelf (e.g., personal communications - D. Hemilright, NC; E. Sander, FL).

Spiny Dogfish schools are known to distribute in response to rapid changes in environmental conditions off the coast of North Carolina (Rulifson and Moore 2009). Our acoustic data indicated that sharks can move quickly (e.g., one shark traveled 106 kilometers in one day), but may revisit array sites multiple times in a season. It is possible that this shark could have been consumed by a predator. Our acoustic tag data would not be indicative of a predation event; however, this could be investigated by comparing known movement rates of spiny dogfish and known predators of spiny dogfish (e.g., larger sharks).

Mark-recapture and acoustic data suggest that sharks that overwinter in North Carolina may distribute northward (starting in March or April) in the summer to nearshore habitats along the Massachusetts coast, specifically between Cape Ann and Cape Cod. Therefore, we propose this area as the northern extent of the contingent range and the site of a possible area of spatial overlap between the hypothesized mid-Atlantic and Gulf of Maine contingents. Approximately fifteen percent of tagged Spiny Dogfish were either redetected or recaptured north of Cape Ann, Massachusetts, and approximately one-quarter of spiny dogfish were recaptured or redetected between Chatham, Massachusetts and Cape Ann, Massachusetts (Figure 51). Research conducted in the Cape Cod region by Rulifson et al. (2012) found that a majority (60-70 percent) of sharks tagged north and south of Cape Cod tended to be recaptured on the same side of Cape Cod, further exemplifying the hypothesis of this region as a mixing ground. The sharks then spend roughly five months of the year between southern New England (i.e., Rhode Island, or 41º Latitude) and the central Gulf of Maine (i.e., roughly along the New Hampshire – Maine border) before heading back to wintertime habitats in the mid-Atlantic. The migration between summer and winter habitats takes approximately three to five months; mark-recapture data suggest that the southward (fall) migration may take less time than the northward (spring) migration.

Notable numbers of sharks were recaptured (external tags) and redetected (acoustic tags) at northern and southern extents of the range; however, comparatively few animals were detected in between these regions. Acoustic data indicate that groups of dogfish tagged in one year do not necessarily undertake the same migratory pathways as groups of dogfish tagged in a subsequent year; similarly, individually tagged dogfish may not undertake the same movements from one year to the next. Furthermore, while several of the sharks that were tagged off the North Carolina coast were redetected in subsequent years on the North Carolina array, this type of an annual detection event was not strongly observed in other locations. For example, a relatively large number of sharks were only detected off the coast of Delaware in one year (2009). Also of note is the fact that some sharks detected in coastal North Carolina in 2009 or 2010 disappeared, and went a year or more before being redetected. There are indications from mark-recapture data of dogfish not being susceptible to fisheries for extended periods of time, and large numbers of tagged sharks are not recaptured. Dogfish that were at large 1,000 – 1,800 days (three to five years) were recaptured off the coast of North Carolina, and dogfish that were at large for 2,000 to 3,000 days (five to eight years) were caught between New Jersey and Nantucket (Figure 46). Maximum time at liberty from the mark-recapture research discussed herein was attributed to a shark tagged in March 2000 off North Carolina; this animal was at liberty for 4,567 days (12.5 years) before its recapture event off Rhode Island. Maximum time at liberty for sharks tagged in separate research studies conducted off Newfoundland (Templeman 1984), in the Gulf of Maine (Jensen 1961), and off British Columbia (McFarlane and King 2003) ranged between 10 and 20 years.

It is important to note that the gaps in detections between seasons or years could be a function of the deployment schedules for receivers from other institutions; if receivers are not in the water year round, then inferences based on detections would have to account for the deployment schedules of all arrays. Future research with these data will re-evaluate detections in light of other researcher's deployment schedules. Similarly, mark-recapture data used to evaluate the distribution of sharks based on recaptures would be affected by the relative amount of fishing effort, closures, and timing of both directed spiny dogfish fisheries and incidental fisheries. We did not account for this in the evaluation of mark-recapture data, and would recommend that future studies using these data identify and account for fishery-dependent conditions that could influence the probability of recapture.

So where do sharks at liberty for extended periods of time go? Campana et al. (2008) argue that populations of dogfish off Newfoundland and other parts of Atlantic Canada make onshore and offshore migrations between summer and winter habitats, respectively. Based on research completed with PSAT tags, Carlson et al. (2014) noted that some Spiny Dogfish tagged off the coast of North Carolina and Massachusetts spent considerable time in exceptionally deep waters far east of the continental shelf. Tagged Spiny Dogfish off North Carolina, in particular, moved east and northward away from the continental shelf. Our data suggest that while some tagged sharks remain in coastal continental shelf waters, a component of the population that could comprise a hypothetical Mid-Atlantic Spiny Dogfish contingent may venture into deep, offshore waters and become unavailable to the fishery (or to acoustic detection gear deployed in coastal areas) for extended periods of time (i.e., 99 percent of the tagged sharks were not recaptured – perhaps they are unavailable to the fishery due to off-shelf migration?). Spiny Dogfish were detected on a Gulf of Maine Ocean Observing System (GoMOOS) buoy floating in the central Gulf of Maine, far offshore from any coastal habitats. A small number of tag returns came from deepwater trawl fisheries in areas well east of the continental shelf (data not shown), and one tag return came from Iceland (released January 26, 2005 off the Outer Banks of North Carolina, and recaptured by longline August 30, 2009 (1,677 days later) approximately 5,091 km from the release site in 70 meters of water). Given that some dogfish seemingly appeared between Cape Hatteras and the Cape Cod region without being detected on coastal arrays in between, we hypothesize that some of these sharks may complete part of the migratory cycle off the continental shelf. The propensity to be in shallower waters on the continental shelf or deeper waters off the continental shelf may be driven by dogfish response to environmental factors. Additional research with PSAT tags, or deployment of Remote Operated Vehicles with compatible receivers for acoustic tags, could be used in the future to evaluate spiny dogfish movements along the continental shelf.

The mark-recapture and acoustic data, along with PSAT analyses conducted by Carlson et al. (2014) and consideration of previous research on Spiny Dogfish, suggest that some modifications to Figure 19 may be appropriate to more accurately depict the northern and southern extent of migration for a hypothesized contingent of sharks that migrate through the Mid-Atlantic Bight to reach overwinter grounds or summer habitats. A generalized depiction of behavior undertaken by Spiny Dogfish that overwinter off the coast of North Carolina is shown in Figure 52. North Carolina-tagged spiny dogfish were frequently recaptured or detected at the end points of migration (i.e., North Carolina or southern New England/coastal Massachusetts, shaded in yellow circles). However sharks were not observed to undertake the same migration pathway in consecutive years based on acoustic detections, and sharks were frequently either not detected on coastal arrays for extended periods of time or had lengthy times at liberty. We therefore propose that sharks could make part of the migration in deeper areas of the continental shelf or off-shelf (indicated by dashed lines leading to question marks). Furthermore, PSAT studies by Carlson et al. (2014) suggest that dogfish do venture off-shelf. As shown in Chapter 4, Spiny Dogfish are extremely sensitive to environmental fluctuations (in particular, water temperature) and distribution is known to be influenced by oceanographic conditions (Sargarese et al. 2014). Therefore the migration pathway is depicted as either occurring along the coast (hyphenated line) or at or off the continental shelf (solid line), with the exact location on the shelf likely dictated by environmental conditions (short arrows between the two pathways depicting on- and off-shelf movement). Finally, there is documented evidence of dogfish moving south of Cape Hatteras, both in terms of acoustic detections, conventional tag recaptures, surveys conducted further south (e.g., SC DNR longline survey off Charleston SC), and anecdotal evidence and data provided by fishermen (e.g., Johnny Mercer Pier dogfish tournament). The southern extent of the migration is thus expanded by hyphenated lines suggesting movement south of Cape Lookout, North Carolina both along the coast and along the continental shelf, with arrows also suggestive of on and off-shelf movement.

In conclusion, the combined mark-recapture external tag study and acoustic tag study represent close to fifteen years of tagging research on Spiny Dogfish, and constitutes the largest tagging study on Spiny Dogfish in the northwest Atlantic Ocean. This chapter discusses general trends in two types of data, and identifies the migration patterns of sharks that could be part of the proposed Mid-Atlantic Migratory Contingent of Spiny Dogfish. However, these hypotheses can and should be further explored via additional modeling efforts with these data. Results should also be further evaluated in the greater context of studies discussing distribution of Spiny Dogfish from wide-ranging survey data (e.g., NEFSC trawl survey data (Sagarese et al. 2014) or DFO Canada groundfish trawl survey data (Shepherd et al. 2002)), ongoing tag studies such as the NOAA Fisheries' Cooperative Research Spiny Dogfish Tag Study (2011 to present), and high resolution satellite tag data (e.g., Carlson et al. 2014) to further refine understanding of the stock structure of Northwest Atlantic Spiny Dogfish.

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Kneebone, B. Hoffman; Coastal NJ/NY – Stony Brook Univ., K. Dunton; Gulf of Maine - Univ. of Maine, G. Zydlewski / NOAA, P. Music, J. Hawkes.

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Figure 30. Detections of 2010-tagged Spiny Dogfish on the Hatteras Acoustic Array. Red boxes indicate periods in which the array was deployed. Horizontal lines are a visual guide for tracing the temporal distribution of detections of individually tagged fish (tag ID numbers shown on the y-axis).

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Figure 35. Radial plot showing the hour within which single detection events first occurred on the Hatteras Acoustic Array (all detections between 2009-2011)). Each "pie piece" shows a one hour interval. The length of the pie segment corresponds to the number of detections (range of 3 to 16 detections).

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Figure 38. Log-transformed travel rate (distance in kilometers between detection points / days between detections) by arrival region for sharks initially tagged and released in NC waters.

Figure 39. Reported recapture locations of Spiny Dogfish tagged with external dart tags. Recapture locations of sharks released north of Cape Cod (north of the 42º N Latitude line) are shown in blue. Recapture locations of sharks released south of the 42º N Latitude line (either along Cape Cod or off Rhode Island) are shown in shades of pink.

Figure 40. Northern recapture locations of North Carolina tagged Spiny Dogfish sharks. Grid cells are colored to represent the number of recapture events. Cells are labeled with the month(s) of recapture events (e.g., 6 = June, 7 = July, etc). Circled areas are regions where North Carolina tagged sharks are consistently captured from late spring through early fall.

Figure 41. Recapture locations of sharks in June, coupled with an analysis of recapture data earlier and later in the year, suggests northward movements along Cape Cod in June. Alternatively, sharks may make a circuit through the central Gulf of Maine in June.

Figure 42. Location of recapture events between October and December, with the strongest evidence of alongshore, southward movement near Cape Cod occurring in October. Each colored grid cell contains 1 recapture event.

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Figure 48. Latitude of recapture versus calendar day of recapture for all tags returned to East Carolina University. NC = tagged sharks released off North Carolina. MA = tagged sharks released off Massachusetts. NS = tagged sharks released off Nova Scotia. Red line shows the approximate latitude of Cape Ann, Massachusetts, a generalized northern extent for the proposed Mid-Atlantic Contingent of Spiny Dogfish.

Figure 49. Comparison of latitude of external tag recaptures and acoustic tag detections from sharks tagged off the coast of North Carolina by calendar day of recapture or detection. The red line indicates the approximate latitude of Cape Ann, Massachusetts; only 15 percent of the recaptures and detections occurred north of this location.

Figure 50. Location and approximate spatial extent of dogfish aggregations found south of Cape Hatteras, North Carolina (Newman et al. 2000; Rulifson and Moore 2009).

Figure 51. Number and percentage of Spiny Dogfish recaptured (mark-recapture study) and redetected (acoustic tag study) in sub-regions of New England.

Figure 52. Hypothetical migration pathways for North Carolina-tagged spiny dogfish. Shaded circles are generalized depictions of overwintering grounds and summer feeding habitats.

Tables and Figures

Table 17.

Year of Release	Number of Tags Released	Location of Release
1996	990	Nova Scotia
1997	677	North Carolina
1998	7,274	North Carolina
1999	1,292	North Carolina
2000	904	North Carolina
2001	0	----------
2002	1,999	North Carolina
2003	3,000	North Carolina
2004	3,385	North Carolina
2005	2,729	North Carolina (n =1,985) Nova Scotia (n =744)
2006	10,713	North Carolina
2007	5,285	North Carolina
2008	920	Massachusetts
2009	53	North Carolina
2010	2,671	North Carolina (n = 40) Massachusetts (n = 2,631)
2011	5,114	Massachusetts
2012	0	--------
Total:	47,006	Nova Scotia (n = 1,734) Massachusetts (n = 8,485) North Carolina (n = 36,607

Table 18.

NC Array Redetections of Sharks Tagged in 2009					
Tag ID	**Sex**	**TL**	**2009**	**2010**	**2011**
54052	M	779	X	X	
54056	F	833	X		
54060	F	820	X	X	
54062	F	837	X		
54065	F	807		X	X
54068	F	814			X
54069	F	880			X
54072	F	845			X
54073	F	845		X	X
54074	F	823		X	
54075	F	809			X
54077	F	788	X		
54083	F	810			X
54086	F	840			X
54088	F	814	X		
54092	F	844	X		X
54099	F	995	X		

Table 19.

NC Array Redetections of Sharks Tagged in 2010				
Tag Code	**Sex**	**TL**	**2010**	**2011**
63940	F	871	X	
63941	F	855	X	
63942	F	820	X	
63943	F	885		X
63944	F	964	X	X
63946	F	916	X	
63947	F	881		X
63948	F	890	X	
63949	F	916	X	X
63951	F	890	X	X
63952	F	945	X	X
63954	F	980		X
63955	F	868	X	
63958	F	860	X	
63959	F	820		X
63963	F	870	X	X
63964	M	750		X
63965	F	810	X	X
63968	F	870	X	
63970	F	950	X	X
63971	F	910	X	X
63972	F	830		X
63977	F	870	X	X
63978	F	840	X	X
63979	F	855	X	X
63980	F	900	X	X

Table 20.

Tag Code	Sex	TL	Release Location	2009			2010					2011
				Coastal North Carolina	Delaware Bay	Coastal Mass.	Coastal North Carolina	Long Island Sound	Delaware Bay	Gulf of Maine	Coastal Mass.	Coastal North Carolina
7829	F	852	north of Oregon Inlet		X		X					
54052	M	779	north of Oregon Inlet		X		X					
54053	F	853	north of Oregon Inlet		X							
54054	F	795	north of Oregon Inlet		X				X			
54056	F	833	north of Oregon Inlet	X								
54057	F	826	north of Oregon Inlet								X	
54058	F	860	north of Oregon Inlet		X							
54059	F	838	north of Oregon Inlet		X	X					X	
54060	F	820	north of Oregon Inlet	X			X				X	
54062	F	837	north of Oregon Inlet	X						X		
54063	F	867	north of Oregon Inlet		X							
54064	F	830	north of Oregon Inlet								X	
54065	F	807	north of Oregon Inlet	X			X				X	X
54066	M	816	north of Oregon Inlet		X					X	X	
54067	F	824	north of Oregon Inlet		X							
54068	F	814	north of Oregon Inlet	X						X		X
54069	F	880	north of Oregon Inlet								X	X
54072	F	845	north of Oregon Inlet								X	X
54073	F	845	north of Oregon Inlet				X					X
54074	F	823	north of Oregon Inlet				X					
54075	F	809	north of Oregon Inlet		X							X
54077	F	788	north of Oregon Inlet	X								
54078	F	786	north of Oregon Inlet		X							
54082	F	826	north of Oregon Inlet								X	
54083	F	810	north of Oregon Inlet								X	X
54084	F	801	north of Oregon Inlet		X					X	X	
54085	F	832	north of Oregon Inlet							X		
54086	F	840	north of Oregon Inlet								X	X
54087	F	849	north of Oregon Inlet					X				
54088	F	814	north of Oregon Inlet	X			X				X	

Tag Code	Sex	TL	Release Location	2009			2010					2011
				Coastal North Carolina	Delaware Bay	Coastal Mass.	Coastal North Carolina	Long Island Sound	Delaware Bay	Gulf of Maine	Coastal Mass.	Coastal North Carolina
54089	F	808	north of Oregon Inlet								X	
54090	F	858	north of Oregon Inlet							X	X	
54091	F	808	north of Oregon Inlet				X					
54092	F	844	north of Oregon Inlet	X								X
54093	F	824	north of Oregon Inlet								X	
54095	M	756	north of Oregon Inlet								X	
54097	F	843	north of Oregon Inlet		X				X			X
54099	F	995	north of Oregon Inlet	X	X							
54100	F	885	north of Oregon Inlet		X							

Table 21.

Tag Code	Sex	TL	Release Location	2010				2011				2012
				Coastal North Carolina	Delaware Bay	Coastal Mass.	Gulf of Maine	Coastal North Carolina	Delaware Bay	Coastal Mass.	Gulf of Maine	Coastal NJ/NY
63940	F	871	Cape Lookout	X		X						
63941	F	855	Cape Lookout	X		X						
63942	F	820	Cape Lookout	X								
63943	F	885	Cape Lookout					X				X
63944	F	964	Cape Lookout	X				X				X
63945	F	888	Cape Lookout			X	X					
63946	F	916	Cape Lookout	X								
63947	F	881	Cape Lookout			X		X				
63948	F	890	Cape Lookout	X					X			
63949	F	916	Cape Lookout	X								
63951	F	890	Cape Lookout	X		X		X				X
63952	F	945	Cape Lookout	X		X		X				
63953	F	850	Oregon Inlet									X
63954	F	980	Cape Lookout					X				X
63955	F	868	Cape Lookout	X		X	X					
63956	F	810	Oregon Inlet			X				X		
63957	F	810	Oregon Inlet									X
63958	F	860	Oregon Inlet	X								
63959	F	820	Oregon Inlet			X	X	X				
63960	F	855	Cape Lookout			X						
63961	F	810	Oregon Inlet			X	X					
63962	F	820	Oregon Inlet			X					X	
63963	F	870	Oregon Inlet	X				X				
63964	M	750	Oregon Inlet			X		X				
63965	F	810	Wimble Shoals	X				X				
63966	F	870	Oregon Inlet									X
63967	F	850	Oregon Inlet			X						X
63968	F	870	Wimble Shoals	X								X
63969	F	830	Wimble Shoals	X		X	X					
63970	F	950	Hatteras Bight	X								

Tag Code	Sex	TL	Release Location	2010				2011				2012
				Coastal North Carolina	Delaware Bay	Coastal Mass.	Gulf of Maine	Coastal North Carolina	Delaware Bay	Coastal Mass.	Gulf of Maine	Coastal NJ/NY
63971	F	910	Wimble Shoals	X		X		X				
63972	F	830	Oregon Inlet					X				
63973	F	820	Oregon Inlet							X		X
63974	F	820	Oregon Inlet			X						
63975	F	870	Oregon Inlet			X						
63976	F	820	Wimble Shoals	X		X						
63977	F	870	Hatteras Bight	X		X	X	X				
63978	F	840	Hatteras Bight	X		X	X	X		X		
63979	F	855	Hatteras Bight	X		X		X			X	
63980	F	900	Hatteras Bight	X		X		X				X

Table 22.

North to South			Year Tagged	South to North		
2009	2010	2011		2009	2010	2011
7 (13)*	3 (6)**	7 (13)**	2009 (n = 53)	1 (2)*	5 (9)**	0
-----	5 (12.5)**	10 (25)**	2010 (n = 40)	-----	14 (35)**	8 (20)**
7 (13)	8 (9)^	17 (18)^	Total (n = 93)	1 (2)	19 (20)^	8 (9)^

*Based on detections on the acoustic array.

**Based on subsequent detections on either side of Hatteras Shoals, on consecutive detections on arrays north of Cape Hatteras and then south of Cape Hatteras (or vice versa), or redetection on a non-ECU, northern array in the same year as release.

^In 2010, a total of 93 animals were at large.

Table 23.

Number of Tagged Fish	# of Independent Detection Events
50	0
11	1
3	2
6	3
14	5
5	10
2	15
1	25

Table 24.

Recapture Location	Release Location			Recapture % by Location
	Nova Scotia	Massachusetts	North Carolina	
Iceland	0	0	1	0.16
Canada	6	0	1	1.13
Newfoundland	1	0	0	0.16
New Brunswick	1	0	2	0.48
Nova Scotia	30	1	20	8.24
Prince Edward Island	0	0	1	0.16
Gulf of Maine	1	0	0	0.16
New England	0	0	1	0.16
Maine	2	4	11	2.91
New Hampshire	0	1	17	2.91
Massachusetts	10	89	116	37.32
Rhode Island	0	10	40	8.24
New York	0	1	9	1.62
New Jersey	0	9	50	10.18
Delaware	0	0	3	0.48
Maryland	0	2	5	1.29
Virginia	0	5	24	4.85
North Carolina	0	7	104	18.09
Overall Recapture Percentage by Release Location				
Total # Recaptured	51	139	410	**619**
Total Released	1,734	8,485	36,607	**46,826**
Recapture Percent	2.94	1.64	1.12	**1.32**

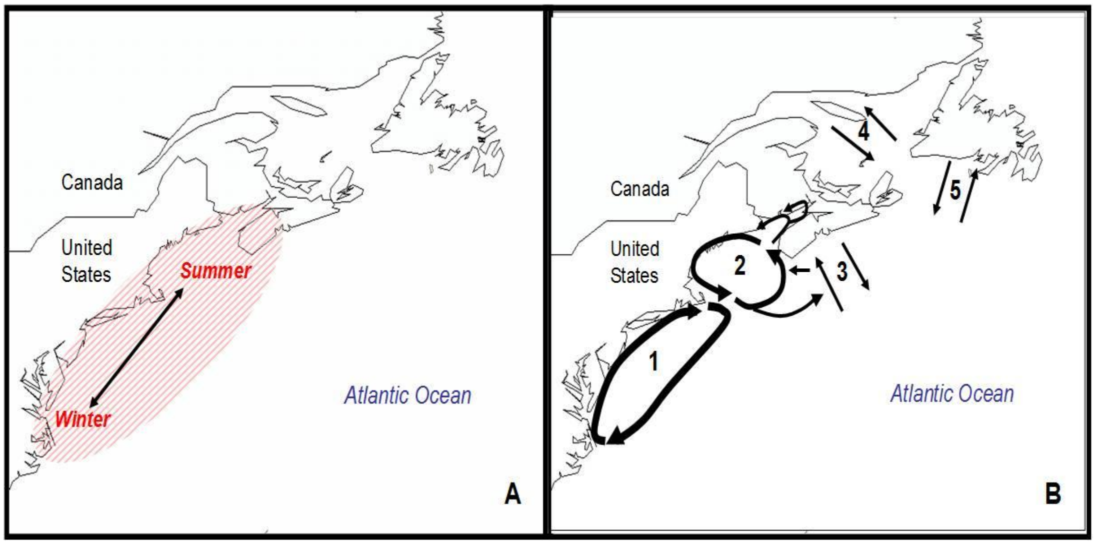
Table 25.

Release Year	**Recapture Year**																	**Total**
	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	
1997	15	9	1															25
1998		55	9		1				1	1								67
1999			10	1	2													13
2000				15	2	3	1	2	1		1					1		26
2002						6	5	4	2		1		1	1				20
2003							9	4	1	1	3		1					19
2004								7	10	4	4	1		4	1	1	1	33
2005									6	7	4	1	4			2	1	25
2006										41	32	17	15	4	6	4	2	121
2007											33	7	6	1	1	2		50
2010														2				2
2011															2			2
Total	15	64	20	16	5	9	15	17	21	54	78	26	27	12	10	10	4	403

Table 26.

Distance (km)	**Percentage of Total**	**Cumulative Percentage**
0 to 5.0	3.66	3.66
5.1 to 10	3.66	7.32
10.1 to 25	14.63	21.95
25.1 to 50	12.20	34.15
50.1 to 100	32.93	67.07
100.1 to 200	13.41	80.49
200.1 to 500	14.63	95.12
500.1 to 1,000	3.66	98.78
1,000.1 +	1.22	100.00

Figure 19.



Canada
United States
Summer
Winter
Atlantic Ocean
A
Canada
United States
1
2
3
4
5
Atlantic Ocean
B

Figure 20.

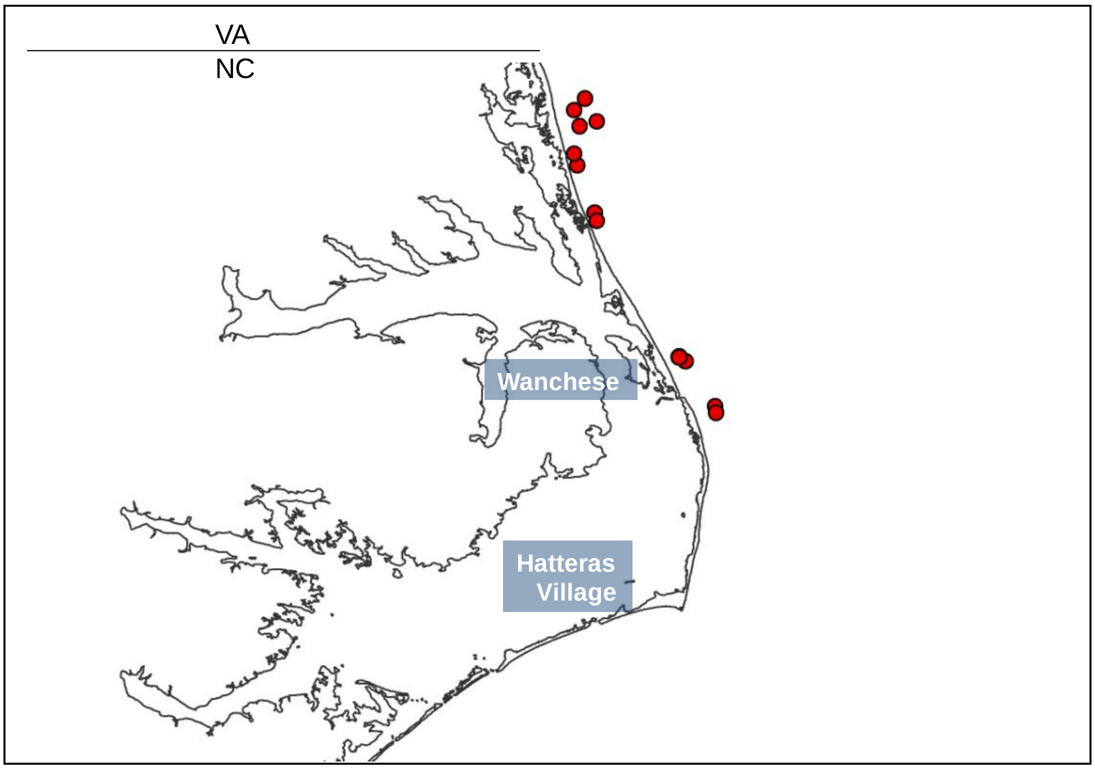


Figure 21.

Figure 22.

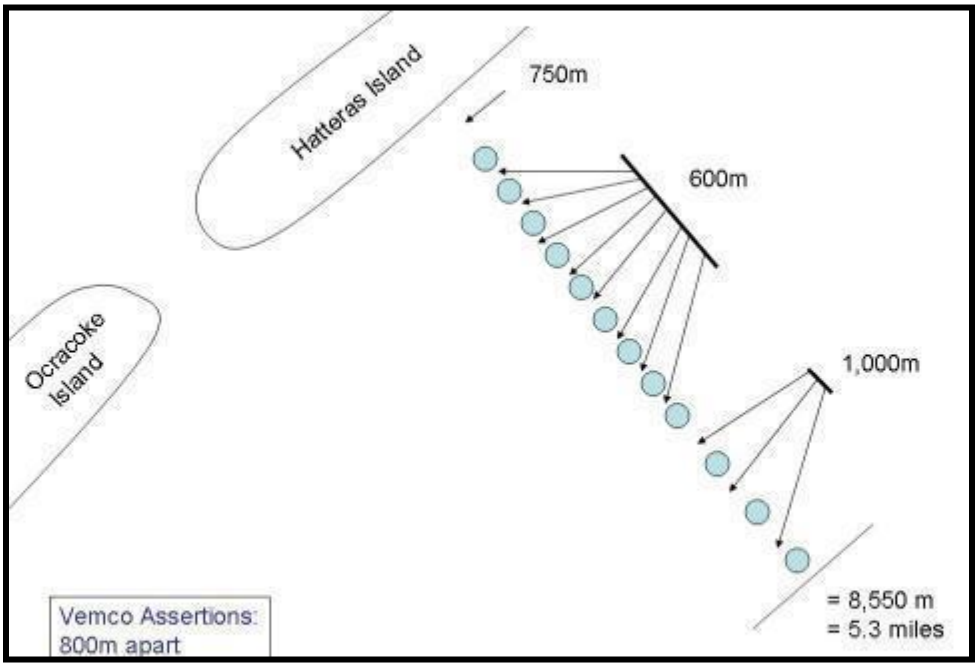

Hatteras Island
750m
600m
Ocracoke Island
1,000m
= 8,550 m
= 5.3 miles
Vemco Assertions:
800m apart

Figure 23.

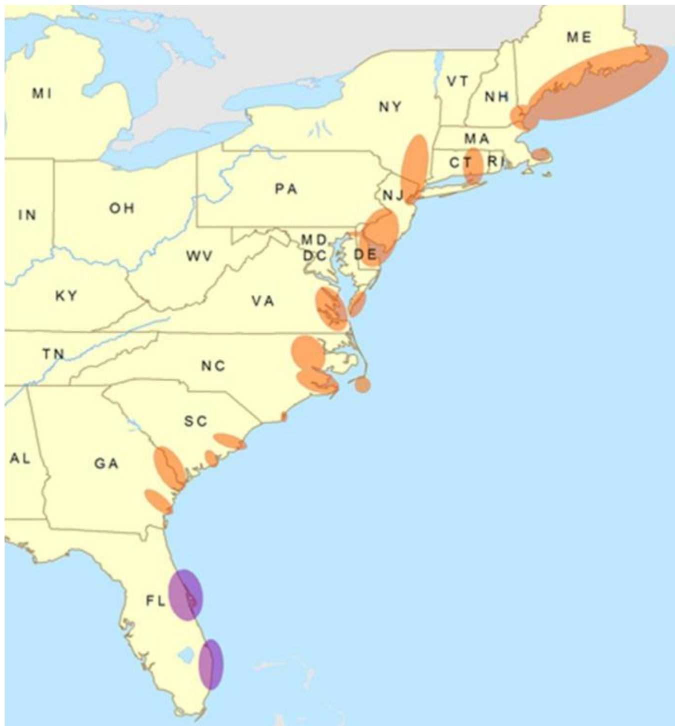


Figure 24.

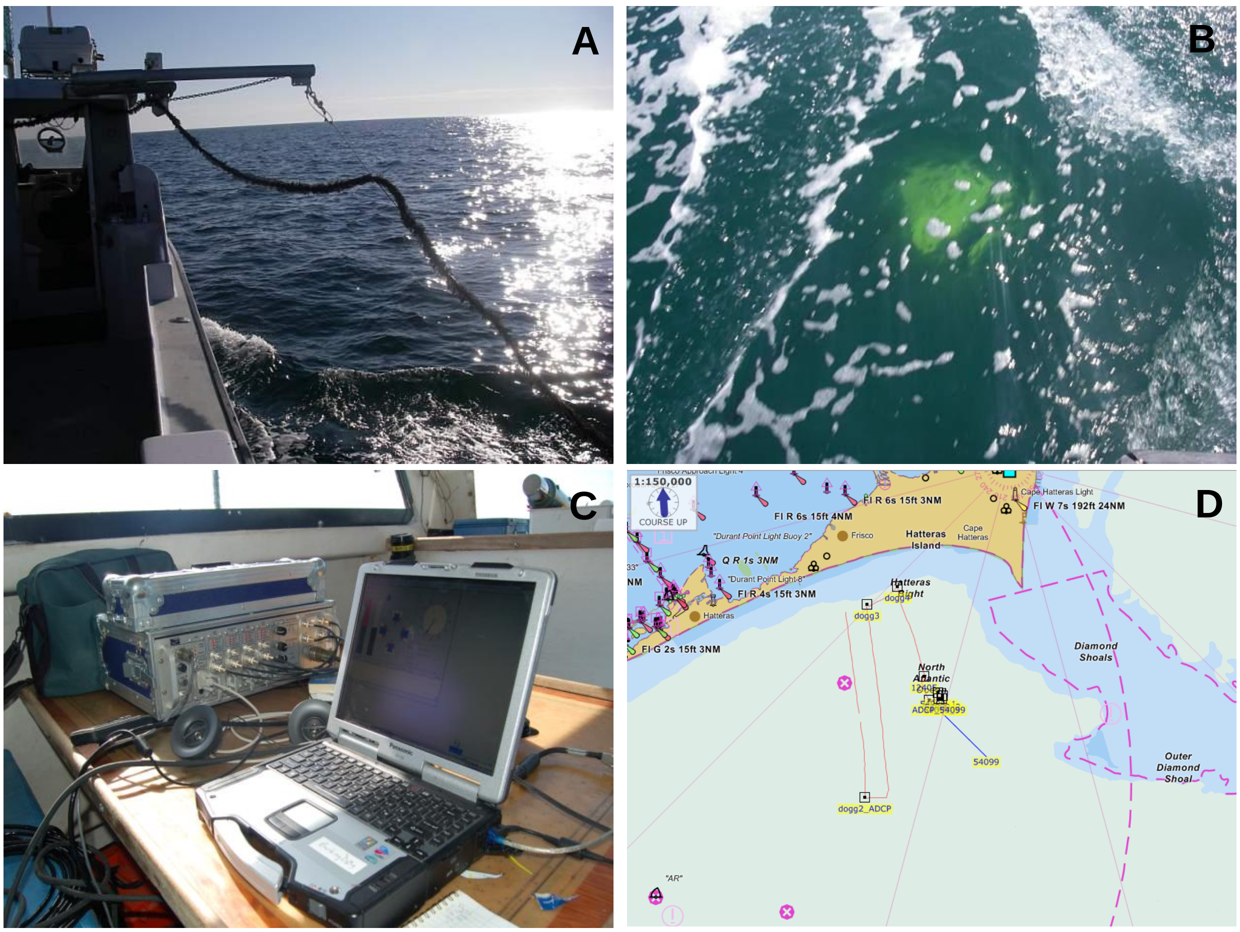

A
B
C
D
1:150,000
COURSE UP
Fl R 6s 15ft 4NM
Fl R 6s 15ft 3NM
Fl W 7s 192ft 24NM
Cape Hatteras Light
"Durant Point Light Buoy 2"
Frisco
Hatteras Island
Cape Hatteras
Q R 1s 3NM
"Durant Point Light 8"
Fl R 4s 15ft 3NM
Hatteras Light
Hatteras
dogg3
Fl G 2s 15ft 3NM
Diamond Shoals
North Atlantic
ADCP_54099
54099
Outer Diamond Shoal
dogg2_ADCP
"AR"

Figure 25.

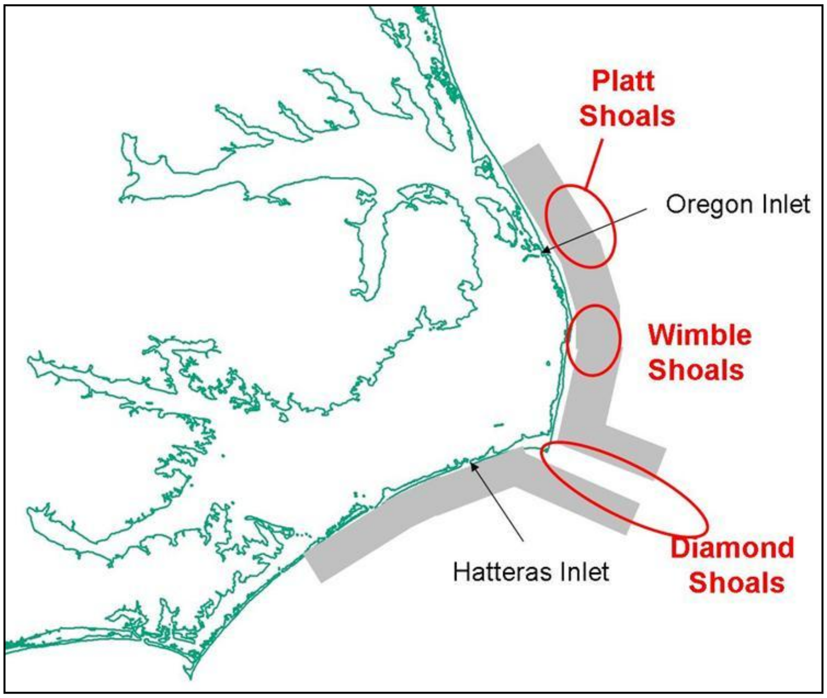

Platt Shoals
Oregon Inlet
Wimble Shoals
Hatteras Inlet
Diamond Shoals

Figure 26.

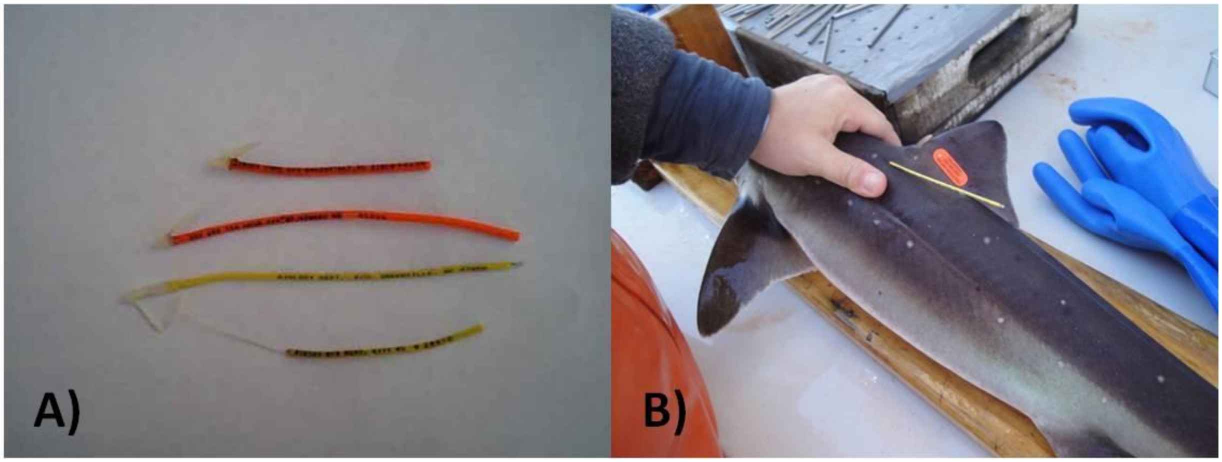


Figure 27.

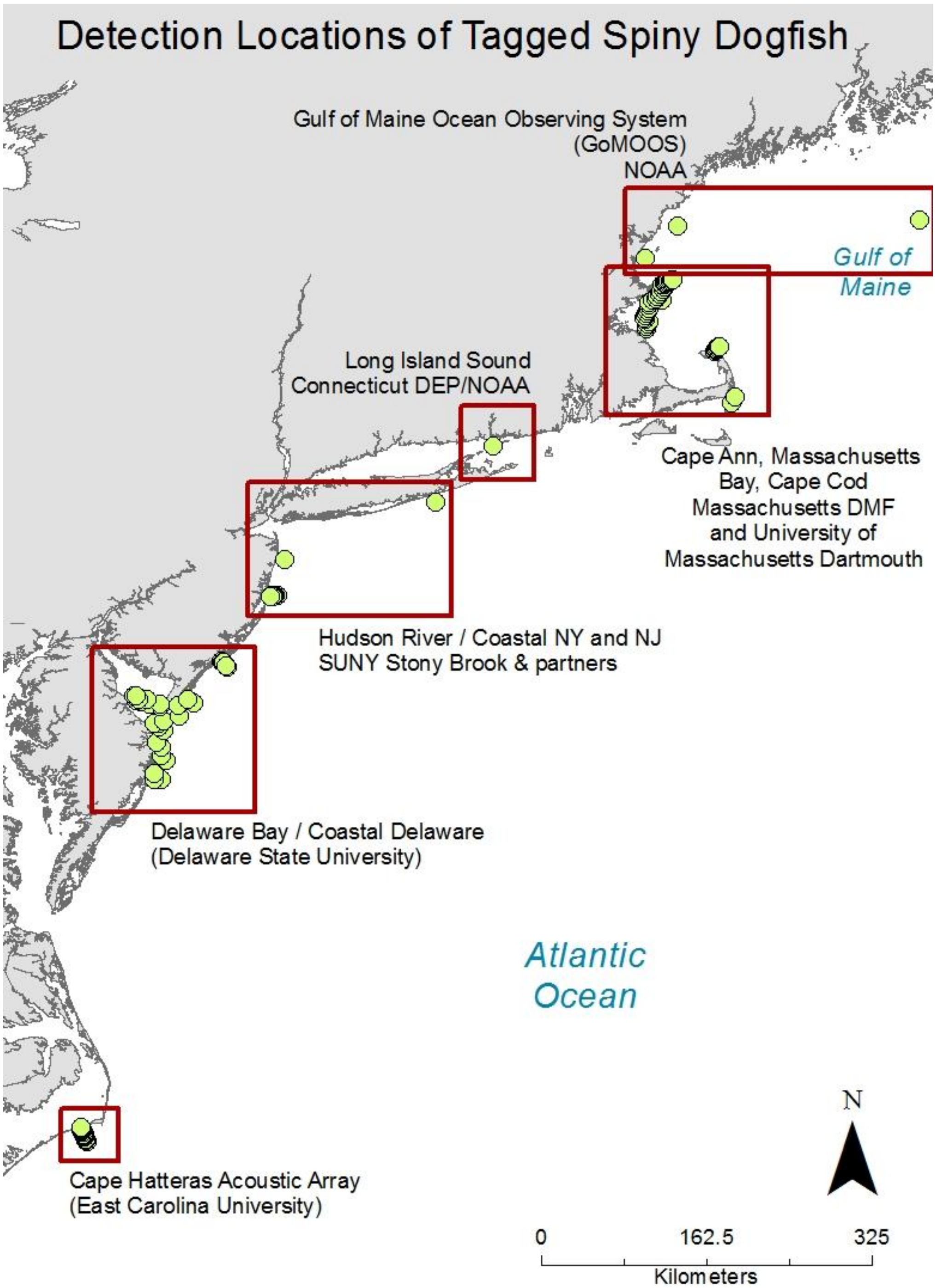
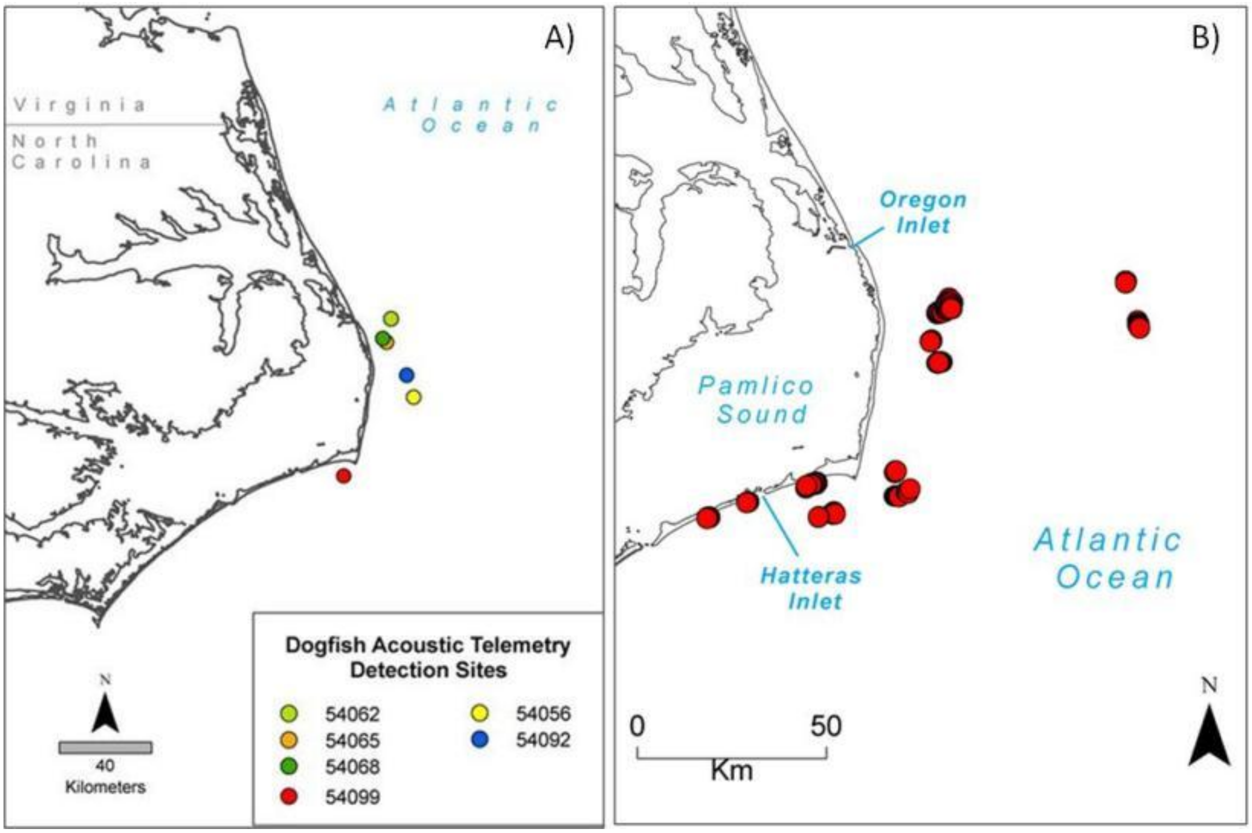
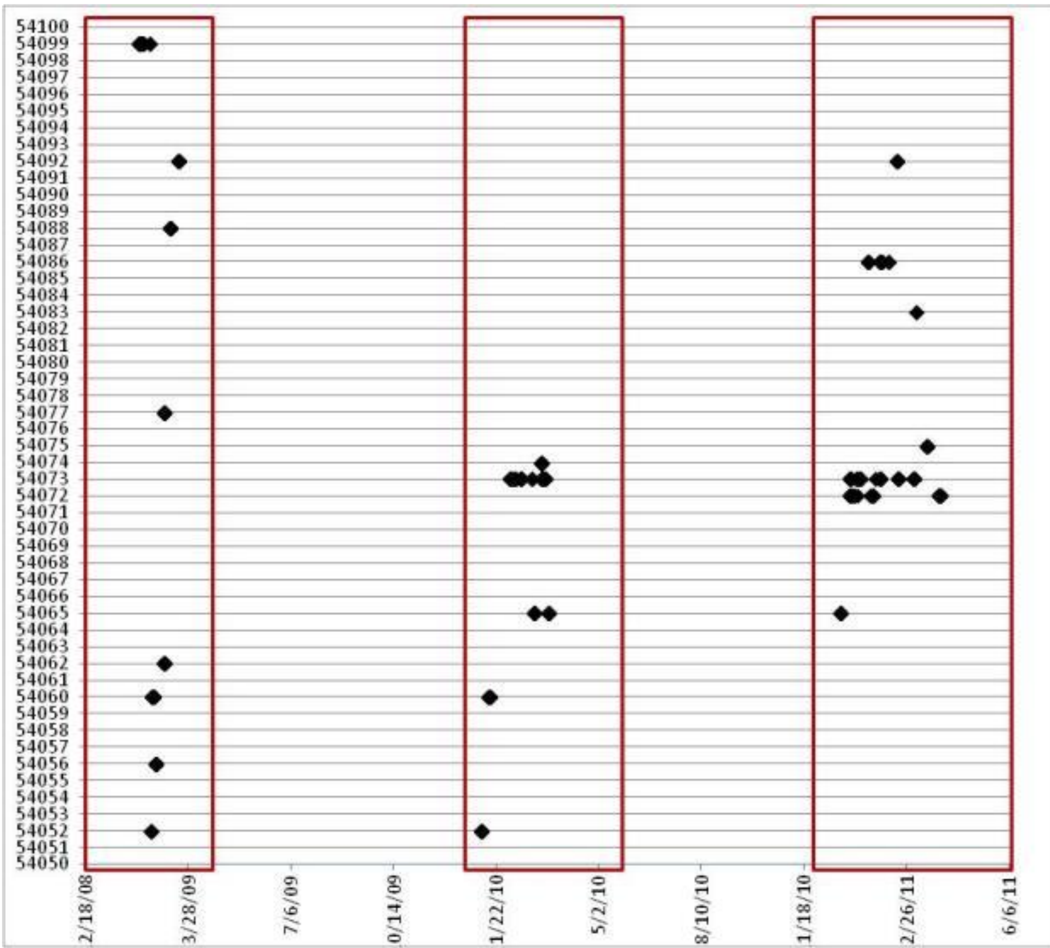

Detection Locations of Tagged Spiny Dogfish
Gulf of Maine Ocean Observing System
(GoMOOS)
NOAA
Gulf of
Maine
Long Island Sound
Connecticut DEP/NOAA
Cape Ann, Massachusetts
Bay, Cape Cod
Massachusetts DMF
and University of
Massachusetts Dartmouth
Hudson River / Coastal NY and NJ
SUNY Stony Brook & partners
Delaware Bay / Coastal Delaware
(Delaware State University)
Atlantic
Ocean
N
Cape Hatteras Acoustic Array
(East Carolina University)
0
162.5
325
Kilometers

Figure 28.



A)
Virginia
North Carolina
Atlantic Ocean
Dogfish Acoustic Telemetry Detection Sites
54062
54065
54068
54099
54056
54092
N
40
Kilometers
B)
Oregon Inlet
Pamlico Sound
Hatteras Inlet
Atlantic Ocean
0
50
Km
N

Figure 29.


54100
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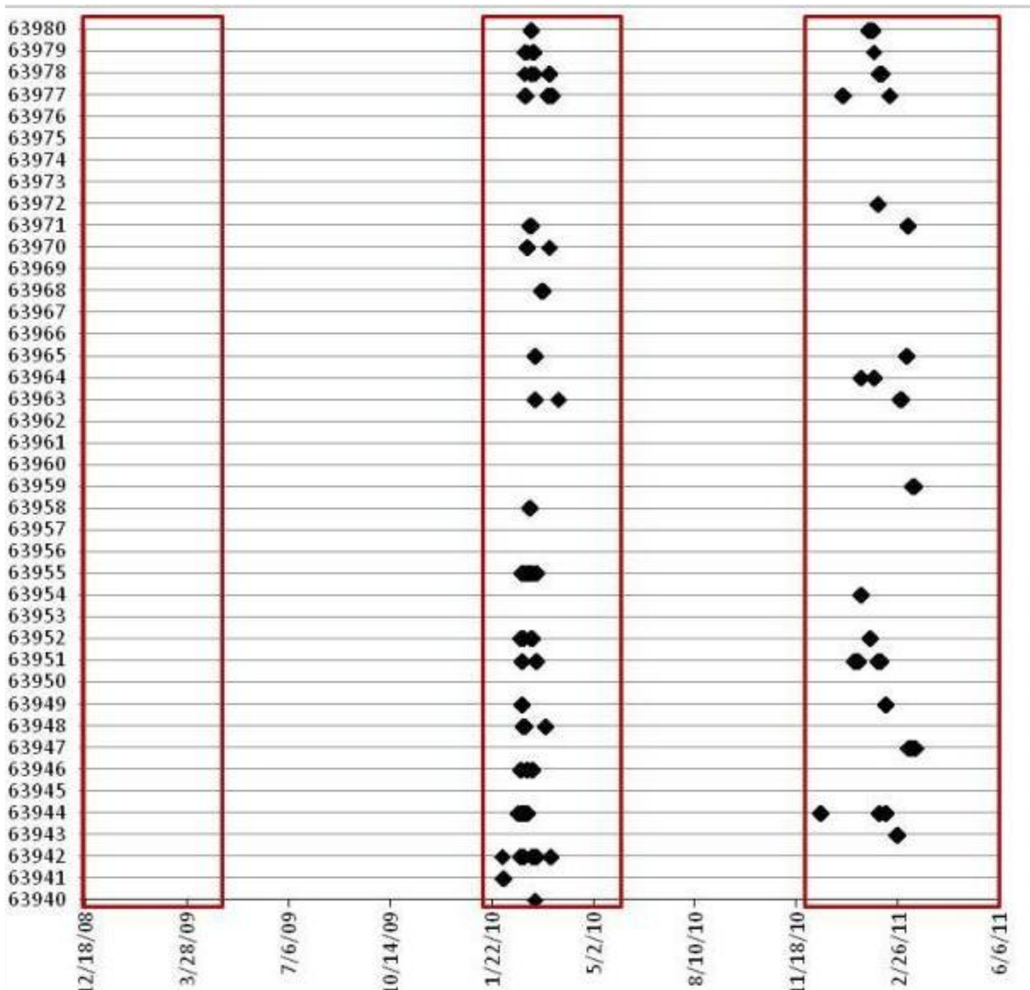
54050
2/18/08
3/28/09
7/6/09
0/14/09
1/22/10
5/2/10
8/10/10
1/18/10
2/26/11
6/6/11

Figure 30.


63980
63979
63978
63977
63976
63975
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63973
63972
63971
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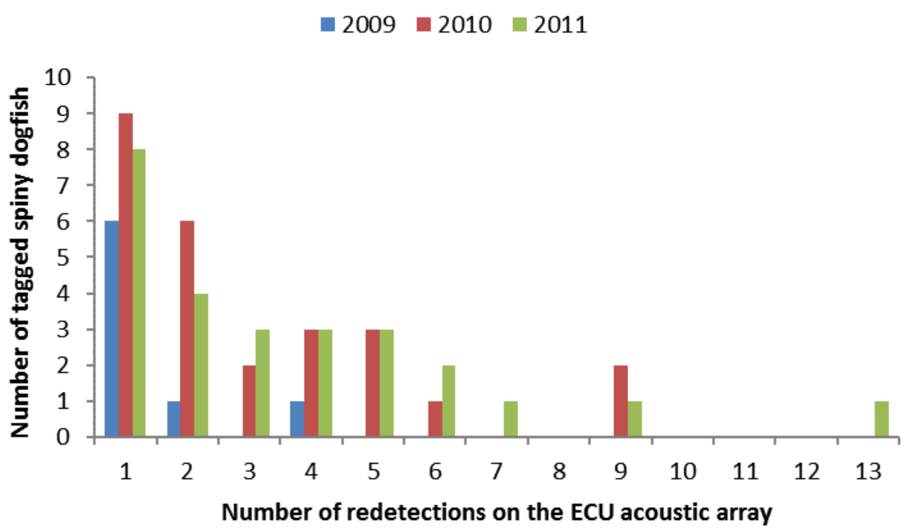
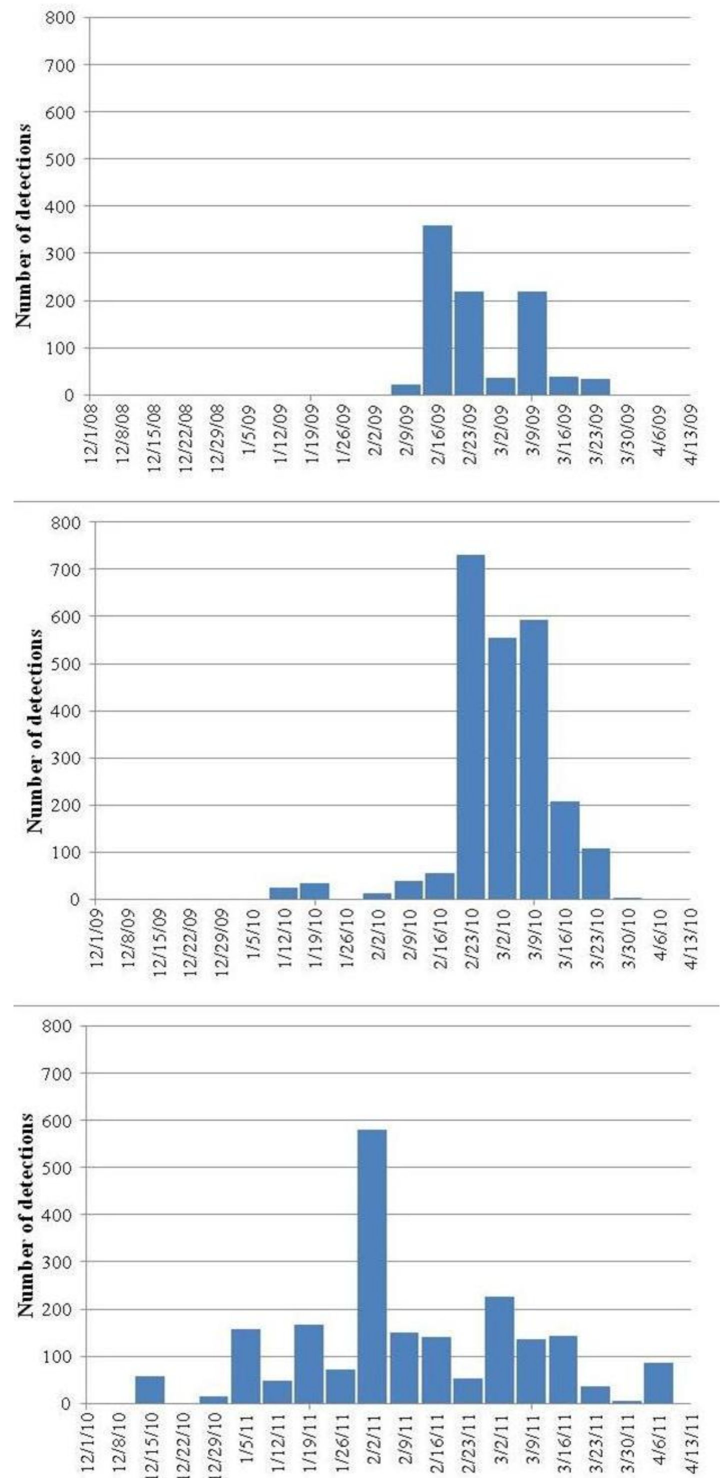
63968
63967
63966
63965
63964
63963
63962
63961
63960
63959
63958
63957
63956
63955
63954
63953
63952
63951
63950
63949
63948
63947
63946
63945
63944
63943
63942
63941
63940
12/18/08
3/28/09
7/6/09
10/14/09
1/22/10
5/2/10
8/10/10
11/18/10
2/26/11
6/6/11

Figure 31.



2009
2010
2011
Number of tagged spiny dogfish
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8
9
10
11
12
13
Number of redetections on the ECU acoustic array

Figure 32.



800
700
600
500
400
300
200
100
0
Number of detections
12/1/08
12/8/08
12/15/08
12/22/08
12/29/08
1/5/09
1/12/09
1/19/09
1/26/09
2/2/09
2/9/09
2/16/09
2/23/09
3/2/09
3/9/09
3/16/09
3/23/09
3/30/09
4/6/09
4/13/09
Number of detections
12/1/09
12/8/09
12/15/09
12/22/09
12/29/09
1/5/10
1/12/10
1/19/10
1/26/10
2/2/10
2/9/10
2/16/10
2/23/10
3/2/10
3/9/10
3/16/10
3/23/10
3/30/10
4/6/10
4/13/10
Number of detections
12/1/10
12/8/10
12/15/10
12/22/10
12/29/10
1/5/11
1/12/11
1/19/11
1/26/11
2/2/11
2/9/11
2/16/11
2/23/11
3/2/11
3/9/11
3/16/11
3/23/11
3/30/11
4/6/11
4/13/11

Figure 33.

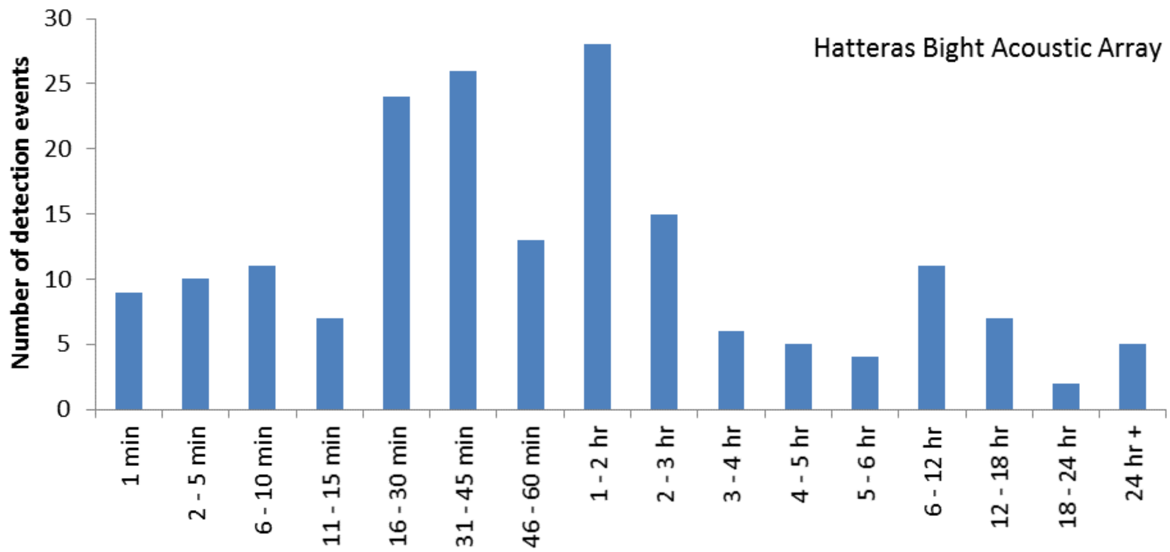

Hatteras Bight Acoustic Array
Number of detection events
30
25
20
15
10
5
0
1 min
2 - 5 min
6 - 10 min
11 - 15 min
16 - 30 min
31 - 45 min
46 - 60 min
1 - 2 hr
2 - 3 hr
3 - 4 hr
4 - 5 hr
5 - 6 hr
6 - 12 hr
12 - 18 hr
18 - 24 hr
24 hr +

Figure 34.

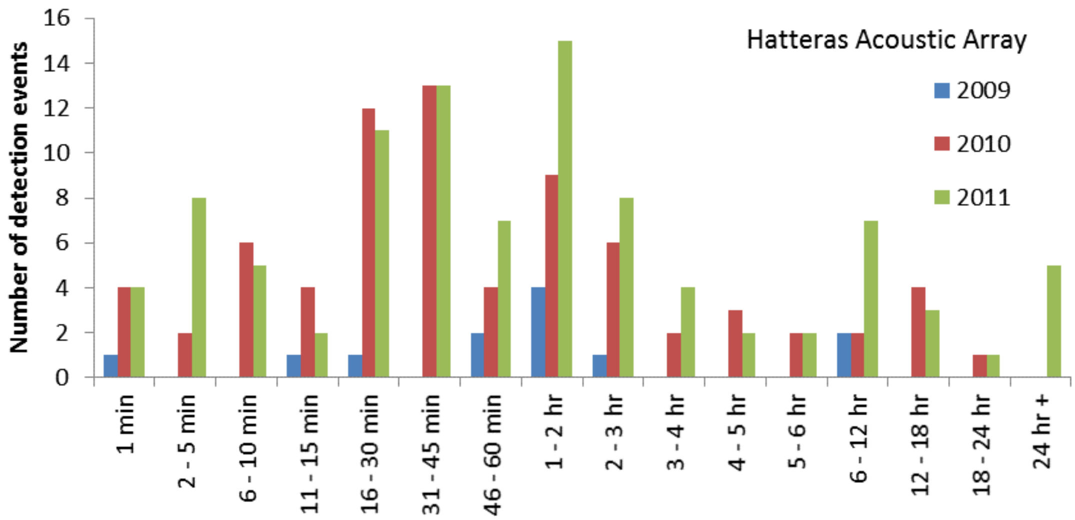

Hatteras Acoustic Array
2009
2010
2011
Number of detection events
16
14
12
10
8
6
4
2
0
1 min
2 - 5 min
6 - 10 min
11 - 15 min
16 - 30 min
31 - 45 min
46 - 60 min
1 - 2 hr
2 - 3 hr
3 - 4 hr
4 - 5 hr
5 - 6 hr
6 - 12 hr
12 - 18 hr
18 - 24 hr
24 hr +

Figure 35.

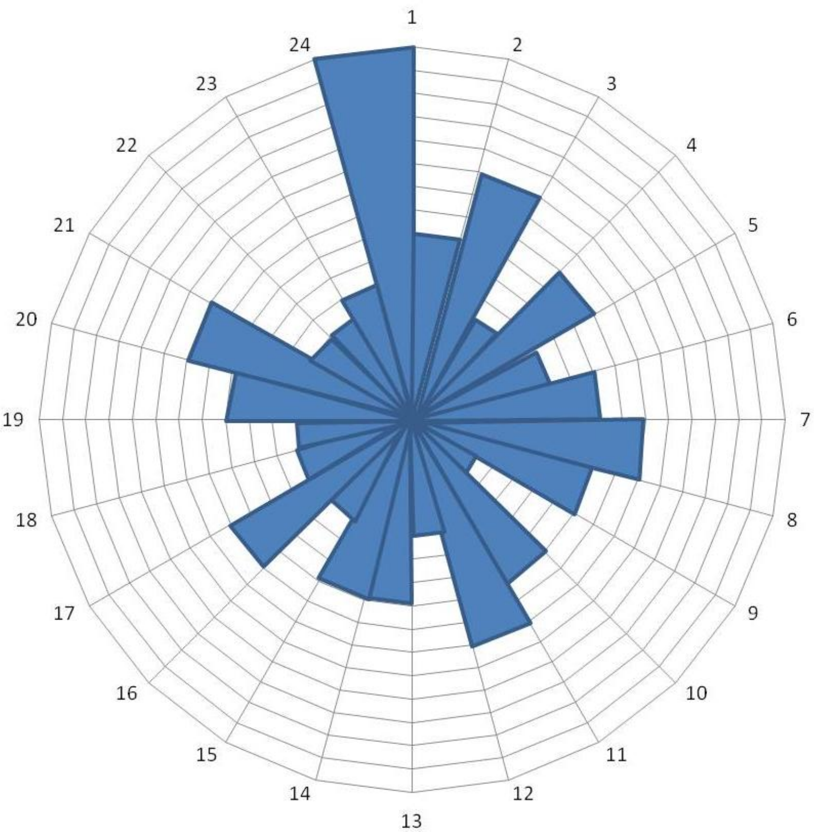
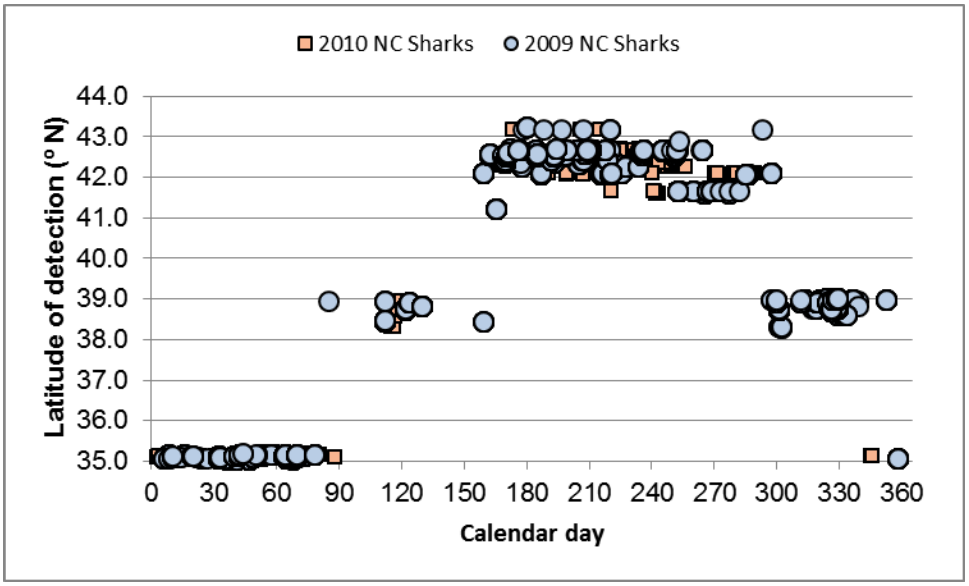
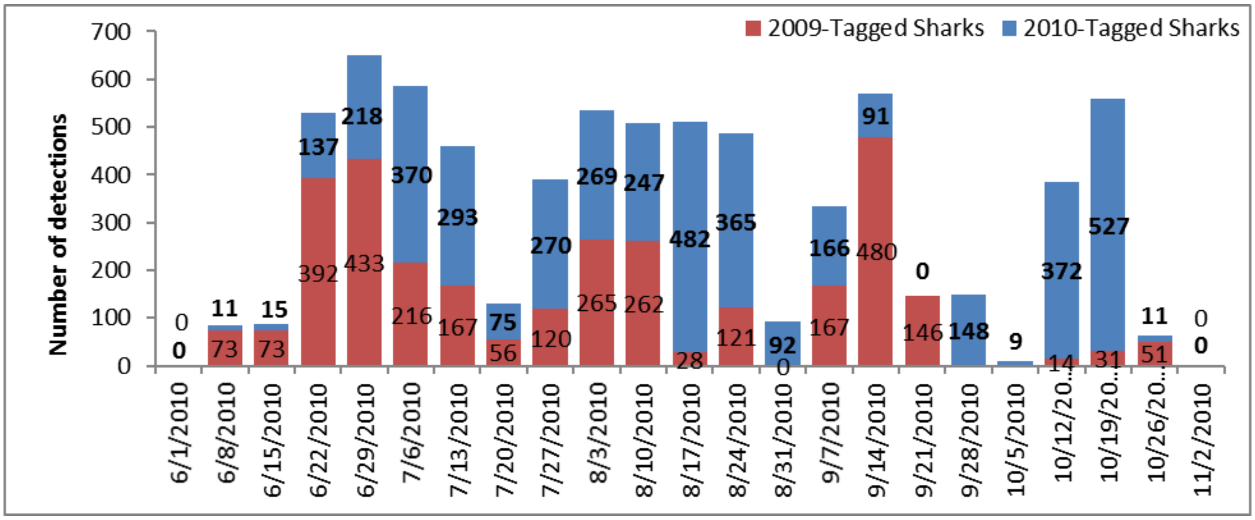


Figure 36.



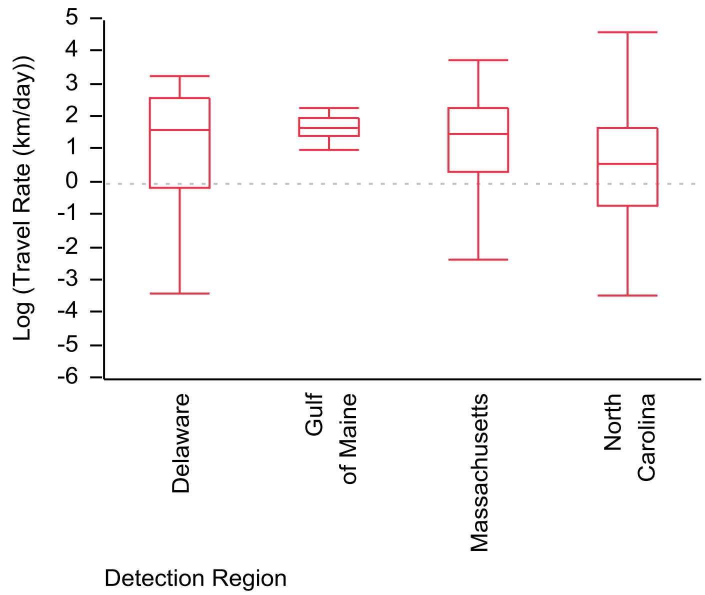
2010 NC Sharks
2009 NC Sharks
Latitude of detection (° N)
44.0
43.0
42.0
41.0
40.0
39.0
38.0
37.0
36.0
35.0
0 30 60 90 120 150 180 210 240 270 300 330 360
Calendar day

Figure 37.



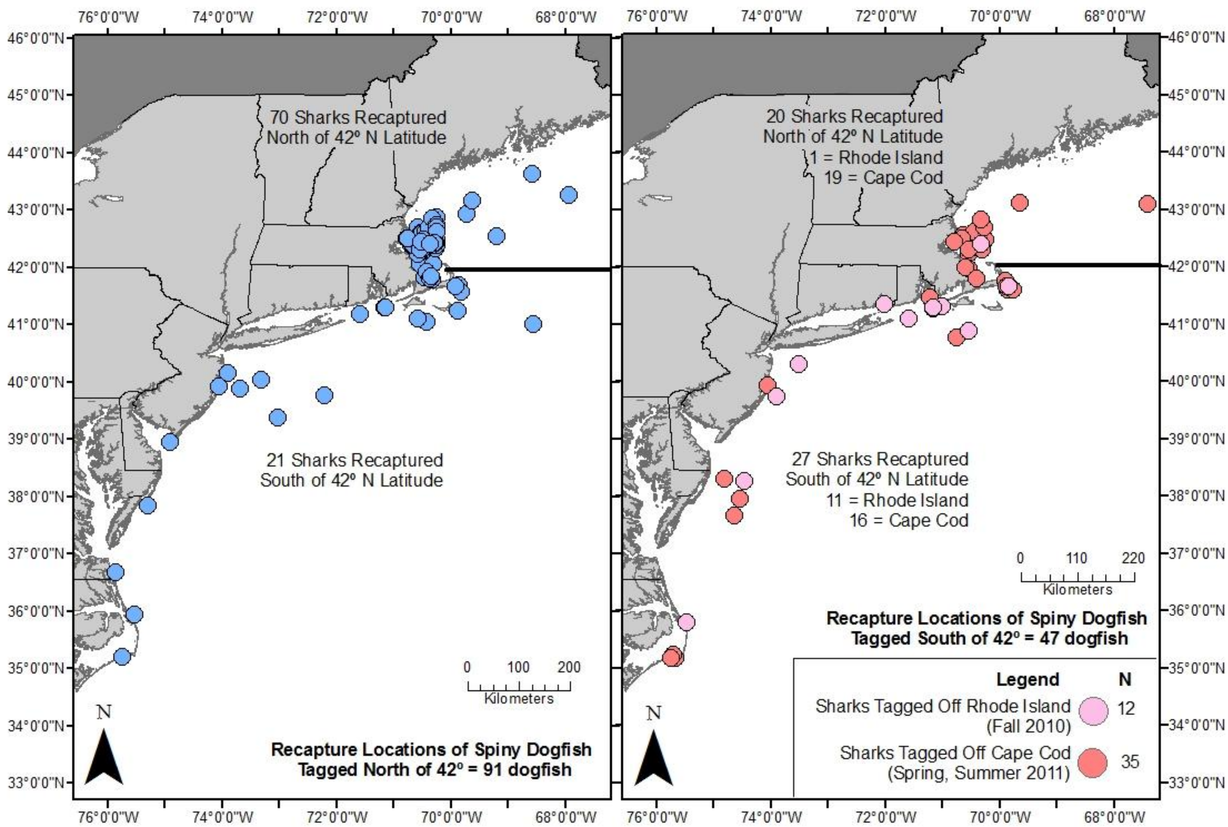
2009-Tagged Sharks
2010-Tagged Sharks
Number of detections
700
600
500
400
300
200
100
0
0
0
73
11
73
15
392
137
433
218
216
370
167
293
56
75
120
270
265
269
262
247
28
482
121
365
0
92
167
166
480
91
146
0
148
9
14
372
31
527
51
11
0
0
6/1/2010
6/8/2010
6/15/2010
6/22/2010
6/29/2010
7/6/2010
7/13/2010
7/20/2010
7/27/2010
8/3/2010
8/10/2010
8/17/2010
8/24/2010
8/31/2010
9/7/2010
9/14/2010
9/21/2010
9/28/2010
10/5/2010
10/12/20…
10/19/20…
10/26/20…
11/2/2010

Figure 38.



5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Log (Travel Rate (km/day))
Delaware
Gulf of Maine
Massachusetts
North Carolina
Detection Region

Figure 39.



Recapture Locations of Externally-Tagged Sharks that were Tagged in the ECU-CFRF Study

Figure 40.

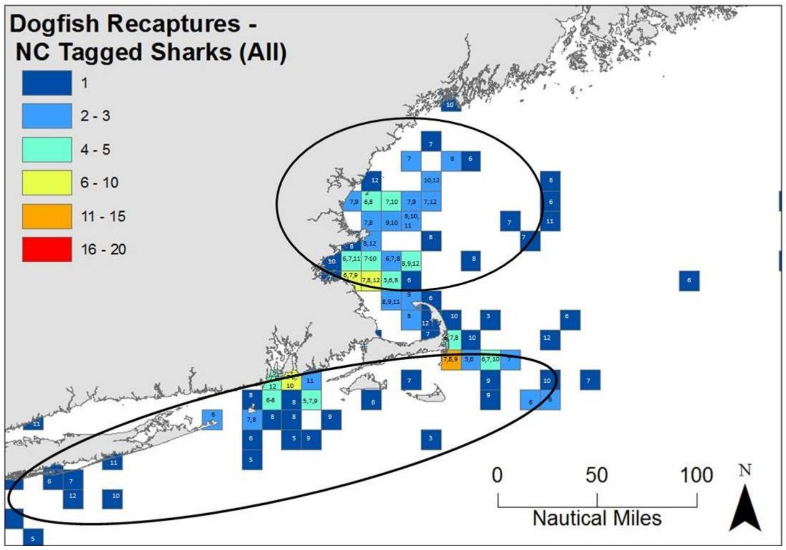
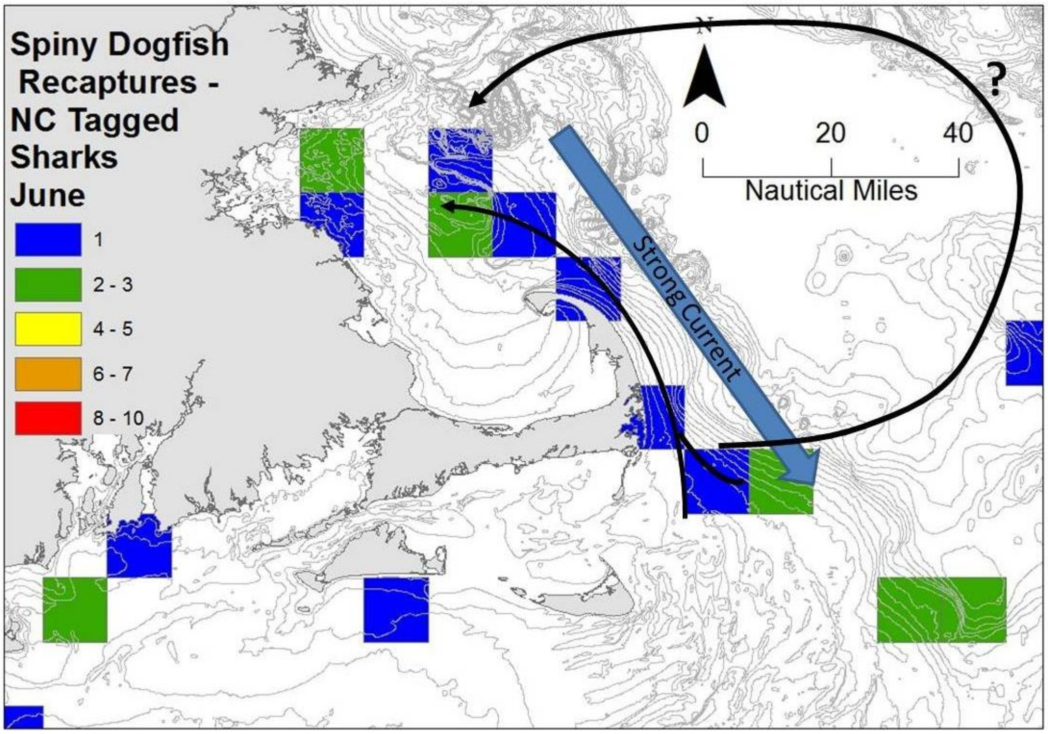

Dogfish Recaptures -
NC Tagged Sharks (All)
1
2 - 3
4 - 5
6 - 10
11 - 15
16 - 20
0
50
100
Nautical Miles
N

Figure 41.



Spiny Dogfish Recaptures - NC Tagged Sharks June
1
2 - 3
4 - 5
6 - 7
8 - 10
N
0
20
40
Nautical Miles
Strong Current
?

Figure 42.

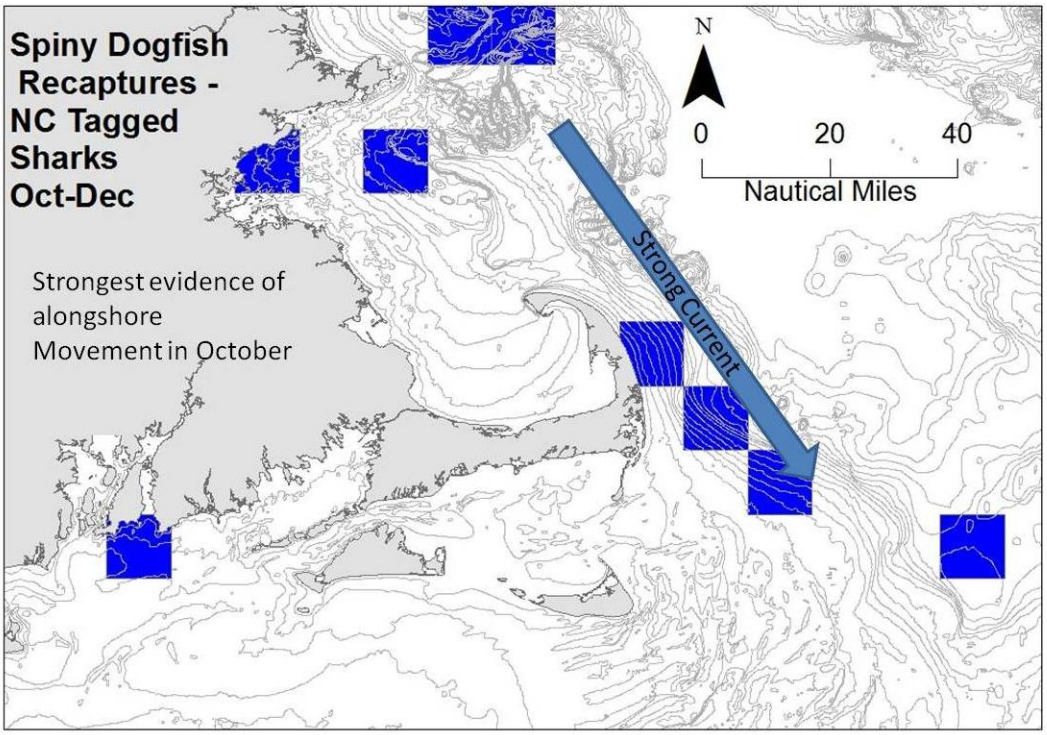
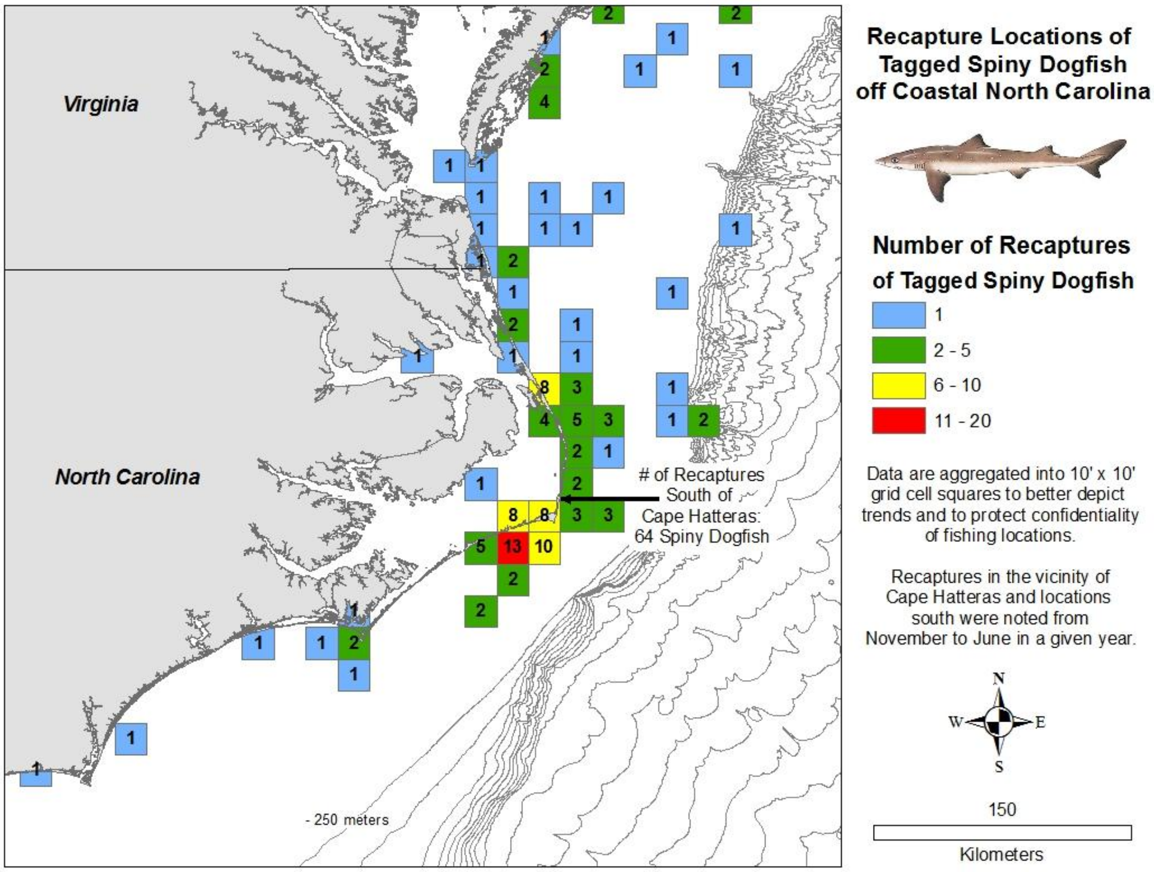
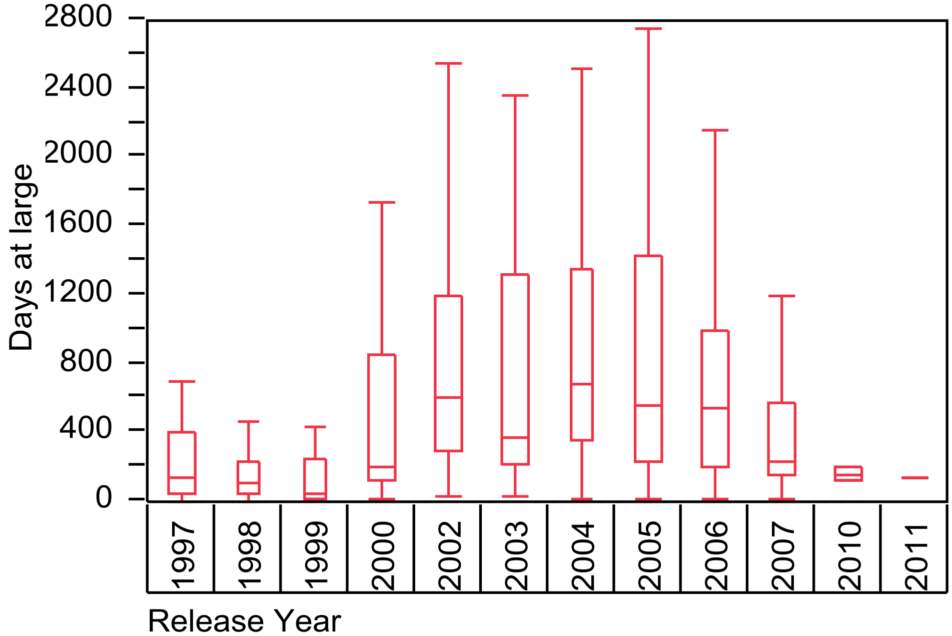

Spiny Dogfish
Recaptures -
NC Tagged
Sharks
Oct-Dec
N
0
20
40
Nautical Miles
Strong Current
Strongest evidence of
alongshore
Movement in October

Figure 43.



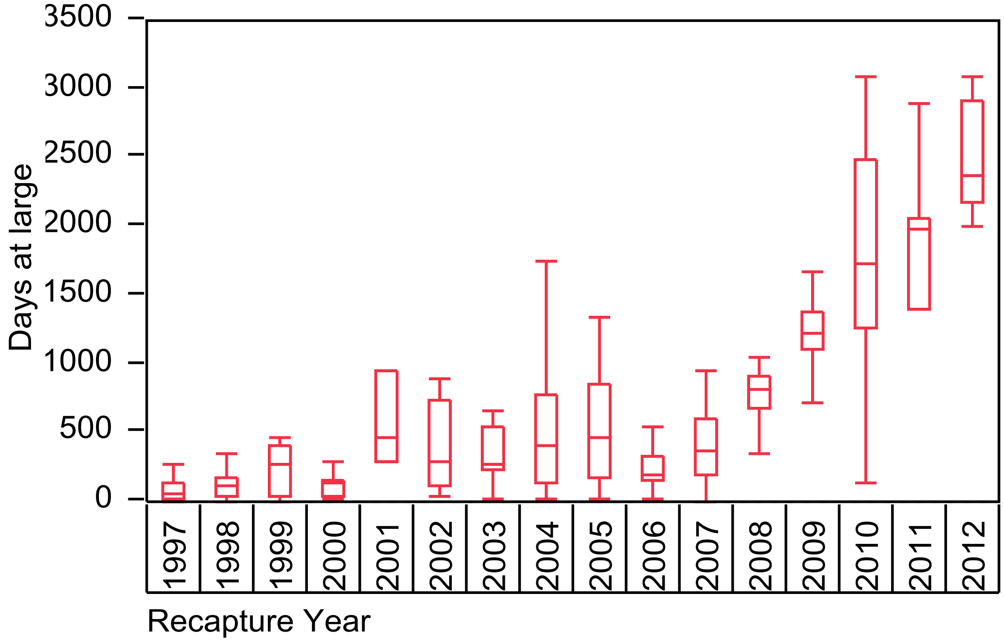
Recapture Locations of Tagged Spiny Dogfish off Coastal North Carolina
Virginia
North Carolina
# of Recaptures South of Cape Hatteras: 64 Spiny Dogfish
- 250 meters
Number of Recaptures of Tagged Spiny Dogfish
1
2 - 5
6 - 10
11 - 20
Data are aggregated into 10' x 10' grid cell squares to better depict trends and to protect confidentiality of fishing locations.
Recaptures in the vicinity of Cape Hatteras and locations south were noted from November to June in a given year.
N
W
E
S
150
Kilometers

Figure 44.



2800
2400
2000
1600
1200
800
400
0
Days at large
1997
1998
1999
2000
2002
2003
2004
2005
2006
2007
2010
2011
Release Year

Figure 45.



3500
3000
2500
2000
1500
1000
500
0
Days at large
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Recapture Year

Figure 46.

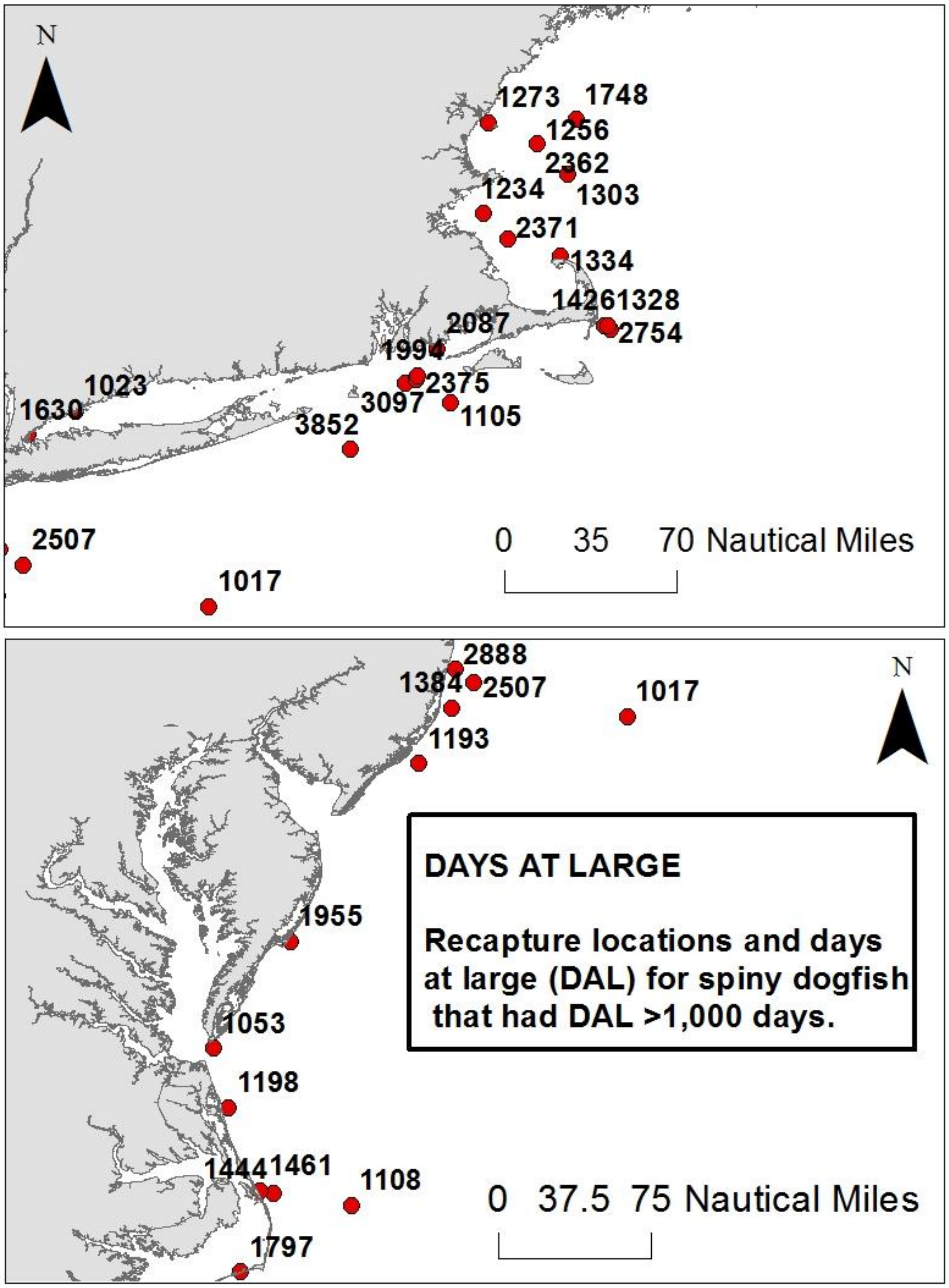
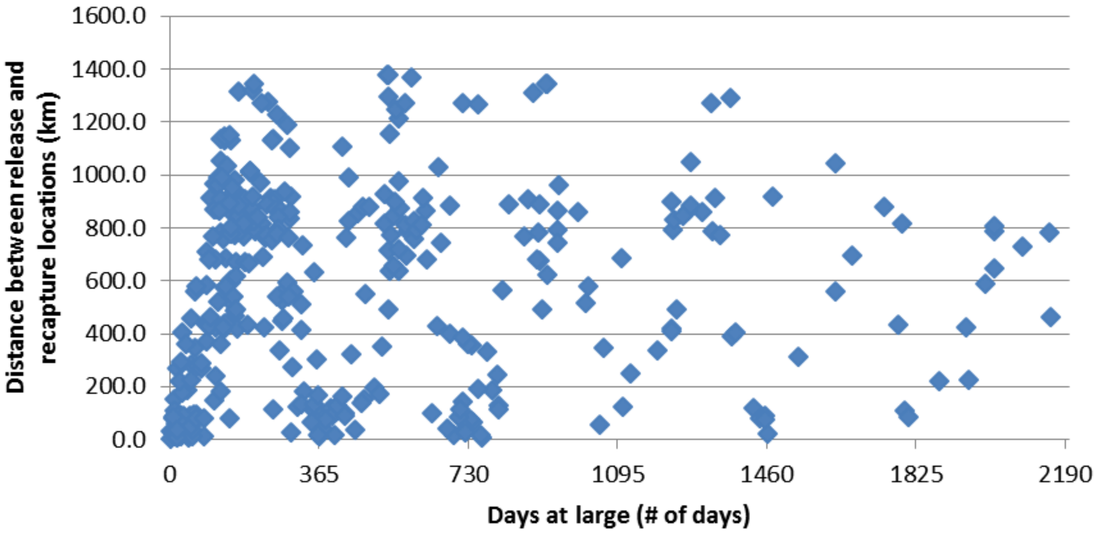

N
1273
1748
1256
2362
1234
1303
2371
1334
14261328
2087
2754
1994
1023
2375
1630
3097
1105
3852
2507
1017
0 35 70 Nautical Miles
2888
1384
2507
1017
N
1193
DAYS AT LARGE
Recapture locations and days at large (DAL) for spiny dogfish that had DAL >1,000 days.
1955
1053
1198
14441461
1108
0 37.5 75 Nautical Miles
1797

Figure 47.



1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Distance between release and recapture locations (km)
0
365
730
1095
1460
1825
2190
Days at large (# of days)

Figure 48.

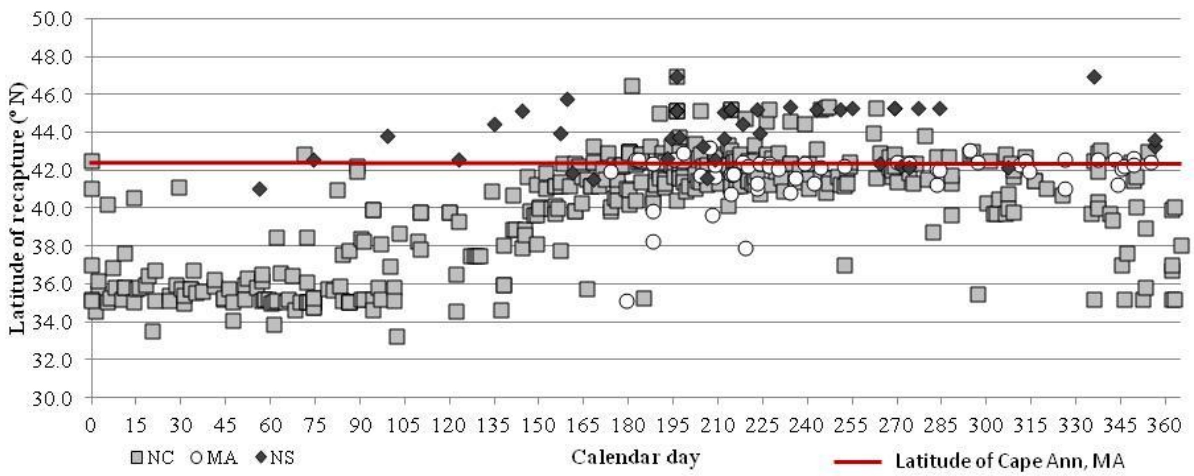
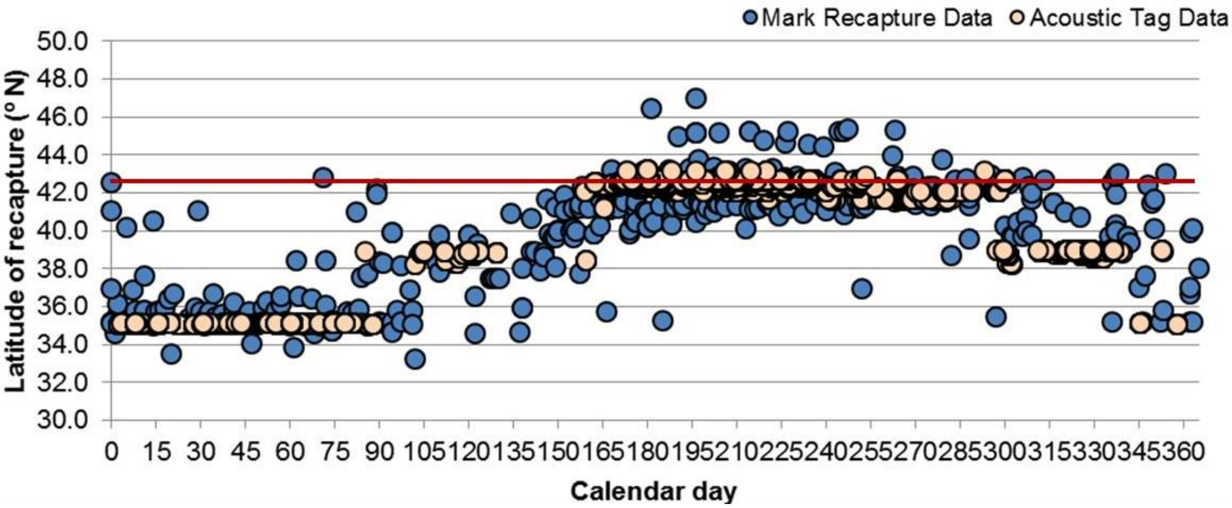
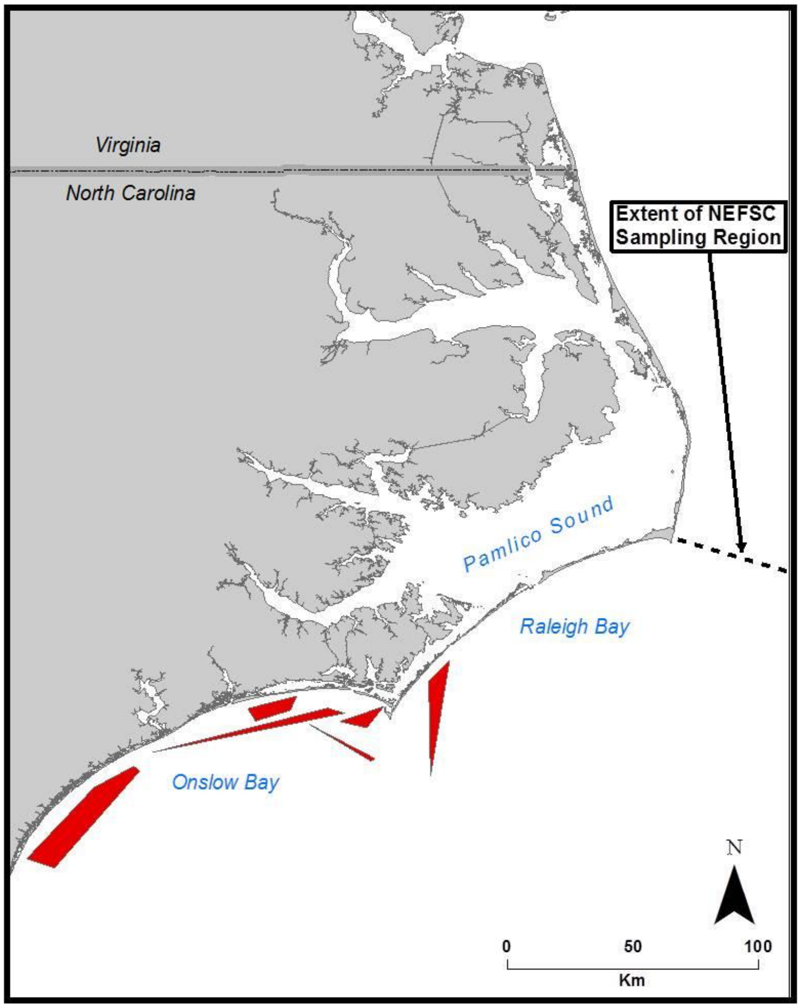

50.0
48.0
46.0
44.0
42.0
40.0
38.0
36.0
34.0
32.0
30.0
Latitude of recapture (° N)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
NC MA NS
Calendar day
Latitude of Cape Ann, MA

Figure 49.



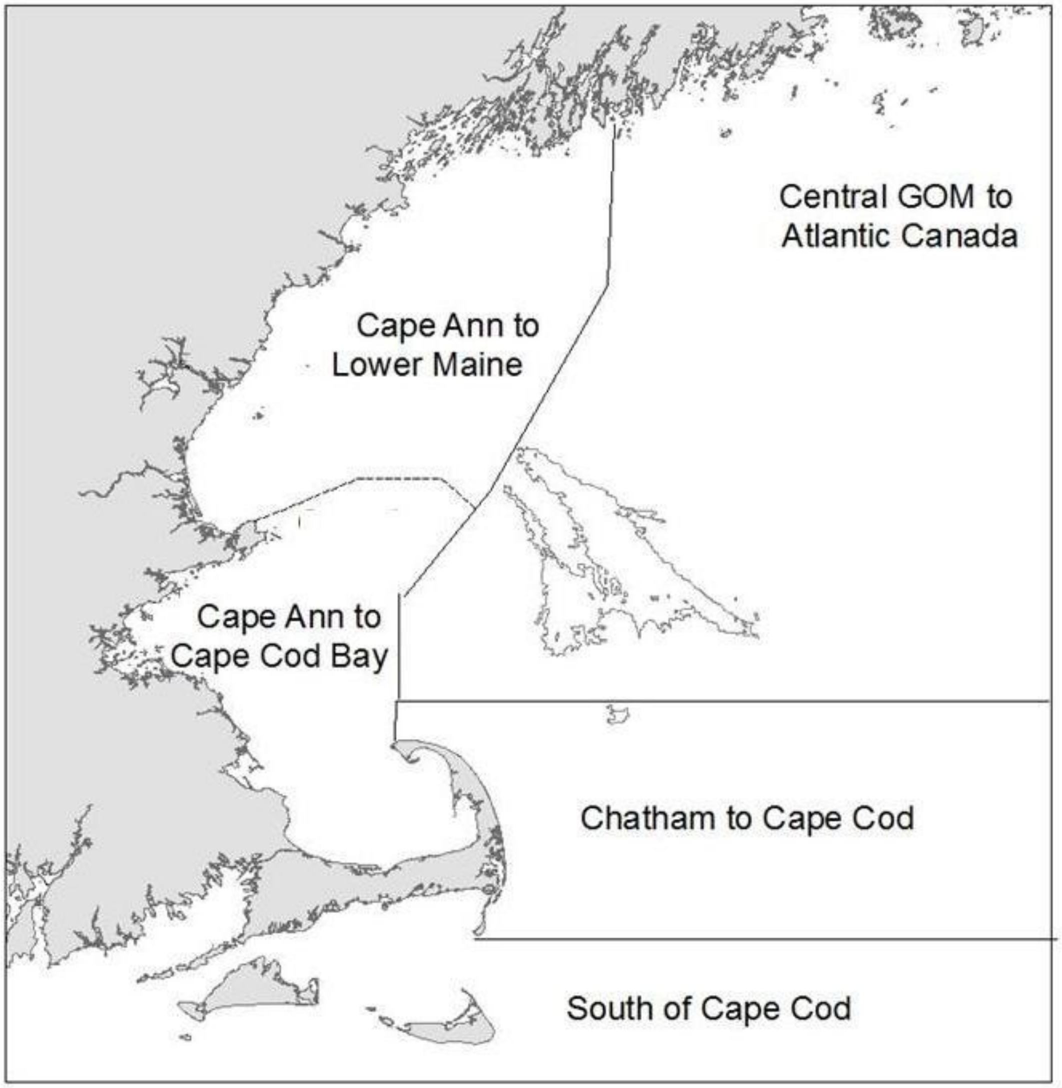
Mark Recapture Data
Acoustic Tag Data
50.0
48.0
46.0
44.0
42.0
40.0
38.0
36.0
34.0
32.0
30.0
Latitude of recapture (° N)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Calendar day

Figure 50.



Virginia
North Carolina
Extent of NEFSC
Sampling Region
Pamlico Sound
Raleigh Bay
Onslow Bay
N
0
50
100
Km

Figure 51.

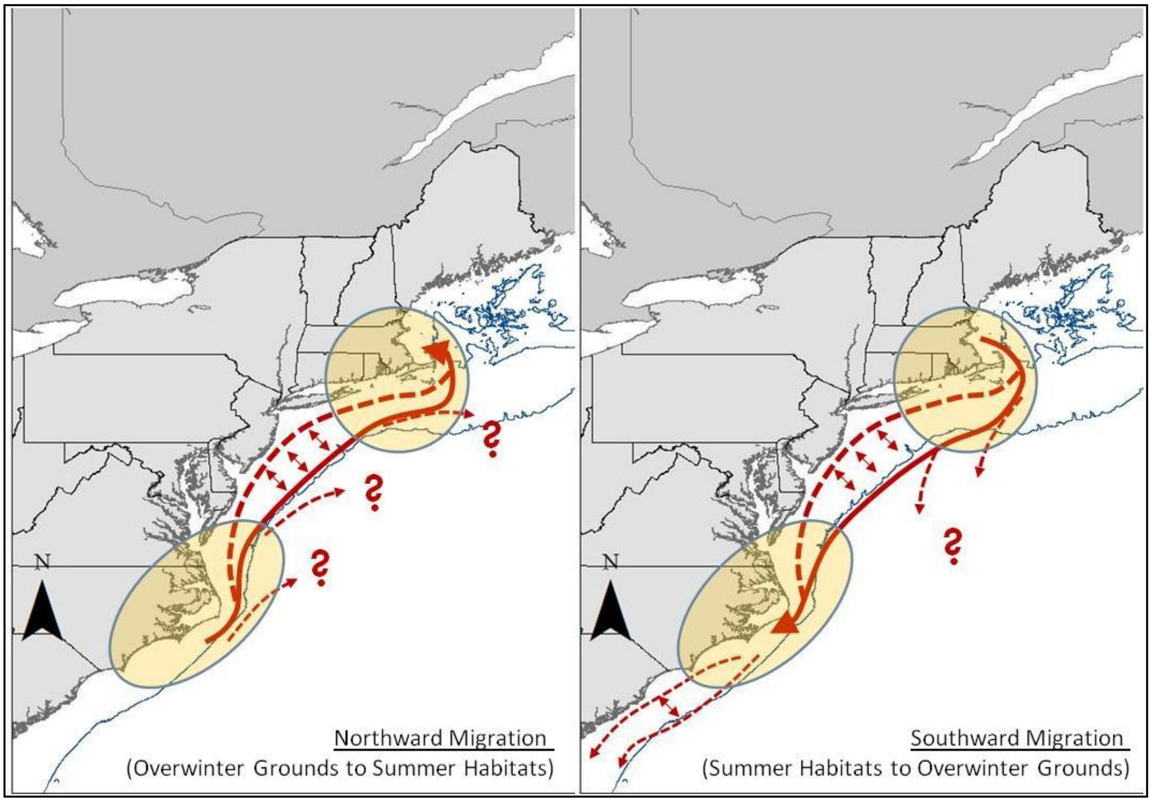


North Carolina Tagged Spiny Dogfish

Recapture Location	Mark-Recapture Study # Recaptures (% Recaptures)	Acoustic Tag Study* # Sharks (% Redetections)
Central GOM / Atlantic Canada	24 (6)	1 (1)
Cape Ann to Lower Maine	37 (9)	13 (14)
Cape Ann to Cape Cod Bay	57 (14)	24 (26)
Chatham to Cape Cod	32 (8)	23 (25)
South of Cape Cod	246 (60)	63 (68)
Specific Location Not Provided	14 (3)	n/a
Total Tagged	410	93

*some sharks were detected in more than one area

Figure 52.


N
Northward Migration
(Overwinter Grounds to Summer Habitats)
N
Southward Migration
(Summer Habitats to Overwinter Grounds)

CHAPTER 4: INFLUENCE OF ENVIRONMENTAL CONDITIONS ON OVERWINTERING SPINY DOGFISH IN THE HATTERAS BIGHT, NORTH CAROLINA.

Abstract

Understanding the environmental conditions that influence localized distribution and migration patterns of commercially exploited fish species allows better prediction of fish behavior. In turn, better prediction allows for the development of appropriately scaled management plans and continued agency responses to such issues as new demands on resources, unexpected changes in the status of populations, or long term response of species range and abundance to climate change. Acoustic detection data were compared to concurrently collected environmental data to evaluate the factors influencing presence of Spiny Dogfish (*Squalus acanthias*) overwintering in coastal waters just south of Cape Hatteras, North Carolinas, in northern Raleigh Bay, known as the Hatteras Bight, NC in 2009 and 2010. Spiny Dogfish ("dogfish") often were detected in the Hatteras Bight at times during directional shifts in water current within the water column or during periods where vertical profiling of horizontal currents was recorded. Increased presence and abundance was positively associated with cooler water temperatures. Acoustically tagged dogfish moved into the Hatteras Bight during favorable weather conditions (high pressure, lower wind speed/gusts, lower wave height) and their presence was recorded on the array when wind direction prevailed from the north or northwest (i.e., when the area is sheltered by land). Dogfish appear to move close to shore when offshore water temperatures increase due to the influence of the Gulf Stream, and when weather conditions are such that nearshore conditions are either sheltered from the weather (i.e., wind from the north or northwest) or during a time when mild or

calm winds out of the south are present (i.e., no high energy systems such as nor'easters with wind directions from the south to southeast). The identified relationships between dogfish presence and environmental factors in the Hatteras Bight, including the first comparison of Spiny Dogfish presence to current patterns, provides examples of the type of conditions under which dogfish may be detected in areas previously considered undesirable to the species. If appropriate microhabitats are available for dogfish, then the functional extent of the dogfish range could extend much further south along the U.S. coastline than the current southern boundary of the management unit.

Introduction

Understanding the environmental conditions that influence localized distribution and migration patterns of commercially exploited fish species allows better prediction of fish behavior. In turn, better prediction allows for the development of appropriately scaled management plans and continued agency responses to such issues as new demands on resources, unexpected changes in the status of populations, or long term response of species range and abundance to climate change. For example, knowledge of general habitat associations, distribution and migration patterns can allow managers to maximize efficiency in survey design by ensuring adequate sampling in areas that could functionally support populations (Smith 1990; Smith et al. 1991), and delineation of appropriate management boundaries.

Organisms select habitats that maximize survival, growth and reproductive potential (Lucas and Baras 2001), but suitability within these habitats may not be permanent due to seasonal changes or ontogenetic requirements (Metcalfe et al. 2002). Both biotic and abiotic factors may influence selection of appropriate habitat (Sims 2003). Localized distribution of fish and sharks can be affected by small and large scale variations in the physical, oceanographic, or biotic environment (Carvalho 1993; Langton et al. 1995). Migrations of many fish species along the mid-Atlantic typically reflect seasonal progressions in response to tolerable isotherms (Able and Grothues 2007). Specific environmental factors known to influence fish and shark migrations include light level, water temperature, hydrology, meteorology, water quality, and the interactions between multiple stimuli (individually reviewed in Lucas and Baras 2001; Able and Grothues 2007).

Studies have inferred habitat preferences of Spiny Dogfish (ASMFC 2002; Shepherd et al. 2002; Sosebee and Rago 2006; Sargarese et al. 2014), a small coastal shark seasonally common in coastal regions of the Northwest Atlantic, but also known as a deepwater shark species that is abundant off the continental shelf. Habitat association research suggests that Spiny Dogfish are strongly associated with the 8ºC (47ºF) isotherm, but are commonly found from 6 to 9ºC (Shepherd et al. 2002). Shepherd et al. (2002) also noted depth associations from Canadian trawl survey data; sharks were found between 88 and 184 meters of depth, but males had a stronger association with deeper water and females with shallower water. Sargarese et al. (2014) noted that the proportion of mature female Spiny Dogfish caught in federal trawl surveys was related to temperature in the Mid-Atlantic Bight, and suggested that oceanographic factors like water temperature could influence population-level trends in distribution and sexual segregation (i.e., sharks were associated with warmer water temperatures, females in particular).

Most research associating Spiny Dogfish distribution and catch-per-unit effort has been undertaken in the northern half of the known Northwest Atlantic dogfish range across extremely large spatial scales (e.g., Shepherd et al 2002 and Sargarese 2014). Tolerance ranges for environmental factors such as temperature are therefore generalized across a wide range of habitats so it is unsurprising that there is variability between associations for temperature and depth for Spiny Dogfish in the northern and southern extents of its range (e.g., Massachusetts versus North Carolina). The federal management unit for Spiny Dogfish (and the southern extent of most sampling and research) ends at Cape Hatteras; however, extremely large schools are known to venture into coastal waters of southeastern North Carolina. Rulifson and Moore (2009) noted that six dogfish aggregations with an estimated one million dogfish were found south of Cape Hatteras, North Carolina, in temperatures that ranged between 8ºC and 15.7ºC and in depths between 10 and 16 m. Hickman et al. (2000) noted no evidence of a strong linear relationship between dogfish catch, latitude, depth, or water temperature in North Carolina waters. Given the complex oceanography of the area (i.e., confluence of the Labrador Current and the Gulf Stream) it is likely that a cold water species such as the Spiny Dogfish will be sensitive to changes in environmental conditions in this area. In order to address the lack of information on Spiny Dogfish habitat associations in the southern part of the range, we compared acoustic detection data with environmental data collected *in situ* and recorded at local weather, tide and buoy stations. In particular we asked the following questions:

- Is dogfish presence/absence or movement related to the presence of particular current profiles (magnitude, direction, vertical profiling/layering of horizontal currents)?
- Is dogfish presence/absence or movement related to bottom water temperatures?
- Are dogfish detections or movements concurrent with predictable cycles in water movement (i.e., tidal cycles) or with extreme events (i.e., storms)?
- Under what conditions do dogfish move close to shore in the Hatteras Bight?

Answers to these questions will provide better understanding of how and where Spiny Dogfish aggregate during the overwintering period, and allow commercial fishers to either target or avoid these aggregations during winter fishing effort.

Methods

In 2009 and 2010 we tagged 93 Spiny Dogfish with Vemco V16 acoustic transmitters north and south of Cape Hatteras, North Carolina. Pilot study data indicated that receiver spacing of 800 m (each of 400-m radius) was sufficiently close to detect a fish and reduce the risk of sharks swimming between receivers without being detected. Acoustic receivers (model VR2W) were deployed in an array consisting of a single line of acoustic receivers deployed at approximately 800-m intervals in 2009 with an array length of roughly 9.65 km (~6 miles, 2009). In 2010, acoustic receivers were deployed up to 1,000 m apart in order to maximize array coverage; array length during that year was 16.09 km (~10 miles, 2010). Arrays were deployed in winter and spring of 2009 and 2010. When a tagged shark swam within range of the acoustic receiver, a date/time stamp and tag ID was recorded by the receiver. Mobile tracking surveys were also conducted for tagged Spiny Dogfish between Oregon Inlet, North Carolina and Cape Lookout, North Carolina with a towable VFIN omnidirectional hydrophone. Data from acoustic receivers and mobile surveys were downloaded, formatted, and analyzed to identify trends in migration and local movements (for details see Chapter 3), to compare against environmental data to evaluate microhabitat selection (this chapter), and to improve understanding of factors that influence distribution in the southern extent of the Spiny Dogfish range.

In 2009, three Teledyne Workhorse Acoustic Doppler Current Profilers (ADCPs) were deployed along the acoustic array at sites 2, 6, and 12 (approximately 1.15, 3.75, and 8.5 km) from shore, respectively). In 2009 we initially deployed ADCPs on metal stands (Figure 53); however, these stands were quickly silted in, were dangerous for divers to deploy due to sharp edges on the stand, and offered little protection to ADCPs from commercial fishing gear towed through the area. The ADCP deployed at site 2 in 2009 was dragged offsite and the stand was damaged, presumably from shrimp trawler activity in the area. The other ADCPs exhibited some evidence of interaction with fishing gear. In 2010, we deployed a single ADCP with an acoustic trawl shield (Figure 53B) at Site 7 (approximately 11 km from shore). The trawl shield was designed to protect the ADCPs from fishing gear, and this proved to be a much more durable platform for ADCP deployment.

Outside Data Sources. Tide data were downloaded from the Tides and Currents webpage maintained by the National Oceanic and Atmospheric Administration (NOAA) for Hatteras Inlet(35°12'31" N latitude, 75°42'15" W longitude), North Carolina (http://tidesandcurrents.noaa.gov/). Tidal height data are recorded in meters from Mean Low Low Water (MLLW). Tide data are recorded every 6 minutes.

Weather data were acquired from two sources. The National Data Buoy Center has archived data from multiple data buoys in the region, including data from buoys off the Cape Lookout shoals (Station CLKN7; 34°37'18" N latitude, 76°31'30" W longitude), at Monitor National Marine Sanctuary (Station 40125; 35°0'22" N latitude, 75°24'7" W longitude), and Hatteras Inlet. Available data from 2009 and 2010 were downloaded from the National Data Buoy Center website (http://www.ndbc.noaa.gov/). After examination of data from different buoys in the region, it was determined that the only buoy that recorded wind speed and direction data throughout the deployment duration in winter 2009 and 2010 was the data buoy deployed at

Cape Lookout Shoals. Wind speed (m/s) data were averaged over an eight-minute period for buoys and a two-minute period for land stations, and reported hourly in the available datasets. Gust speed was the peak 5 or 8 second gust wind speed (m/s) measured during the eight-minute or two-minute period, and reported hourly. Wind direction was recorded as the direction from which the wind was coming in degrees clockwise from true N during the same period used for Wind Speed. Sea level pressure (hPa) is the atmospheric pressure at sea level, and is measured at several of the data buoys. Higher sea level pressure is generally associated with improved weather conditions, while decreasing sea level pressure can be indicative of a weather system. The second source of weather information used as a general reference is the Mariner's Weather Log, a publication of the National Weather Service (http://www.vos.noaa.gov/mwl.shtml). The Mariner's Weather Log documents most significant weather systems that form in the North Atlantic. Contextual information regarding each system, such as date of formation, duration, system characteristics, and movement through the North Atlantic, are reported.

Sea condition data also were available from the data buoys mentioned above. The Monitor National Marine Sanctuary data buoy was the closest in the region to the receiver array that consistently recorded significant wave height (in meters, calculated as the average of the highest one-third of all of the wave heights during the 20-minute sampling period), dominant wave period (period in seconds with the maximum wave energy), average wave period (in seconds, of all waves during the 20-minute period) over the two-year wintertime deployment period, and surface water temperature (used as a proxy for surface water temperature at the offshore end of the acoustic array). These data were not recorded at other data buoys.

Other data downloaded and considered in analyses included minutes of darkness per day, and moon phase tables were downloaded from a website maintained by the U.S. Naval Observatory (http://aa.usno.navy.mil/data/index.php).

Satellite imagery (Advanced Very High Resolution Radiometer, AVHRR) for days of interest were downloaded from Rutgers University's Coastal Ocean Observing System (RUCOOL) laboratory (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0&product=sst). RUCOOL processes raw satellite data and posts approximately nine images per day on a searchable website. Where possible, satellite images closest to the periods of fish detection on the array were used. When the satellite images were obscured by clouds or otherwise contained missing data, the best images from the day were selected for use in contextual analyses of other data sources (e.g., bottom and surface temperature recorded by ADCPs and data buoys).

Data Analyses. ADCP data were downloaded into WinADCP, proprietary software developed by Teledyne RD Instruments that allows the user to visualize, select, and save portions of large ADCP datasets, and to export data into either text or Matlab formats. Data were exported into text format for import into Excel, and exported into Matlab format for additional data visualization and analysis.

Cumulative frequency distributions were generated to examine the naturally occurring range of independent variables (e.g., water temperature, wind speed, wave height, etc) in the environment across the periods when most Spiny Dogfish were detected on the acoustic array in the Hatteras Bight. Lepeltier (1969) noted that the use of cumulative frequency distribution curves in analyzing geological data provided a useful way to visually compare large and complex datasets, and to identify variability in distribution curves that might be further analyzed. For comparison purposes, cumulative frequency distributions were also generated that described the span of conditions under which Spiny Dogfish were detected on the acoustic array. The cumulative frequency curves for each were plotted on the same graphs (Figure 54) to determine whether shark detections were occurring across the full range of different environmental variables recorded in the environment (i.e., no relationship) or if shark detections were disproportionately occurring within specific environmental data bins. Additionally, general linear models were explored to identify variables, or suites of variables, that explained presence and absence of Spiny Dogfish on the acoustic array in SAS JMP version 10. General linear models provided a flexible means to fit responses that do not fit the usual requirements of least square distribution models (e.g., data are not normally distributed; handles data with numerous zeros such as binomial and count variables; data do not appear to have a linear relationship).

Results

Environmental Conditions in the Hatteras Bight. The magnitude and direction of nearshore ocean currents in Hatteras Bight during the appearance of tagged Spiny Dogfish indicated that strongest currents were in the top layers of the water column at these times. Dogfish were detected from February through March in 2009 and from January through March in 2010. For 2009 the overall current magnitude data for each ADCP deployment site were averaged across data collected from each 1-meter depth bin for the February to March period. Waters closest to the beach appeared to be well-mixed as indicated by consistent changes in current magnitude throughout the water column (top plot, Figure 55). However, at the mid-distance (Site 6) and farthest locations (Site 12) water currents were fastest (shown in red) in the upper parts of the water column.

Water current data collected in 2009 in the Hatteras Bight suggested that this environment was highly dynamic, and that prevailing currents may have been influenced by tides and vertical profiling/layering of horizontal currents in the water column. Overall current magnitude tended to be faster in the upper parts of the water column, especially at ADCP sites further offshore (Figure 55). The magnitude of the east-west directional component (Figure 56) was much greater than the magnitude of the north-south component (Figure 57), as evidenced by the darker red and blue colors in the former and the lighter colors in the latter. Furthermore, the east-west directional component appeared to be mostly consistent throughout the water column (especially at Site 2), implying that the various water parcels are moving collectively in an east-west direction. However, the north-south directional component appears more stratified, especially at locations mid-distance and farthest from the beach (Sites 6 and 12).

Water temperatures in Hatteras Bight during the study period changed seasonally and temporally, and exhibited some vertical profiling/layering of horizontal currents with depth in 2009 (Figure 58). Bottom water temperatures in the Hatteras Bight were relatively high in mid-February before decreasing the last week of February and the first week of March. Bottom temperature farthest from shore (Site 12) was usually warmer than the shallower sites, and bottom temperature at Site 2 was usually cooler than at deeper sites (Figure 58). During this four-week period, bottom temperatures at Site 6 reflected the influence of shifting currents, alternating between being more similar to Site 2 than Site 12 (and vice versa).

Analysis of ADCP current data collected between mid-February and mid-March of 2010 reflected periodicity in the environment and some changes in water temperature by as much as seven degrees within two weeks (Figure 59). Similar to the current magnitude data collected at

Site 12 in 2009, the overall current magnitude data recorded at Site 7 in 2010 were variable through the water column. There was a strong eastward directional component in the first week of the month-long period depicted in the plots. During this week, the bottom two-thirds of the water column appeared to be moving predominantly in a northward direction. There were several other instances where the east-west directional component appeared consistent throughout the water column. The north-south directional component tended to be more stratified than the east-west directional component, although there were times when the north-south directional component was also consistent throughout the water column. Bottom water temperatures were colder in mid-February (~8ºC), increased through the beginning of March to roughly 15 ºC, and then decreased for a brief time before rising back to roughly 15ºC.

Although not a universal rule, dogfish often showed up on the acoustic array when ADCP data indicated either strong vertical profiling/layering of horizontal currents in the water column indicative of multiple layers of water, or around times when a big change in water column directionality was noted. However, as the following examples show, it is important to consider more than just a single source of information to fully understand potential drivers of dogfish behavior.

Detection Year 1: February 10, 2009. On February 10, 2009, Tag #54099 was detected 357 times between 11:18 and 18:30. The shark was detected between Sites 5 and 10 during this time, and made a gradual offshore movement (Figure 60). During this time a notable pulse of faster moving water was visible at both Site 2 (Figure 61) and at Site 12 (Figure 62) in the upper half of the water column. Velocity components were further divided for East/West (“v component”) and North/South (“u component”) components in the middle and bottom plots shown in each figure. Water column parcels were moving predominantly in a westerly (onshore) direction throughout the day that this shark was detected. However there were dynamic changes in north-south directionality through the day in the upper parts of the water column, which could be a function of the tidal cycle (Figure 64).

Analysis of depth bins representative of "layers" (see Appendix 4) within the water column at Site 12 indicated that this shark was detected during a time of relatively low current velocities, and when the velocity of shallow, middle and deep water column layers (overall, and in the u- and v-directional components) were very similar during the periods of detection. The ADCP detected a bottom water temperature change during February 11-12, 2009 whereby water temperatures warmed by roughly 5º C. This shark was detected on the acoustic array twice before the temperature shift (on February 8th and February 11th), and was detected at Site 1 early in the evening on February 12th (Figure 63).

Detections occurred immediately after the wind direction changed from southward to northward (Figure 65). Wind direction is shown in Figure 65; however, caution is encouraged in the interpretation of this plot since wind directions of 0 degrees and 360 degrees are both equivalent to a northerly wind. Wind speeds recorded at Cape Lookout Shoals imply that this shark was detected on the Hatteras Bight acoustic array at times when the wind speeds were relatively light (Figure 66). Two noteworthy cyclonic weather systems affected the mid-Atlantic region on either side of this detection window; one event developed over the mid-Atlantic on February 4th and moved northeast across Newfoundland the next day, and a second formed off Florida on Feb 16th and subsequently moved northeast into the north Atlantic Ocean (attaining hurricane force winds within a 24 hour period of time) (Bancroft 2009). Compared to Feb-March

2010; however, the same time period in 2009 was relatively quiet with respect to the prevalence of major storm systems in the mid-Atlantic (e.g., see Bancroft 2010).

Detection Year 2: February 28 – March 6, 2010. Eleven Spiny Dogfish were detected on the acoustic array between February 28 and March 6, 2010. A number of these sharks were detected in shallow waters during the early part of this week, and later detected in deeper waters (Figure 67). In order to understand the potential drivers of offshore movement, ADCP water column profile data from the week in question and covering the time period when sharks were detected at sites 6-10 were analyzed (Figure 68; Figure 69). During a period when several sharks were detected at inshore sites, the overall current velocity at offshore sites (recorded at Site 7) was relatively low (Figure 68) and water direction appeared to deviate between largely northward and south-westward directions at regular intervals.

Two peaks in overall current magnitude were observed; the first occurred between March 3 – March 4 in the upper half of the water column when dogfish were detected on inshore receivers, and the second occurred at roughly the same time on March 5 when dogfish were detected on offshore receivers (Figure 67; Figure 68; Figure 69). Visual examination of data plots suggests that the second peak in water velocity corresponded with a pulse of water moving northward (red throughout nearly the entire water column) during mid-morning (Figure 69). The ADCP then recorded relatively low overall current magnitude, with particles in the water moving southwest, in the bottom half of the water column. Sharks were detected at offshore sites before and after the pulse of faster, northward moving water was detected by the ADCP (Figure 69) between 7:30 – 8:04 and between 14:19 and 06:54. The second set of detections also occurred when a narrow bottom layer of water was moving south and much of the remaining water was moving north (Figure 69).

Analysis of depth bins representative of "layers" (see Appendix 1) within the water column at Site 7 indicated that these sharks were detected during a time when surface and middle "layers" were similar, and fluctuated with the bottom layer with respect to which layers had higher overall current magnitude (Figure 70). The bottom layer tended to have more southward directional movement when sharks were detected offshore than the middle or surface layers (see third plot, showing v-directional component data). During the week of February 28 – March 6, the water temperature decreased from over 15ºC to roughly 10º C; sharks were detected at offshore sites on the array at times when bottom temperature were cooler (mostly between 10-13º C). Examination of satellite data suggested that there was a push of warm water in the Hatteras Bight early in the week, but toward the end of the week cold water had extended southward beyond Cape Hatteras and into the Hatteras Bight.

When compared to tide, buoy and weather data, some additional trends were apparent in this week. For example, detections occurring at onshore sites occurred throughout an entire tidal cycle early in the week, but sharks were detected primarily at offshore sites during low tide (Figure 71). When sharks were detected at onshore sites early during the week of interest, wind speed was highly variable (Figure 72). Moving counterclockwise from the top of the circle, the first detection period featured westerly winds, northerly winds and then back to a northwesterly wind direction. The second detection period occurred when winds changed from moving towards the southwest to moving north. Wind direction was blowing predominantly from the north and northwest during the time period when sharks were detected offshore (red boxes).

Figure 73 shows wind speed (sustained and gusts) during the week that these sharks were detected on the acoustic array. Sharks were detected at nearshore acoustic receivers when wind speed was relatively low, and at offshore acoustic receiver sites after a notable peak in wind speed was recorded. Caution is encouraged in the interpretation of this plot since wind directions of 0 and 360 are both equivalent to a northerly wind.

Mobile Tracking Surveys. ADCP data collected concurrently with mobile tracking surveys indicated that some sharks were detected in locations where surface and bottom "layers" either appeared to be moving in the same direction, in locations where some observable vertical profiling/layering of horizontal currents was present, and in locations where the entire water column appeared to shift direction in water movement (Figure 74). In other words, mobile tracking survey detections did not coincide routinely with a consistent predictable pattern of water column structure or movement in the water column; however, the sample size was small. For example, data collected at the detection location for 63949 showed water particle movement in east and southern directions throughout much of the water column. Data collected at the detection site of Tag# 63951 (Figure 74, far left column) indicated that the shark was detected in a location where the water column shifted from moving in a northward direction to moving in a southward direction. This could happen due to tidal or alongshore current processes. Two sharks (63944 and 63952, Figure 74, right two columns) were detected in locations where most of the water column moved in an easterly direction. However, the bottom parts of the water column had relatively little movement in the east or west direction. Refer to the map library for 2010-tagged sharks in Appendix 3 to see exact locations for these detections.

Modeling Detection Data and Localized Environmental Data: Cumulative Frequency Distribution Analysis. Cumulative frequency distribution analyses showed the distribution of different variables as they occurred in the environment. For comparison purposes, the range of each environmental variable across which detections occurred was also shown. As explained above, the line depicting the range of conditions across which detections occurred, in comparison to the line depicting the natural range of occurrence of environmental conditions, indicated whether dogfish detections occurred disproportionately within certain variable bins (relative to their availability in the environment).

Spiny Dogfish were detected by the acoustic array when bottom water temperatures nearest to the shoreline were cooler (e.g., 95% of dogfish detections occurred when bottom water temperatures at the shallow site were less than or equal to 12ºC) and offshore bottom water temperatures were warmer (Figure 75). Furthermore, the cumulative frequency distribution of surface water temperature data suggested that dogfish were detected more often when surface water temperatures (at Monitor National Marine Sanctuary) were cooler. Results analyzed by cumulative frequency analyses varied by location. Bottom water temperatures were only available for 2009 at shallow and mid-depth ADCP sites because ADCPs were not deployed at these locations in 2010. Bottom water temperatures at the deep sites (which were somewhat close together) reflected conditions at the offshore ADCP deployment sites in 2009 and 2010. Offshore surface water temperatures, recorded at the Monitor National Marine Sanctuary buoy, were recorded in both 2009 and 2010.

Cumulative frequency distribution curves suggest that dogfish were often detected on the acoustic array at times when wind speeds were lower and wave heights were smaller (Figure 76).

When dogfish data were plotted against these data these observations were supported; however recorded wave heights (Figure 77) and wind speed (Figure 78) tended to be lower in 2009 when fewer dogfish were detected on the array. Air pressure cumulative frequency distributions implied that dogfish detections occurred more often when air pressure was lower. This is counter-intuitive, implying that dogfish show up on the acoustic array in poor weather conditions. However, when considering plots of dogfish detections against recorded air pressure it was apparent that dogfish were recorded by the array during high pressure peaks. Variability from one year to the next may have influenced results from these analyses. The 2010 air pressure readings tended to be lower overall in comparison with the same time period in 2009 (Figure 79).

Coarse patterns depicting a relationship between current flow and dogfish detections were identified in the data. Cumulative frequency distribution curves generated from data collected by ADCPs at the deepest site in 2009 (Site 12) and in 2010 (Site 7) suggest that dogfish detections on the acoustic array occurred less often when the magnitude of water movement in the bottom later was less (i.e., dogfish may be recorded by the array when offshore currents are faster), and more often when surface water layer movement is moderate (i.e., between 100-200 mm/s) (Figure 80). Also the bottom layer directional u-component (east vs. west) velocities were relatively similar to the environmental range of occurrence, suggesting that dogfish may have not selected for specific directionalities. Finally, the distribution curve for the v-component (north vs. south) in both surface and bottom layers indicated that dogfish detections may be occurring more often during times of minor to moderate magnitude flows in the northward direction.

Modeling Detection Data and Localized Environmental Data: General Linear Modeling. General linear models were constructed to test variables independently and by different combinations of variables on the presence and absence of dogfish detections by the Hatteras acoustic array (Table 27; Table 28). Models were compared using Akaike's Information Criterion (AIC) score (Akaike 1973). In addition, due to potential correlations between variables, principle components analysis (PCAs) and factor analysis were used to generate new independent variables based on ADCP data and non-ADCP data. A PCA run on ADCP data collected by ADCPs deployed in 2009 and 2010 at the offshore end of the array evaluated the overall magnitude, east-west (u) velocity component, and north-south (v) velocity component of each of three "layers" identified in the water column (see Appendix 4). The PCA indicated that a subsequent factor analysis should contain 4 factors. Rotated factor loading scores indicated that Factor 1 comprised the u-component variables of all three layers, Factor 2 comprised the overall magnitude data collected in each layer, Factor 3 comprised the v-component data from the surface and mid-water column layers, and Factor 4 was dominated by the v-component data from the middle and bottom water column layers.

A PCA run on externally collected environmental data (wave height, pressure, air temperature, water temperature, moon fraction percent, minutes of darkness per day, tide height, wind speed, and wind gusts) resulted in eigenvalues indicating that three factors were appropriate in a subsequent Factor Analysis. Rotated factor loading scores from the Factor Analysis indicated that Factor 1 was dominated by wave height, wind speed, and wind gusts (all positive). The variables with the strongest factor loading scores for Factor 2 included air pressure (positive) and air temperature (negative). The variables with the strongest factor loading scores for Factor 3 included the moon fraction percent (positive) and tide height (positive). In this model, surface water temperature and minutes of darkness had moderate loading scores in Factor 3, and Factors 2 and 3, respectively.

Models testing the effects of single variables on the presence/absence of dogfish detections tended to have higher AIC scores than models with multiple variables (Table 27). Other models using different combinations of externally collected data and ADCP data had worse AIC scores. The models that were run solely on the rotated factor scores (#5 and #6, see Table 28) produced worse AIC scores than models based on the raw data; however, Factor 1 was noted to have a strong significant effect on presence/absence of dogfish detections. These models indicated that several environmental variables had a driving influence on the presence or absence of Spiny Dogfish detections, especially the timing, water temperature and weather conditions. Model parameters and diagnostics are shown for the three best models (based on AICc scores) in Table 29, Table 30, and Table 31. Of all modeling efforts completed, a binomial GLM model (logit link, firth adjustment method controlling for bias) explaining the presence and absence of dogfish detections against non-ADCP, environmental data ("externally collected data") had the best AIC score (Table 29). Examination of effects tests suggested that the significant variables in this model represented the timing of detections (year, week within a year) and water temperature.

Discussion

Habitat selection studies in northwestern Atlantic Spiny Dogfish to date have focused on the comparison of catch-per-unit-effort (CPUE) data collected on federal trawl surveys to environmental data (e.g., salinity, temperature and depth data collected concurrently with trawl catches) to examine associations across broad geographic ranges. For example, Shepherd et al.

(2002) and Sargarese et al. (2014) identified salinity, depth, and temperature associations for male and female Spiny Dogfish across the extent of surveys completed by the U.S. and Canadian governments in the U.S. EEZ (Maine to North Carolina) and in the EEZ of the Canadian maritime provinces, respectively. To our knowledge, this study represented the first research program in the northwestern Atlantic to identify factors that could influence habitat selection of individual Spiny Dogfish. Since there were no habitat studies available for direct comparison and discussion, there is value in considering habitat studies involving other coastal elasmobranchs to identify other potentially important environmental variables that may drive microhabitat selection in coastal elasmobranchs (including Spiny Dogfish).

Physical aspects of habitat are often important for species that utilize multiple types of coastal habitats, such as estuaries, inlets, reefs, and bathymetric features like shoals or canyons. We detected dogfish in proximity to complex bathymetric features (e.g., continental shelf break, Hatteras Inlet, near shorelines, and in proximity to shoal and reef habitats). Simpfendorfer et al (2010) studied fine scale movement patterns of Smalltooth Sawfish (*Pristis pectinata*) and identified physical habitat parameters (proximity to shoreline, substrate type) and tide as important factors influencing the distribution of tagged individuals. We did not analyze proximity to shoreline or substrate type in the models included in this chapter; however, Scott (1982) studied 22 species of groundfish and their associations with sediment size on the Scotian Shelf. Spiny Dogfish were reported as generalists compared to other species because they were associated with both coarse and fine grain substrates. We did analyze tidal height, and dogfish were often detected on the acoustic array at tidal heights slightly above mean low low water (MLLW). Further analysis of dogfish detection data with tide data using harmonic analysis might provide additional information on dogfish occurrence in relation to tidal cycles.

This research project, and recent other projects completed by the Rulifson lab, support the concept that Spiny Dogfish are found in a tremendous variety of environmental conditions (Bigelow and Schroeder 1953), and have broad tolerance ranges for oceanographic conditions (Shepherd et al. 2002; Sargarese et al. 2014). The Hatteras acoustic array was deployed in a somewhat homogeneous habitat with respect to substrate type – the immediate area around the array consists mostly of sandy bottom. However there are locations with hard bottom reef further offshore, in the vicinity of Diamond Shoals and in Hatteras Inlet. Furthermore, tagging data published in this dissertation indicate that dogfish also move off the continental shelf into deeper waters. We did not observe an affinity of Spiny Dogfish for a singular current profile type, and mobile tracking data did not indicate affinities for specific habitats. North of Cape Hatteras, some Spiny Dogfish were detected via mobile tracking surveys in sloughs within reef and shoal habitats, and on the northern edge of Diamond Shoals. The intended study design of mobile tracking surveys was to cover as much ground as possible and to identify site "fixes" of tagged Spiny Dogfish, and not necessarily to do intensive long-term tracking of individually tagged Spiny Dogfish. There is certainly a need for this type of research to further explore associations of Spiny Dogfish with physical habitat types in overwintering habitat off coastal North Carolina.

Relationships between water temperatures and detections by the Hatteras Bight acoustic array were observed in this study; sharks were often detected at offshore locations when bottom temperatures were less than 13ºC, and were detected at inshore receiver sites when offshore water temperatures were warm (due to the influence of the Gulf Stream). Adult Spiny Dogfish are known to have an affinity for water temperatures between 7 and 11º C (Stehlik 2007), but these sharks are tolerant of a wide range in water temperature. This likely enables them to successfully adapt to an environment like the Hatteras Bight, where they can experience extremely cold water temperatures (4ºC) and the much warmer Gulf Stream (25-30ºC) in relatively close proximity. While principally a marine species, Spiny Dogfish are known to occur in the sounds and estuaries of North Carolina from November through June (Bangley and Rulifson 2014), so variables such as dissolved oxygen and salinity may be just as important to Spiny Dogfish in inshore regions as these other species. Elasmobranchs adapted to live in estuaries may respond to different environmental drivers due to increased tolerance of brackish waters (e.g., Bull shark, (*Carcharhinus leucas)* Ortega et al. 2009 and Drymon et al. 2014; coastal sharks of Georgia, Belcher and Jennings 2010; Bonnethead (*Sphyrna tiburo)*, Atlantic Sharpnose (*Rhizoprionodon terraenovae)*, and Blacktip (*C. limbatus)* shark, Smith 2012). In addition to water saltiness, water temperature was also observed to be an important predictor variable for juvenile Lemon sharks (*Negaprion brevirostris*) off southeastern Florida (Reyier et al. 2014); Leopard sharks off southern California (Nosal et al. 2014); Lemon sharks off Bimini (Morrissey 1991); Gray Smoothhound (*Mustelus californicus*) in restored coastal estuarine habitats of coastal California (Espinoza 2010); Bull sharks in a coastal Alabama estuary (Drymon et al. 2014); and three elasmobranchs in Tomales Bay, California - the Bat Ray, *Myliobatis californica*, the Leopard shark, *Triakis semifasciata*, and the Brown Smoothhound shark, *Mustelus henlei* (Hopkins and Cuch 2003).

Sims et al. (2006) further explored the bioenergetics of microhabitat selection of *Scyliorhinus canicula* through a study that used short- and long-term acoustic and archival tag studies. Sharks were observed to actively avoid spending long periods in warm water temperatures, even when food resources were extremely abundant. Rather, these sharks would make brief excursions into warmer water to ingest food and then return to cooler water to rest and digest (a "hunt warm-rest cool" strategy). Although our research did not explore microhabitat selection at the bioenergetic level, Spiny Dogfish are known to have affinities for specific temperatures, and detections were observed on the acoustic array seemingly in response to temperature fluctuations that occur in the Hatteras Bight as a result of the confluence of the Gulf Stream and Labrador Current (and also the effluence of cold estuarine water through the inlets of the Outer Banks and from Chesapeake Bay).

Predator adaptation to prey behavior has been observed in other elasmobranchs (e.g., Broadnose Sevengill sharks, *Notorynchus cepedianus*, Barnett et al. 2010; White sharks, *Carcharodon carcharias*, Jewell et al. 2013), and we suspect that Spiny Dogfish in the Hatteras Bight may have taken advantage of the abundance of prey in proximity to Hatteras Inlet. Nosal et al. (2013) used active tracking methods to study movement patterns of Leopard sharks (*Triakis semifasciata*) near the head of a submarine canyon off southern California. The authors noted that sharks exhibited tendencies to distribute into different habitats based on time of day, possibly following the abundance of prey, and actively utilized habitats with specific substrate types.

Habitat selection also may be related to differences in sexual behaviors. Most of the Spiny Dogfish tagged and tracked with acoustic tags in this research project were female, and nearly all of the repeat detection data on the Hatteras Array (and beyond) were from females. However, sexual segregation of male and female Spiny Dogfish schools was well reported in the literature (e.g., Bigelow and Schroeder 1953; Nammack et al. 1985; Shepherd et al. 2002; Sargarese et al. 2014), and happens to some extent off the North Carolina coast (R.W. Laney, J. Osborne and R.A. Rulifson; East Carolina University and ASMFC, unpublished data).

Similarly, Dell'Apa et al. (2014) hypothesized that sexual segregation of Spiny Dogfish off Cape Cod may be a result of female avoidance of males. Sexually segregated behavior is also known in other elamobranchs (Kock et al 2013). Sims et al. (2001) explored behavior of male and female Lesser Spotted catsharks (*Scyliorhinus canicula*) in coastal habitats using active acoustic tracking (n = 4) and mark-recapture (n = 62) studies. Movements for males and females in this study varied by time of day. Males selected shallower habitats during crepuscular and nighttime periods and deeper waters during the day; male behavior was hypothesized to be driven by availability in food resources. Females tended to shelter in caves or under rocks in shallow areas not selected for by males, and the authors hypothesized that this behavior was likely a reproductive behavior (avoiding males to conserve energy).

ADCPs have been used to study microhabitat selection of animals, although these studies often focus on flow aspects important to riverine species (e.g., McDonald et al. 2010 analyzed water velocity with an ADCP for input into a model describing effects of flow and sediment transport in White Sturgeon spawning habitat) or on the distribution and biology of the backscatters (i.e., plankton and nekton). For example, Roe et al. (1996) identified changes in the water column profile detected during ship-based surveys at major current fronts and eddies, hypothesizing that the changes at fronts and eddies are visible in water column profiles due to aggregation and diel behavior of plankton and nekton in the water column. Davoren et al. (2007) used ADCPs to study the diel vertical migration of zooplankton as part of an overall study of Capelin (*Mallotus villosus*) behavior. Several studies have used ADCPs to aid in microhabitat selection studies of marine fishes. Vessel mounted ADCPs were used to examine and characterize (turbidity, small scale oceanography, current flow and profiled bottom topography) Black Jewfish (*Protonibea diacanthus*) aggregation sites off the Northern Territory, Australia

(Meekan et al. 2008). ADCP data were used to generate a 3-dimensional map of the study area and to characterize current flow patterns in key sites. Affinity to specific current flow patterns such as eddies were not observed because currents were found to be unidirectional and the water column well-mixed; however, the authors did note a relationship to local tidal cycles. Kopach (2004) hypothesized that gray whale habitat selection (in relation to the current flow patterns affecting planktonic prey) may be affected by fine scale current flow patterns, but results indicated that whales did not select for specific current velocities.

No studies were found linking fine scale oceanographic data recorded by ADCPs to Spiny Dogfish distribution and behavior. Given the dynamic nature of the Hatteras Bight (i.e., tidal flow, alongshore currents, confluence of two major currents), it was difficult to elucidate whether detections occurred under specific flow regimes. Our results indicate that Spiny Dogfish detections occurred more often when offshore currents were moderate in speed and flowing northward in models that only considered ADCP data. However, other models combining ADCP and externally collected environmental data suggested that magnitude and the east-west velocity component might be important as well. Therefore, further experimentation and the development of more sophisticated models are needed to better characterize specific flow patterns and determine if any are highly predictive of dogfish detections. Additional studies should also include the deployment of ADCPs and acoustic receivers across more complex environments in two-dimensional arrays, and the use of tags with pressure and temperature sensors to help refine observations. We only deployed a single line of acoustic receivers and a small number of ADCPs in a relatively homogeneous habitat. Spiny Dogfish may have been cued to move inshore due to environmental conditions in an unsampled or more complex habitat (e.g., adjacent shoals, the shelf break, hardbottom reefs). Improved understanding of prey resource distribution and environmental factors influencing prey presence and absence would likely aid in understanding distribution patterns of Spiny Dogfish, and is consistent with increased calls for ecosystem based fisheries management by major interjursidictional fishery management institutions (e.g., ASMFC, federal fishery management councils, NMFS, USFWS).

This research suggests that dogfish detections on the acoustic array may be linked to water temperature and weather patterns. Data has not conclusively suggested that dogfish are responding to certain vertical water column profiles on a microscale; however, these animals are capable of rapid movements, are often detected on the array for short periods of time (see Chapter 3), appear to be responsive to water temperature, and are hypothesized to follow prey moving through the area. While they may not be responding to a specific directionality of water movement, given the dynamic nature of the currents in the area, it is not unreasonable to infer that dogfish may be directly or indirectly responding to the movement of water masses around the area (e.g., tidal influxes, alongshore currents, location of the Gulf Stream, cold water pushes around Cape Hatteras, location of eddies, etc). The location of these water masses is likely influenced by weather. Given the stark differences in the Gulf Stream and Labrador Current, water temperature can be a signal of the presence and processes affecting the different oceanographic currents in the study area. For example, we related the onshore presence and offshore movement to water temperatures measured *in situ* and from satellite imagry between February 28, 2010 and March 7, 2010. These movements occurred at times 1) when a cold water refuge may have been available along shore and offshore water temperatures were warmer due to the location of the Gulf Stream, 2) a significant winter storm event occurred along the eastern United States between March 1-3, and 3) the ingress of the Labrador Current around Cape Hatteras and into the Hatteras Bight was noted following the weather event. Since these sharks are highly responsive to local conditions, future analyses would be aided considerably from an oceanographic evaluation of currents in response to weather events.

Conclusions

Due to a large combination of environmental variables that can act to influence distribution of marine animals, it was difficult to isolate a single factor that may be of greatest importance in predicting Spiny Dogfish distribution and habitat selection. However, by examining dogfish detections and relating them to environmental data collected in the same area we were able to provide answers to the questions initially posed for the research project:

- Is dogfish presence/absence or movement related to the presence of particular current profiles (magnitude, direction,vertical profiling/layering of horizontal currents)?

  Dogfish often were detected on the Hatteras Array at times when changes in water column direction were noted or during periods where strong current vertical profiling/layering of horizontal currents was visible in the water column. Dogfish detections occurred disproportionally more often when the offshore ADCP site experienced minor to moderate northward currents. Models suggested a potential relationship between shark presence and increasing magnitude of northward currents (v-component), but also suggested that the east-west directionality (u-component) could be important.

- Is dogfish presence/absence or movement related to bottom water temperatures?

Yes. There is a clear indication that dogfish detections were disproportionately greater during cooler water temperatures. Dogfish detections at offshore sites were often recorded at times when offshore bottom water temperatures were colder (i.e., less than 12ºC); when offshore water temperatures were warmer (warmer than 15º) dogfish detections usually occurred close to shore.

- Are dogfish detections or movements concurrent with predictable cycles in water movement (i.e., tidal cycles) or with extreme events (i.e., storms)?

Yes. Dogfish appear to move into the Hatteras Bight during favorable weather conditions (high pressure, lower wind speed/gusts, lower wave height) and are often detected when wind direction is from the north or northwest (i.e., when the area is sheltered by land). Model results imply a potential relationship between dogfish presence, increasing air pressure, and cooler air temperature.

- Under what conditions do dogfish move close to shore in the Hatteras Bight?

Dogfish appear to move close to shore when offshore water temperatures increase due to the influence of the Gulf Stream, and when weather conditions are such that nearshore conditions are either sheltered from the weather (i.e., wind from the north or northwest) or during a time when winds out of the south are weak or calm (i.e., no high energy systems such as nor'easters with wind directions from the south to southeast).

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Table 27.

Model Number	Independent Variables	Whole Model Test	AICc score
1	Wave height	$X^2 = 49.36$, df = 1, p < 0.001	1255
2	Air pressure	$X^2 = 3.86$, df =1, p = 0.0494	1331
3	Air temperature	$X^2 = 0$, df =1, p = 1.00	1342
4	Offshore surface water temperature	$X^2 = 7.54$, df =1, p = 0.006	1320
5	Moon fraction (percent)	$X^2 = 9.87$, df =1, p = 0.0017	1331
6	Minutes of darkness per day	$X^2 = 38.83$, df =1, p < 0.001	1302
7	Tide height (m)	$X^2 = 4.58$, df =1, p < 0.001	1337
8	Flood or Ebb tide	$X^2 = 0.31$, df =1, p = 0.58	1341
9	Bottom temperature at end of array (deep ADCP deployment site)	$X^2 = 19.56$, df =1, p < 0.001	1322
Additive Models			
10	Wave height, air pressure	$X^2 = 88.15$, df =2, p < 0.001	1213
11	Wave height, air pressure, air temperature	$X^2 = 110.24$, df =3, p < 0.001	1192
12	Wave height, air pressure, air and water temperature	$X^2 = 110.06$, df =4, p < 0.001	1187
13	Wave height, air pressure, air and water temperature, moon fraction	$X^2 = 130.12$, df =5, p < 0.001	1169
14	Wave height, air pressure, air and water temperature, moon fraction, minutes of darkness	$X^2 = 165.35$, df =6, p < 0.001	1135
15	Wave height, air pressure, air and water temperature, moon fraction, minutes of darkness, tide height	$X^2 = 168.14$, df =7, p < 0.001	1135
16	Wave height, air pressure, air and water temperature, moon fraction, minutes of darkness, tide height, flood or ebb tide, bottom temperature	$X^2 = 181.60$, df =9, p < 0.001	1126

Table 28.

Model Number	Independent Variables	Effects Tests (<0.05)	Effects Tests (<0.001)	AICc score	Whole Model Test
1	Year, air pressure, air pressure x year, offshore surface water temperature, tide height, Flood or Ebb Tide, week number, wind speed		Year, offshore surface water temperature, week number	1066	$X^2 = 282.97$, df = 15, p < 0.001
2	Wave height, air pressure, offshore surface water temperature, air temperature, moon fraction (percent), minutes of darkness per day, Flood or Ebb Tide, tide height, wind speed, wind gusts, ADCP deep site bottom layer conditions	Air pressure, air temperature, u- and v-component in middle water column layer, u-component in bottom water column layer	Wave height, moon fraction (percent), minutes of darkness	1119	$X^2 = 208.27$, df = 19, p < 0.001
3	ADCP magnitude, u-component, and v-component data for surface, mid, and bottom water column layers at offshore end of array in 2009 and 2010 (i.e., 9 variables)	Middle water column v-component, bottom layer magnitude	Surface magnitude	1295	$X^2 = 62.80$, df = 9, p < 0.001
4	Factor Scores: externally collected environmental variables (n = 3 Factors)	Factor 2 (Env), Factor 3 (Env)	Factor 1 (Env)	1257	$X^2 = 36.93$, df = 3, p < 0.001
5	Factor Scores: ADCP data at offshore site (n = 4 factors)	Factor 3 (ADCP)		1333	$X^2 = 62.80$, df = 9, p < 0.001
6	Combined Factor Scores from Model #4and Model #5	Factor 3 (ADCP), Factor 2 (Env)	Factor 1 (Env)	1254	$X^2 = 48.35$, df = 7, p < 0.001

Table 29.

Data Modeling Type	Source	Parameter Estimates: Estimate	Parameter Estimates: Chi Square	Parameter Estimates: Prob > Chi Square	Effects Test*: DF	Effects Test*: ChiSquare	Effects Test*: Prob > ChiSq
--------	Intercept	40.739	28.372	0.127			
Ordinal	Year	-2.365	0.306	<0.0001	1	99.512	<0.001
Nominal	Air Pressure	-0.0338	0.027	0.196	1	1.67	0.196
Cross / Interaction Effect	Air Pressure x Year	-0.0484	0.031	0.167	1	1.912	0.167
Nominal	Surface Water Temperature	-0.055	0.0176	0.002	1	9.513	0.002
Nominal	Tide Height (m)	-1.228	1.206	0.339	1	0.914	0.339
Categorical	Flood or Ebb Tide (F or E)	0.056	0.084	0.526	1	0.402	0.526
Nominal	Windspeed (Cape Lookout)	0.062	2.795	0.0946	1	2.795	0.095
Ordinal	Week Number				8	180.278	<0.0001
Ordinal	*Week Number [7-6]*	*-1.109*	*4.124*	*0.0423*	**Whole Model Test**		
Ordinal	*Week Number [8-7]*	*-1.512*	*18.862*	*<0.0001*	**Model**	**-Log Likelihood**	**Chi Sq**
Ordinal	*Week Number [9-8]*	*-0.214*	*0.665*	*0.415*	Difference	141.48	282.973
Ordinal	*Week Number [10-9]*	*-0.254*	*0.996*	*0.318*	Full	517.158	
Ordinal	*Week Number [11-10]*	*1.803*	*36.186*	*<0.0001*	Reduced	658.644	
Ordinal	*Week Number [12-11]*	*-0.104*	*0.004*	*0.95*		**DF**	**Prob > ChiSq**
Ordinal	*Week Number [13-12]*	*2.913*	*17.49*	*<0.0001*		15	<0.001
Ordinal	*Week Number [14-13]*	*-1.002*	*0.198*	*0.656*	**AICc: 1066.51**		

Response variable: Presence / absence

Predictor variables: Year, Air Pressure, Year x Air Pressure, Surface Water Temperature, Tide Height (m), Flood or Ebb tide category, Week Number, Wind Speed (Cape Lookout).

General Linear Model, binomial distribution, logit link, Firth Adjusted Maximum Likelihood

Table 30.

Data Modeling Type	Source	Parameter Estimates^ / Effects Test Results*			
		Estimate^	Std Error^	Chi Square^*	Prob > Chi Square^*
--------	Intercept	-52.305	14.363	13.709	0.0002*
Nominal	Wave Height (m)	1.219	0.180	55.178	<.0001*
Nominal	Air Pressure	0.040	0.015	7.566	0.0059*
Nominal	Air Temperature	0.078	0.025	10.036	0.0015*
Nominal	Surface Water Temperature	0.017	0.022	0.640	0.4235
Nominal	Moon Fraction (%)	-1.267	0.293	19.252	<.0001*
Nominal	Minutes of Darkness	0.016	0.004	24.751	<.0001*
Nominal	Tide Height (m)	1.391	1.233	1.296	0.2549
Categorical	Flood or Ebb Tide	0.102	0.086	1.385	0.2392
Nominal	Wind Speed	0.048	0.044	1.160	0.2815
Nominal	Wind Gust	0.039	0.041	0.924	0.3363
Nominal	Surface Magnitude	0.002	0.002	1.459	0.227
Nominal	Surface u-comp	-0.002	0.002	1.441	0.23
Nominal	Surface v-comp	0.000	0.002	0.068	0.794
Nominal	Mid Layer Magnitude	0.002	0.002	0.811	0.3678
Nominal	Mid Layer u-comp	0.004	0.002	5.372	0.0205*
Nominal	Mid Layer v-comp	-0.004	0.002	7.007	0.0081*
Nominal	Bottom magnitude	-0.003	0.001	3.685	0.0549
Nominal	Bottom u-comp	-0.001	0.001	2.023	0.1549
Nominal	Bottom v-comp	0.003	0.001	6.106	0.0135*
Whole Model Test					
Model	**-Log Likelihood**	**Chi Sq**	**DF**	**Prob > Chi Square**	**AICc**
Difference	104.137	208.274	19	<0.0001	1119
Full	539.28				
Reduced	643.417				

Response variable: Presence / absence
Predictor variables: Air Pressure, Air Temperature, Surface Water Temperature, Moon Fraction (%), Minutes of Darkness, Tide Height, Flood or Ebb Tide, Wind Speed and Gust, ADCP data recorded at the deep site in 2009 and 2010 (averaged across surface, middle and bottom “layers” in the water column).
General Linear Model, binomial distribution, logit link, Firth Adjusted Maximum Likelihood

Table 31.

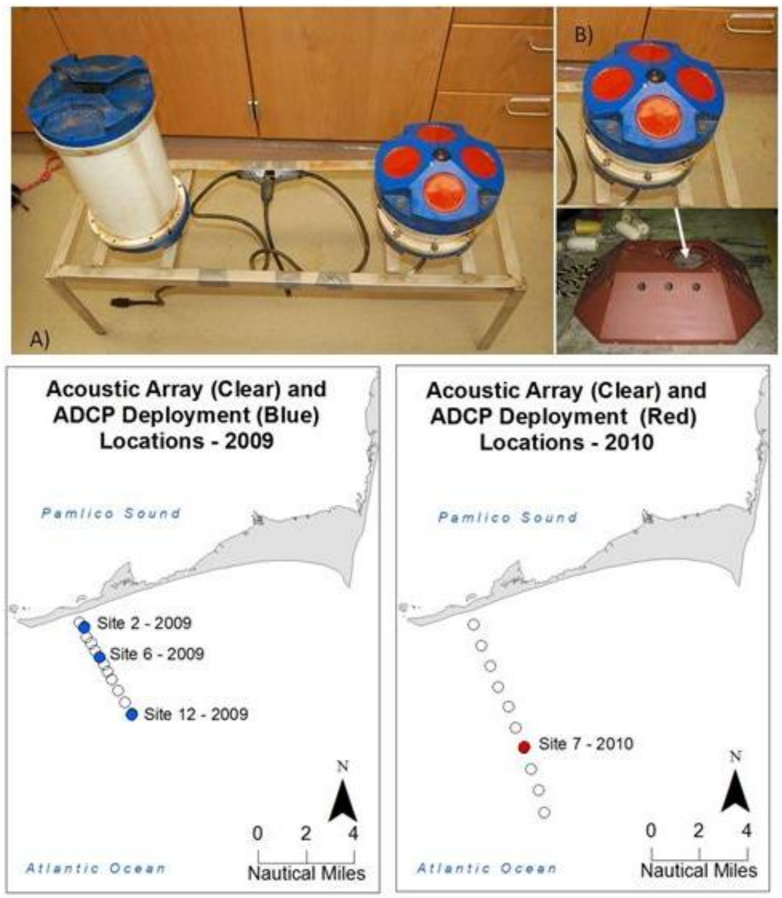
Data Modeling Type	Source	Parameter Estimates^ / Effects Test Results*			
		Estimate^	**Std Error^**	**Chi Square^***	**Prob > Chi Square^***
--------	Intercept	-40.109	13.947	8.293	0.004
Nominal	Wave Height (m)	1.18	0.157	70.604	<0.0001
Nominal	Air Pressure	0.031	0.014	4.789	0.0286
Nominal	Air Temperature	0.085	0.023	13.856	0.0002
Nominal	Surface Water Temperature	0.025	0.02	1.594	0.2067
Nominal	Moon Fraction (%)	-1.203	0.276	19.549	<0.0001
Nominal	Minutes of Darkness	0.015	0.003	27.298	<0.0001
Nominal	Tide Height (m)	1.967	1.222	2.671	0.1022
Categorical	Flood or Ebb Tide	0.105	0.084	1.556	0.2122
Nominal	Bottom Temperature (Deep Site ADCP)	-0.117	0.035	11.794	0.0006

Whole Model Test

Model	-Log Likelihood	Chi Sq	DF	Prob > Chi Square	AICc
Difference	90.802	181.604	9	<0.001	1126
Full	552.813				
Reduced	643.615				

Response variable: Presence / absence
Predictor variables: Wave Height (m), Air Pressure (kPa), Surface Air Temperature, Surface Water Temperature, Moon Fraction (%), Minutes of Darkness, Tide Height (m), Flood or Ebb Tide, Bottom Water Temperature (measured by ADCP at deep deployment site in 2009 and 2010).
General Linear Model, binomial distribution, logit link, Firth Adjusted Maximum Likelihood

Figure 53.



B)
A)
Acoustic Array (Clear) and
ADCP Deployment (Blue)
Locations - 2009
Pamlico Sound
Site 2 - 2009
Site 6 - 2009
Site 12 - 2009
N
0 2 4
Nautical Miles
Atlantic Ocean
Acoustic Array (Clear) and
ADCP Deployment (Red)
Locations - 2010
Pamlico Sound
Site 7 - 2010
N
0 2 4
Nautical Miles
Atlantic Ocean

Figure 54.

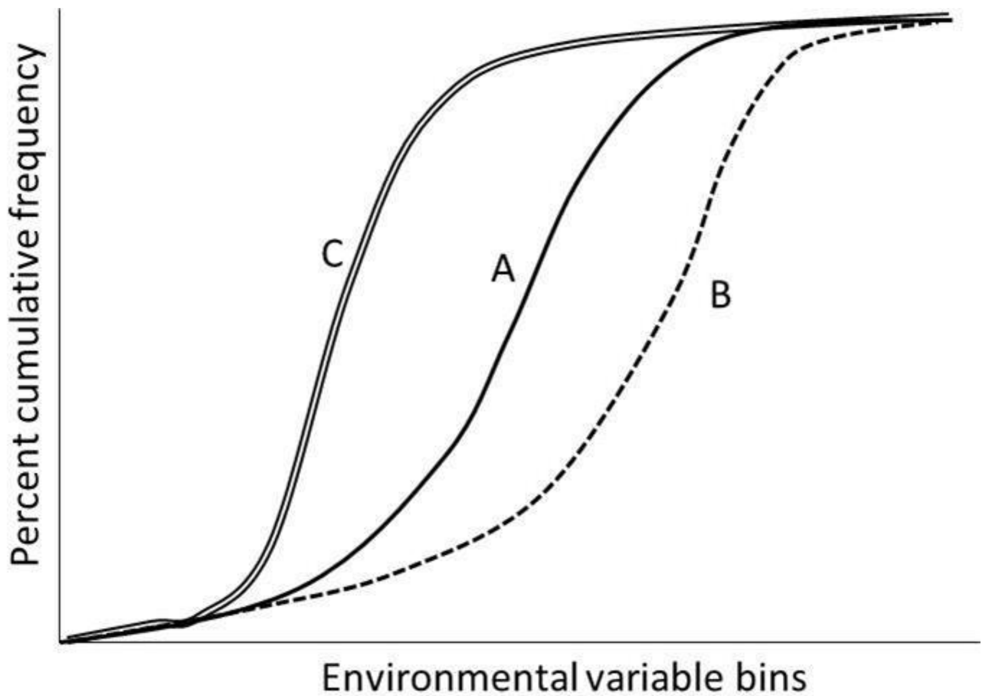
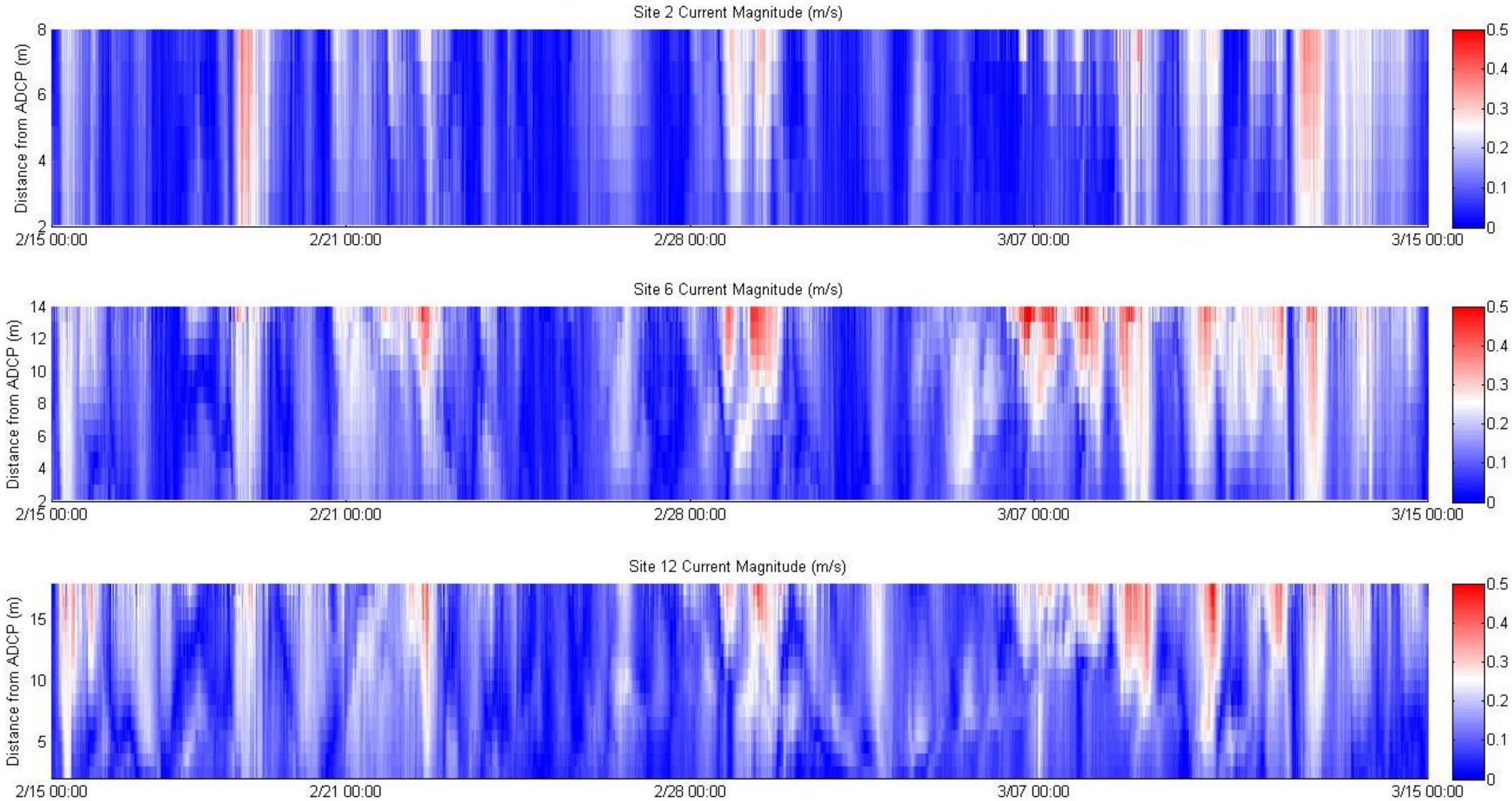
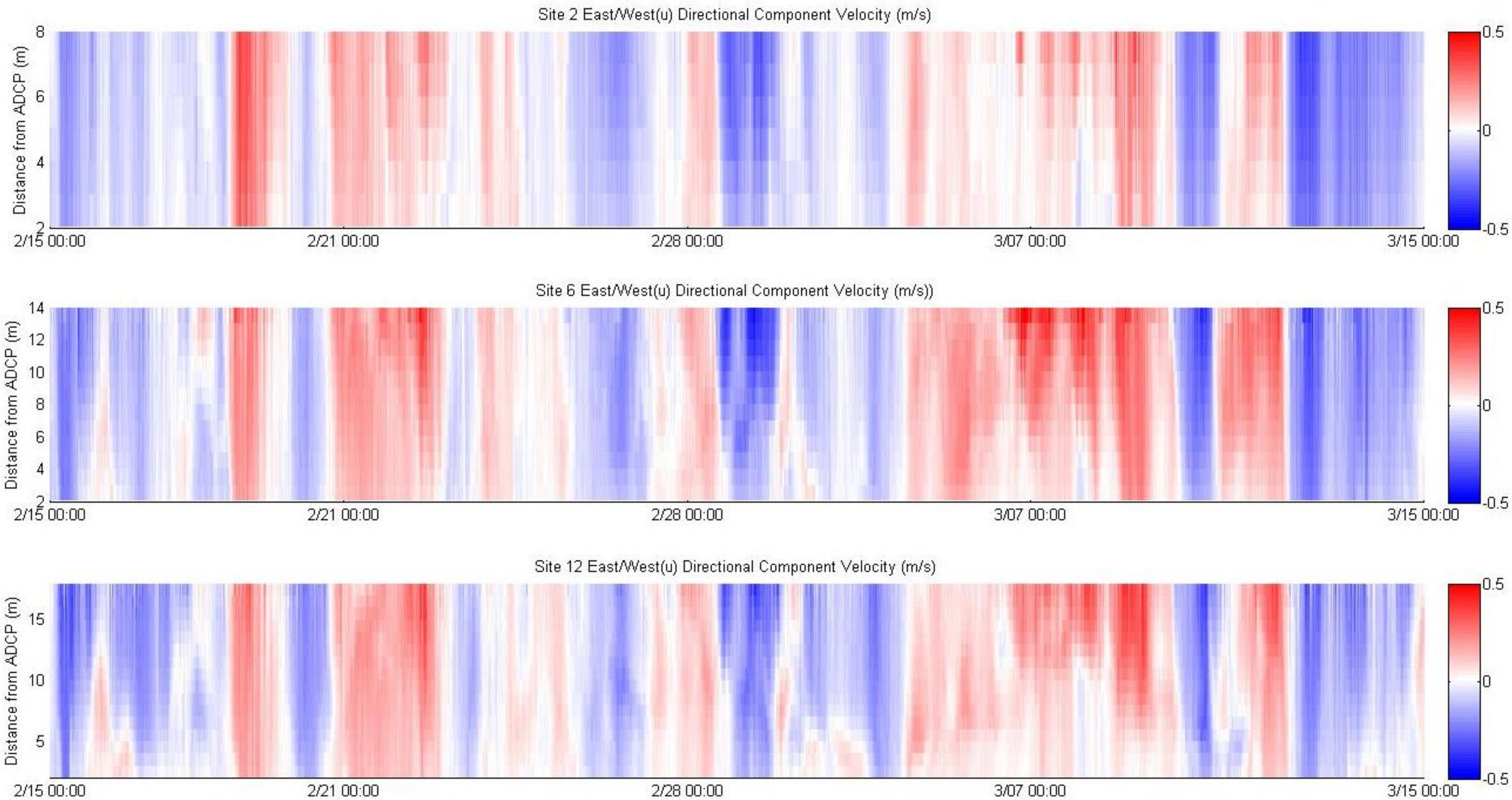

Percent cumulative frequency
C
A
B
Environmental variable bins

Figure 55.



Site 2 Current Magnitude (m/s)
Distance from ADCP (m)
8
6
4
2
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0.4
0.3
0.2
0.1
0
Site 6 Current Magnitude (m/s)
Distance from ADCP (m)
14
12
10
8
6
4
2
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0.4
0.3
0.2
0.1
0
Site 12 Current Magnitude (m/s)
Distance from ADCP (m)
15
10
5
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0.4
0.3
0.2
0.1
0

Figure 56.



Site 2 East/West(u) Directional Component Velocity (m/s)
Distance from ADCP (m)
8
6
4
2
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0
-0.5
Site 6 East/West(u) Directional Component Velocity (m/s))
Distance from ADCP (m)
14
12
10
8
6
4
2
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0
-0.5
Site 12 East/West(u) Directional Component Velocity (m/s)
Distance from ADCP (m)
15
10
5
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0
-0.5

Figure 57.

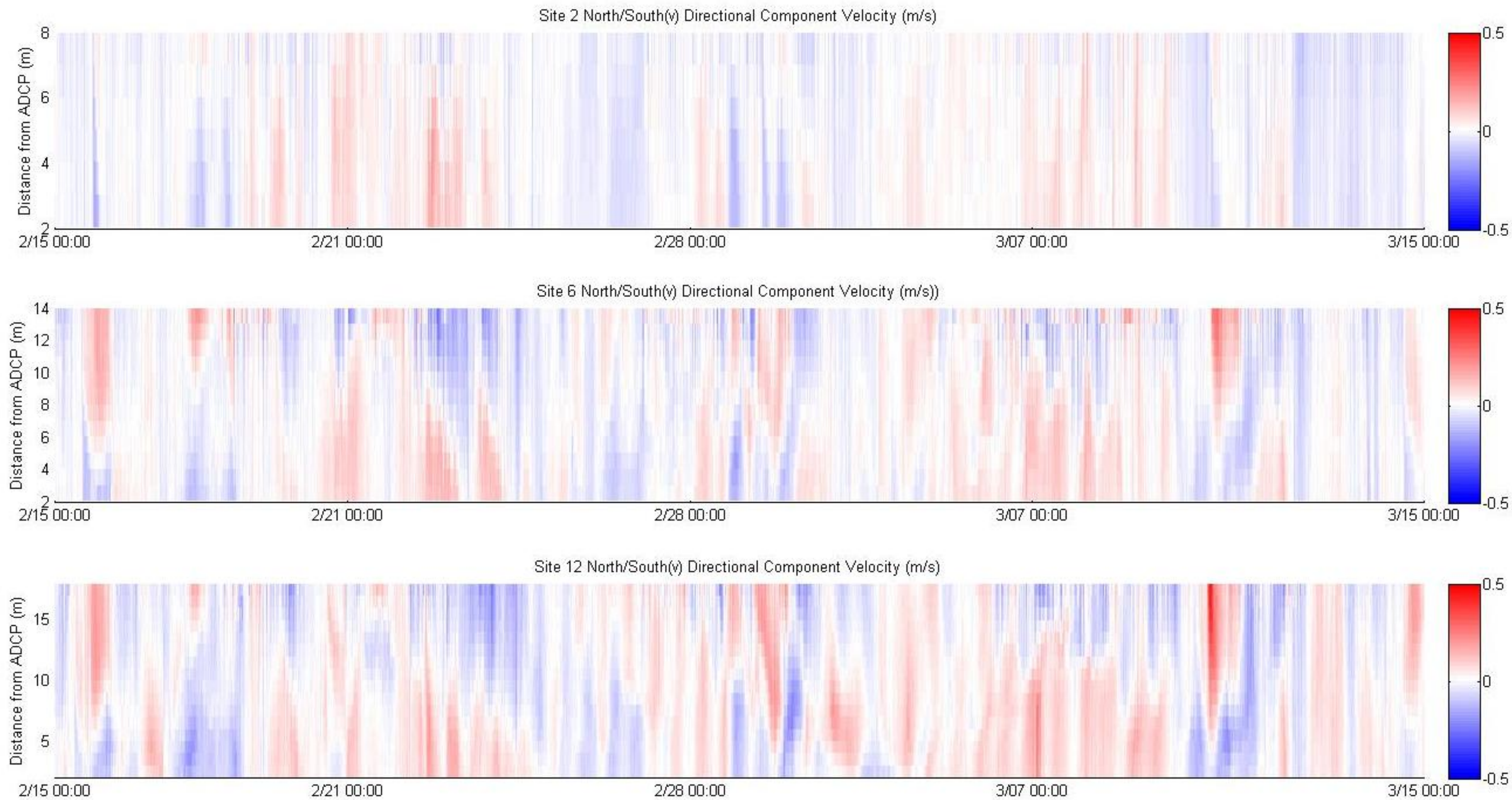

Site 2 North/South(v) Directional Component Velocity (m/s)
Distance from ADCP (m)
8
6
4
2
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0
-0.5
Site 6 North/South(v) Directional Component Velocity (m/s))
Distance from ADCP (m)
14
12
10
8
6
4
2
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0
-0.5
Site 12 North/South(v) Directional Component Velocity (m/s)
Distance from ADCP (m)
15
10
5
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
0.5
0
-0.5

Figure 58.

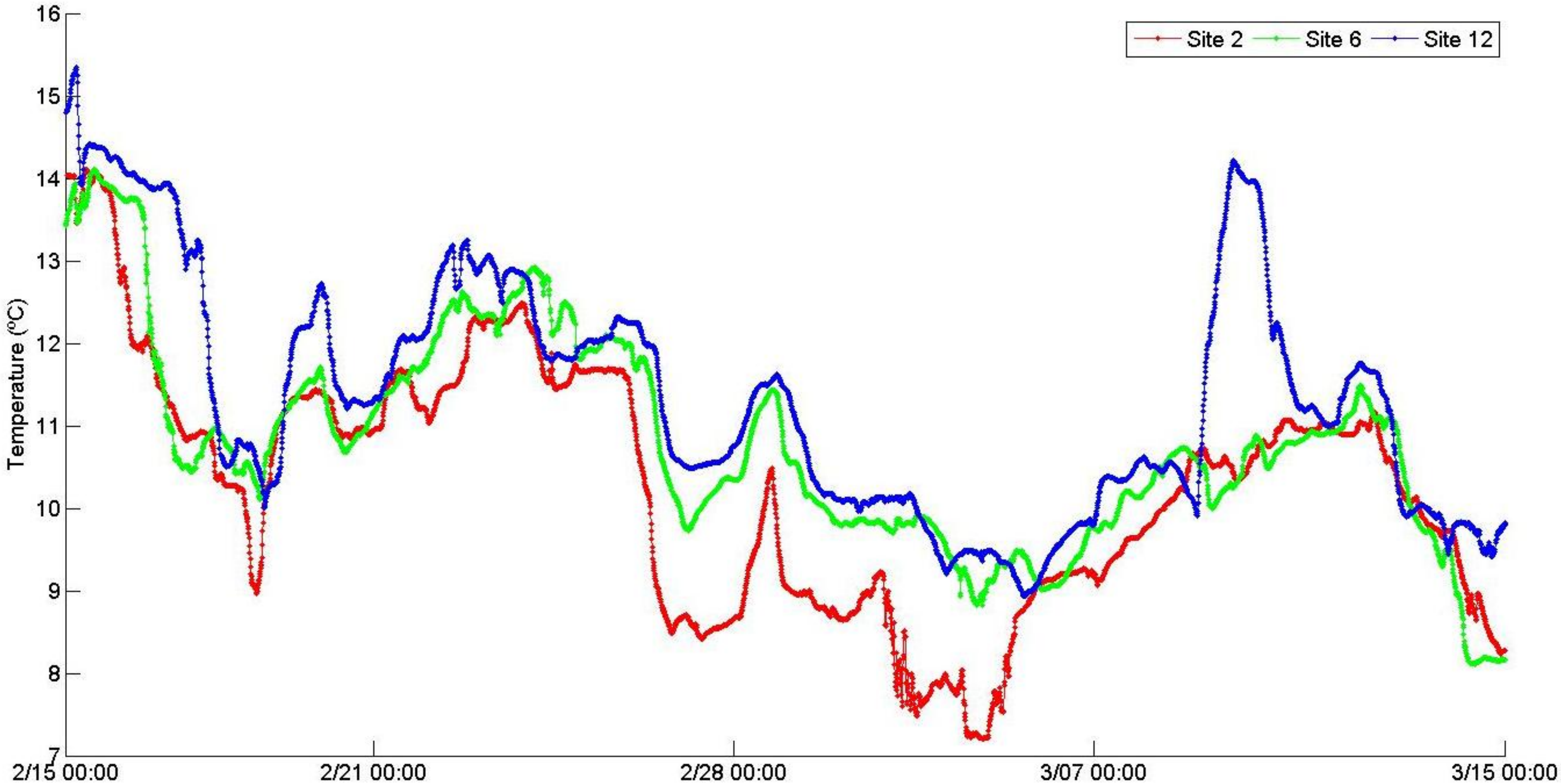

Site 2
Site 6
Site 12
Temperature (ºC)
16
15
14
13
12
11
10
9
8
7
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00

Figure 59.

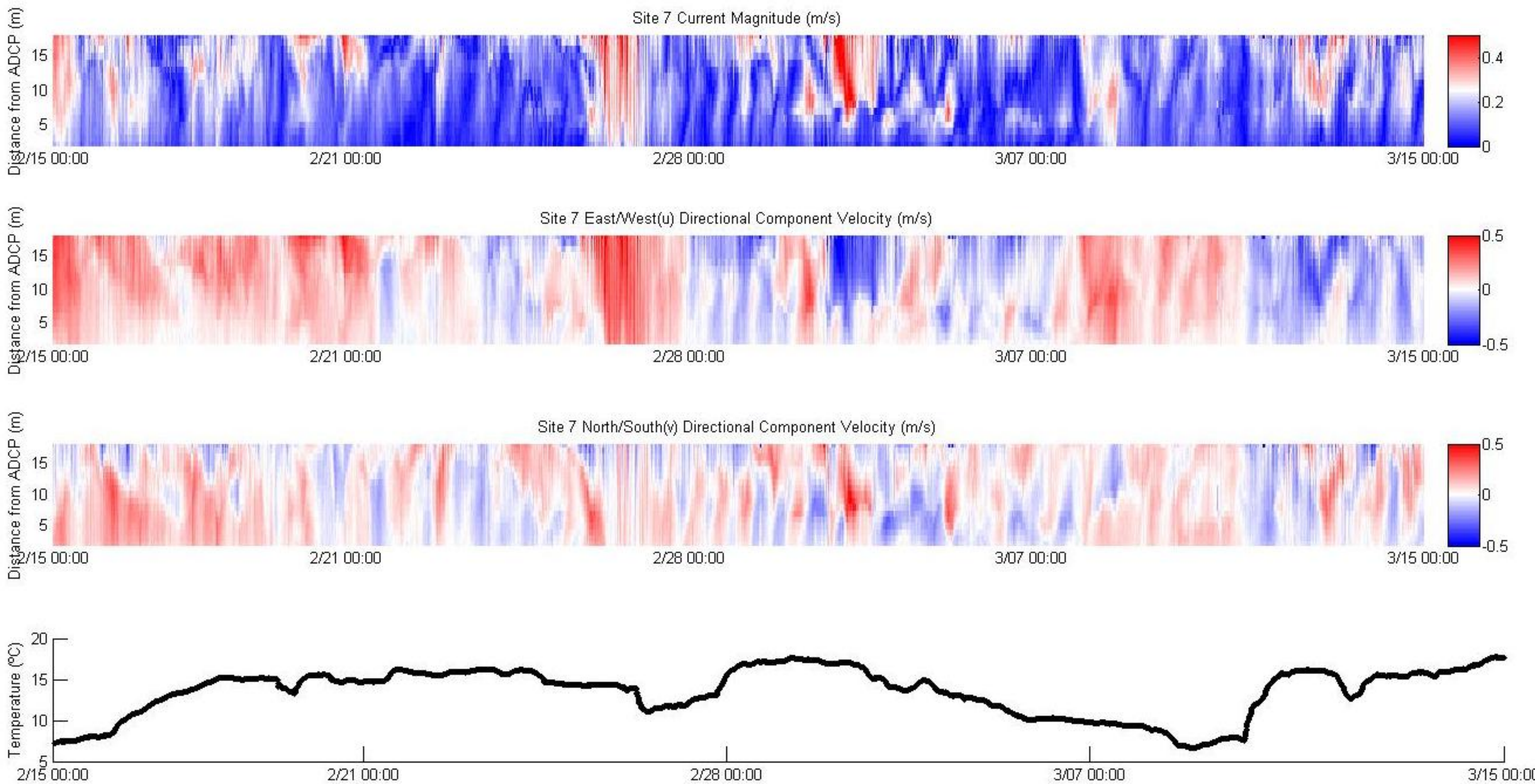

Site 7 Current Magnitude (m/s)
Distance from ADCP (m)
5
10
15
0
0.2
0.4
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
Site 7 East/West(u) Directional Component Velocity (m/s)
Distance from ADCP (m)
5
10
15
-0.5
0
0.5
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
Site 7 North/South(v) Directional Component Velocity (m/s)
Distance from ADCP (m)
5
10
15
-0.5
0
0.5
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00
Temperature (ºC)
5
10
15
20
2/15 00:00
2/21 00:00
2/28 00:00
3/07 00:00
3/15 00:00

Figure 60.

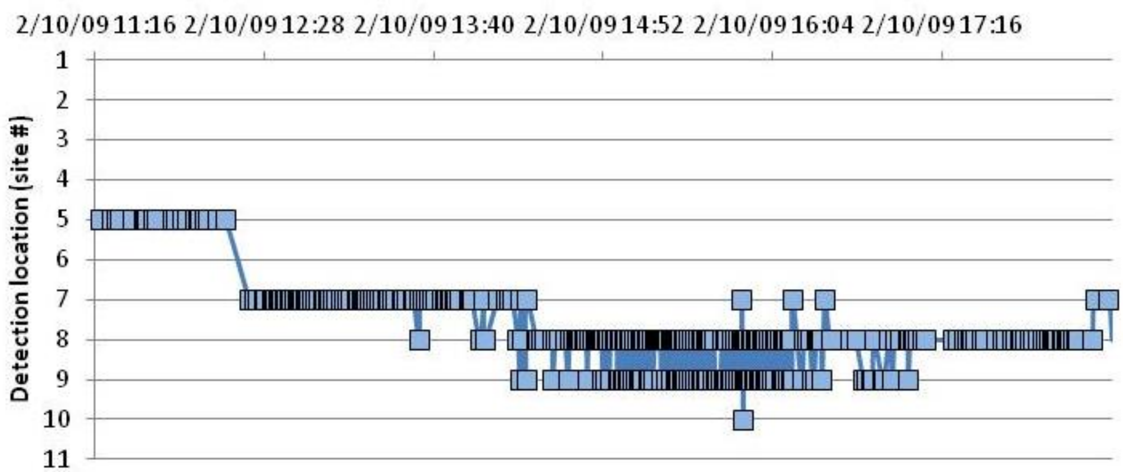

2/10/09 11:16
2/10/09 12:28
2/10/09 13:40
2/10/09 14:52
2/10/09 16:04
2/10/09 17:16
Detection location (site #)
1
2
3
4
5
6
7
8
9
10
11

Figure 61.

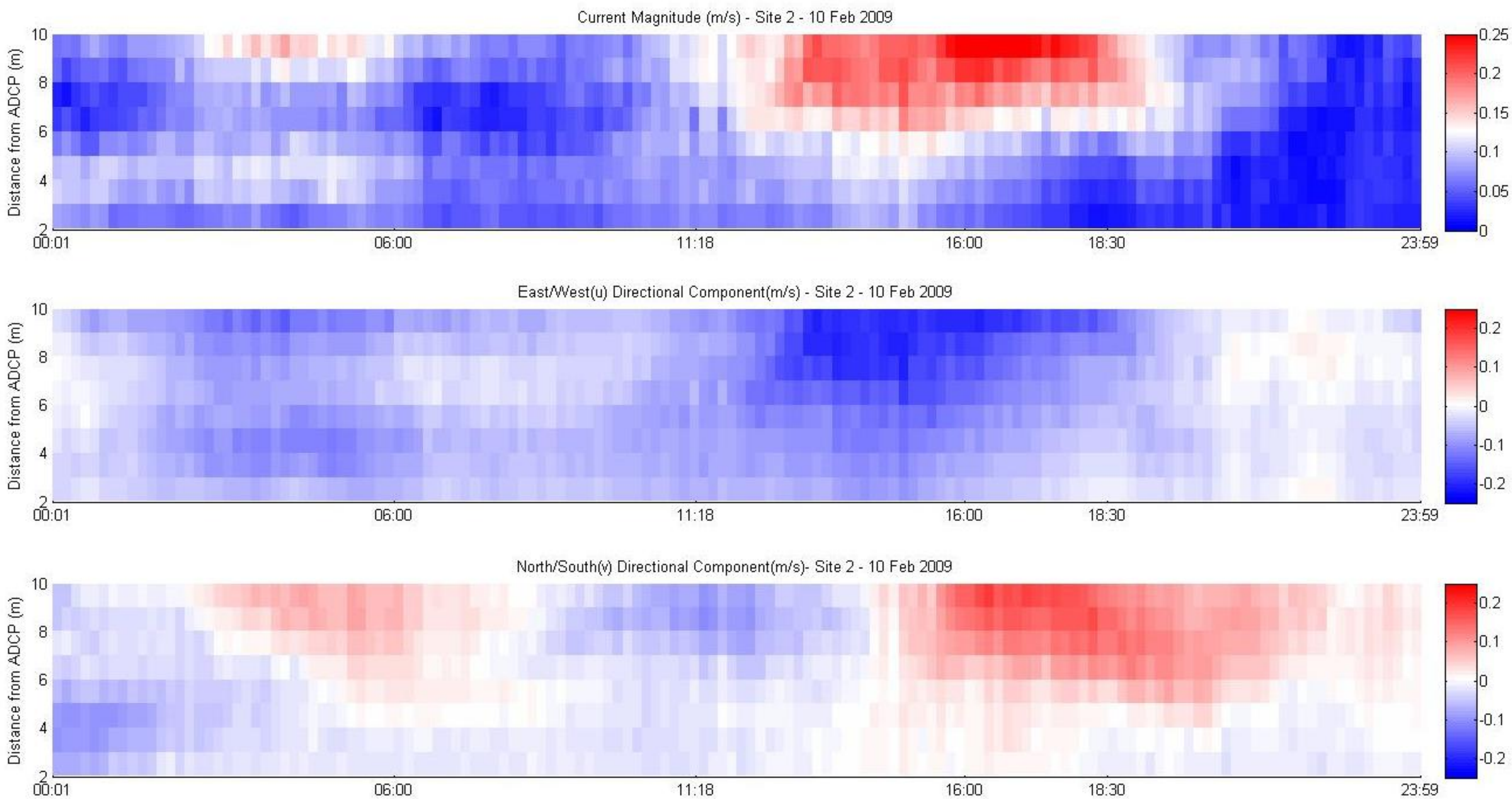
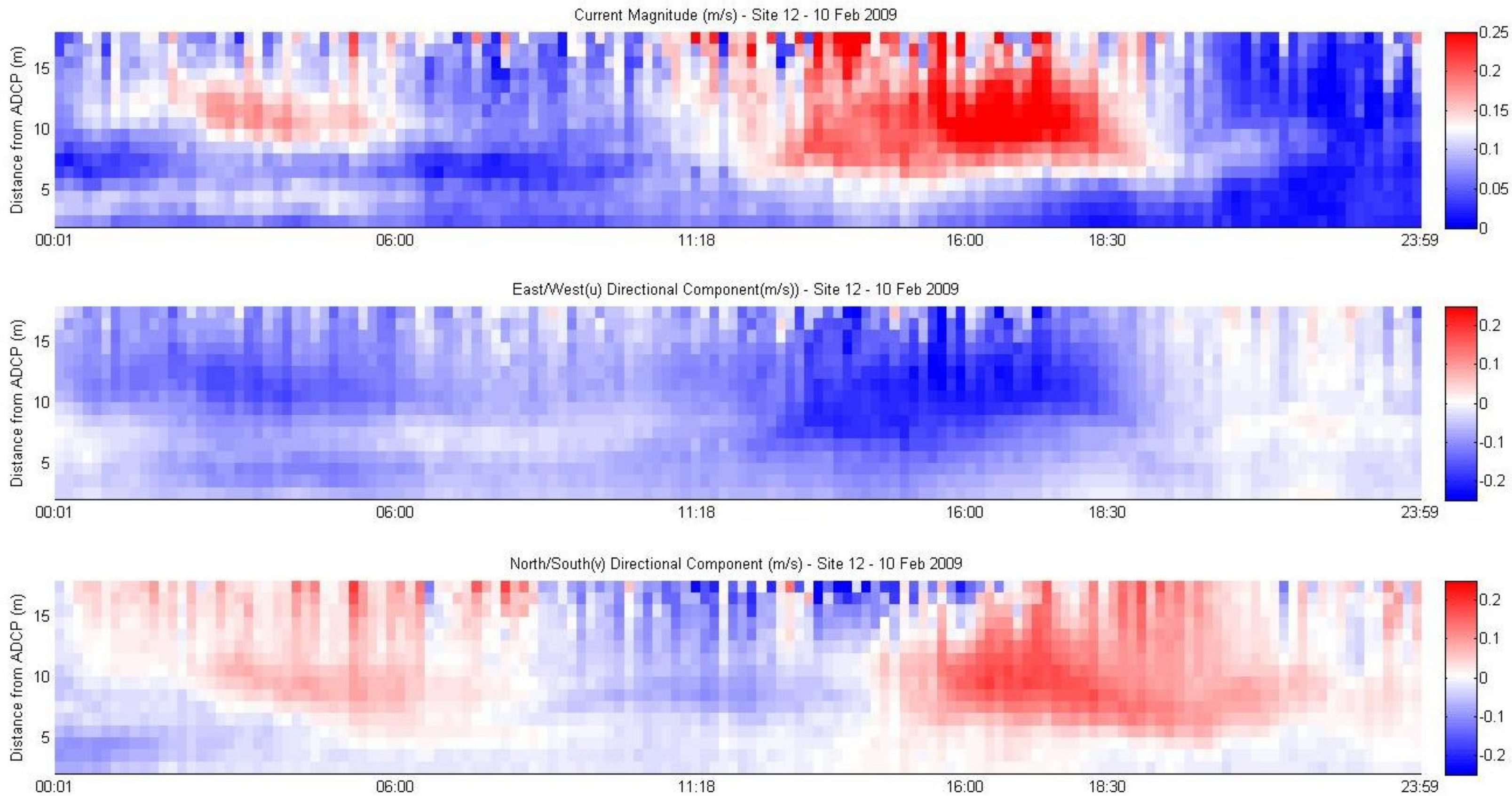

Current Magnitude (m/s) - Site 2 - 10 Feb 2009
Distance from ADCP (m)
10
8
6
4
2
00:01
06:00
11:18
16:00
18:30
23:59
0.25
0.2
0.15
0.1
0.05
0
East/West(u) Directional Component(m/s) - Site 2 - 10 Feb 2009
Distance from ADCP (m)
10
8
6
4
2
00:01
06:00
11:18
16:00
18:30
23:59
0.2
0.1
0
-0.1
-0.2
North/South(v) Directional Component(m/s)- Site 2 - 10 Feb 2009
Distance from ADCP (m)
10
8
6
4
2
00:01
06:00
11:18
16:00
18:30
23:59
0.2
0.1
0
-0.1
-0.2

Figure 62.



Current Magnitude (m/s) - Site 12 - 10 Feb 2009
Distance from ADCP (m)
15
10
5
00:01
06:00
11:18
16:00
18:30
23:59
0.25
0.2
0.15
0.1
0.05
0
East/West(u) Directional Component(m/s)) - Site 12 - 10 Feb 2009
Distance from ADCP (m)
15
10
5
00:01
06:00
11:18
16:00
18:30
23:59
0.2
0.1
0
-0.1
-0.2
North/South(v) Directional Component (m/s) - Site 12 - 10 Feb 2009
Distance from ADCP (m)
15
10
5
00:01
06:00
11:18
16:00
18:30
23:59
0.2
0.1
0
-0.1
-0.2

Figure 63.

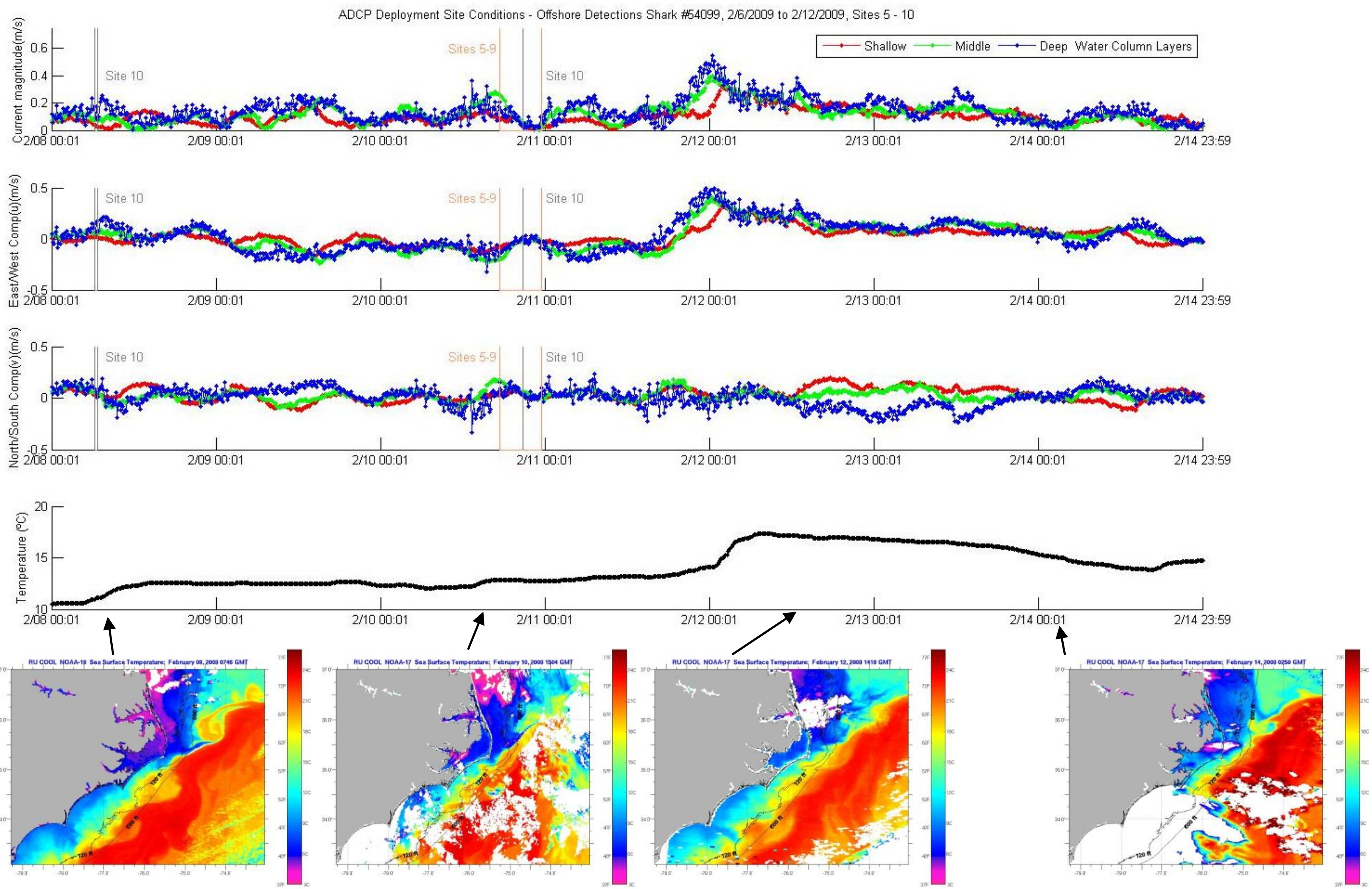

ADCP Deployment Site Conditions - Offshore Detections Shark #54099, 2/6/2009 to 2/12/2009, Sites 5 - 10
Shallow
Middle
Deep Water Column Layers
Current magnitude(m/s)
East/West Comp(u)(m/s)
North/South Comp(v)(m/s)
Temperature (°C)
Site 10
Sites 5-9
Site 10
2/08 00:01
2/09 00:01
2/10 00:01
2/11 00:01
2/12 00:01
2/13 00:01
2/14 00:01
2/14 23:59
RU COOL NOAA-18 Sea Surface Temperature; February 08, 2009 0746 GMT
RU COOL NOAA-17 Sea Surface Temperature; February 10, 2009 1504 GMT
RU COOL NOAA-17 Sea Surface Temperature; February 12, 2009 1418 GMT
RU COOL NOAA-17 Sea Surface Temperature; February 14, 2009 0250 GMT

Figure 64.

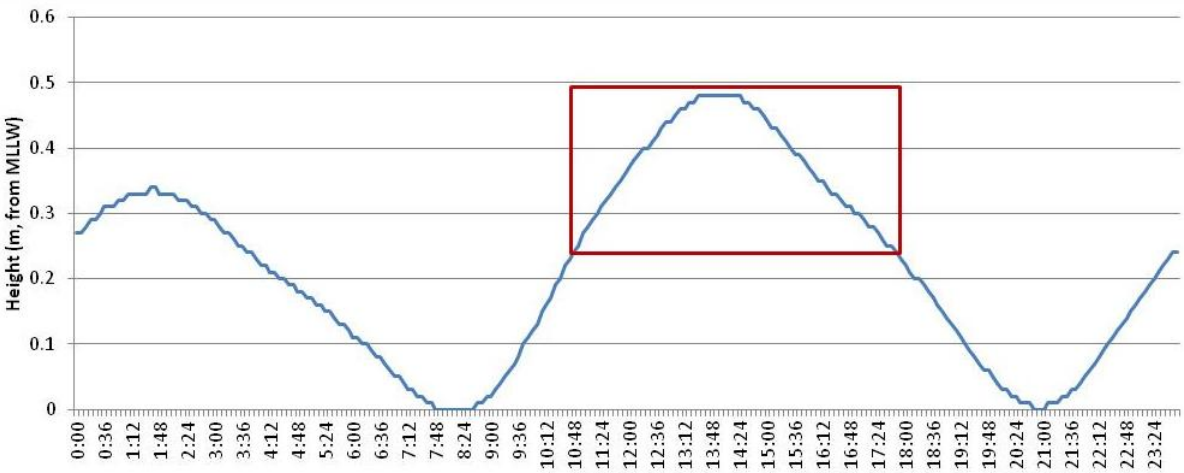

Height (m, from MLLW)
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00
0:36
1:12
1:48
2:24
3:00
3:36
4:12
4:48
5:24
6:00
6:36
7:12
7:48
8:24
9:00
9:36
10:12
10:48
11:24
12:00
12:36
13:12
13:48
14:24
15:00
15:36
16:12
16:48
17:24
18:00
18:36
19:12
19:48
20:24
21:00
21:36
22:12
22:48
23:24

Figure 65.

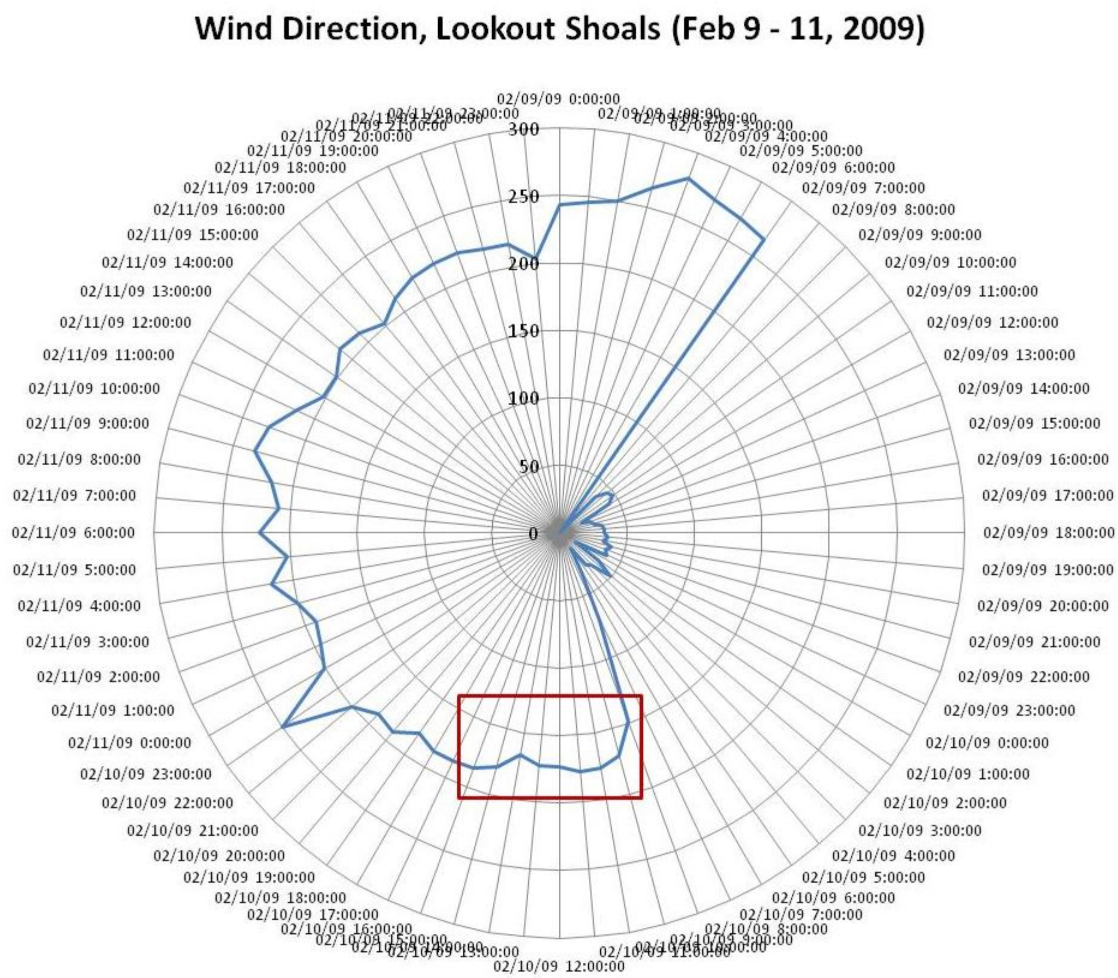
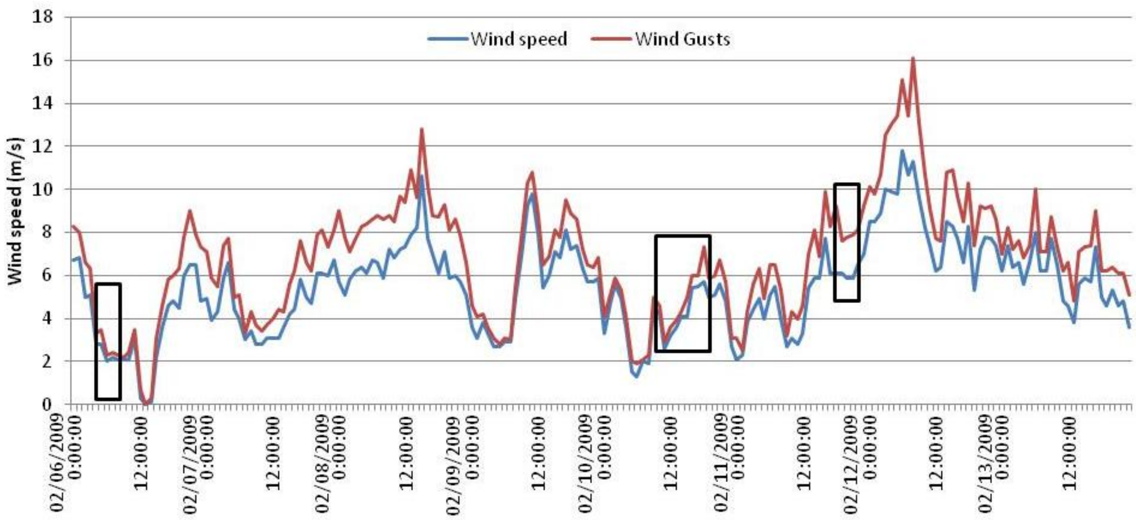
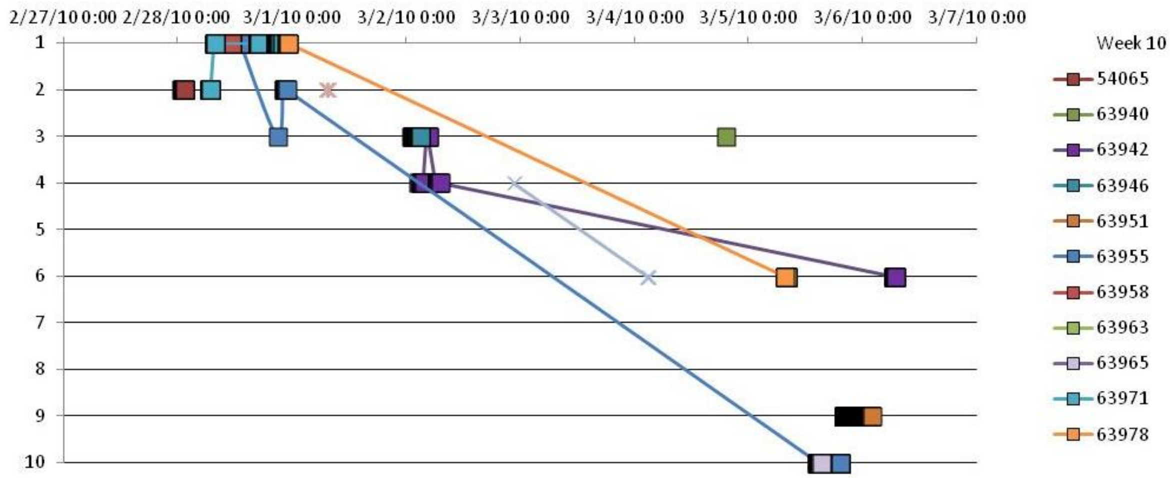

Wind Direction, Lookout Shoals (Feb 9 - 11, 2009)
300
250
200
150
100
50
0
02/09/09 0:00:00
02/09/09 5:00:00
02/09/09 6:00:00
02/09/09 7:00:00
02/09/09 8:00:00
02/09/09 9:00:00
02/09/09 10:00:00
02/09/09 11:00:00
02/09/09 12:00:00
02/09/09 13:00:00
02/09/09 14:00:00
02/09/09 15:00:00
02/09/09 16:00:00
02/09/09 17:00:00
02/09/09 18:00:00
02/09/09 19:00:00
02/09/09 20:00:00
02/09/09 21:00:00
02/09/09 22:00:00
02/09/09 23:00:00
02/10/09 0:00:00
02/10/09 1:00:00
02/10/09 2:00:00
02/10/09 3:00:00
02/10/09 4:00:00
02/10/09 5:00:00
02/10/09 6:00:00
02/10/09 7:00:00
02/10/09 8:00:00
02/10/09 12:00:00
02/10/09 16:00:00
02/10/09 17:00:00
02/10/09 18:00:00
02/10/09 19:00:00
02/10/09 20:00:00
02/10/09 21:00:00
02/10/09 22:00:00
02/10/09 23:00:00
02/11/09 0:00:00
02/11/09 1:00:00
02/11/09 2:00:00
02/11/09 3:00:00
02/11/09 4:00:00
02/11/09 5:00:00
02/11/09 6:00:00
02/11/09 7:00:00
02/11/09 8:00:00
02/11/09 9:00:00
02/11/09 10:00:00
02/11/09 11:00:00
02/11/09 12:00:00
02/11/09 13:00:00
02/11/09 14:00:00
02/11/09 15:00:00
02/11/09 16:00:00
02/11/09 17:00:00
02/11/09 18:00:00
02/11/09 19:00:00
02/11/09 20:00:00

Figure 66.



Wind speed
Wind Gusts
Wind speed (m/s)
18
16
14
12
10
8
6
4
2
0
02/06/2009 0:00:00
12:00:00
02/07/2009 0:00:00
12:00:00
02/08/2009 0:00:00
12:00:00
02/09/2009 0:00:00
12:00:00
02/10/2009 0:00:00
12:00:00
02/11/2009 0:00:00
12:00:00
02/12/2009 0:00:00
12:00:00
02/13/2009 0:00:00
12:00:00

Figure 67.



2/27/10 0:00
2/28/10 0:00
3/1/10 0:00
3/2/10 0:00
3/3/10 0:00
3/4/10 0:00
3/5/10 0:00
3/6/10 0:00
3/7/10 0:00
1
2
3
4
5
6
7
8
9
10
Week 10
54065
63940
63942
63946
63951
63955
63958
63963
63965
63971
63978

Figure 68.

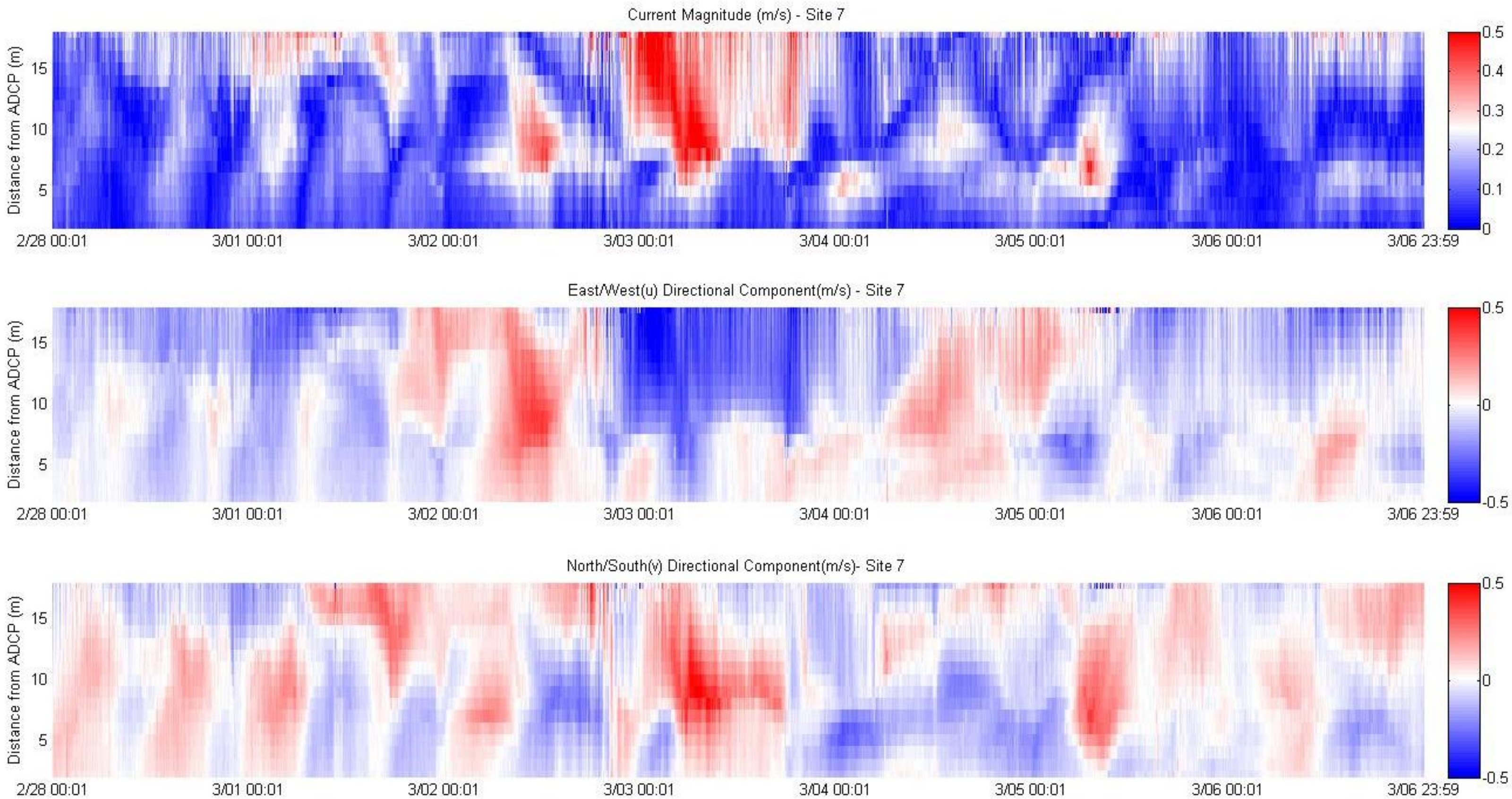

Current Magnitude (m/s) - Site 7
Distance from ADCP (m)
15
10
5
2/28 00:01
3/01 00:01
3/02 00:01
3/03 00:01
3/04 00:01
3/05 00:01
3/06 00:01
3/06 23:59
0.5
0.4
0.3
0.2
0.1
0
East/West(u) Directional Component(m/s) - Site 7
Distance from ADCP (m)
15
10
5
2/28 00:01
3/01 00:01
3/02 00:01
3/03 00:01
3/04 00:01
3/05 00:01
3/06 00:01
3/06 23:59
0.5
0
-0.5
North/South(v) Directional Component(m/s)- Site 7
Distance from ADCP (m)
15
10
5
2/28 00:01
3/01 00:01
3/02 00:01
3/03 00:01
3/04 00:01
3/05 00:01
3/06 00:01
3/06 23:59
0.5
0
-0.5

Figure 69.

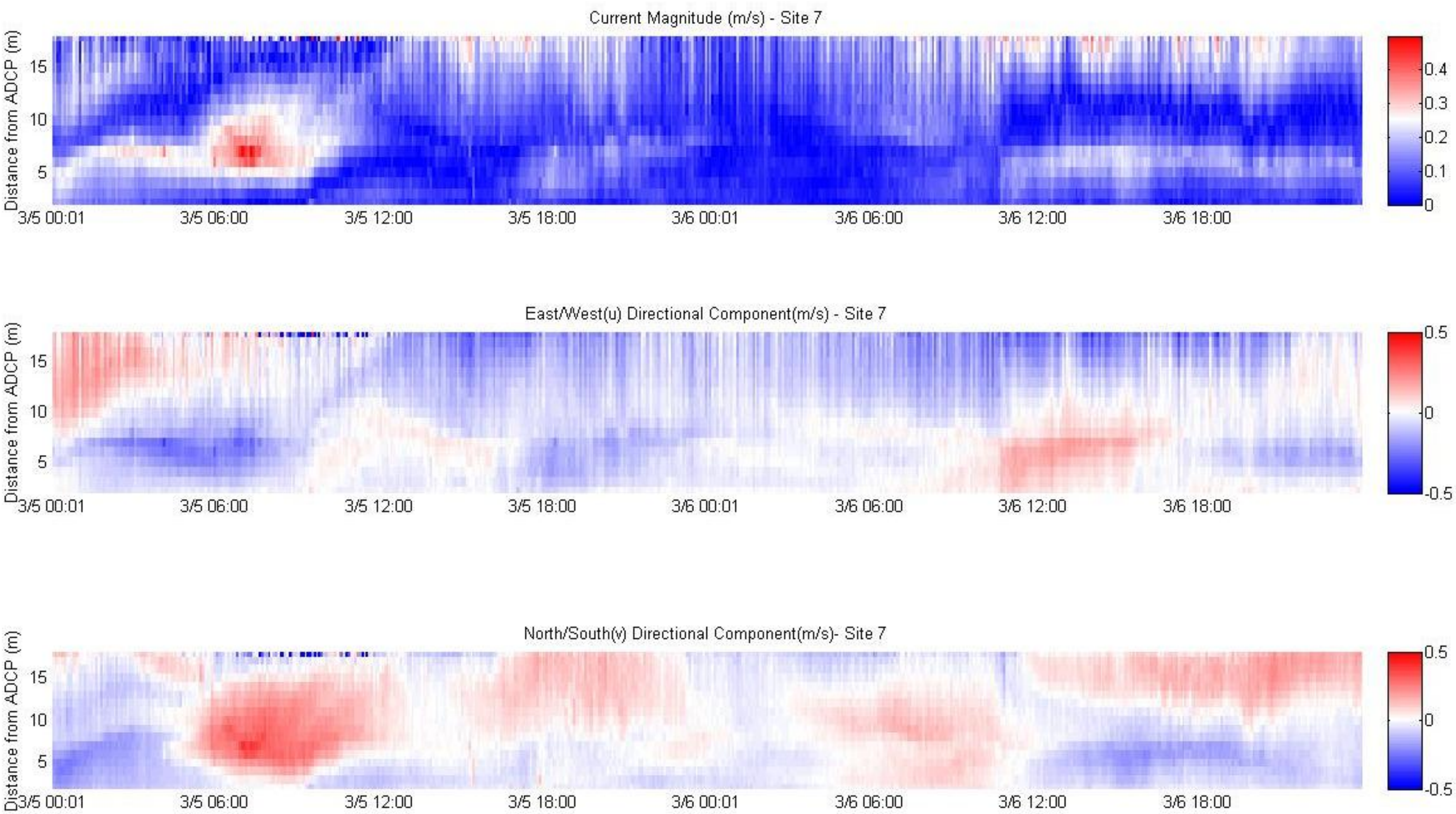

Current Magnitude (m/s) - Site 7
Distance from ADCP (m)
15
10
5
3/5 00:01
3/5 06:00
3/5 12:00
3/5 18:00
3/6 00:01
3/6 06:00
3/6 12:00
3/6 18:00
0.4
0.3
0.2
0.1
0
East/West(u) Directional Component(m/s) - Site 7
Distance from ADCP (m)
15
10
5
3/5 00:01
3/5 06:00
3/5 12:00
3/5 18:00
3/6 00:01
3/6 06:00
3/6 12:00
3/6 18:00
0.5
0
-0.5
North/South(v) Directional Component(m/s)- Site 7
Distance from ADCP (m)
15
10
5
3/5 00:01
3/5 06:00
3/5 12:00
3/5 18:00
3/6 00:01
3/6 06:00
3/6 12:00
3/6 18:00
0.5
0
-0.5

Figure 70.

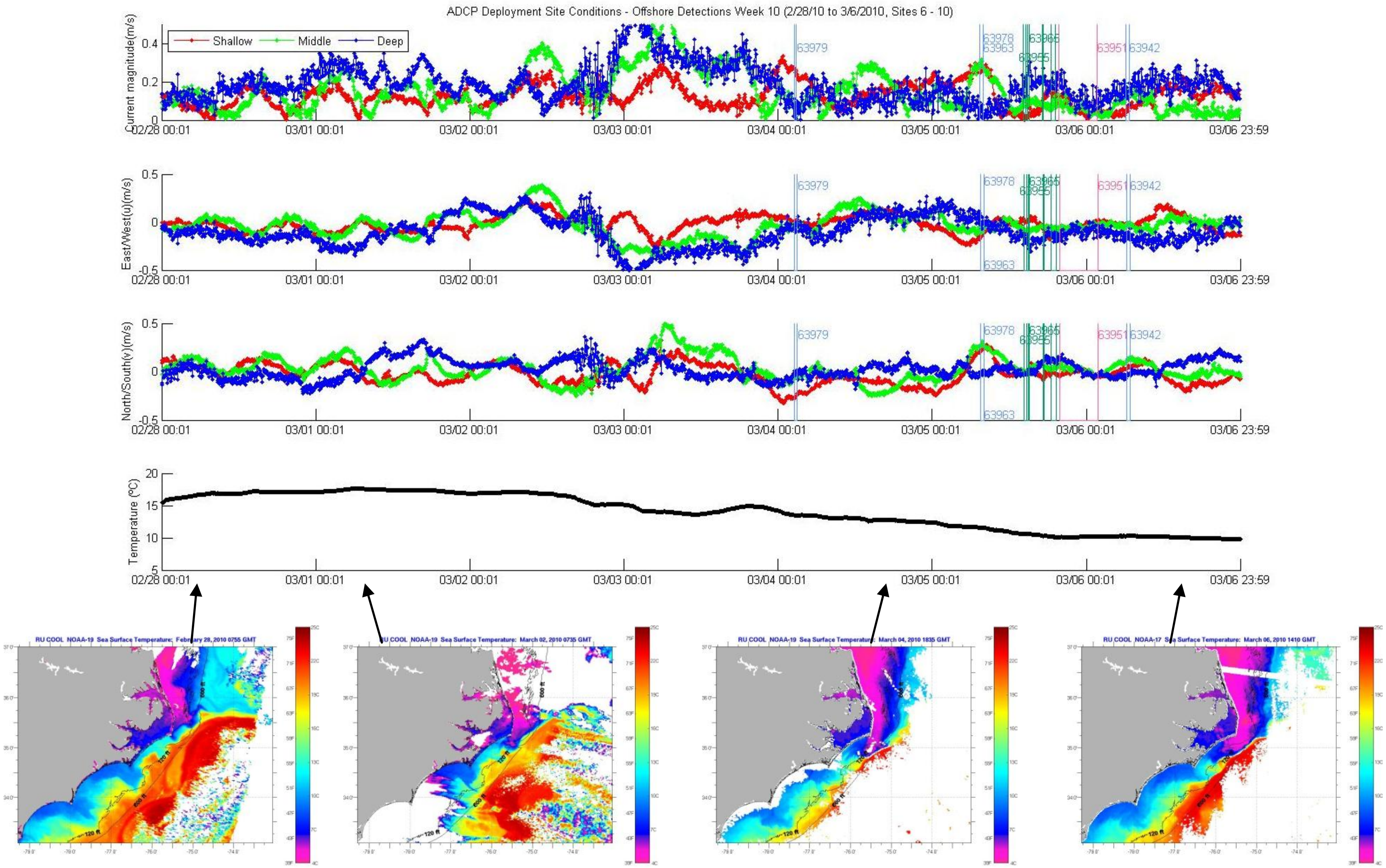

ADCP Deployment Site Conditions - Offshore Detections Week 10 (2/28/10 to 3/6/2010, Sites 6 - 10)
Shallow
Middle
Deep
Current magnitude(m/s)
East/West(u)(m/s)
North/South(v)(m/s)
Temperature (°C)
02/28 00:01
03/01 00:01
03/02 00:01
03/03 00:01
03/04 00:01
03/05 00:01
03/06 00:01
03/06 23:59
63979
63978
63963
63965
63955
63951
63942

Figure 71.

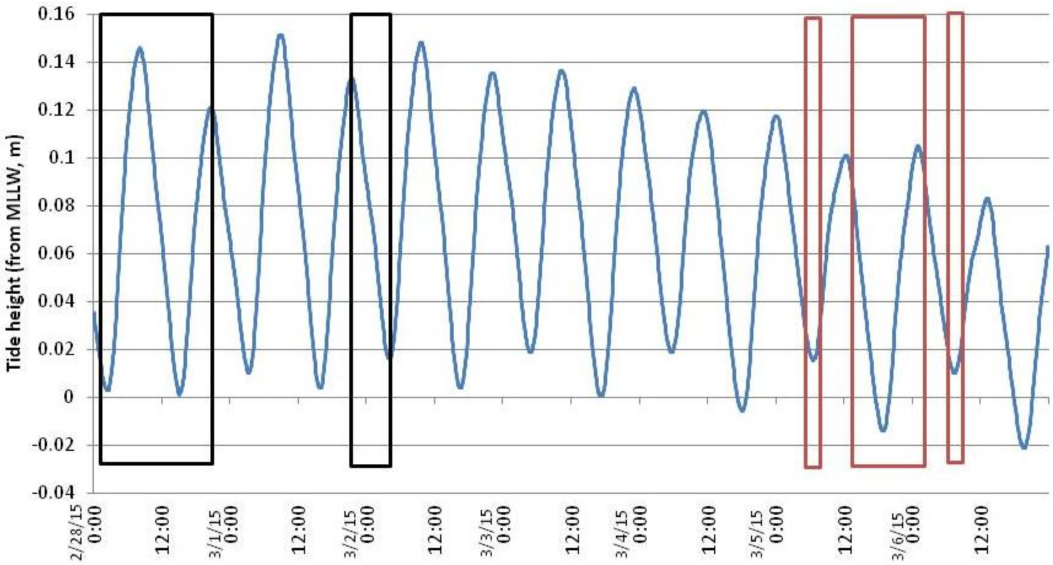

0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
Tide height (from MLLW, m)
2/28/15 0:00
12:00
3/1/15 0:00
12:00
3/2/15 0:00
12:00
3/3/15 0:00
12:00
3/4/15 0:00
12:00
3/5/15 0:00
12:00
3/6/15 0:00
12:00

Figure 72.

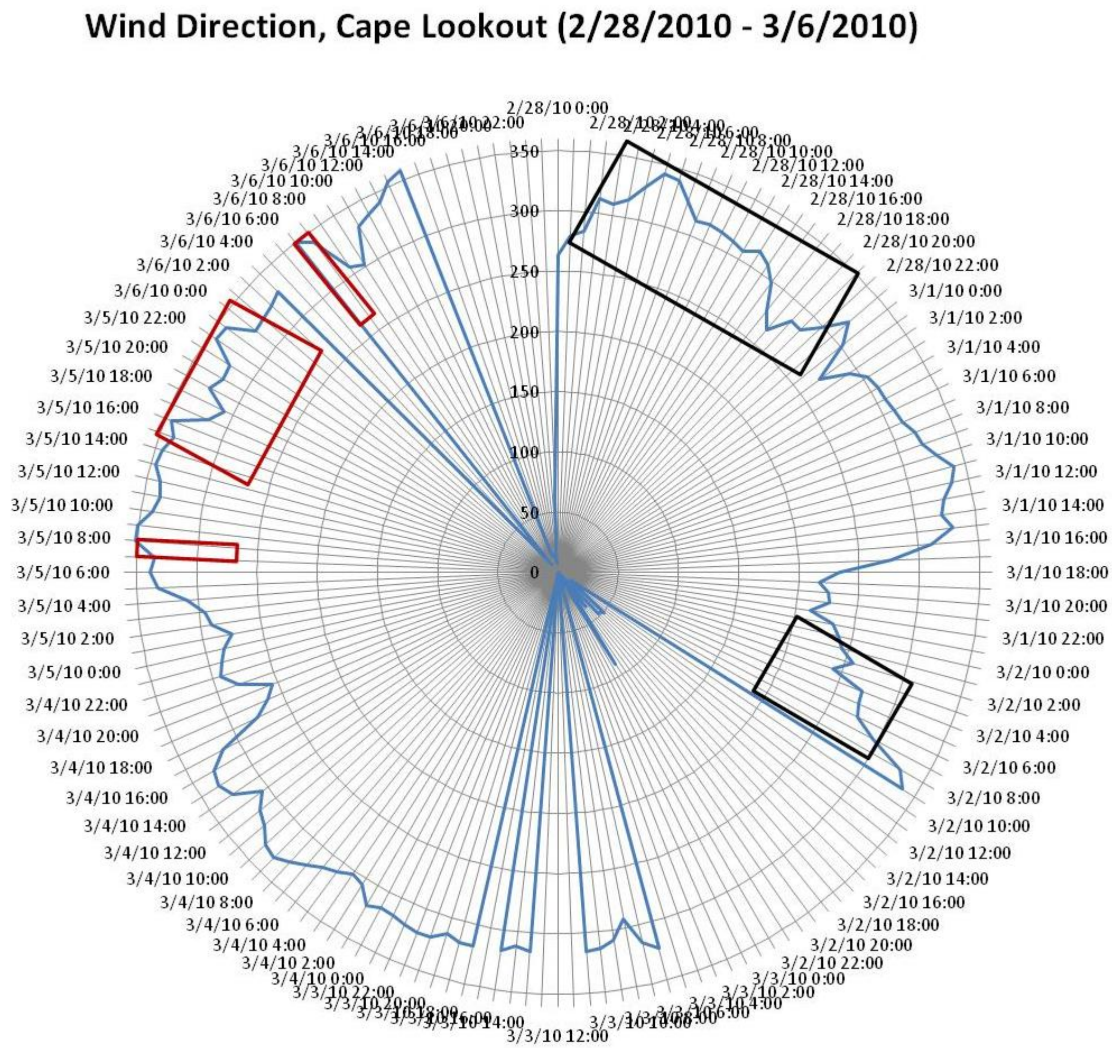
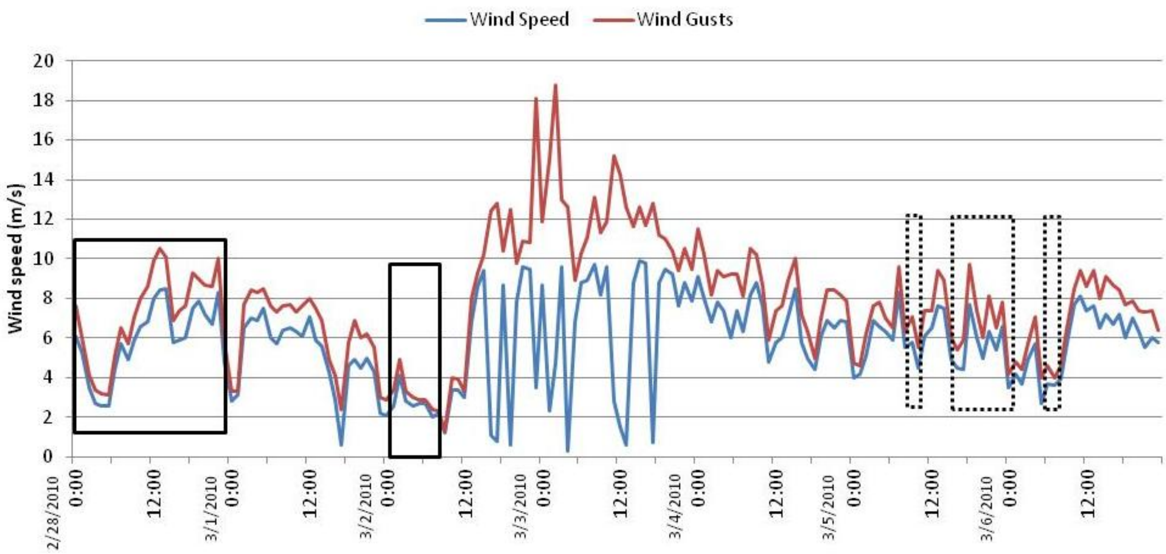
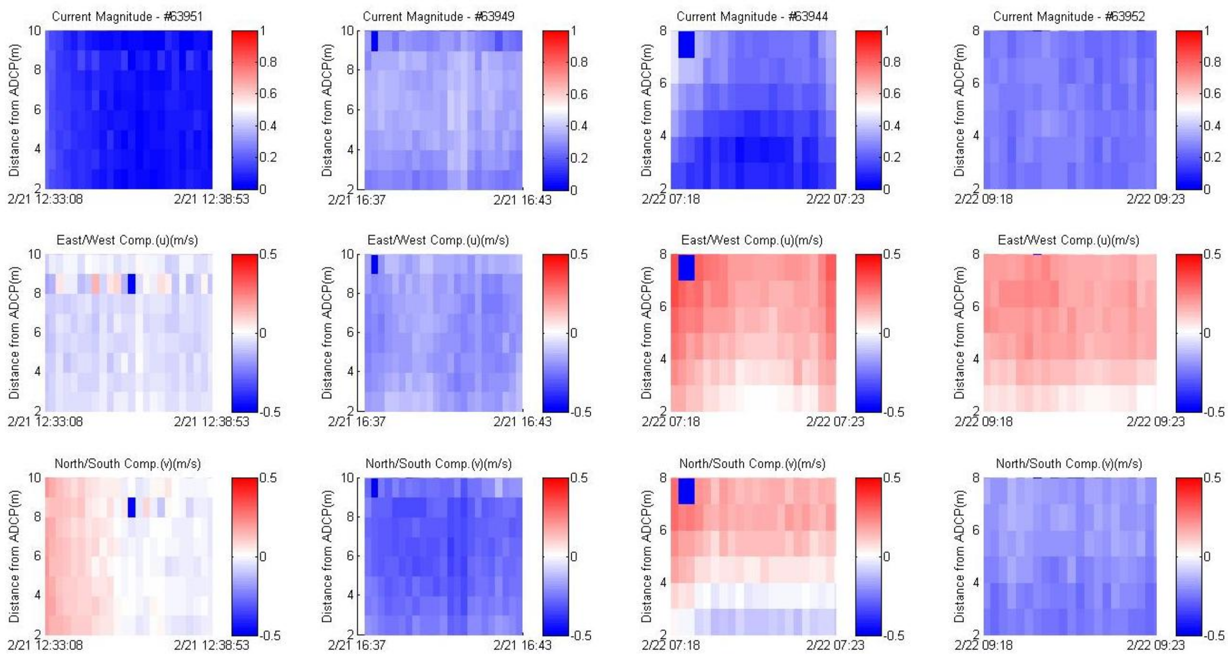

Wind Direction, Cape Lookout (2/28/2010 - 3/6/2010)
2/28/10 0:00
2/28/10 10:00
2/28/10 12:00
2/28/10 14:00
2/28/10 16:00
2/28/10 18:00
2/28/10 20:00
2/28/10 22:00
3/1/10 0:00
3/1/10 2:00
3/1/10 4:00
3/1/10 6:00
3/1/10 8:00
3/1/10 10:00
3/1/10 12:00
3/1/10 14:00
3/1/10 16:00
3/1/10 18:00
3/1/10 20:00
3/1/10 22:00
3/2/10 0:00
3/2/10 2:00
3/2/10 4:00
3/2/10 6:00
3/2/10 8:00
3/2/10 10:00
3/2/10 12:00
3/2/10 14:00
3/2/10 16:00
3/2/10 18:00
3/2/10 20:00
3/2/10 22:00
3/3/10 0:00
3/3/10 2:00
3/3/10 12:00
3/4/10 0:00
3/4/10 2:00
3/4/10 4:00
3/4/10 6:00
3/4/10 8:00
3/4/10 10:00
3/4/10 12:00
3/4/10 14:00
3/4/10 16:00
3/4/10 18:00
3/4/10 20:00
3/4/10 22:00
3/5/10 0:00
3/5/10 2:00
3/5/10 4:00
3/5/10 6:00
3/5/10 8:00
3/5/10 10:00
3/5/10 12:00
3/5/10 14:00
3/5/10 16:00
3/5/10 18:00
3/5/10 20:00
3/5/10 22:00
3/6/10 0:00
3/6/10 2:00
3/6/10 4:00
3/6/10 6:00
3/6/10 8:00
3/6/10 10:00
3/6/10 12:00
3/6/10 14:00
350
300
250
200
150
100
50
0

Figure 73.



Wind Speed
Wind Gusts
Wind speed (m/s)
20
18
16
14
12
10
8
6
4
2
0
2/28/2010 0:00
12:00
3/1/2010 0:00
12:00
3/2/2010 0:00
12:00
3/3/2010 0:00
12:00
3/4/2010 0:00
12:00
3/5/2010 0:00
12:00
3/6/2010 0:00
12:00

Figure 74.



Current Magnitude - #63951
Current Magnitude - #63949
Current Magnitude - #63944
Current Magnitude - #63952
East/West Comp.(u)(m/s)
North/South Comp.(v)(m/s)
Distance from ADCP(m)
2/21 12:33:08
2/21 12:38:53
2/21 16:37
2/21 16:43
2/22 07:18
2/22 07:23
2/22 09:18
2/22 09:23

Figure 75.

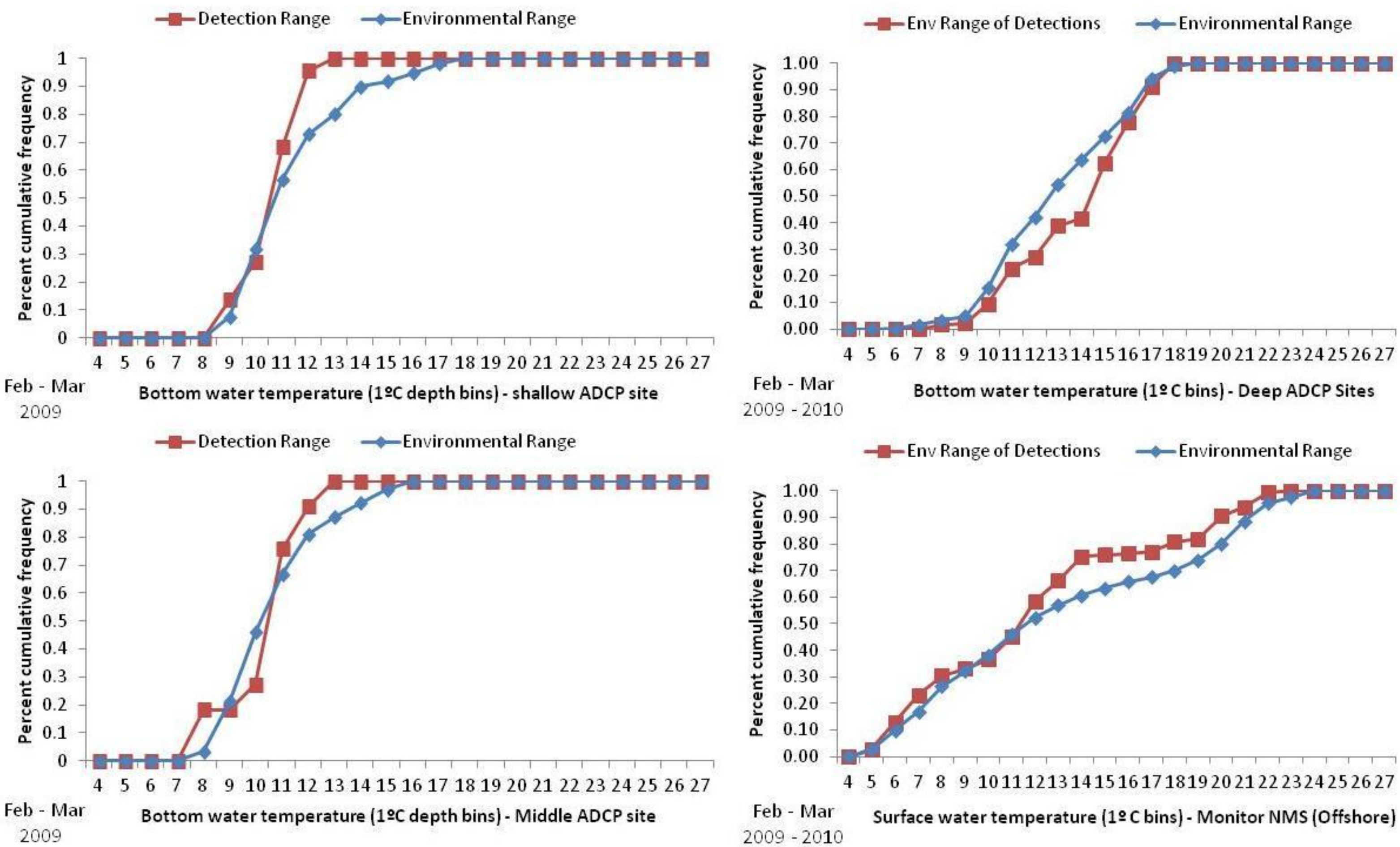
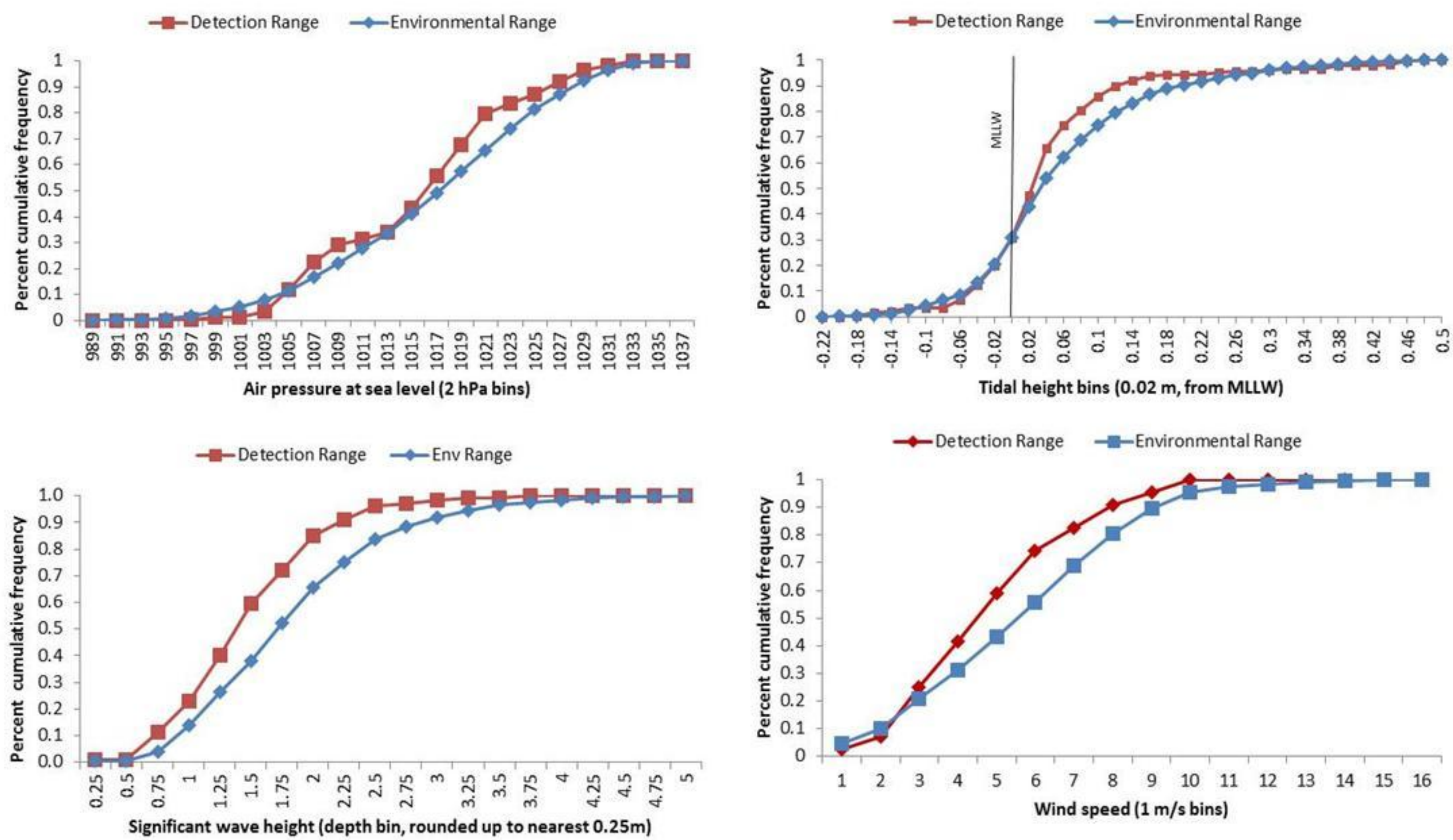
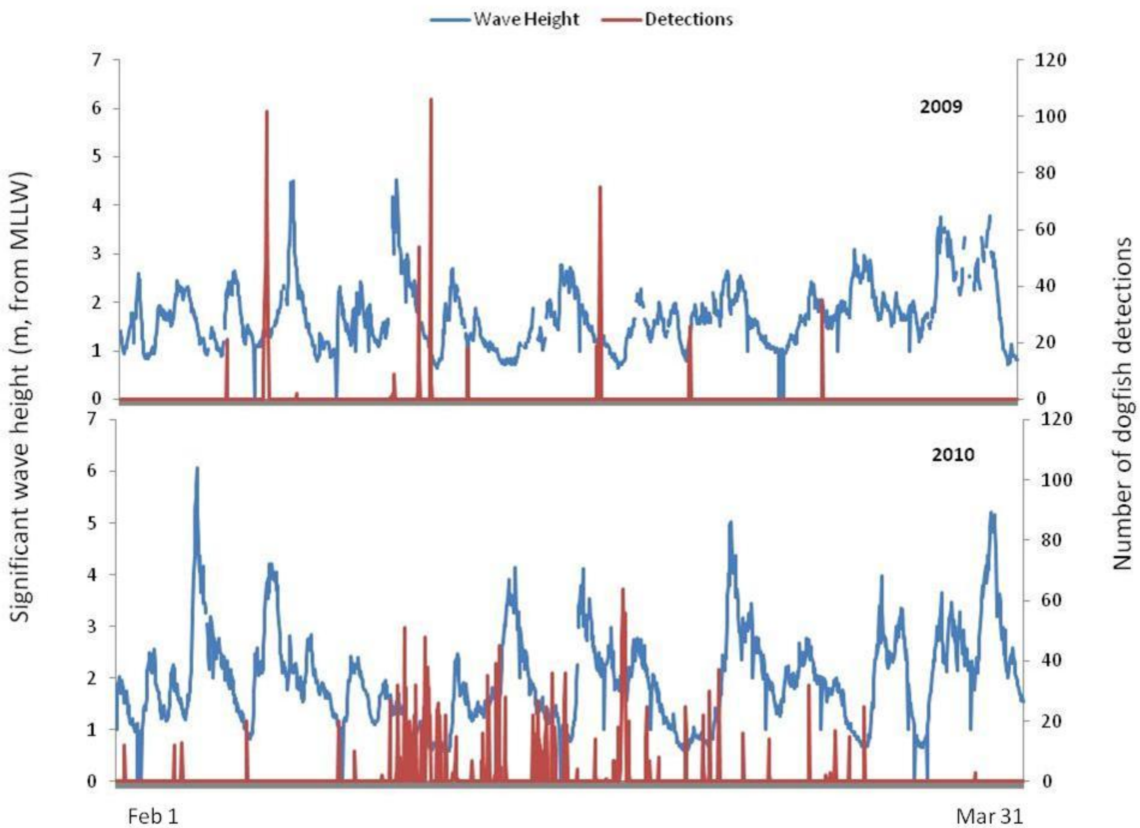

Detection Range
Environmental Range
Percent cumulative frequency
Feb - Mar 2009
Bottom water temperature (1ºC depth bins) - shallow ADCP site
Env Range of Detections
Environmental Range
Percent cumulative frequency
Feb - Mar 2009 - 2010
Bottom water temperature (1º C bins) - Deep ADCP Sites
Detection Range
Environmental Range
Percent cumulative frequency
Feb - Mar 2009
Bottom water temperature (1ºC depth bins) - Middle ADCP site
Env Range of Detections
Environmental Range
Percent cumulative frequency
Feb - Mar 2009 - 2010
Surface water temperature (1º C bins) - Monitor NMS (Offshore)

Figure 76.



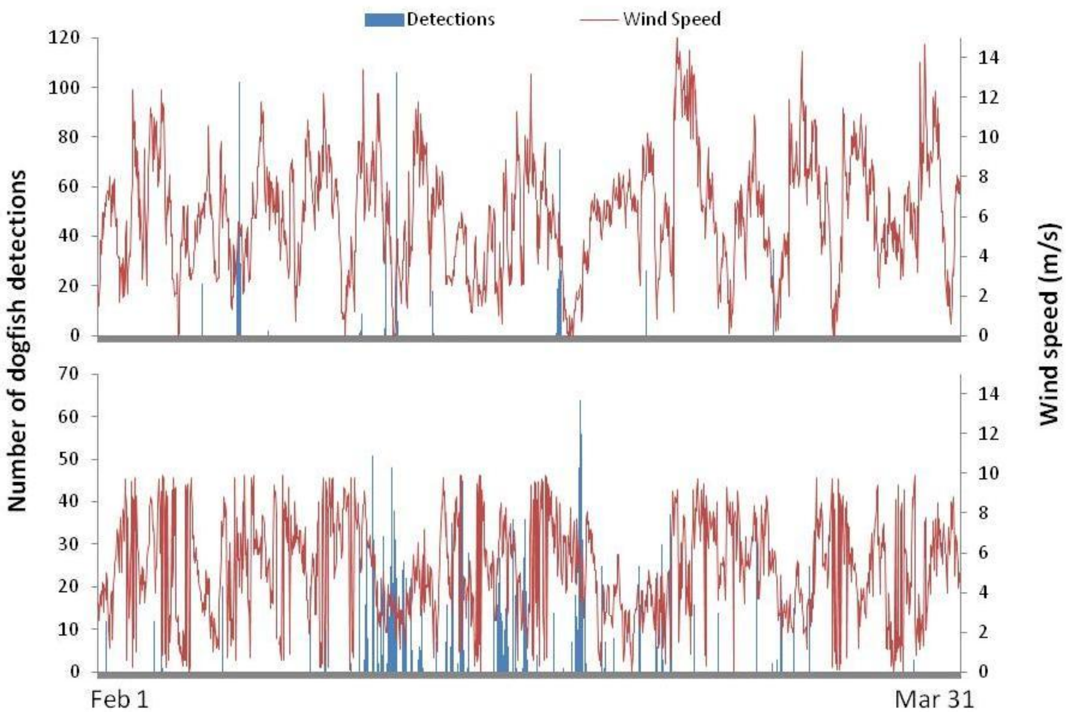
Detection Range
Environmental Range
Percent cumulative frequency
Air pressure at sea level (2 hPa bins)
Detection Range
Environmental Range
MLLW
Percent cumulative frequency
Tidal height bins (0.02 m, from MLLW)
Detection Range
Env Range
Percent cumulative frequency
Significant wave height (depth bin, rounded up to nearest 0.25m)
Detection Range
Environmental Range
Percent cumulative frequency
Wind speed (1 m/s bins)

Figure 77.



Wave Height
Detections
2009
2010
Significant wave height (m, from MLLW)
Number of dogfish detections
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
Feb 1
Mar 31

Figure 78.



Detections
Wind Speed
Number of dogfish detections
Wind speed (m/s)
120
100
80
60
40
20
0
14
12
10
8
6
4
2
0
70
60
50
40
30
20
10
0
14
12
10
8
6
4
2
0
Feb 1
Mar 31

Figure 79.

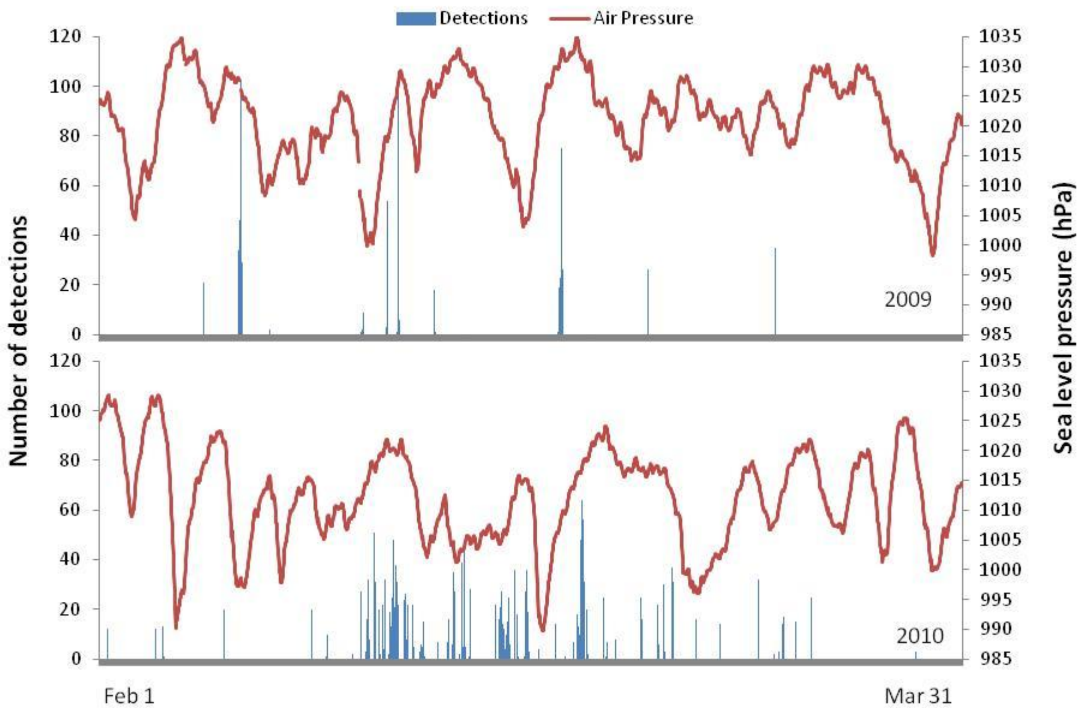
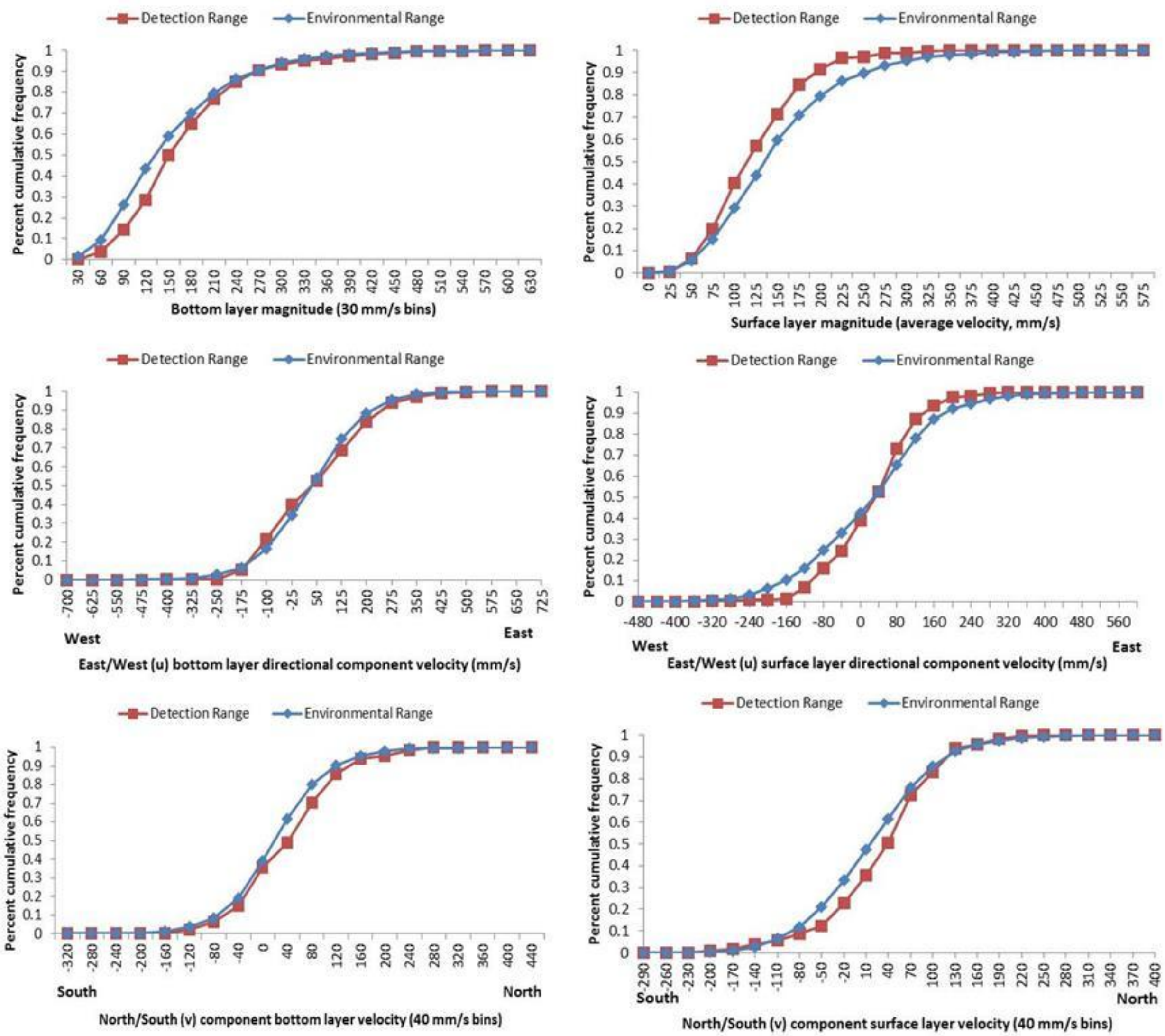

Detections
Air Pressure
Number of detections
Sea level pressure (hPa)
120
100
80
60
40
20
0
1035
1030
1025
1020
1015
1010
1005
1000
995
990
985
2009
2010
Feb 1
Mar 31

Figure 80.



Detection Range
Environmental Range
Percent cumulative frequency
Bottom layer magnitude (30 mm/s bins)
Surface layer magnitude (average velocity, mm/s)
West
East
East/West (u) bottom layer directional component velocity (mm/s)
East/West (u) surface layer directional component velocity (mm/s)
South
North
North/South (v) component bottom layer velocity (40 mm/s bins)
North/South (v) component surface layer velocity (40 mm/s bins)

CHAPTER 5: THE SPINY DOGFISH CONTINGENT HYPOTHESIS – PROPOSED DELINEATION OF MID-ATLANTIC AND GULF OF MAINE MIGRATORY CONTINGENTS

Abstract

Fisheries managers and biologists have not conclusively explained the rapid rebuilding of the Spiny Dogfish stock in the northwestern Atlantic Ocean; however, recent research has implied that the stock structure may be more complex than previously thought. Using data presented in this dissertation and previously published research, this chapter evaluates the Spiny Dogfish Contingent Hypothesis, which hypothesizes the presence of as many as five behavioral contingents of dogfish. Contingents are groups of genetically indistinct fish engaged in predictable, divergent movement patterns and seasonal migrations that connect feeding, overwintering, and spawning areas. Although contingent theory is widely recognized in the fishery literature, this review found that management is typically not conducted at the contingent level. Practical applications of contingent management for the Spiny Dogfish fishery are discussed, along with possible socio-economic implications of shifting from a single-unit stock management plan to a contingent-based management plan.

Introduction: The Contingent Hypothesis

Current fishery management models typically rely on the compartmentalization of fishery resources into manageable units, which are sampled and compared to reference parameters (e.g., spawning stock biomass, abundance indices, age-at-maturity, recruitment, etc.). These management units are usually described as a "stock"; however, this term has been broadly defined across the fisheries literature. Simply put, a stock can be described as a group of fish that maintains and sustains itself over time in a definable area (Booke 1981). A fishery can be classified into varying levels of complexity based on how many stocks are managed simultaneously by an agency. A “single stock fishery” assumes that the entire managed population within this fishery is a single group that exhibits common behavior patterns and is not genetically distinct (e.g., American Eel), whereas a “multi-stock fishery” usually constitutes several behaviorally or genetically distinct groups of fish (FAO 2010). The Food and Agricultural Organization of the United Nations (FAO UN) noted on its website that “*the greatest source of error in fisheries stock assessment and management is to underestimate the extent of a unit stock*” (http://www.fao.org/fishery/topic/14787/en).

The extent of a management unit, or stock, is simply the physical (“where”), biological (“who”), and functional (“why”) framework used to identify and manage an available resource (Secor 1999). A defined management unit may or may not constitute a biological or ecological entity such as a “population” or a “species” (Secor 2005). Management units are often defined by biological or genetic structure (required for advanced protection under U.S. laws like the Endangered Species Act). However there are times when recognizing population structure based on spatial scales, spatial features, or behavior may be as important. For example, Gulf of Maine Atlantic cod stocks are thought to be comprised of many groups that exhibited unique behaviors, including the utilization of different migration corridors to partially isolated spawning grounds that were susceptible to particularly heavy fishing pressure (Ames 2003). Lack of recognition of these unique subgroups, and appropriately scaled management, is one factor that led to some of these groups becoming functionally extinct and the slow recovery of Atlantic Cod populations in the Gulf of Maine (Ames 2003; Robichaud and Rose 2004). Secor (1999, 2005) proposed that groups of fish that exhibit unique behaviors, but are otherwise not genetically distinct from each other, may warrant separate management approaches as discrete "contingents" of fish.

The contingent hypothesis was developed by Clarke (1968) to describe a unique group of fish that "*engage(s) in a common pattern of seasonal migration between feeding areas, wintering areas, and spawning areas"*, and, once established, *"maintain its integrity by engaging in a distinct pattern of seasonal migration not shared by fish of other contingents."* Contingents can be, but are not necessarily, genetically distinct sub-populations (Clark 1968). Clark's contingent hypothesis was initially developed to describe unique behaviors observed in tagged Striped Bass in the Hudson River, Long Island Sound and the New York Bight. One contingent was identified as having migration patterns that were wholly contained within the Hudson River estuary, and moved between overwintering grounds in the river to summer habitats in the bays and estuary ("Hudson Estuary Contingent"). A second contingent, the "Hudson-West Sound Contingent", was hypothesized to spend the summers in Long Island Sound and winters in the Hudson River. A third contingent, the "Hudson-Atlantic" contingent was proposed to move into the Hudson River only for spring spawning and spent summers and winters in an unspecified location. Contingent theory was traditionally identified as reflective of divergent behavior from the same population (Clark 1968), and divergent behavior may result from conditions experienced during early life history (Secor et al. 1999). Life strategy contingents have since been documented in the Hudson (Secor et al. 1999; Zlokovitz et al. 2003) and Roanoke Rivers (Zurlo 2014) via otolith microchemical analysis for Striped Bass. Based on subsequent usage in the literature, contingents may be defined based on broad behavioral descriptions, such as whether the groups of fish in question are resident or migratory (Elsdon and Gillanders 2006), or from more specific classifications of behavior (Clark 1968), and may collectively comprise a metapopulation (e.g., Smedbol and Wroblewski 2002). Contingents may also overlap in time and space; for example, the contingents initially identified by Clark (1968) migrated back into the Hudson River to overwinter and for spawning, but spent summers in different locations.

The contingent hypothesis was not initially accepted for several reasons: small sample sizes; only juvenile males and immature females were tagged (ontogenetic migration or sex-specific migration could have been interpreted as contingent behavior); and the study was conducted over a short time period and therefore did not cover the lifespan of study specimens, which made it difficult to assess whether contingent membership varied across the lifespan of a fish (Waldman 1986; Waldman et al. 1990; Secor 1999). Secor (1999) re-evaluated the contingent hypothesis using otolith microchemistry, finding unique behaviors that persisted throughout the lifespan of individual striped bass ("resident", "estuarine" and "migratory"). Contingent theory has since been applied to describe many examples of divergent behavior patterns observed within fish populations (this chapter).

How Are Contingents Maintained? Contingents reflect observable patterns in behavior; however, membership within a contingent can be fluid, and may vary through the lifespan of a member (Secor et al. 1999). Contingents that are not wholly contained often intermix with each other (e.g., Studholme et al. 1999). Stocks with multiple behavioral contingents may exhibit partial migration (i.e., a population may consist of both resident and migratory contingents), which results in portions of a population or stock utilizing different types of habitats or undertaking separate behaviors (Secor 1999). In contrast to Secor (1999), in which contingent adoption is based on early life history divergence due to energy allocation, McQuinn (1997) proposes that divergent behavior was the result of migratory behavior "learned" during the first spawning migration and reinforced in subsequent migrations (Secor 1999). Entrainment and persistence of certain behavior patterns likely happen as young recruit into contingents or as members of contingents stray between contingents; in cases where contingents are depleted or there are no older members of a contingent to "teach," then certain migration routes, or overwintering or reproductive grounds may become unavailable to a stock (Petitgas et al. 2010). Straying between contingents may be a result of learned behavior as a result of intermingling fish stocks (i.e., fish adopting one life history strategy that intermix and recruit into a different contingent "learn" the new behavior) (McQuinn 1997). One interesting question that should be further explored is whether there is a threshold of intermingling or mixing that would nullify the application of contingent theory.

This type of population structuring may enhance the ability of stocks to withstand disturbance and promote long-term stability and health of fish stocks. Kerr et al. (2009) notes a correlation between environmental conditions and the prevalence of different behavioral contingents, implying that partial migration may be an adaptation to inter-annual variability in environmental conditions. Contingent structuring of a Chesapeake Bay White Perch population may be a response to conditions experienced in the early life history of fish (Kerr et al. 2008). White Perch (*Morone americana*) recruitment to migratory contingents is high during years of high flow in riverine environments (Kerr et al. 2009). Recruitment to resident contingents is higher in low flow years, and absolute in drought years. Contingents adopting different behavioral strategies may in turn experience differences in vital rates and productivity as a result of exposure to different environmental conditions (Kerr et al. 2010). Complex structuring of contingents within a population may enhance resiliency, especially if divergent behaviors exposes certain contingents to periodic, favorable conditions that promote high yield and buffers population level responses against unfavorable conditions (Secor 2007; Kerr et al. 2010). Kraus and Secor (2004) hypothesize that resident contingents lead to long term stability (i.e., a population can maintain its integrity and persist despite disturbance), whereas dispersive contingents contribute to population-level productivity and enhance overall resilience (i.e., ability to return to an equilibrium state after disturbance) (definitions and further analysis of concepts are available in McCann 2000; Kerr et al. 2010; Petitgas et al. 2010). Disruption of biological mechanisms supporting persistence of contingent behavior (and completion of contingent life cycles) can undermine the health of stocks and contribute to stock depletion or collapse (Petitgas et al. 2010). Petitgas et al. (2010) note that in cases where contingent behavior is damaged as a result of overexploitation, recovery of collapsed stocks may take much longer than expected, and depends on the re-establishment of behavioral patterns. Depleted stocks that still retained contingent behavior recovered much more quickly.

The Spiny Dogfish Contingent Hypothesis: Overview

Spiny Dogfish (*Squalus acanthias*) were long assumed to exhibit a general northward-southward and on-shore offshore movement between summer and winter habitats (Burgess 2002; MAFMC 1999; ASMFC 2002). U.S. and Canadian shark biologists met in 2007 to discuss Spiny Dogfish stock structure, migration, abundance trends, and current state of knowledge of the Canadian component of the northwest Atlantic dogfish stock (Campana et al. 2008). Analyses of tagging data completed at this meeting suggested the potential for a Spiny Dogfish metapopulation of dogfish, with “groups” of dogfish identifiable in the Gulf of St. Lawrence, the Scotian Shelf, the Bay of Fundy, coastal regions of Newfoundland, and off Massachusetts and North Carolina. Campana et al. (2008) hypothesized that Canadian dogfish “groups” were residential and exhibited onshore-offshore migration. Southern (U.S.) populations of dogfish were proposed to undertake north-south migrations in response to seasonal changes in the availability of preferred temperatures along the east coast of the United States. In 2010, shark experts at the Transboundary Resource Assessment Committee (TRAC) meeting hypothesized that Spiny Dogfish form unique migratory contingents since tagging studies have indicated the potential for complex population structuring within a single unit stock (Figure 81; TRAC 2010). Two migratory contingents were proposed, one that exhibited a north-south seasonal migration between North Carolina and Cape Cod, and another that exhibited a gyre-like migration around the Gulf of Maine. The latter included sharks found in the Bay of Fundy, and featured limited exchange with Scotian Shelf Spiny Dogfish. In addition, the resident groups observed off the Scotian Shelf, in the Gulf of St. Lawrence, and off Newfoundland were proposed to be separate contingents.

One purpose of this dissertation is to evaluate the contingent hypotheses and determine whether definitive supporting evidence exists from multiple tagging studies. In the discussion below, I characterize the potential Mid-Atlantic Spiny Dogfish Contingent based on Clark's hypothesis of unique behaviors connecting reproductive, feeding, and overwintering grounds (albeit for a shark instead of an anadromous fish). This dissertation is largely focused on the behavior of the Mid-Atlantic Spiny Dogfish, and I review data presented in Chapter 3 that establish the northern and southern extents of range. Our analysis of dogfish detection data against environmental data (Chapter 4), coupled with what is known regarding distribution of dogfish across broader scales, highlights the species' sensitivity to fluctuations within the environment. A southern functional extent is also discussed, based on consideration of additional environmental information and records of interactions south of Cape Hatteras. To our knowledge this is the first time that the contingent hypothesis has been directly applied to elasmobranchs; however, there are multiple studies of shark metapopulations which suggest that groups of sharks exhibit some degree of population structuring and philopatry for specific feeding, reproductive and overwintering areas (e.g., Hueter et al. 2005; Ashe et al. 2015; Sandoval-Castillo and Beheregaray 2015).

Classification of Spiny Dogfish into some contingents may be appropriate because distinct behavior patterns have been observed through multiple tagging studies (Hickman et al. 2000; Rulifson et al. 2002; Campana et al. 2008; TRAC 2010; *this dissertation*) which may connect overwintering habitats in the southern extent of the range to feeding grounds further north. This dissertation does not irrefutably prove nor disprove the existence of contingents. Strict interpretation of Clark's 1968 hypothesis suggests that there is no intermixing between contingents. The Spiny Dogfish Contingent Hypothesis as originally described offered a clear separation between the Mid-Atlantic migratory contingent and the Gulf of Maine migratory contingents, with Cape Cod serving as a boundary. Our research does not support absolute separation of the proposed contingents at Cape Cod. Up to a quarter of Spiny Dogfish tagged off North Carolina venture into areas hypothesized to be part of the migratory route undertaken by the Gulf of Maine contingent. In particular, large numbers of Spiny Dogfish were recaptured or detected on receivers along Cape Cod and up the coast of Massachusetts to Cape Ann. Coastal Massachusetts, including Cape Cod, may be an area of spatial overlap between migratory contingents and some degree of mixing may occur between contingents. Smaller numbers of North-Carolina tagged spiny dogfish were both detected and recaptured of Maine, in the central Gulf of Maine or Atlantic Canada, areas that are clearly beyond the areas frequented by a large proportion of North-Carolina tagged spiny dogfish. These Spiny Dogfish, which are hypothesized to be part of the Mid-Atlantic contingent, may have adopted the behaviors of a separate contingent (e.g., the Gulf of Maine or the Scotian Shelf Contingents). However, I believe this Hypothesis should not be seen as depicting an absolute definition of migration pathways for each proposed Contingent, per Clark's definition. Rather it should reflect some of the ideas expanded upon by Secor (e.g., 1999, 2003) and others as Contingent Theory has continued to be evaluated under different case studies.

The Spiny Dogfish Contingent Hypothesis: Description of the Proposed Mid-Atlantic Migratory Contingent

Summer Habitats: Northern Extent of Proposed Contingent Range. The original Spiny Dogfish contingent hypothesis proposed in TRAC (2010; Figure 81) suggested that New England, and especially the Cape Cod area, was the natural intermixing ground for the US and Canadian stocks. Cape Cod was hypothesized to serve as a natural boundary between a proposed Mid-Atlantic Contingent and a Gulf of Maine Contingent of Spiny Dogfish. Migration to summer habitats in the northern extent of the range was initiated in March and appeared to take roughly two months, based on mark-recapture and acoustic tagging data presented in Chapter 3. Recapture data suggested that the northward migration took place over a longer period of time than the southward migration into overwintering grounds. Recapture data also suggested that Spiny Dogfish appear to distribute north around Cape Cod in June, with the return migration occurring in October. To further test the hypothesis that Cape Cod constituted mixing grounds between proposed contingents, the Rulifson lab conducted a tagging experiment off Cape Cod to identify the amount of mixing that occurred between the Mid-Atlantic Bight and the Gulf of Maine contingents, and to evaluate sexual segregation north and south of Cape Cod (Rulifson et al. 2012; Dell'Apa et al. 2014). The 42º N latitude line was proposed as a boundary based on recommendations from commercial fishermen. Sharks were tagged north and south of Cape Cod and along Cape Cod (just south of the 42ºN latitude parallel). Overall the estimated average rate of intermixing between sharks on the north side and sharks on the south side of Cape Cod, based on external tag return data, was 28 percent. The rate of intermixing of sharks tagged south of Cape Cod (i.e., they were recaptured north of Cape Cod) was higher than the rate of intermixing of sharks tagged north of Cape Cod. However, the acoustic tag and mark-recapture data suggested that Spiny Dogfish tagged to the south do venture north of Cape Cod. In particular, a large number of tag returns were received from sharks captured between Cape Cod and Cape Ann, in coastal waters of Massachusetts (in particular, along Cape Cod and within Cape Cod Bay and Massachusetts Bay). The distribution of recaptures was consistent with the areas with the greatest catch per unit effort for the NOAA Fisheries NEFSC fall bottom trawl survey (McMillan and Morse 1999).

Fifteen of 93 (16 percent) North-Carolina tagged sharks were redetected on acoustic arrays maintained by the Gulf of Maine Ocean Observing System (GoMOOS) north of Cape Ann and in the middle of the Gulf of Maine. Fifty-three of 410 (approximately 13 percent) of tag returns analyzed for this dissertation were returned from New Hampshire, Maine, or the Canadian Maritimes (north of the proposed terminus at Cape Ann). Results suggested that the northern extent of the proposed Mid-Atlantic contingent extends to Cape Ann, Massachusetts, with a small number of sharks (less than 20 percent) moving further north into the areas utilized by the proposed Gulf of Maine contingent.

Overwintering Habitats: Southern Extent of Contingent Range. Our research strongly supported the idea that the southern Mid-Atlantic Bight (and areas further south) may serve as overwintering grounds for a unique group of Spiny Dogfish due to the fact that 1) notable numbers of acoustically tagged sharks were redetected over the duration of the study (sometimes in consecutive years, sometimes after 2-3 years), and 2) that many sharks tagged with external dart tags were often recovered subsequent years after tagging within a relatively short distance of the release location. Based on external conventional tagging and acoustic tagging, the southward migration to overwintering habitats is initiated in October. Spiny Dogfish were reported by commercial fishermen to show up as early as November (D. Hemilright, pers comm.), a contention that was supported by a small number of tag returns from the mark-recapture study. Tag returns from North Carolina usually began in earnest in December, the same month that tagged Spiny Dogfish showed up on the Hatteras Bight acoustic array in the winter of 2010-2011. The southern extent of the hypothesized Mid-Atlantic contingent appeared to be depicted in Figure 81 as Cape Hatteras, North Carolina. However, the results of both the acoustic and mark-recapture study implied that Spiny Dogfish do migrate around Cape Hatteras. In 2009, acoustic tagging was focused solely on sharks captured north of Cape Hatteras; thirteen percent of tagged sharks were redetected south of Cape Hatteras in the same year of tagging. In subsequent years, as many as 25 percent of the tagged animals at liberty were re-detected south of Cape Hatteras. Numerous other studies have noted large numbers of Spiny Dogfish between Cape Hatteras and the North Carolina-South Carolina line (Hickman et al. 2000; Newman et al. 2002). Sufficient numbers of Spiny Dogfish exist off Wilmington, NC to support an annual dogfish-fishing tournament in January; in 2010 approximately 66 dogfish were captured by anglers participating in the tournament (A. Baird, pers. comm., Dec 2013). Spiny Dogfish have also been captured in surveys conducted by the South Carolina Department of Natural Resources (B. Frazier, South Carolina Department of Natural Resources, Marine

Resources Division, Charleston). Many of these reports of Spiny Dogfish occur at times when water temperatures are unusually cool in these areas. However, Spiny Dogfish have also been noted south of Cape Hatteras later in the spring than the timing of departure implied by tagging and mark-recapture data in water temperatures that are much higher than the previously assumed tolerance limits for Spiny Dogfish (22-28ºC; Bangley and Rulifson 2014). A longline survey for sharks conducted by the University of North Carolina-Wilmington off Cape Lookout, North Carolina in Onslow Bay notes the presence of Spiny Dogfish in late spring (April and May) in 1978, 1979, 1986, 1989, and 1999. The southern functional extent of Spiny Dogfish very likely may extend well south of Cape Hatteras along the continental shelf. Appropriate conditions likely also exist for this species off the continental shelf, under and seaward of the Gulf Stream.

It is unclear why dogfish would remain off the coast of North Carolina for so long in a given year, unless sufficient thermal refugia exist or the bioenergetic trade-off is such that dogfish tolerate unfavorable conditions long enough in order to take advantage of abundant prey resources (e.g., many species of anadromous fish move through the area to complete spring spawning activity). I observed dramatic differences in water temperature between regions close to shore (due to cold water outflow from the Pamlico-Albemarle Sound estuary system) and water temperatures offshore that may be influenced by the Gulf Stream, and I noted several instances where acoustically-tagged dogfish moved onshore when temperatures increased offshore (and vice versa). Given the narrow width of the continental shelf off southeastern North Carolina, dogfish would not have to travel far in order to reach the shelf break and presumably colder waters underneath the Gulf Stream and on the abyssal plain. I also hypothesize that movements around Cape Hatteras may be linked to changes in available temperature regimes and weather patterns.

The Migration Pathway. The original Spiny Dogfish Contingent Hypothesis noted distinct seasonal migration patterns to feeding and overwintering grounds (Clark 1968; Secor 1999; Figure 81). I used mark-recapture and acoustic tagging, along with substantial evidence from other surveys and research programs, to delineate a potential northern and southern extent for the TRAC-proposed Mid-Atlantic Contingent of Spiny Dogfish. However the same behavior was typically not observed in acoustically-tagged individuals in consecutive years. For example, in 2009, large numbers of sharks occurred consecutively in North Carolina and Delaware Bay from the late winter through late spring. Sharks were then sporadically detected on arrays in the Gulf of Maine and New England, but not in large numbers. In the fall of 2009, a moderate number of Spiny Dogfish were again detected on the acoustic array, before returning to North Carolina waters in 2010. A large number of 2009-tagged sharks showed up later in the year on acoustic arrays in the Gulf of Maine and New England, and several of these sharks showed up back in North Carolina waters in winter 2011. By comparison, 2010 tagged dogfish were strongly present on acoustic arrays off North Carolina (in winter of 2010 and 2011), coastal Massachusetts (summer and fall 2010), and on acoustic arrays deployed off New York and New Jersey in 2011. Collectively, these data suggest that dogfish may not undertake the same migration pathways on an annual basis. Furthermore, dogfish periodically disappeared for periods of time, as exemplified by few 2009-tagged dogfish being detected in large numbers on any acoustic array in the northern part of the range, and individual dogfish only showing up on the Cape Hatteras acoustic array in Year 2 or Year 3 of our study. The mark-recapture tagging study suggests that some dogfish become unavailable to the fishery for multiple years in a row, based on extremely lengthy amounts of time between release and recapture of tagged Spiny Dogfish. I therefore hypothesized that 1) dogfish may vary the exact migration pathway based on environmental conditions between North Carolina and the Gulf of Maine, 2) that some individuals complete part of the migration off the continental shelf or beyond the range of any coastal acoustic arrays, and 3) some dogfish may remain off the continental shelf for extended periods of time before returning to feed or overwinter on the continental shelf. Additionally, I propose some additional modifications to the Spiny Dogfish Contingent Hypothesis that encompass the migration pathways noted from mark-recapture and acoustic tagging studies presented in this dissertation (Figure 82). Some evidence is available which implies dogfish movement off the continental shelf. A small number of tagged Spiny Dogfish were recaptured far off the continental shelf (R.A. Rulifson, East Carolina University, Greenville, NC, pers comm.). Additional research completed by Carson et al. (2014) noted that Spiny Dogfish tagged and released with satellite tags off the coast of North Carolina disperse either along the continental shelf, or eastward into deep waters off the continental shelf, sometimes beyond the extent of the U.S. Exclusive Economic Zone.

Spiny Dogfish Reproductive Behavior: Contingent or Metapopulation? Contingent behavior is partially defined by Clark (1968) as a unique migration pathway that is inclusive of reproductive grounds; however, contingent theory usually refers to divergent behaviors that result in different groups of fish dispersing spatially along unique migration pathways (Kraus and Secor 2004). Contingents are thought to have a common reproductive ground (Kraus and Secor 2004). Metapopulations, on the other hand, are comprised of discrete, persistant sub-units within a stock that may home to specific spawning and feeding habitats. These sub-units are spatially linked to each other and experience some degree of exchange between sub-units (Hanski and Gilpin 1997). Metapopulation theory as applied to marine fish stocks is highly dynamic, as sub-units within a metapopulation may undergo temporary extinction, recolonization, expansion, contraction, or development in new areas (Smedbol and Wroblewski 2002). Exact pupping grounds for Spiny Dogfish are unknown, but pregnant females with near-term pups, neonates and juveniles are known to occur in a handful of areas. The location of known pupping areas could provide additional evidence to discern whether it is more appropriate to regard Spiny Dogfish as contingents or as a metapopulation. Furthermore, consideration should also be given to the reproductive grounds where mating occurs. Contingent theory as applied to diadromous fishes often has genetically indistinct groups of fish converging at some point during a migration cycle. Knowing if spiny dogfish contingents spatially overlapping off New England in the summer were inter-breeding could further explain the genetically indistinct nature of the stock and refine understanding of stock structure (and perhaps provide additional arguments to accept or refute the Spiny Dogfish Contingent Hypothesis).

Pregnant Spiny Dogfish off the northeastern United States are suspected to migrate offshore or to Georges Bank to give birth on the edge of the continental shelf (Jensen 1966; Nammack et al. 1985; Campana et al. 2009), perhaps in fall and winter (Soldat 1979; Nammack et al. 1985; Burgess 2002). Spiny Dogfish have a gestation period of 1.5-2 years (Nammack et al. 1985; NEFSC 2006), which would conceivably permit a pregnant Spiny Dogfish to complete at least one seasonally-based migration circuit (based on our tagging data). Sulikowski et al. (2013) noted large number of neonates in trawl surveys conducted off Block Island, RI and suggest that this region may also constitute pupping grounds. These neonates were found in February 2012. Were the 32,000+ neonate dogfish estimated to have been trawled up by Sulikowski et al. (2013) part of a specific group? Existing evidence is unclear on whether dogfish parturition is isolated to specific areas, or if it occurred along the entire length of the shelf break between Georges Bank and North Carolina. If the latter, then the neonate dogfish observed by Sulikowski et al. (2013) could be part of the hypothesized Mid-Atlantic Contingent; however, given the known migratory and overwintering behavior of Spiny Dogfish in the Gulf of Maine it was also possible that these are proposed Gulf of Maine Contingent dogfish.

Pregnant females and young Spiny Dogfish were documented to occur off the continental shelf in the mid-Atlantic Bight (Burgess 2002; Castro and Peebles 2011). Results from the 13-year mark-recapture study analyzed in Chapter 3 suggest that over 75% of wintertime (Jan – March) recaptures of the dogfish tagged and released off North Carolina occurred off Virginia and North Carolina. Females carrying near-term pups (Stage V, Moore 1998 and Register 2006) were found along the shelf break of Mid-Atlantic Bight waters of North Carolina and Virginia on annual spring bottom trawl surveys conducted by the Northeast Fisheries Science Center (K. Sosebee, pers comm.) and on the shelf in coastal habitats on the U.S. Fish and Wildlife Service-led Cooperative Winter Tagging Cruise (a trawl survey conducted off North Carolina and Virginia in January or February of a given year; ASMFC, ECU, MDDNR, NCDMF, NMFS, and USFWS, unpublished data). Pregnant female dogfish were also often captured for reproductive research purposes using commercial fishing gear in a number of studies off the coast of North Carolina (e.g., Rulifson et al. 2002; Register 2007). Although the composition of the female reproductive stages varied by study, between 25 to 45 percent of the pups were full term (Stage V). We observed females on the Cooperative Winter Tagging Cruise periodically birthing full-term pups on the deck or in the trawl net, possibly as a stress response to capture. Young juveniles were occasionally encountered by small mesh gillnet fishermen in the Hatteras Bight (C. Hickman, pers comm.; Rulifson et al. 2013). However, compared to the number of females with near-term pups, the number of neonates and juveniles found in coastal waters of North Carolina were relatively small. Tagged juvenile Spiny Dogfish released in the Hatteras Bight were never redetected on coastal arrays in North Carolina or further north (Rulifson et al. 2013). Juveniles observed on the shelf near Cape Hatteras may have been temporary residents in coastal habitats before moving offshore, or up into the middle of the water column and therefore not susceptible to fishing gear (Beamish and Sweeting 2009).

Our research demonstrates that large, reproductively mature females (>800 mm TL) tagged and released with both acoustic and conventional mark-recapture tags completed migration circuits between North Carolina and Massachusetts, and sometimes returned to coastal North Carolina waters in consecutive years. Our mark-recapture tag return data comparing distance of travel between release and recapture sites and days at large suggests a strong cyclic pattern in the geographic distribution of dogfish through time. Therefore, it is possible that overwintering habitats in the southern extent of the proposed Mid-Atlantic Contingent range may serve as an important part of the dogfish reproductive cycle. Given that we know individuals (this study) or large schools of dogfish (Newman et al. 2000) do not remain in coastal areas of the Hatteras Bight for extended periods of time, and that individually tagged sharks move on and off the shelf in response to environmental conditions (Chapter 4), it is possible that presumptive Mid-Atlantic Contingent sharks may move offshore to give birth (or that small numbers of sharks give birth in inshore waters). Hanchet (1988) suggests that pregnant Spiny Dogfish move inshore during the first year of gestation, and offshore during the second year to give birth at the start of winter (i.e., May to June in the southern hemisphere). Pregnant females found off the coast of North Carolina may therefore also be within the first year of gestation before disappearing offshore to parturition sites. This provides a possible explanation for why some tagged dogfish may not have been detected on coastal arrays in consecutive years.

Management of Behavioral Contingents

I have used the data presented within this dissertation to make a potential case for the delineation of a Mid-Atlantic Migratory Contingent of Spiny Dogfish. The question remains whether it is appropriate to manage at the contingent resolution for this species, if contingents truly do exist. In order to address this, I make a case for management at the appropriate unit stock through examination of fisheries in which stock collapse can be partially attributed to a misunderstanding of stock structure. I review examples where management at the contingent level is plausible, and I also consider cases in which contingents are recognized but the resolution of management is higher (coarser) than at the level of contingent. Finally I discuss whether Spiny Dogfish could be managed at a contingent level, noting that Spiny Dogfish have undergone a revolution in management that responds to greater local and regional fishery needs which indirectly reflects the behavior of the proposed northern and Mid-Atlantic Migratory Contingents.

Consequences of Stock Management at Inappropriate Resolutions. Identification and delineation of appropriate stock units are essential for understanding the true state of a fish stock, and for the creation of effective and sound fishery management measures (Stephenson 1999). Modern fisheries management strategies and stock assessments assume discrete populations (Stephenson 1999); however, simply identifying the stock to be managed or assessed can be a challenge. Most applied population models used in stock assessments are developed to describe a known group of fish with homogeneous vital rates (e.g., growth, maturity, mortality) and a closed, definable life cycle (Cadrin et al. 2014). Often, fishery managers must attempt to describe stocks and predict appropriate levels of harvest with incomplete information, usually at a much simpler scale and under a tight set of assumptions that do not actually reflect the full range of environmental, biological and anthropogenic factors that affect the status and health of fish stocks. Simply defining the management unit can be a great challenge, since it can be based on many things (e.g., population structure, behavior, genetic delineation of stocks, geophysical boundaries, political/jurisdictional boundaries, etc). Secor (2013) summarizes three criteria that affect the definition of stock structure: 1) identification of the stock; 2) evaluation of the stock unit area, or the geographic boundaries that contain the movements and processes associated with a stock; and 3) the long term stability of a stock and its boundaries (Begg et al. 1999; Cope and Punt 2009; Link et al. 2011).

Many migratory species were initially managed as single-stock fisheries until population declines forced managers to consider alternatives that redefined the unit stock. Multiple spawning units have long been known to exist for Striped Bass (*Morone saxatilis*), Atlantic Cod (*Gadus morhua*), Atlantic Herring (*Clupea harengus)* and Pacific (*Oncorhynchus* spp.) and Atlantic (*Salmo salar*) salmon, but management of these species was initially focused on single unit stock approaches that disregarded complex population structures and the importance of individual spawning groups (Sinclair 1988; Sinclair and Iles 1988; Stephenson 1999). Overfishing and erosion of population sub-components, even under management thought to occur at the appropriate scale for overall stock units, may still occur (Stephenson 1998), as is evidenced by the collapse of northwest Atlantic Cod off the coasts of the United States and Canada.

The collapse of the Gulf of Maine Atlantic Cod through the second half of the 20th century provided an excellent example of the critical need to identify stock structure, and manage fishery resources at an appropriate scale. Despite improved scientific understanding of cod meta-population structure (Wise 1963; Serchuk and Wigley 1993; Myers et al. 1997) and repeated warnings from scientists about the decline in cod populations, the New England Fishery Management Council (NEFMC) still permitted unsustainable harvest levels (Dobbs 2000). System-wide assessments did not capture the status and importance of individual population subgroups (Ames 2003). The U.S. identified three to four different stocks of cod through the 1990s in the Gulf of Maine. These stocks were comprised of many contingents that exhibited unique behaviors, including different migration corridors to partially isolated spawning grounds (Ames 2003). Certain contingents of cod were exposed to such high levels of directed fishing that they became functionally extinct, and have yet to recover via meta-population processes of exchange and colonization (Robichaud and Rose 2004).

A concurrent collapse of cod was also noted in Canadian waters for six of seven cod populations by the early 1990s. Many biologists noted that the inability to control fishing mortality was largely to blame for poor stock health (Hutchings and Myers 1994; Myers et al. 1997). In particular, fishing mortality was consistently underestimated and underreported; the ability of fleets to continue to catch fish efficiently at low abundance levels due to the efficiency of fleets and increased effort (and concurrent assumption that catch per unit effort can be comparable to stock abundance); and increased discarding and non-reporting of small fish. As a result, the population abundance of cod was overestimated in stock assessment models, and fishing mortality was underestimated (Myers et al. 1997). Robichaud and Rose (2001) noted a significant difference between the spatial extent of stocks (as management units) and the total range of cod populations off Newfoundland, Canada.

Delineating a stock includes a geographic component, such that fishery managers must be able to adequately identify and audit the internal dynamics of groups of fish against the effects of fishing activities within a specified area (Cadrin and Secor 2009). Identifying the physical boundaries of where a stock may be distributed is critical in ensuring that data are collected on the entirety of the stock for a more complete audit. It is not unusual for fishery management boundaries to be mismatched with the spatial distribution of populations, since stocks may be operationally defined by geopolitical boundaries, the geographic extent of fishing, or other physical aspects of the fishery (Cadrin and Secor 2009). A lack of understanding of the geographic scope and extent of a stock can undermine management efforts. Migratory species in U.S. territorial waters that cross jurisdictional boundaries may be exposed to varying degrees of management by states, interstate commissions, and the federal government. Armstrong et al. (1998) note that successful management of Atlantic salmon depends more than just identifying and protecting adult fish, since there are a tremendous number of factors at multiple scales that can affect reproductive success. These factors may vary from very large (climate change) to very localized (fish passage) or very direct (fishing mortality) management issues that must all be managed for in the maximization of cohort survival to adulthood and a reproductive event.

Management of Contingents. Successful management of contingents, at its core, requires a robust understanding of life history strategies that may drive the adoption of different behaviors within a population. Identification of contingents is particularly robust in the literature dealing with diadromous species whose populations also display partial migration. This phenomenon occurs when a fraction of a population migrates and the remainder stays resident to a particular area. Partial migration is extremely widespread, distributed across orders of fish, occurs in a variety of habitats, and occurs across multiple scales (Chapman et al. 2012). The adoption of different behavioral strategies may result in groups characterized by different vital rates (e.g., productivity, growth rates). Gillanders et al. (2015) identified partial migration in Black Bream (*Acanthopagrus butcheri*) otoliths collected from fish in the Murray River, Australia. Inclusion of contingent type (resident or migrant) improved the ability of models to explain variation in growth rates 56 times more than models that simply used age as a variable. Such spatial structuring within populations may represent a means of bet-hedging against competition and unfavorable environmental conditions (Secor 2007; Kerr et al. 2010). Petitgas et al. (2010), in reviewing and applying the contingent theories established by Secor (1999) to Atlantic Cod, noted that resident contingents confer stability, whereas migratory contingents confer productivity, and connectivity between the two tends to increase stock size. Strong year classes produced by resident contingents supported recovery for depleted populations. Fisheries that disproportionately exploit one behavioral contingent may lead to population decline if environmental conditions favor the strategy of the overfished contingent.

Management can prioritize the conservation of one or more contingents depending on management goals. Kraus and Secor (2004) identified a resident freshwater contingent of white perch and a migratory brackish water contingent. They noted that if biomass production is the primary goal of management, then protection of brackish juvenile habitats of White Perch should be prioritized since the brackish water contingent of white perch had higher growth and survival rates. If long-term viability is important, then protection of freshwater contingent habitats should be prioritized (in this case, freshwater habitats are spatially restricted and vulnerable, but support the reproductive potential of white perch during poor recruitment years). The most effective management plan would have to consider the health and protection of habitat for each contingent (Kerr et al. 2010). Through simulation modeling, Kerr et al. (2009) noted the sensitivity of population stability, productivity, and resilience to the proportion of behavioral contingents within a population. Increased numbers of migratory contingents of white perch yielded increased productivity and resilience but decreased stability, whereas increases in the proportion of the resident contingent conferred stability but decreased productivity and resilience. Kerr et al. (2009) conclude that contingents play different roles in the dynamics of populations. Partial migration and contingent theory are thus key concepts in decision-making regarding fisheries management due to observed differences in growth rates, differential exploitation on the most productive components of a stock, affects on sex ratios or age structure, and otherwise reduced phenotypic and genotypic diversity (Chapman et al. 2012).

Management actions for stocks that are known to have unique behavioral contingents should be crafted to be broad enough to protect all contingents, if management at the contingent level is not practical. Common Snook (*Centropomus undecimalis*) is a catadromous subtropical species common in Florida that provides an important recreational fishery there. The species is thought to use riverine habitats in the winter (overwintering and feeding) and estuarine habitats in the summer (spawning). Population declines were observed anecdotally through the 1950s, and eventual sampling completed by the Florida Fish and Wildlife Conservation Commission indicated that populations had declined 70 percent between 1977 and 1981 (FL FWC, http://myfwc.com/research/saltwater/fish/snook/management/). Recent research by Lowerre-Barbieri et al. (2014) suggests that Common Snook contingents may use different overwintering habitats (some exhibit typical catadromous behavior of moving into fresh water to feed and grow, whereas others remained in the estuary year-round). Current management measures exist to sufficiently protect both contingents. Management of the species is focused on maximizing standing stock biomass across the state through bag limits, closures, and slot limits. For example, the Florida snook fishery is closed during the months of January and February to protect overwintering snook, and from June through August to protect spawning aggregations (Florida Fish and Wildlife Conservation Commission, http://myfwc.com/research/saltwater/fish/snook/management/). Since these regulations are not spatially implemented, they provide protection for both contingents observed by Lowerre-Barbieri et al. (2014).

Sometimes certain contingents are subject to greater fishing pressure due to ease of access by fishery participants. Sargarese and Frisk (2011) studied contingents of Winter Flounder (*Pseudopleuronectes americanus*; an inshore contingent that lives in coastal bays, a contingent that is connected to multiple inshore areas, and a dispersive contingent that moves from offshore to onshore in winter to spawn). Inshore populations of Winter Flounder have declined since the 1980s, possibly as a result of excessive exploitation of inshore populations that are subject to greater effort from commercial and recreational fisheries. Fisheries focused on a particular contingent may also disrupt critical life history behaviors or focus effort on the most fecund individuals within a stock. Collins et al. (2015) studied inshore and offshore spawning components ("contingents") within the same unit stock of Hogfish (*Lachnolaimus maximus*) in the eastern Gulf of Mexico due to differences in growth rates and mortality experienced within the first 2-3 years of life. Offshore contingents are characterized by larger, more fecund adults; faster growth experienced by juveniles; and sexual transitions (female to male) occurring in fish that are larger and older than inshore contingents. The transition from female to male can take time, males are the larger fish, excessive fishing pressure on the largest means a sexually selective fishery, or a fishery that targets the most fecund fish. The nearshore contingent has greater fishing pressure, less harem stability and reduced spawning periods vs. the offshore one.

Larger Hogfish offshore may buffer loss of reproductive potential from the more heavily fished inshore contingent. Collins et al. (2015) recommended the use of spatially explicit Hogfish stock assessments to acknowledge potential roles of offshore and inshore contingents in overall population status.

Some contingents undertaking different behavioral patterns or partial migration may be subject to successive, high levels of fishing pressure. Tsukamoto et al (1998) noted populations of silver European (*Anguilla anguilla)* and Japanese (*Anguilla japonica*) eels captured from the North Sea and the South China Sea that did not appear, based on otolith microchemical analyses of Sr:Ca ratios, to have a freshwater phase. Identification of marine contingents is prevalent in coastal and riverine studies. Behavioral contingents were recently identified in Japanese Eel (Tzeng et al. 2002), whereby Sr:Ca ratios in otoliths suggested that three contingents of eel were present and were behaviorally distinguished by elver residency in freshwater, saltwater, or both. Lin et al. 2012 used otolith microchemistry to identify estuarine, freshwater and marine contingents of Japanese Eel. Eels from one contingent (estuarine) made up the majority of recaptures. However, results also suggested that yellow-phase eels have a relatively small home range in sampled riverine habitats, and the authors noted the risk of localized depletion and overfishing of yellow-phase eels in freshwater habitats. Lamson (2005) noted the presence of three contingents in a sampled population of American Eel (*Anguilla rostrata*) (freshwater, facultative (inter-habitat shifters), and marine), with observed differences in growth rates between the three contingents that could have implications for population modeling and stock assessments. Lamson (2005) also noted that the freshwater and facultative contingents experience an extended duration of cumulative exposure to commercial fishing, suggesting that freshwater fisheries be managed more conservatively than marine fisheries in order to protect these more vulnerable contingents.

Contingents may be recognized as part of the life history or in a stock assessment, but may not serve as the basis for the definition of a formal management unit or be managed separately within a fishery management plan. Atlantic Mackerel are recognized to be part of two major contingents that are harvested in Canadian and U.S. waters that experience different growth rates (Sette 1950). One contingent spawns in the mid-Atlantic Bight and moves northward into waters of the Gulf of Maine and Nova Scotia, whereas the other moves from offshore overwintering habitats along the coast of Newfoundland to the Gulf of St. Lawrence for spawning (Studholme et al. 1999). Between 1973 and 1977, total allowable catches (TACs) were set for different contingents (MAFMC 1998). Moores et al. (1975) hypothesizes that the international fishery was supported in greater proportion by the northern contingent. However, a lack of genetic differentiation or distinctions between contingent contribution to total population resulted in the stock being managed as a single transboundary unit stock after 1975 (Anderson 1982; MAFMC 1994; Studholme et al. 1999). Three migrating groups of Bluefish (*Pomatomus saltatrix*) are known to occur offshore of New Jersey (an inshore, mid-shelf, and an offshore contingent) (Freeman and Turner 1977); however, the Bluefish management plan is based on a single unit stock. Sometimes structuring at the contingent level may represent too fine a resolution for practical management. For example, Mather et al. (2013) noted that tagged Striped Bass from a coastal Massachusetts estuary consistently undertook at least nine different routes to at least three overwintering destinations. As evidenced in the discussion above, many species whose population structure is comprised of multiple contingents experience intermixing between contingents. A lack of understanding of the spatial structure of these populations can contribute to bias in sampling and population estimation. The Atlantic Herring (*Clupea harengus*) interstate fishery management plan acknowledges the potential for overestimation of abundance on surveys from herring of different groups mixing and becoming highly available (locally) to the survey (ASMFC 1993). Periodic high abundance of one contingent may mask declines in another contingent (Sargarese and Frisk 2011). Kerr et al. (2010) suggest either management of contingent relative abundance through habitat or conservation efforts (assuming that abundance is linked to a preferred habitat state), or management of separate contingents within a population or stock in such a way that fishing effort is focused on the most productive contingents.

Is Management of Proposed Spiny Dogfish Contingents Appropriate? The above discussion highlights the importance of accounting for unique behavioral contingents in the development of management plans. The research covered within this dissertation and previous tagging studies analyzed by Campana et al. (2008) and at the 2010 TRAC suggest that northwestern Atlantic Spiny Dogfish population structure may be more complex than previously thought, and is hypothesized to be comprised of multiple behavioral contingents. Spatial structuring and partial migration has been observed in migratory and resident Pacific Spiny Dogfish (*Squalus suckleyi*), which are closely related to the species covered in this dissertation, off the Pacific Northwest coasts of the United States and Canada (McFarlane and King, 2003). The question of whether it is appropriate to manage Spiny Dogfish at the contingent level remains, and should be evaluated as new information regarding stock structure is elucidated in future analyses of these data and through new research programs.

This dissertation provides some new migratory information on sharks that could comprise the proposed Mid-Atlantic Migratory Contingent, but does not irrefutably prove nor disprove the Spiny Dogfish Contingent Hypothesis. Given the overlap in behavior, the fact that acoustically-tagged spiny dogfish did not undertake the same migration pathway each year between summer and winter habitats (likely due to environmental conditions encountered along the way), and the lack of genetic distinction, arguments could also be made using these data in favor of a single-stock hypothesis that wholly disregards the incorporation of Contingent Theory. Mark-recapture data comparing latitude of recapture by calendar day (see Figure 48 and Figure 49) could be interpreted as spiny dogfish undertaking similar behaviors based purely on latitude of recapture, especially since the amount of tagging effort undertaken off New England is a fraction of what was undertaken off North Carolina. I recommend that future research projects continue to refine the boundaries and behaviors of Gulf of Maine and Mid-Atlantic Spiny Dogfish to verify or validate that contingents exist, and evaluate growth rates and production between known members of each proposed contingent to further evaluate the need for management at a contingent level.

From an international management perspective, the analyses presented in Campana et al. (2008) and TRAC (2010) suggest that U.S. and Canadian Spiny Dogfish should not be managed in isolation (in part due to a proposed 10-20% mixing between dogfish in U.S. and Canadian waters). Contributors to both reports believed that sufficient evidence exists to suggest the presence of multiple groups of dogfish in Atlantic Canada, including 3 known residential groups of Spiny Dogfish off Newfoundland, the Scotian Shelf, and in the Gulf of St. Lawrence that complete seasonal onshore-offshore migrations, and 2 known migratory groups of dogfish that move around the Gulf of Maine and between the Mid-Atlantic and the Gulf of Maine.

Furthermore, recruitment in Canadian waters was thought to be somewhat dependent on U.S. dogfish; and that colonization, extended residency, and departure of dogfish aggregations from Canadian waters have all been hypothesized for certain groups of dogfish based on tagging and survey data (Campana et al. 2008). As a result of evidence implying more complex stock structure, the Transboundary Resource and Assessment Committee (TRAC) examined two projection models that either considered two components that intermixed (a northern resident and a southern migratory population) or a single unit stock (TRAC 2010). However, neither model was accepted by the TRAC due to unsatisfactory model fits to time series data from research surveys and strong influences from initial starting conditions. The 2010 TRAC report specifically referenced a need for additional tag studies to clarify movement patterns and mixing rates, and to further explore the models comprising single and multi-unit stocks. Since U.S. fisheries management agencies can only manage stocks under the authority of the Magnuson-Stevens Act in U.S. waters, and special international management provisions have not been established for spiny dogfish as of yet, the management discussion that follows is primarily focused on dogfish that are hypothesized to constitute the proposed Gulf of Maine and Mid-Atlantic migratory contingents.

Spiny Dogfish have long been managed in the U.S. as a single unit stock, but in recent years the management strategies undertaken by U.S. federal and interstate management agencies have been increasingly tailored to allow adaption to local and regional abundance and availability of the species to commercial fisheries. The fishery management plans (FMPs) were initially designed to reflect seasonal availability to the fishery. NMFS created two fishing periods, May 1 through October 31 and November 1 through April 30. The assignment of quota to each semi-annual period in both ASMFC and federal FMPs was based on historical landings data. However, due to the species distribution and availability to fisheries the entire federal quota was taken within three months in the first year of federal implementation (ASMFC 2002). Dogfish were available year-round to New England fisheries, but were only seasonally available to Mid-Atlantic fisheries in high enough volume to make a fishery economically viable. During the 2011-2012 fishing year, the Period 2 quota for Spiny Dogfish was reached in mid-January of 2012, which resulted in the exclusion of Mid- Atlantic fishermen from the most productive part of their fishery. Under Amendment 3 to the Spiny Dogfish federal FMP, the seasonal allocation of the commercial quota was eliminated for federal waters. This action was intended to improve accessibility to the dogfish resource in federal waters, eliminate confusion with interstate management actions, and better align federal management with interstate management (79 FR 41141; July 15, 2014).

The interstate FMP developed by the Atlantic States Marine Fisheries Commission has been adjusted through time to address the equity concerns raised by fishermen. States at the extreme southern end of the Spiny Dogfish range felt that they were not provided fair opportunity to harvest a portion of the quota. Spiny Dogfish were available year round to fishermen off southern New England; however, mid-Atlantic fishermen (in particular those from North Carolina and Virginia) had much less time to participate in the fishery and had to compete with fishermen up through Maine (ASMFC 2011). The timing of dogfish arrival in the southern half of the range has varied in recent years. Addendum II was implemented by ASMFC in 2008 to remove the seasonal allocation scheme and instead divide the interstate quota up between management regions so that each received a percentage share (ASMFC 2008); 58 percent was allocated to the northern region (Maine through Connecticut), 26 percent was allocated to a more southern region (New York through Virginia), and 16 percent was allocated to North Carolina.

Addendum II to the ASFMC FMP included a specific allocation for North Carolina because dogfish were not becoming available until late in the season. The result of this management change in North Carolina was immediately felt by the local fishery. In the 2007 fishing year (May 2007 – April 2008), the North Carolina commercial fishery landed 127,747 pounds of Spiny Dogfish. In the 2008 and 2009 fishing years, North Carolina landed 1.4 million and 1.7 million pounds of dogfish, respectively. While this was an improvement, there was still contention that states in the southern region did not have fair and equitable access to the dogfish resource. The management structure was adjusted again in 2011, when ASMFC implemented Addendum III to dissolve the southern region and allocate percentages of the quota to states based on historical landings in order to preserve access (ASMFC 2011). Mid-Atlantic fishermen still noted fluctuations in dogfish availability from one year to the next; however, their access to the fishery was more strongly protected under the current interstate management plan and recent amendments. Recent management actions undertaken by ASMFC include setting possession limits for the northern region, but allowing southern states to set their own possession limits.

Some of the contingent-level management strategies suggested for other species have already been tried for the Spiny Dogfish fishery. The lack of management in the 1980s and 1990s meant that the proposed Mid-Atlantic contingent of dogfish was heavily exploited throughout the continental shelf phase of its migration cycle. Management strategies based on seasonal quotas did reflect the temporal availability of dogfish throughout the Mid-Atlantic and were originally designed around a "north in summer, south in winter" migration of the stock; however, there was no spatial component that assured the distribution of landings would follow the availability of the stock. After the implementation of management, the fishery remained concentrated in New England waters until the ASMFC developed regional interstate management measures that separated New England fisheries from mid-Atlantic fisheries. If spatial and seasonal restrictions (May to Oct and Nov to April) had been simultaneously implemented (by the same management body), then a framework could have been in place to have management actions reflect the presumed distribution of a Mid-Atlantic contingent. For example, if quota had been distributed to a southern fishery for only the time period of November through April, then protection of a proposed Mid-Atlantic migratory contingent could have been achieved through quota monitoring and subsequent closure of the fishery. However, the spatial extent of southern and northern regions, as later defined in ASMFC management plans, would not have covered the biological range of a defined mid-Atlantic contingent. Thus, even if a "southern fishery" was closed due to excessive fishing mortality and landings, any Mid-Atlantic contingent would still be subject to overfishing once the stock moved into the "northern" region in summer. The current management strategy retains the northern region, but splits the stock between states that comprise the southern extent of the proposed Mid-Atlantic contingent range. This strategy better meets the social and economic needs of the fishery, but the boundaries may not reflect the biology of the Mid-Atlantic contingent, if it truly exists.

Based on the migration patterns identified from my research, regional management based on behavioral contingents could constitute moving the regional split utilized by ASMFC to a dividing line somewhere between Cape Ann and Cape Cod, Massachusetts (Cape Cod would likely be an easier landmark to work with than Cape Ann). Since a change back to simple regional quota management is unlikely given the documented issues with equitable access between the states, the proposed regions could include a Gulf of Maine region (Maine through Massachusetts) and a mid-Atlantic region with quotas for individual states based on historical participation in the fishery (Massachusetts through North Carolina). The overall quota would have to be reallocated between the two regions through rulemaking, and then apportioned to states in the Mid-Atlantic region based on historical composition of the fishery. Since the division between contingents would occur along a geographic feature and not a geopolitical feature (e.g., Cape Cod), managers would have to decide whether to allow individuals on either side of Cape Cod to participate in the other fishery in the event of a closure. However, most fishermen in areas north of the 42º N latitude parallel frequent fishing grounds to the north of this line, and fishermen in areas south of the 42ºN latitude parallen tend to remain south due to the local availability of dogfish close to home and lengthy travel times that would be required to traverse around Cape Cod (Rulifson et al. 2012). NMFS and the ASMFC would have to monitor landings from each region, and, in the event that landings exceed quota, consider closure of regional fisheries and implementation of accountability measures in subsequent years.

In order to justify a regional split, the "vital rates" (biomass, reproduction, growth) would need to be quantified for each proposed contingent, along with overall contribution of each contingent to the Northwest Atlantic reproductive biomass and to the fishery. Relative indices of abundance would need to be developed for each contingent, which either necessitates the ability to distinguish individuals captured in areas of spatial overlap or sampling of areas that are utilized by a particular contingent (e.g., overwintering grounds off the Mid-Atlantic and Georges Bank?). If the best opportunity to sample stocks is during the summer during periods of spatial overlap between proposed contingents, science would need to develop a way to more conclusively identify individuals from each contingent, either through morphometrics, rapid bio-assays or other molecular techniques, or perhaps through continued development of analyses of hard parts (e.g., contingent membership in diadromous fishes can be inferred from otolith microchemistry; perhaps similar approaches could be utilized on the spines or vertebral columns of Spiny Dogfish). From a management perspective, if the percent contribution of proposed contingents towards a breeding stock was known, then managers would have additional justification to protect the most productive contingents.

There would likely be some resistence to management at the contingent level. This type of a management program would require the cessation or alteration of programs that are 16 years in development and enacted through the cooperation of multiple management bodies (the federal government, two councils, the ASMFC, and fourteen states). There would likely be institutional resistance to a proposed change without substantial biological justification. Furthermore, the management and socio-economic implications of this type of change may prevent this from being a realistic option given that 1) the stock is now considered rebuilt and the perceived need for further restructuring of management may not make this a priority; and 2) the proportion of new recruits to the overall fishable U.S. dogfish stock that come from any Mid-Atlantic contingent are unknown. This type of a change could have negative socio-economic effects on the fishery, but changes would likely be most pronounced in select areas that rely most heavily on the dogfish fishery. For instance, states with high production like North Carolina, Virginia, and New Jersey could be subjected to quota changes under a reallocation scheme that might not be favorable once Massachusetts landings are incorporated. Massachusetts consistently has the greatest number of participants and landings in the Spiny Dogfish fishery (MAFMC 1999; ASMFC 2002; ASMFC 2013). It might be challenging to identify and account for historical landings in the two regions that would border Massachusetts. Splitting the region into Gulf of Maine and Mid-Atlantic management regions (with further subdivisions by state) could generate confusion regarding fishery regulations between the regions and states, and could reduce the options available to commercial fishermen in case of inclement weather (i.e., fishing inside the hook of Cape Cod could generate profit in poor weather because Cape Cod Bay is somewhat sheltered). However, a regional closure on one side of Cape Cod would not affect fishing opportunities on the other side of the Cape. Fishermen on the north side of Cape Cod tend to remain on the north side of Cape Cod, and vice versa (M. Pratt, pers comm., 2009). Quota monitoring reinforced with regional closures might also slow down the market production of Spiny Dogfish in certain areas. The Spiny Dogfish Advisory Panel for the Mid Atlantic Fishery Management Council noted that flooding the market with a lot of product is harmful, and on Cape Cod the local processors have instituted mandatory days off since 2013 to slow down the volume that was coming to processors (MAFMC 2015).

The rapid decline and recovery of Spiny Dogfish stocks in the 2000s is worth remembering, as science cannot yet explain how a species that was supposed to take decades to rebuild did so in a fraction of the time expected. Although the stock was successfully rebuilt, we are not much closer to understanding the population level mechanisms that enabled recovery and therefore cannot manage the stock in a way that fully protects these mechanisms.

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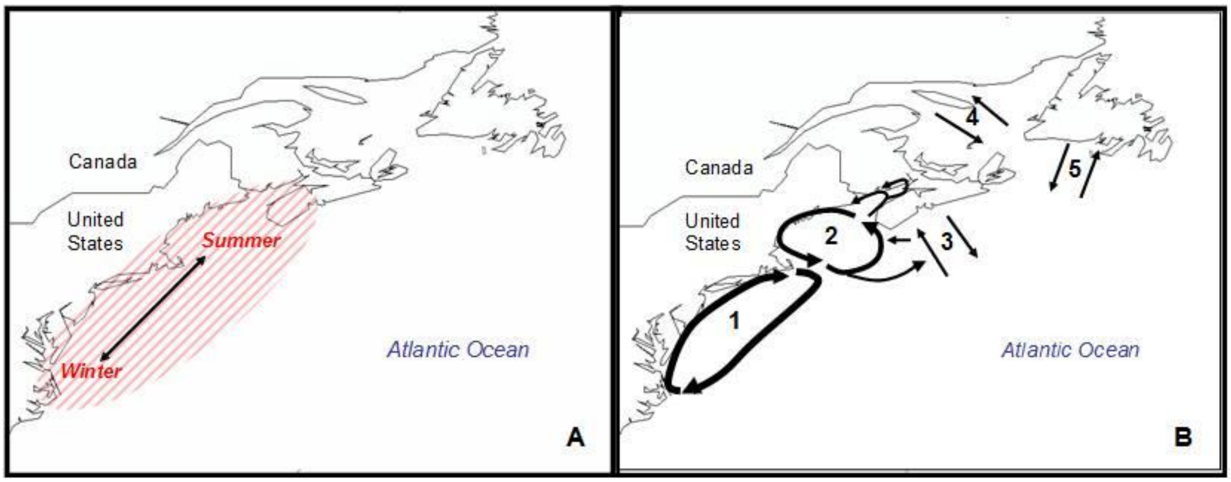
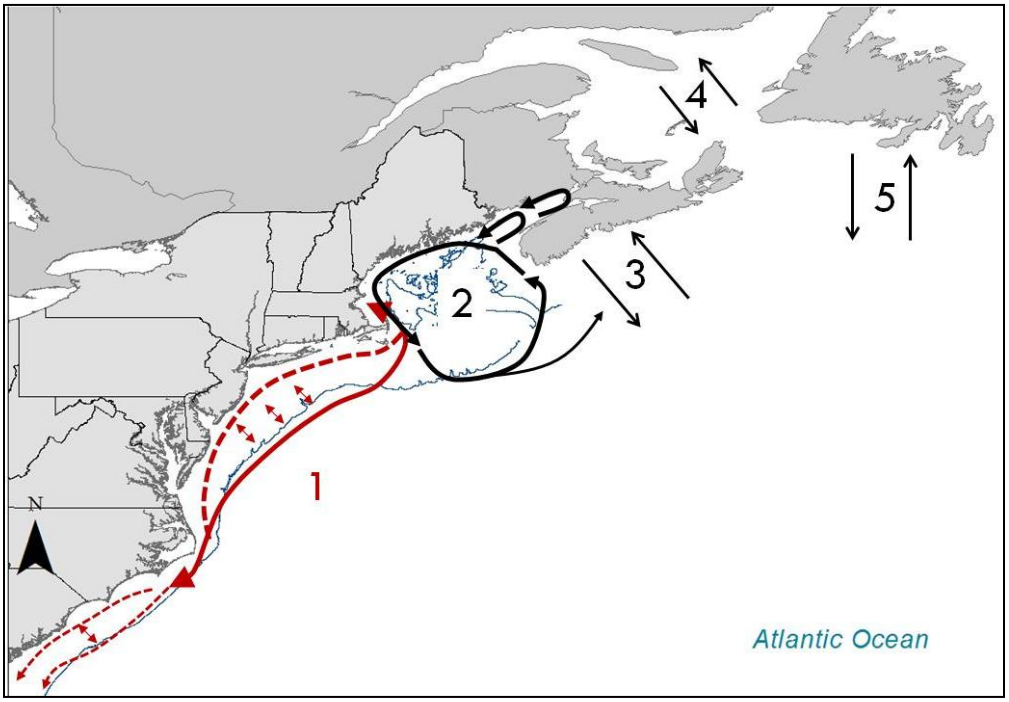


Figure 82.



APPENDIX 1. LITERATURE REFERENCED IN ACOUSTIC TELEMETRY META-ANALYSIS (CHAPTER 2)

This appendix lists the articles included in the meta-analysis of CHAPTER 2: DESIGN CONSIDERATIONS FOR OFFSHORE ACOUSTIC ARRAYS TO SUPPORT BEHAVIORAL RESEARCH., separated by whether they fall into the elasmobranch or non-elasmobranch sample of articles.

Non Elasmobranch Articles

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Alos, J., D. March, M. Palmer, A. Grau, and B. Morales-Nin. 2011. Spatial and temporal patterns in *Serranus cabrilla* habitat use in the NW Mediterranean revealed by acoustic telemetry. Marine Ecology Progress Series 427:173-186.

Annandale, S.F. 2014. Diel movement patterns of *Scarus rubroviolaceus* and *Scarus psittacus* examined using acoustic telemetry in Puako, Hawaii. M.Sc Thesis. University of Hawaii at Hilo.

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 66:1230-1244.

Bass, A.L., T. O. Haugen, and L.A. Vollestad. 2014. Distribution and movement of European Grayling in a subarctic lake revealed by acoustic telemetry. Ecology of Freshwater Fish 23:149-160

Bultel, E., E. Lasne, A. Acou, J. Guillaudeau, C. Bertier, and E. Feuneun. 2014. Migration behaviour of silver eels (*Anguilla anguilla*) in a large estuary of Western Europe inferred from acosutic telemetry. Estuarine, Coastal and Shelf Science 137:23-31

Castagna, J. 2010 Corps Fish Study Nets Useful Data Pages 141-144 in K.S. Wolf, and J.S. O'Neal (eds.). PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities: Pacific Northwest Aquatic Monitoring Partnership Special Publication 2010-002, chap. 4, p. 69-94.

Chateau, O., and L. Wantiez. 2007. Site fidelity and activity patterns of a Humphead Wrasse, *Cheilinus undulatus* (Labridae), as determined by acoustic telemetry. Environmental Biology of Fishes 80:503-508.

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Danylchuk, A.J., S.J. Cooke, T.L. Goldberg, C.D. Suski, K.J. Murchie, S.E. Danylchuk, A.D. Shultz, C.R. Haak, E.J. Brooks, A. Oronti, J.B. Koppelman, D.P. Phillipp. 2011. Aggregations and offshore movements as indicators of spawning activity of Bonefish (*Albula vulpes*) in the Bahamas. Marine Biology 158:1981-1999. DOI 10.1007/s00227-011-1707-6

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Grotheus, T.M., and K.W. Able. 2007. Scaling acoustic telemetry of Bluefish in an estuarine observatory: detection and habitat use patterns. Transactions of the American Fisheries Society 136:1511-1519.

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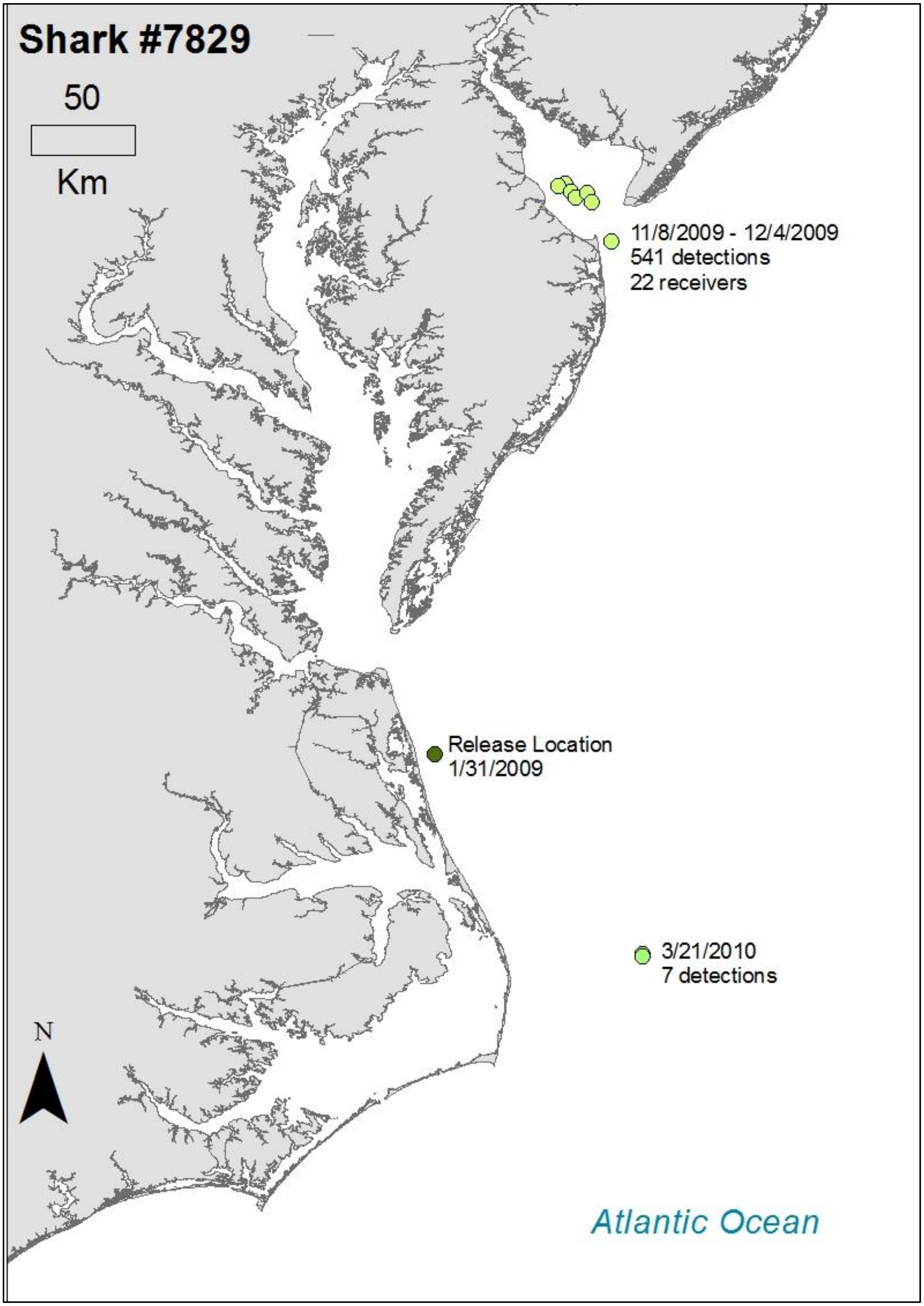
APPENDIX 2. MAP LIBRARY OF ACOUSTIC DETECTIONS – 2009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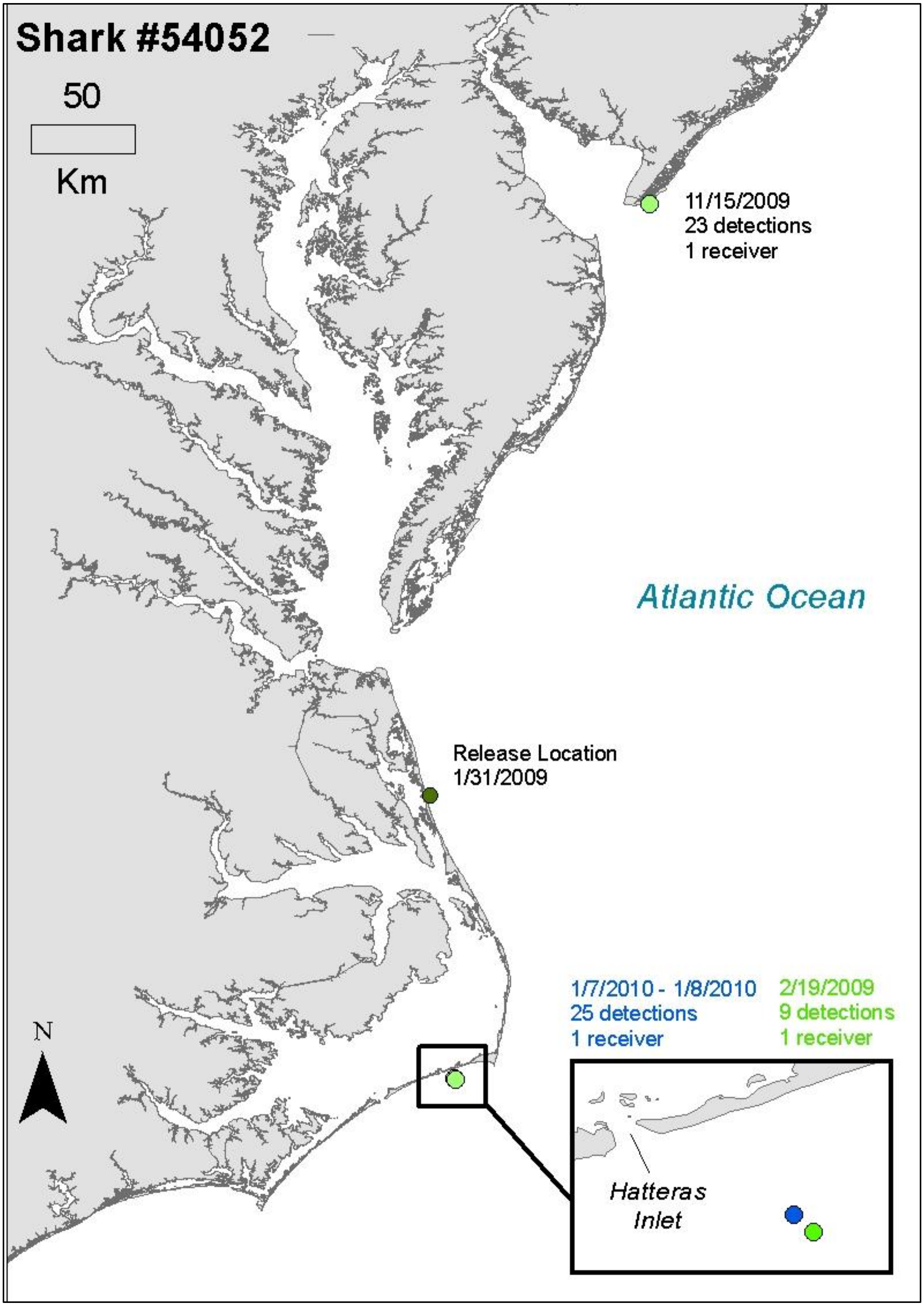
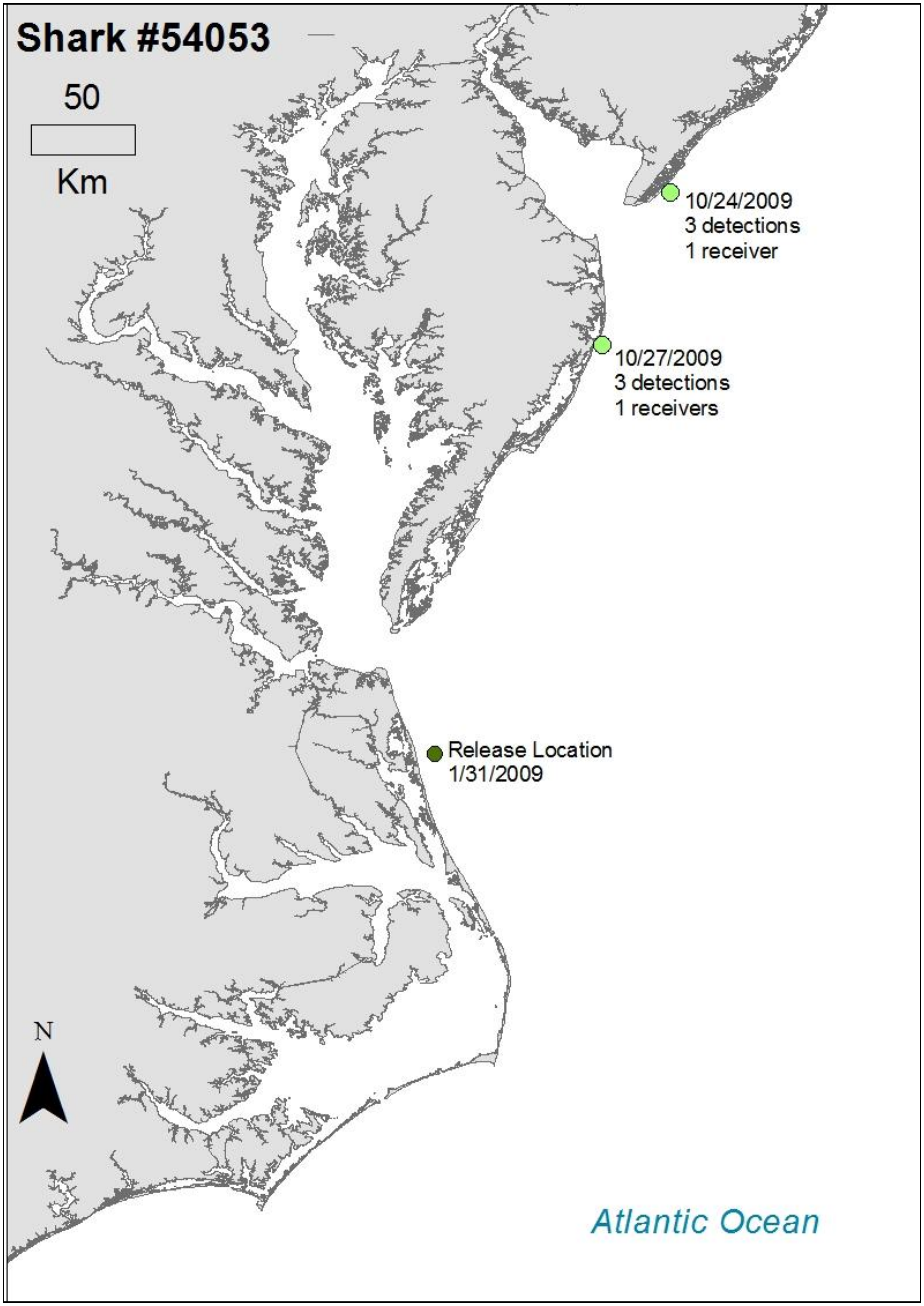
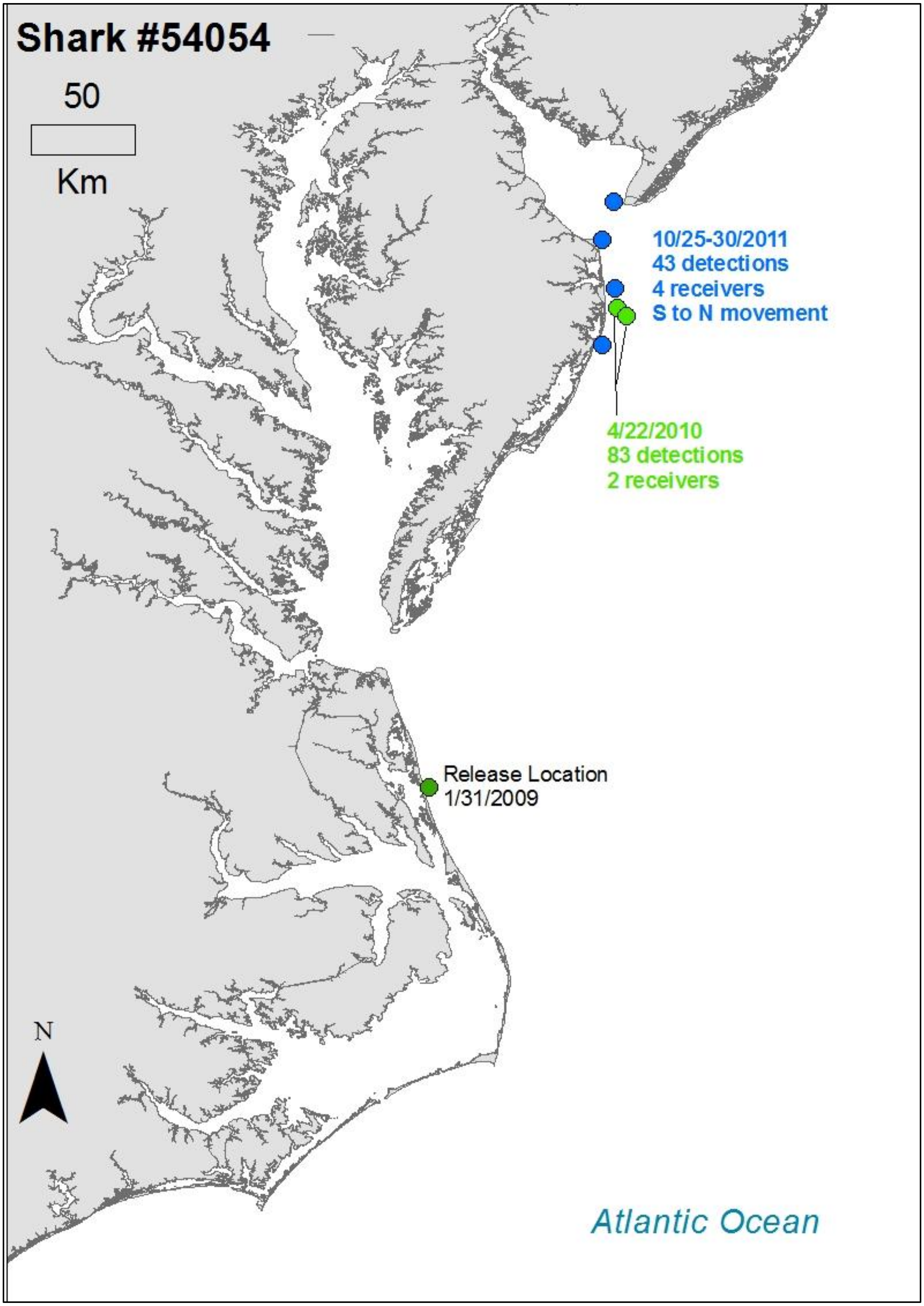
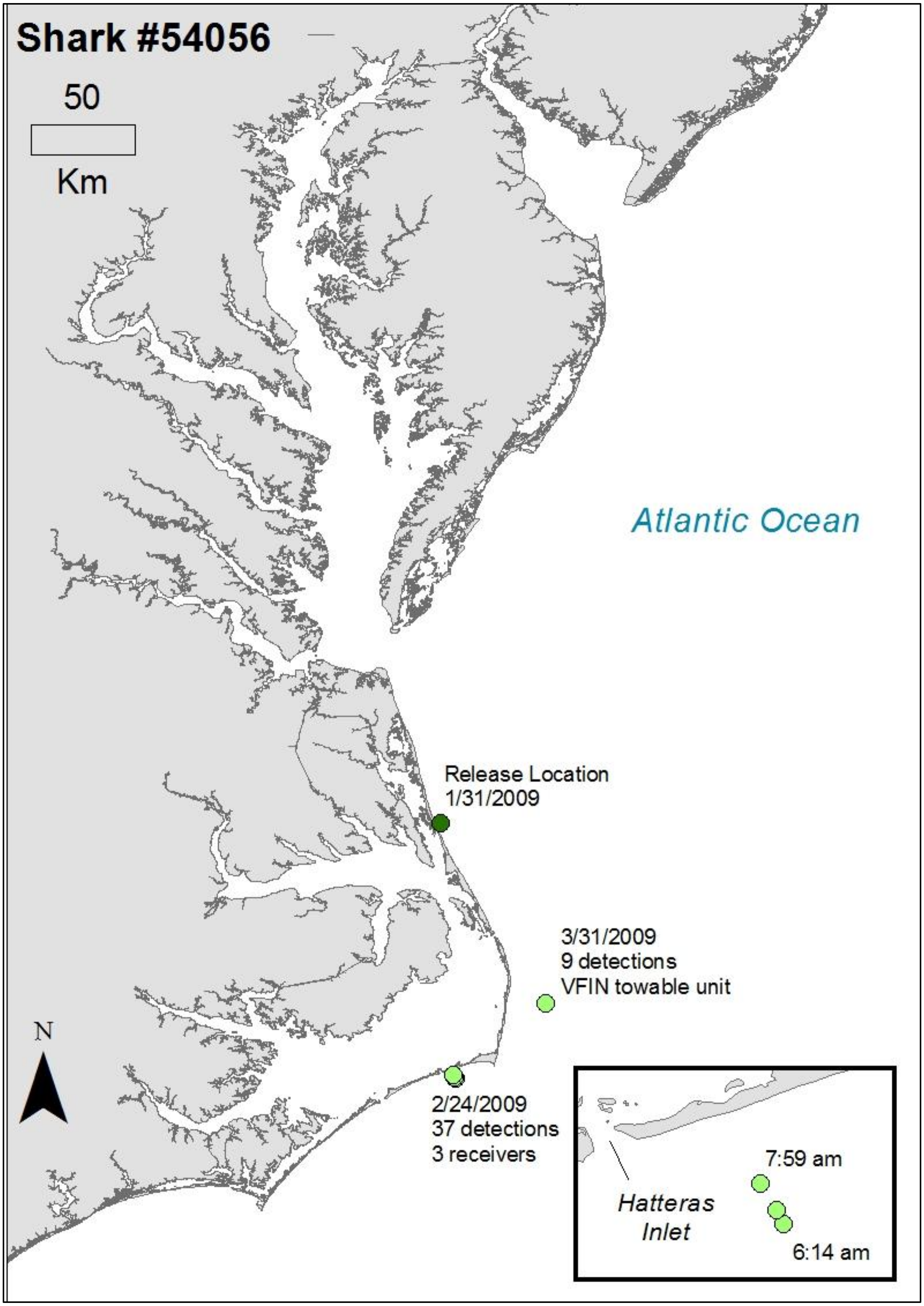
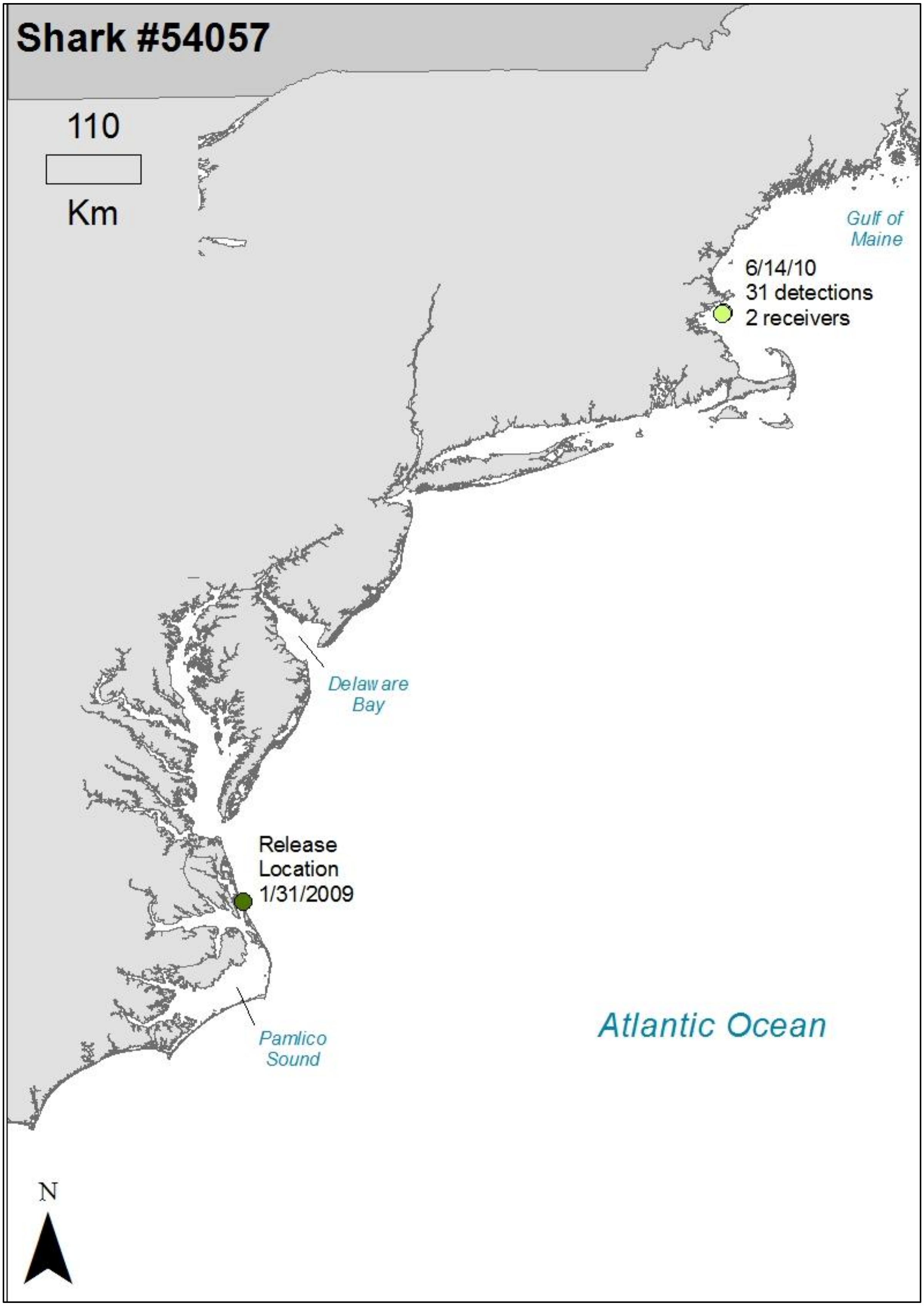
Km
11/8/2009 - 12/4/2009
541 detections
22 receivers
Release Location
1/31/2009
3/21/2010
7 detections
N
Atlantic Ocean

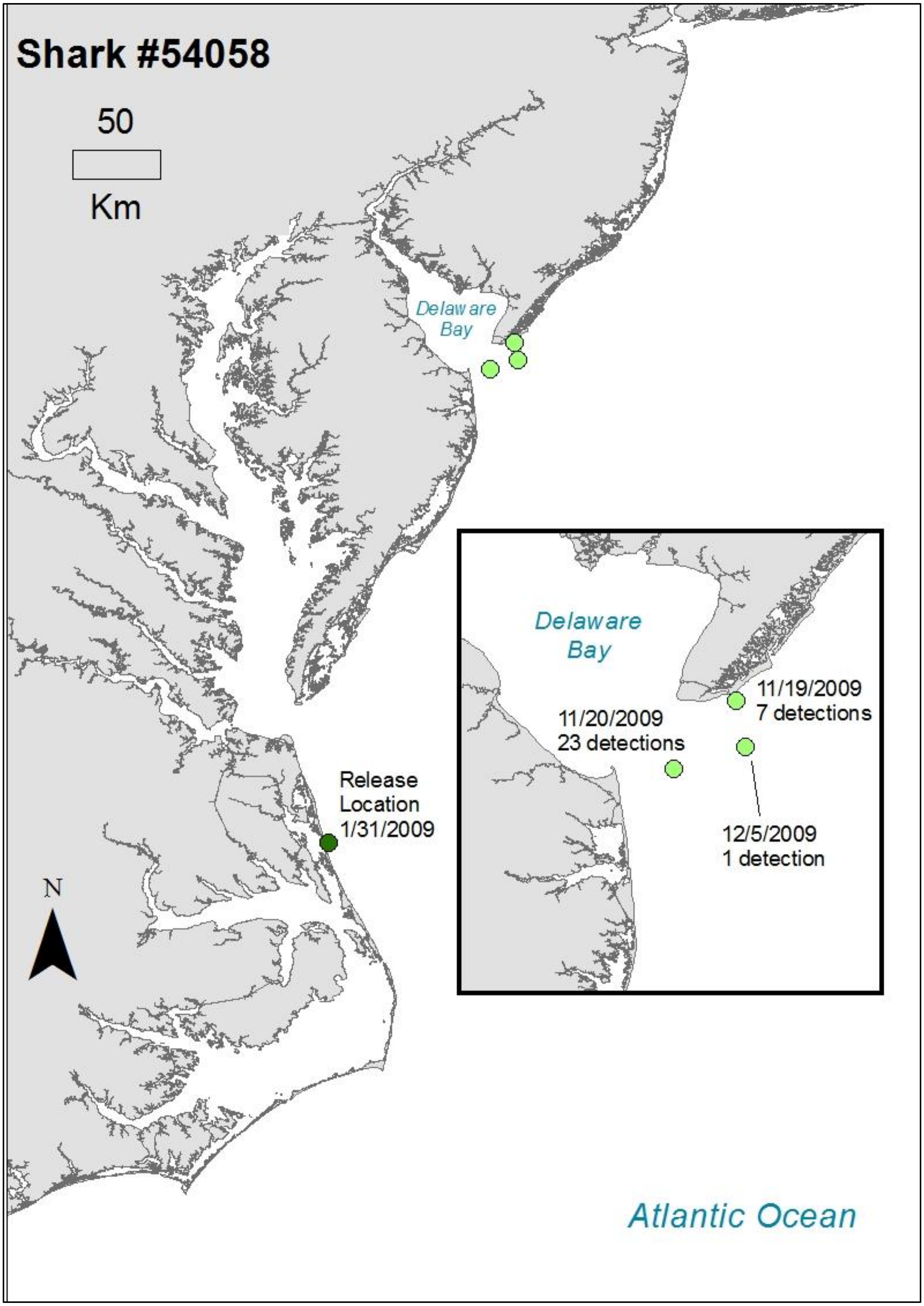

Shark #54052
50
Km
11/15/2009
23 detections
1 receiver
Atlantic Ocean
Release Location
1/31/2009
1/7/2010 - 1/8/2010
25 detections
1 receiver
2/19/2009
9 detections
1 receiver
N
Hatteras
Inlet

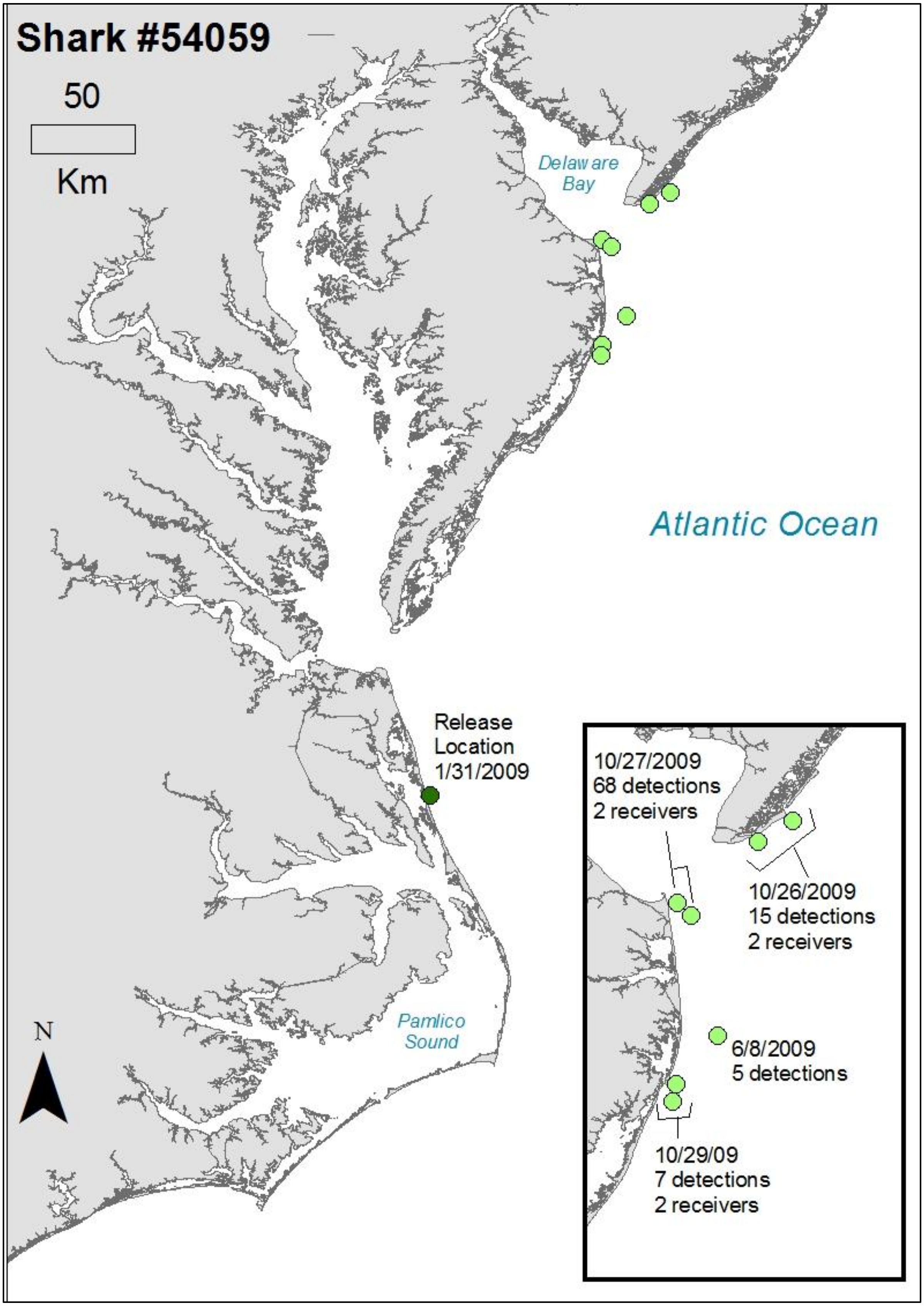

Shark #54053
50
Km
10/24/2009
3 detections
1 receiver
10/27/2009
3 detections
1 receivers
Release Location
1/31/2009
N
Atlantic Ocean


Shark #54054
50
Km
10/25-30/2011
43 detections
4 receivers
S to N movement
4/22/2010
83 detections
2 receivers
Release Location
1/31/2009
N
Atlantic Ocean

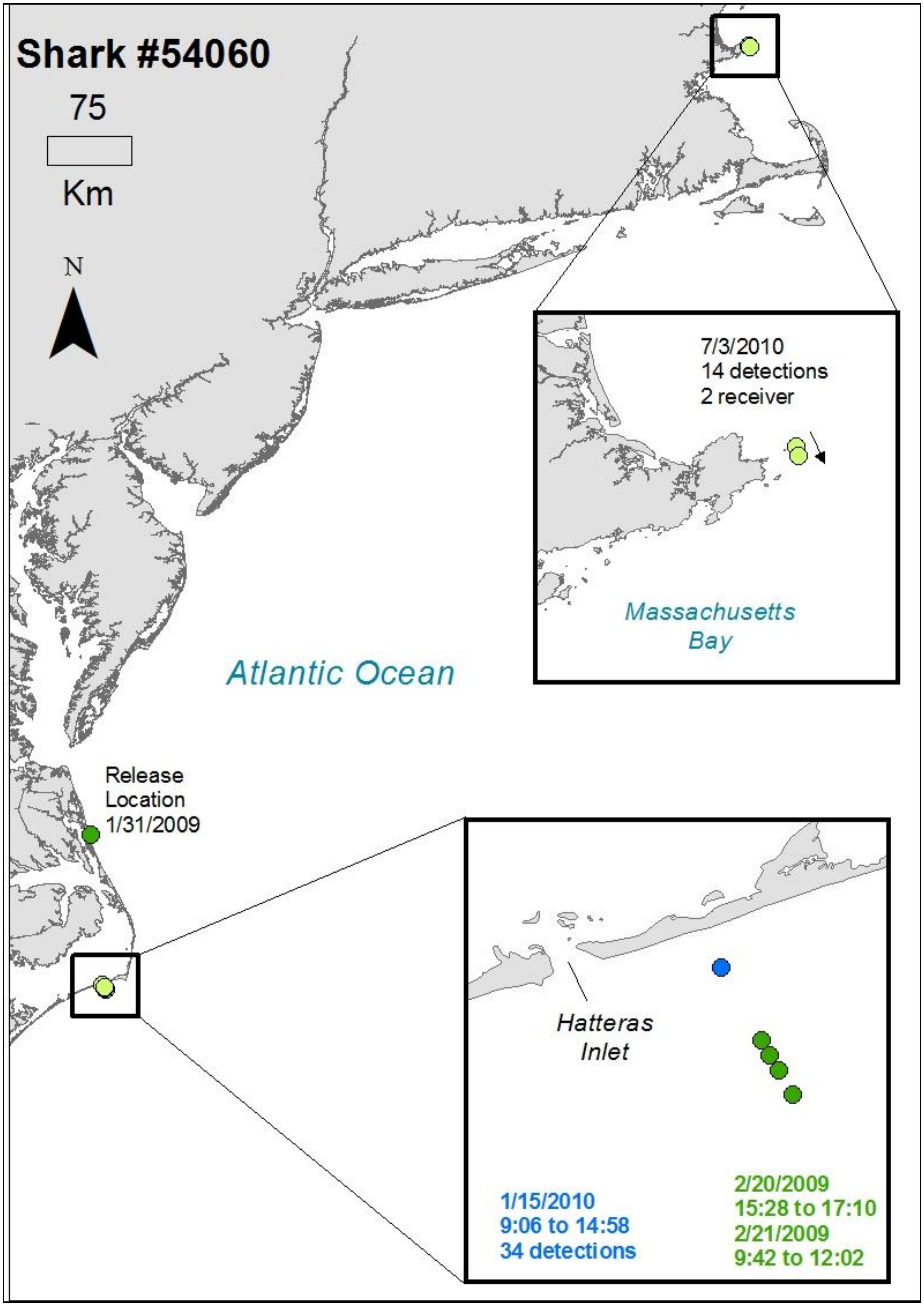

Shark #54056
50
Km
Atlantic Ocean
Release Location
1/31/2009
3/31/2009
9 detections
VFIN towable unit
2/24/2009
37 detections
3 receivers
N
7:59 am
Hatteras
Inlet
6:14 am


Shark #54057
110
Km
Gulf of Maine
6/14/10
31 detections
2 receivers
Delaware Bay
Release Location
1/31/2009
Pamlico Sound
Atlantic Ocean
N

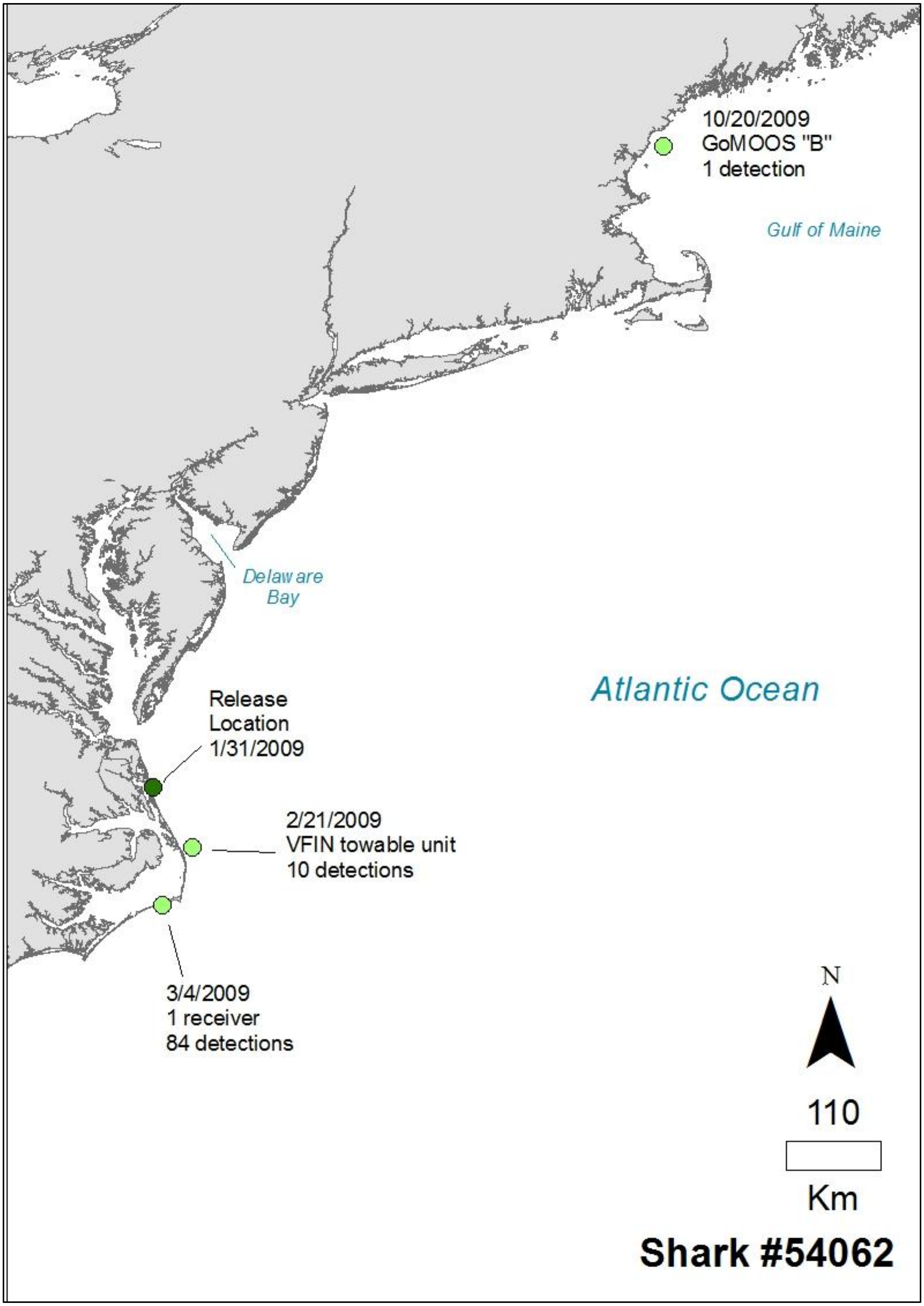

Shark #54058
50
Km
N
Delaware Bay
Release Location 1/31/2009
Delaware Bay
11/19/2009
7 detections
11/20/2009
23 detections
12/5/2009
1 detection
Atlantic Ocean

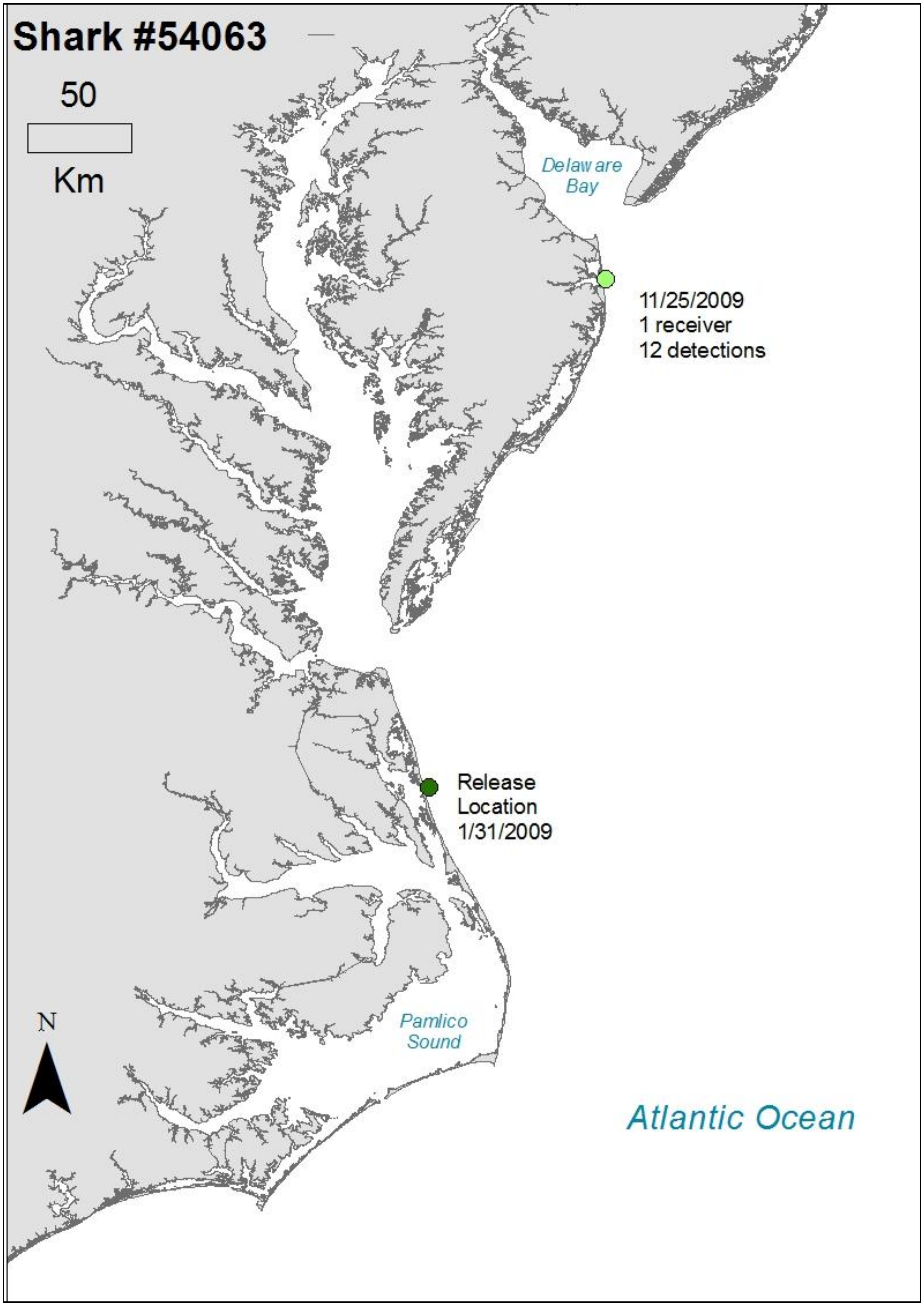


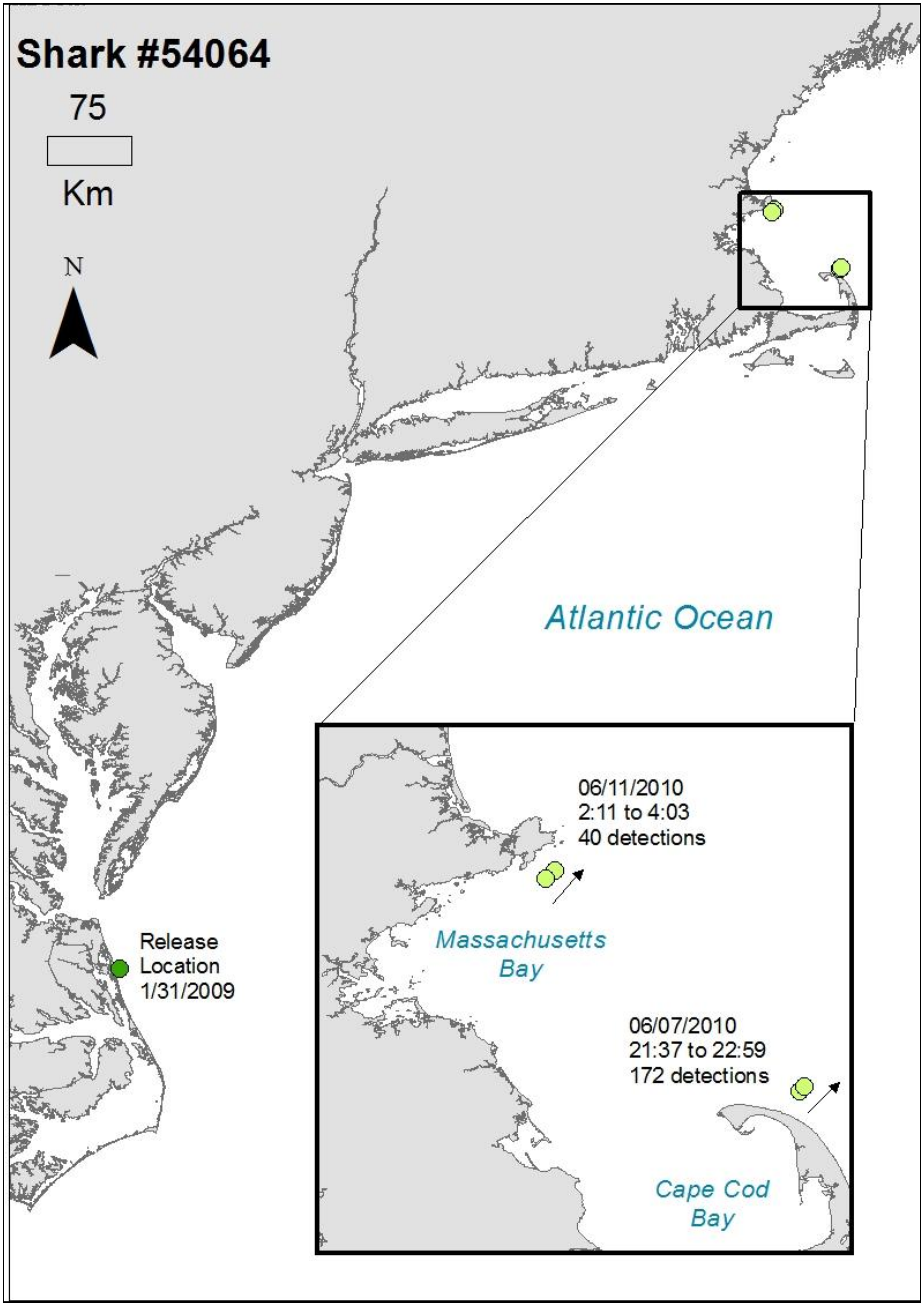
Shark #54059
50
Km
Delaware Bay
Atlantic Ocean
Release Location 1/31/2009
Pamlico Sound
N
10/27/2009
68 detections
2 receivers
10/26/2009
15 detections
2 receivers
6/8/2009
5 detections
10/29/09
7 detections
2 receivers

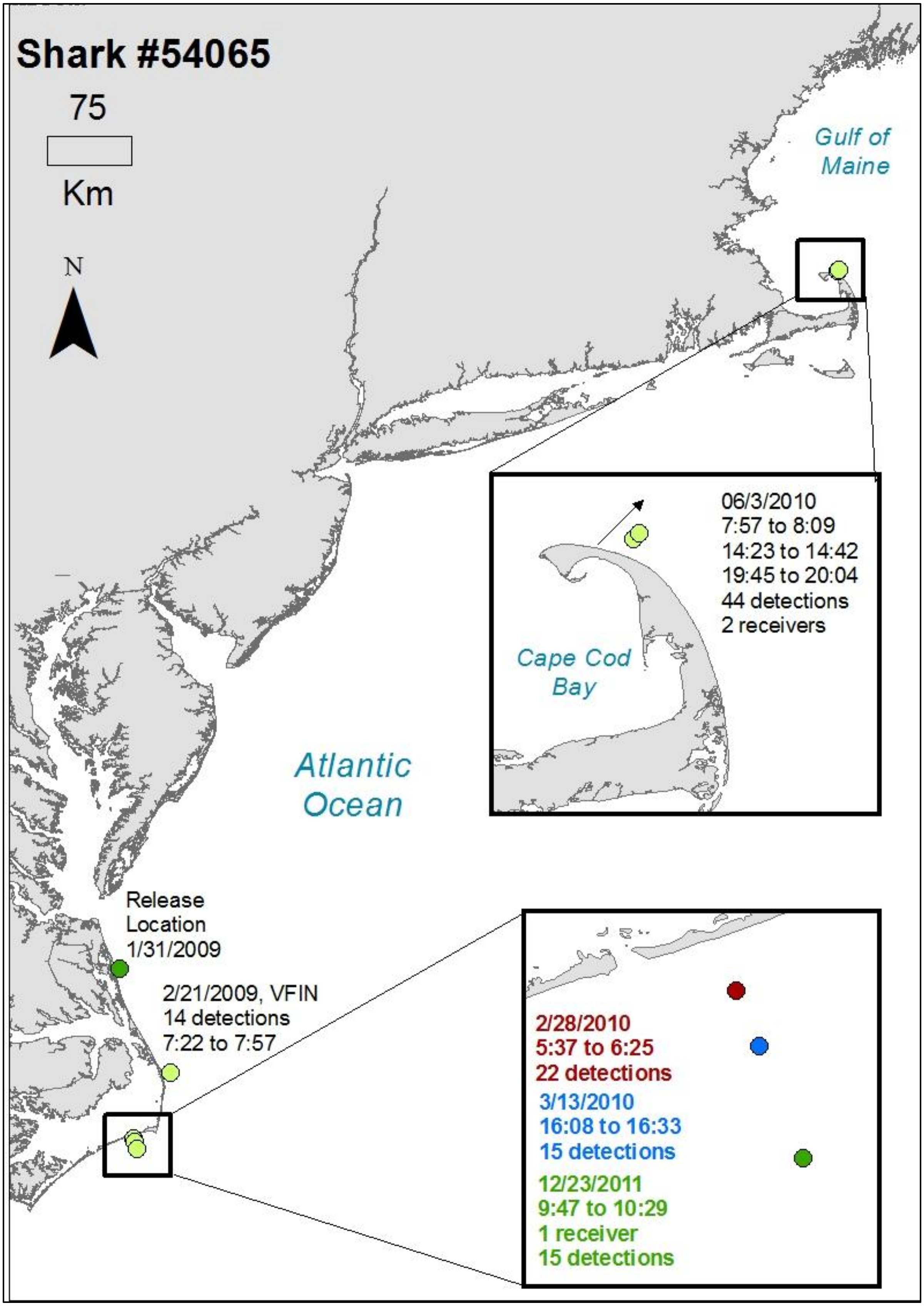


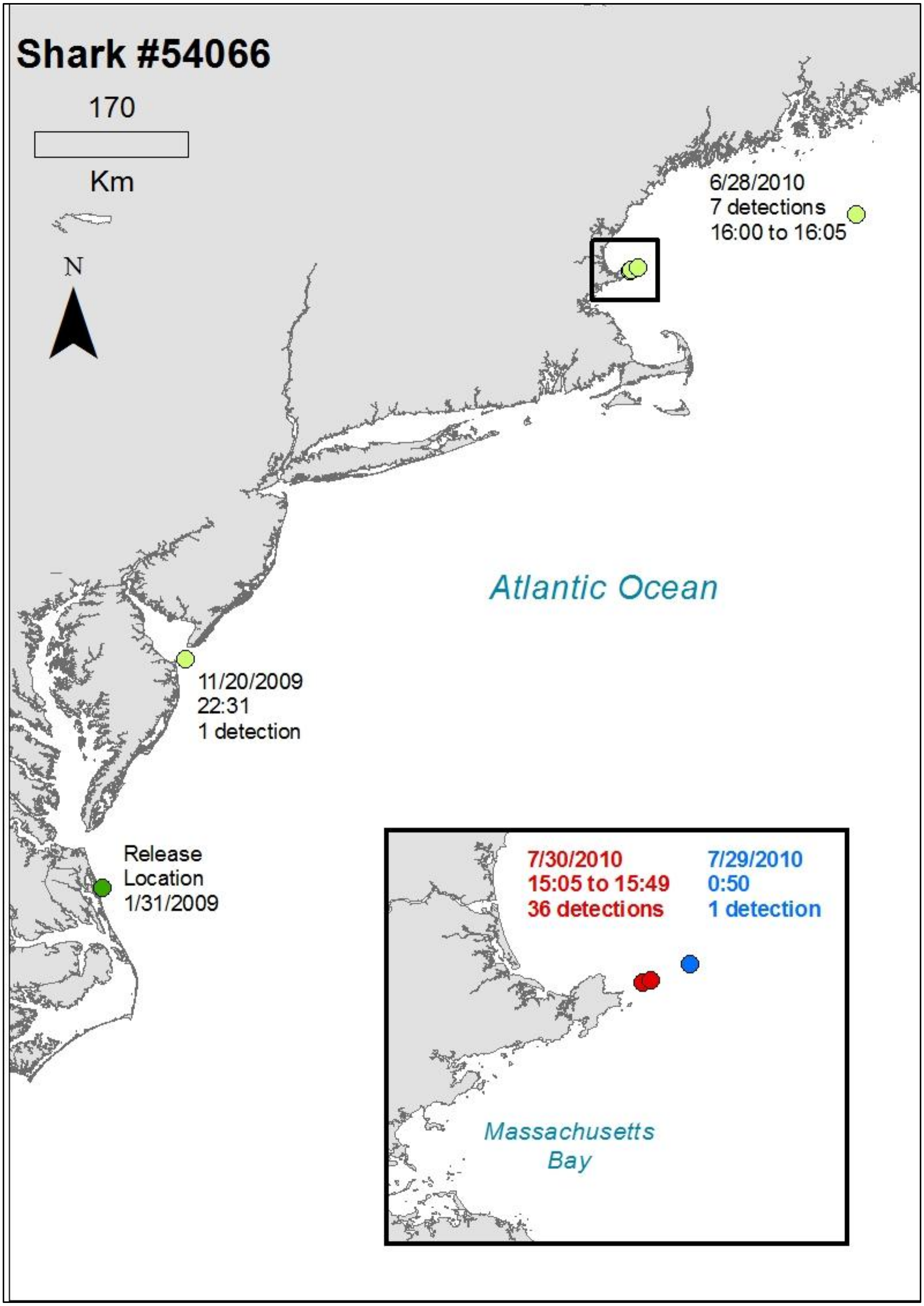
Shark #54060
75
Km
N
7/3/2010
14 detections
2 receiver
Massachusetts
Bay
Atlantic Ocean
Release
Location
1/31/2009
Hatteras
Inlet
1/15/2010
9:06 to 14:58
34 detections
2/20/2009
15:28 to 17:10
2/21/2009
9:42 to 12:02

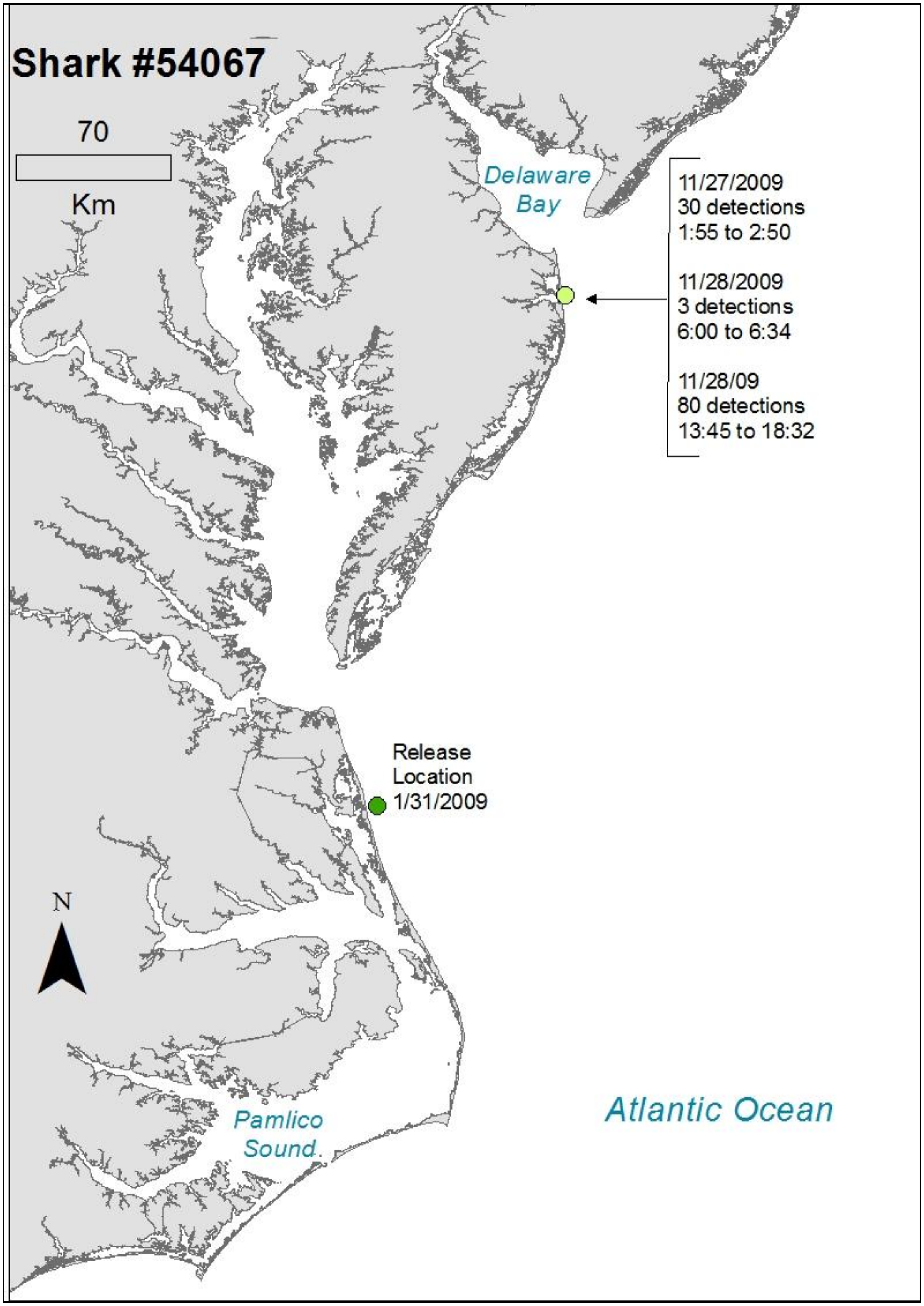

10/20/2009
GoMOOS "B"
1 detection
Gulf of Maine
Delaware
Bay
Atlantic Ocean
Release
Location
1/31/2009
2/21/2009
VFIN towable unit
10 detections
3/4/2009
1 receiver
84 detections
N
110
Km
Shark #54062

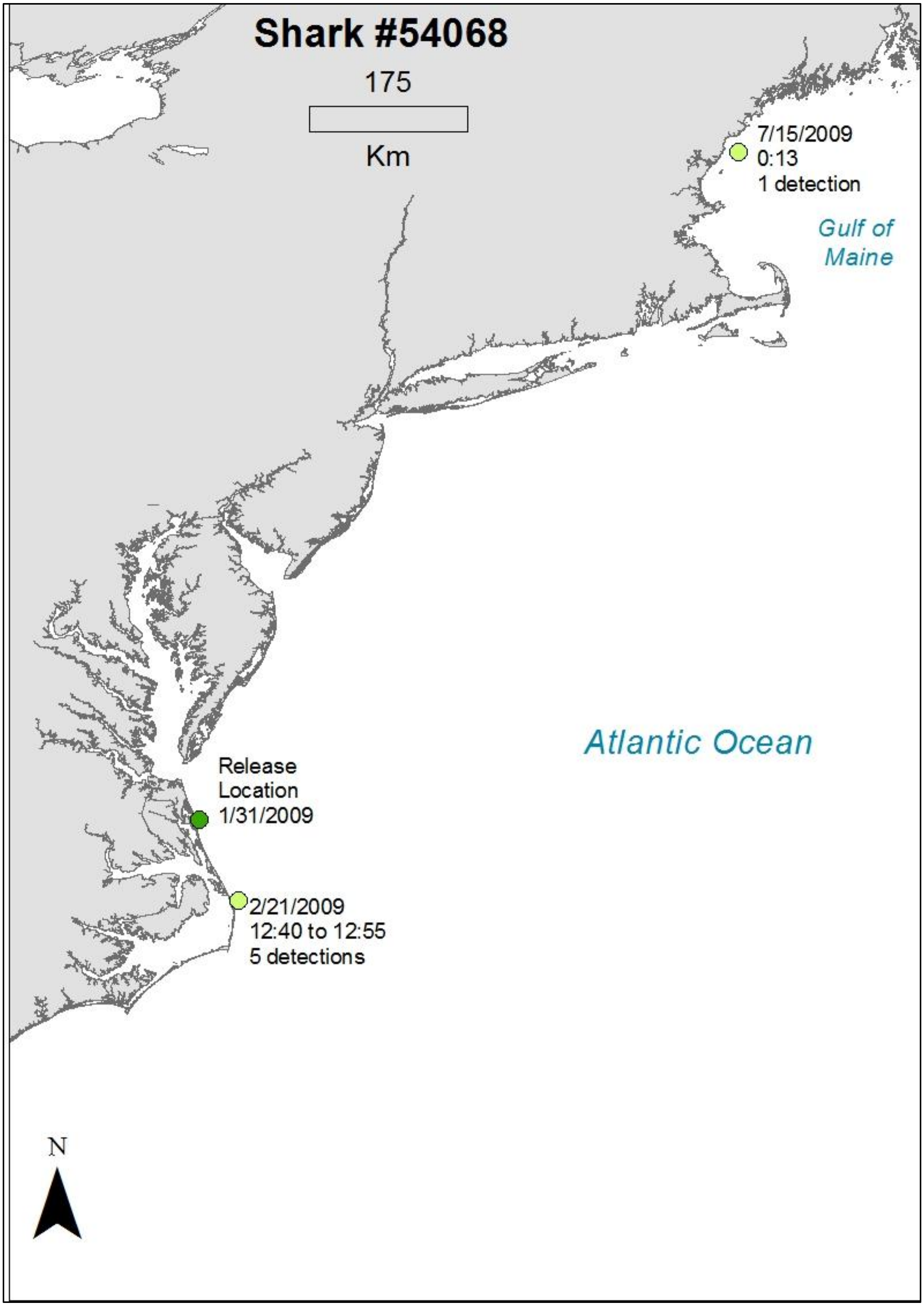

Shark #54063
50
Km
Delaware Bay
11/25/2009
1 receiver
12 detections
Release
Location
1/31/2009
Pamlico Sound
N
Atlantic Ocean

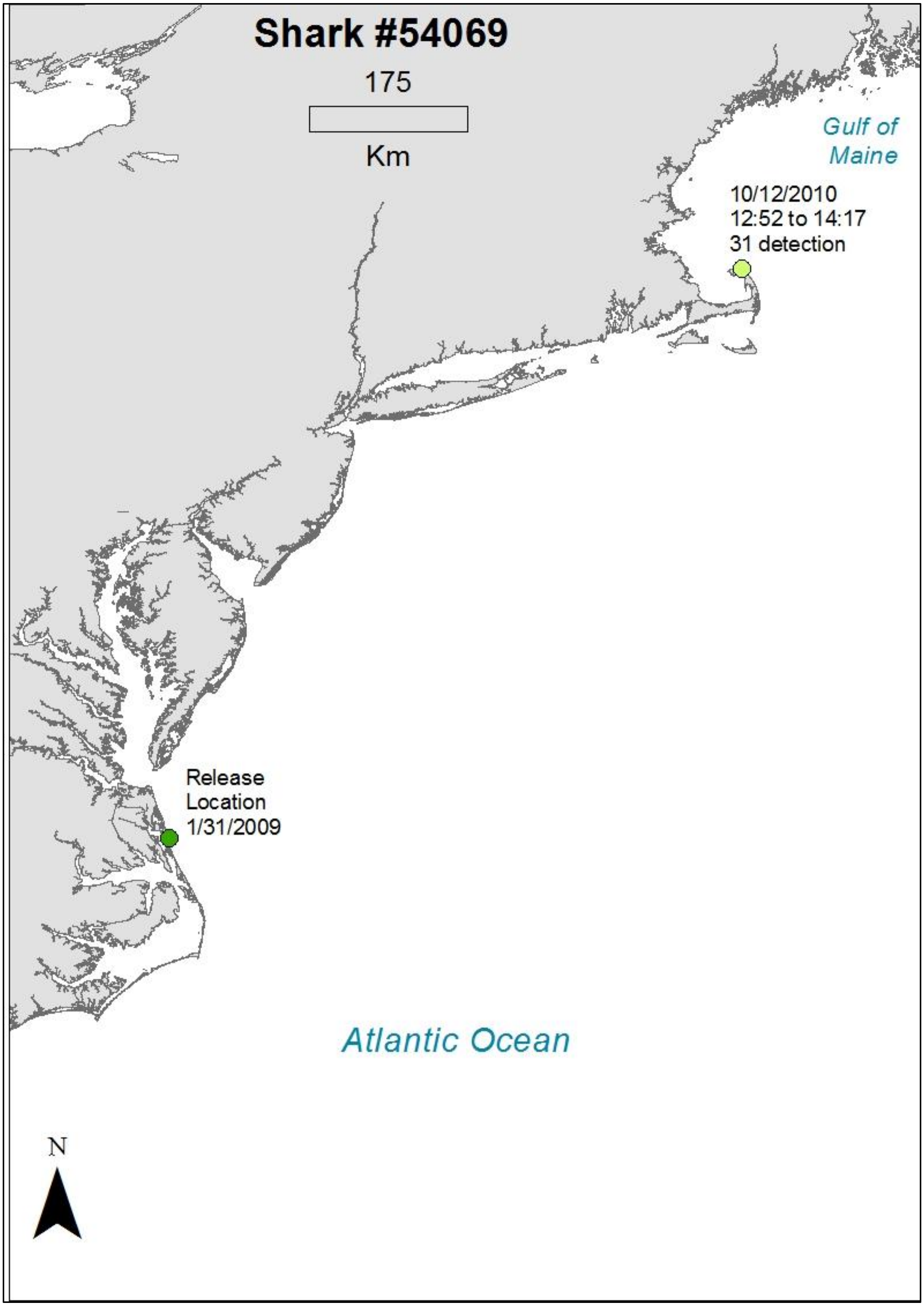

Shark #54064
75
Km
N
Atlantic Ocean
Release
Location
1/31/2009
06/11/2010
2:11 to 4:03
40 detections
Massachusetts
Bay
06/07/2010
21:37 to 22:59
172 detections
Cape Cod
Bay

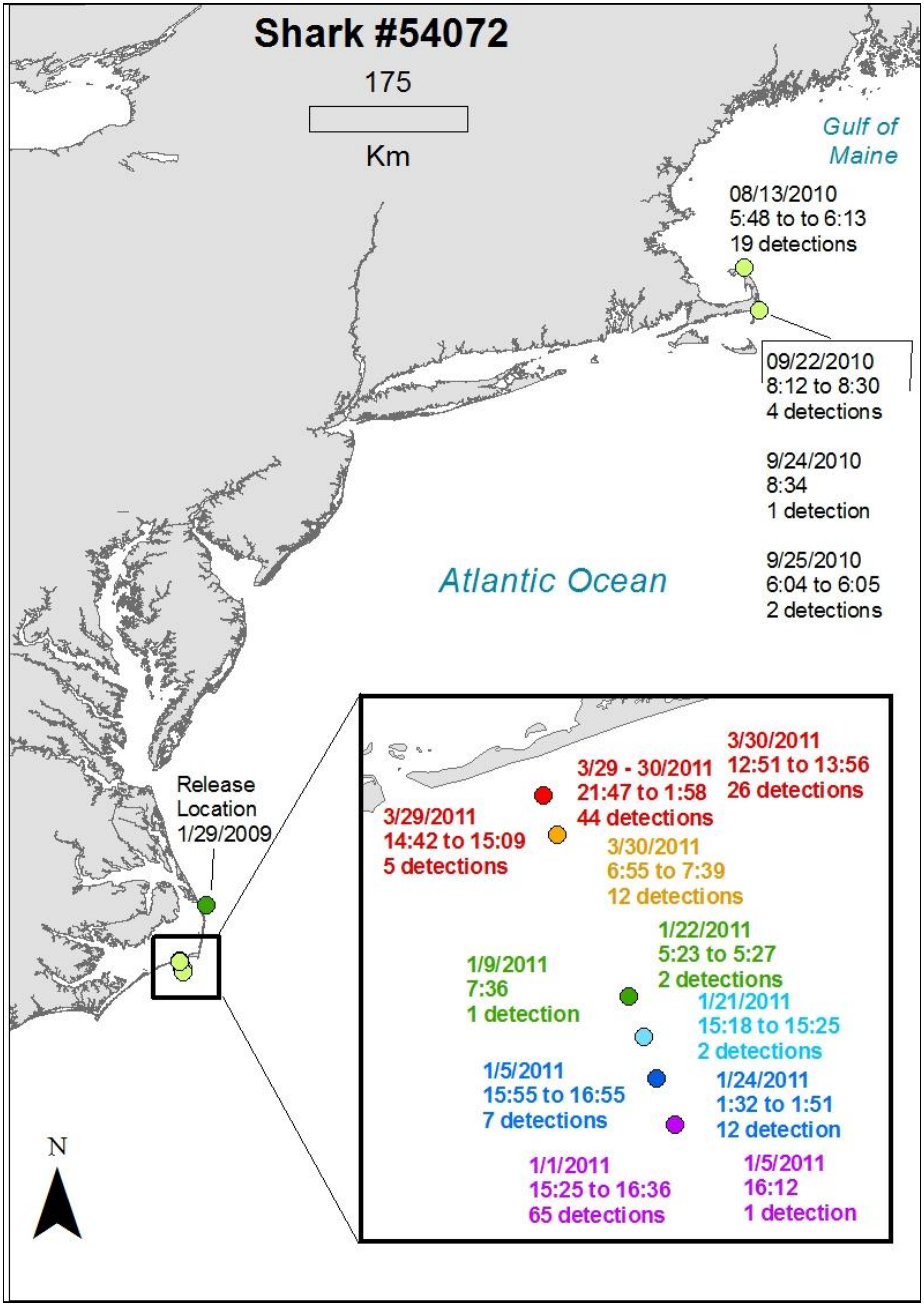

Shark #54065
75
Km
N
Gulf of
Maine
06/3/2010
7:57 to 8:09
14:23 to 14:42
19:45 to 20:04
44 detections
2 receivers
Cape Cod
Bay
Atlantic
Ocean
Release
Location
1/31/2009
2/21/2009, VFIN
14 detections
7:22 to 7:57
2/28/2010
5:37 to 6:25
22 detections
3/13/2010
16:08 to 16:33
15 detections
12/23/2011
9:47 to 10:29
1 receiver
15 detections


Shark #54066
170
Km
N
6/28/2010
7 detections
16:00 to 16:05
Atlantic Ocean
11/20/2009
22:31
1 detection
Release
Location
1/31/2009
7/30/2010
15:05 to 15:49
36 detections
7/29/2010
0:50
1 detection
Massachusetts
Bay

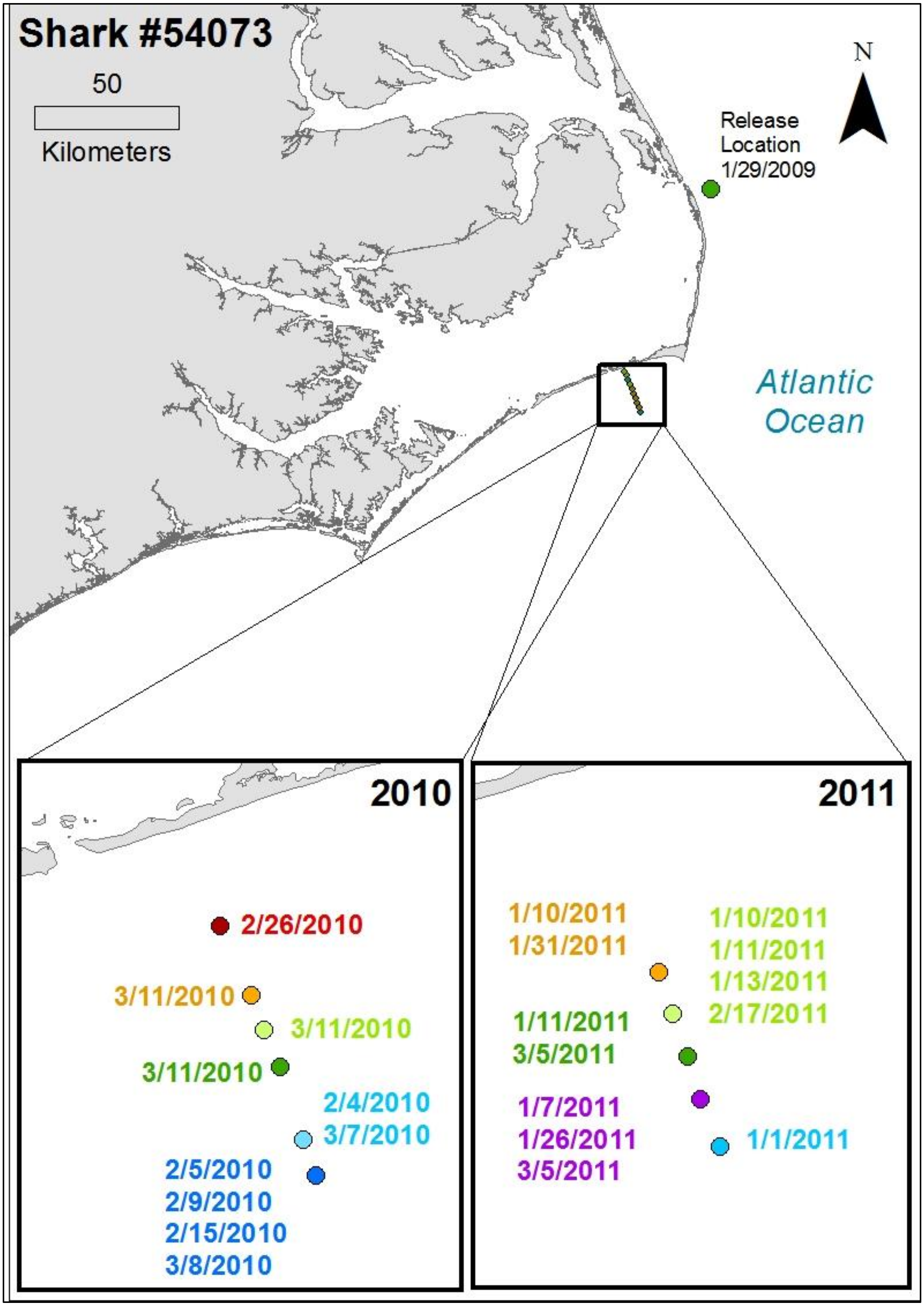

Shark #54067
70
Km
Delaware
Bay
11/27/2009
30 detections
1:55 to 2:50
11/28/2009
3 detections
6:00 to 6:34
11/28/09
80 detections
13:45 to 18:32
Release
Location
1/31/2009
N
Pamlico
Sound
Atlantic Ocean

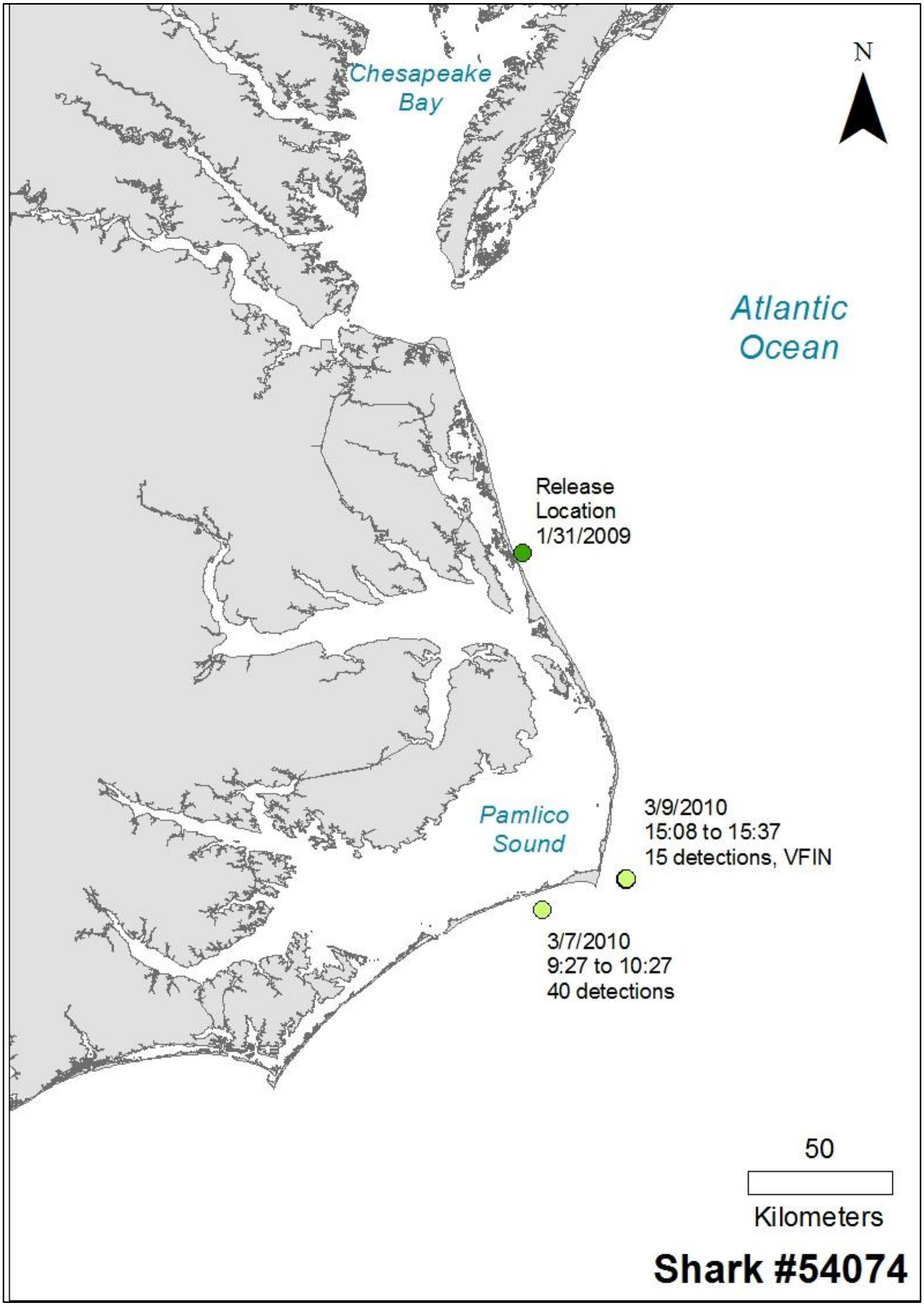

Shark #54068
175
Km
7/15/2009
0:13
1 detection
Gulf of
Maine
Atlantic Ocean
Release
Location
1/31/2009
2/21/2009
12:40 to 12:55
5 detections
N

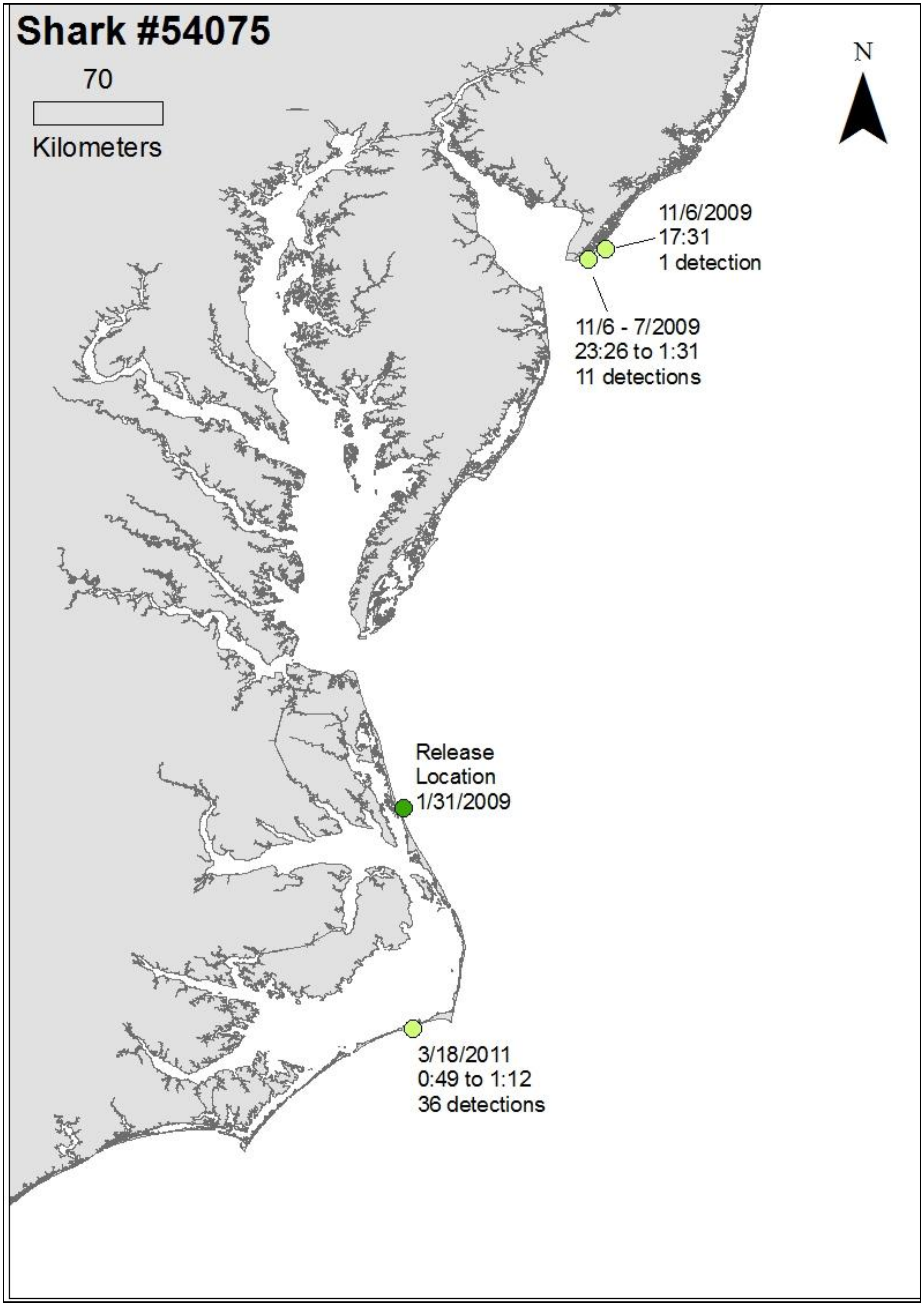

Shark #54069
175
Km
Gulf of
Maine
10/12/2010
12:52 to 14:17
31 detection
Release
Location
1/31/2009
Atlantic Ocean
N

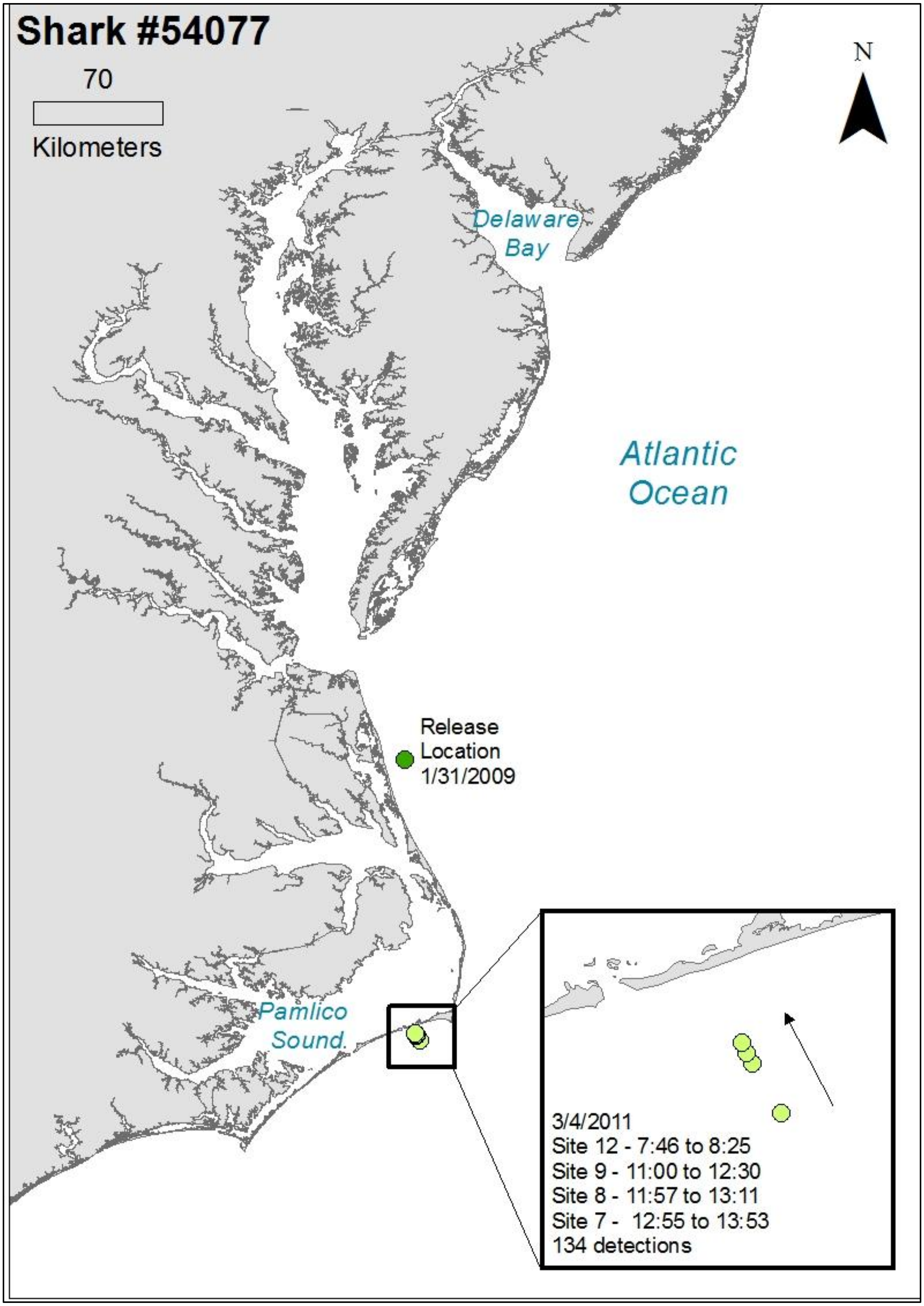


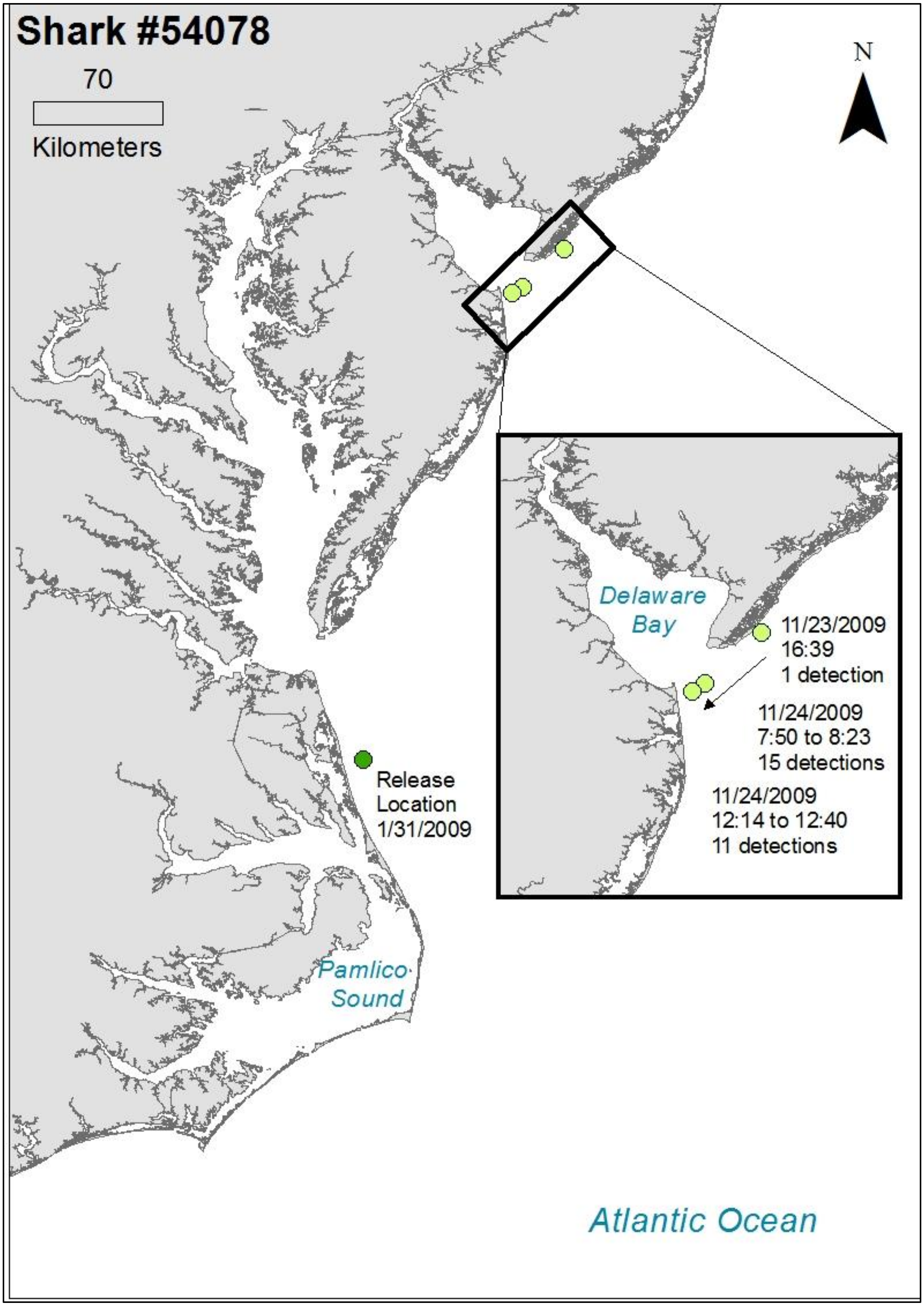
Shark #54072
175
Km
Gulf of Maine
08/13/2010
5:48 to to 6:13
19 detections
09/22/2010
8:12 to 8:30
4 detections
9/24/2010
8:34
1 detection
9/25/2010
6:04 to 6:05
2 detections
Atlantic Ocean
Release Location 1/29/2009
3/30/2011
12:51 to 13:56
26 detections
3/29 - 30/2011
21:47 to 1:58
44 detections
3/29/2011
14:42 to 15:09
5 detections
3/30/2011
6:55 to 7:39
12 detections
1/22/2011
5:23 to 5:27
2 detections
1/9/2011
7:36
1 detection
1/21/2011
15:18 to 15:25
2 detections
1/5/2011
15:55 to 16:55
7 detections
1/24/2011
1:32 to 1:51
12 detection
1/1/2011
15:25 to 16:36
65 detections
1/5/2011
16:12
1 detection
N

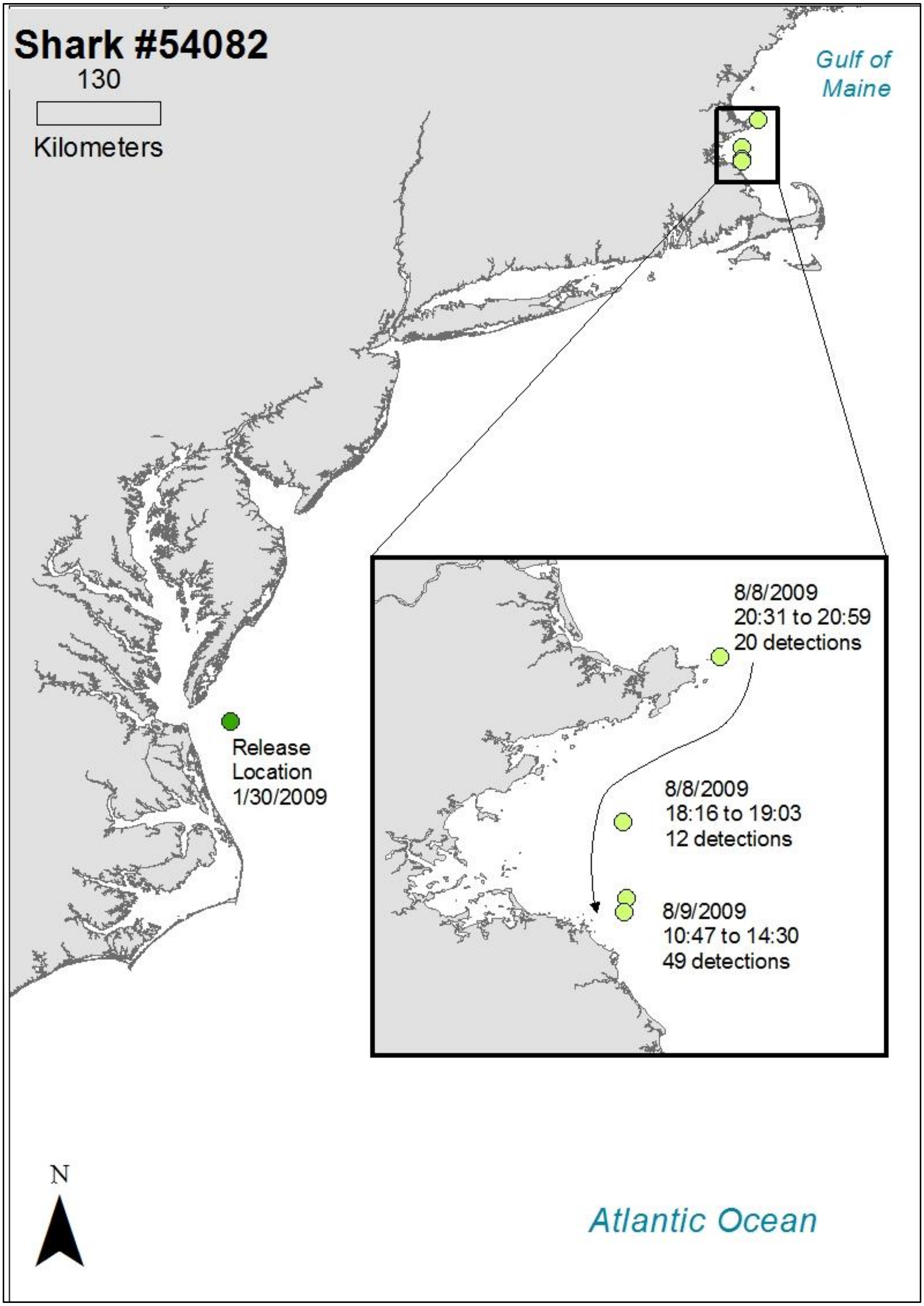

Shark #54073
50
Kilometers
N
Release
Location
1/29/2009
Atlantic
Ocean
2010
2/26/2010
3/11/2010
3/11/2010
3/11/2010
2/4/2010
3/7/2010
2/5/2010
2/9/2010
2/15/2010
3/8/2010
2011
1/10/2011
1/31/2011
1/10/2011
1/11/2011
1/13/2011
2/17/2011
1/11/2011
3/5/2011
1/7/2011
1/26/2011
3/5/2011
1/1/2011


Chesapeake Bay
Atlantic Ocean
N
Release Location 1/31/2009
Pamlico Sound
3/9/2010
15:08 to 15:37
15 detections, VFIN
3/7/2010
9:27 to 10:27
40 detections
50
Kilometers
Shark #54074

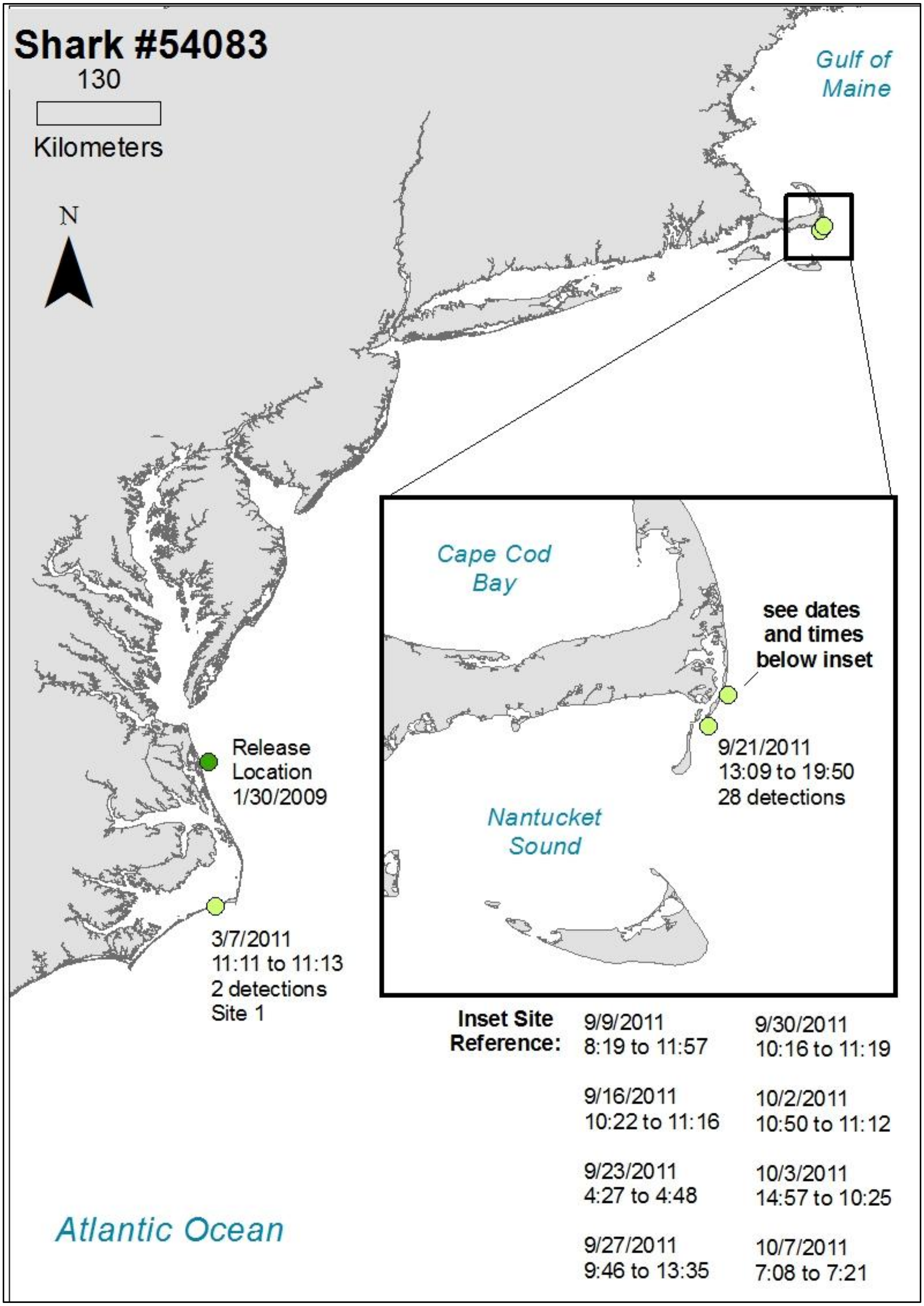

Shark #54075
70
Kilometers
N
11/6/2009
17:31
1 detection
11/6 - 7/2009
23:26 to 1:31
11 detections
Release
Location
1/31/2009
3/18/2011
0:49 to 1:12
36 detections

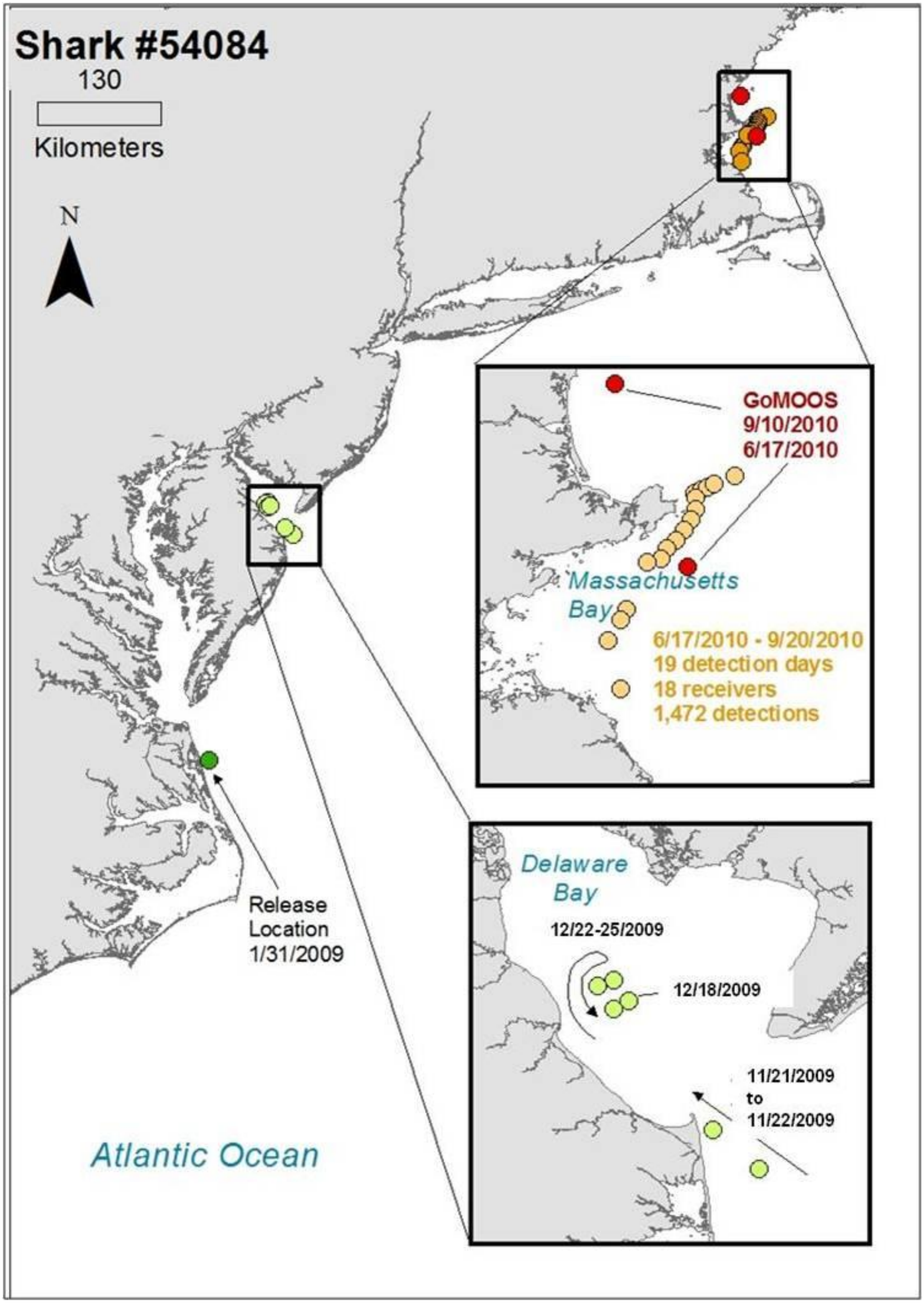

Shark #54077
70
Kilometers
N
Delaware Bay
Atlantic Ocean
Release Location 1/31/2009
Pamlico Sound.
3/4/2011
Site 12 - 7:46 to 8:25
Site 9 - 11:00 to 12:30
Site 8 - 11:57 to 13:11
Site 7 - 12:55 to 13:53
134 detections


Shark #54078
70
Kilometers
N
Release
Location
1/31/2009
Pamlico
Sound
Delaware
Bay
11/23/2009
16:39
1 detection
11/24/2009
7:50 to 8:23
15 detections
11/24/2009
12:14 to 12:40
11 detections
Atlantic Ocean

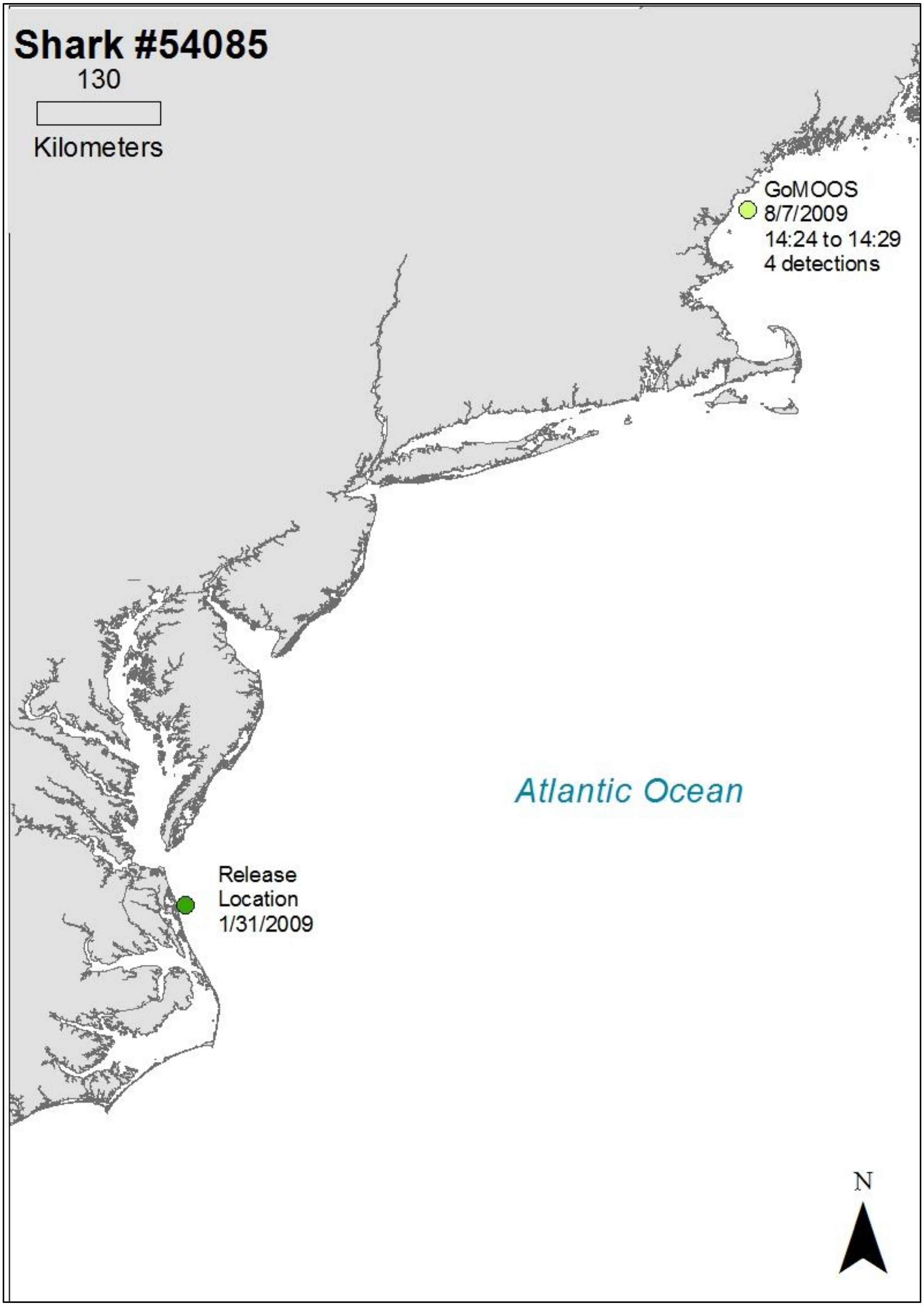


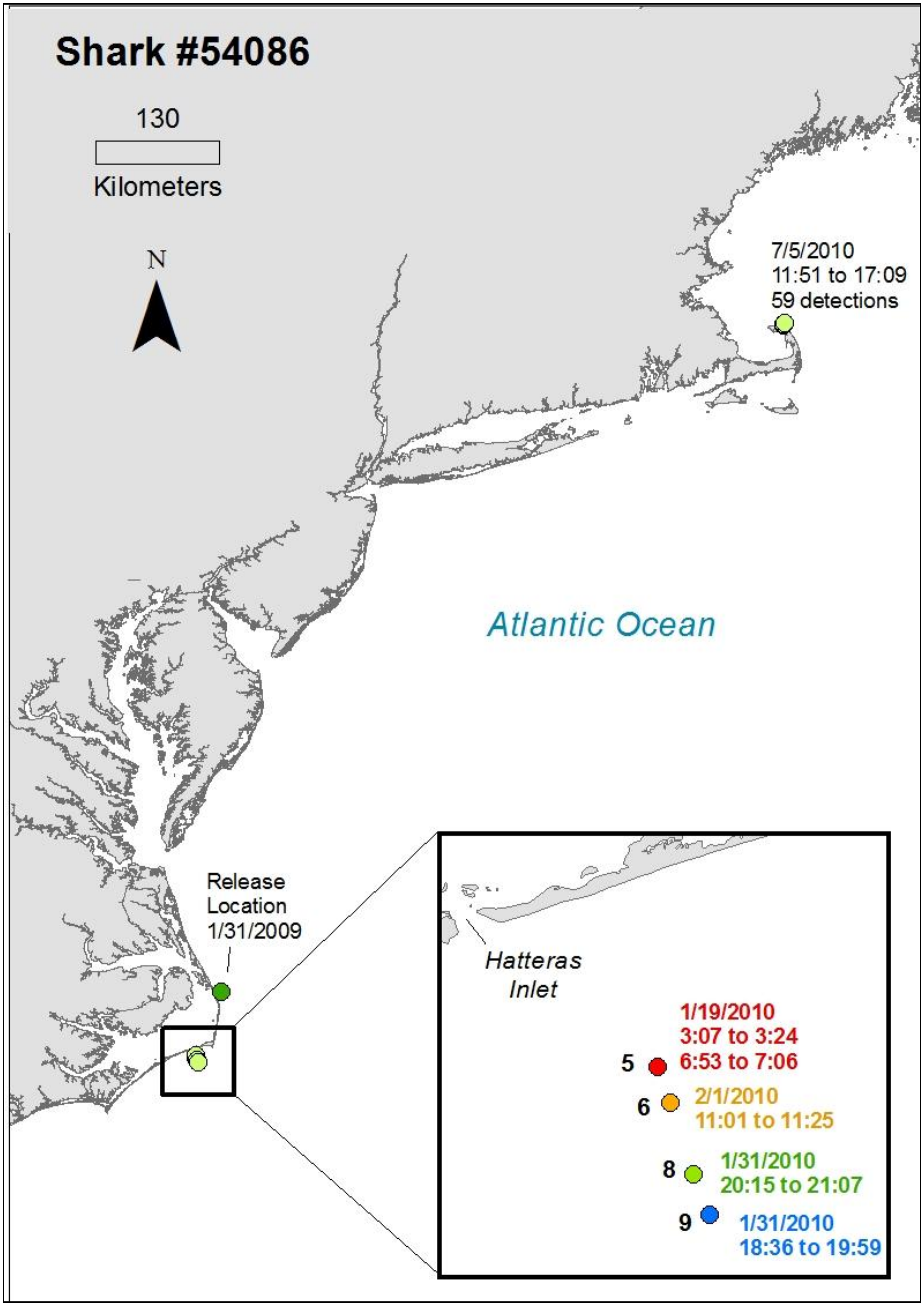
Shark #54082
130
Kilometers
Gulf of Maine
Release Location 1/30/2009
8/8/2009
20:31 to 20:59
20 detections
8/8/2009
18:16 to 19:03
12 detections
8/9/2009
10:47 to 14:30
49 detections
N
Atlantic Ocean


Shark #54083
130
Kilometers
N
Gulf of Maine
Cape Cod Bay
see dates and times below inset
9/21/2011
13:09 to 19:50
28 detections
Nantucket Sound
Release Location
1/30/2009
3/7/2011
11:11 to 11:13
2 detections
Site 1
Inset Site Reference:
9/9/2011
8:19 to 11:57
9/30/2011
10:16 to 11:19
9/16/2011
10:22 to 11:16
10/2/2011
10:50 to 11:12
9/23/2011
4:27 to 4:48
10/3/2011
14:57 to 10:25
9/27/2011
9:46 to 13:35
10/7/2011
7:08 to 7:21
Atlantic Ocean

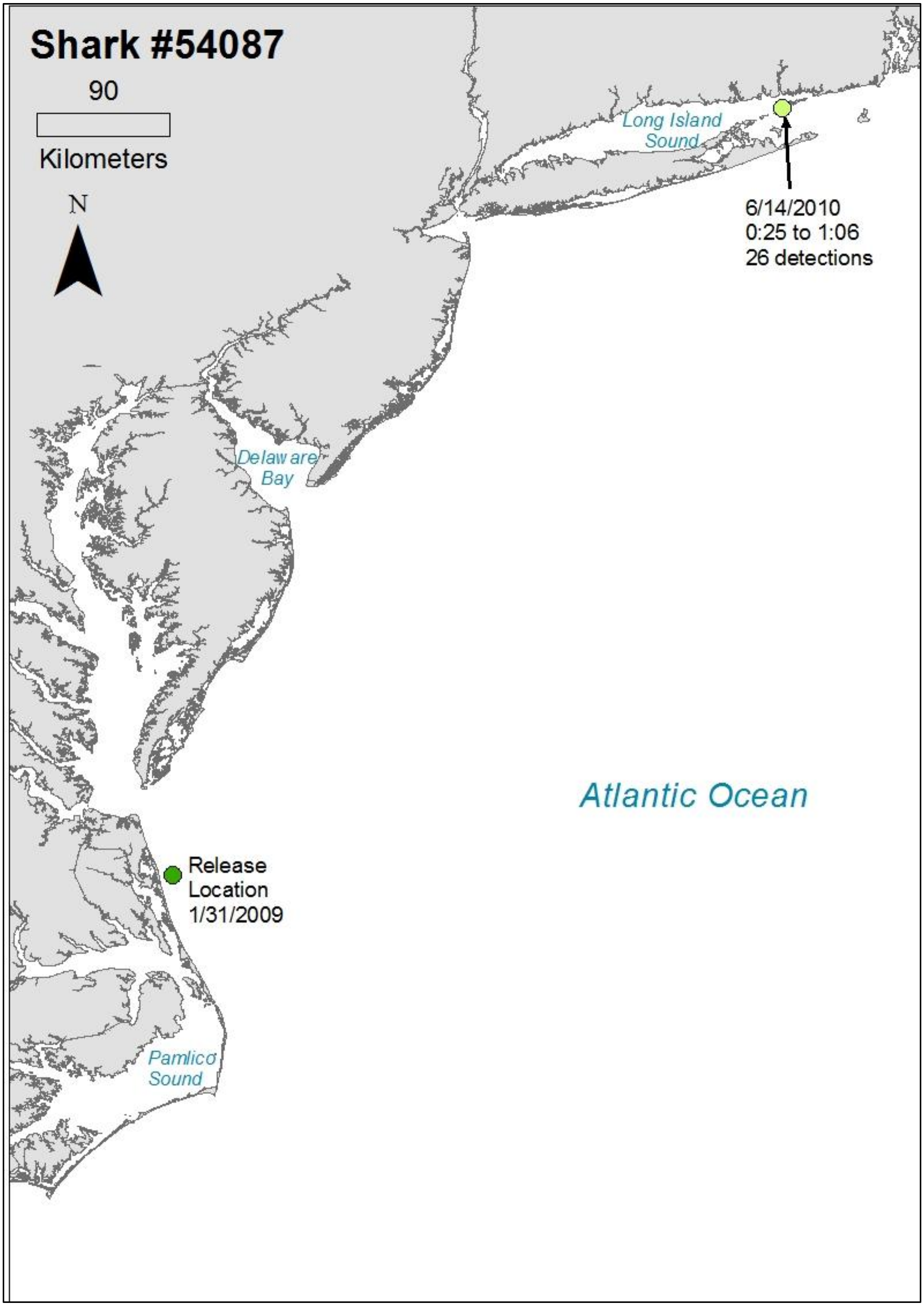


Shark #54084
130
Kilometers
N
GoMOOS
9/10/2010
6/17/2010
Massachusetts
Bay
6/17/2010 - 9/20/2010
19 detection days
18 receivers
1,472 detections
Delaware
Bay
12/22-25/2009
12/18/2009
11/21/2009
to
11/22/2009
Release
Location
1/31/2009
Atlantic Ocean

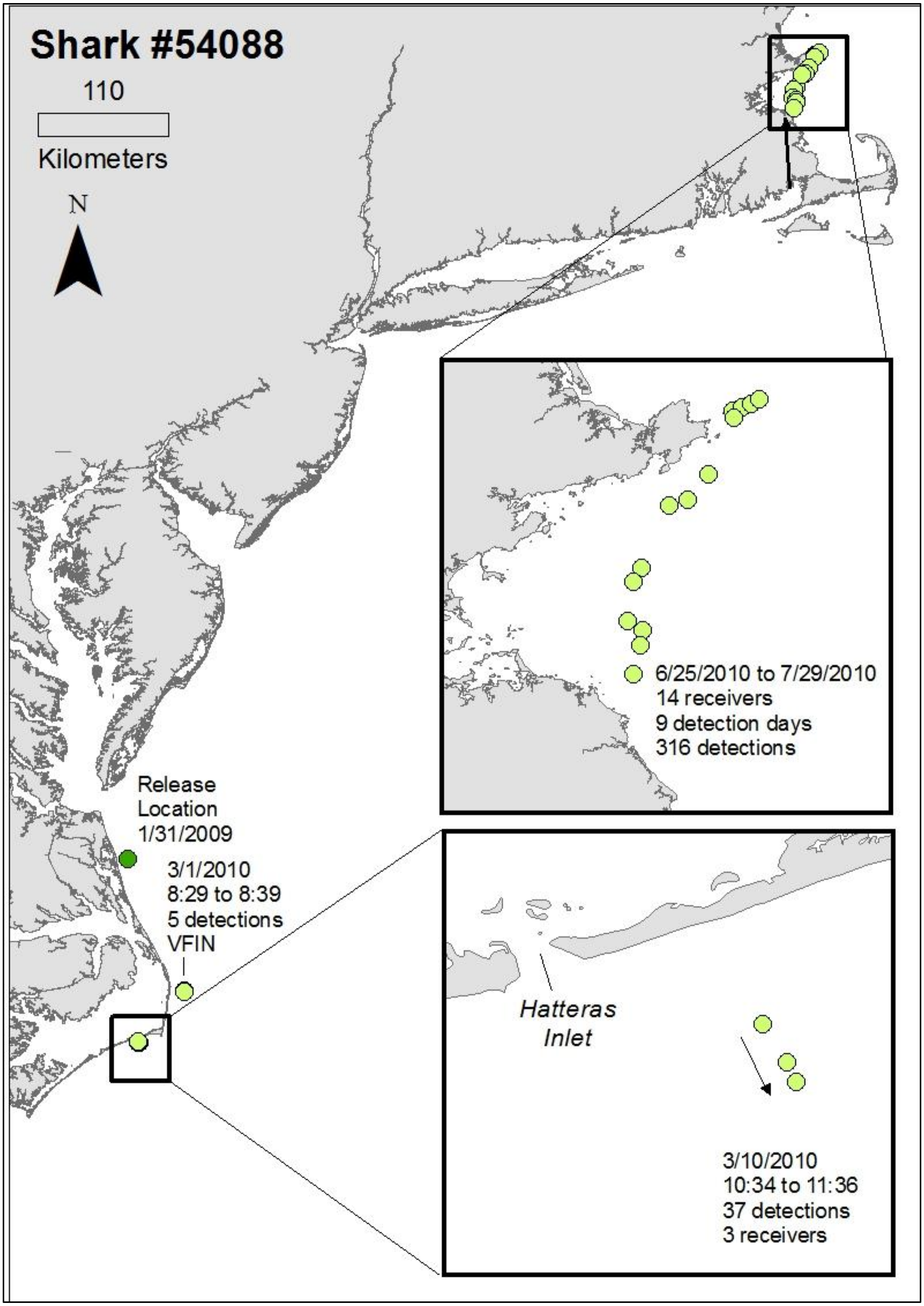

Shark #54085
130
Kilometers
GoMOOS
8/7/2009
14:24 to 14:29
4 detections
Atlantic Ocean
Release
Location
1/31/2009
N



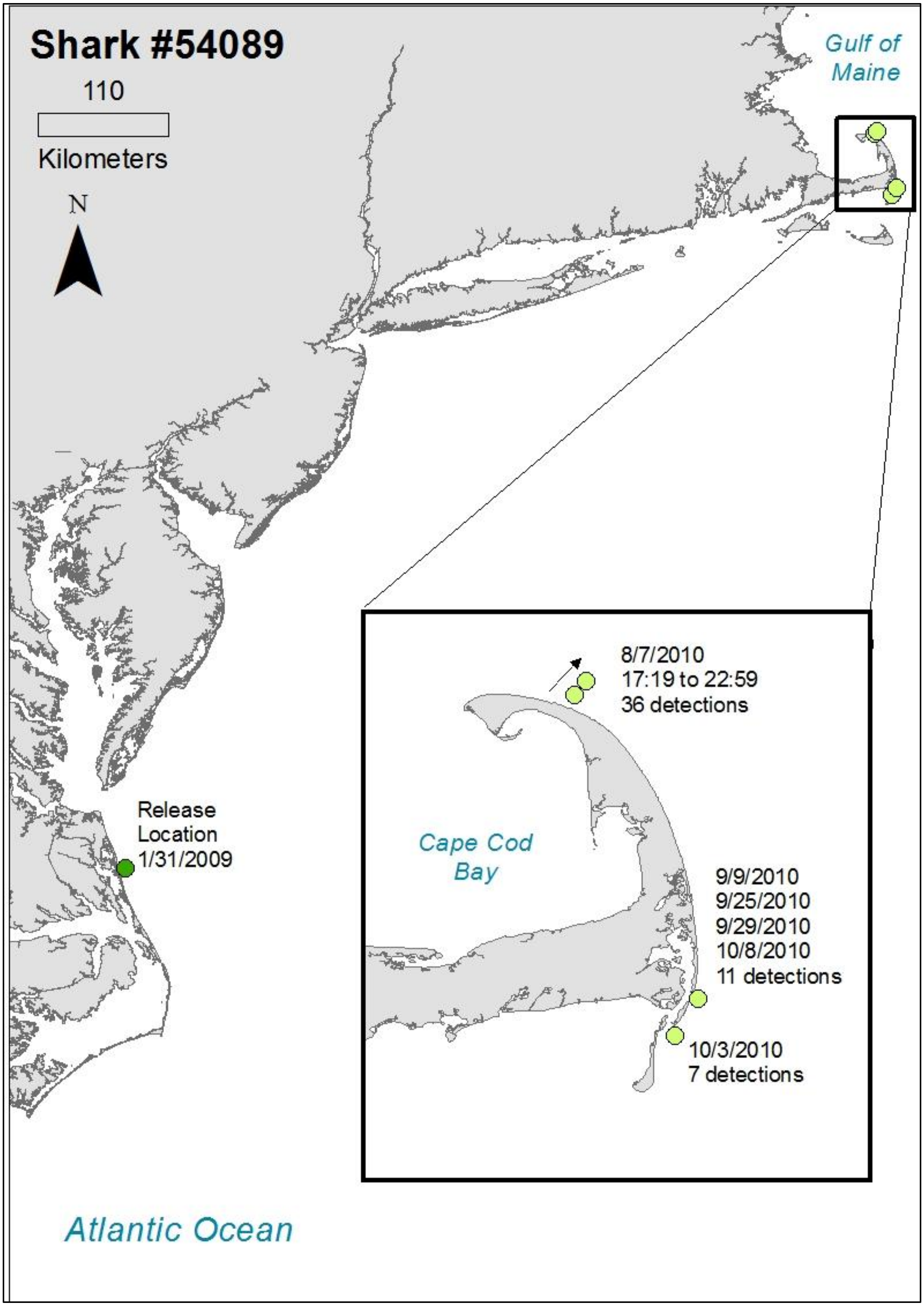
Shark #54086
130
Kilometers
N
7/5/2010
11:51 to 17:09
59 detections
Atlantic Ocean
Release
Location
1/31/2009
Hatteras
Inlet
1/19/2010
3:07 to 3:24
6:53 to 7:06
5
6
2/1/2010
11:01 to 11:25
8
1/31/2010
20:15 to 21:07
9
1/31/2010
18:36 to 19:59

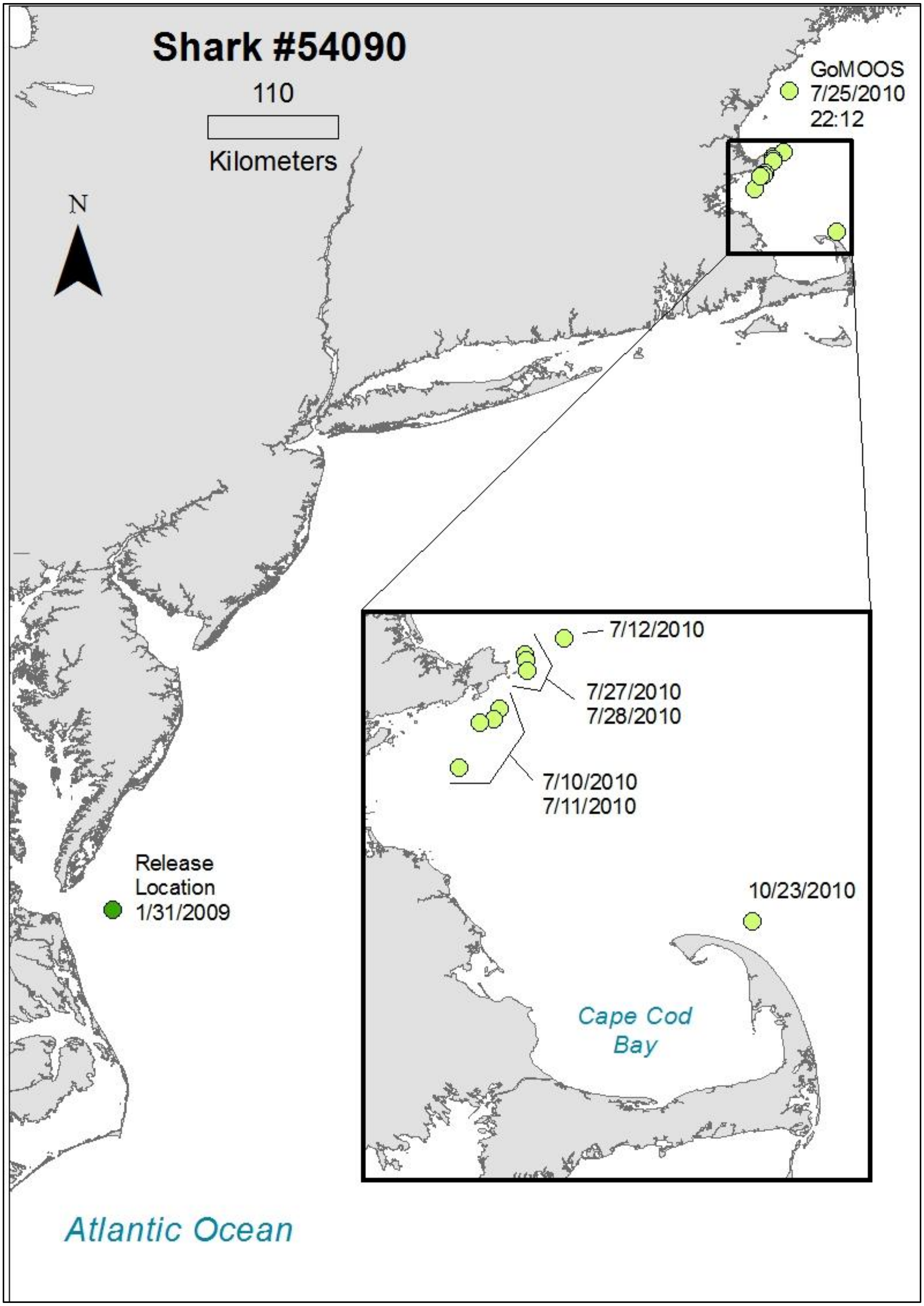


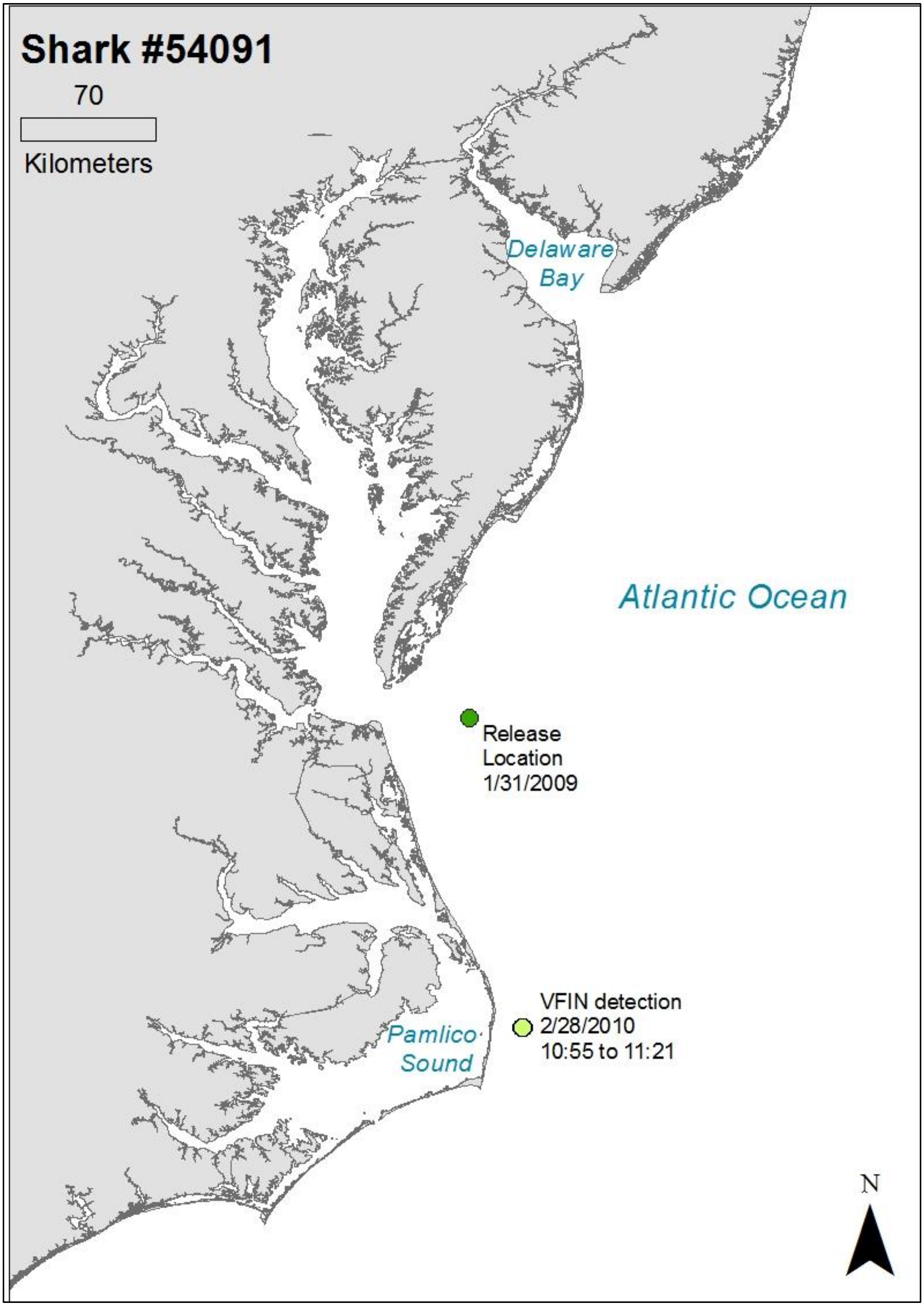
Shark #54087
90
Kilometers
N
Long Island Sound
6/14/2010
0:25 to 1:06
26 detections
Delaware Bay
Atlantic Ocean
Release Location
1/31/2009
Pamlico Sound

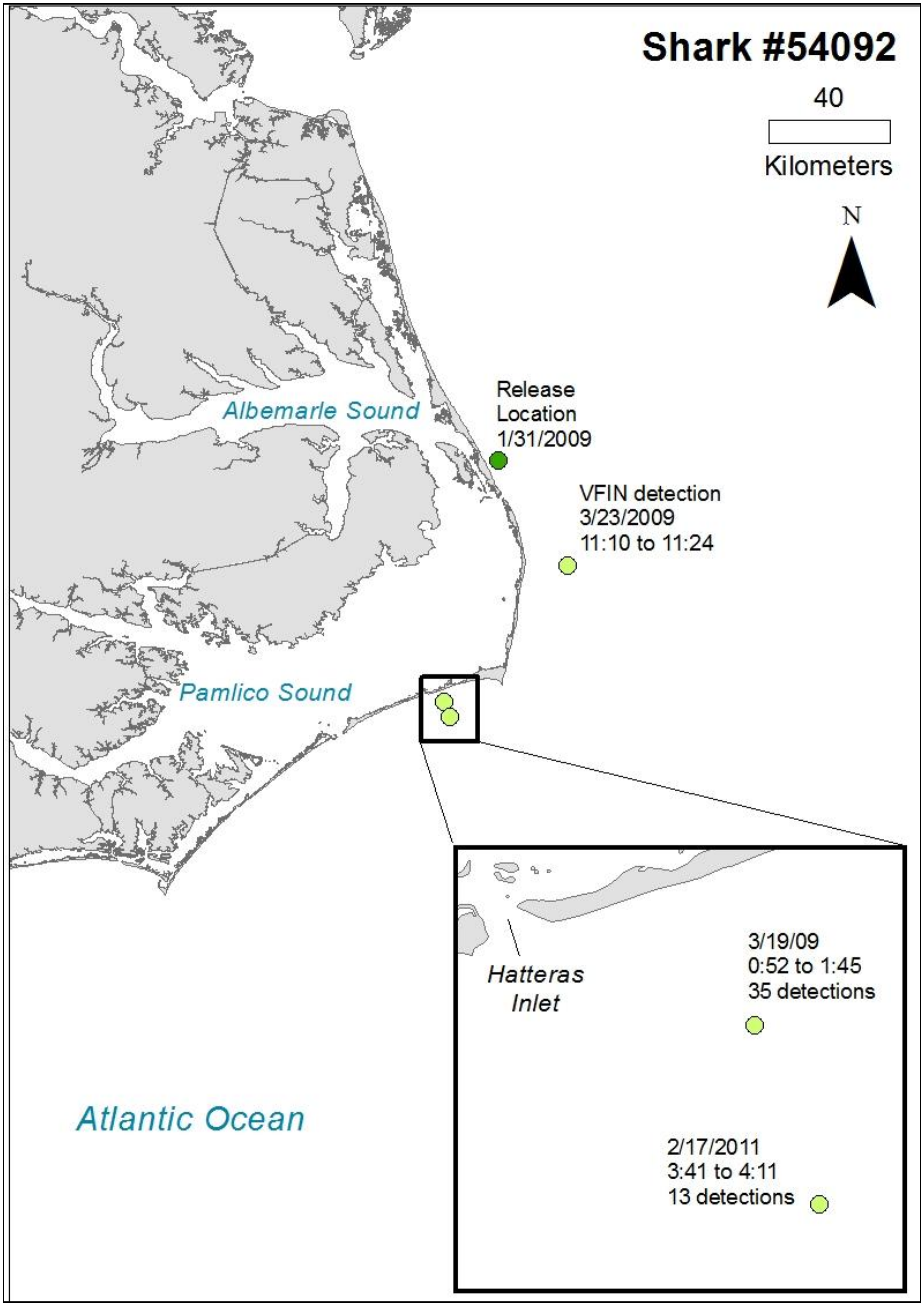


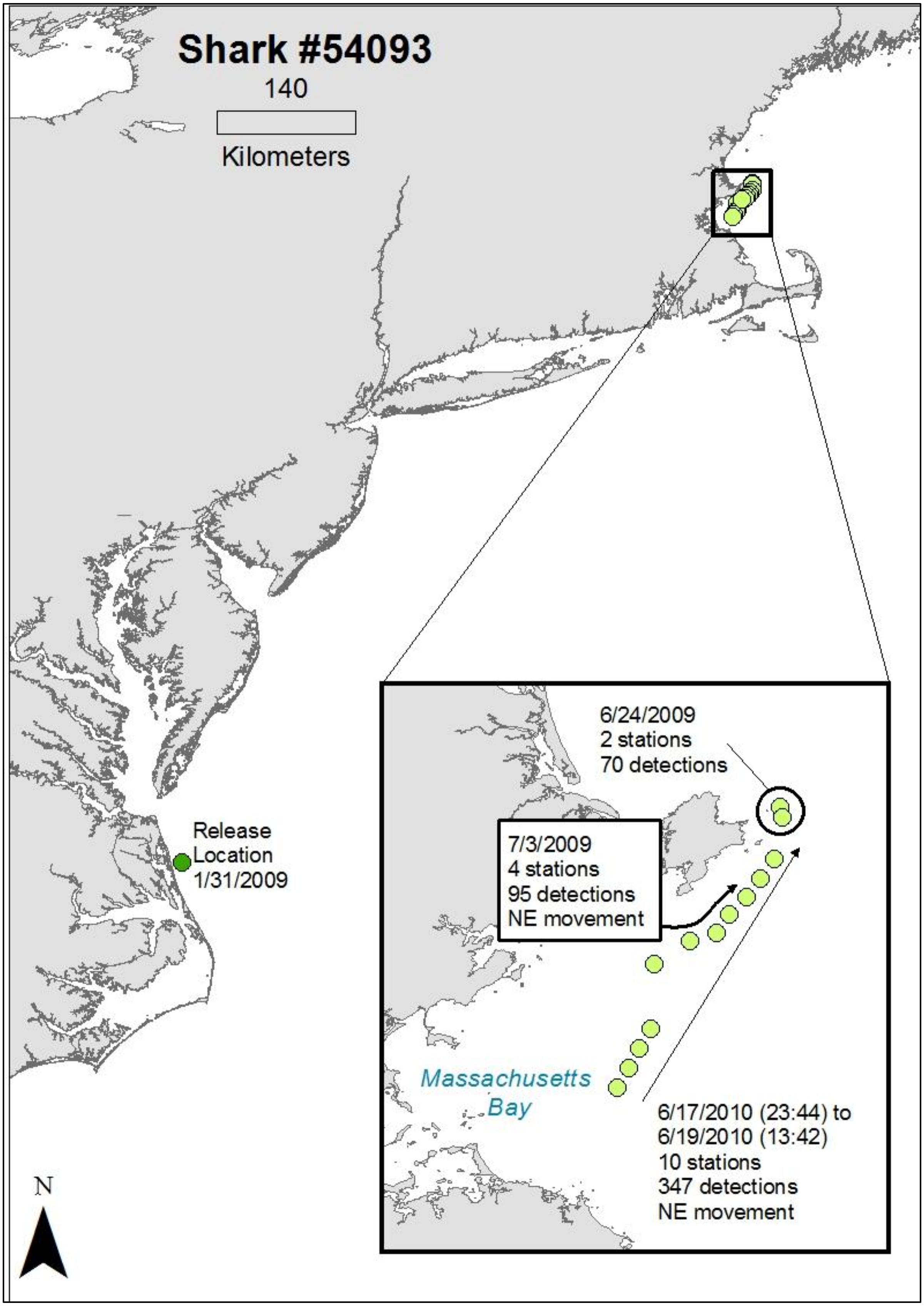
Shark #54088
110
Kilometers
N
6/25/2010 to 7/29/2010
14 receivers
9 detection days
316 detections
Release
Location
1/31/2009
3/1/2010
8:29 to 8:39
5 detections
VFIN
Hatteras
Inlet
3/10/2010
10:34 to 11:36
37 detections
3 receivers


Shark #54089
110
Kilometers
N
Gulf of
Maine
Release
Location
1/31/2009
8/7/2010
17:19 to 22:59
36 detections
Cape Cod
Bay
9/9/2010
9/25/2010
9/29/2010
10/8/2010
11 detections
10/3/2010
7 detections
Atlantic Ocean

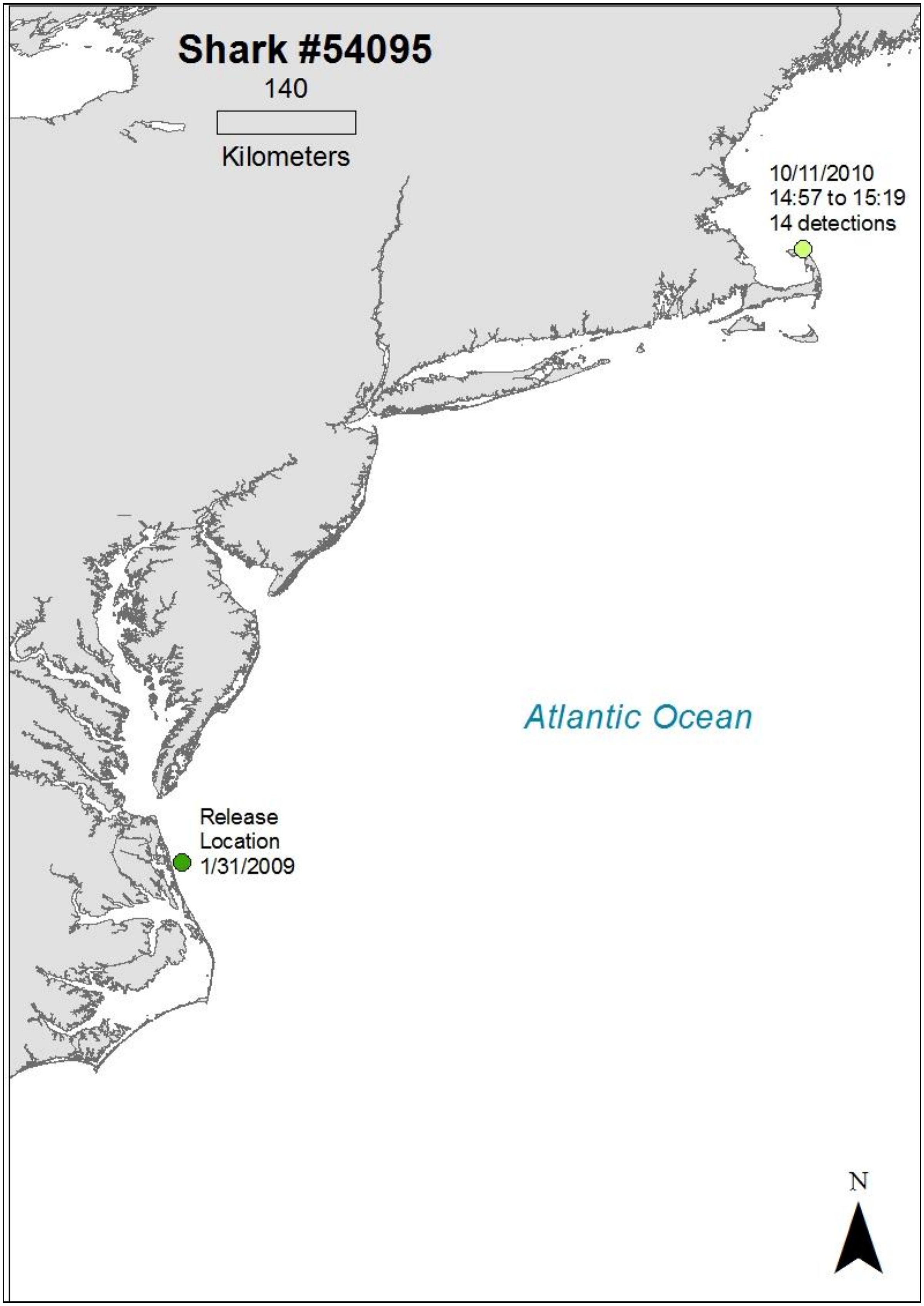

Shark #54090
110
Kilometers
N
GoMOOS
7/25/2010
22:12
7/12/2010
7/27/2010
7/28/2010
7/10/2010
7/11/2010
10/23/2010
Cape Cod
Bay
Release
Location
1/31/2009
Atlantic Ocean


Shark #54091
70
Kilometers
Delaware Bay
Atlantic Ocean
Release Location 1/31/2009
VFIN detection 2/28/2010 10:55 to 11:21
Pamlico Sound
N

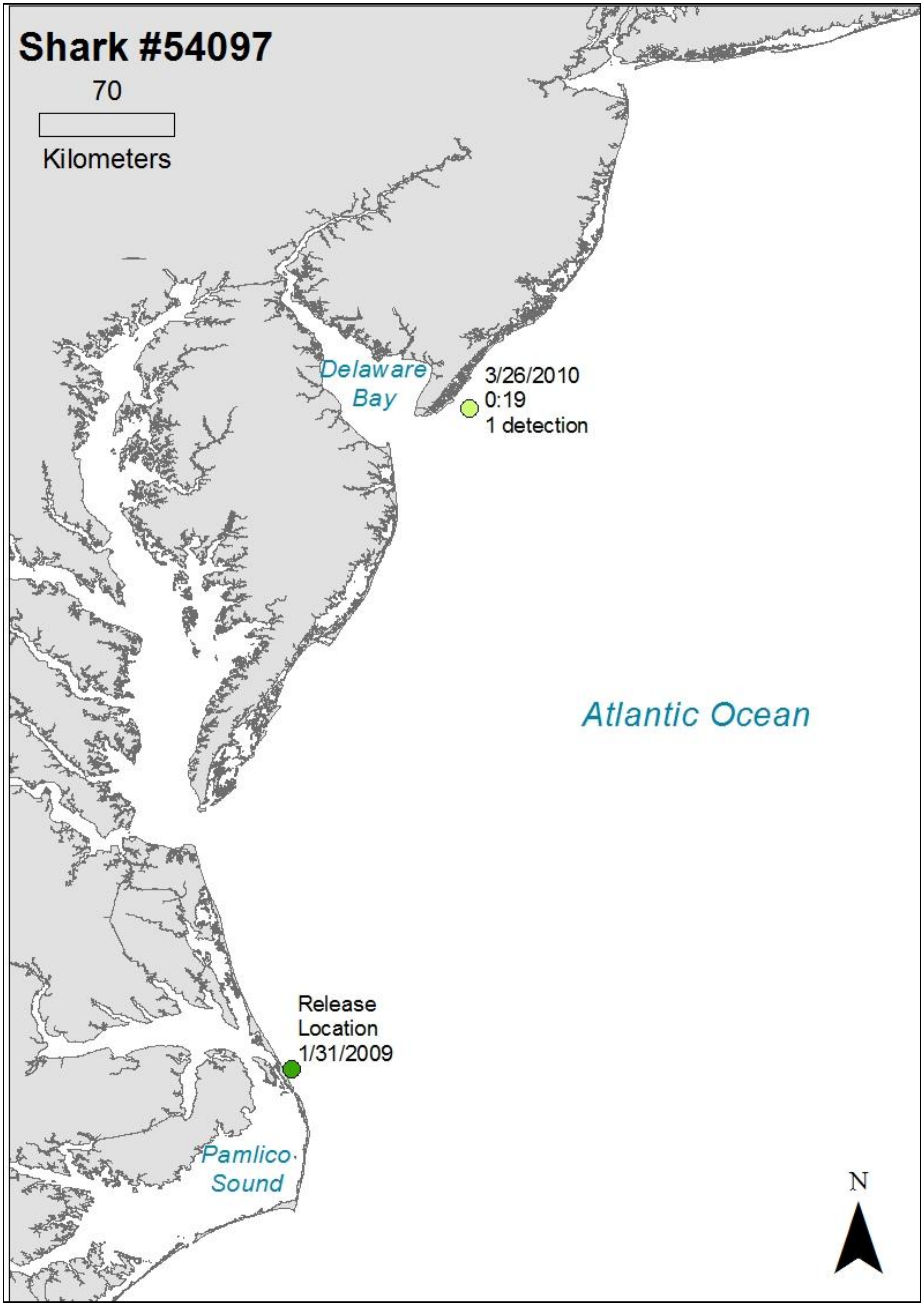

Shark #54092
40
Kilometers
N
Release
Location
1/31/2009
VFIN detection
3/23/2009
11:10 to 11:24
Albemarle Sound
Pamlico Sound
Atlantic Ocean
Hatteras
Inlet
3/19/09
0:52 to 1:45
35 detections
2/17/2011
3:41 to 4:11
13 detections

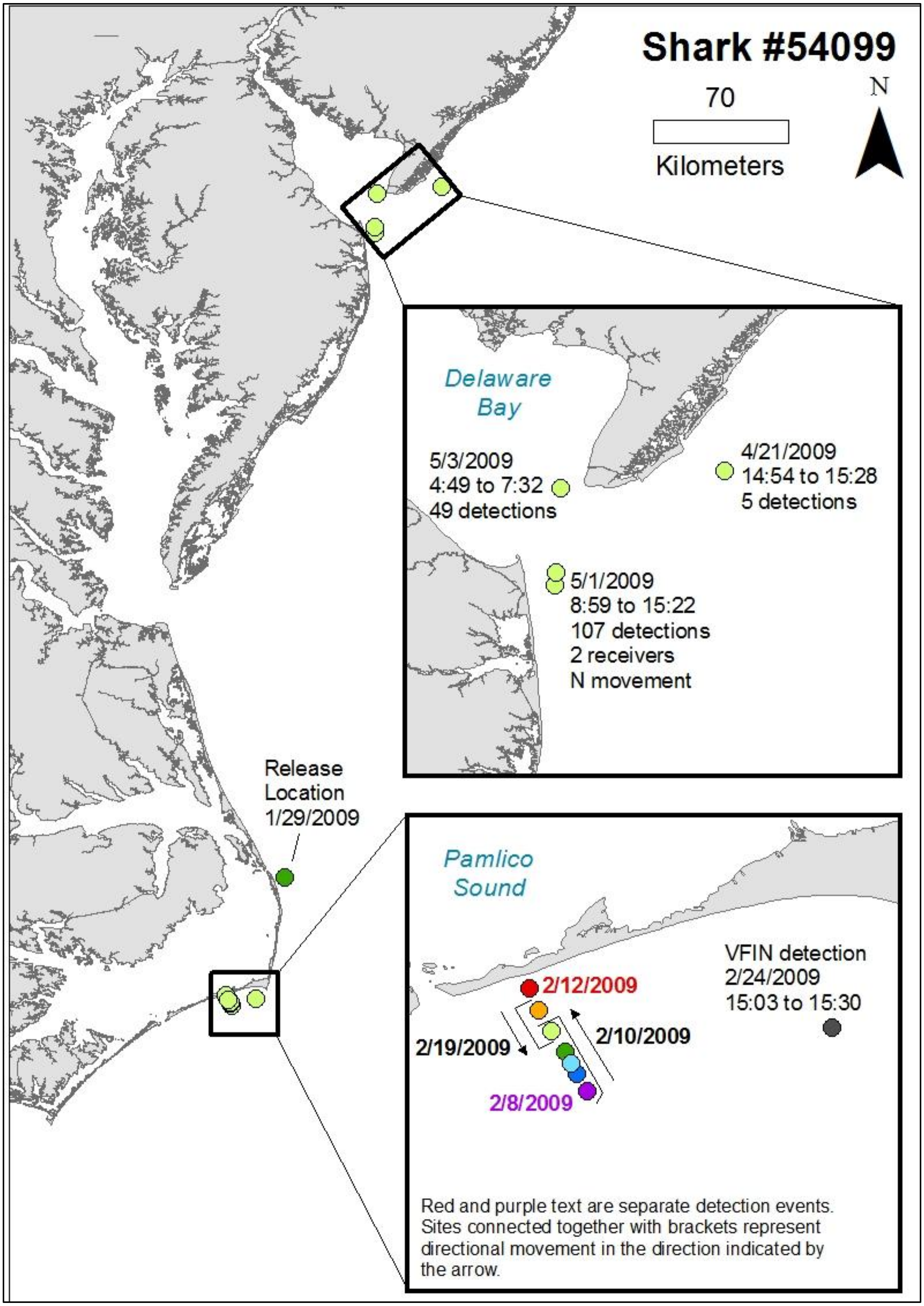


Shark #54093
140
Kilometers
Release
Location
1/31/2009
6/24/2009
2 stations
70 detections
7/3/2009
4 stations
95 detections
NE movement
Massachusetts
Bay
6/17/2010 (23:44) to
6/19/2010 (13:42)
10 stations
347 detections
NE movement
N

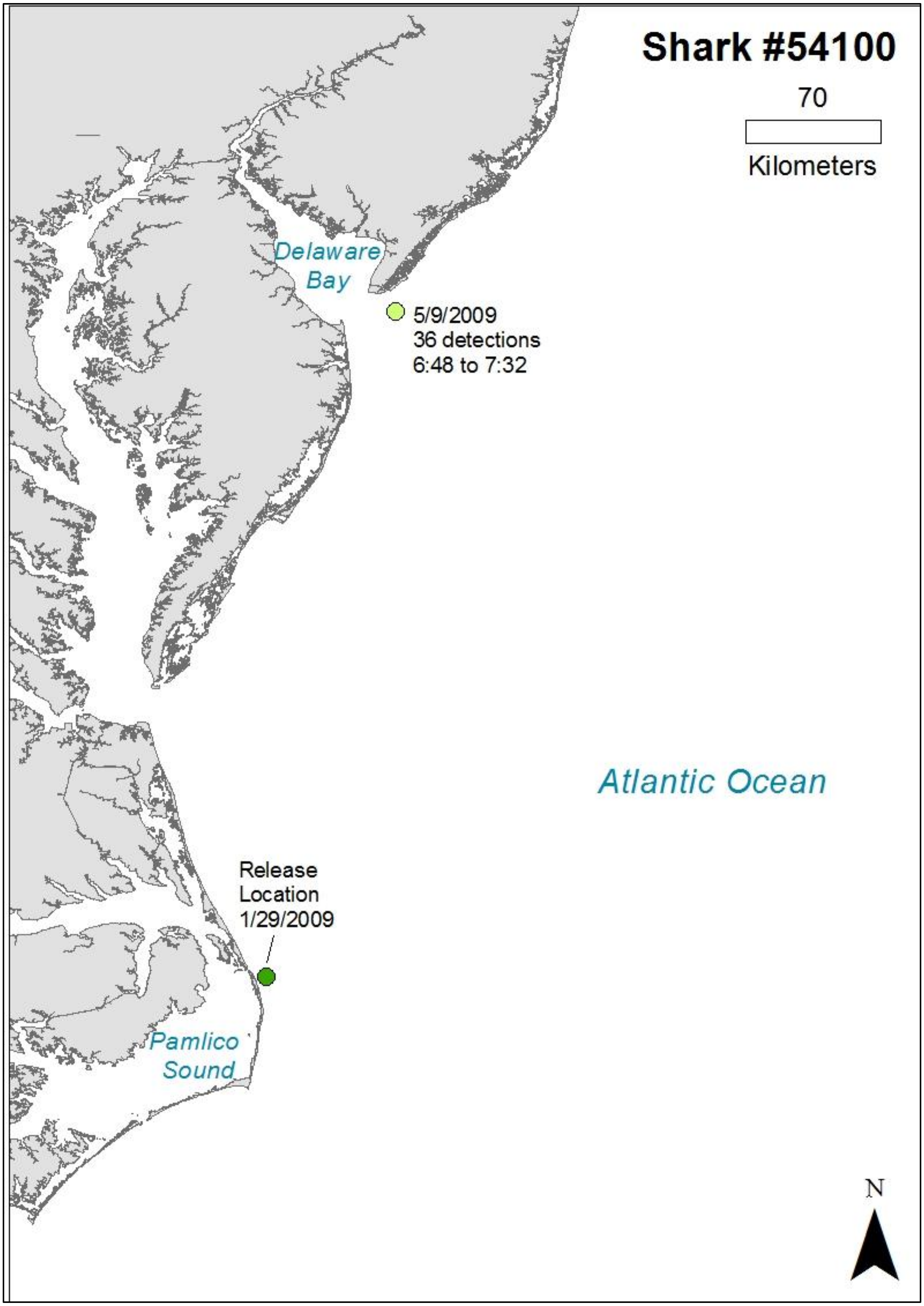


Shark #54095
140
Kilometers
10/11/2010
14:57 to 15:19
14 detections
Atlantic Ocean
Release
Location
1/31/2009
N


Shark #54097
70
Kilometers
Delaware Bay
3/26/2010
0:19
1 detection
Atlantic Ocean
Release
Location
1/31/2009
Pamlico Sound
N

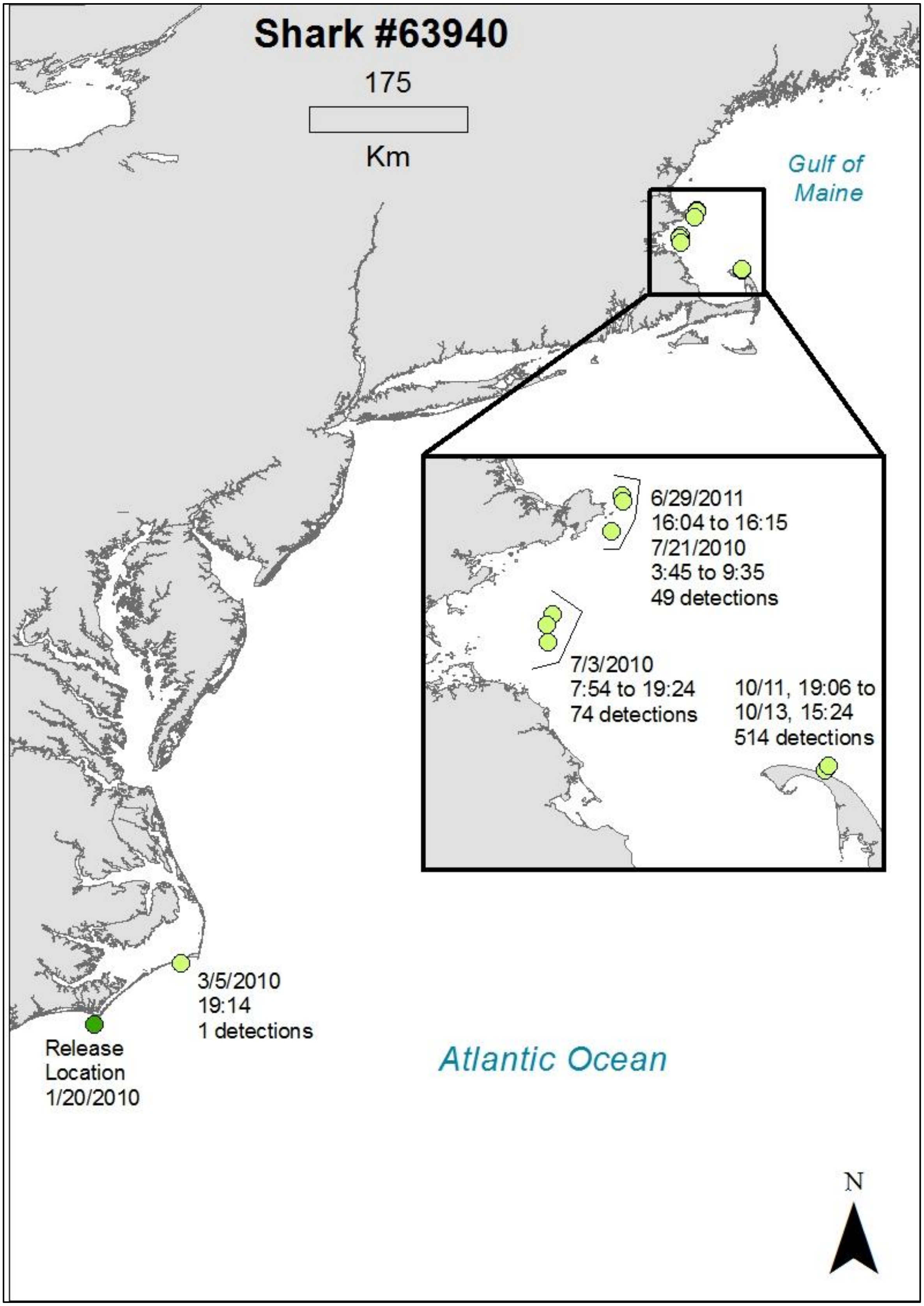


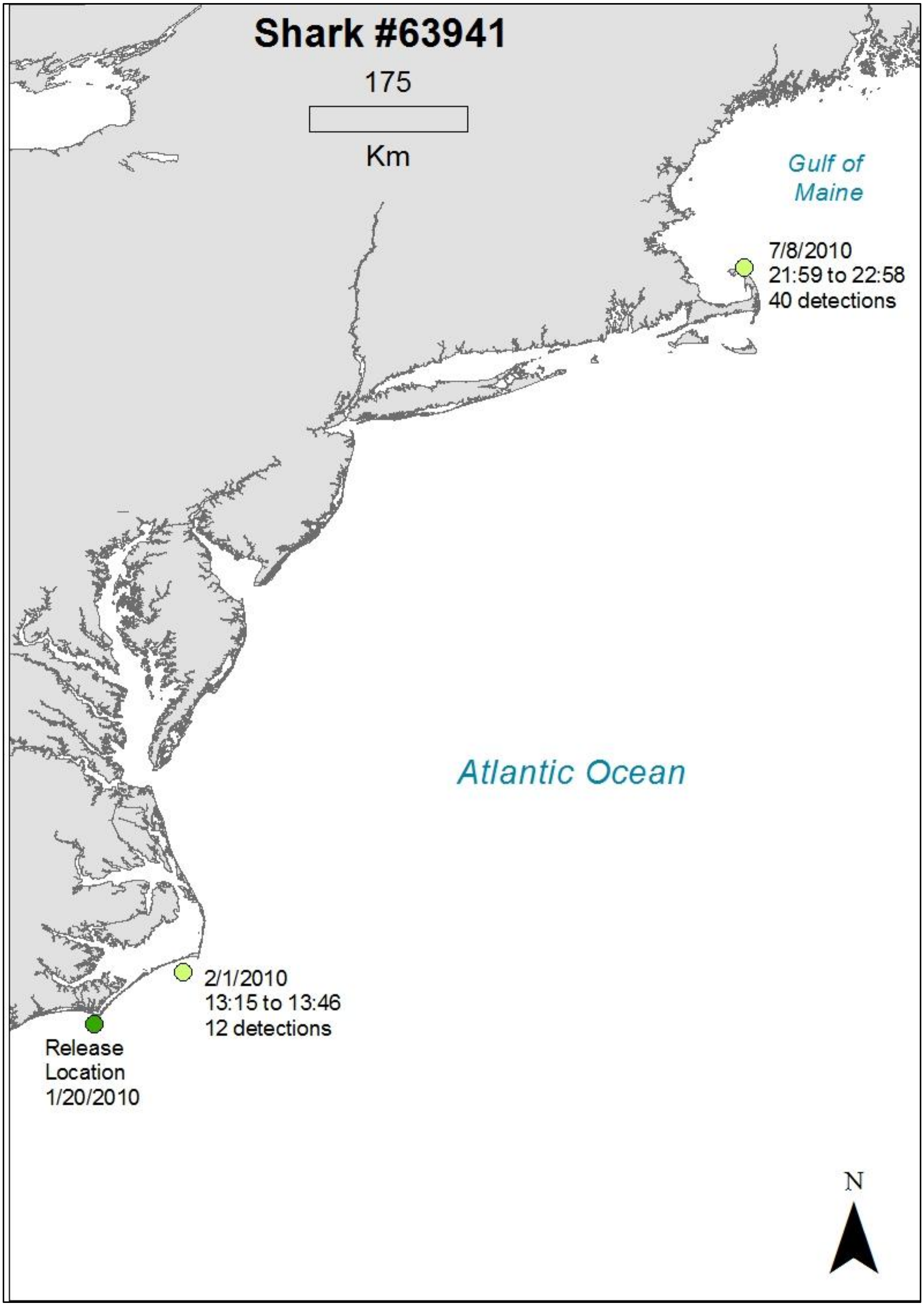
Shark #54099
70
Kilometers
N
Delaware Bay
5/3/2009
4:49 to 7:32
49 detections
4/21/2009
14:54 to 15:28
5 detections
5/1/2009
8:59 to 15:22
107 detections
2 receivers
N movement
Release Location 1/29/2009
Pamlico Sound
VFIN detection
2/24/2009
15:03 to 15:30
2/12/2009
2/10/2009
2/19/2009
2/8/2009
Red and purple text are separate detection events. Sites connected together with brackets represent directional movement in the direction indicated by the arrow.



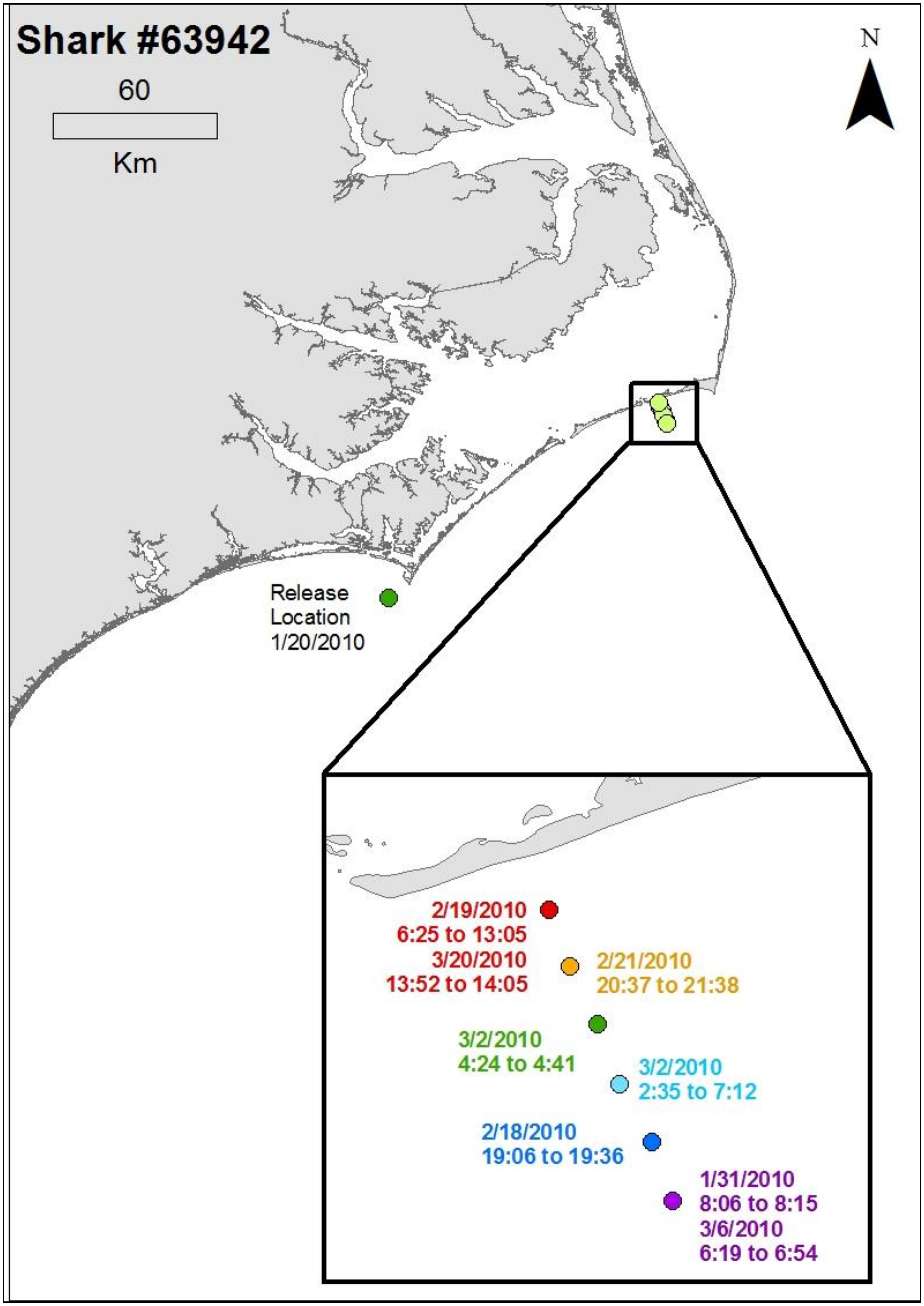
Shark #54100
70
Kilometers
Delaware Bay
5/9/2009
36 detections
6:48 to 7:32
Atlantic Ocean
Release
Location
1/29/2009
Pamlico
Sound
N

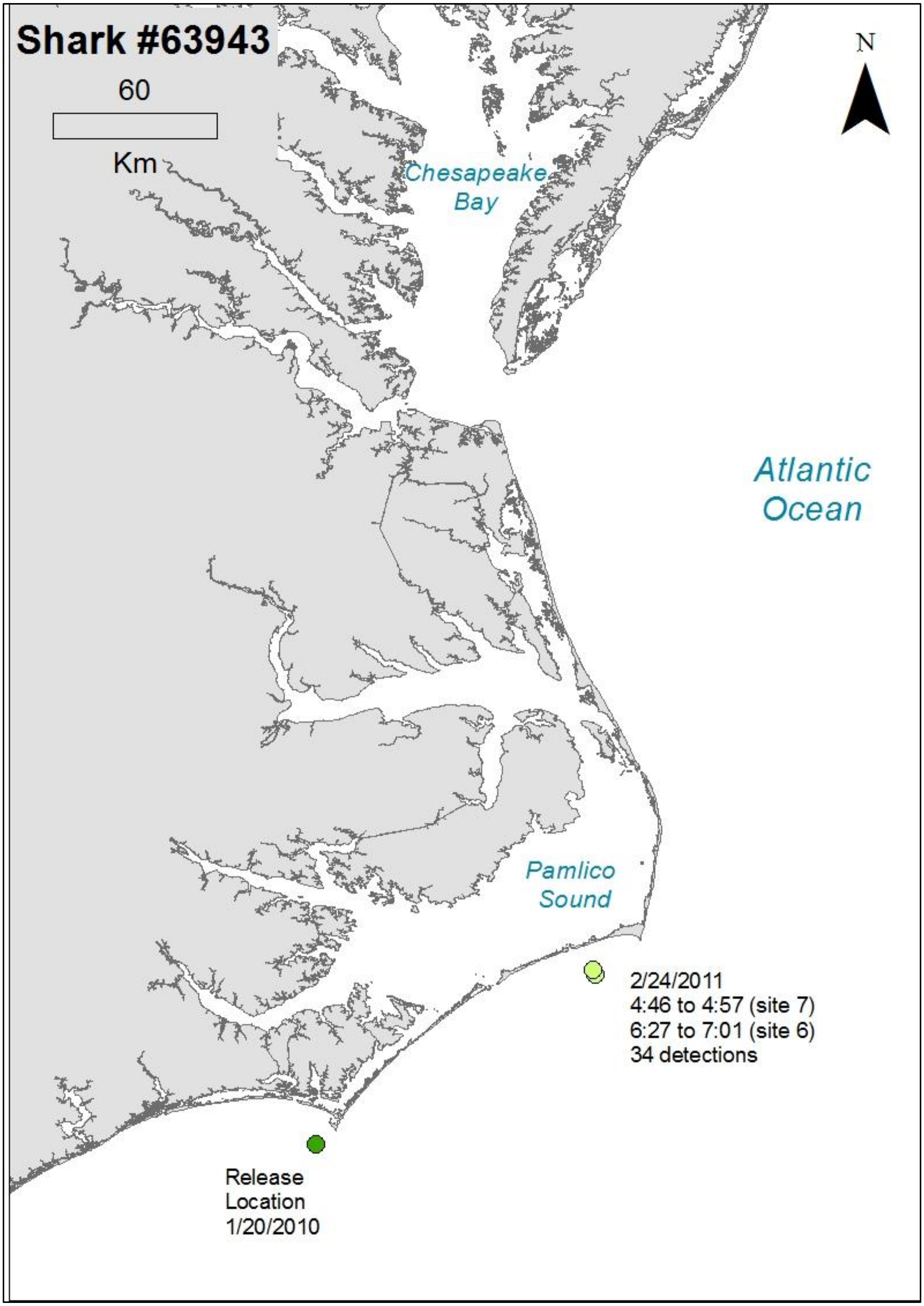
APPENDIX 3. MAP LIBRARY OF ACOUSTIC DETECTIONS – 2010

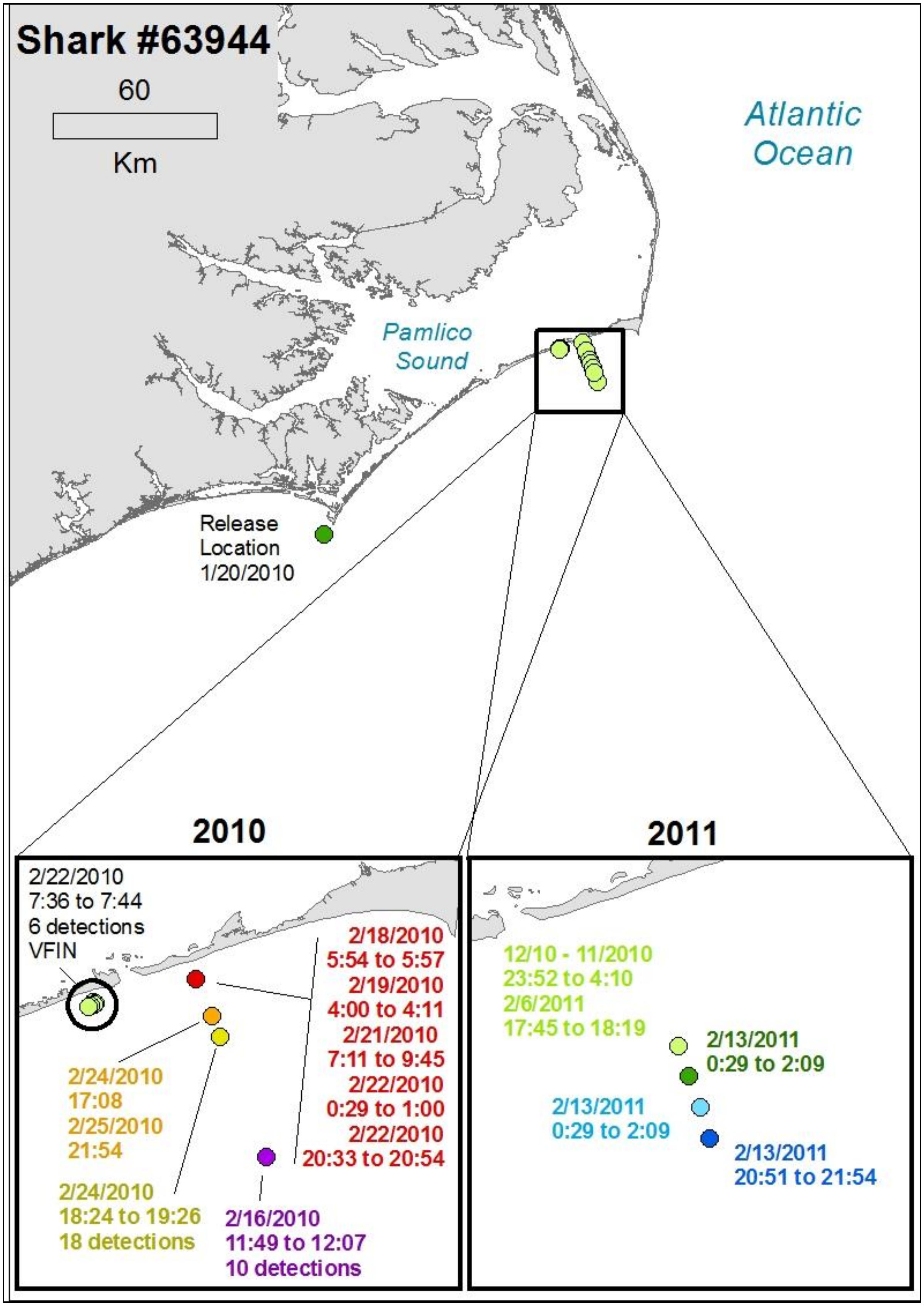

Shark #63940
175
Km
Gulf of Maine
6/29/2011
16:04 to 16:15
7/21/2010
3:45 to 9:35
49 detections
7/3/2010
7:54 to 19:24
74 detections
10/11, 19:06 to
10/13, 15:24
514 detections
3/5/2010
19:14
1 detections
Release
Location
1/20/2010
Atlantic Ocean
N



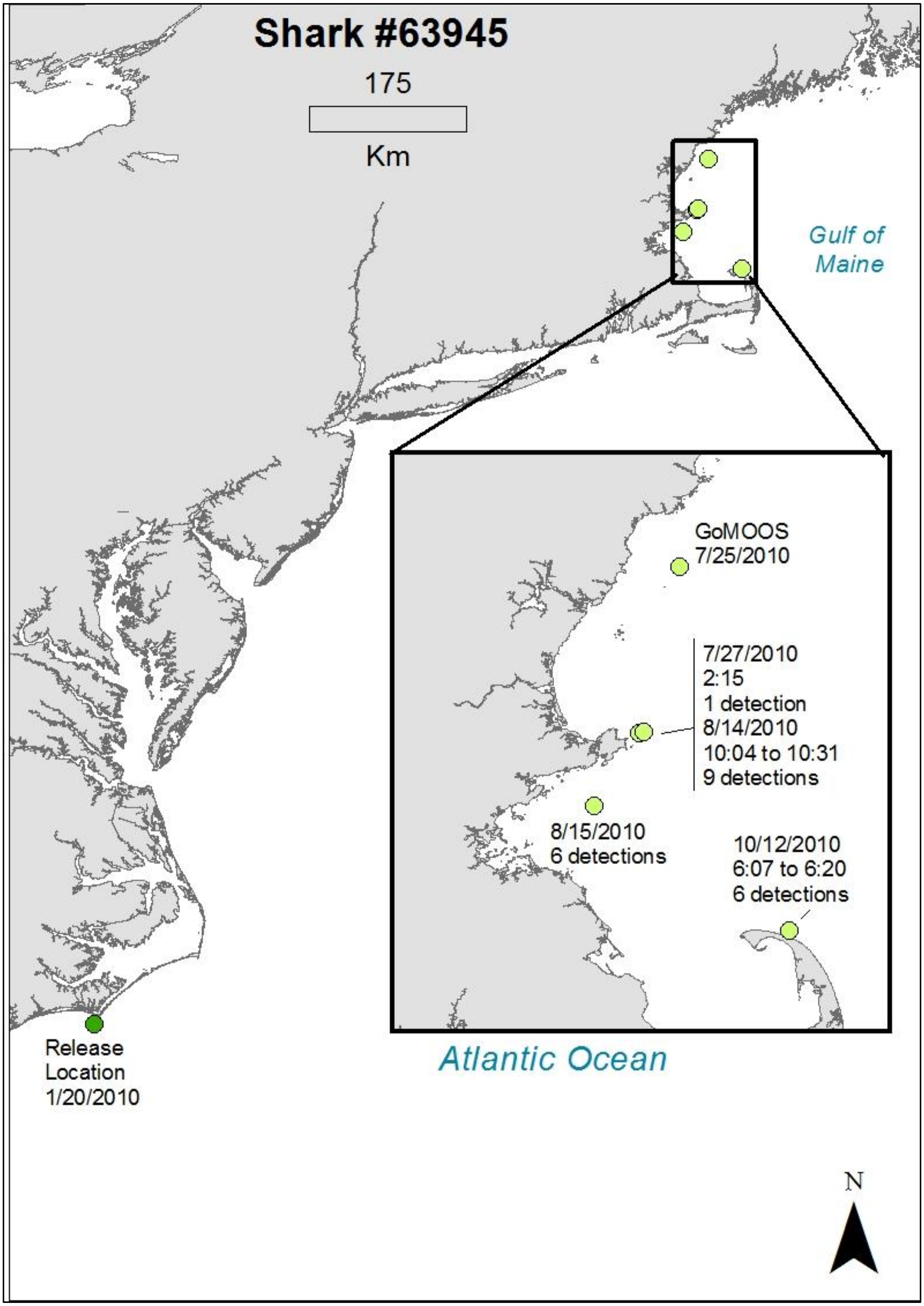
Shark #63941
175
Km
Gulf of
Maine
7/8/2010
21:59 to 22:58
40 detections
Atlantic Ocean
2/1/2010
13:15 to 13:46
12 detections
Release
Location
1/20/2010
N

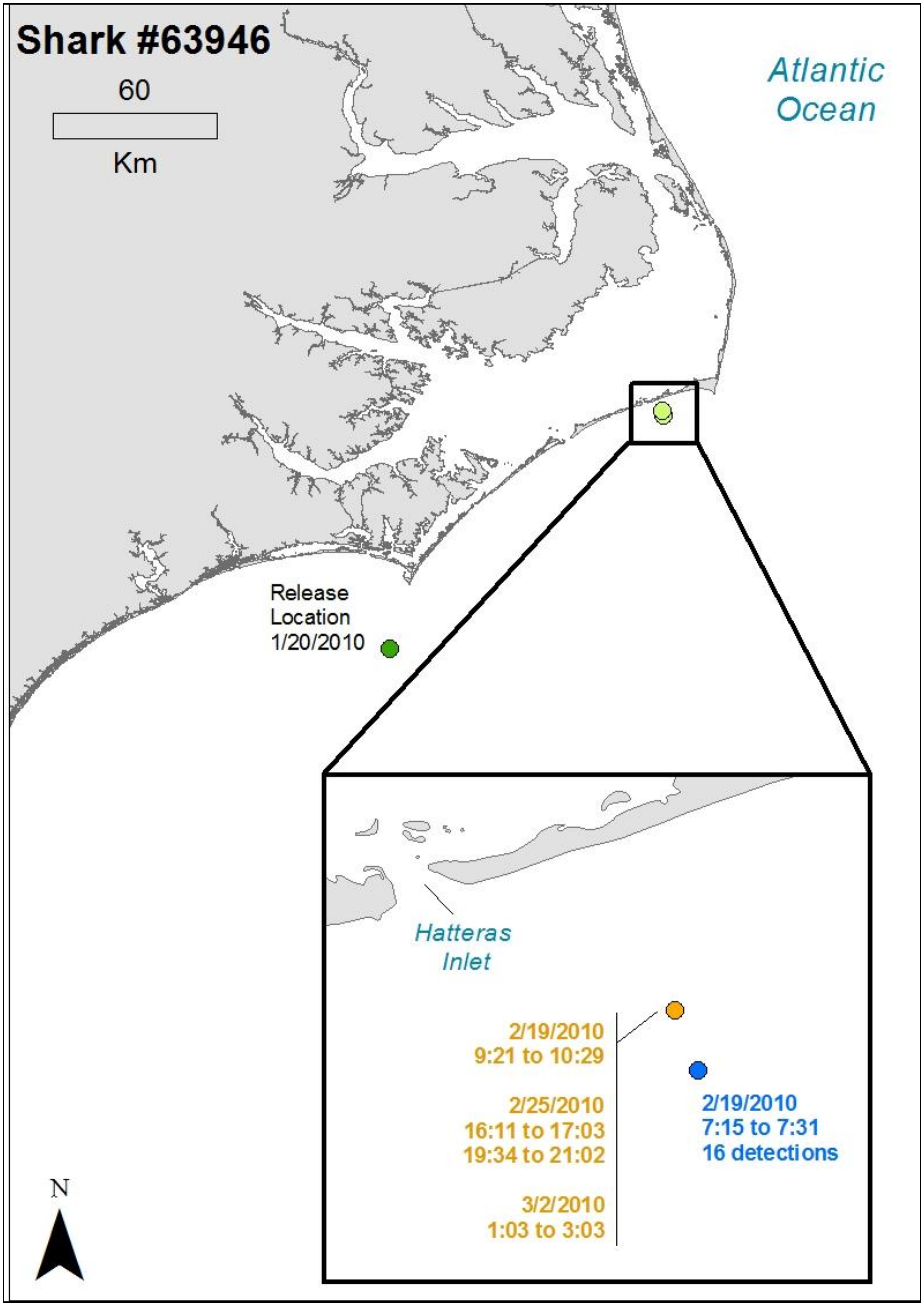

Shark #63942
60
Km
N
Release
Location
1/20/2010
2/19/2010
6:25 to 13:05
3/20/2010
13:52 to 14:05
2/21/2010
20:37 to 21:38
3/2/2010
4:24 to 4:41
3/2/2010
2:35 to 7:12
2/18/2010
19:06 to 19:36
1/31/2010
8:06 to 8:15
3/6/2010
6:19 to 6:54

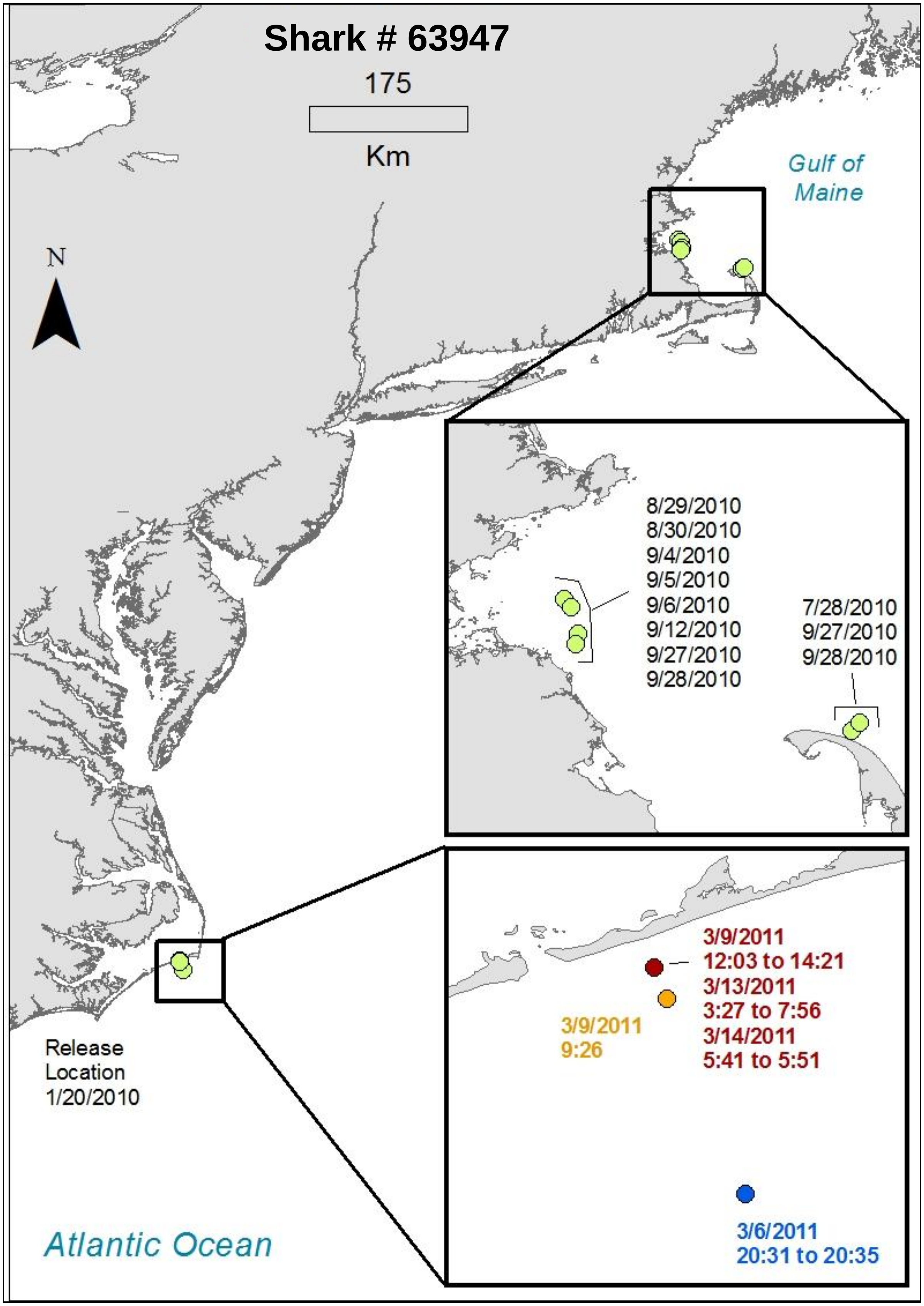

Shark #63943
60
Km
N
Chesapeake Bay
Atlantic Ocean
Pamlico Sound
2/24/2011
4:46 to 4:57 (site 7)
6:27 to 7:01 (site 6)
34 detections
Release Location
1/20/2010



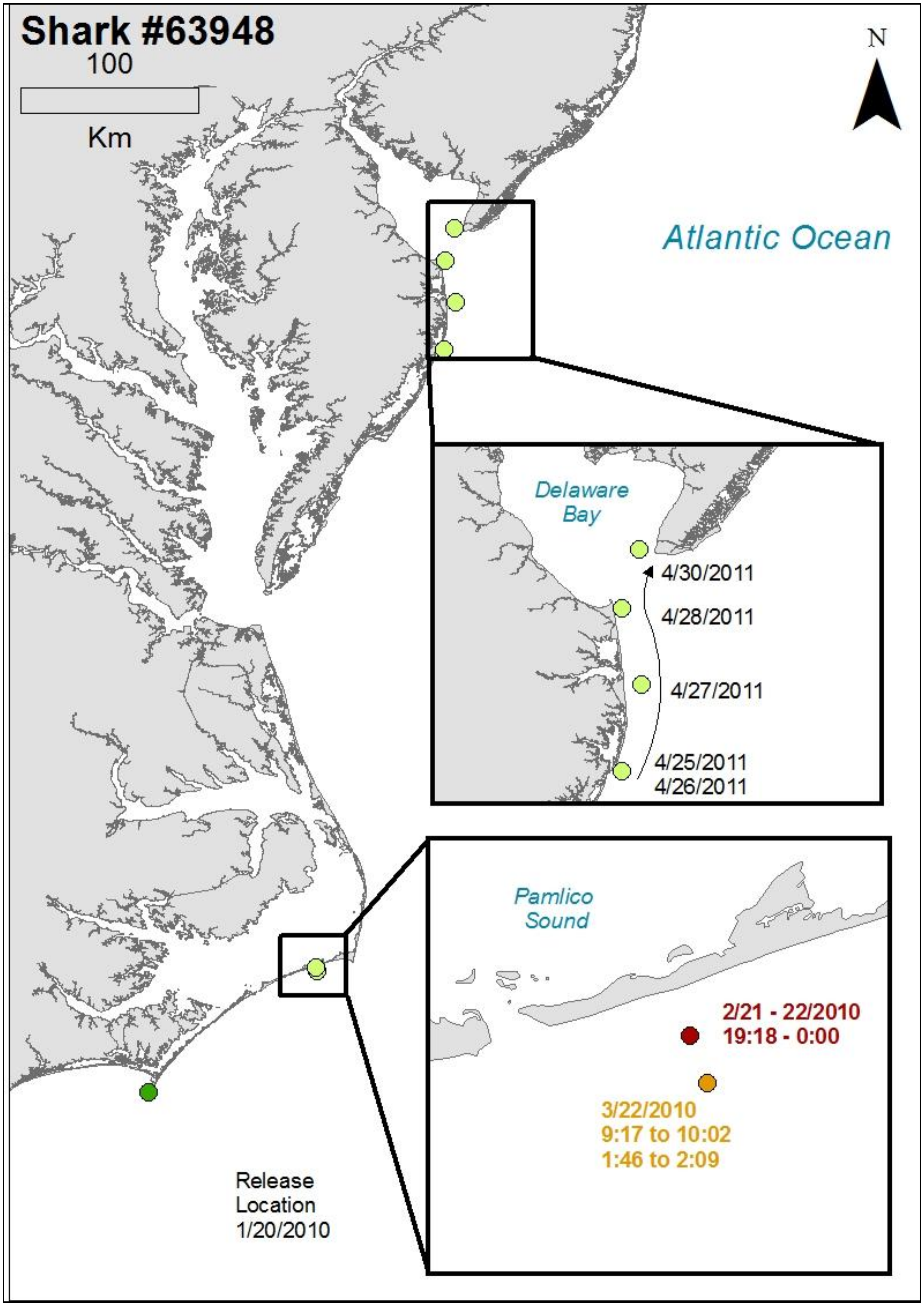
Shark #63944
60
Km
Atlantic Ocean
Pamlico Sound
Release Location 1/20/2010
2010
2011
2/22/2010
7:36 to 7:44
6 detections
VFIN
2/18/2010
5:54 to 5:57
2/19/2010
4:00 to 4:11
2/21/2010
7:11 to 9:45
2/22/2010
0:29 to 1:00
2/22/2010
20:33 to 20:54
2/24/2010
17:08
2/25/2010
21:54
2/24/2010
18:24 to 19:26
18 detections
2/16/2010
11:49 to 12:07
10 detections
12/10 - 11/2010
23:52 to 4:10
2/6/2011
17:45 to 18:19
2/13/2011
0:29 to 2:09
2/13/2011
0:29 to 2:09
2/13/2011
20:51 to 21:54

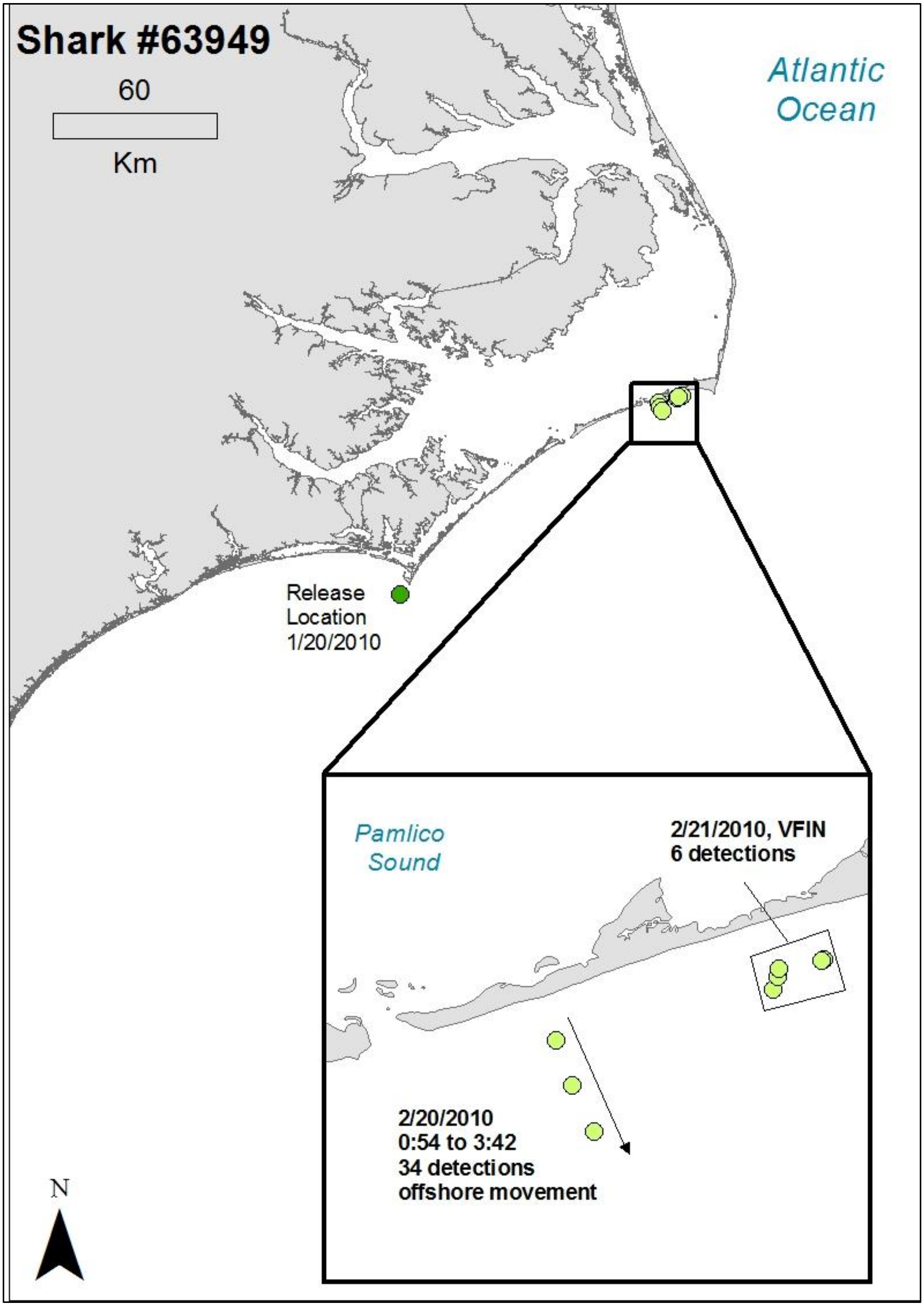

Shark #63945
175
Km
Gulf of
Maine
GoMOOS
7/25/2010
7/27/2010
2:15
1 detection
8/14/2010
10:04 to 10:31
9 detections
8/15/2010
6 detections
10/12/2010
6:07 to 6:20
6 detections
Release
Location
1/20/2010
Atlantic Ocean
N

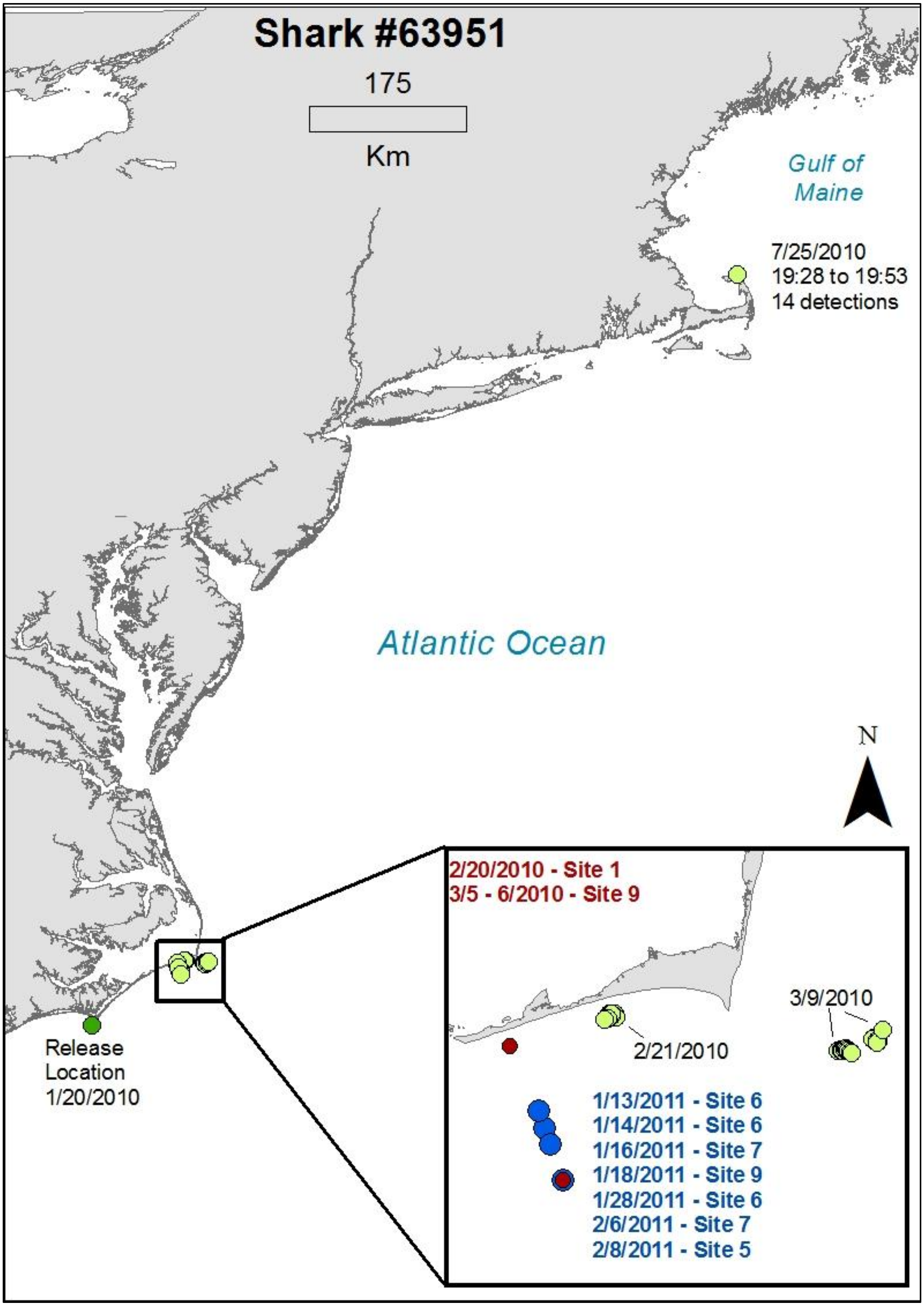

Shark #63946
60
Km
Atlantic
Ocean
Release
Location
1/20/2010
Hatteras
Inlet
2/19/2010
9:21 to 10:29
2/25/2010
16:11 to 17:03
19:34 to 21:02
3/2/2010
1:03 to 3:03
2/19/2010
7:15 to 7:31
16 detections
N



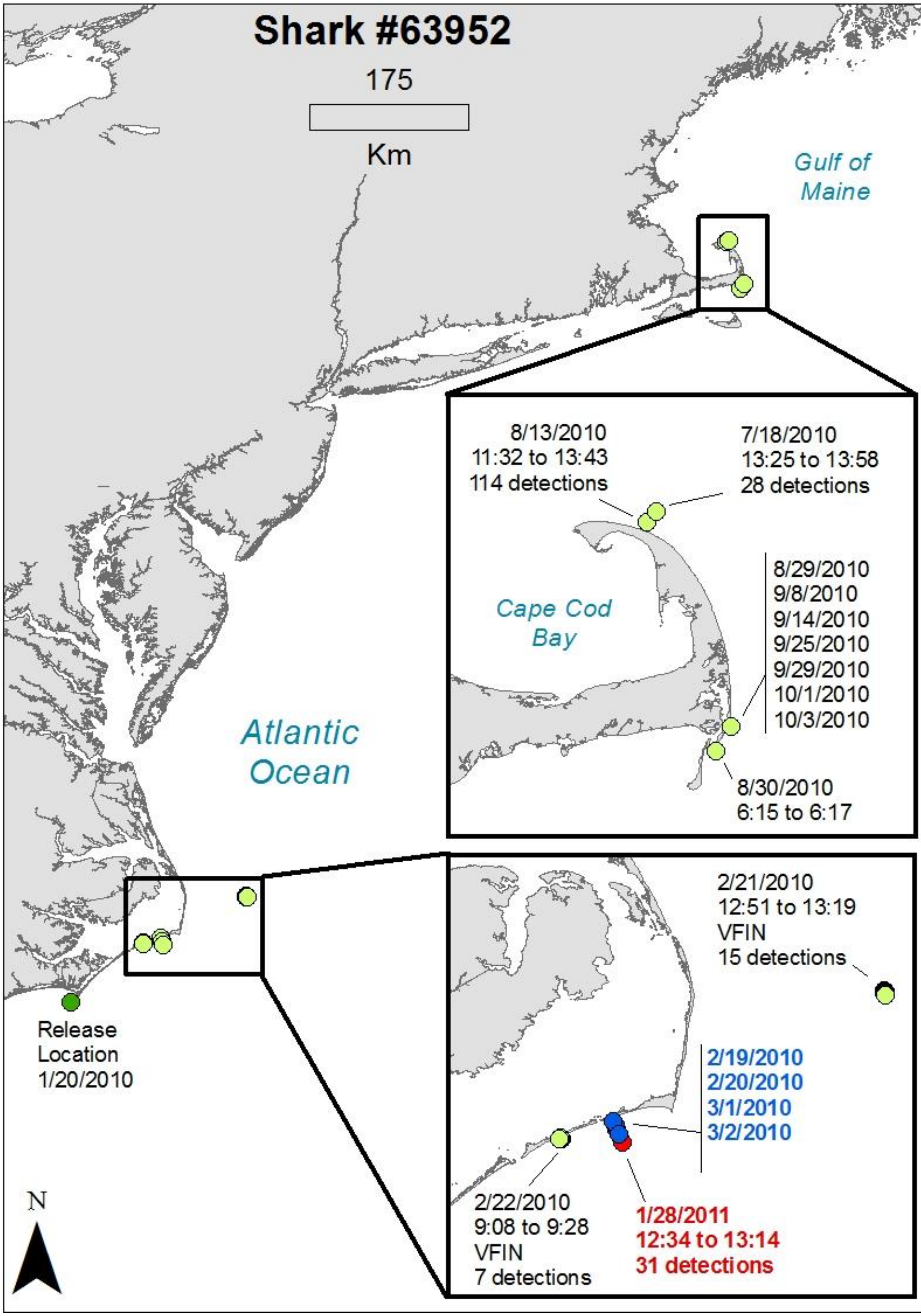
Shark # 63947
175
Km
N
Gulf of Maine
8/29/2010
8/30/2010
9/4/2010
9/5/2010
9/6/2010
9/12/2010
9/27/2010
9/28/2010
7/28/2010
9/27/2010
9/28/2010
3/9/2011
12:03 to 14:21
3/13/2011
3:27 to 7:56
3/14/2011
5:41 to 5:51
3/9/2011
9:26
Release Location 1/20/2010
3/6/2011
20:31 to 20:35
Atlantic Ocean


Shark #63948
100
Km
N
Atlantic Ocean
Delaware Bay
4/30/2011
4/28/2011
4/27/2011
4/25/2011
4/26/2011
Pamlico Sound
2/21 - 22/2010
19:18 - 0:00
3/22/2010
9:17 to 10:02
1:46 to 2:09
Release Location
1/20/2010

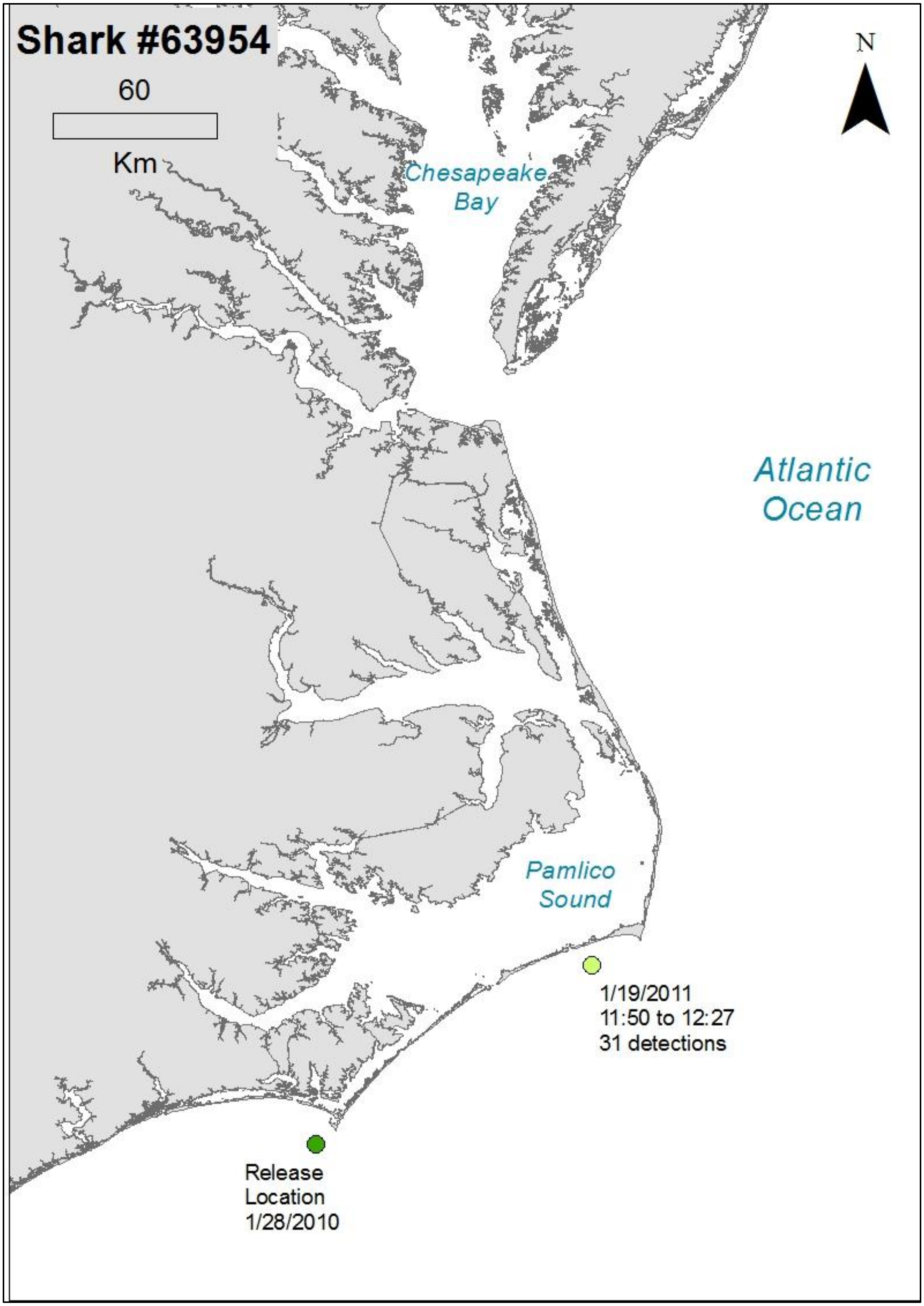

Shark #63949
60
Km
Atlantic
Ocean
Release
Location
1/20/2010
Pamlico
Sound
2/21/2010, VFIN
6 detections
2/20/2010
0:54 to 3:42
34 detections
offshore movement
N

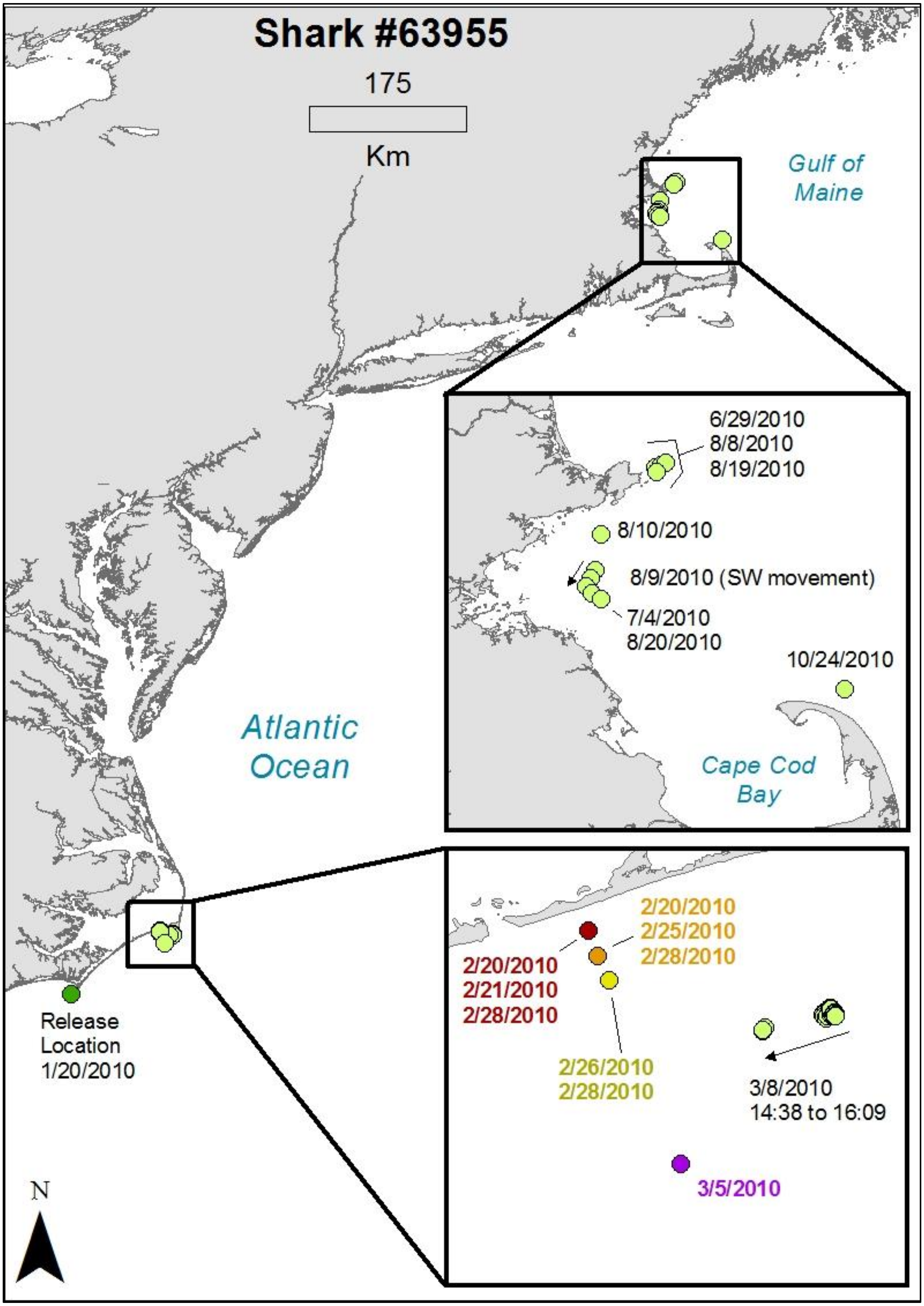


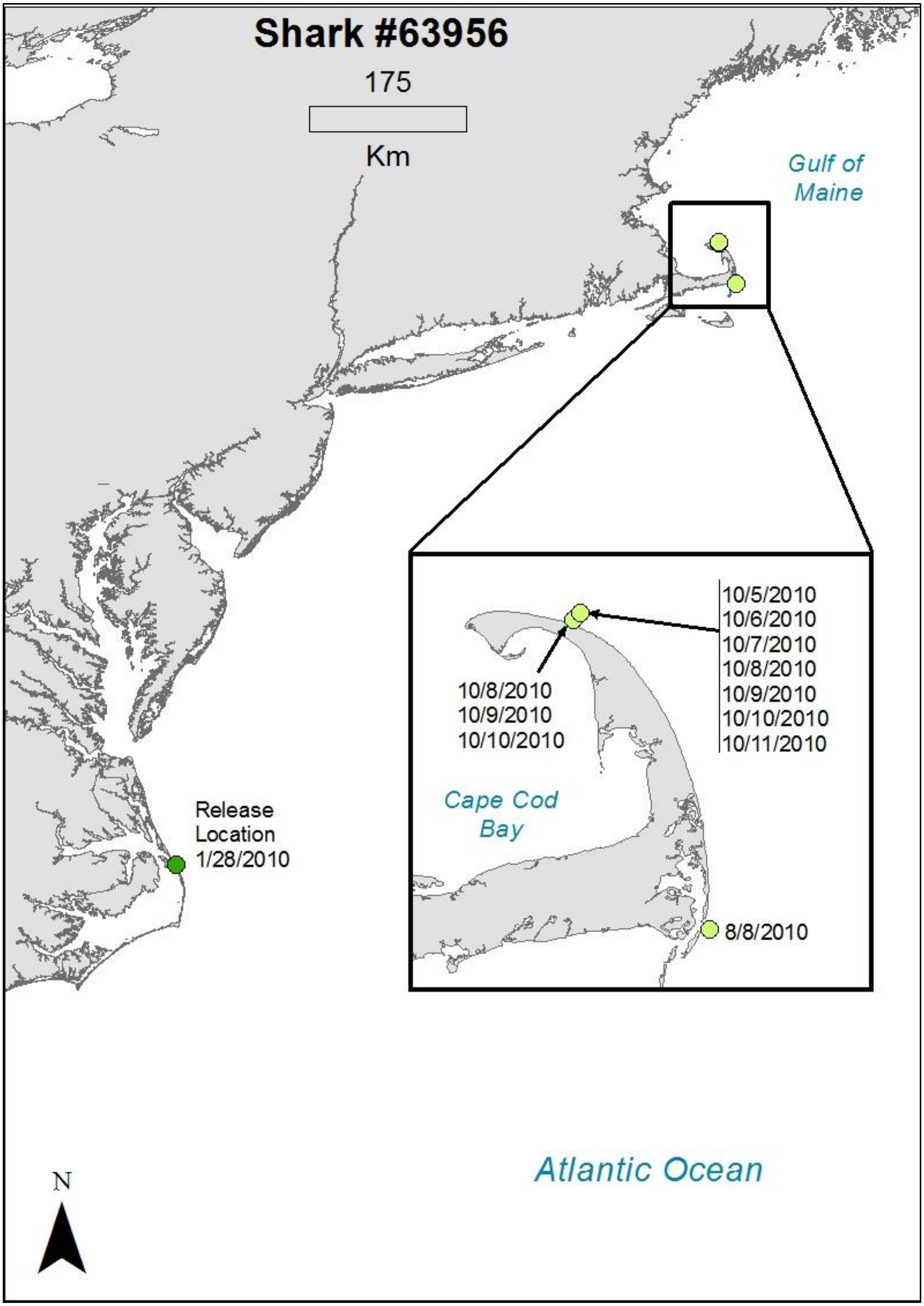
Shark #63951
175
Km
Gulf of Maine
7/25/2010
19:28 to 19:53
14 detections
Atlantic Ocean
N
Release Location 1/20/2010
2/20/2010 - Site 1
3/5 - 6/2010 - Site 9
3/9/2010
2/21/2010
1/13/2011 - Site 6
1/14/2011 - Site 6
1/16/2011 - Site 7
1/18/2011 - Site 9
1/28/2011 - Site 6
2/6/2011 - Site 7
2/8/2011 - Site 5



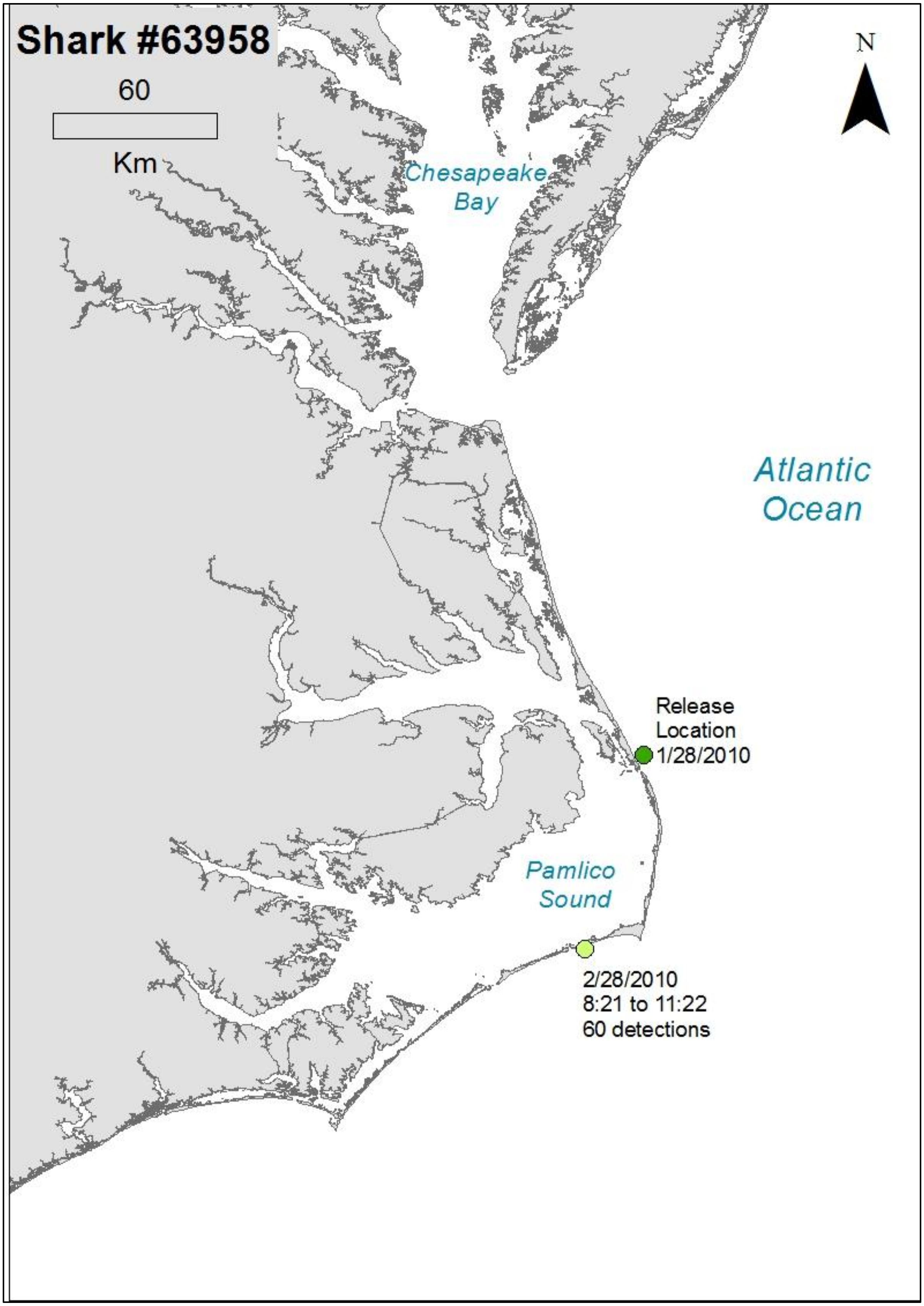
Shark #63952
175
Km
Gulf of
Maine
8/13/2010
11:32 to 13:43
114 detections
7/18/2010
13:25 to 13:58
28 detections
Cape Cod
Bay
8/29/2010
9/8/2010
9/14/2010
9/25/2010
9/29/2010
10/1/2010
10/3/2010
8/30/2010
6:15 to 6:17
Atlantic
Ocean
2/21/2010
12:51 to 13:19
VFIN
15 detections
Release
Location
1/20/2010
2/19/2010
2/20/2010
3/1/2010
3/2/2010
2/22/2010
9:08 to 9:28
VFIN
7 detections
1/28/2011
12:34 to 13:14
31 detections
N

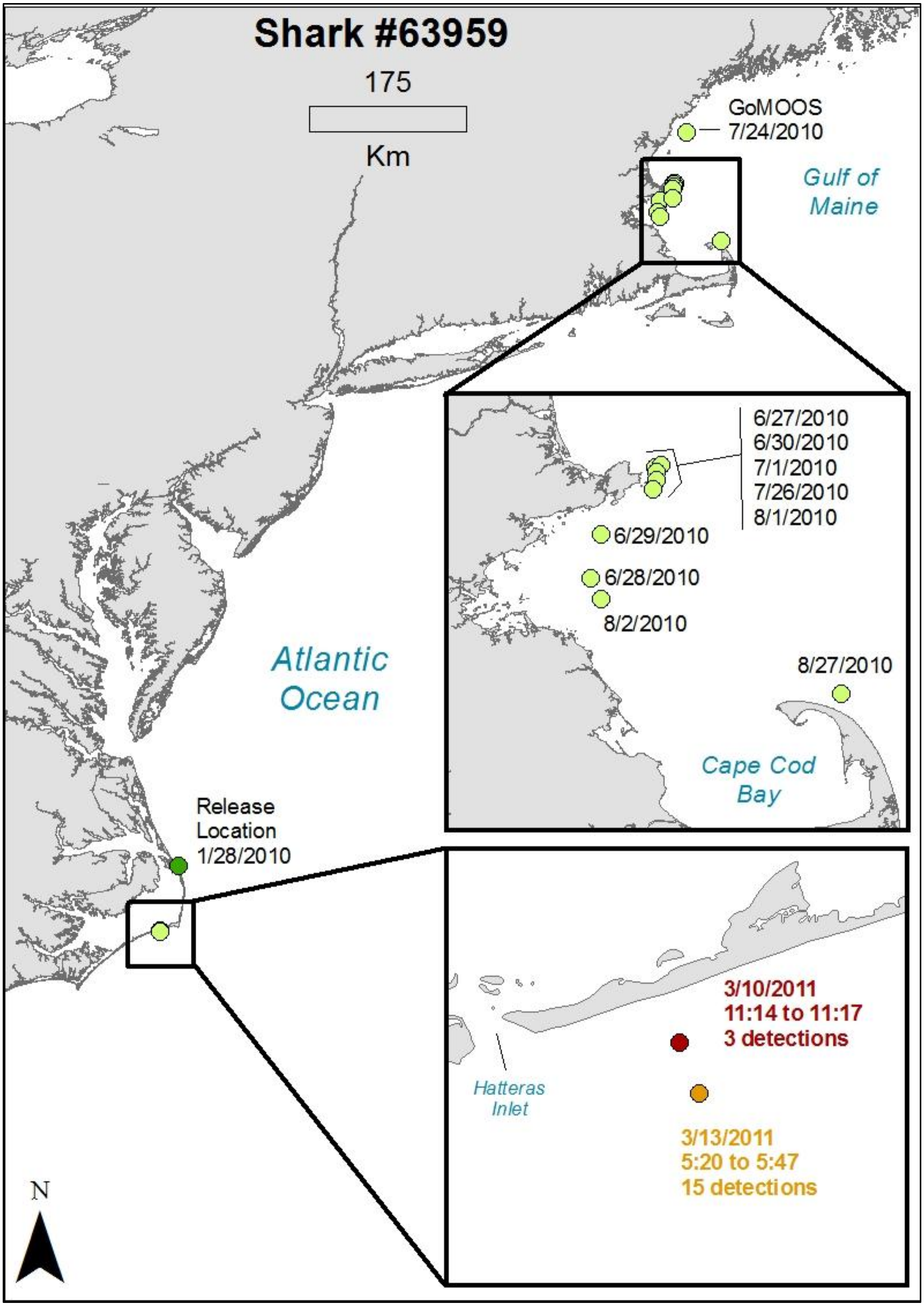

Shark #63954
60
Km
N
Chesapeake
Bay
Atlantic
Ocean
Pamlico
Sound
1/19/2011
11:50 to 12:27
31 detections
Release
Location
1/28/2010

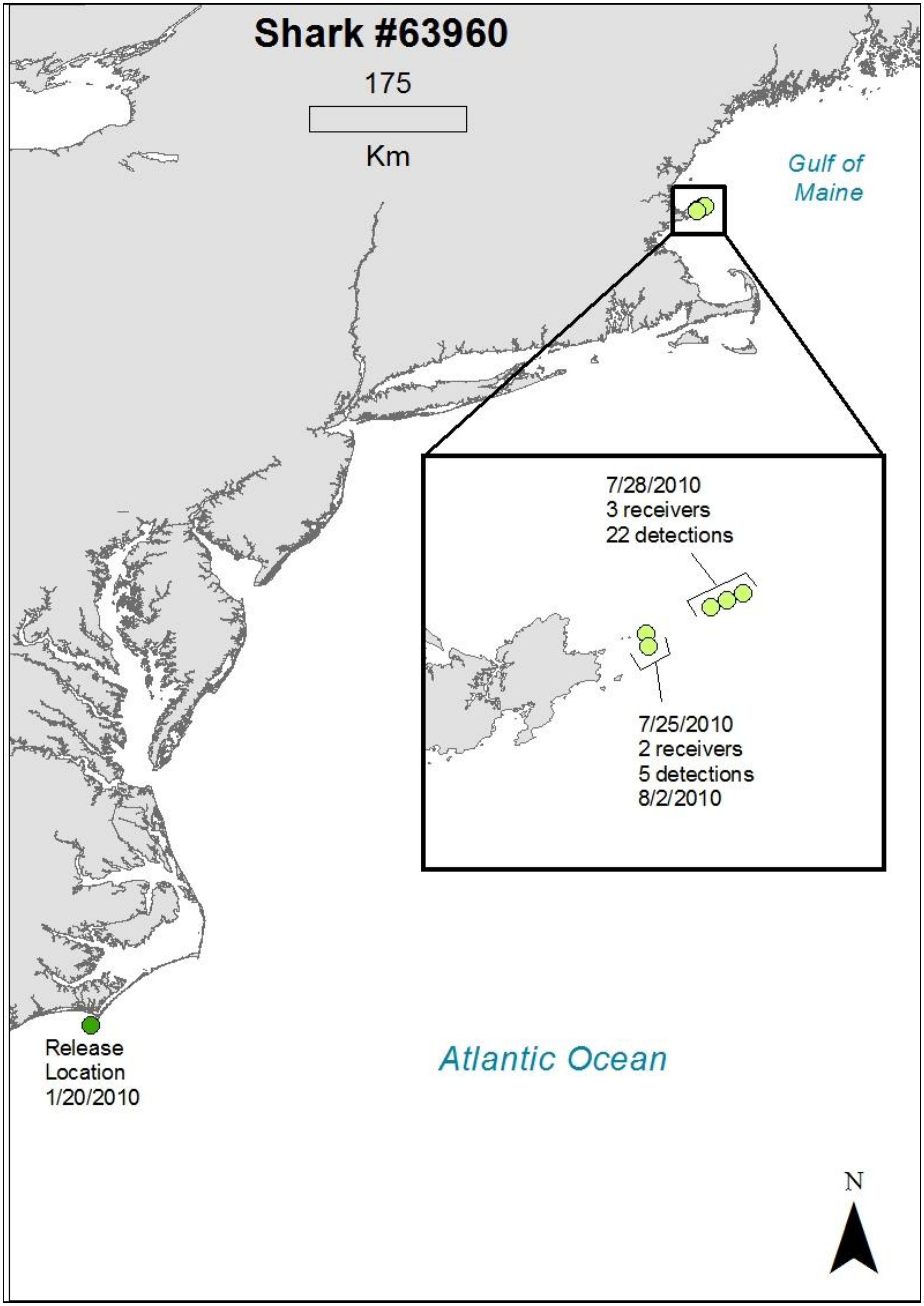

Shark #63955
175
Km
Gulf of Maine
Atlantic Ocean
6/29/2010
8/8/2010
8/19/2010
8/10/2010
8/9/2010 (SW movement)
7/4/2010
8/20/2010
10/24/2010
Cape Cod Bay
2/20/2010
2/25/2010
2/28/2010
2/20/2010
2/21/2010
2/28/2010
2/26/2010
2/28/2010
3/8/2010
14:38 to 16:09
3/5/2010
Release Location 1/20/2010
N



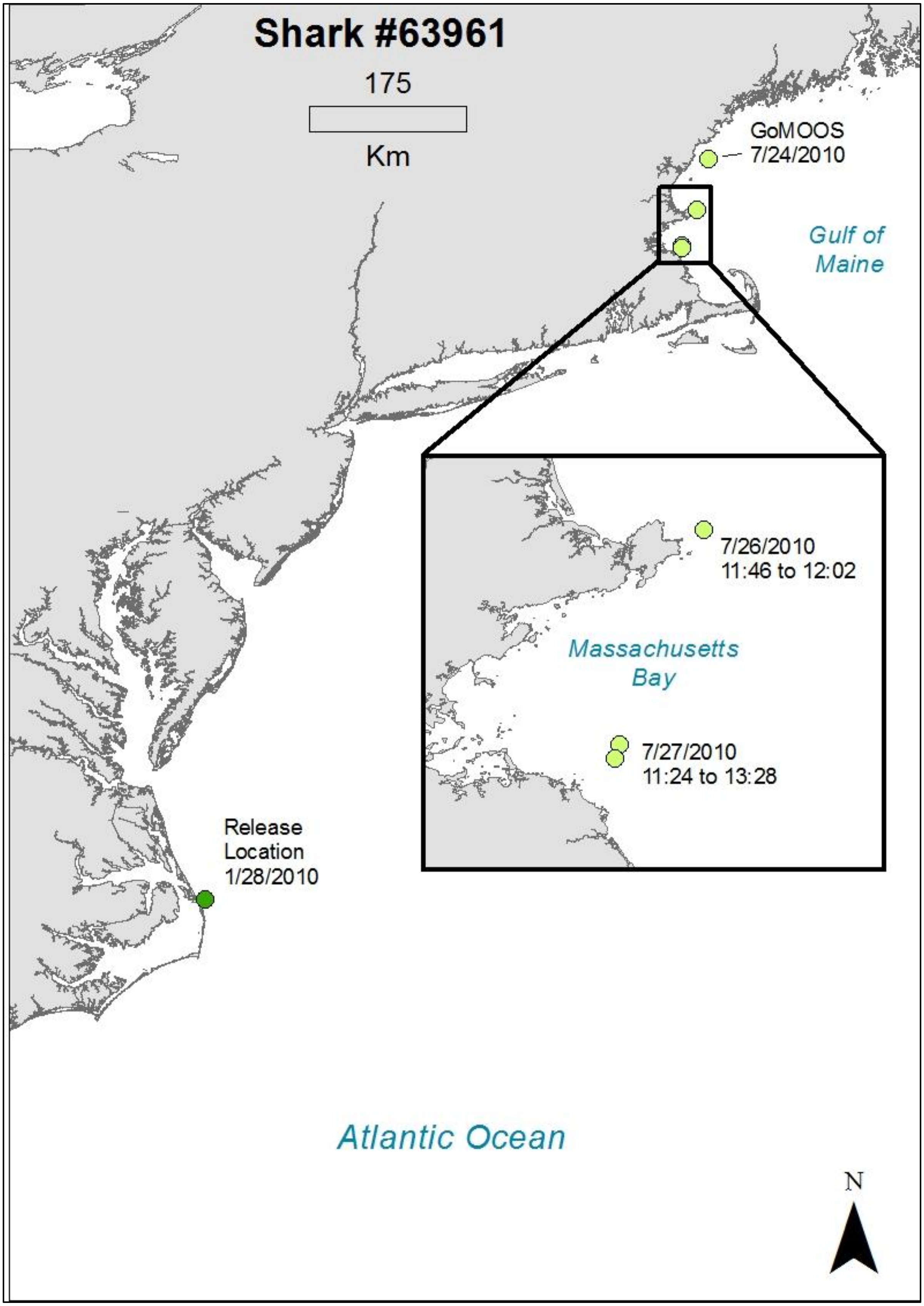
Shark #63956
175
Km
Gulf of Maine
Release Location 1/28/2010
10/5/2010
10/6/2010
10/7/2010
10/8/2010
10/9/2010
10/10/2010
10/11/2010
10/8/2010
10/9/2010
10/10/2010
Cape Cod Bay
8/8/2010
Atlantic Ocean
N

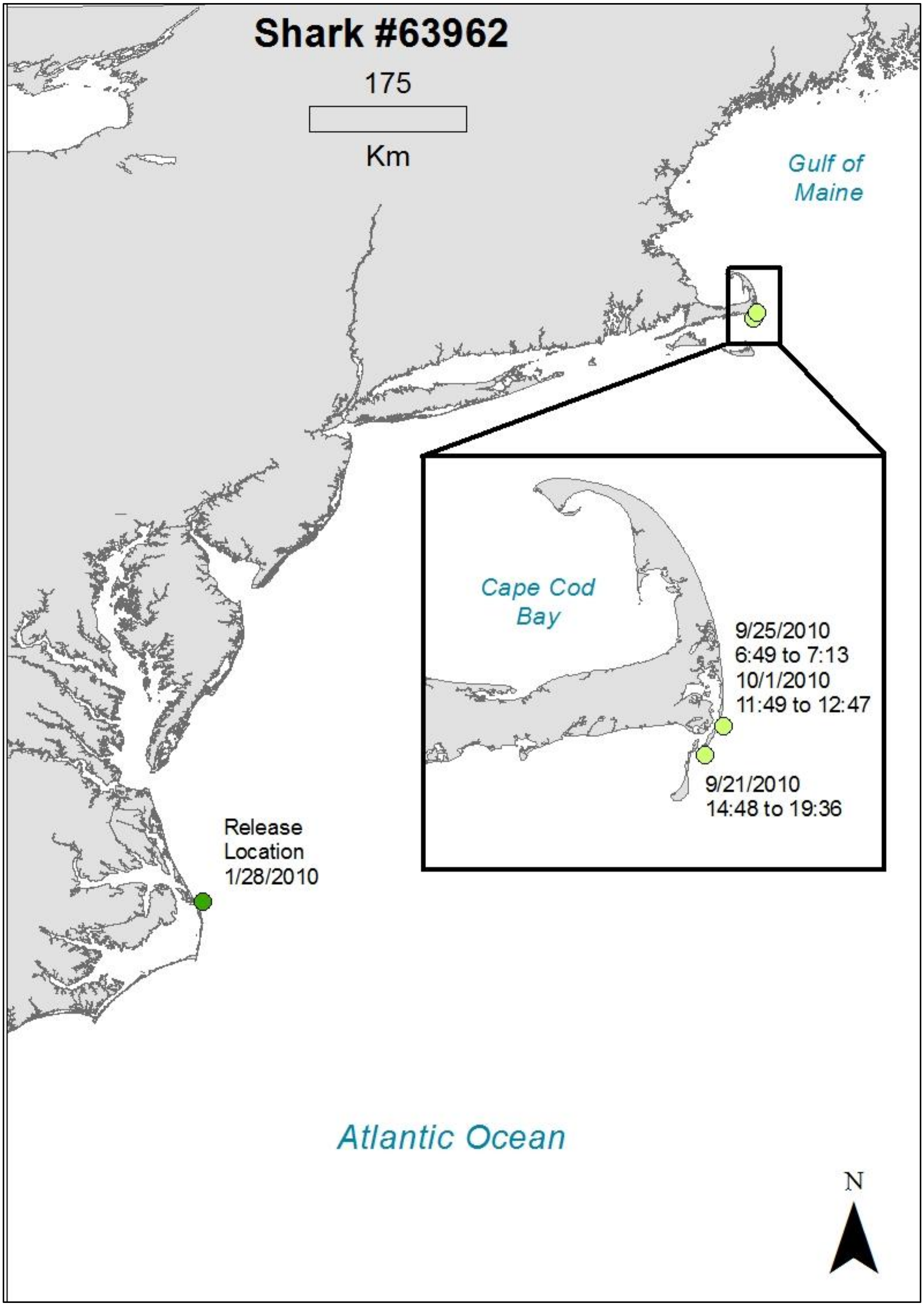

Shark #63958
60
Km
N
Chesapeake
Bay
Atlantic
Ocean
Release
Location
1/28/2010
Pamlico
Sound
2/28/2010
8:21 to 11:22
60 detections

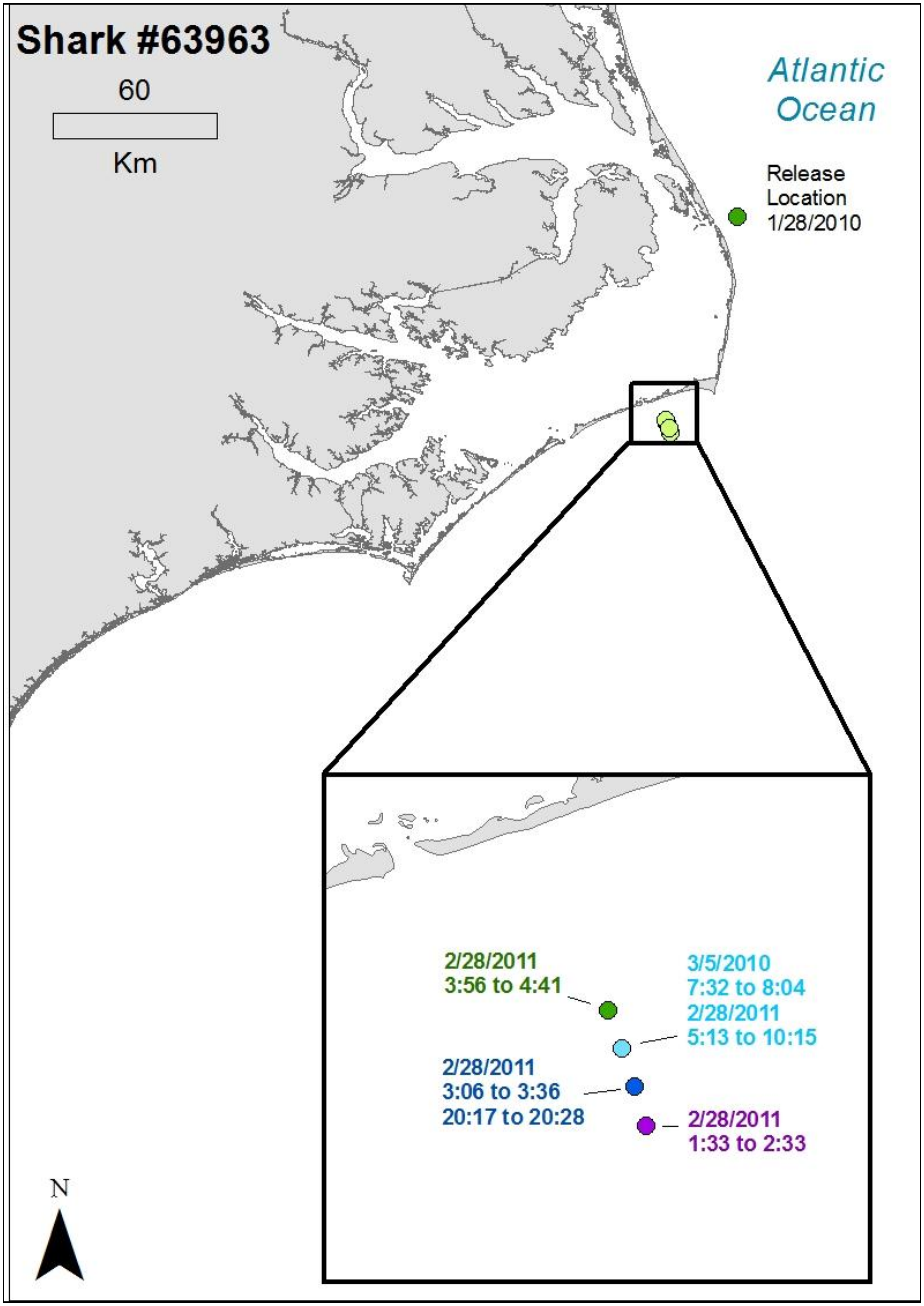

Shark #63959
175
Km
GoMOOS
7/24/2010
Gulf of Maine
6/27/2010
6/30/2010
7/1/2010
7/26/2010
8/1/2010
6/29/2010
6/28/2010
8/2/2010
8/27/2010
Cape Cod Bay
Atlantic Ocean
Release Location 1/28/2010
3/10/2011
11:14 to 11:17
3 detections
Hatteras Inlet
3/13/2011
5:20 to 5:47
15 detections
N



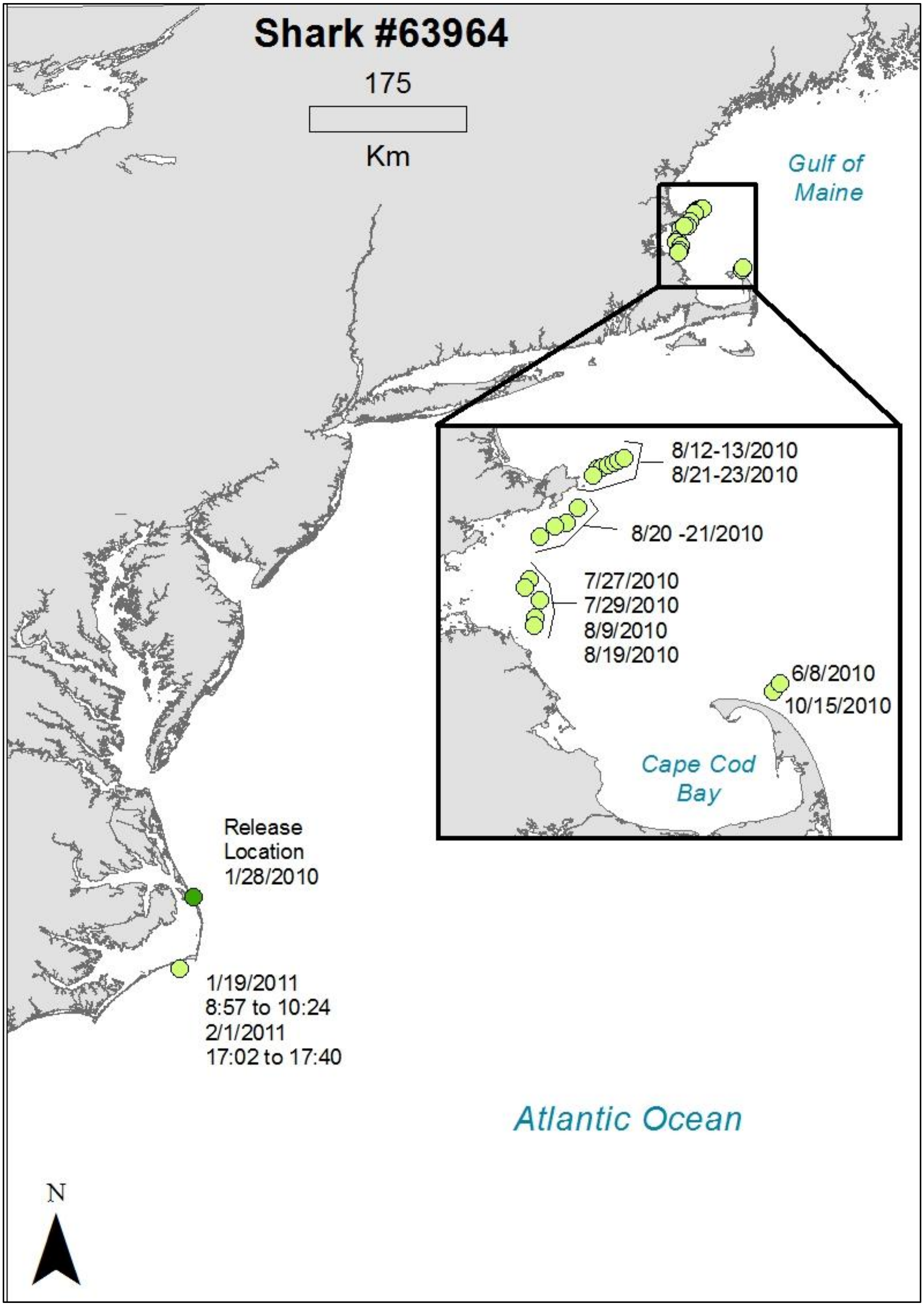
Shark #63960
175
Km
Gulf of Maine
7/28/2010
3 receivers
22 detections
7/25/2010
2 receivers
5 detections
8/2/2010
Release Location 1/20/2010
Atlantic Ocean
N


Shark #63961
175
Km
GoMOOS
7/24/2010
Gulf of Maine
7/26/2010
11:46 to 12:02
Massachusetts Bay
7/27/2010
11:24 to 13:28
Release Location
1/28/2010
Atlantic Ocean
N

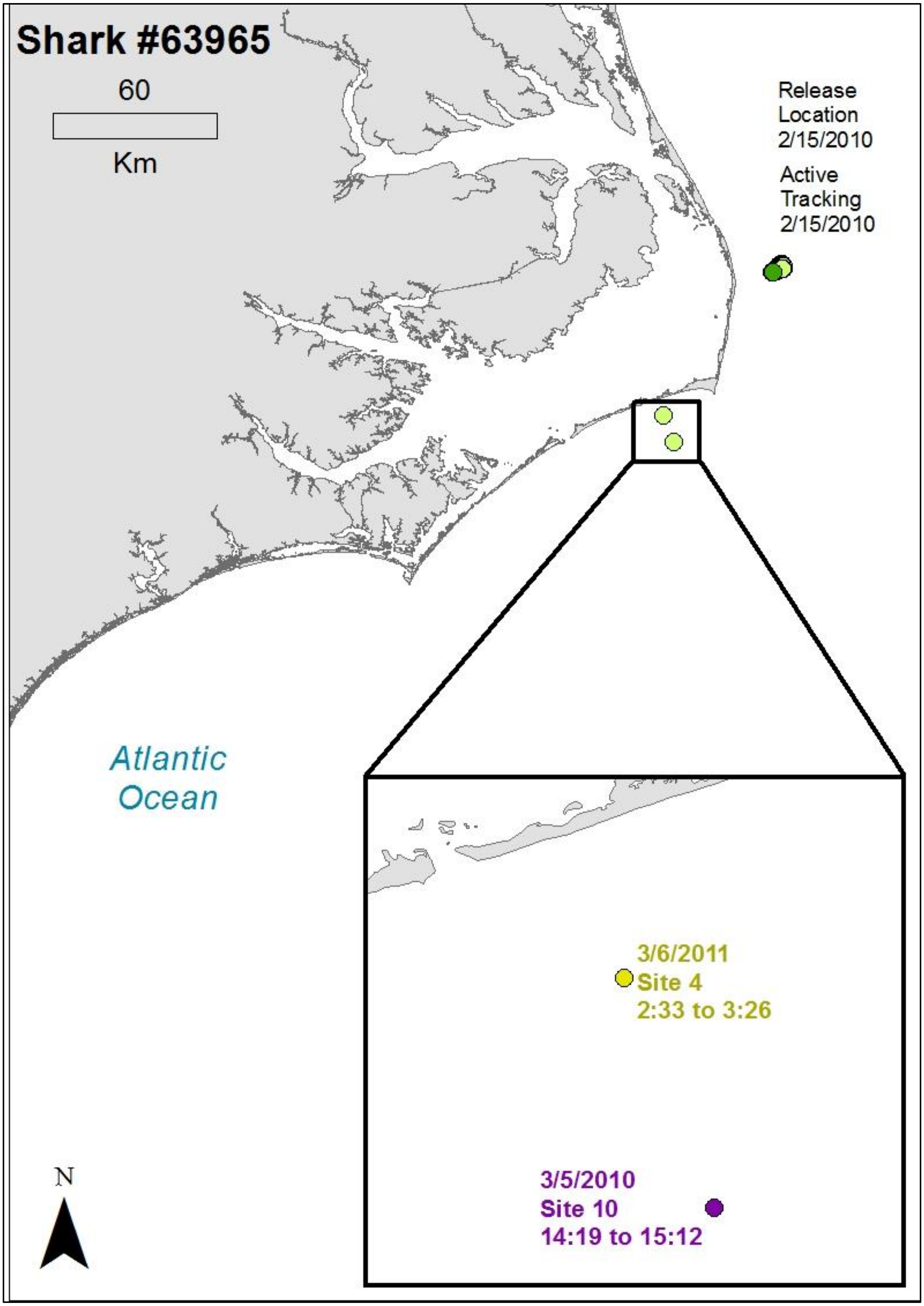

Shark #63962
175
Km
Gulf of
Maine
Cape Cod
Bay
9/25/2010
6:49 to 7:13
10/1/2010
11:49 to 12:47
9/21/2010
14:48 to 19:36
Release
Location
1/28/2010
Atlantic Ocean
N



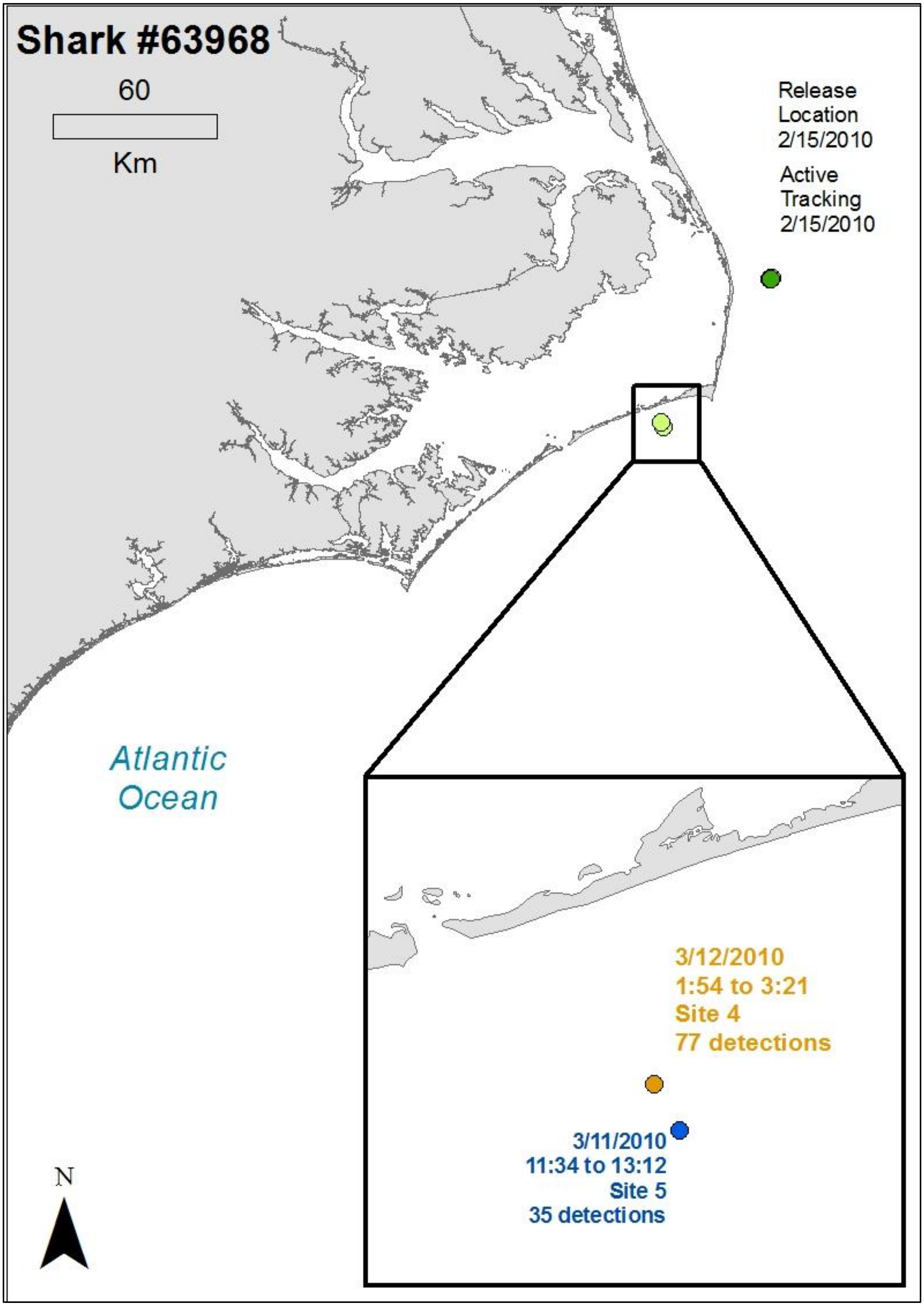
Shark #63963
60
Km
Atlantic Ocean
Release Location 1/28/2010
2/28/2011
3:56 to 4:41
3/5/2010
7:32 to 8:04
2/28/2011
5:13 to 10:15
2/28/2011
3:06 to 3:36
20:17 to 20:28
2/28/2011
1:33 to 2:33
N

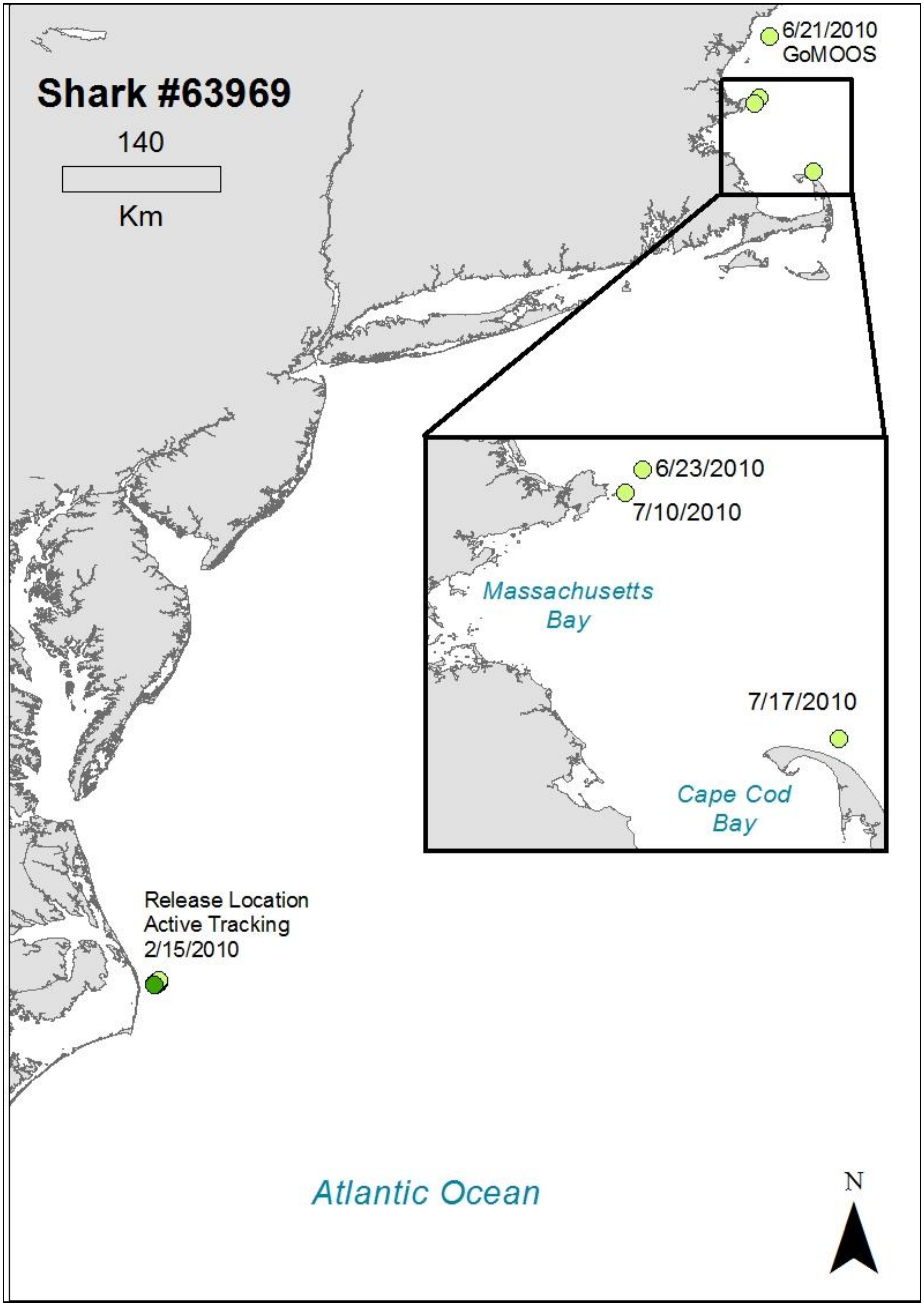


Shark #63964
175
Km
Gulf of Maine
8/12-13/2010
8/21-23/2010
8/20 -21/2010
7/27/2010
7/29/2010
8/9/2010
8/19/2010
6/8/2010
10/15/2010
Cape Cod Bay
Release Location 1/28/2010
1/19/2011
8:57 to 10:24
2/1/2011
17:02 to 17:40
Atlantic Ocean
N

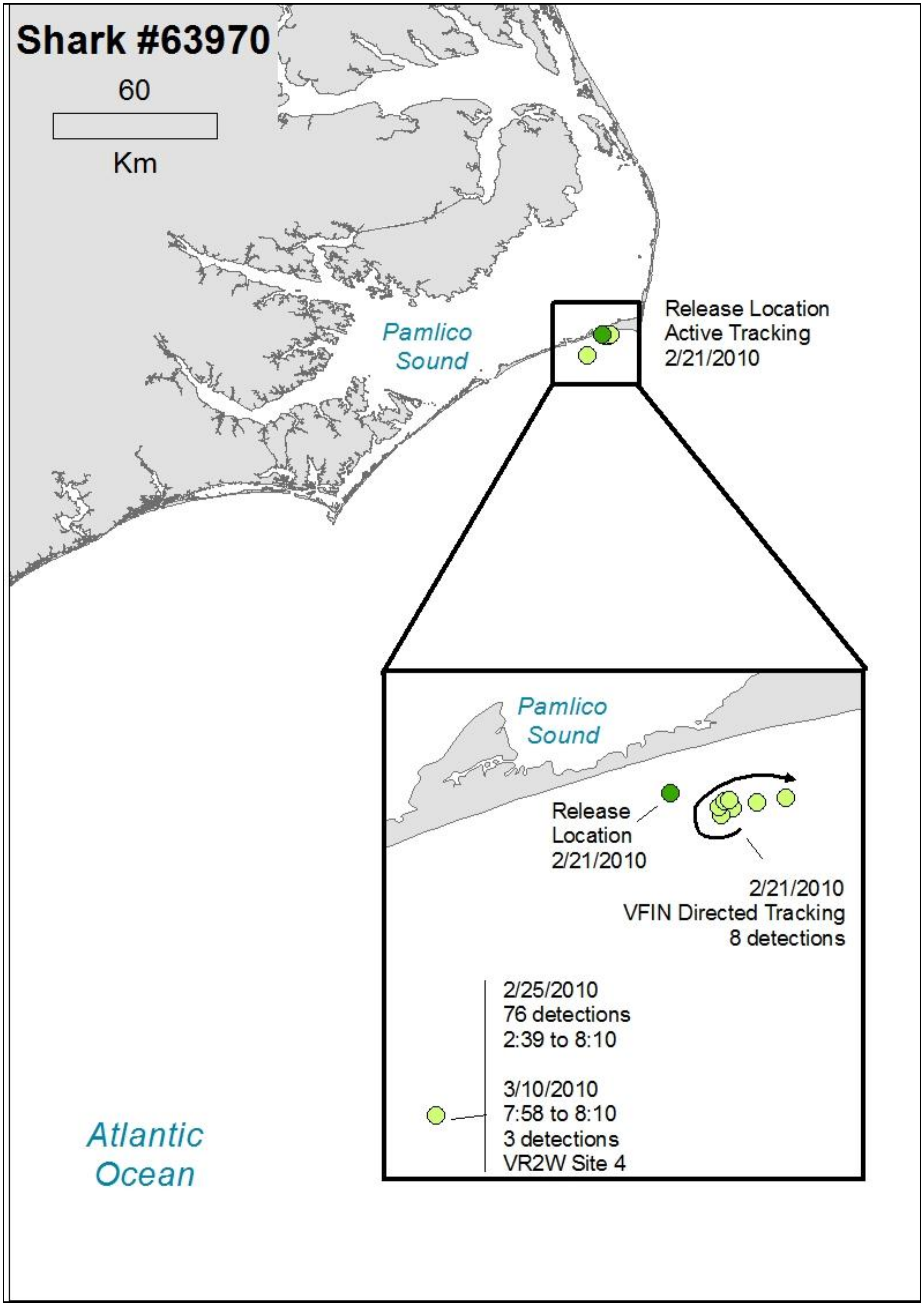

Shark #63965
60
Km
Release
Location
2/15/2010
Active
Tracking
2/15/2010
Atlantic
Ocean
3/6/2011
Site 4
2:33 to 3:26
3/5/2010
Site 10
14:19 to 15:12
N

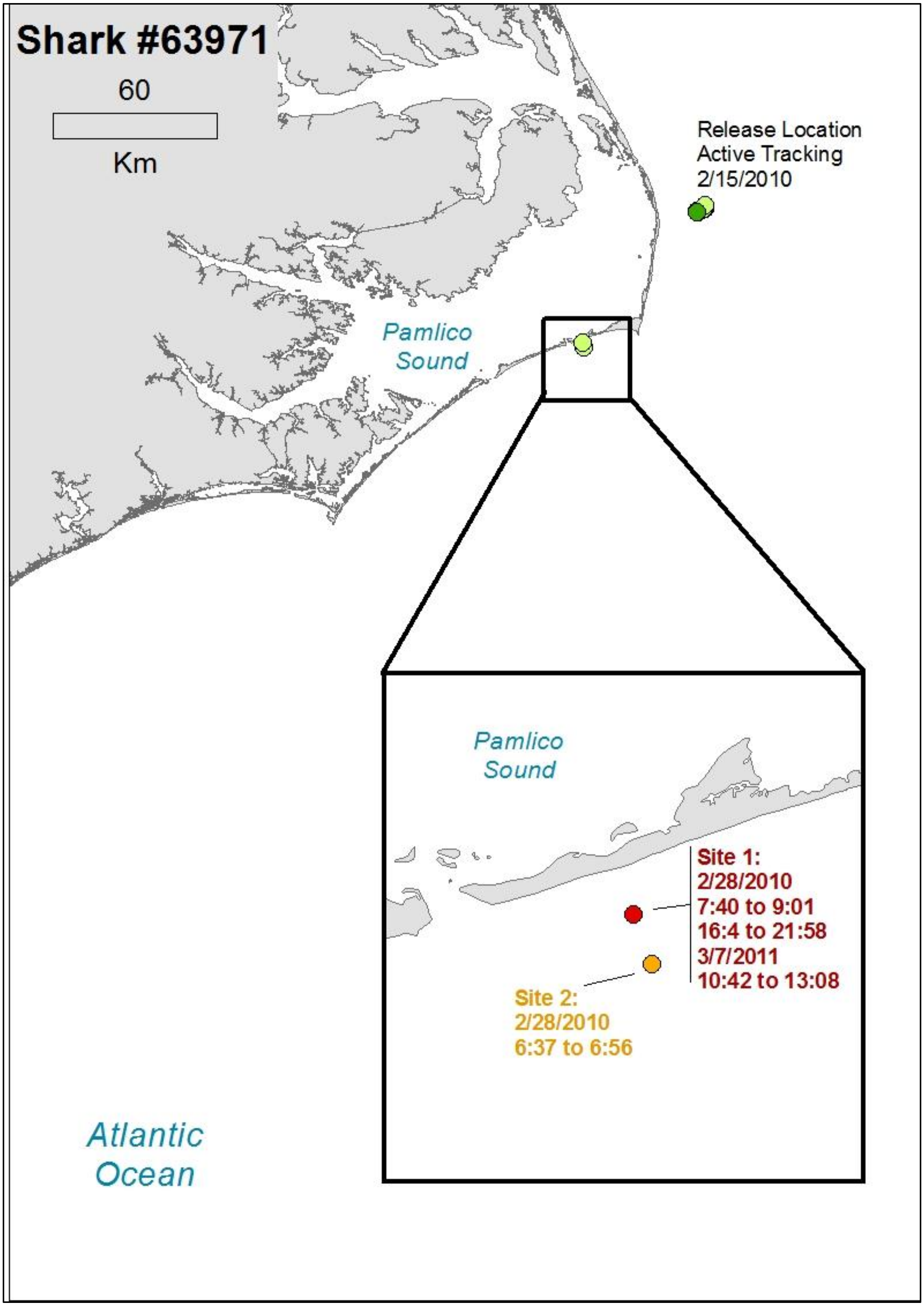
Shark #63967
180
Km
Gulf of Maine
8/3/2010
5 detections
3/7/2012
25 detections
Atlantic Ocean
Release
Location
1/20/2010
N

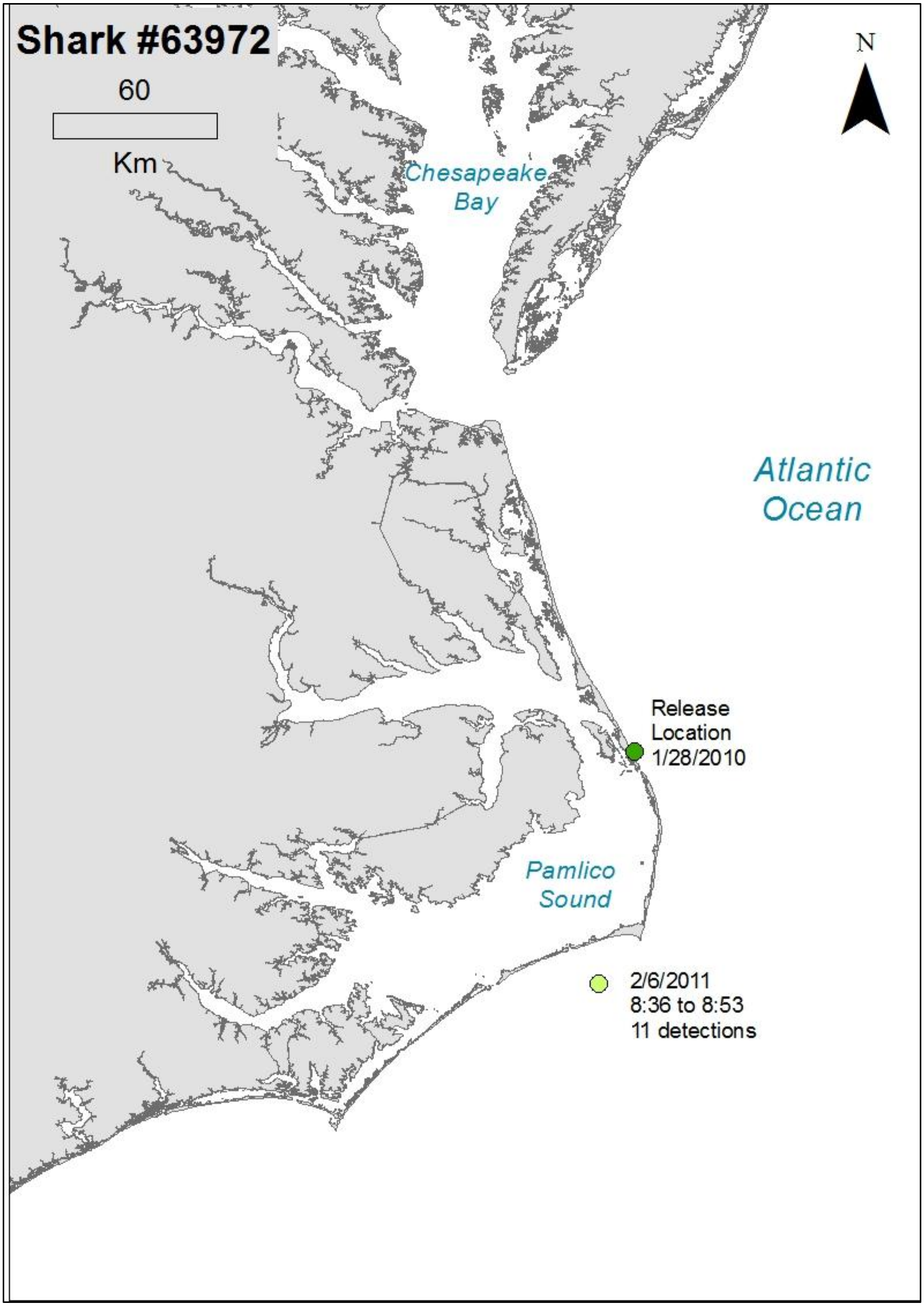

Shark #63968
60
Km
Release
Location
2/15/2010
Active
Tracking
2/15/2010
Atlantic
Ocean
3/12/2010
1:54 to 3:21
Site 4
77 detections
3/11/2010
11:34 to 13:12
Site 5
35 detections
N



Shark #63969
140
Km
6/21/2010
GoMOOS
6/23/2010
7/10/2010
Massachusetts Bay
7/17/2010
Cape Cod Bay
Release Location
Active Tracking
2/15/2010
Atlantic Ocean
N


Shark #63970
60
Km
Pamlico
Sound
Release Location
Active Tracking
2/21/2010
Pamlico
Sound
Release
Location
2/21/2010
2/21/2010
VFIN Directed Tracking
8 detections
2/25/2010
76 detections
2:39 to 8:10
3/10/2010
7:58 to 8:10
3 detections
VR2W Site 4
Atlantic
Ocean

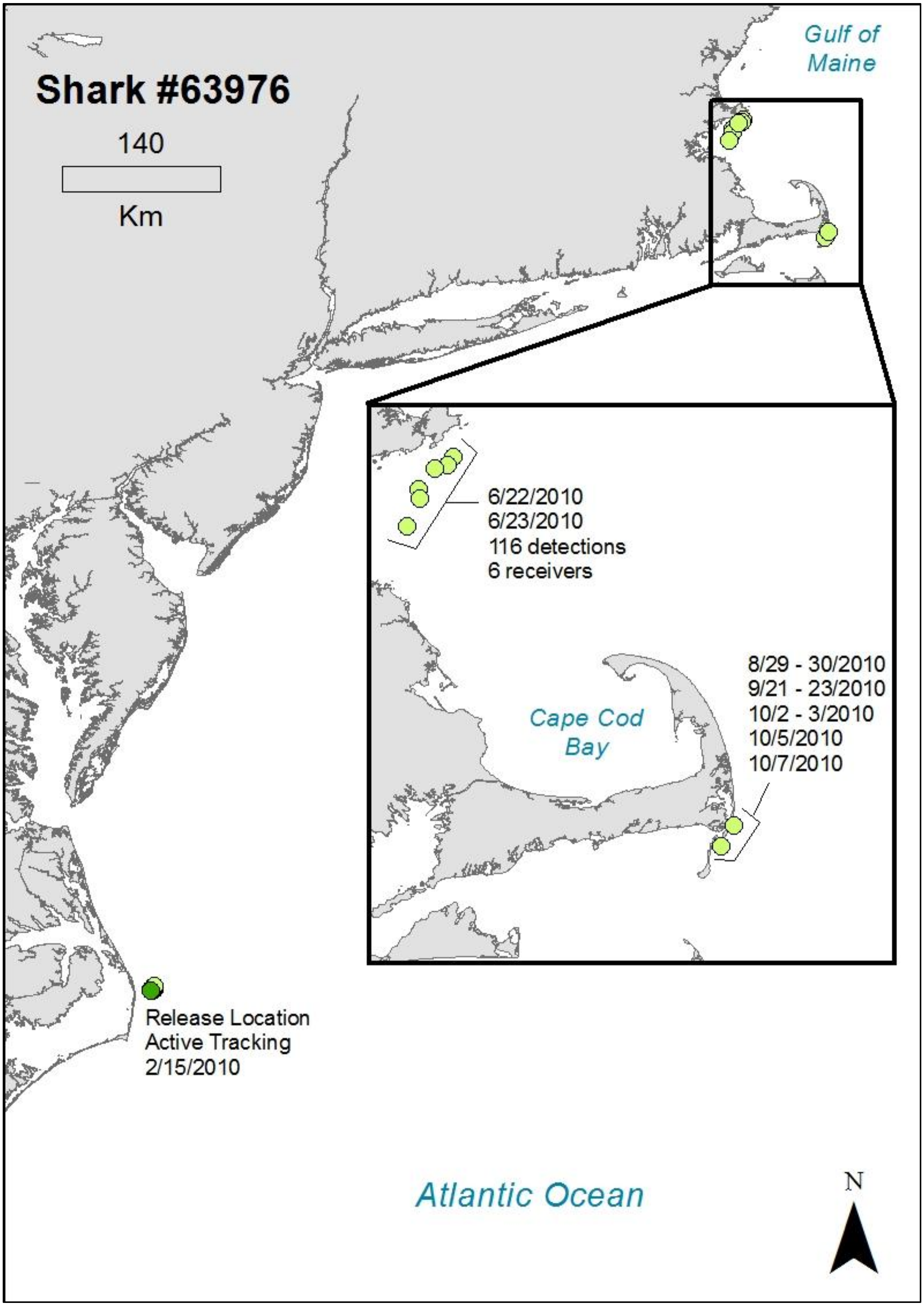

Shark #63971
60
Km
Release Location
Active Tracking
2/15/2010
Pamlico
Sound
Pamlico
Sound
Site 1:
2/28/2010
7:40 to 9:01
16:4 to 21:58
3/7/2011
10:42 to 13:08
Site 2:
2/28/2010
6:37 to 6:56
Atlantic
Ocean

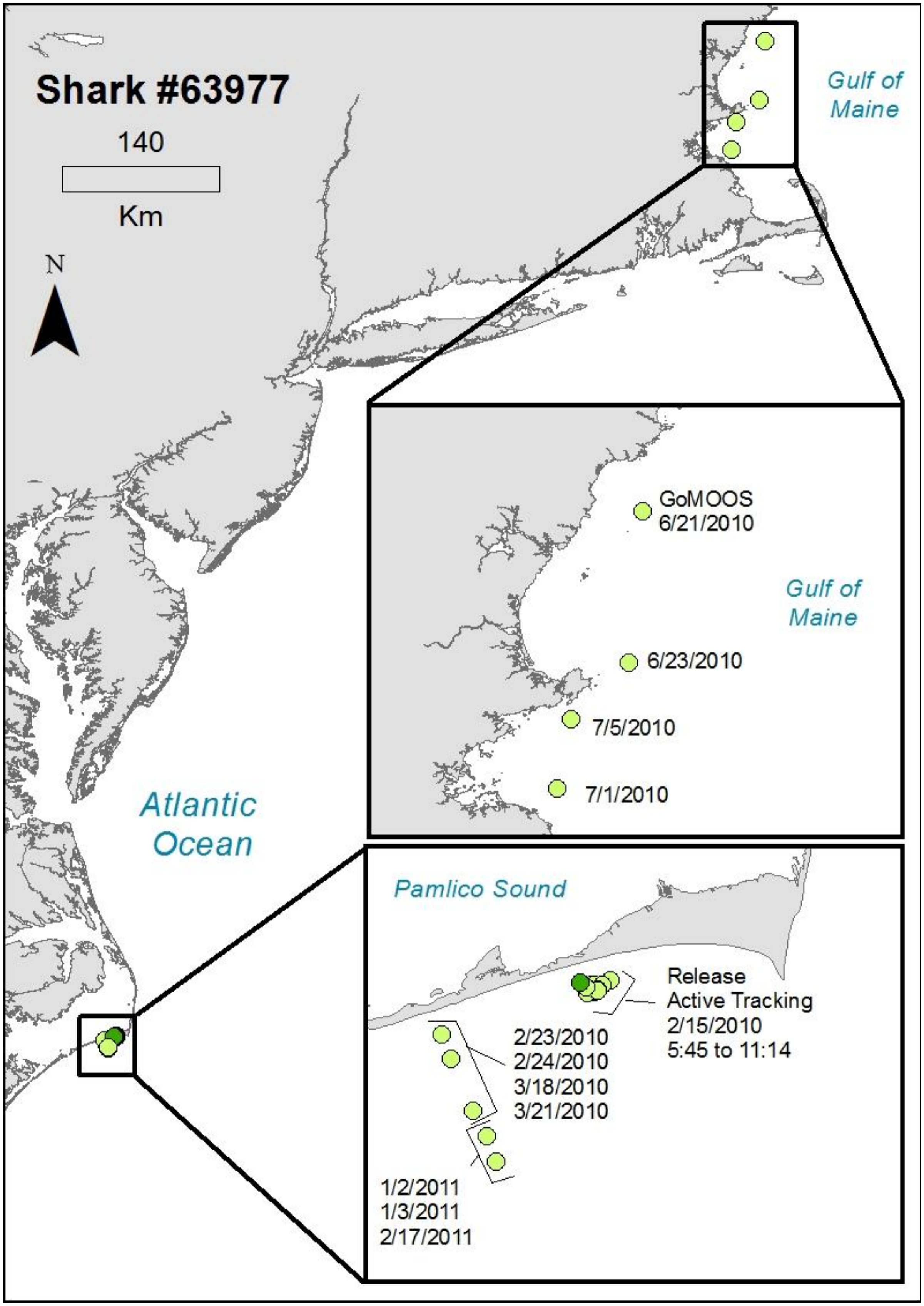


Shark #63972
60
Km
N
Chesapeake Bay
Atlantic Ocean
Release Location 1/28/2010
Pamlico Sound
2/6/2011
8:36 to 8:53
11 detections

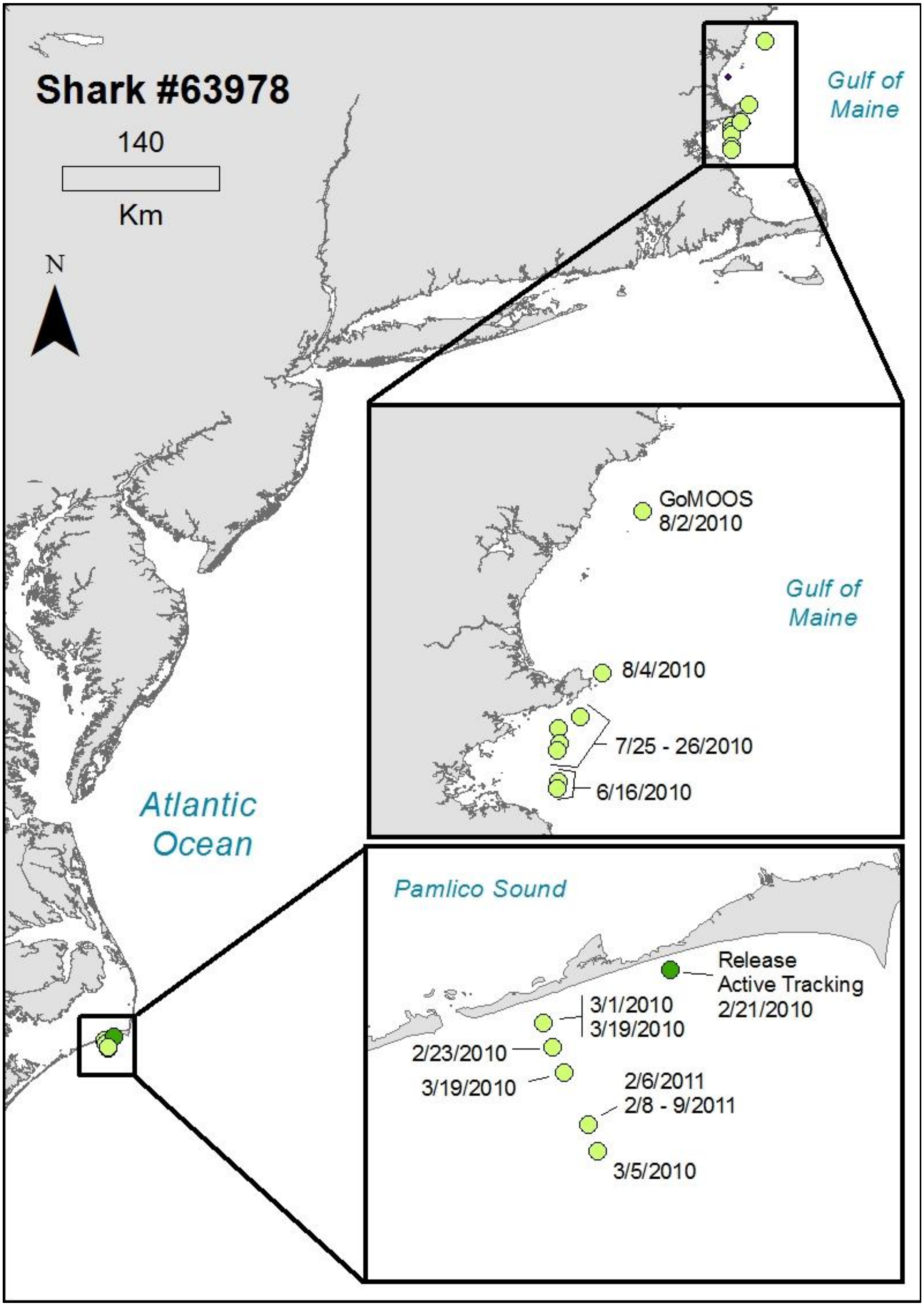
Shark #63974
140
Km
6/13/2010
14 detections
18:13 to 18:44
Atlantic Ocean
Release Location
Active Tracking
2/15/2010
N

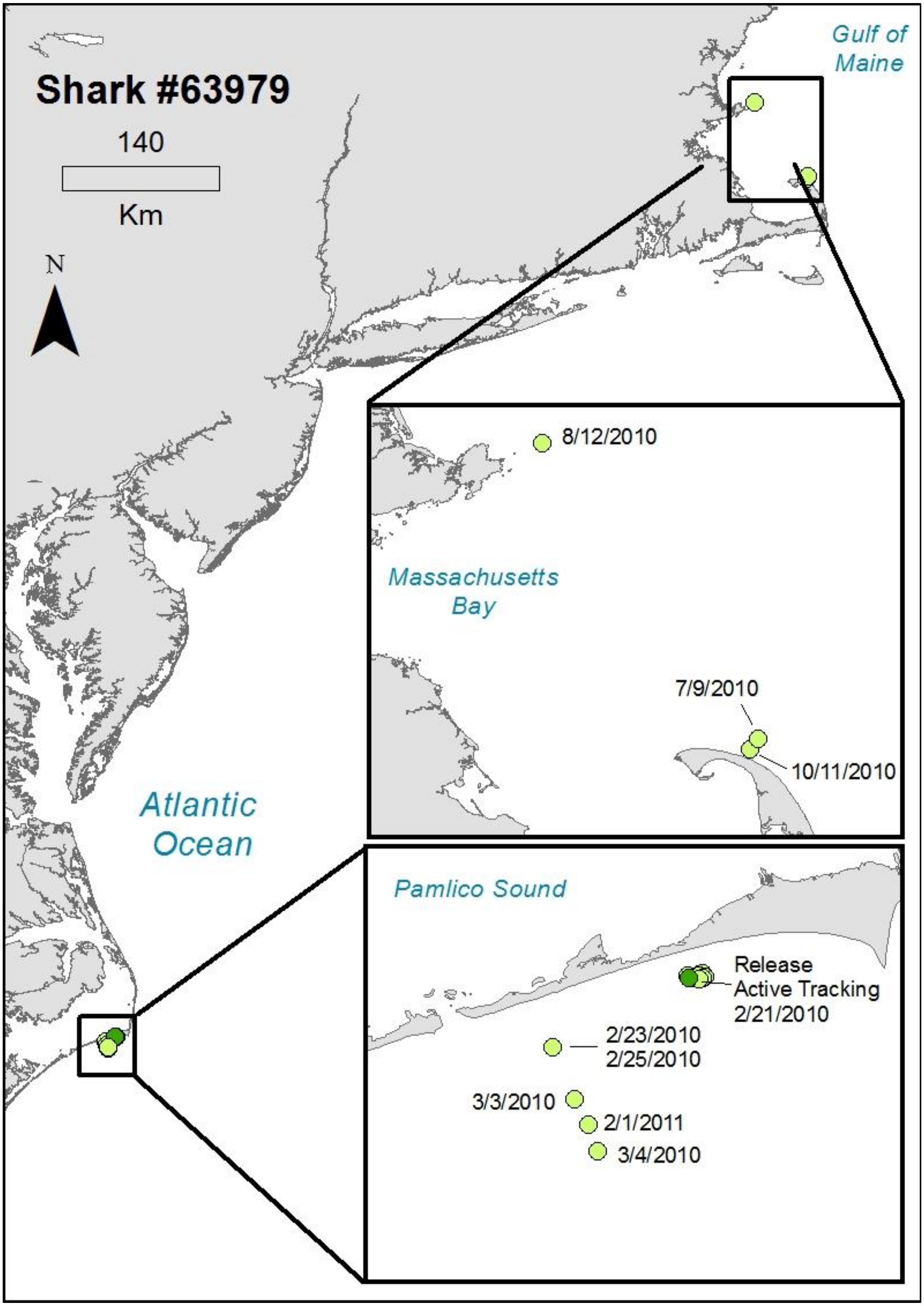
Shark #63975
140
Km
6/27/2010
21 detections
1:29 to 2:07
Atlantic Ocean
Release Location
Active Tracking
2/15/2010
N

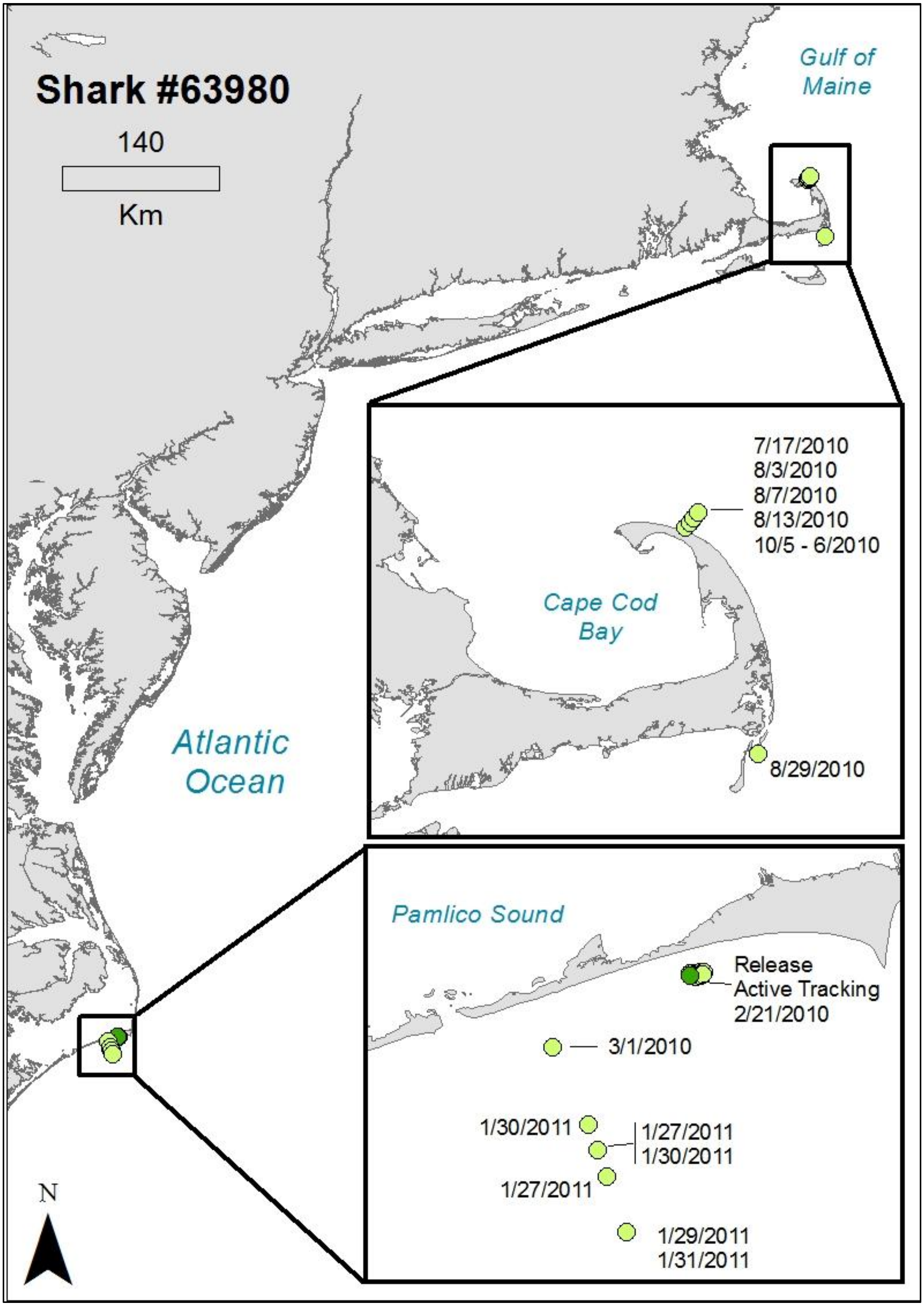

Shark #63976
140
Km
Gulf of
Maine
6/22/2010
6/23/2010
116 detections
6 receivers
8/29 - 30/2010
9/21 - 23/2010
10/2 - 3/2010
10/5/2010
10/7/2010
Cape Cod
Bay
Release Location
Active Tracking
2/15/2010
Atlantic Ocean
N



Shark #63977
140
Km
N
Gulf of Maine
GoMOOS
6/21/2010
Gulf of Maine
6/23/2010
7/5/2010
7/1/2010
Atlantic Ocean
Pamlico Sound
Release
Active Tracking
2/15/2010
5:45 to 11:14
2/23/2010
2/24/2010
3/18/2010
3/21/2010
1/2/2011
1/3/2011
2/17/2011


Shark #63978
140
Km
N
Gulf of Maine
Atlantic Ocean
GoMOOS
8/2/2010
Gulf of Maine
8/4/2010
7/25 - 26/2010
6/16/2010
Pamlico Sound
Release
Active Tracking
2/21/2010
3/1/2010
3/19/2010
2/23/2010
3/19/2010
2/6/2011
2/8 - 9/2011
3/5/2010


Shark #63979
140
Km
N
Gulf of Maine
Massachusetts Bay
8/12/2010
7/9/2010
10/11/2010
Atlantic Ocean
Pamlico Sound
Release
Active Tracking
2/21/2010
2/23/2010
2/25/2010
3/3/2010
2/1/2011
3/4/2010


Shark #63980
140
Km
Gulf of
Maine
Atlantic
Ocean
N
7/17/2010
8/3/2010
8/7/2010
8/13/2010
10/5 - 6/2010
Cape Cod
Bay
8/29/2010
Pamlico Sound
Release
Active Tracking
2/21/2010
3/1/2010
1/30/2011
1/27/2011
1/30/2011
1/27/2011
1/29/2011
1/31/2011

APPENDIX 4. IDENTIFICATION OF WATER COLUMN "LAYERS" USING ACOUSTIC DOPPLAR CURRENT PROFILER (ADCP) DATA

Introduction

In Chapter 4, we analyzed Acoustic Doppler Current Profiler (ADCP) data to evaluate microhabitat selection by Spiny Dogfish in an extremely dynamic region. The Hatteras Bight was subject to tidal flow through inlets, alongshore currents, significant weather events, and was adjacent to the wintertime boundary of the Gulf Stream and the southernmost extent of the Labrador current. Therefore variability in the water column profile was unsurprising, and a comparison of Spiny Dogfish detection data against ADCP data was undertaken to improve understanding of the environmental cues that drive behavior of these sharks.

ADCPs use backscattered sound to estimate the direction and speed of particle movement, and are capable of generating profiles of the water column by averaging ADCP data collected within a vertical section of the water column (i.e., a "bin") (Teledyne RD Instruments 2011). Depending on the type of analysis, we might consider overall current magnitude (m/s), directional velocity in u- and v-components (m/s), or overall direction of movement in specific depth bins, or in "layers" of the water column that are comprised of groups of adjacent bins which may be similar. For example, bins near the bottom of the water column may exhibit similar patterns in current speed and direction, and bins near the surface of the water column may be likewise grouped. The purpose of this analysis was to classify the depth bins into separate "layers" of the water column that could be used in subsequent analyses with Spiny Dogfish detection data.

Methods

ADCPs were deployed at three locations in 2009, and at one location in 2010 (Figure 83). Data were downloaded from the ADCPs, visualized in WinADCP, and exported to excel and matlab data formats. Data were plotted to identify the maximum depth ranges in each location (Figure 84) and to identify bins with a large proportion of missing data that should be excluded from analyses. It is common practice to exclude data collected within the first ADCP bin (i.e., those data closest to the ADCP head) because they may be subject to a higher amount of error. The echo from a hard surface such as the sea surface or bottom is so much stronger than the echo from scatterers in the water that it can overwhelm the side lobe suppression of the transducer (Teledyne RDI Instruments 2011). Kohut et al. (2006) recommend that for an ADCP with a Janus configuration (i.e., 4 beams), sidelobe contamination is expected to affect the top 10% of surface bins. Therefore the bins representing the top 10 percent of the water column were also excluded from analyses.

Magnitude and error velocity data were subjected to goodness of fit tests for normality. In all cases, data were transformed using a variety of techniques and tested; however, all transformations tested indicated that non-parametric analyses were best.

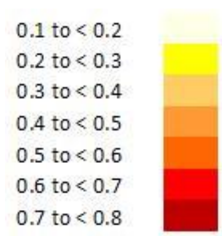
Error velocity is the difference between multiple estimates of vertical velocity computed for each depth bin by the ADCP (Teledyne RDI Instruments 2011). A non-parametric Spearman's rho (ρ) correlation analysis of velocity error was completed in order to analyze the variability in the error between bins, with the assumption that adjacent bins subject to similar conditions would be have similar velocity error. Spearman's rho tests generate correlation coefficients computed on the ranks of the data values instead of on the values themselves.

Multivariate statistics were used to explore and reduce the ADCP data into a smaller number of variables that represent layers of the water column (using software JMP 10). Principle Components Analysis, or “PCA” (Hotelling 1933; Hatcher and Stepanski 1994) is a variable reduction procedure that generates artificial variables that represent a number of correlated variables and account for most of the variance in observed data. These components account for a greater amount of variance than has been contributed by one variable. Output from a PCA includes the generation of eigenvalues for each principle component, which indicates the amount of variance accounted for out of the total variance (Manly 2005). The output of a PCA can guide input for a factor analysis. Factor analysis, in comparison to a PCA, assumes that covariation in observed variables is due to an underlying causal structure; perhaps in the case of the ADCP data, by variability as a result of oceanographic conditions and vertical profiling/layering of horizontal currents of the water column. Provisional factor loadings are assumed to be equivalent to the number of principle components that meet the Kaiser criterion of eigenvalues greater than or equal to 1.0 (Kaiser 1960; Manly 2005). Rotated factor score tables produced from the factor analysis were examined to identify depth bins that had the highest factor loading scores for each factor. Manly (2005) suggests that factor loadings greater than 0.5 and 0.7 constitute moderate and large loadings, respectively. Water column “layers” were identified by grouping the depth bins by factor loading scores.

Results

Deployment locations for 2009 and 2010 are shown together in Figure 83a, and by year in Figure 83b and Figure 83c. Depth ranges for these locations are shown in Figure 84; the maximum depth reflects the maximum number of bins considered for inclusion in additional analyses. Summary statistics were then generated for each bin to identify trends and to analyze the amount of missing data. For example, Figure 84 and Figure 85 shows that while the recorded maximum depth of ADCP data collected at Site 7 (2010) was approximately 24 meters, there was a large amount of missing data in depth bins 19-24. These bins were therefore excluded from additional analyses. In several cases, the removal of these depth bins also accounted for sidelobe contamination that is expected to occur in the top 10% of data bins near the surface (for ADCPs mounted on the ocean floor). Data bins retained for analysis and display are shown in Table 32.

Spearman's Rho correlation coefficients were derived for velocity error derived for each depth bin for ADCP data collected between February 1 and March 31 of each year (i.e., the time span when most detections occurred). Table 33 shows an example of the output organized in a color coded table, coded according to the following color scheme:



The weaker correlations occurred between 1) depth bins that were not adjacent to each other in the water column, and 2) adjacent depth bins at the surface and bottom of the water column. The strongest correlations occurred in depth bins that are in deeper water, such as those between depth bin 14 and depth bin 15 ($\rho = 0.7344$). These trends were observed across all sites and years.

Eigenvalues produced from Principle Components Analyses were used to identify the number of factors that could be used in subsequent analyses (Figure 86). Three components had eigenvalues derived from data collected at Site 7 (2009) and Site 12 (2010) that met the Kaiser criterion. Two components had eigenvales derived from data collected at Site 6 (2009) that met the Kaiser criterion. Only one component had an eigenvalue derived from data collected at Site 2(2009) that met the Kaiser criterion; however, the second component had an eigenvalue that was extremely close to meeting this threshold (0.9828). Therefore, I selected 3 factors for Factor Analyses run on data from Site 7 (2010) and Site 12 (2009) and 2 factors for Factor Analyses run on data from Site 6 and Site 2.

Rotated factor loading scores were used to identify "layers" in the water column (Figure 87). Factor scores are generally color coded such that warmer colors (e.g., red and orange) reflect the highest factor scores and cooler colors (e.g., green and blue) reflect low to moderate factor scores. Depth bins with the highest factor scores are grouped together in boxes, and represent different "layers". In cases where a depth bin had moderate to high scores in two factors, the depth bin was assigned to the Factor that had the highest factor score. For example, under Site 7 (2010), depth bin number 7 ("mag7", which was 7 meters from the ADCP head) had a Factor 2 score of 0.5359 and a Factor 3 score of 0.7403. This depth bin was assigned to the "layer" identified by strong factor scores under Factor 3. Table 34 shows the final assignment of depth bins to "water column layers". Sites 7 and 12 had three identifiable water column layers based on results from factor analyses, and Sites 6 and 2 had two identifiable water column layers. Visual examination of ADCP data over different time periods suggested that it was not unusual to see "layers" in the water column, distinguishable either by variations in current magnitude (m/s) and directional u- and v-components (Figure 88).

Discussion

Acoustic Doppler Current Profilers are designed to detect backscattered acoustic waves propagated back to the ADCP unit after striking an object (e.g., particles or plankton) in the water column. Because these systems can simultaneously measure particle (and hence, water) speed and direction at multiple points simultaneously, they are often used to profile the entire water column and can aid in the identification and study of flow dynamics and circulation patterns of the water column (including the identification of "layers" within a study area that might exhibit different flow patterns). ADCPs have been used successfully to study flow dynamics both surface mounted on vessels (e.g., Griffiths and Roe 1993; Roe et al. 1996; Bourles et al. 1999) and moored to the bottom (e.g., Kohut et al. 2004).

In many cases, visual examination of the data appears to be enough to identify discrete layers in the water column. Roe et al. (1996) also identified as many as 16 "layers" in the water column within the top 350m, ranging from 10m to over 100m in thickness. Griffiths and Roe (1993) noted that it is common to see two or three "biological layers" in sonar records collected in the Atlantic.

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List of Tables and Figures

Figure 86. Output from Principle Components Analyses run on ADCP data collected at each site. Eigenvalues shown on the left side of each figure were used to determine the number of factors that were included in a subsequent Factor Analysis.

Figure 87. Factor loading scores for Factor Analyses run on ADCP data collected at each ADCP deployment site.

Figure 88. ADCP data collected at Site 7 in 2010 during a time period when fish were detected on an adjacent acoustic array (March 1, 2010).

Tables and Figures

Table 32.

Deployment Site (Year)	**Bin Numbers (each bin = 1 meter of depth)**
Site 7 (2010)	2-18
Site 12 (2009)	2-18
Site 6 (2009)	2-15
Site 2 (2009)	2-10

Table 33.

Spearman's rho correlation coefficient Untransformed data (velocity error)																			
	Bin1	Bin2	Bin3	Bin4	Bin5	Bin6	Bin7	Bin8	Bin9	Bin10	Bin11	Bin12	Bin13	Bin14	Bin15	Bin16	Bin17	Bin18	Bin19
Bin1		0.2408	0.1319	0.0748	0.0343	0.0021	0.0173	0.0197	0.0008	-0.0048	-0.0159	-0.0332	-0.0268	-0.012	-0.0155	-0.0059	0.0067	0.0229	0.0111
Bin2	0.2408		0.3482	0.2176	0.1032	0.0198	0.0268	-0.0045	-0.0081	-0.013	-0.0216	-0.0283	-0.0285	-0.0284	-0.0269	-0.0216	-0.0124	0.0235	-0.0108
Bin3	0.1319	0.3482		0.4276	0.147	0.0083	0.0191	0.0018	-0.0237	-0.0541	-0.047	-0.0281	-0.0205	-0.0242	-0.0293	-0.0078	-0.0014	0.0318	0.0088
Bin4	0.0748	0.2176	0.4276		0.3772	0.124	0.0422	0.0272	-0.0331	-0.0765	-0.0865	-0.0778	-0.0592	-0.0249	-0.0275	-0.0086	0.0143	0.0397	0.0234
Bin5	0.0343	0.1032	0.147	0.3772		0.4163	0.1279	0.1009	0.0382	-0.0155	-0.0274	-0.0212	-0.0136	0.0174	0.0279	0.0737	0.0847	0.0862	0.0438
Bin6	0.0021	0.0198	0.0083	0.124	0.4163		0.3091	0.2258	0.1335	0.076	0.0678	0.0615	0.0708	0.0637	0.0629	0.0854	0.1008	0.1025	0.0579
Bin7	0.0173	0.0268	0.0191	0.0422	0.1279	0.3091		0.41	0.2796	0.1946	0.1694	0.1583	0.1683	0.1461	0.1323	0.1565	0.1605	0.1517	0.0296
Bin8	0.0197	-0.0045	0.0018	0.0272	0.1009	0.2258	0.41		0.4843	0.3053	0.2419	0.2219	0.1924	0.1798	0.1805	0.1873	0.1934	0.1815	0.0919
Bin9	0.0008	-0.0081	-0.0237	-0.0331	0.0382	0.1335	0.2796	0.4843		0.574	0.4096	0.3324	0.2658	0.2227	0.2055	0.2111	0.1946	0.1663	0.0751
Bin10	-0.0048	-0.013	-0.0541	-0.0765	-0.0155	0.076	0.1946	0.3053	0.574		0.6605	0.4726	0.347	0.2613	0.2136	0.2263	0.2067	0.1531	0.0879
Bin11	-0.0159	-0.0216	-0.047	-0.0865	-0.0274	0.0678	0.1694	0.2419	0.4096	0.6605		0.6538	0.455	0.3271	0.27	0.2668	0.2347	0.1641	0.0981
Bin12	-0.0332	-0.0283	-0.0281	-0.0778	-0.0212	0.0615	0.1583	0.2219	0.3324	0.4726	0.6538		0.6631	0.4706	0.3875	0.3505	0.3022	0.2019	0.0919
Bin13	-0.0268	-0.0285	-0.0205	-0.0592	-0.0136	0.0708	0.1683	0.1924	0.2658	0.347	0.455	0.6631		0.6845	0.5227	0.4105	0.3668	0.2457	0.0991
Bin14	-0.012	-0.0284	-0.0242	-0.0249	0.0174	0.0637	0.1461	0.1798	0.2227	0.2613	0.3271	0.4706	0.6845		0.7344	0.5352	0.4422	0.2934	0.1149
Bin15	-0.0155	-0.0269	-0.0293	-0.0275	0.0279	0.0629	0.1323	0.1805	0.2055	0.2136	0.27	0.3875	0.5227	0.7344		0.7113	0.5135	0.3155	0.1349
Bin16	-0.0059	-0.0216	-0.0078	-0.0086	0.0737	0.0854	0.1565	0.1873	0.2111	0.2263	0.2668	0.3505	0.4105	0.5352	0.7113		0.6586	0.4093	0.1453
Bin17	0.0067	-0.0124	-0.0014	0.0143	0.0847	0.1008	0.1605	0.1934	0.1946	0.2067	0.2347	0.3022	0.3668	0.4422	0.5135	0.6586		0.5108	0.1643
Bin18	0.0229	0.0235	0.0318	0.0397	0.0862	0.1025	0.1517	0.1815	0.1663	0.1531	0.1641	0.2019	0.2457	0.2934	0.3155	0.4093	0.5108		0.2543
Bin19	0.0111	-0.0108	0.0088	0.0234	0.0438	0.0579	0.0296	0.0919	0.0751	0.0879	0.0981	0.0919	0.0991	0.1149	0.1349	0.1453	0.1643	0.2543	

Table 34.

Deployment Site (Year)	Surface “Layer”	Mid “Layer”	Bottom “Layer”
Site 7 (2010)	12 – 18	7 - 11	2 - 6
Site 12 (2009)	12 - 18	8 – 11	2 - 7
Site 6 (2009)	8 – 15	n/a	2 - 7
Site 2 (2009)	6 - 10	n/a	2 - 5

Figure 83.

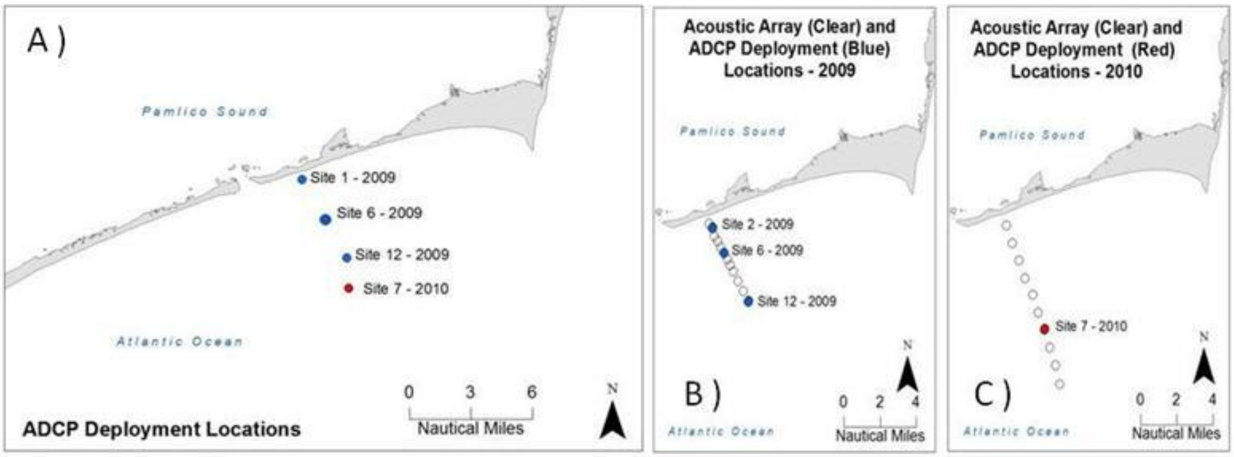
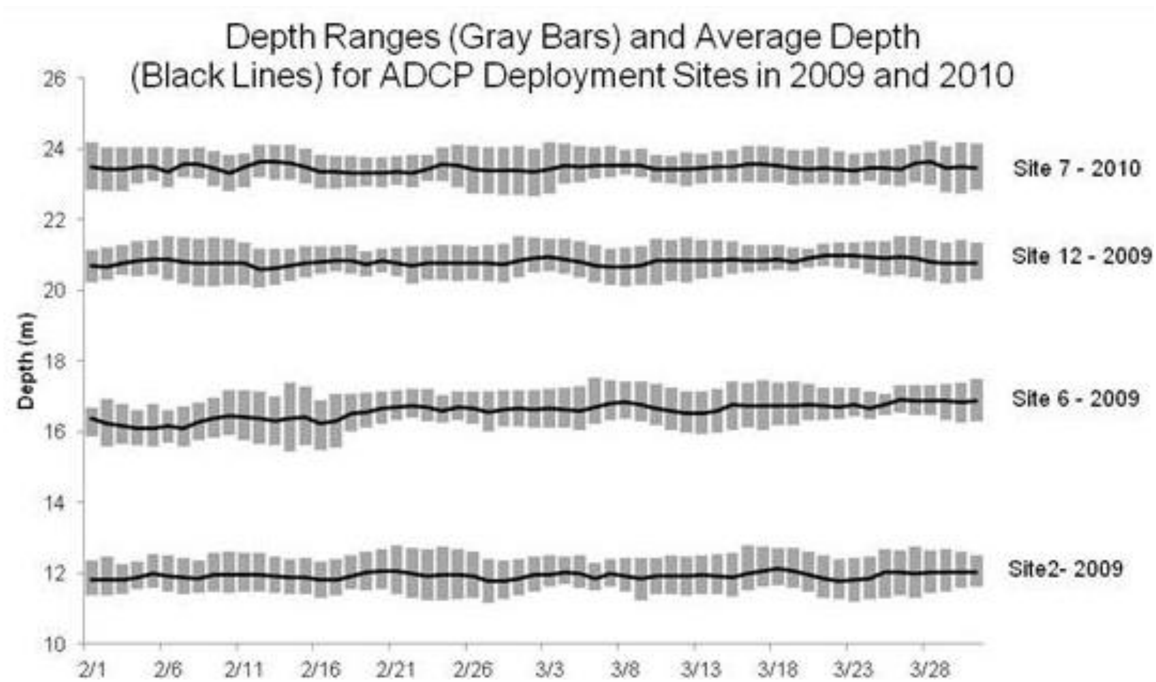

A)
Pamlico Sound
Site 1 - 2009
Site 6 - 2009
Site 12 - 2009
Site 7 - 2010
Atlantic Ocean
0 3 6
Nautical Miles
N
ADCP Deployment Locations
Acoustic Array (Clear) and
ADCP Deployment (Blue)
Locations - 2009
Pamlico Sound
Site 2 - 2009
Site 6 - 2009
Site 12 - 2009
B)
Atlantic Ocean
0 2 4
Nautical Miles
Acoustic Array (Clear) and
ADCP Deployment (Red)
Locations - 2010
Pamlico Sound
Site 7 - 2010
C)
Atlantic Ocean
0 2 4
Nautical Miles

Figure 84.



Depth Ranges (Gray Bars) and Average Depth
(Black Lines) for ADCP Deployment Sites in 2009 and 2010
Depth (m)
26
24
22
20
18
16
14
12
10
2/1
2/6
2/11
2/16
2/21
2/26
3/3
3/8
3/13
3/18
3/23
3/28
Site 7 - 2010
Site 12 - 2009
Site 6 - 2009
Site2- 2009

Figure 85.

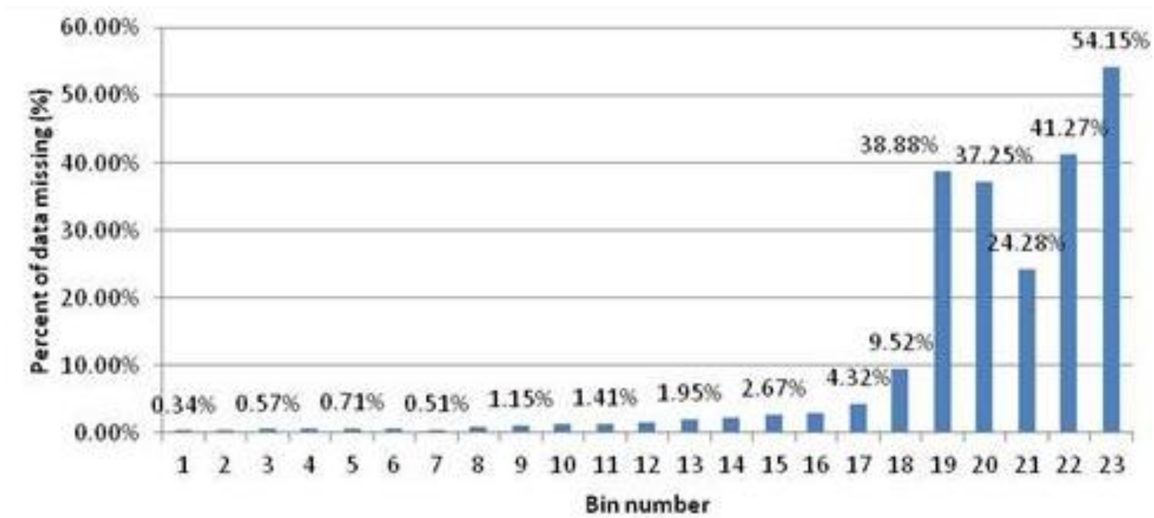

60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Percent of data missing (%)
0.34%
0.57%
0.71%
0.51%
1.15%
1.41%
1.95%
2.67%
4.32%
9.52%
38.88%
37.25%
24.28%
41.27%
54.15%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Bin number

Figure 86.

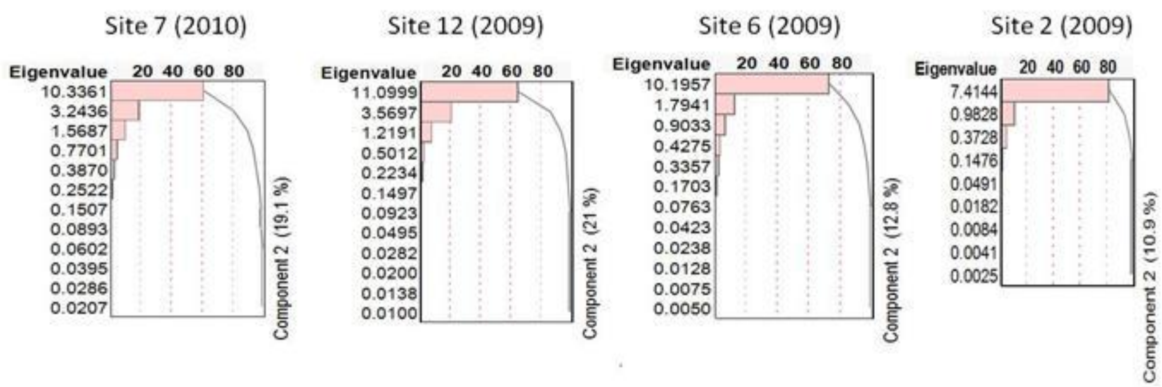

Site 7 (2010)
Eigenvalue
20 40 60 80
10.3361
3.2436
1.5687
0.7701
0.3870
0.2522
0.1507
0.0893
0.0602
0.0395
0.0286
0.0207
Component 2 (19.1 %)
Site 12 (2009)
Eigenvalue
20 40 60 80
11.0999
3.5697
1.2191
0.5012
0.2234
0.1497
0.0923
0.0495
0.0282
0.0200
0.0138
0.0100
Component 2 (21 %)
Site 6 (2009)
Eigenvalue
20 40 60 80
10.1957
1.7941
0.9033
0.4275
0.3357
0.1703
0.0763
0.0423
0.0238
0.0128
0.0075
0.0050
Component 2 (12.8 %)
Site 2 (2009)
Eigenvalue
20 40 60 80
7.4144
0.9828
0.3728
0.1476
0.0491
0.0182
0.0084
0.0041
0.0025
Component 2 (10.9 %)

Figure 87.

Site 7 – 2010

Rotated Factor Loading- Magnitude, Bins 2-18

	Factor 1	Factor 2	Factor 3
Mag2	0.2243790	0.8154018	0.2073078
Mag3	0.1962319	0.9094155	0.2085913
mag4	0.1491565	0.9568144	0.2148373
mag5	0.1188320	0.9005326	0.3108406
mag6	0.1028613	0.7651421	0.4798035
mag7	0.1657644	0.5359760	0.7402992
mag8	0.2159917	0.4088060	0.8539266
mag9	0.2856951	0.3343090	0.8913376
mag10	0.4055354	0.2789647	0.8440589
mag11	0.5473602	0.2389989	0.7364261
mag12	0.7006318	0.1992086	0.5883010
mag13	0.8367283	0.1662820	0.4329704
mag14	0.9280058	0.1419208	0.2871720
mag15	0.9279749	0.1312329	0.2064544
mag16	0.8646498	0.1121372	0.1504348
mag17	0.7391585	0.1114148	0.1228107
mag18	0.6050279	0.1478633	0.1032727

Site 12 - 2009

Rotated Factor Loading

	Factor 1	Factor 2	Factor 3
Bin2	0.1571063	0.7831799	0.1364750
Bin3	0.1372240	0.8692275	0.1155961
Bin4	0.1193468	0.9363398	0.1425491
Bin5	0.1205895	0.9444927	0.2557124
Bin6	0.1468946	0.8591262	0.4229057
Bin7	0.2020638	0.7229551	0.5788646
Bin8	0.2720539	0.5855673	0.7087056
Bin9	0.3574507	0.4533431	0.7940913
Bin10	0.4703367	0.3374460	0.8082279
Bin11	0.5935898	0.2495148	0.7418278
Bin12	0.7187729	0.1918008	0.6232937
Bin13	0.8208981	0.1635133	0.4957704
Bin14	0.8980256	0.1596082	0.3768505
Bin15	0.9446791	0.1572071	0.2775088
Bin16	0.9482593	0.1501156	0.2051025
Bin17	0.9240246	0.1478805	0.1508600
Bin18	0.8325149	0.1209358	0.0970152

Site 6 – 2009

Rotated Factor Loading – Velocity Magnitude

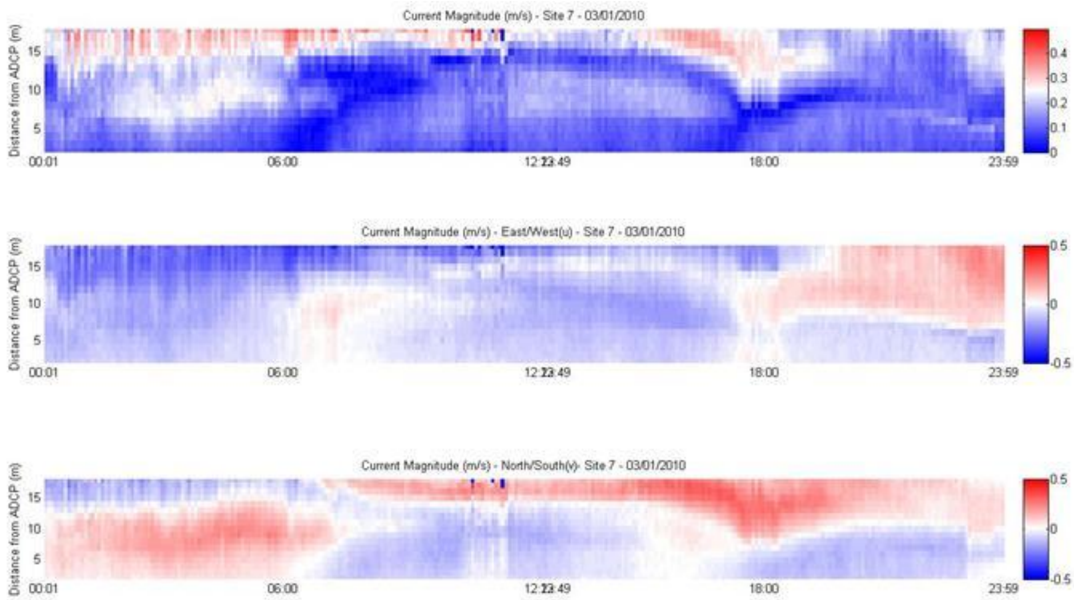
	Factor 1	Factor 2
Bin2	0.2594270	0.7981953
Bin3	0.2777981	0.8644937
Bin4	0.3224623	0.9126733
Bin5	0.3983379	0.9076430
Bin6	0.5206708	0.8261737
Bin7	0.6499888	0.7093806
Bin8	0.7612448	0.5948255
Bin9	0.8474816	0.5015724
Bin10	0.9018202	0.4273605
Bin11	0.9063600	0.3753889
Bin12	0.8787299	0.3370013
Bin13	0.8172252	0.3186281
Bin14	0.5434056	0.1714378
Bin15	0.4185273	0.1291852

Site 2 - 2009

Rotated Factor Loading – Velocity Magnitude (2 factors)

	Factor 1	Factor 2
Bin 2	0.8613244	0.3563057
Bin 3	0.8947187	0.3942222
Bin 4	0.8835685	0.4670845
Bin 5	0.7920322	0.5938457
Bin 6	0.6687850	0.7302081
Bin 7	0.5497269	0.8353480
Bin 8	0.4536237	0.8627038
Bin 9	0.3796165	0.8109421
Bin 10	0.2198386	0.5773240

Figure 88.



Current Magnitude (m/s) - Site 7 - 03/01/2010
Current Magnitude (m/s) - East/West(u) - Site 7 - 03/01/2010
Current Magnitude (m/s) - North/South(v)- Site 7 - 03/01/2010
Distance from ADCP (m)
00:01
06:00
18:00
23:59

APPENDIX 5: INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE – ANIMAL USE PLANS (AUPS)

Project Title: Coastal Movements of Spiny Dogfish Overwintering off the Outer Banks, NC

Approval Granted: January 15, 2009

AUP and Approval Letters are Attached.

Animal Care and Use Committee
East Carolina University
212 Ed Warren Life Sciences Building
Greenville, NC 27834
252-744-2436 office • 252-744-2355 fax

EAST CAROLINA UNIVERSITY

January 15, 2009

Roger Rulifson, Ph.D.
Department of ICSP/Biology
Flanagan 385
East Carolina University

Dear Dr. Rulifson:

Your Animal Use Protocol entitled, "Coastal Movements of Spiny Dogfish Overwintering off the Outer Banks, NC," (AUP #D230) was reviewed by this institution's Animal Care and Use Committee on 1/15/09. The following action was taken by the Committee:

"Approved as submitted"

A copy is enclosed for your laboratory files. Please be reminded that all animal procedures must be conducted as described in the approved Animal Use Protocol. Modifications of these procedures cannot be performed without prior approval of the ACUC. The Animal Welfare Act and Public Health Service Guidelines require the ACUC to suspend activities not in accordance with approved procedures and report such activities to the responsible University Official (Vice Chancellor for Health Sciences or Vice Chancellor for Academic Affairs) and appropriate federal Agencies.

Sincerely yours,

Robert G. Carroll, Ph.D.

Robert G. Carroll, Ph.D.
Chairman, Animal Care and Use Committee

RGC/jd

enclosure

East Carolina University.

Animal Care and Use Commitee
212 Ed Warren Life Sciences Building
East Carolina University
Greenville, NC 27834

252-744-2436 office
252-744-2355 fax

August 17, 2010

Roger Rulifson, Ph.D.
Department of ICSP/Biology
Flanagan 385
East Carolina University

Dear Dr. Rulifson:

Your Animal Use Protocol entitled, "Is Cape Cod a Natural Delineation for Migratory Patterns in U.S. and Canadian Spiny Dogfish Stocks?," (AUP #D249) was reviewed by this institution's Animal Care and Use Committee on 8/17/10. The following action was taken by the Committee:

"Approved as submitted"

A copy is enclosed for your laboratory files. Please be reminded that all animal procedures must be conducted as described in the approved Animal Use Protocol. Modifications of these procedures cannot be performed without prior approval of the ACUC. The Animal Welfare Act and Public Health Service Guidelines require the ACUC to suspend activities not in accordance with approved procedures and report such activities to the responsible University Official (Vice Chancellor for Health Sciences or Vice Chancellor for Academic Affairs) and appropriate federal Agencies.

Sincerely yours,

Robert G. Carroll, Ph.D.

Robert G. Carroll, Ph.D.
Chairman, Animal Care and Use Committee

RGC/jd

enclosure

APPENDIX 6: INSTITUTIONAL REVIEW BOARD (IRB) HUMAN SUBJECT RESEARCH PLAN

A human subject research plan was initiated for this research project. However, that aspect of the dissertation was dropped in consultation with my research advisor and committee in 2010 and 2011. The study was officially closed with the IRB in Fall 2015.

University and Medical Center Institutional Review Board
East Carolina University • Brody School of Medicine
600 Moye Boulevard • Old Health Sciences Library, Room 1L-09 • Greenville, NC 27834
Office **252-744-2914** • Fax **252-744-2284** • **www.ecu.edu/irb**
Chair and Director of Biomedical IRB: L. Wiley Nifong, MD
Chair and Director of Behavioral and Social Science IRB: Susan L. McCammon, PhD

TO: Jennifer Cudney, Doctoral Student, 379 Flanagan Building, Coastal Resources Management, ECU

FROM: UMCIRB KK

DATE: October 28, 2009

RE: Expedited Category Research Study

TITLE: "Assimilating local ecological knowledge(LEK) of the North carolina spiny dogfish (Squalus acanthias) popluation of supplement 12 years of life history and fishery data"

UMCIRB #09-0619

This research study has undergone review and approval using expedited review on 10.21.09. This research study is eligible for review under an expedited category because it is on collection of data from voice, video, digital, or image recordings made for research purposes. It is a research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.)
The Chairperson (or designee) deemed this **Coastal Resources Management/Institute for Coastal Science and Policy Summer Research Award** sponsored study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **10.21.09** to **10.20.10**. The approval includes the following items:

- Internal Processing Form (received 8.7.09)
- Informed Consent (received 10.15.09)
- Background Information Question
- COI Disclosure Form (dated 8.7.09)
- Summary of the Proposal

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418
IRB00004973 East Carolina U IRB #4 (Behavioral/SS Summer) IORG0000418
Version 3-5-07

UMCIRB #09-0619
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EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board
Office for Human Research Integrity
4N-70 Brody Medical Sciences Building• 600 Moye Boulevard • Greenville, NC 27834
Office 252-744-2914 • Fax 252-744-2284 • www.ecu.edu/irb

TO:	Jennifer Cudney Cudneyj01@students.ecu.edu
FROM:	UMCIRB KWB
DATE:	September 25, 2015
RE:	Research Study Closure
TITLE:	Assimilating Local Ecological Knowledge (LEK) of the North Carolina Spiny Dogfish (*Squalus acanthias*) Populations to Supplement 12 Years of Life History and Fishery Data
UMCIRB #	09-0619

A final review report was submitted by the investigator on 09/14/2015. This research study has undergone expedited review for closure on 09/22/2015 . This unfunded research study has been closed by the principal investigator who reports she never undertook the research.

It is the responsibility of this investigator to retain all research-related documents, included the informed consent forms (if applicable), for a period of no less than three years. If you have any questions or need for any reason to re-open this research study, please contact the UMCIRB Office prior to implementing any research actions.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.