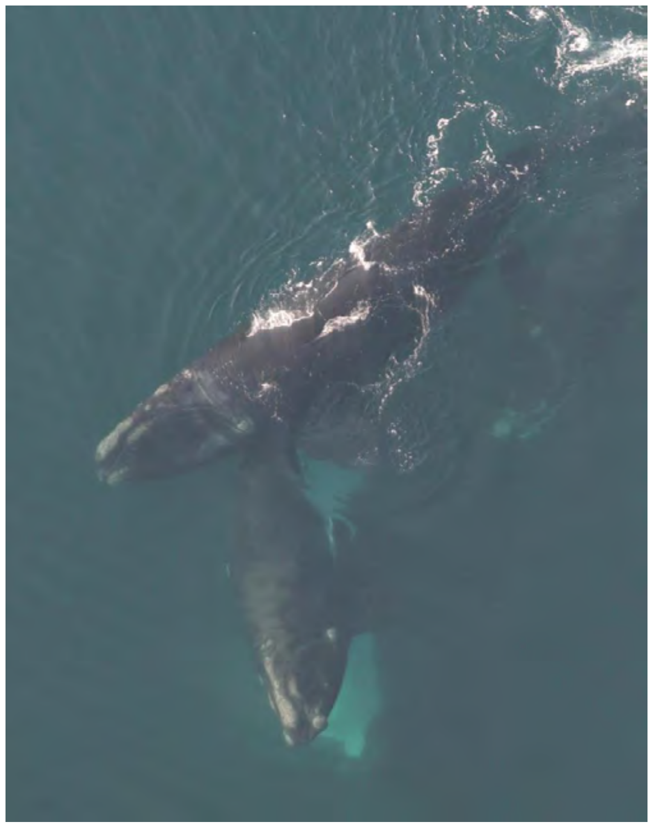
# Surveillance, Monitoring and Management of North Atlantic Right Whales in Cape Cod Bay and Adjacent Waters - 2009

**Final Report**



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# EXECUTIVE SUMMARY

In 2009, the Provincetown Center for Coastal Studies (PCCS)'s right whale surveillance program, supported by the Commonwealth of Massachusetts Division of Marine Fisheries (DMF) was conducted in Cape Cod Bay (CCB) and adjacent waters between January 1 and May 31. Weather permitting, the program included regular aerial surveys and weekly habitat sampling. Upon completion of each survey, all sightings were reported to the NOAA Fisheries Sighting Advisory System (SAS).

During the 2009 winter and spring season, PCCS performed 23 aerial surveys, amounting to 124 hours of flight time covering CCB and adjacent waters east of Cape Cod, and an additional survey of Massachusetts Bay/ Stellwagen Bank, comprising an additional 7 hours of flight time. 354 sightings of 196 „individual' right whales were made by the aerial survey team during the survey season. To date, 187 unique individuals have been matched to known whales, from photographs collected during the 2009 field season, representing 49% of the entire right whale population known to be alive in 2009. The first right whale was sighted in CCB by the aerial team on 26 January, and right whales were last documented in the bay on the 17$^{th}$ of April and on eastern track lines on the 18$^{th}$. Habitat surveys last sighted right whales in CCB on the 27$^{th}$ of April, thus right whales were present in CCB for a minimum of 92 days in 2009. The longest maximum possible residency time (time from first to last sighting in the bay) for any individual, as detected by aerial surveys, was 59 days. In 2009, in contrast to observations in previous years, the number of sightings per unit effort peaked in the middle of March, then decreased slightly but remained high through early April. A total of 39 right whale calves were documented to have been born in the 2009 season. Of those calves, five were seen with their mothers in CCB in 2009. Other marine mammal species sighted during aerial surveys were: humpback whales, fin whales, minke whales, Atlantic white-sided dolphins, harbor porpoises, grey seals and harbor seals. All vessels and fishing gear sighted during aerial surveys were also recorded and the data was forwarded to DMF.

R/V *Shearwater* completed 19 habitat sampling cruises in the Cape Cod Bay Right Whale Critical Habitat and adjacent waters between 13 January and 24 May 2009. A total of 669 zooplankton samples were collected and analyzed during these cruises. Preliminary assessment, risk assessment and advisory, and habitat assessment documents, including maps detailing the spatial dynamics of zooplankton and caloric distributions throughout the sampling season, were generated from the data collected, and were issued to a range of recipients including DMF and research collaborators. In addition, 101 right whale sightings were photographed opportunistically during habitat sampling cruises, comprising 89 unique individual right whales and including one individual not documented by the aerial survey team.

## ACKNOWLEDGEMENTS

We are grateful to all of our colleagues who worked with us in the air, on the water and in the lab to make this work possible. The aerial survey team is indebted to our pilots, John Williams & Joe Chronic, for providing excellent aircraft services and going out of their way to assist in the running of the program in 2009. We thank John Williams for his years of work with the aerial survey team; his skills and enthusiasm will be greatly missed. Tim Howard at Chatham Municipal Airport provided mechanical skills and gave of his time beyond the call of duty during the 2009 season. We also thank Brad Payne at Eagle Cap Aviation. We also thank our colleagues at NEFSC, especially Tim Cole, Pete Duley, Allison Glass and Christin Khan, for support, assistance and exchange of information. Kate Longley supervised the day-to-day running of the aerial survey program, whilst Heather Foley, Laura Ganley and Kelly Keen provided excellent observer, matching and data processing skills. The enthusiasm and dedication of this team was an essential part of a successful season.

The habitat team thanks Marc Costa for his expertise as captain of the R/V *Shearwater*, and Joe Warren for assistance with field equipment. Susie Tharratt and Sarah Fortune were integral to the tasks of data collection, processing and analysis for the Habitat Program. We thank all the staff at PCCS for their assistance in many ways during the busy right whale season. Special thanks to the PCCS Marine Disentanglement Team, and Tanya Grady.

The staff of the Right Whale Research Lab at the New England Aquarium provided valuable assistance with photo-identification. Special thanks to Moe Brown, Philip Hamilton, Amy Knowlton, Marilyn Marx and Monica Zani for guidance, data processing and providing information for this report. Drs Richard and Nina Evans once more kindly opened their home to our teams' seasonal staff for a nominal fee.

As always, we thank the many individuals who work on the waters of CCB and maintain vigilance with respect to right whales. We would also like to extend special thanks to the United States Coast Guard Sector Southeastern New England, for their continued commitment to ensuring our safety by facilitating scheduled communications during aerial surveys. Thanks also to Dan McKiernan, Deputy Director, Massachusetts DMF, and Erin Burke, protected Species Specialist with DMF, for their ongoing support of and involvement with the right whale programs at PCCS.

Aerial and shipboard surveys were conducted under Scientific Permit to Take Marine Mammals No. 633-1763-01, issued by NOAA Fisheries to Dr. Chares Mayo. Shoreline and boundary data used in GIS plots were obtained courtesy of the United States Geological Survey.

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# GENERAL INTRODUCTION

## Status

The North Atlantic right whale, *Eubalaena glacialis*, is one of the most endangered species of large whale in the world (IUCN Red List 2008), despite international protection from hunting since 1935. Whaling brought the species to the brink of extinction in the 1800s, and unlike many other species of cetacean, the North Atlantic right whale has not recovered well from this drastic reduction in population. No more than 400 individuals remain (CeTAP 1982, Brownell *et al*. 1986, Kraus *et al*. 1988, NMFS 1991, Knowlton *et al*. 1994, IWC 2001, Kraus *et al*., 2005, Kraus & Rolland 2007). In the United States, the northern right whale is listed as "endangered" under the Endangered Species Act (ESA) of 1973, and the Marine Mammal Protection Act of 1972 (Marine Mammal Commission) requires that this species and its habitats are protected and monitored.

## Threats

Marine mammals face a growing number of threats in this age (Reynolds *et al*. 2009), and for the North Atlantic right whale, a number of these threats have likely impeded the recovery of the population, post-whaling. In an analysis of strandings data, entanglement records and photographic data, Kraus (1990) suggested that at least a third of all right whale mortalities were due to anthropogenic activities. At this level, such sources of injury and mortality may be a significant factor impeding the recovery of this species (Cole *et al*. 2006; Knowlton & Kraus 2001). Between 1970 and the present time, a total of 84 right whale mortalities have been documented, of which 28 (33%) were due to ship strike (including 7 calves), 10 (12%) were due to entanglement (including 2 calves), 24 were due to unknown causes and the remaining 22 involved calves (natural or undetermined causes; A. Knowlton pers. comm.). Examining more recent cases only, since 2006 there have been four documented mortalities due to ship strike, three due to entanglement, four of unknown cause and five involving calves. Naturally, these numbers are only a minimum estimate since many mortalities likely go unobserved and thus undocumented (Knowlton & Kraus 2001).

Ship collisions kill more right whales than any other documented cause (Knowlton & Brown 2007; Campbell-Malone *et al*. 2008). Right whales are slow moving and very difficult for vessel-based observers to see, especially when whales are engaged in sub-surface feeding. They do not always appear to avoid approaching vessels, especially when socializing or feeding near the surface. There is a moderate level of commercial shipping in the CCB Critical Habitat, and Kite-Powell and Hoagland (2002) estimated that there are about 550 transits annually, by inbound and outbound vessels, through the Cape Cod Canal and along the western portion of the Bay. The combination of these factors makes Massachusetts waters a region of high potential vulnerability for right whales. Modelling work to identify areas of potential risk to right whales from shipping traffic in the bay generated an expected rate of 1.9 encounters between right whales and vessels, per year (Nichols and Kite-Powell 2005). In 2009, two vessel routing proposals, submitted by the US to the International Maritime Organization (IMO) to reduce the risk of ship strike to right whales, came into effect (Bettridge & Silber 2009). A recommended, seasonal area to be avoided (ATBA) in the Great South Channel off Massachusetts was implemented for ships of 300 gross tons and above and is in effect each year from April 1 to July 31, a time and location of significant right whale aggregation (http://www.nmfs.noaa.gov/pr/shipstrike/). The other measure is a modification of the north-south leg of the IMO-adopted traffic separation scheme (TSS) in the approach to Boston, by narrowing the width of each of the lanes from two miles to a mile and a half, leaving the western boundary of the TSS and the width of the mile separation zone unchanged. This amendment is intended to move ships away from the greatest density of right whales and minimize the overlap between whale distribution and ship traffic. Vanderlaan *et al*. (2008) suggested that a seasonal recommendatory area to be avoided (ATBA) in the Bay of Fundy and Roseway Basin areas in Canadian waters could be designed to reduce the risk imposed by vessels upon right whales in the region, a suggestion which has similarly contributed to management measures implemented in this area by the IMO.

Interactions between fisheries and non-target marine vertebrates are of global concern, impact a wide range of taxa (e.g. Silvani *et al*. 1999; Norman 2000; Hays *et al*. 2003; Lewison *et al*. 2004; Page *et al*. 2004; Read et al. 2006; Leeney *et al*. 2008a; Moore *et al*. 2009), and involve effects as diverse as bycatch (mortality), entanglement and ingestion of fishing gear. Entanglements in the western North Atlantic are a major source of injury and mortality for many large whale species, including right whales (Johnson *et al*. 2006). Lobster pot and gillnet gear are most commonly implicated in right whale entanglements, although many gear types can be involved (Johnson *et al*. 2006). Knowlton & Kraus (2001) note that whilst ship strike is more immediately fatal, entanglements are likely responsible for a high level of mortality through the long-term deterioration of an animal's health. Right whales are especially at risk of entanglement in fixed fishing gear. In response to the risk of right whale entanglement in fixed fishing gear, the Massachusetts Division of Marine Fisheries (DMF) has taken management action to mitigate the threat to right whales. In Cape Cod Bay Critical Habitat, the use of gillnet gear is prohibited between January 1 and May 15, while lobster gear fished during that period must be modified to comply with seasonal restrictions (322 CMR 12.05). In particular, the use of floating groundline in the pot and gillnet fisheries is prohibited year-round in Massachusetts state waters. This sinking groundline requirement went into effect on January 1, 2007. DMF also carries out "ghost gear removal" projects in the winter months, assisted by gear sightings information provided by the PCCS aerial survey team, to further reduce entanglement risk.

Various studies have documented diverse responses by cetaceans to acoustic disturbance (e.g. Stone 2003; Foote *et al*. 2004; Tougaard *et al*. 2004), but there is now little doubt that the ever-increasing levels of anthropogenic noise in our oceans are detrimental to marine mammals (McKenna 2008). Parks *et al*. (2007) documented changes in vocalization behavior of North Atlantic right whales in high-noise conditions. The authors suggest that such behavioral responses may indicate that increased underwater noise could have effects on reproduction and recovery of the species. The noise of ships themselves have been shown to elicit no response from right whales (Nowacek *et al*.

2004), which suggests that that they have become habituated to such noise, potentially placing them at higher risk from ship strike. High noise levels from shipping and seismic surveys have been shown to displace other large whale species from their normal movements (Richardson *et al*. 1995).

Other indirect effects may negatively impact the health and longevity of right whales and thus have an effect on the recovery of the population (Knowlton *et al*. 1994). Habitat loss, pollutants and climate change may all affect marine mammals in ways which are difficult to assess or predict. Concerns have been growing about the effects of climate change on many species of marine vertebrates (e.g. Hawkes *et al*. 2009; MacLeod 2009; MacLeod *et al.* 2008; MacLeod *et al*. 2005; Perry *et al*. 2005). Climate change has the potential to affect right whales both directly, through temperature effects, and indirectly through effects on prey resources and reproduction (Kenney 2007). The effects of pollutants on right whales are poorly understood. Studies of other species have shown that immuno-suppression and other direct effects on health and reproduction can be caused by exposure to contaminants. Van Bressem *et al*. (2009) suggest that cetaceans utilizing inshore habitats may incur higher risks to infectious diseases than pelagic cetaceans, due to high levels of environmental stressors in these habitats - anthropogenic factors such as chemical and biological contamination, fisheries interactions, traumatic injuries from vessel collisions and climate change. The rate of reproduction in North Atlantic right whales is considerably lower than that of the southern right whale (Knowlton *et al*. 1994; Best *et al*. 2001; Kraus *et al*. 2001), and it is thought that the lower „quality' of habitat in the North Atlantic (due to higher levels of vessel traffic, anthropogenic noise and pollutants, for example) may been in large part responsible for this (Kraus *et al*. 2007).

**Cape Cod Bay**

The Cape Cod Bay (CCB) ecosystem is one of five known, seasonal high-use habitat areas for right whales in the western North Atlantic, the others being along the southeast coast of Florida and the Great South Channel in US waters, and the Bay of Fundy and Roseway Basin in Canadian waters. Over two-thirds of western North Atlantic right whales aggregate seasonally in one of these habitats (Kraus & Rolland 2007). There is, however, a gap in our understanding of habitat use by right whales in the migratory corridor along the eastern seaboard of the United States. Schick *et al.* (2009) characterized habitat suitability in migrating right whales in relation to depth, distance to shore, and the recently enacted ship speed regulations near major ports. They found that the range of suitable habitat exceeds previous estimates, and that a 30 nautical mile buffer would protect more habitat for right whales than the 20 nautical mile buffer currently in place.

Photographic identifications date from 1959 (Hamilton *et al*. 1997) to the present, and whaling records provide evidence of right whales in Cape Cod Bay in the late autumn and winter through late spring, from at least the early 1600s (Allen 1916, Mitchell and Reeves 1983, Reeves *et al*. 1999, Reeves *et al*. 2002). For the period of 1978 through 1986, using photographed sightings of right whales collected from whale watch boats and research cruises, the total number of individually identified right whales in Cape Cod Bay ranged from a single animal in 1978 to 47 individuals in 1986 (Hamilton and Mayo 1990). To gain a better understanding of the spatial and temporal distribution of individually identified right whales in Cape Cod Bay, an extensive surveillance and monitoring research program was initiated by PCCS in the winter and spring of 1998 and has continued ever since (Brown & Marx 1998, 1999, 2000; Brown *et al*. 2001b, 2002, 2003; Mayo *et al*. 2004; Jaquet *et al*. 2005, 2006, 2007; Leeney *et al*. 2008b). The program of research directly addresses concerns identified by the Right Whale Conservation Plan, submitted by the Commonwealth of Massachusetts to federal courts in 1996 and by the Northeast Implementation Team, and supports goals of the federal Atlantic Large Whale Take Reduction Plan, the Right Whale Recovery Plan (NMFS 1991) and the Endangered Species Act.

At present, in the Cape Cod Bay area, data on right whales is collected as part of regular monitoring programs by two institutions: the Provincetown Center for Coastal Studies, which carries out an annual intensive field season focusing on this species between January and May every year, and NEFSC, which carries out less regular, more broad-scale aerial surveys throughout the year over many parts of the Gulf of Maine, including Cape Cod Bay and Massachusetts Bay. Data from recent years have shown the Cape Cod Bay area to be an important feeding, nursing and socializing area from late December through early May, some years for over 40% of the known living catalogued population (Brown and Marx 1998, 1999, 2000, Brown *et al*. 2001b, 2002, 2003, Mayo *et al.* 2004, Jaquet *et al.* 2005, 2006, 2007; Leeney *et al*. 2008b).

CCB is a Seasonal Management Area (SMA), requiring that, between January 1 and May 15, all vessels of 65 ft (19.8 m) or longer must travel at 10 knots or less when in this area. However, NOAA's Northeast US Right Whale Sightings Advisory System (SAS) also designates Dynamic Management Area (DMA) status to areas outside of SMAs, when sightings of right whales in these areas occur. Mariners are alerted to areas of right whale activity through Coast Guard and NOAA Weather Radio broadcasts, the Mandatory Ship Reporting System, email and the NOAA SAS website. The size and shape of DMAs is determined by the sightings data provided by research teams in the region. The primary function of PCCS surveys in recent years is to provide near real-time information to DMF and relevant authorities on the locations of right whales using CCB and surrounding waters (aerial surveys), and to provide data which facilitates the predictive modeling of right whale movement, aggregation and behavior in the region (habitat surveys). In addition to the immediate use of the near-real-time sightings data, the collection of detailed information on the location and behavior of every individual sighted in the study area on both aerial and habitat surveys, along with photographic data, allows for many in-depth studies on habitat use, behavior and the health of individuals.

Finally, the collaboration of the right whale aerial survey and habitat survey teams with the PCCS disentanglement team provides extra power to detect entangled right whales during the period of peak abundance in CCB, and an immediate, effective and coordinated response to any such incident, whenever possible. For a species of such limited numbers, the disentanglement of every individual represents a significant contribution to population viability.

## Program Objectives 2009

The objectives of the PCCS 2009 surveillance, monitoring and management program in Cape Cod Bay and adjacent waters were as follows:

**1. Photo-identification**
To document right whales in the Cape Cod Bay Right Whale Critical Habitat and adjacent waters from early January through mid-May, using photo-identification techniques to identify individual whales. These data provide information on the distribution and abundance of right whales in the study area, as well as details on demography, patterns of habitat use and reproductive activity. The data also contribute to the longer-term wide-range analyses on presumed mortality and incidence of visible injuries. Photographic and sightings data are integrated into the right whale photo-identification catalogue at the New England Aquarium and the sightings database at the University of Rhode Island.

**2. Short-term Management**
To provide sightings data to the National Marine Fisheries Sighting Advisory System (SAS). Sighting locations of right whales are reported promptly after each survey to NMFS/ SAS, who then issue alerts to mariners based on the locations of whales relative to areas of high vessel traffic. The goal is ultimately to reduce the probability that right whales will be killed by collisions with large vessels by providing near „real-time' sighting data within Massachusetts waters to port authorities, commercial and military vessels, and other maritime operations. The winter portion of PCCS's surveys provide a large portion of the data for the NMFS advisory system in the northeast.

**3. Entanglements**
To monitor right whales in the study area for evidence of entanglement. Each right whale sighted is examined visually for evidence of attached gear or serious injury. The PCCS disentanglement team is on standby throughout the right whale season, ready for immediate dispatch in the event of the sighting of an entangled whale. All PCCS research teams, as required, assist with the disentanglement effort.

**4. Habitat Monitoring**
To collect data on food resources in CCB, during weekly vessel cruises from January to mid-May. The sampling protocol is designed to develop an understanding of the characteristics of the habitat to which right whales respond. The dataset collected by PCCS, which spans 25 years, provides insight, over a significant study period, into the conditions and processes which affect movements and activities of right whales in CCB. Management agencies (e.g. MA DMF, NMFS) have used these data to forecast whale movements and residency times, data which in turn can inform vessel speed advisories and seasonal fishing gear restrictions.

**5. General monitoring**
To document the distribution and abundance of other marine mammal species, shipping activity and fishing gear in CCB and adjacent waters during the study period.

Objectives 1 through 3 and 5 are the focus of the Aerial Survey Program (Section 1), whilst the Habitat Program focuses on Objective 4 (Section 2) and contributes also to Objective 1.

# SECTION 1: SURVEILLANCE, RESIDENCY & DEMOGRAPHICS OF NORTH ATLANTIC RIGHT WHALES IN CAPE COD BAY & ADJACENT WATERS IN 2009

## 1.1 INTRODUCTION

The following section addresses Objectives I through III and Objective V of the PCCS/ DMF right whale surveillance and monitoring program.

The PCCS Right Whale Aerial Survey Program was set up in 1998 and has run annually since then, documenting right whale abundance and distribution in Cape Cod Bay and adjacent waters over the winter and early spring. The main purpose of the aerial surveys is to collect photo-identification data for every right whale sighted. Photographs of right whale callosity patterns are used as a basis for identification and cataloguing of individuals, following methods developed by Payne *et al*. (1983) and Kraus *et al*. (1986). The cataloguing of individually identified animals is based on using high quality photographs of distinctive callosity patterns (raised patches of roughened skin on the top and sides of the head), ventral pigmentation, lip ridges, and scars (Kraus *et al*. 1986, Hamilton and Martin 1999, Kraus and Rolland 2007). Aerial surveys allow for the full head of a right whale to be photographed, and photographs can also include the rest of the body of the whale, thus other recognizable features such as scars can also be captured. In contrast, from vessels, any given photograph includes information from one side of the whale only, and a very limited „profile' of the animal is usually available to photograph from water-level. Thus, aerial photography has proved a valuable research and identification tool for this species, although it should be noted that photographs from vessels can also include valuable information and may provide more detailed images of certain aspects, such as lip ridges and scarring, than aerial photographs can. In addition, aerial surveys also allow for a large area to be covered in a limited time, and in the case of the PCCS aerial surveys, the very fine-scale survey methodology employed aims to document every right whale in the bay on any given survey. Originally implemented as a management tool to prevent conflicts between right whales and fisheries in the Northeast, the PCCS Cape Cod Bay aerial surveys have been extended beyond this mission and continue to provide valuable information on habitat quality, fine-scale habitat use, individual health and population status for right whales (Brown *et al*. 2007).

NEAq has curated the right whale photo-identification catalogue since 1980 and to the best of their knowledge, all photographs of right whales taken in the North Atlantic since 1935 have been included in NEAq's files. This catalogue allows scientists to enumerate the population, and, from re-sightings of known individuals, to monitor the animals' reproductive status, births, deaths, scarring, distribution and migrations. 50,659 sightings of 554 individual right whales have been documented between 1935 and the present, of which 379 are believed to be alive as of November 2, 2009 (P. Hamilton, pers. comm.).

In addition to running aerial surveys, this program oversees the analysis of the photo-identification data collected by the Right Whale Habitat Program (Section 3); thus the methods for collection and analysis of these data, and the results, are presented as part of this section.

## 1.2 METHODS

### 1.2.1 Aerial survey protocol

Aerial surveys were conducted regularly, from mid-January to late May, 2009, in the Cape Cod Bay Critical Habitat and adjacent waters. The aerial survey protocol for Cape Cod Bay, as described in Kraus *et al*. (1997), was adopted with some modifications. Fifteen track lines were flown latitudinally at 1.5 nautical mile (nm) intervals from the mainland to the Cape Cod Bay shoreline (Figure 1.1a). An additional outer Cape Cod track line, 35 nm in length, paralleled the outer coast of Cape Cod from east of Chatham to the eastern end of track line one at a distance of about three nm from shore (Fig. 1.1a, track line number 16). The east-west flight pattern in Cape Cod Bay was chosen for technical and safety reasons. In these latitudes, winter aerial surveys are hampered by low sun angles in the early and late hours of a survey day and this glare is a significant factor in sightability of marine mammals. On east-west track lines, although glare was a factor in one of the forward quadrants of the observers' view, there was always a section of the survey swath that could be observed without being compromised by glare. It was also deemed safer to have the aerial survey track lines begin and end near land. The turn at the end of each track line was initiated and completed about 1.5 nm from shore in Cape Cod Bay to maximize the opportunity to observe any whales near shore. A total of 306 nm of „on-track line' miles were flown during each completed survey (Appendix I, Table 1a). "On-track line" miles were those miles flown while surveying due east or due west in Cape Cod Bay and along the outer coast of Cape Cod, but excluded all miles flown between track lines (cross legs) or while circling. In addition to the CCB study area, we intermittently flew a series of track lines, also running east west from the Cape to approximately 15 nm offshore (Fig. 1.1a). At the end of the 2009 field season, due to an excess of remaining available flight time, we flew for the first time a new series of track lines (spaced 3 nm apart; 420 nm track line distance) over Massachusetts Bay and Stellwagen Bank (Fig. 1.1b); this survey has not been included in the main analyses presented in the Results section, since it covered a region not frequented by this program and since no right whales were sighted there.

The surveys were flown under pre-determined flight conditions of sea states up to and including Beaufort sea state four. Surveys were aborted in Beaufort sea state five and/or when visibility decreased below two miles in fog, rain or snow. All aerial surveys originated at Chatham Airport, Chatham, MA, and were conducted in a Cessna 337 Skymaster (N48WP), a twin engine, high wing aircraft with retractable landing gear. The aircraft was equipped with two GPS (global positioning system) navigation systems, full IFR (instrument flight rules) instrumentation, and a marine VHF radio with external antenna. Safety equipment included a life raft, four immersion suits, a floating ditch kit containing a medical kit, a waterproof VHF radio, a portable 406 MHz EPIRB, and an aircraft mounted ELT (emergency locator transmitter). All occupants wore Nomex flight suits and FAA-approved life vests with the following equipment attached: 406 MHz Personal Locator Beacon (PLB), Helicopter Aircrew Breathing Device (HABD), strobe light, dye marker, knife, and signal mirror. Additional safety measures adopted during the 2003 field season (Brown *et al*. 2003) were continued with minor modifications, most of which were made to comply with NOAA Fisheries Northeast Region Commercial Aviation Services Requirements (CASR, 26 October 2003).

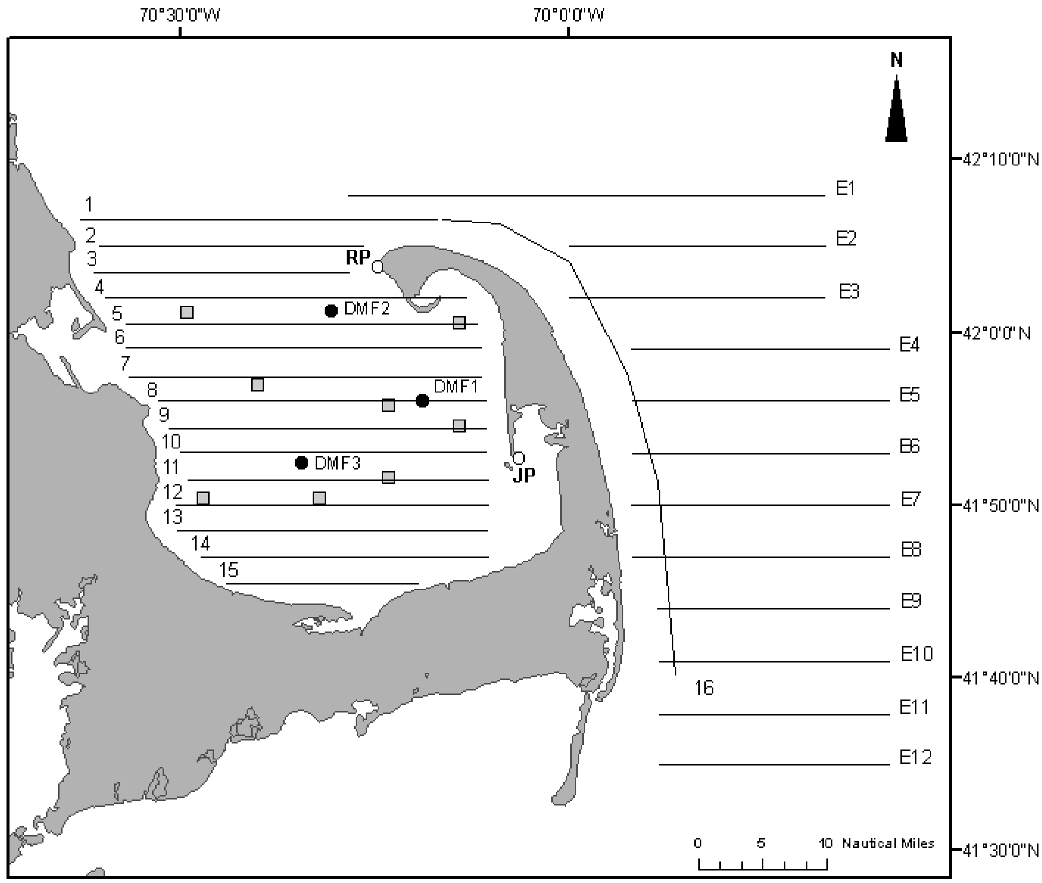


**Fig. 1.1:** (a) The Cape Cod Bay study area, showing numbered track lines (running east-west) inside and east of the Cape, habitat sampling stations (grey boxes), DMF acoustic buoys and points of reference – Race Point (RP) and Jeremy Point (JP).

Surveys were conducted at a standard altitude of 750 feet (229 meters) and a ground speed of approximately 100 knots, using methodology developed by CeTAP (Scott and Gilbert 1982, CeTAP 1982). The survey team consisted of two pilots and two observers positioned on each side of the aircraft in the rear seats. The two rear seat observers scanned the water surface from 0° - 90°, out to at least two nautical miles and recorded sightings when they were abeam of the aircraft. In order to maintain a standardized sighting effort, the pilots were instructed not to alert the observers to any sighting of marine mammals until after it had been passed by the aircraft and clearly missed by the observers.

Data were recorded by one observer (the right hand side one) using a laptop computer running an interactive data-logging program (Logger 2000, International Fund for Animal Welfare). Logger 2000 was configured to automatically record an event at 5-second intervals. At each event, latitude, longitude, time, altitude, and heading were obtained through an interface with the aircraft GPS. All sightings were logged by one observer recording the sighting data into a digital voice recorder (Sony ICD-ST10). A distinct voice file was created for each event which included the time to the second (read from a stopwatch which was synchronized with the plane's laptop

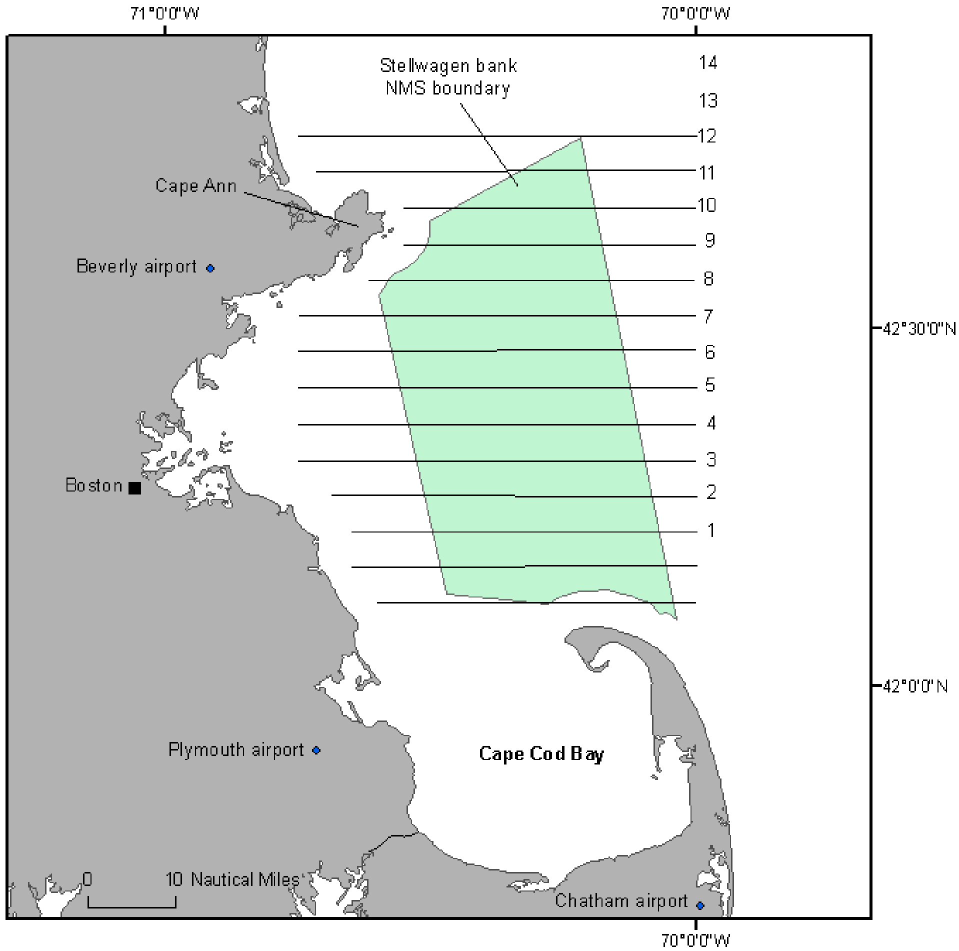


**Fig. 1.1:** (b) Survey track lines over Massachusetts Bay.

computer), the sighting and the distance of the sighting from the plane. The voice recordings were later transcribed into the database created by Logger 2000 with each recording being assigned to the nearest second[1]. This protocol allowed the observer to enter data without taking his/her eyes from the survey area.

All sightings of marine animals, except birds, were recorded. Sightings identified as species other than right whales were counted, logged and passed without breaking the track line in order to maximize flight time available for investigating right whale sightings. Sightings of all vessels in the area were recorded by location and type. When an observer sighted a right whale or another large whale not immediately identified by species, the aircraft departed from the track and circled over the animal to determine species and obtain identification photographs. Photographs were obtained of as many individual right whales within a given aggregation as possible. For each right whale sighting, behavior and interaction with other whales or any nearby vessels or fishing gear was noted. At the conclusion of photographic effort at each sighting, the aircraft returned to the track line at the point of departure as recorded by the pilot's GPS. These methods conform to

[1] Logger 2000 records at 5-second intervals, thus the event to which a voice recording is assigned was never more then two seconds from the time recorded. At a survey speed of 100 knots, 102 meters is covered in two seconds. Therefore, the position of the event in the Logger database that the recording was assigned to was never more then 102 meters from the exact position of the sighting.

research protocols followed by the North Atlantic Right Whale Consortium and approved by NOAA Fisheries.

***Identification Photographs***
During aerial and shipboard surveys, photographs were taken using a hand held 35 mm Canon digital camera equipped with 300-mm telephoto lenses. From the air, photographers attempted to obtain good perpendicular photographs of the entire rostral callosity pattern and back of every right whale encountered as well as any other scars or markings. Photographs were taken from a rear, opening window to prevent distortion of the image. From vessels, photographers attempted to collect good photographs of both sides of the head and chin, the body and the flukes. The data recorder on both platforms was responsible for keeping a written record in the daily log of the image numbers shot by each photographer. Digital images were downloaded and backed up immediately following each flight and cruise.

### 1.2.2 Vessel-based photo-identification protocol

Surveys to sample the habitat in Cape Cod Bay were carried out on board the R/V Shearwater. Photo-identification of encountered right whales as carried out opportunistically during these surveys, thus the data collected are by no means representative of the full complement of right whales in the bay on any given day. At least one observer was on watch at all times during habitat cruises, and usually two people were on watch simultaneously, stationed on the observation platform above the wheelhouse, at a height of approximately 4 m above sea level. Details of all marine mammal sightings, as well as sightings of fishing gear and vessels, were radioed down to the wheelhouse where the time, position, distance and bearing to the sighting and species/ gear type/ vessel type were recorded. A log of the entire track covered by the vessel on each survey was tracked using a hand-held GPS unit, and this track was downloaded post-survey.

When right whales were sighted at or near samplings stations (see Section 2 for details on habitat sampling station locations and protocol), or en route to a station, photographs were taken whenever the whale was within close enough range that images would be useful for identification purposes. When photo-identification commenced on any given individual or group of right whales, the observer recorded time, location, bearing and distance of the whale(s) to the vessel, both at the start and end of the encounter. The photographer focused primarily on capturing head shots from each individual, from as many angles as possible (including mandibular and post blowhole callosities), and then took further images of each individual’s body, tail stock, and fluke when possible. Right whales in the area which were not close enough to be photographed were counted and noted, in order to document the approximate number of individuals encountered. The behavior of whales, and associations between individuals, was also noted. Post-survey data management was as for aerial survey (Section 2.2.3).

### 1.2.3 Post-survey data management

At the end of each aerial survey, data from the voice recorder and track data from the day were downloaded and backed up on CD-R and two external hard drives. Digital voice files were managed and played back using proprietary software (Digital Voice Editor v. 2.13, Sony Corp.). Data recorded in individual voice files during the flight were manually transcribed into corresponding entries in the MS Access database created by Logger 2000. The database was then queried to generate a table formatted for compatibility with the North Atlantic Right Whale Consortium database. Data from aerial surveys were submitted to Dr. Robert D. Kenney, curator of the Right Whale Consortium Database maintained at the University of Rhode Island.

All images from a day were downloaded from the camera onto a computer and into a folder labeled with the date and platform. Every right whale photographed in a day was considered a "sighting". Time, latitude, longitude, EG letter (the whale identifier for the day), and notes for each sighting were entered and the corresponding images were assigned by a simple click and drag feature. Each sighting was coded for behavior, association (mother/calf, Surface Active Group, echelon feeding, etc), and for 26 identification criteria, including callosity pattern, scars, and other notable features. The identification coding allows for future searches and comparison to both identified and unidentified whales. In addition to sighting coding, each image is also coded for quality, body-part visible, view direction and photographer. This coding system aids the matching process and simplifies image access for ongoing studies such as entanglement scar analysis and health assessment (Pettis *et al*. 2004).

***Photographic Data Archiving***
Original digital images are kept on file at PCCS on CD-R and two external hard drives. As digital photography has only been used for the last four years, an in-house system that allows image management and archiving in the same manner as slides is not in place at the time of this writing. However, in 2008, the PCCS aerial survey team created a small online matching database using the "Multiply" website, and continued this practice in 2009. The PCCS group on this website is accessible to members only, and contains a series of images for each right whale sighted during PCCS aerial surveys in each year. This proved an extremely efficient way to match whales which were re-sighted on several days, and also allowed researchers outside of PCCS to aid in real-time with the matching process for individuals already identified from other regions earlier in the season. All PCCS digital images from the 2009 season have been archived at NEAq and are available for access by collaborators per North Atlantic Right Whale Consortium protocols.

***Photo-Analysis and Matching***
The matching process consists of separating photographs of right whales into individuals, which are given a letter of the alphabet until they have been assigned a catalogue number. Composite drawings and photographs of the callosity patterns of individual right whales are then compared to a limited subset of the catalog that includes animals with a similar appearance. For whales that look alike in the preliminary analysis, the original photographs of all probable matches are examined for callosity similarities and supplementary features, including scars, pigmentation, lip crenulations, and morphometric ratios. A match between different sightings is considered positive when the callosity pattern and at least one other feature can be independently matched by at least two experienced researchers (Kraus *et al*. 1986). Exceptions to this multiple identifying feature requirement include whales that have unusual callosity patterns, large scars or birthmarks, or deformities so unique that matches from clear photographs can be based on only one feature. Preliminary photo-analysis and inter-matching was carried out at PCCS by experienced researchers, with matches confirmed using original photographs catalogued and archived at NEAq.

Once images were submitted to NEAq, analysis was conducted using DIGITS software (developed by Philip Hamilton and colleagues at the New England Aquarium). DIGITS was developed to help right whale researchers process digital images of whales, link them to sighting records, and code those sightings and images for subsequent searching and matching.

### 1.2.4 Data Analysis

***Data filtering***

Finalised data from PCCS, including all the numbers of individuals matched by the PCCS team, are sent to the New England Aquarium for confirmation. Provisionally-confirmed and corrected identifications (provided by NEAq after careful checking, and listed as "Unconfirmed EgNo"), are provided by NEAq after several months.

Data presented include the following:

1. For numbers of individual whales sighted on any given survey, the number of unique individuals, as assessed by PCCS researchers, are presented. This number includes whales with intermatch codes[2], since, from a given survey's photo analysis, intermatched individuals are unlikely to be the same as any whale which has been matched to the catalogue during the course of the survey season.
2. For distribution on a given survey, a single location (the first sighting per survey) for each unique individual (as assessed by PCCS researchers, whether given an unconfirmed identification by NEAq or not) is presented. This ensures that, within the limitations of the survey coverage on any survey, the observed distribution of whales is portrayed regardless of whether they have been matched to the catalog or not.
3. For describing the demography of the whales identified in our study area, only whales with a confirmed or unconfirmed identification have been included (i.e. no intermatch coded whales or unmatched individuals).

Integration of the sighting data collected during these surveys with previously collected data were used to describe the number, age, sex, and reproductive status of the right whales sighted in Cape Cod Bay in 2009. Sightings data from the aircraft were plotted to establish patterns of distribution and assess the seasonal and spatial residency patterns of right whales in the critical habitat and adjacent waters. Sightings of all other cetacean species sighted during aerial surveys were also mapped. The data on vessel locations were plotted for comparison with the locations of right whales to assess the level of overlap between right whales and vessels in the area. We used the individual identifications of right whales obtained during this study to examine residency and number of days between first and last sighting in Cape Cod Bay. An analysis of the age and sex composition of the winter and spring population was carried out using data from all PCCS surveys to assess demographics and habitat use patterns. Right whales, first identified as calves, ranging in age from one to eight years of age were classified as juveniles, individuals age nine or older were classified as adults (based on classifications by Hamilton *et al*. 1995). Whales that were not first sighted as calves were classified as unknown age for the first eight years of their sighting history and as adults thereafter. All females who had calved were classified as adult. Sexes were assigned based on one of three methods: 1) by direct observation of the genital area; 2) by association with a calf; 3) by testing biopsy samples with a sex-specific DNA marker (Brown *et al*. 1994).

In order to assess the utilization of an area by right whales, it is important not only to quantify the number of different individuals identified in an area, but also to take into account the residency time of individuals. The variable "whale-day", the number of different individuals multiplied by the number of days each had been identified, provides a measure of overall habitat use. Although meaningful, this variable is negatively biased by long periods without survey effort (such as during periods of bad weather). Furthermore, the number of different individuals is also important in providing an understanding of the proportion of the population utilizing a given area at any

[2] As per NEAq guidelines, PCCS assigns its own „season codes' to whales which cannot be matched to the catalog. For PCCS, the code involves "M" (for Massachusetts), followed by a 3-digit number assigned sequentially, regardless of year of first sighting. Hence, the first PCCS intermatch coded animal was M001.

stage, and in understanding the number of whales that may be threatened by entanglements or ship strike in this area. Both variables have therefore been used to describe habitat utilization of right whales.

### 1.2.5 Notification of Agencies

Prior to and following an aerial survey, both US Coast Guard Sector Southeastern New England and Air Station Cape Cod at Otis Air National Guard Base were notified of our planned survey, departure time and estimated time of return. In addition, we notified the shift commander at the Pilgrim Nuclear Power Plant of our flights. Following the completion of each aerial survey and habitat sampling cruise, the number of right whales seen and the location of these sightings were verbally reported to the NOAA Fisheries Sighting Advisory System (SAS) coordinator. The NOAA Fisheries/SAS office disseminates this information by fax, e-mail, Navtex, and marine weather radio to the appropriate agencies and mariners. Any additional sightings made by PCCS research vessels were also included in this report. A daily summary of the location and number of right whale sightings from each aerial survey was emailed to DMF and other researchers working in the region. In the event that a right whale was seen in Cape Cod Bay, the US Army Corps of Engineers Canal operators were also notified at the completion of a flight so they could relay the sighting location to transiting ships. If right whales were sighted in close proximity to Canal traffic, sightings were relayed during flight via VHF radio.

## 1.3 RESULTS

### 1.3.1. Aerial Survey effort

In 2009, the PCCS/DMF aerial survey team was in position to survey for 135 days, from 15 January through 30 May. 23 surveys, complete or incomplete, were flown during these 4.5 months: 17 surveys were flown in Cape Cod Bay, five surveys were flown exclusively over adjacent waters, covering 12 track lines east of Cape Cod Bay, and in an expansion of recent years' survey efforts, one survey was flown in Massachusetts Bay. Out of these 23 surveys, three were aborted due to inclement weather and four were not completed as high numbers of whales meant that the surveys continued late into the day and were limited by daylight hours. Sightings of entangled right whales were few, thus stand-by time to assist the PCCS Disentanglement Team, which amounted to 13% of all survey time in 2008, was comparatively low in 2009, amounting to 1.6 hours (1% of all flight time).

In total, 5,358 miles were flown on standard track lines (CCB and eastern tracks), amounting to 124 hours of flight time. Most of the aerial survey effort was concentrated within CCB with 3,479 nm of transects flown in CCB (tracks 3-15), and 1,879 nm of transects flown in adjacent waters (tracks 1, 2, 16 and east of CCB). Track lines in Massachusetts Bay amounted to 420 nm of survey effort. We flew an average of 1.0 surveys per week in CCB (23 Jan-20 May; excluding surveys in adjacent waters) compared to 1.4 surveys per week in 2008, 1.5 surveys per week in 2007, 1.6 in 2006 and 1.9 in 2005 (Table 1). Technical difficulties with our aircraft, and spells of bad weather, prevented good survey coverage during several periods, particularly the latter half of

April and into early May. Appendix 1 shows the dates, associated effort, study area and numbers of sighted right whales for the 2009 survey season.

**Table 1:** Summary of aerial survey effort, 2004 – 2009.

| Year | # surveys in CCB (incl. track 16) | # surveys in adjacent waters | Total # nautical miles flown | Total # hours flown |
|---|---|---|---|---|
| 2004 | 25 | 3 | 7,164 | 139 |
| 2005 | 37 | 4 | 10,855 | 175 |
| 2006 | 32 | 4 | 9,219 | 170 |
| 2007 | 30 | 1 | 8,262 | 157 |
| 2008 | 26 | 2 | 5,630 | 159[3] |
| 2009 | 17 | 6[4] | 5,778 | 124 |

### 1.3.2 Right whale sightings – aerial survey data

The first right whale was sighted in CCB by the aerial team on the 26th of January, in the same general time period as in recent years (January 12 in 2008, February 21 in 2007, and February 7 in 2006). Right whales were last documented in the bay on the 17th of April and on eastern track lines on the 18th, but a period of 19 days without survey effort following this date makes it impossible to describe residency after this period. It is likely that some right whales remained in the study area through April. The last documented sighting by aerial surveys occurred on the 15th of May in 2008, and the 13th of May in 2007. The mean duration of CCB surveys in 2009 was 5.9 hours (5.8 in 2008; 5.6 in 2007). This increase in average CCB survey duration in comparison to previous years is likely due to the high number of right whales present in the bay during any one day during March and early April. The highest number of individuals photographed on a single day was 61, on the 15th of March. This is substantially greater than in previous years - up to 59 individuals were photographed on a single day in 2008 (Leeney *et al.* 2008b), one month later than this peak in 2009, and up to 40 in 2007, 37 in 2006 and 22 in 2005 (Table 2; Jaquet *et al.*, 2005, 2006, 2007).

Right whales were sighted on 16 of the surveys run in 2009; the first sighting occurring on the 26th of January, and the last on the 18th of April. Including all intermatch-coded individual whales, and 2009 calves, 354 sightings (excluding repeat sightings on the same day) were made of 196 „individuals' by the aerial survey team during the survey season. To date, 187 unique individuals have been matched to known whales, from photographs collected during our 2009 field season (not including individuals given 2009 intermatch codes, or 2009 calves), representing 49% of the entire right whale population known to be alive in 2009 (P. Hamilton, pers. comm.). This minimum figure of 187 individuals is comparable with the number of unique individuals identified from data collected in CCB and adjacent waters by PCCS in 2008 (192; updated 2008 data, as of August, 2009). 117 of the individuals sighted in 2009 were also sighted in CCB or adjacent waters by the PCCS team in 2008.

[3] 20.6 h were spent in support of the disentanglement team in 2008, resulting in a net 138.4 h of actual survey effort.
[4] Five surveys on eastern track lines, and one of Massachusetts Bay.

### *Patterns of Relative Abundance*

Figure 1.2 shows the year-on-year patterns in sightings in CCB by the PCCS aerial survey team[5]. It is evident that both 2008 and 2009 have been peak years for right whale abundance in the study area. It appears that, since 2002, the number of right whales sighted per 100 nm of survey effort has increased yearly. Figure 1.3 shows the pattern of sightings per unit effort on a survey-by-survey basis, in CCB, over the course of the right whale season each year between 2007 and 2009. A different pattern is evident in each year. 2007 and 2008 follow the same general pattern, with low numbers of whales present until early March, a slow increase through March with a peak in mid- to late-April, and a sharp decrease in numbers in early May. In 2009, in contrast, the sightings rate peaked considerably earlier, in the middle of March (see arrow, Fig. 1.3), then decreased slightly but remained high through early April. A good understanding of the dynamics of habitat use over the rest of this month is lacking, due to the absence of survey coverage in late April. No right whale sightings from PCCS survey platforms occurred in May of 2009.

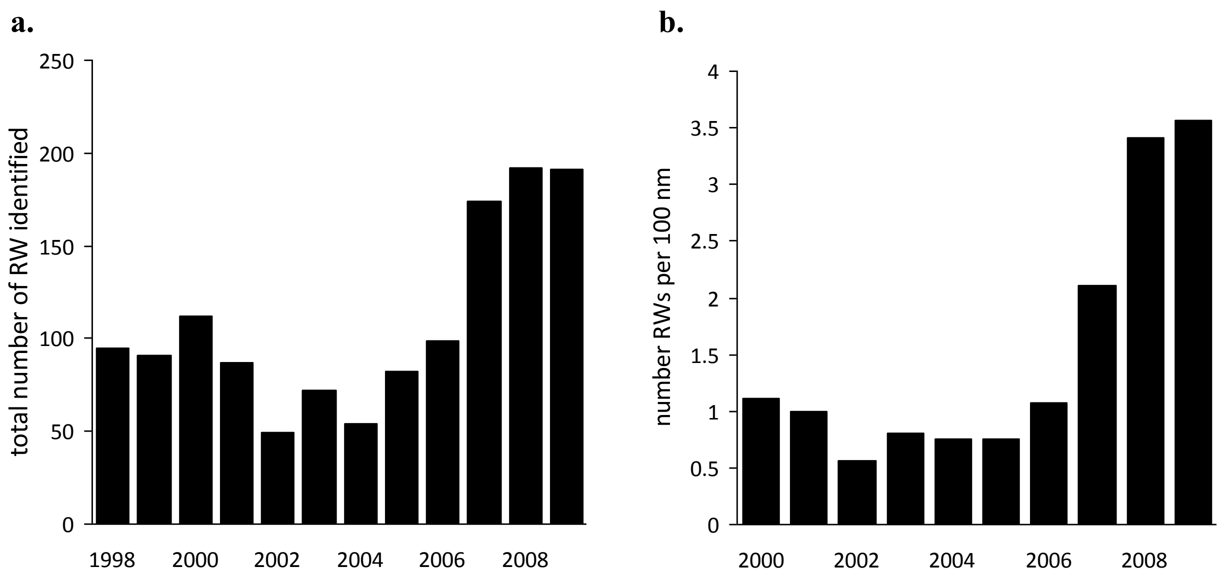


**Fig. 1.2:** (a) Total number of individual right whales sighted per year, 1998-2009, and (b) number of right whales sighted per 100 nm survey effort, 2000-2009 (effort data unavailable 1998-1999).

[5] The „standard' CCB survey includes track 16 and thus encompasses about 35 nautical miles of survey outside the Bay (Fig. 1). However, as noted in previous reports (Jaquet *et al*., 2005, 2006), right whales seen on track 16 are seldom observed within CCB. According to the delineation of Cape Cod Bay in the Right Whale Consortium photo-identification database, CCB encompasses only the water south of 42°04' and thus only tracks 3 to 15. All analyses which follow thus differentiate between CCB and adjacent waters (tracks 1 & 2 are classified as Massachusetts Bay (MB); track 16 and eastern tracks are classified as Great South Channel (GSC)). Since in some previous reports, tracks 1 and 2 were included in the CCB delineation, all analyses herein state clearly which datasets are involved, in order to allow for comparisons with previous years and previous reports.

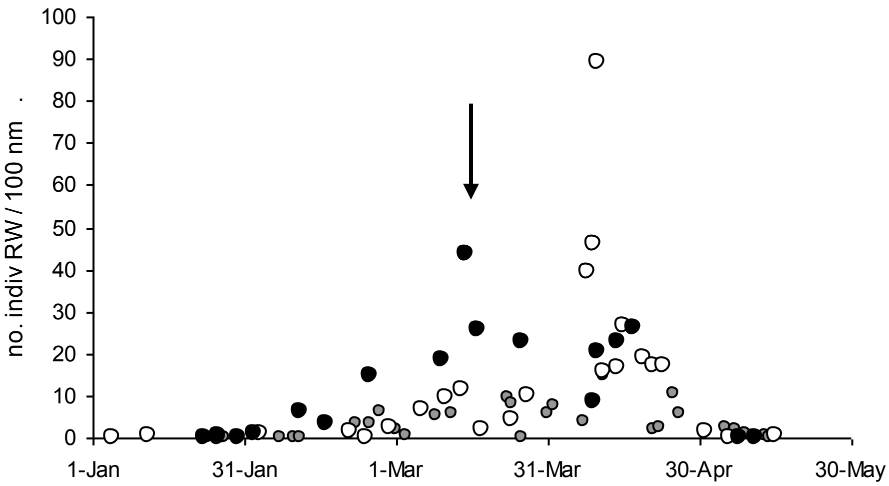


**Fig. 1.3:** Number of right whales sighted per 100 nm survey effort, over the course of the survey season, in 2007 (grey), 2008 (white) and 2009 (black). Data from CCB (tracks 3-15) only.

### *Distribution*

Maps of the distribution of right whales, as detected by aerial surveys, on a survey-by-survey basis, are located at the end of Section 1 (Appendix 2). A2.1 depicts all sightings made during aerial surveys in 2009, and the critical habitat boundary is shown. Only a single right whale was sighted in January (A2.2a). In February, right whales were sighted in small number in central and northern CCB, especially around Race Point (A2.2b, c). A survey on the eastern track lines also detected small numbers, southeast of the Cape (A2.2b). Right whales were sighted in central and eastern parts of the bay in March, also in northern parts of the bay later in the month (A2.2d, e). In early April, sightings were concentrated in the eastern portion of the bay (A2.2f), whereas more sightings were located in central & southwest parts, later in April (A2.2g). Of the 354 sightings of right whales in 2009, only 2 sightings in the CCB area (tracks 1-15) did not occur within the critical habitat boundary; including an additional 18 sightings made on eastern track lines, a total of 20 sightings (6% of all sightings) were made outside the CCB critical habitat boundary (A2.1).

### *Demography*

A total of 39 right whale calves were documented to have been born in the 2009 season. Of those calves, five were seen with their mothers in CCB in 2009 (Table 2). One right whale calf, a neonate, was documented dead in 2009, and all but one (EgNo 2660) of the 2009 documented mothers were observed with their calves later in the season, thus the final count for surviving right whale calves in 2009 is 38. 2009 was thus the highest calving year on record. The proportion of all calves born this year, which were sighted in CCB, was comparable with 2007 and 2008 (Fig. 1.4).

**Table 2:** Mother-calf pairs sighted in CCB in 2009.

| Mother EgNo | Year of birth | N previous calves | First sighted CCB 2009 | N days seen | Residency |
|---|---|---|---|---|---|
| 1711 | 1987 | 2 | 17 April | 1 | 1 |
| 2145 | 1991 | 4 | 10 April | 4 | 17 |
| 2320 | unknown | 1 | 10 April | 2 | 7 |
| 3101 | 2001 | 1 | 17 April | 1 | 1 |
| 3290 | 2002 | 1 | 18 April | 2 | 9 |

To date in the NEAq right whale catalogue, there are 526 unique individuals, of which 379 are thought to be alive at present, comprising 138 known females, 191 known males and 50 individuals of unknown sex (P. Hamilton pers. comm.). By age class, 277 individuals are categorized as adults (of 9 years or older, as defined in Hamilton *et al.* 1998), 86 are categorized as juveniles (aged 1 to 8) and there are 16 individuals for which the age class is unknown. (This does not include calves of 2009). Of the 188 matched individuals identified in 2009 (calves of the year excluded from the total 192), 179 were sighted at least once in CCB. Of these whales, 42 were females, 93 were males and 44 were of unknown sex. These 188 individuals comprised 110 adults, 56 juveniles and 13 individuals for which age class is unknown (Table 3).

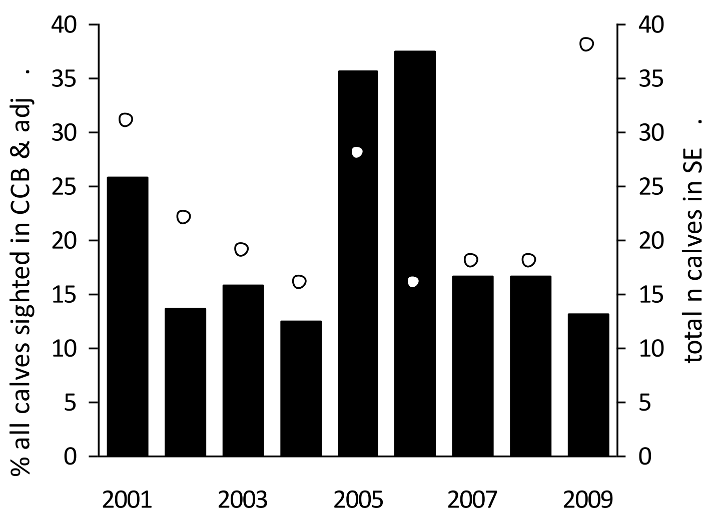


**Fig. 1.4:** Proportion of all caves born in the southeast US which were sighted in CCB & adjacent waters, 2001-2009 (bars) & total number of calves documented per year (points). Between 1998 and 2000, no calves were sighted in this region.

**Table 3:** Sex- and age-ratios for right whales sighted in CCB, during 2009 aerial surveys.

| | Female | Male | Unknown sex | Total |
|---|---|---|---|---|
| **Adult** | 29 | 68 | 13 | 110 |
| **Juvenile** | 12 | 24 | 20 | 56 |
| **Unknown** | 1 | 1 | 11 | 13 |
| **Total** | 42 | 93 | 44 | 179 |

***Residency***

Right whales were present in CCB for a minimum of 82 days in 2009. This is a considerably shorter time period than 2008 (125 days; Table 4). During the 12 years that the aerial survey program has run, right whales were present over the longest time period (140 days) in 1999. However, the earlier commencement of the program in previous years allowed for an earlier detection of occasional individual whales in the region. The acoustic buoys deployed by DMF in CCB have, in recent times, fulfilled this function. Including sightings data from the habitat surveys, which last detected right whales in CCB on the April 27th survey, this period of known use of CCB by right whales can be extended to a minimum of 92 days.

As far as can be assessed by aerial surveys, individual right whales had maximum possible residency times (the time span between the first and last documented sightings of an individual; assumes the individual did not leave the study area between those dates) of between 1 and 67 days (mean 12.5 days), for the entire study area. Individuals were sighted between one and five times (mean of 2.0) during the course of the season.

10 individuals were sighted only on eastern track lines (GSC) or adjacent waters (MB), 172 individuals were sighted only in CCB, and 14 individuals were sighted both in CCB and MB/ GSC. Whilst in previous years, individuals have been documented to leave and re-enter CCB (determined by a sighting in MB or GSC in between two CCB sightings), this was not observed in 2009.

**Table 4:** Right whale residency in CCB, 1998-2009. Numbers in brackets represent the number of individuals identified on the sighting date. Numbers in square brackets represent the total number of individual right whales identified in CCB during the year. (CCB is defined here as tracks 1-15).

| Year | Date of 1st aerial survey | Date of 1st aerial sighting of RW in CCB | Date of last aerial sighting of RW in CCB | Minimum no. days when right whales were present in CCB |
|---|---|---|---|---|
| 1998 | 04 Jan (9) | 04 Jan (9) | 21 Apr (1) | 108 [75] |
| 1999 | 13 Dec (5) | 13 Dec (5) | 02 May (1) | 140 [86] |
| 2000 | 20 Jan (1) | 20 Jan (1) | 11 Apr (3) | 82 [86] |
| 2001 | 19 Dec (5) | 19 Dec (5) | 29 Apr (2) | 132 [87] |
| 2002 | 06 Jan (0) | 07 Feb (1) | 15 Mar (3) | 36 [24] |
| 2003 | 10 Dec (0) | 25 Jan (5) | 30 Apr (8) | 95 [26] |
| 2004 | 21 Jan (0) | 10 Feb (2) | 10 May (1) | 90 [54] |
| 2005 | 09 Dec (0) | 30 Jan (3) | 26 Apr (6) | 86 [45] |
| 2006 | 10 Jan (0) | 04 Feb (1) | 06 May (12) | 91 [59] |
| 2007 | 24 Jan (0) | 21 Feb (2) | 13 May (2) | 82 [116] |
| 2008 | 05 Jan (0) | 12 Jan (1) | 15 May (1) | 125 [192] |
| 2009 | 23 Jan (0) | 26 Jan (1) | 17 Apr (0) | 82 [191] |

Of the 186 individuals sighted at some point in CCB, whales were sighted between one and 5 times over the course of the season, with the longest maximum possible residency time being 59 days, for one individual (Fig. 1.5). The mean maximum possible residency time was 11 days, and mean number of sightings per individual was 1.9. Infrequent surveys on the eastern track lines makes any comparison of demography or residency patterns, between whales in this area and CCB, inappropriate.

***Behavior***

In baleen whales, a „group' is often defined as two or more individuals within one or two body lengths of each other, co-ordinating their movements and/ or behavior. For this report, the term "cluster" has been used to define such an association. Investigating cluster size and occurrence in right whales provides insight into aggregative behavior and the underlying causes for the same. The monthly mean cluster size observed in 2009 is shown in Table 5. Clusters were fewer (due to fewer sightings overall), but larger, in adjacent waters than in CCB. In both areas, cluster size was greatest in the month of March. This contrasts with the 2008 findings, in which cluster size was greatest in April (Leeney *et al.* 2008b).

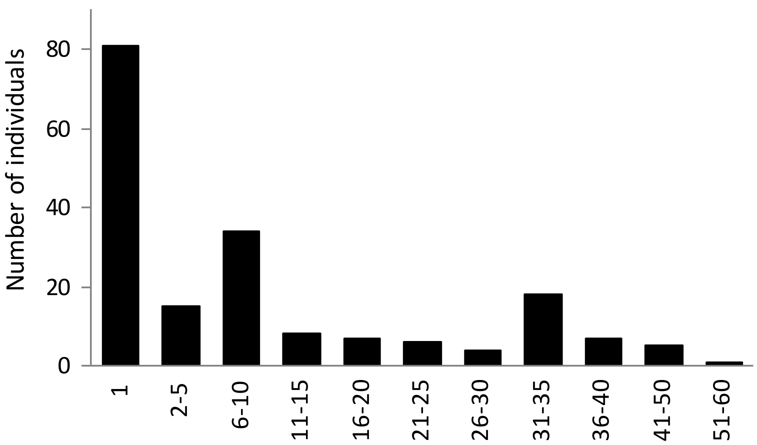


**Fig. 1.5:** Frequency distribution for maximum possible residency times for all sightings in CCB (tracks 3-15), in 2009.

Surface Active Groups (SAGs) were observed in CCB and adjacent waters in the months of February, March and April. In total, 37 SAGs were observed, of which 34 occurred in CCB, one was located just north of the bay and the other two were sighted east of the Cape. SAGs ranged in size from two to six whales, but those of three or four individuals were most commonly observed (Fig. 1.6).

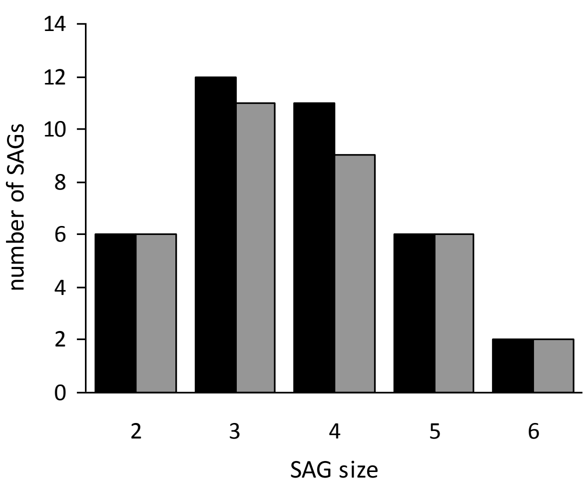


**Fig. 1.6:** Size of SAGs observed in CCB and adjacent waters (black), and on tracks 3-15 only (grey), in 2009.

Skim feeding and sub-surface behaviors are commonly observed in CCB in the latter part of the season. In 2009, we observed these behaviors in the months of March and April. Skim feeding and sub-surface behaviors are commonly observed in CCB in the latter part of the season. In 2009, we observed these behaviors in the months of March and April. Relative to all sighted whales in a given month, a greater proportion of whales was observed engaged in feeding behavior in April, compared to March. Sub-surface feeding was slightly more frequently observed than skim feeding in March, whereas both behaviors were equally observed in April (Fig. 1.7a). Sub-surface feeding behavior appears to be most frequent in the morning, between 10:00 and 12:59, and occurs at low levels throughout the rest of the daylight hours. The hourly proportions of all sighted individuals engaged in sub-surface feeding appears lower compared to observations made in 2008 (Leeney *et al*. 2008b). Skim feeding was most commonly observed later in the day, between 17:00 and 18:59, and was rarely observed during the middle of the day (Fig. 1.7b). On an hourly basis, total number of sightings (uncorrected for effort) is highest late-morning (11:00-12:59) and early afternoon (15:00-15:59; Fig. 1.7b).

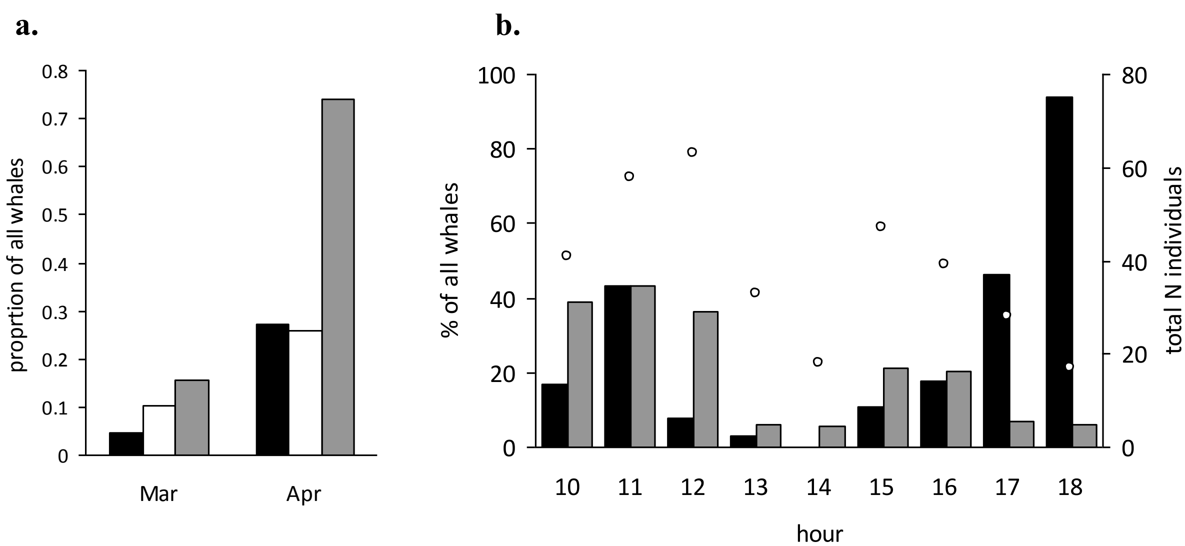


**Fig. 1.7:** (a) Proportion of all sightings which were documented to be engaged in skim feeding only (black), sub-surface feeding only (white), and either (including whales engaging in both), in March and April. (b) Proportion of all whales observed in each hour which were engaged in skim feeding (black) and sub-surface feeding (grey) (not excluding other feeding behaviors), and total number of individuals*survey days (white points) per hour. CCB data only.

**Table 5:** Mean cluster size per month, in CCB (tracks 3-15) and adjacent waters/ eastern tracks.

| | Mean 3-15 | Mean adj/ E |
|---|---|---|
| Jan | 1 | n/a |
| Feb | 1.42 | 1.6 |
| Mar | 1.57 | 1.8 |
| Apr | 1.46 | 2 |

### *Entanglements*

During aerial surveys in 2009, the aerial team observed two entangled animals, 1140 ("Wart", on February 25) and 3346 ("Kingfisher", on April 14 and 17). Injured animal 3530, "Ruffian", was also sighted on four occasions. This right whale was first observed with severe scarring in 2008, and was sighted in CCB on numerous occasions last year. The scars appear to have healed considerably since then.

### 1.3.3 Right whale sightings – habitat survey data

The first right whale was sighted in CCB by the habitat survey team on the 30th of January, and right whales were last documented in the bay on the 27th of April.
87 unique individuals were sighted by the habitat survey team (unconfirmed by NEAq as of November 2009). Table 6 shows the sex- and age ratios of the sighted whales.

**Table 6:** Sex- and age-ratios for right whales sighted in CCB during habitat surveys in 2009.

| | Female | Male | Unknown sex | Total |
|---|---|---|---|---|
| **Adult** | 15 | 30 | 6 | 51 |
| **Juvenile** | 9 | 12 | 8 | 29 |
| **Unknown** | 1 | 1 | 5 | 7 |
| **Total** | 25 | 43 | 19 | 87 |

101 photographed sightings of right whales were made during habitat cruises (unchecked data as of November 2009), from which 87 individuals were identified, including two of the five calves of the year, sighted by the aerial survey team. Of these 87, a possible eight individual whales were identified only by photographs taken by the habitat team, suggesting that aerial surveys did not comprehensively document all right whales in CCB (however, these matches are unchecked by NEAq as of November 2009).

### 1.3.4 Other sightings

***Cetacean sightings***

Other marine mammal species sighted during aerial surveys were: Humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), harbor porpoises (*Phocoena phocoena*), grey seals (*Halichoerus grypus*) and harbor seals (*Phoca vitulina*). Appendix 3 (Fig.s A3.1-A3.5) shows the distribution of sightings of all cetaceans, by month. Seals were largely sighted, hauled out or in the water, around Jeremy Point, especially earlier in the season.

There is a distinct seasonality to sightings of other cetaceans within the study area. Sightings are sparse in January, whilst in February, fin whales were sighted in some number, east of the Cape and around Race Point (A3.1, A3.2). A number of large groups of unidentified dolphins (likely Atlantic white-sided dolphins) were also present in the northern parts of the study area. In March, fin whales were present in the eastern part of CCB, whilst a number of humpback whales were sighted east of the Cape (A3.3). During April, many large groups of white-sided dolphins (and unidentified dolphins) were sighted around the Race Point area. Fin whales and humpback whales were numerous in CCB and just to the north of it, and minke whales were sighted in small numbers, east of

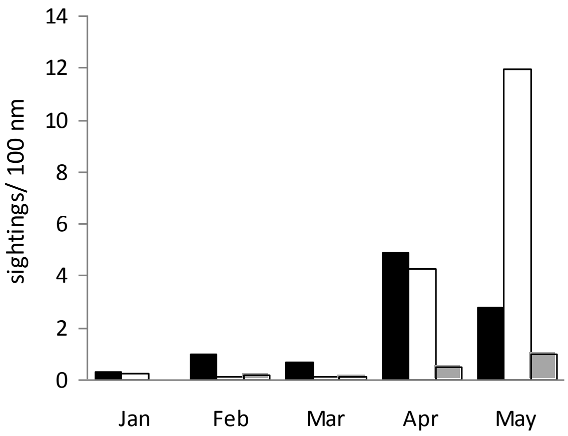


**Fig. 1.8:** Sightings rates for fin whales (black), humpback whales (white) and minke whales (grey) in CCB, 2009.

the Cape (A3.4). Sightings of these species were even more numerous in May (A3.5). Humpback whale sightings were most numerous throughout CCB, east of the Cape and on Stellwagen Bank (detected during the Massachusetts Bay survey). Large groups of white-sided dolphins were again sighted north of Race Point, but also to the northeast and southeast of the Cape. Several harbor porpoises were sighted in CCB, whilst minke whales were sighted in CCB, on Stellwagen Bank and to the southeast of the Cape.

Sightings rates for these baleen whale species show a distinct seasonality, with very low numbers of sightings in the first three months of the year, followed by a marked increase in sightings of both humpback and fin whales, per unit effort, in April and May (Fig. 1.8). The same pattern was noted in 2008 (Leeney *et al.* 2008b) and likely represents an increase in prey for these species, as the right whales' copepod prey resource in CCB declines in the spring. Minke whales are sighted in much lower numbers than both humpbacks and fin whales, during the survey season.

### *Vessel & fishing gear sightings*

All vessels and fishing gear sighted during aerial surveys were recorded; sightings of vessels have been mapped by month (A4.1-A4.5). In January and February, small numbers of fishing vessels or unidentified craft were present, mostly around the periphery of CCB and just north of the bay. Fishing vessels were more numerous in southern CCB in March, and several recreational and research vessels were also present in the bay. In April, there were more sightings of recreational vessels in CCB and to the north, and of research vessels, whilst fishing vessels were present throughout the bay and east of the Cape. In May, vessel sightings were very numerous throughout the study area and especially north of CCB in Massachusetts Bay; large numbers of fishing vessels were sighted east of the Cape and inside the bay, and whale watching vessels were also numerous. Gear sightings are passed on to DMF, and facilitate their program for monitoring and removal of illegal and ghost fishing gear over the winter months.

No vessel-whale interactions were documented during aerial surveys in 2009.

## 1.4 DISCUSSION

The number of unique individuals documented in CCB and adjacent waters in 2009 was the second highest on record since the aerial survey program began. Updated identification data for 2008 suggest that 50% of all catalogued right whales were sighted by the PCCS aerial survey team in 2008, and numbers for 2009 will likely be similarly high. These data are, as always is the case for such annual reports, based on matches to the right whale catalogue which, whilst checked by several researchers, are nonetheless still classified as "unconfirmed" by NEAq. Frasier *et al*. (2009) recently noted that there is likely to be a level of about 0.03 errors per identification for photo-identification data for this species. Thus, for the 187 catalogue matches to date for individuals sighted by the PCCS aerial survey team in 2009, this would suggest that 6 errors in identification have been made. Nonetheless, the 2009 season was clearly another year in which CCB was an important habitat for a large proportion of the right whale population.

Jaquet *et al.* (2006, 2007) noted that many right whales observed in CCB are repeat visitors and are more likely to be sighted in the bay in successive years than in other areas within the known range. A comparison of data from 2007 and 2008 revealed that over half of all the individuals sighted in the study area in 2007 were also present last year (Leeney *et al*. 2008b); likewise, of the 192 individuals documented in CCB in 2008, 61% returned to the bay in 2009. Such site fidelity reinforces the importance of CCB as a critical habitat for a large proportion of the population. It is less reliable to discuss „new' individuals to the bay on a yearly basis, since aerial surveys do not reliably document every individual which occurs in CCB in any given year and thus there is potential, especially during periods without survey coverage, to miss the opportunity of documenting every individual in the area. Overall, sightings rates the last three years have been very high relative to earlier years in the program. Whether this suggests an increasing number of individuals visiting CCB or simply a strong food resource in those years is difficult to assess at present, but as the data collected by the habitat survey team undergoes a comprehensive investigation of inter-annual variability, it may become possible to better understand this recent increase in right whale occurrence in CCB.

Jaquet *et al*. (2007) noted that food resources in CCB are highly variable amongst years. This variability in patterns of habitat quality was particularly evident in 2009, when right whale abundance peaked earlier than had been observed for many previous years, with higher than expected sightings rates from early March on, and the season's documented peak occurring in the middle of March. This might suggest a high quality prey resource in CCB in 2009. However, the habitat team found that both surface and water column zooplankton densities, throughout the season, were low compared with many previous years of the study, and in fact below right whale feeding threshold for the entirety of the season (Section 2). It is likely, though, that these findings represent the resource at a regional scale, and that prey concentration *was* in fact high, but at a scale finer than that sampled by the habitat team. Similarly, 2009 was unusual in the lack of significant prey concentration in the surface water, which typically occurs during early to mid-April (Section 2). In previous years, this surface-concentrated resource has led to the aggregation and surface feeding of numerous right whales. The fact that surface waters never reached the significantly rich spring-time peak which has been documented in years past might have suggested an early departure of right whales from CCB, and indeed, they were detected by the habitat team only until late April, where recent years have recorded their presence in the bay until early May (Jaquet *et al*. 2006, 2007; Leeney *et al*. 2008b).

Nevertheless, surface-feeding behavior was observed in 2009, in March and April. Skim feeding appeared to be most commonly observed in the later part of the day and approaching dusk, similar to findings in 2008 (Leeney *et al*. 2008b). Sims *et al*. (2003) suggested that the time spent at the surface by basking sharks, another zooplankton-feeder, depended primarily on the minimum abundance of prey in the surface layer and the time of day. The authors noted a decrease in surface swimming by basking sharks after midday, which they suggested was due to a decrease in the surface abundance of the calanoid copepods on which the sharks were feeding. Diel vertical migration has been documented in many species and life stages of copepod (e.g. Williams & Conway 1984; Durbin *et al*. 1995; Hays *et al*. 1997). The increased proportion of right whales observed skim feeding towards dusk may thus be due to a diel vertical migration of the right whales' plankton prey. Interestingly, of the high number of right whales sighted in March, lower proportions were observed skim feeding or sub-surface feeding than in April. This is not an uncommon pattern, but suggests that if high numbers of whales were present before the surface concentration of food resources in April, perhaps copepods were concentrated at depth in this earlier period. As mentioned above, this prey resource may simply have not been detected at the scale at which the habitat team was sampling.

On an hourly basis, the total number of sightings (uncorrected for effort) is highest in the late-morning (11:00-13:00) and early afternoon (15:00-16:00). However, survey flights usually take-off by 9:30-10:00, and a plane endurance of four hours implies that most surveys would be ongoing until around 14:00 before landing to refuel. A more detailed analysis needed on these observations, but it appears that the probability of sighting right whales may be lower at mid-day, despite high levels of survey effort at this time. This in turn may be due to the observed decrease in the proportion of skim feeding whales in the middle of the day, perhaps linked directly with surface availability of prey.

2009 was an exceptional year for right whale calves – 39 new mothers were documented, the highest number on record. Yet, despite this high rate of calving in 2009, only five calves were sighted in CCB, reinforcing the idea that this region is not used by the majority of right whale mothers, many of whom appear to utilize the Bay of Fundy as a key foraging ground and are never or rarely sighted in CCB (Malik *et al.* 1999; M. Marx pers. comm.). Despite a lower total survey effort in 2009, more SAGs were observed (37) than in 2007 (30 SAGs) and 2008 (31). These groups involved between two and six individuals, however, whereas in 2008, SAGs of up to 13 individuals were sighted. Jaquet *et al*. (2007) documented no monthly pattern in SAG occurrence amongst years, suggesting that these groups form simply when aggregations of right whales occur, which is usually in latter months of the CCB survey season, but can be as early as January.

Entangled right whales were less numerous in CCB and adjacent waters than in 2008, however, a number of entangled right whales have been documented throughout the remainder of the year. It remains essential to monitor the species throughout its range for the incidence of entanglement, and to maintain efforts to understand the nature and origin of these entanglements.

The sightings and photo-identification data was collected in a more structured way in 2009, with a dedicated team member on board RV Shearwater for this purpose. These data proved an important contribution to the documentation of right whales in CCB, as not only do they provide additional high-quality, boat-based images for the identification of individual whales, but in 2009, they also detected several individuals not documented by aerial surveys. Because of an extended period in late April when no aircraft was available, aerial survey data was not able to comprehensively document the residency period of right whales in the bay, but with the contribution of sightings data from habitat surveys, this gap was lessened. Using data from both platforms combined, right whales can be assumed to have been present in CCB for a minimum of 92 days in 2009, from 26 January (first aerial sighting) to 27 April (last habitat survey sighting). This demonstrates the importance of continuing to utilize the habitat sampling platform as a platform of opportunity for the collection of supplementary photo-identification data.

Sightings of multiple cetacean species around Cape Cod in 2009 also highlight the importance of this area, not only for right whales in winter and spring, but for many other species of cetacean and throughout the year. Correspondingly, the data collected on vessel and fishing gear sightings demonstrates the level of anthropogenic influence in this part of the North Atlantic; cetaceans invariably encounter fishing gear and boat traffic at much higher rates than they might in other habitats. Our close working relationship with Mass DMF ensures that data on fishing gear, whale-vessel interactions and other relevant information is relayed to the appropriate authorities in a timely manner, thus facilitating its incorporation into any management decision or action for the area.

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## APPENDICES – Aerial Survey

**Appendix 1:** Aerial survey effort in 2009. Survey areas: Cape Cod Bay (CCB), Eastern Tracks (ET), Massachusetts Bay/ Stellwagen Bank survey (MB).

| Date | Area | Survey effort (nm) | No. individual RWs |
|---|---|---|---|
| 23 Jan | CCB | 306 | 0 |
| 26 Jan | CCB | 306 | 1 |
| 30 Jan | CCB | 306 | 0 |
| 02 Feb | CCB | 306 | 2 |
| 10 Feb | ET | 184 | 11 |
| 11 Feb | CCB | 216 | 8 |
| 16 Feb | CCB | 295 | 7 |
| 25 Feb | CCB | 195 | 17 |
| 10 Mar | CCB | 260 | 36 |
| 14 Mar | ET | 184 | 3 |
| 15 Mar | CCB | 168 | 61 |
| 17 Mar | CCB | 278 | 53 |
| 26 Mar | CCB | 210 | 44 |
| 09 Apr | CCB | 118 | 6 |
| 10 Apr | CCB | 306 | 45 |
| 14 Apr | CCB | 250 | 34 |
| 17 Apr | CCB | 306 | 58 |
| 18 Apr | ET | 184 | 4 |
| 08 May | CCB | 306 | 0 |
| 11 May | CCB | 306 | 0 |
| 12 May | ET | 184 | 0 |
| 20 May | ET | 184 | 0 |
| 25 May | MB | 420 | 0 |

**Appendix 2:** Maps of right whale sightings, 2009.
Fig. A 2.1
Fig. A2.2 a-g

**Appendix 3:** Maps of cetacean sightings (excluding right whales) made by the aerial survey team, 2009.
Fig. A3 Jan - May

**Appendix 4:** Maps of vessels, by month, 2009.
Fig. A4 Jan - May

**Fig. A2.1: All right whale sightings, Jan - May 2009**

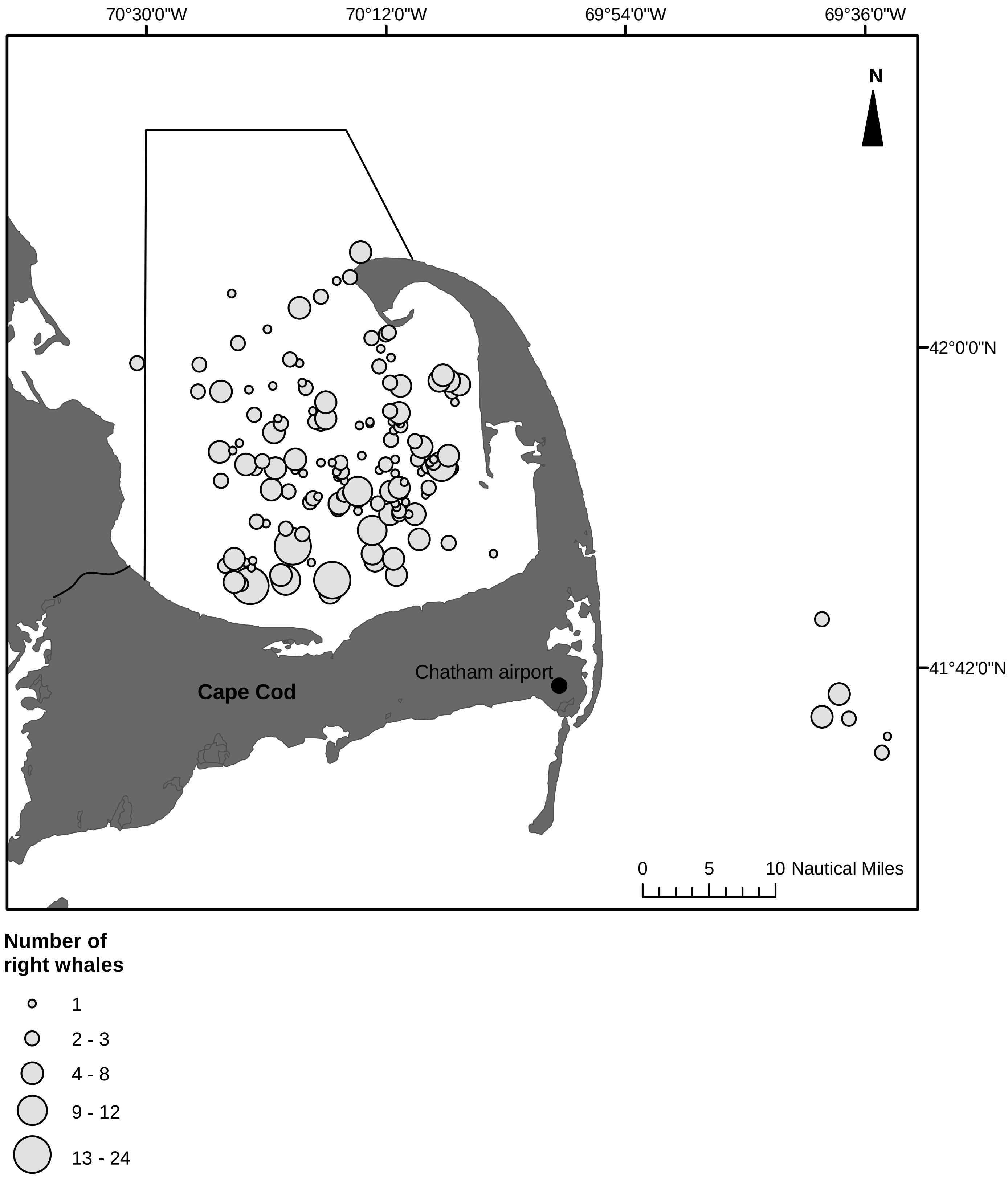


**Fig. A2.2: Distribution of right whale sightings, (a) Jan 26 (1 individual) and (b) Feb 2 (white), 10 (black) & 11 (grey).**

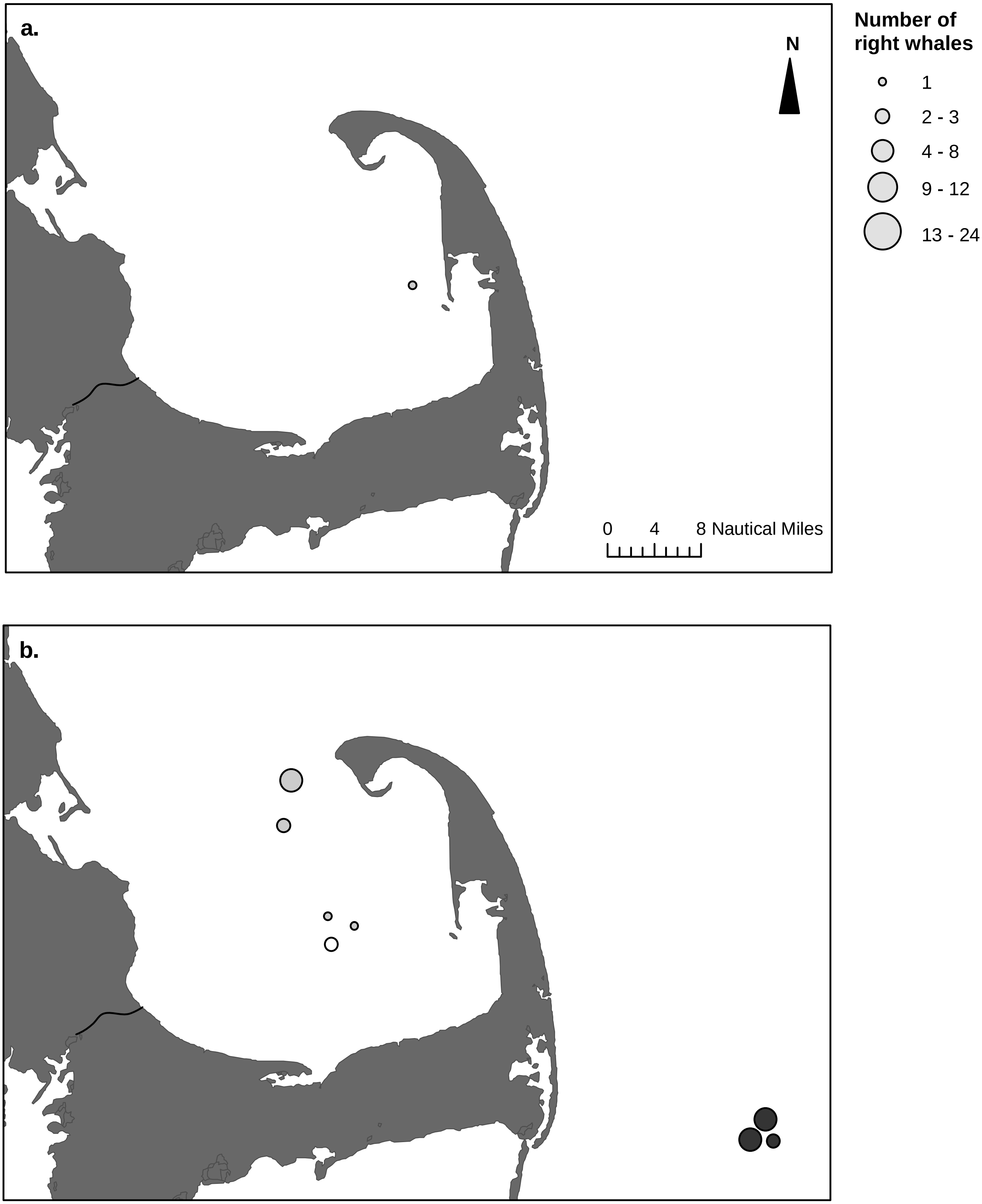


**Fig. A2.2: Distribution of right whale sightings, (c) Feb 16 (white), 25 (grey) and (d) Mar 10 (white), 14 (black), 15 (grey).**

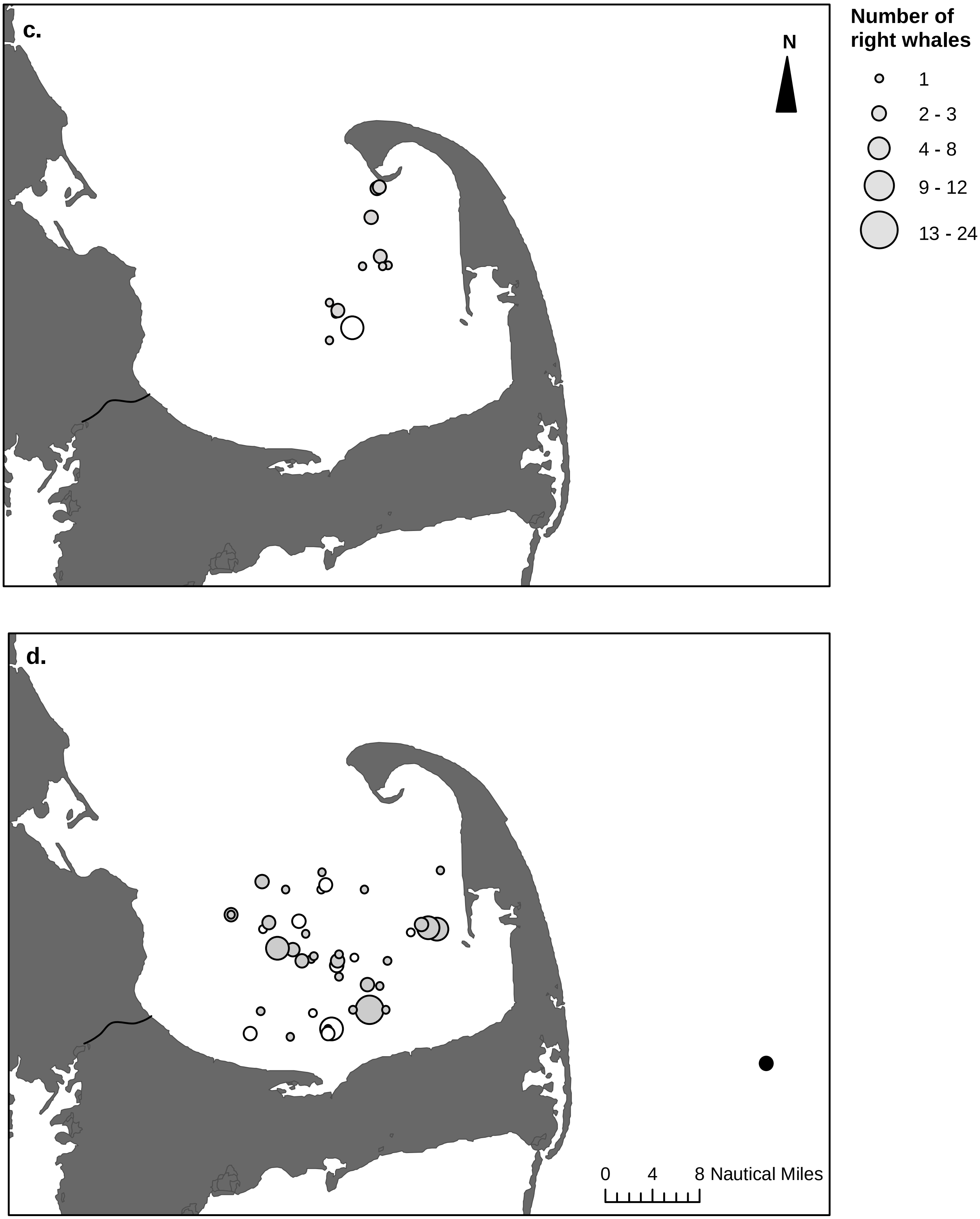


**Fig. A2.2: Distribution of right whale sightings, (e) Mar 17 (white), 26 (grey) and (f) Apr 9 (grey), 10 (white).**

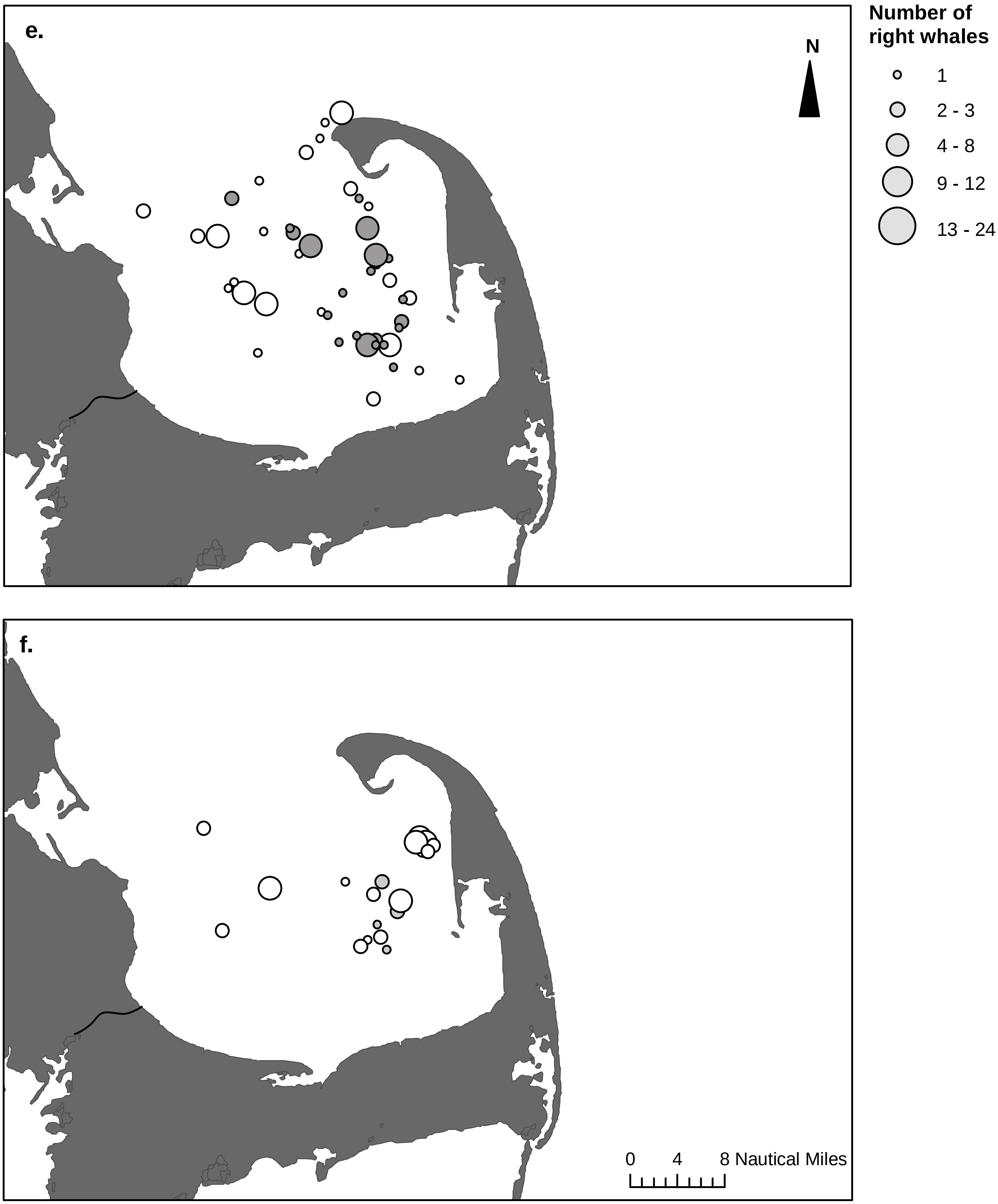


**Fig. A2.2: Distribution of right whale sightings, (g) Apr 14 (white), 17 (grey), 18 (black).**

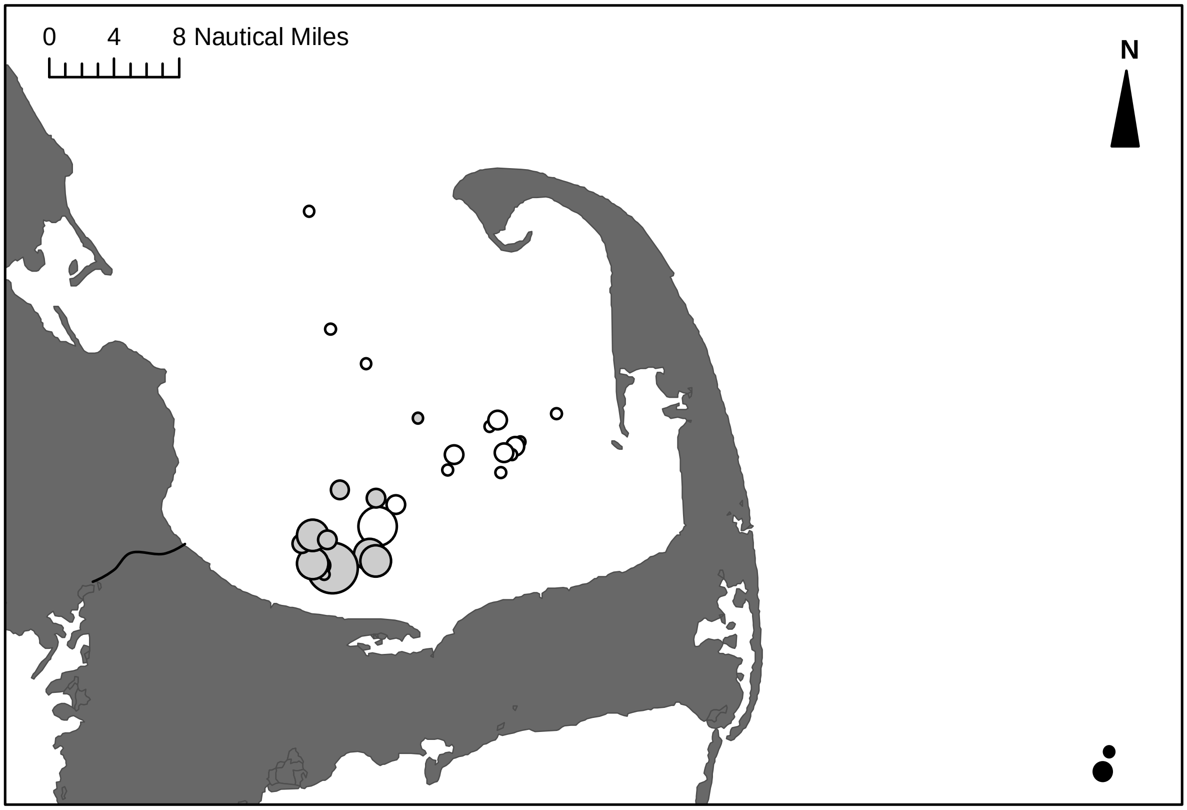


**Fig. A3: All non-right whale cetacean sightings, by month. Fin whales (black), humpback whales (red), minke whales (royal blue), white-sided dolphins (white), harbour porpoises (light blue), unidentified dolphins (grey)**

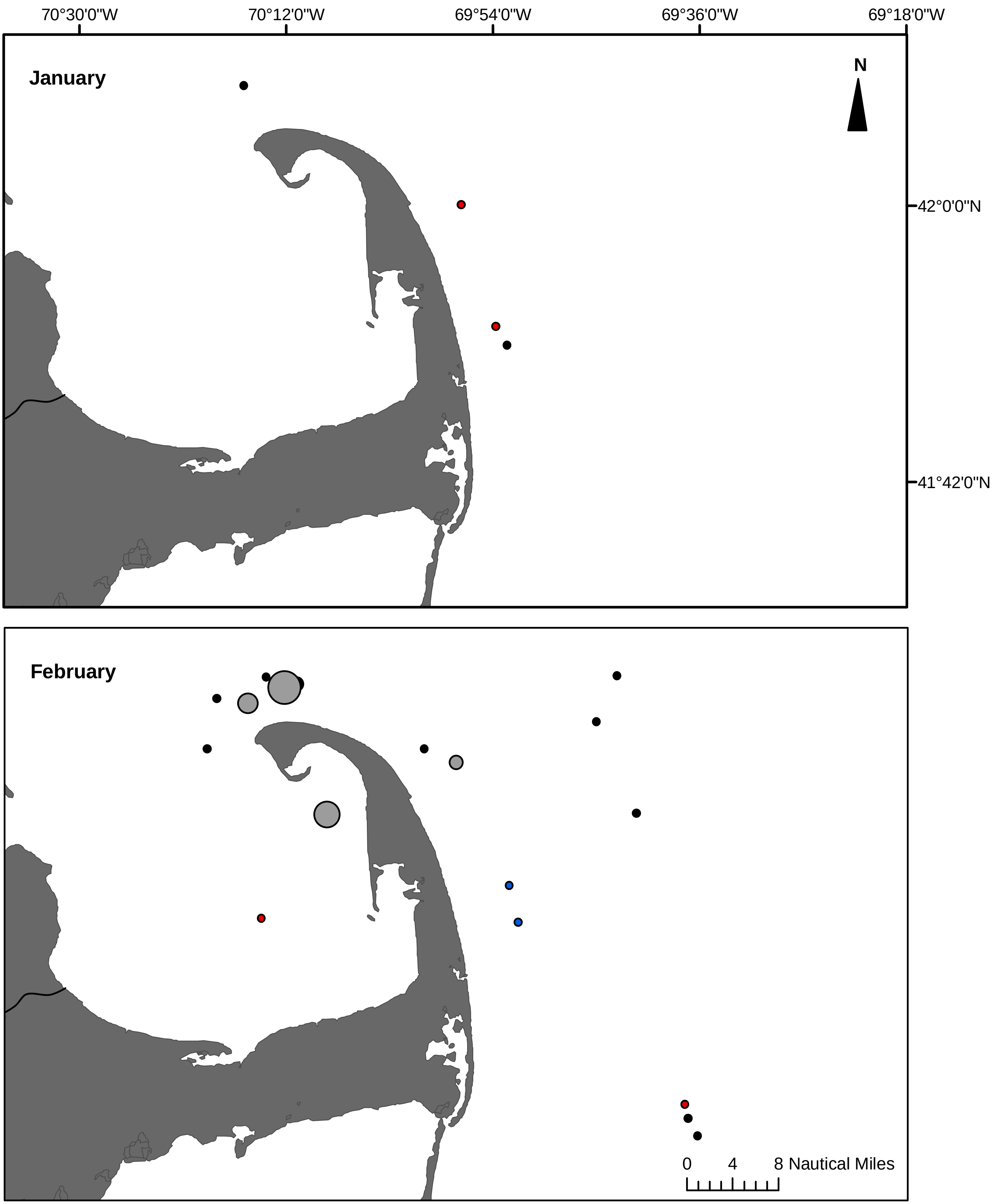


**Fig. A3: All non-right whale cetacean sightings, by month.**

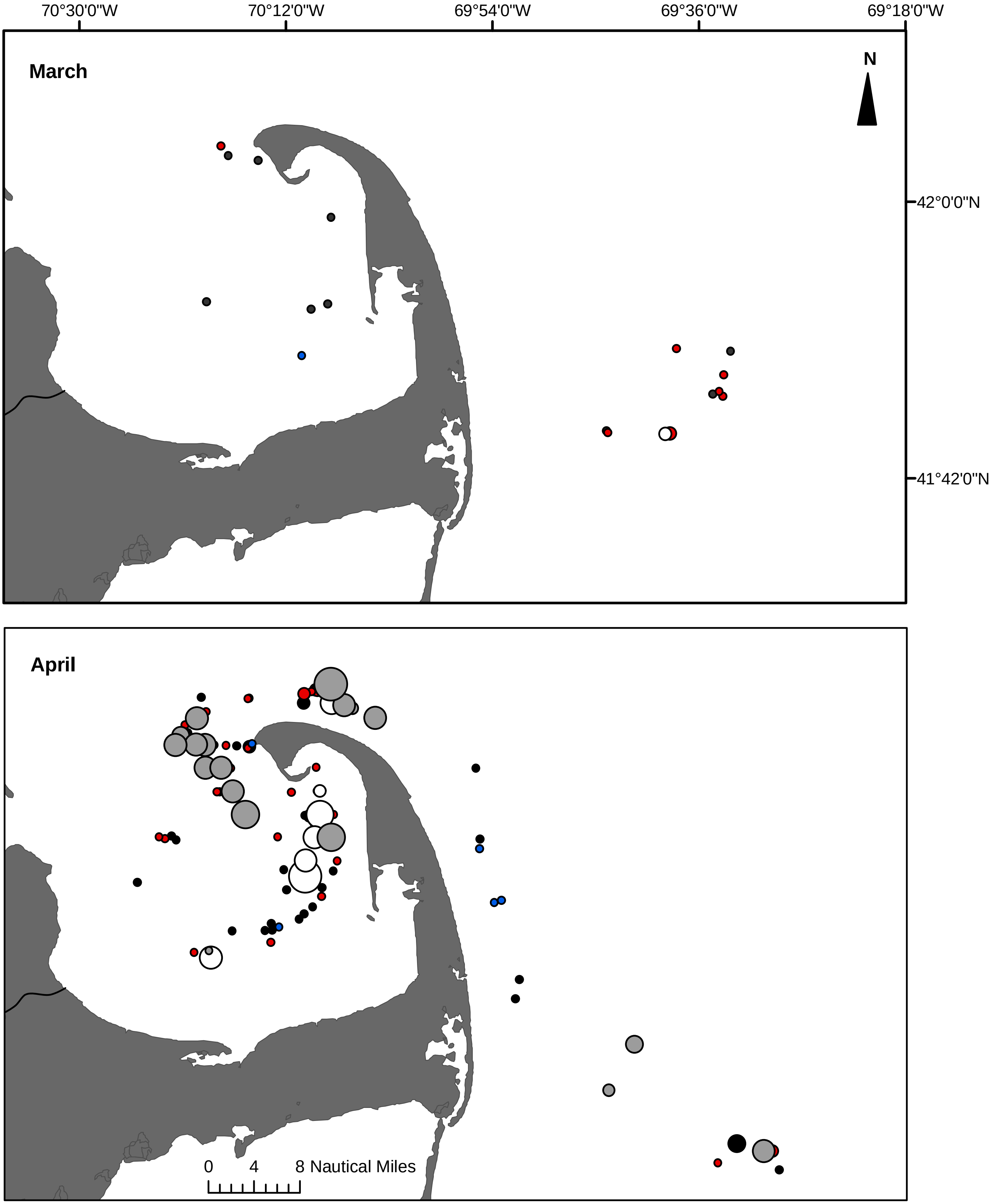


Fig. A3: All non-right whale cetacean sightings, by month.

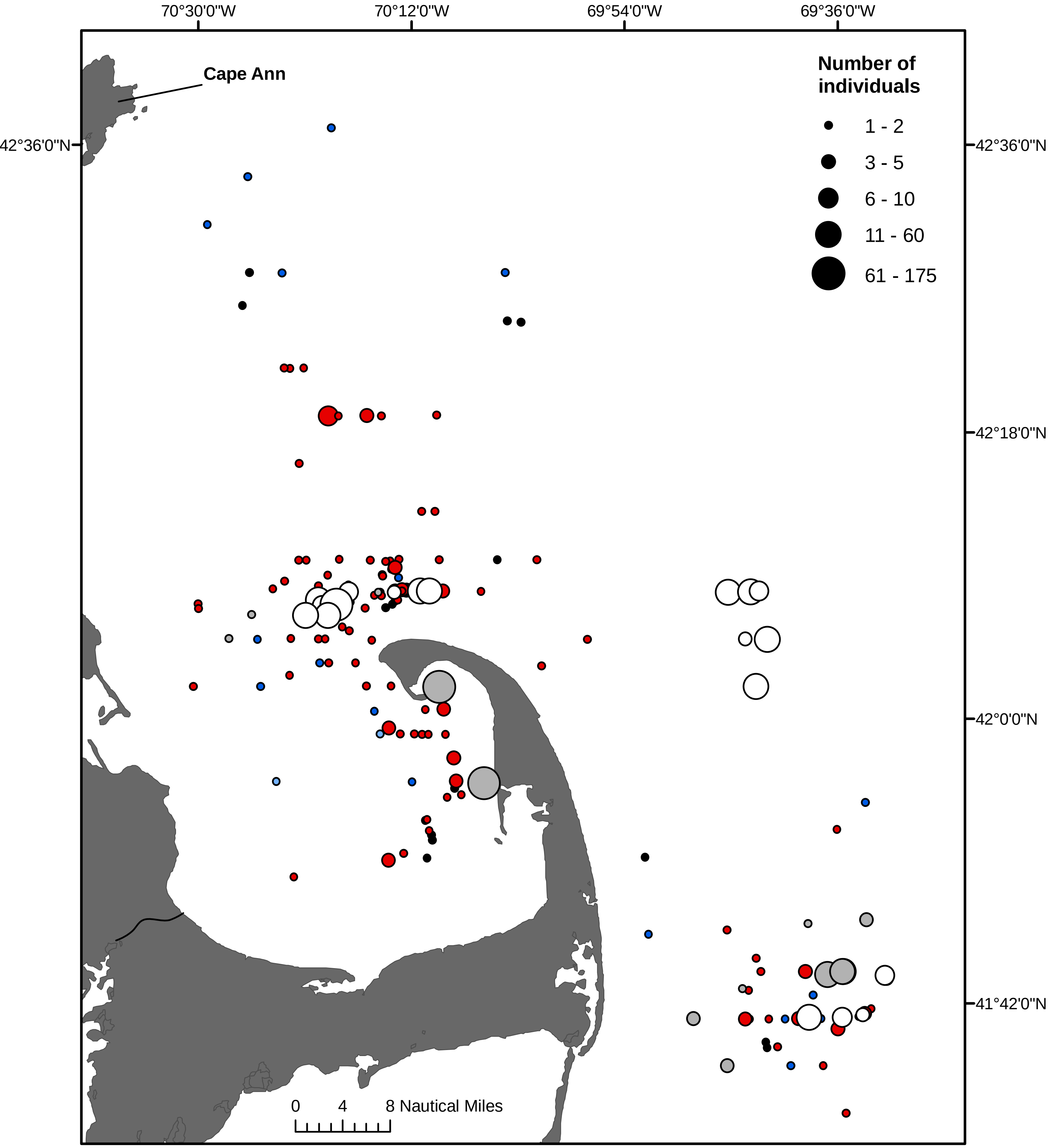
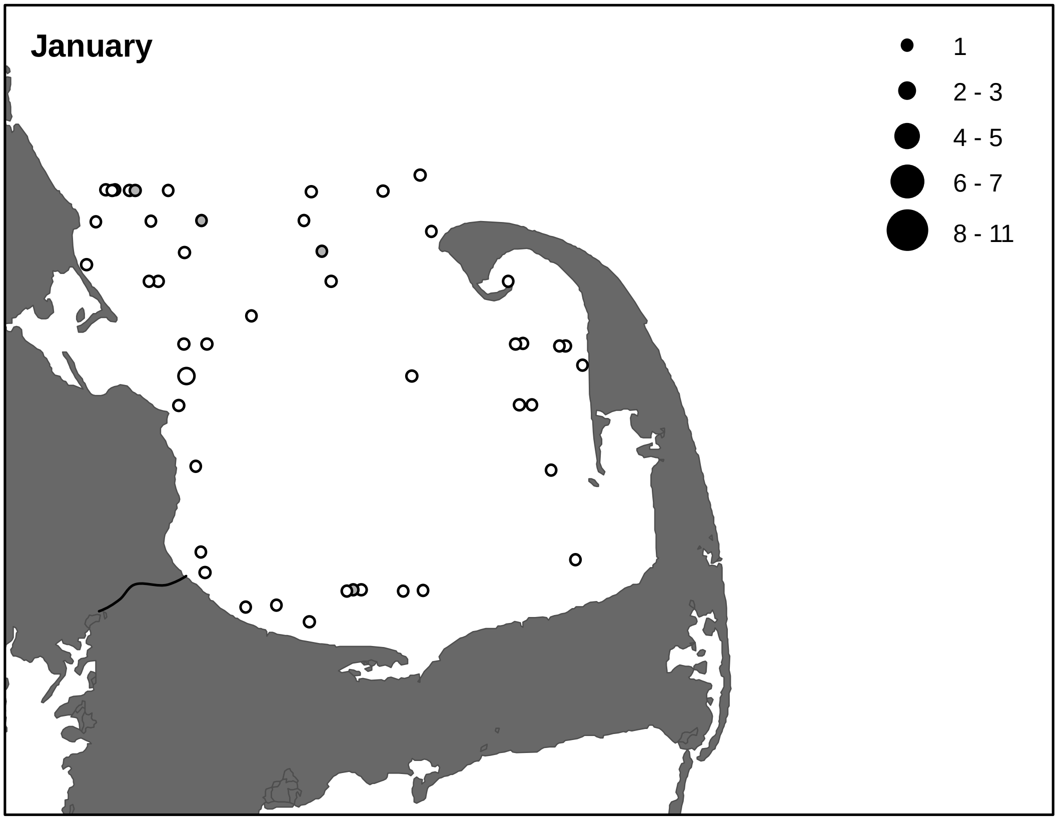


**Fig. A4: Vessel sightings in January & February. Color-coded as fishing vessels (white), recreational vessels (blue), whalewatch vessels (green), coastguard vessels (red), research vessels (yellow) & unidentified vessels (grey).**



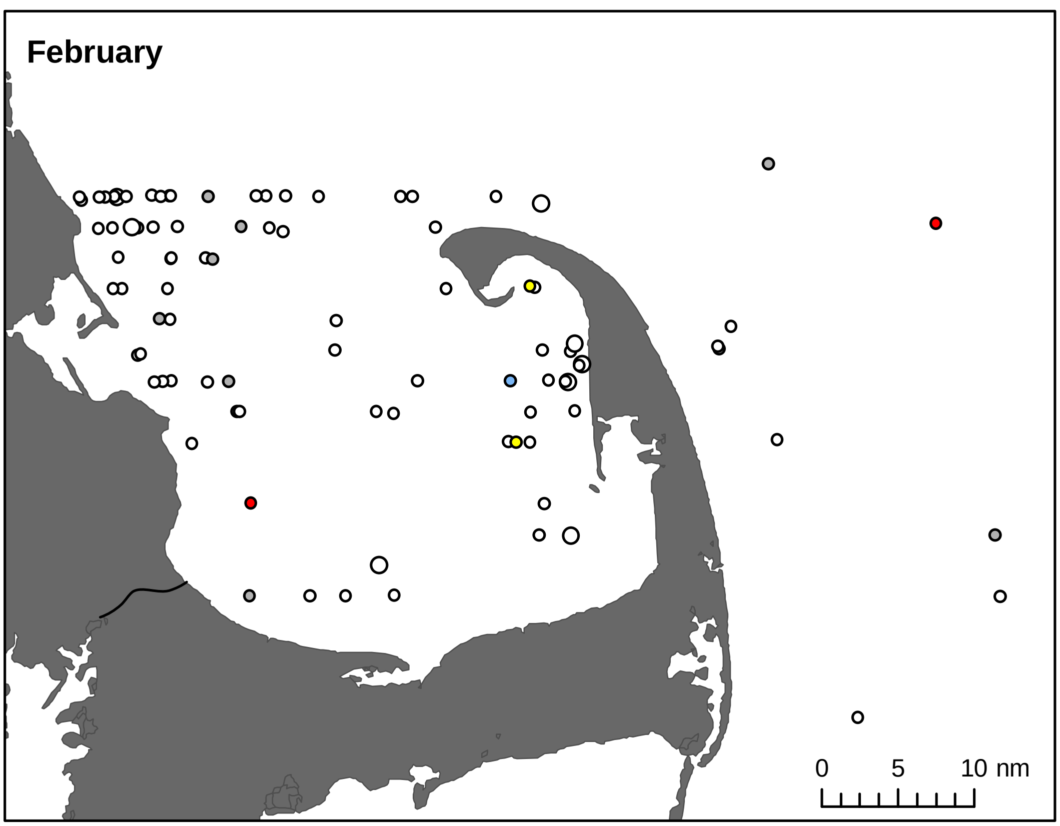
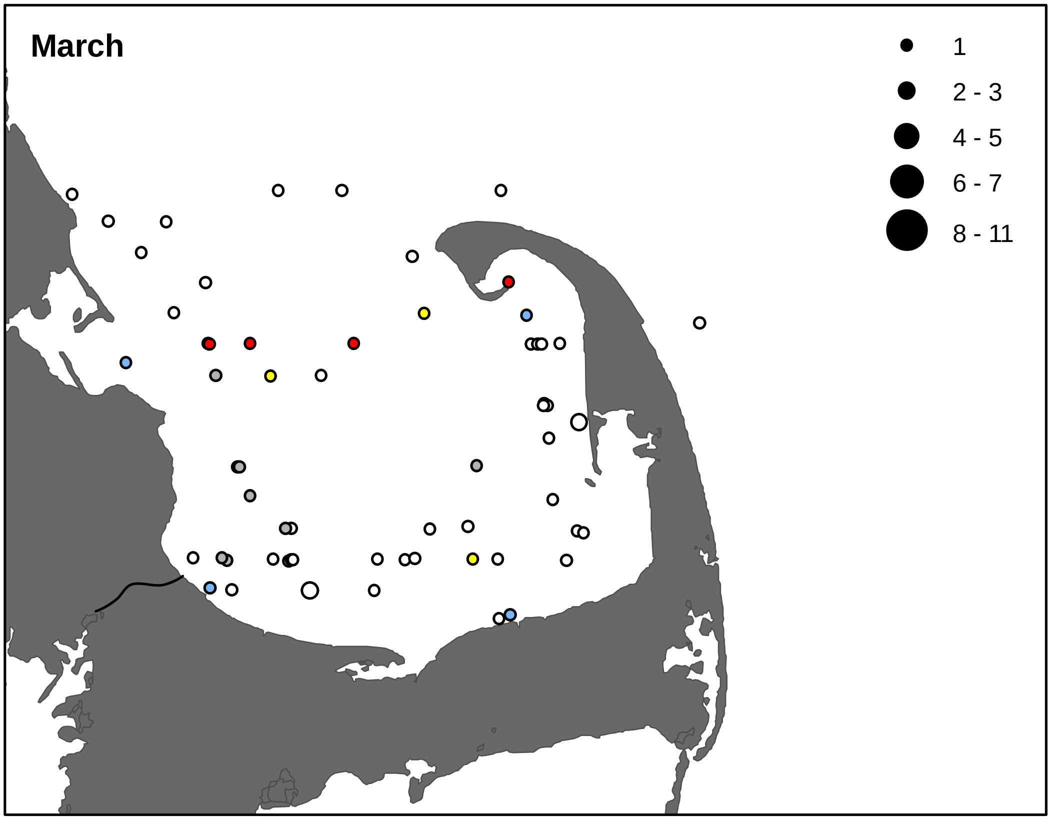



**Fig. A4: Vessel sightings in March & April.**



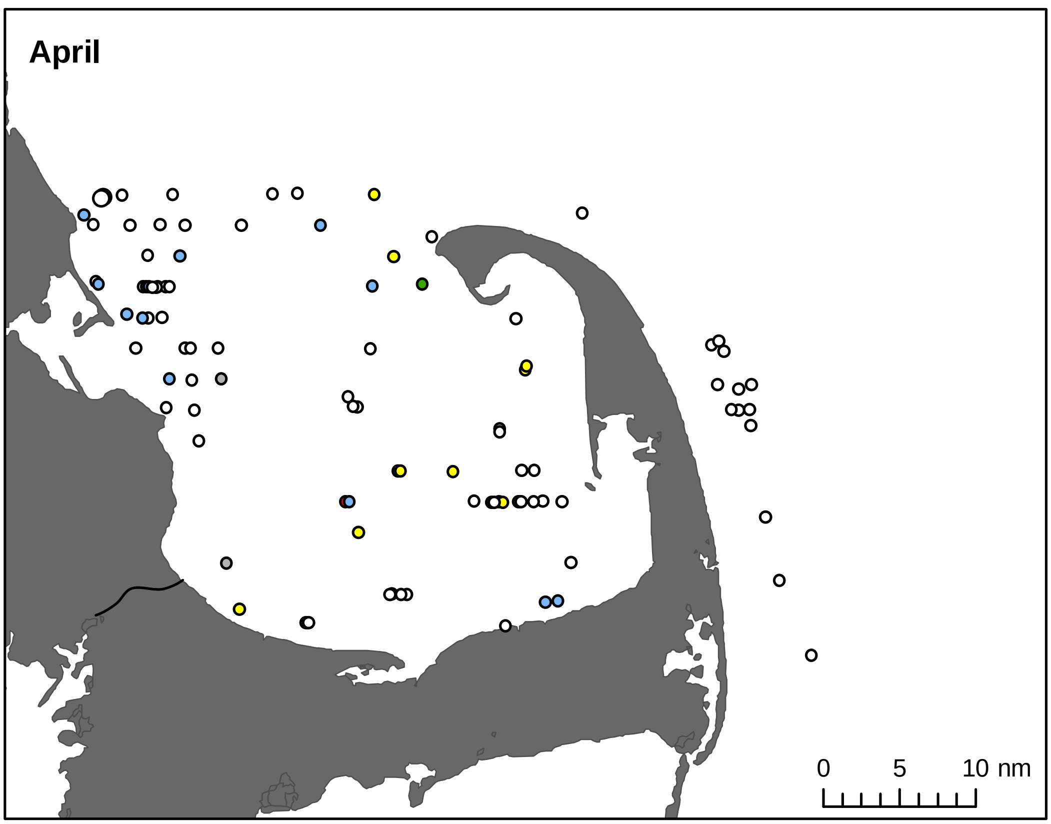
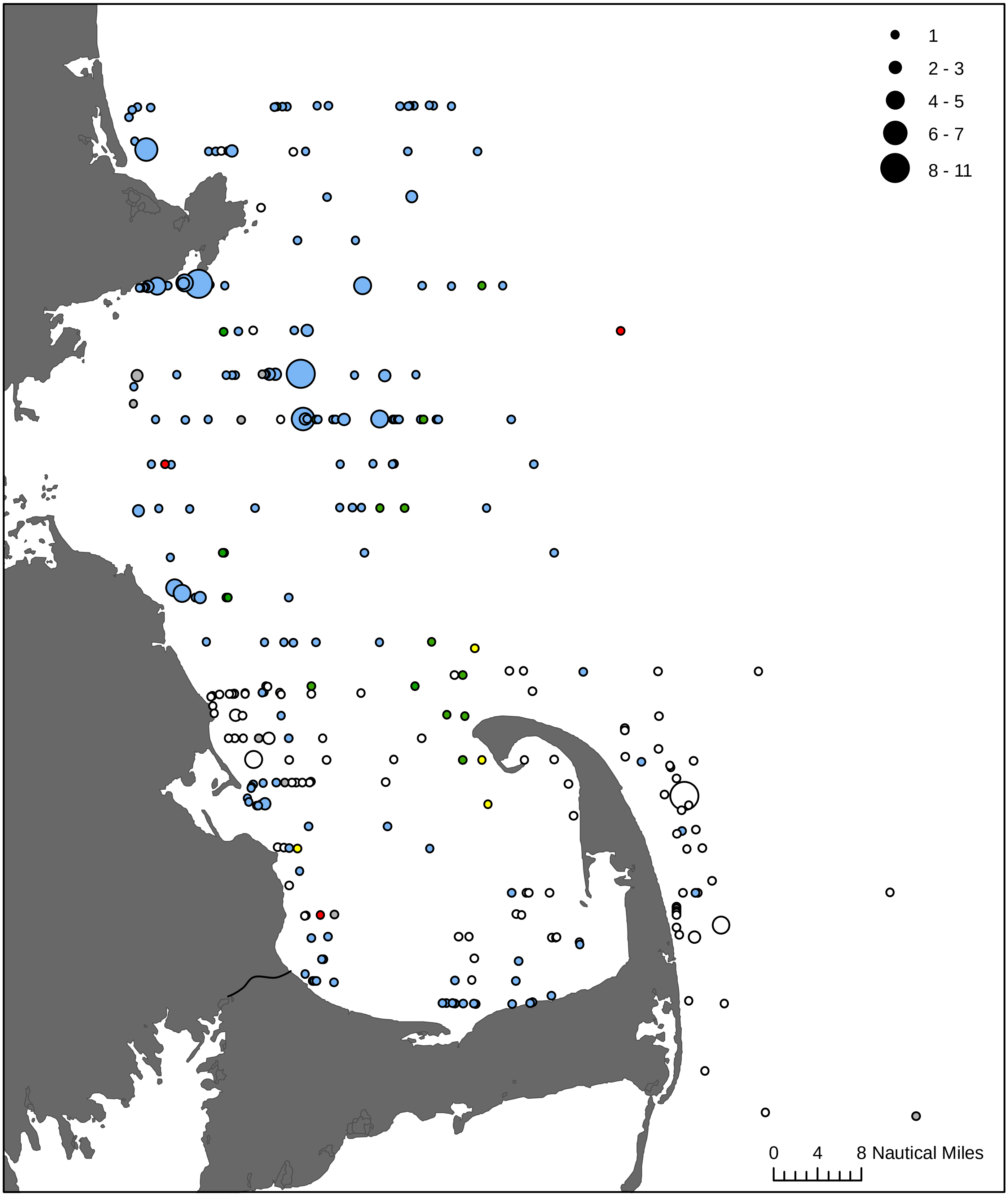



**Fig. A4: Vessel sightings in May. Color-coded as fishing vessels (white), recreational vessels (blue), whalewatch vessels (green), coastguard vessels (red), RV Shearwater (yellow) & unidentified vessels (grey)**



**Appendix 5:** (a) Aerial Survey track line co-ordinates – CCB & adjacent waters survey.

| Track line number | Latitude | Longitude West end | Longitude East end | Track line Length (nm) |
|---|---|---|---|---|
| **1** | 42° 06.5 | -70° 37.9 | -70° 10.0 21 | 21 |
| **2** | 42° 05.0 | -70° 36.3 | -70° 15.8 15 | 15 |
| **3** | 42° 03.5 | -70° 36.8 | -70° 17.0 15 | 15 |
| **4** | 42° 02.0 | -70° 35.7 | -70° 07.7 21 | 21 |
| **5** | 42° 00.5 | -70° 34.2 | -70° 07.0 20 | 20 |
| **6** | 41° 59.0 | -70° 34.2 | -70° 06.6 21 | 21 |
| **7** | 41° 57.5 | -70° 34.2 | -70° 06.6 21 | 21 |
| **8** | 41° 56.0 | -70° 31.6 | -70° 06.3 19 | 19 |
| **9** | 41° 54.5 | -70° 30.9 | -70° 06.3 18 | 18 |
| **10** | 41° 53.0 | -70° 30.0 | -70° 06.1 18 | 18 |
| **11** | 41° 51.5 | -70° 29.5 | -70° 06.1 18 | 18 |
| **12** | 41° 50.0 | -70° 30.3 | -70° 06.1 18 | 18 |
| **13** | 41° 48.5 | -70° 30.2 | -70° 06.1 18 | 18 |
| **14** | 41° 47.0 | -70° 28.3 | -70° 06.1 17 | 17 |
| **15** | 41° 45.5 | -70° 26.5 | -70° 11.4 11 | 11 |
| **16*** | 41° 40.0 | -69° 52.0 35 | | 35 |
| Track line miles in Cape Cod Bay (3-15) | | | | **235** |
| Track line miles outside Cape Cod Bay (1, 2, 16) | | | | **71** |
| **Total track line miles** (tracks 1-16) | | | | **306** |

* Track line 16 begins at this point, east of Chatham, continues north parallel to the eastern shore of Cape Cod approximately 3 nautical miles offshore, and joins the eastern end of track line 1 (Fig 1).

**Appendix 5:** (b) Aerial Survey track line co-ordinates – Eastern track lines.

| Track line number | Latitude | Longitude West end | Longitude East end | Distance (nm) |
|---|---|---|---|---|
| **1** | 42° 08.0 | -70° 17.0 | -69° 40.0 | 27 |
| **2** | 42° 05.0 | -70° 00.0 | -69° 40.0 | 15 |
| **3** | 42° 02.0 | -70° 00.0 | -69° 40.0 | 15 |
| **4** | 41° 59.0 | -69° 55.0 | -69° 35.0 | 15 |
| **5** | 41° 56.0 | -69° 55.0 | -69° 35.0 | 15 |
| **6** | 41° 53.0 | -69° 55.0 | -69° 35.0 | 15 |
| **7** | 41° 50.0 | -69° 55.0 | -69° 35.0 | 15 |
| **8** | 41° 47.0 | -69° 55.0 | -69° 35.0 | 15 |
| **9** | 41° 44.0 | -69° 53.0 | -69° 35.0 | 13 |
| **10** | 41° 41.0 | -69° 53.0 | -69° 35.0 | 13 |
| **11** | 41° 38.0 | -69° 53.0 | -69° 35.0 | 13 |
| **12** | 41° 35.0 | -69° 53.0 | -69° 35.0 | 13 |
| **Track line miles for East of CCB survey** (tracks 1-12) | | | | **184** |
| **Total survey including transit and cross-legs** | | | | **~ 252** |

**Appendix 5:** (c) Aerial Survey track line co-ordinates – Massachusetts Bay survey.

| Track line number | Latitude | longitude West end | longitude East end | Distance (nm) |
|---|---|---|---|---|
| **1** | 42.11667 | -70.6 | -70.0 | 27 |
| **2** | 42.16667 | -70.65 | -70.0 | 29 |
| **3** | 42.21667 | -70.65 | -70.0 | 29 |
| **4** | 42.26667 | -70.6833 | -70.0 | 30 |
| **5** | 42.31667 | -70.75 | -70.0 | 33 |
| **6** | 42.36667 | -70.75 | -70.0 | 33 |
| **7** | 42.41667 | -70.75 | -70.0 | 33 |
| **8** | 42.46667 | -70.75 | -70.0 | 33 |
| **9** | 42.51667 | -70.75 | -70.0 | 33 |
| **10** | 42.56667 | -70.6167 | -70.0 | 27 |
| **11** | 42.61667 | -70.55 | -70.0 | 24 |
| **12** | 42.66667 | -70.55 | -70.0 | 24 |
| **13** | 42.71667 | -70.7167 | -70.0 | 32 |
| **14** | 42.76667 | -70.75 | -70.0 | 33 |
| | | | | |
| **Total** | | | | **420** |
| **Total survey including transit & cross-legs**** | | | | **550** |

** Track lines spaced 3nm apart; transit from CQX to the eastern end of track 14 = 65 nm, transit from eastern end of track 1 = 26 nm.

# SECTION 2: THE HABITAT OF NORTH ATLANTIC RIGHT WHALES IN CAPE COD BAY: CONDITIONS, ASSESSMENT, AND PREDICTION

## 2.1 Introduction

Studies conducted during the 2009 winter-spring season by the PCCS Right Whale Habitat Studies Program in Cape Cod Bay were focused on monitoring the distribution and abundance of right whales in the context of their habitat, characterized by the quality and quantity of their zooplanktonic food resources available in the bay. Past annual reports have illustrated the strength of the relationship between right whale and zooplankton distribution; we continued to document this interaction, while exploring new patterns and processes that contribute to the movement of right whales and their prey. Specifically, we focused on the vertical distribution of zooplankton layers, and began a study of diel rhythms in zooplankton distribution and right whale behavior.

Eleven years of partnered study and management by PCCS and DMF have demonstrated the application of habitat studies to conservation. In accordance with the goals set forth in Objective IV by PCCS/DMF (see General Introduction), surveillance and monitoring activities were aimed to provide management agencies with information to assist in their time-critical decision making (e.g., amendments to seasonal gear restrictions or the issuance of vessel speed restrictions), intended to mitigate human impacts on right whales in the waters of Cape Cod Bay. As in 2008, immediate post-cruise "Preliminary Assessments" (Appendix II) were distributed electronically to interested managers and colleagues during the 2009 season of right whale residency in Cape Cod Bay; these documents provided a synopsis of each research cruise including sampling performed, marine mammals sighted, preliminary interpretations of habitat conditions, and forecasts concerning the interaction of right whales, habitat conditions and potential risks. These documents also included "Right Whale Risk Alerts" (Appendix III), addressing the need to alert DMF to conditions in Cape Cod Bay deserving immediate management attention. These documents were only issued when a situation that could result in the over-lap of right whales and industrial activities, such as shipping and/or fishing, appeared likely. In 2009, complete "Habitat Assessments" were also written and distributed to interested colleagues (Appendix IV). These documents detailed the results of each cruise, including zooplankton resource distribution and quality, as well as right whale distribution, behavior and habitat use. As the season progressed, station, quadrant, and bay-wide trends in zooplankton and caloric density were shown graphically. Each assessment also contained a discussion of the cruise results and trends to date in the context of the 2009 season and right whale habitat studies in past years.

In addition to the bay-wide study of right whales and zooplankton, the 2009 habitat studies were also aimed at continuing efforts started in 2008 to study the intricacies of and scale at which right whale-zooplankton interactions are strongest. Particular attention was paid to diel cycles of zooplankton distribution, and the dynamic between vertical migration of zooplankton and changes in the behavior of right whales foraging on the migrating resource. With a greater understanding of these dynamics we hope to improve our ability to predict the behavior and movement of the whales, thereby better informing DMF's management efforts.

In this section of the 2009 annual report, we review and summarize the foundational relationship between right whales and their prey, the dynamics of the prey fields, and the strategies and movement of whales that, when documented, permit the predictive aspects of the assessment analysis and risk alerts. The principal spatial and temporal dynamics that were observed in Cape Cod Bay habitat in 2009 are presented, integrating detailed analyses of the zooplankton resource with right whale distributional information. We also explore the more intricate patterns of zooplankton distribution that were observed during the season: patterns that reveal pertinent details about the relationship between right whales and the dynamics of Cape Cod Bay food resources. Finally, we discuss the use of environmental factors to predict the presence and absence of right whales, and their behavior.

## 2.2. Application of Habitat Studies to the Management Process

The on-going efforts of the PCCS Right Whale Habitat Studies program to understand the physical and biological processes governing the distribution of zooplankton and right whales in Cape Cod Bay is integral to the management of human activities that may threaten North Atlantic right whale population recovery. As detailed in previous reports, zooplankton may be seen to "control" the distribution and occurrence of the whales within the federally designated Right Whale Critical Habitat. Therefore, the characteristics of the zooplankton resource may be used to monitor and predict the movement, aggregation, and behavior of the whales, thereby informing management.

In order to assess the habitat conditions controlling the occurrence of right whales in Cape Cod Bay, the Right Whale Habitat Studies program surveys the zooplankton resource in the bay, along with a variety of physical parameters, and produces a forecast of movement and occurrence patterns of the whales based on the distribution of their food. As described in further detail in the 2007 Right Whale Habitat Studies Program Report, the aggregative property of zooplankton combined with the foraging patterns of right whales leads the whales to gather in areas of rich food patches, optimizing their energy intake. The nature of the whales' feeding behavior while aggregated around these zooplankton patches puts the whales at higher risk of injury from industrial activities, particularly shipping and fishing, when the whales and human activities overlap. By understanding both the broad characteristics and the nuances of the relationship between the zooplankton patches and the whales' foraging strategies, it is possible to predict the distribution patterns of the whales in Cape Cod Bay. The more refined the scale and understanding of these distribution patterns, the more accurately human activities can be managed to avoid the co-occurrence of anthropogenic risks and whales.

Our assessment reporting system is aimed at forecasting locations where whales may occur as a reflection of zooplankton patch formation and movement. Zooplankton samples collected systematically on weekly habitat cruises are analyzed in the laboratory and used to characterize the zooplankton resource throughout Cape Cod Bay. This data provides information such as zooplankton abundance, spatial distribution, and species composition, on which short- to medium-term movement and aggregation of whales may be forecast. During each cruise, fishing gear and vessel locations are also recorded, as they represent the two of major anthropogenic threats to right whales: ship strike and entanglement.

*Immediately* following each cruise, a “Preliminary Assessment” and, when necessary, a “Right Whale Risk Alert” are issued and sent to managers, alerting them of potentially high-risk conditions for right whales in the bay. Nineteen such “Preliminary Assessment” reports (Appendix II) and one “Risk Alert” (Appendix III) were distributed in 2009, identifying the distribution and quality of the zooplankton resource that influenced the aggregation of right whales in locations where vessel strike risk was particularly high.

Upon analyzing the collected samples, we author and electronically distribute a more detailed Cape Cod Bay “Habitat Assessment” document (Appendix IV) to inform the DMF and interested agencies of the intricacies of the zooplankton resource present in the bay, where right whales may aggregate in the near future, and where human activities that place whales at risk are likely to overlap the forecasted distribution of whales. In 2009, these documents were expanded to also include special sampling done during the associated cruise, as well as a discussion of the findings within the context of the rest of the season, and right whale-zooplankton ecology. For several years these assessment instruments have been developed and refined, contributing significantly to the management of the Cape Cod Bay Critical Habitat. These documents taken together demonstrate the evolving interaction between the PCCS surveillance program and state agencies leading to management action triggered by the habitat assessment studies.

The sentinel role played by habitat assessment and reporting, in conjunction with aircraft survey observations, underpins the capacity of DMF to respond with management action to forecasted changes in whale distribution and occurrence. As the exchanges between DMF and PCCS demonstrate, it has proven possible to translate field observations into predictions and then alerts over appropriately short time scales. Such alerts are reviewed by DMF and, if deemed necessary, converted into advisories that apply to various user groups that may interact with right whales in the field. The forecasting of right whale presence and subsequent management action and advisories are unique in the management of threats to whales. The tight connection between field observation, science, and the management process described represents a model scenario for the management of one of the most endangered marine mammals in the world, and sets a precedent for management based soundly in ecosystem science.

## 2.3. Methods: Data Collection and General Protocols

The observations documented in this report are based upon collections and field notes made during Cape Cod Bay habitat surveys and directed sampling on board the R/V *Shearwater* in 2009. R/V *Shearwater* is a 40ft (12m) twin diesel engine research vessel equipped with plankton nets, a vertical plankton pump, a CTD (Conductivity-Temperature-Depth profiler), a PAR (light) meter, and a fluorometer. This suite of instruments was assembled to satisfy the need for a variety of oceanographic and marine biological observations.

The zooplankton samples that form the core of the assessment and risk-alert system were collected at nine fixed ("regular") stations in Cape Cod Bay; the techniques used to sample the surface water have been relatively unchanged since right whale habitat observations started in 1984; the uniformity of the techniques over decades permits the comparison of contemporary zooplankton data with a long time-series data, lending context to the forecasting process. The stations, many of which have been sampled by PCCS annually for more than two decades, are located throughout the Bay (Figure 1); they provide spatial coverage of the entire system, allowing characterization of zooplankton distribution and dynamics during the season of right whale residency in the Bay. Weather-permitting, from 1 January 2009 to mid-May, these stations were visited regularly to collect zooplankton from the surface waters and in the upper 19 meters of the water column. Samples were collected using standard 333-micrometer (µm) mesh conical nets fitted with General Oceanics helical flow meters. At each station, surface sampling involved towing a 30cm-diameter net in a circle horizontally for 5 minutes; towing along a circular path permitted net sampling on the margin of the vessel's wake in relatively undisturbed water.

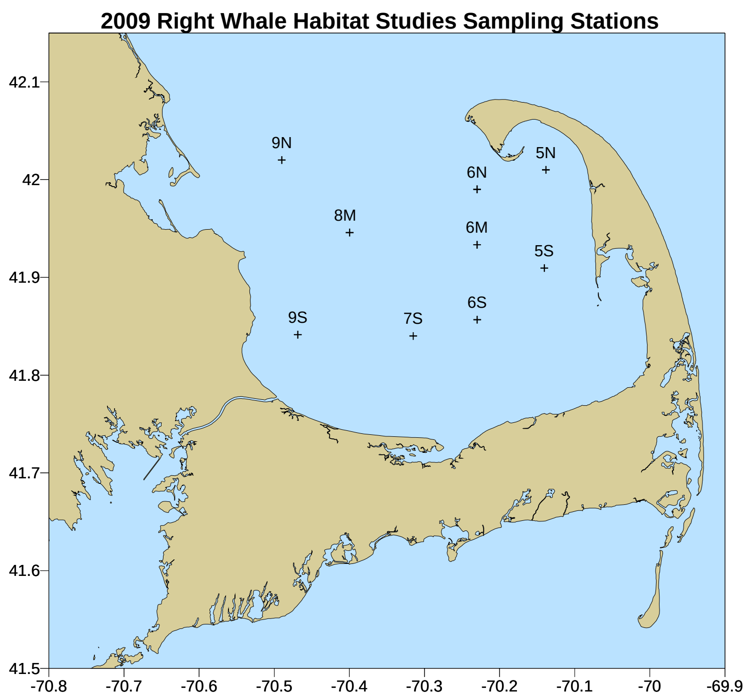



**Figure 1. Map of "regular" sampling stations in Cape Cod Bay that were visited approximately weekly between 13 January and 13 May 2009**

Water column collections were made by vertically dropping a 60 cm-diameter net on-station and retrieving it obliquely through the upper 19 meters of the water column. Because the same surface sampling techniques have been employed every winter since 1984, the collected samples provide an invaluable comparative measure of the conditions that have supported the feeding activities of right whales in Cape Cod Bay over the last two decades.

All field samples were kept in seawater and preserved with 6-8% formalin on board the vessel. In the laboratory, the zooplankton samples were again preserved in fresh 6-8% formalin and settled overnight in graduated cylinders in order to estimate the "settled volume" as part of the evaluation of the quality of the habitat. Zooplankton were identified and counted within 12-24 hours of collection and the results of the counts were expressed in organisms per cubic meter (organisms/$m^3$). Estimates of relative caloric value were made from the enumerated zooplankton density and individual genera identification.

In addition to the regular station sampling regime, directed or "special" samples were collected near feeding right whales in order to characterize the abundance, species composition, and spatial extent of the zooplankton resource on which the animals were feeding. Analysis and interpretation of the special station samples was used to characterize the durability of the resource, as well as to forecast the likelihood of continued whale aggregation and residency in those specific areas. Data at collected at these stations helped to refine the knowledge of right whale foraging ecology, and the predator-prey interaction between right whales and zooplankton. The special station analyses were also important to the formulation of the assessments and alerts on which appropriate management responses (e.g., delineating zones where vessel speeds should be limited) were made by DMF.

As in 2008, during the 2009 season of right whale residency, the behavior of the whales and distribution of the zooplankton was such that vertical pump sampling was at times more appropriate for describing the availability of the controlling zooplankton resource than surface and water column plankton net tows. The 3-dimensional structure of zooplankton patches upon which whales fed was investigated on several occasions, with collections from pump profiles, both vertical and horizontal. In particular, vertical pump samples were taken throughout the season to investigate zooplankton layer formation and right whale exploitation of such layers, preferential feeding of right whales on different copepod taxa at different depths, as well as the vertical migration of zooplankton and associated changes in right whale behavior. For vertical pump collections, zooplankton samples were obtained at targeted depths using a pump sampler deployed on a CTD frame; horizontal transect samples were also sampled with a pump and were collected from the near-surface as the vessel steamed along a horizontal transect. All samples were concentrated by filtering through a 333μm mesh and the volume of the water sampled by the pump system was recorded.

Although the intensive collection of food resource data from Cape Cod Bay did not permit the application of traditional survey methods for systematically sighting whales, all observations of right whales during the cruises were both recorded and, as possible, photographed by observers aboard *Shearwater*. These vessel-based opportunistic whale observations served as supplements to the aerial survey's data; because R/V *Shearwater* surveys were non-systematic, such opportunistically collected data were not included as part of analyses that yield right whale density estimates used in both sections of this report. The photographic information collected from *Shearwater* was processed in much the same fashion as that collected from the aerial surveillance effort.

Using a computer data logging system developed by PCCS, information on all species of marine mammals and on a variety of human activities in Cape Cod Bay was collected on cruises during the 2009 winter-spring season. In particular, because of the interest of DMF in fixed fishing gear, special note was made of the types and locations of fixed fishing gear which might pose a risk to right whales. After every cruise, DMF was informed via a post-cruise report of the activities of the day and of fixed fishing gear records from that day's cruise. Observations of immediately threatening conditions were relayed to DMF via cell phone and in post-cruise Risk Alert reports. Post-cruise sample analysis, data processing, and reporting were conducted as rapidly as possible with the goal of delivering to DMF time-critical information that could assist in the management of the Critical Habitat. In support of the general goal of documenting any conditions that may deserve management action, PCCS maintained a database including extensive observations on fixed fishing gear and vessel locations throughout the 2009 surveillance season. During each cruise and in the laboratory analyses particular attention was paid to food resource distribution and right whale aggregation when conditions were predicted to place whales at a significant risk of ship strike and entanglement.

## 2.4. Results and Discussion

### 2.4.1. Habitat Cruises and Reporting

R/V *Shearwater* completed 19 habitat sampling cruises, respectively, in the Cape Cod Bay Right Whale Critical Habitat and adjacent waters between 13 January and 24 May 2009. On each *Shearwater* cruise the data logging computer was used to record information on sample collections, right whale observations, information on other marine mammals, and a wide variety of physical, biological and human activity information that underpin PCCS habitat studies. During the 2009 cruises a total of 669 zooplankton samples were collected and analyzed (Table 1), 148 samples more than in 2008, and approximately double the number of samples collected in 2007. CTD profiles were recorded on-station during each cruise, as well as coincident with all vertical pump sample stations.

During the 2009 season, 101 right whale sightings were photographed opportunistically during habitat sampling cruises for inclusion in the analysis of individual whales. A total of 89 unique individual right whales were represented in the collected photographs, including one individual not documented by the aerial survey team and two calves. Boat-based photographs are important in addition to aerial photographs because they provide important information about the health of individual animals.

Maps detailing the spatial dynamics of zooplankton and caloric distributions throughout the sampling season are compiled in Appendix I, Figures A1 through A24. To review the assessments circulated after each cruise, the reader is referred to Appendices II, III and IV where all preliminary assessment, risk assessment and advisory, and habitat assessment documents are reproduced, respectively.

Table 1. 2009 Cape Cod Bay Habitat Cruises and Collected Zooplankton Samples.

| | | ZOOPLANKTON SAMPLES | | | | | |
|---|---|---|---|---|---|---|---|
| **Cruise** | **Date** | **On-Station Surface Tows** | **Off-Station Suface Tows** | **On-Station Oblique Tows** | **Off-Station Oblique Tows** | **Pump Samples*** | **Total** |
| ***SW727*** | 13 Jan | 9 | . | 9 | . | . | **18** |
| ***SW728*** | 23 Jan | 9 | . | 9 | . | . | **18** |
| ***SW729*** | 30 Jan | 9 | 1 | 9 | 1 | . | **20** |
| ***SW730*** | 11 Feb | 9 | . | 9 | 1 | 16 | **35** |
| ***SW731*** | 16 Feb | 4 | 2 | 4 | 2 | . | **12** |
| ***SW733*** | 25 Feb | 3 | . | 3 | . | 61 | **67** |
| ***SW734*** | 10 Mar | 9 | . | 9 | . | 18 | **36** |
| ***SW735*** | 15 Mar | 4 | 4 | 4 | 1 | 53 | **66** |
| ***SW736*** | 26 Mar | 9 | 1 | 9 | . | . | **19** |
| ***SW737*** | 1 Apr | 9 | 2 | 10 | 1 | 7 | **29** |
| ***SW738*** | 10 Apr | 9 | 1 | 9 | 1 | 17 | **37** |
| ***SW739*** | 14 Apr | 2 | 4 | 2 | 4 | 81 | **93** |
| ***SW740*** | 18 Apr | . | 5 | . | 1 | 151 | **157** |
| ***SW741*** | 26 Apr | 9 | 1 | 9 | 1 | . | **20** |
| ***SW742*** | 27 Apr | . | 2 | . | 2 | . | **4** |
| ***SW743*** | 30 Apr | 9 | . | 9 | . | . | **18** |
| ***SW744*** | 5 May | . | 1 | . | 1 | . | **2** |
| ***SW745*** | 8 May | 9 | . | 9 | . | . | **18** |
| ***SW746*** | 13 May | . | 3 | . | 2 | . | **5** |
| | **Totals** | **112** | **27** | **113** | **18** | **404** | **669** |

### 2.4.2. Zooplankton Analysis and Research

The conceptual basis for the relationship between habitat assessment and management of right whales is thoroughly detailed in the 2006 report (see Sections 2.4.1 – 2.4.3 of the 2006 report) and summarized briefly in the Introduction to this Section. A simplified version of the concept follows.

In this section of the report we present basic information on the character of the zooplankton resource which was made available to DMF and to the wider list of coordinating agencies and individuals through preliminary and final assessment documents sent via email after analysis of the food resource collected during each cruise. Here we also evaluate the season as a whole in light of the resource-based paradigm used to predict the occurrence of right whales in Cape Cod Bay. As a foundation for this discussion, we summarize the resource conditions that influenced right whale distribution and activity during the 2009 season.

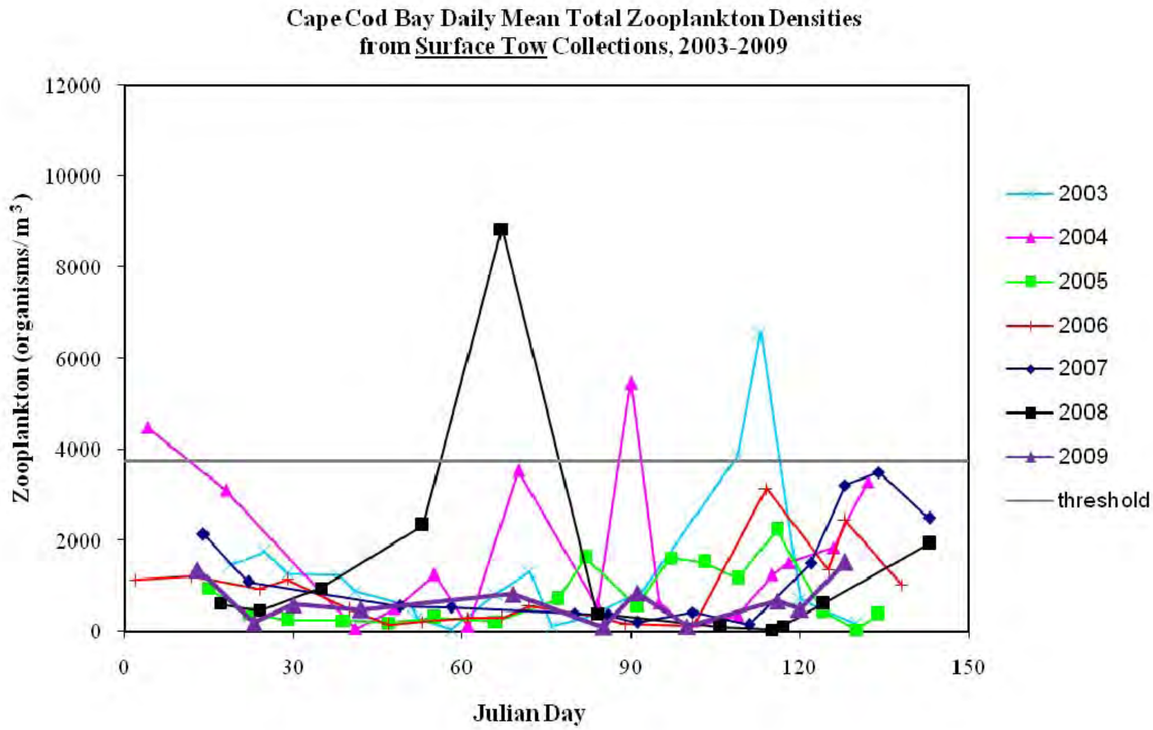
#### 2.4.2.1. General Pattern of Zooplankton Productivity

Understanding the patterns of right whale residency and distribution in Cape Cod Bay requires knowledge of zooplankton composition and density, as well as the seasonal cycles driving these factors. PCCS' sampling techniques allow the consideration of surface water zooplankton separately from water column zooplankton (Section 2.3). Zooplankton patches and/or layers form when oceanographic and/or biological processes concentrate zooplankton that exist at lower "background" levels during certain times of the year. When background levels are high enough, *and* concentrating processes occur, the zooplankton resource will likely reach acceptable levels for right whale feeding. It appears that simultaneous enrichment in the water column and surface waters indicates enrichment in background levels of zooplankton. However, when enrichment occurs in the water column and *not* in surface waters, a zooplankton resource is likely aggregating into patches and/or layers that could trigger right whale feeding, and vise versa. The differentiation between surface water and water column resources is significant because right whales feeding at or near the sea-surface encounter different types of risk than whales feeding deeper in the water column. (Leeney *et al*. 2008; Stamieszkin *et al*. 2008)

In 2009, the gross average zooplankton density at regular sampling stations (Fig. 2) shows that both surface and water column zooplankton densities were low compared with many previous years of the study, and in fact below right whale feeding threshold for the entirety of the season. Only one other year, 2006, showed such low average zooplankton densities throughout the entire season in both the water column and surface waters. All other years sampled (2003-2005, 2007 and 2008) contained a period when at least surface or water column zooplankton densities reached above-threshold levels. Despite low levels of zooplankton abundance, right whales were numerous in the bay in 2009 (section one), thus highlighting the importance of considering the resource-driven paradigm at an appropriate scale, i.e. not on a region-wide scale as recent publications suggest (Pendleton et *al.* 2009).

Historically, average bay-wide water column densities during the winter-spring season of right whale residency have been higher than surface densities; zooplankton abundance during the 2009 season showed the same pattern. Unlike past years was the lack of significant surface water enrichment that typically occurs during early to mid-April. At the beginning of April, approximately the 90th Julian day, a relatively small spike in surface zooplankton concentration was documented and an associated spike in water column zooplankton was not. This peak represents the surface enrichment that, in past years, has led to the aggregation and surface feeding of numerous right whales. The fact that surface waters never reached the significantly rich spring-time peak seen in past years (Fig. 2) is likely a primary reason for the relatively early departure of right whales from Cape Cod Bay in 2009 (section one).

Because the feeding activity of whales in Cape Cod Bay appears strictly controlled by the density of zooplankton in the Bay, it stands to reason that early arriving whales, those entering the Bay between January and mid-March, *generally* encounter higher concentrations of zooplankton in the water column, while whales entering the Bay later in the season *generally* encounter higher concentrations closer to the surface. Previous studies supported by DMF have demonstrated that zooplankton in the water column form high density bottom layers that probably elicit active bottom feeding by whales. During 2009, dense bottom layers were observed early in the season, explaining how the resource in the bay could support numerous right whales, despite the low average water column and surface water densities. Observations of such early to mid winter bottom layers suggest that in Cape Cod Bay entanglement in ground lines, including sinking ground lines, would be more threatening in the first three months of the winter than later in the season. It is likely, though not certain, that floating ground lines would represent an even greater threat.



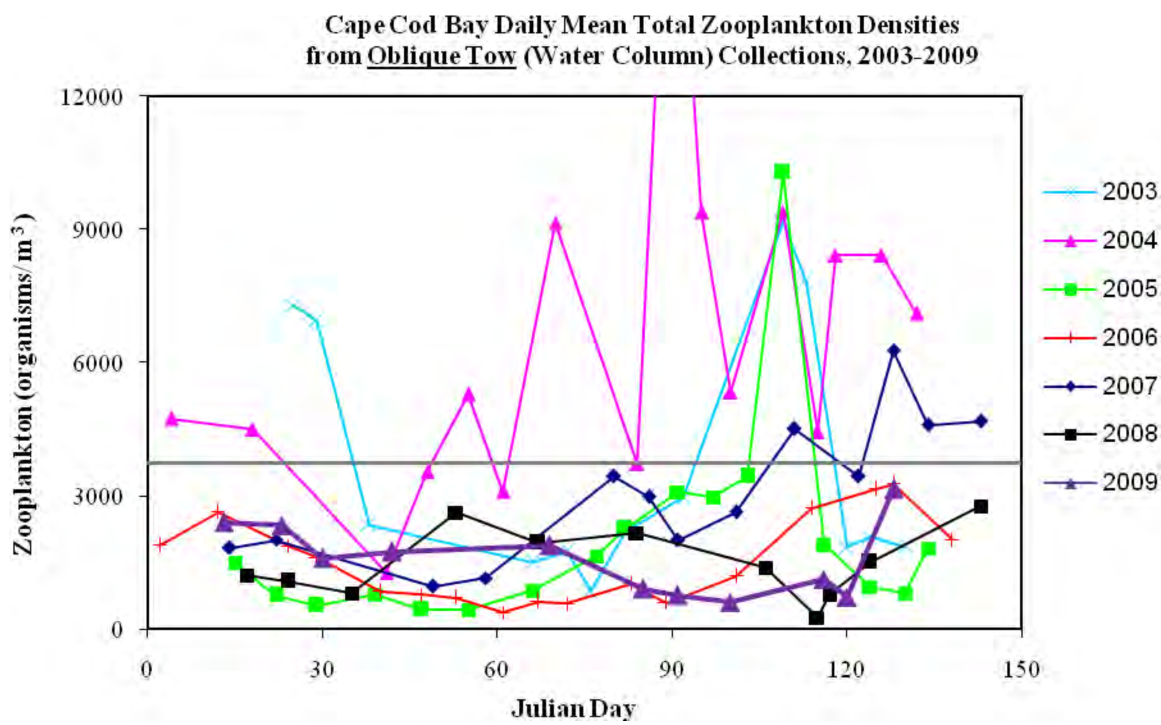




**Figure 2. Temporal progression of the daily mean total zooplankton density in Cape Cod Bay surface waters (top graph) and in the water column (bottom graph), January to mid-May for each year 2003-2009.**

#### 2.4.2.2. General Pattern of Zooplankton Species Composition and Cycles

As previously reported (Jaquet *et al*. 2006; Jaquet *et al*. 2007, Leeney *et al*. 2008), three genera of copepods appear to have the greatest influence on occurrence and behavior of whales in Cape Cod Bay: *Centropages* spp., *Pseudocalanus* spp. and *Calanus finmarchicus*. This assertion is again supported by the 2009 observations; the dominance of these three taxa over other copepods and forms of zooplankton is illustrated in Appendix I figures A25-A51. Figure 3 illustrates the mean surface densities recorded from individual cruises for the three controlling copepod genera during the last ten years. Samples from regular stations only are shown. The cycling of these genera in past years broadly follows similar patterns. *Centropages* plays the role of the fall and early winter dominant taxon, and is responsible for the early winter zooplankton productivity noted in Figure 3, while *Pseudocalanus* is relatively ubiquitous with no strict peak. The *Pseudocalanus* resource however fills in between the early winter *Centropages* and the peaking of the early spring *Calanus*. While all three genera appear to release feeding behavior in right whales, it is clear that the three copepod taxa exhibit seasonal abundance patterns that together spread out the occurrence of right whales over the entire winter and controls their pattern of distribution within the Bay.

Unlike the *Pseudocalanus* trend described above, in 2009, *Pseudocalanus spp.* did have a distinct peak in surface water abundance at around the 69$^{th}$ Julian day, or 10 March (Fig. 3, center plot); this peak was higher than any seen in *Calanus* or *Centropages*. Also unusual was the late-season re-enrichment of *Centropages* in late April and early May (Fig. 3, left plot. This pattern was seen also in 2001 and 2007. Finally, *Calanus* followed a typical pattern of enrichment into the spring, but did not reach maximum levels seen in many past years (Fig. 3, right plot).

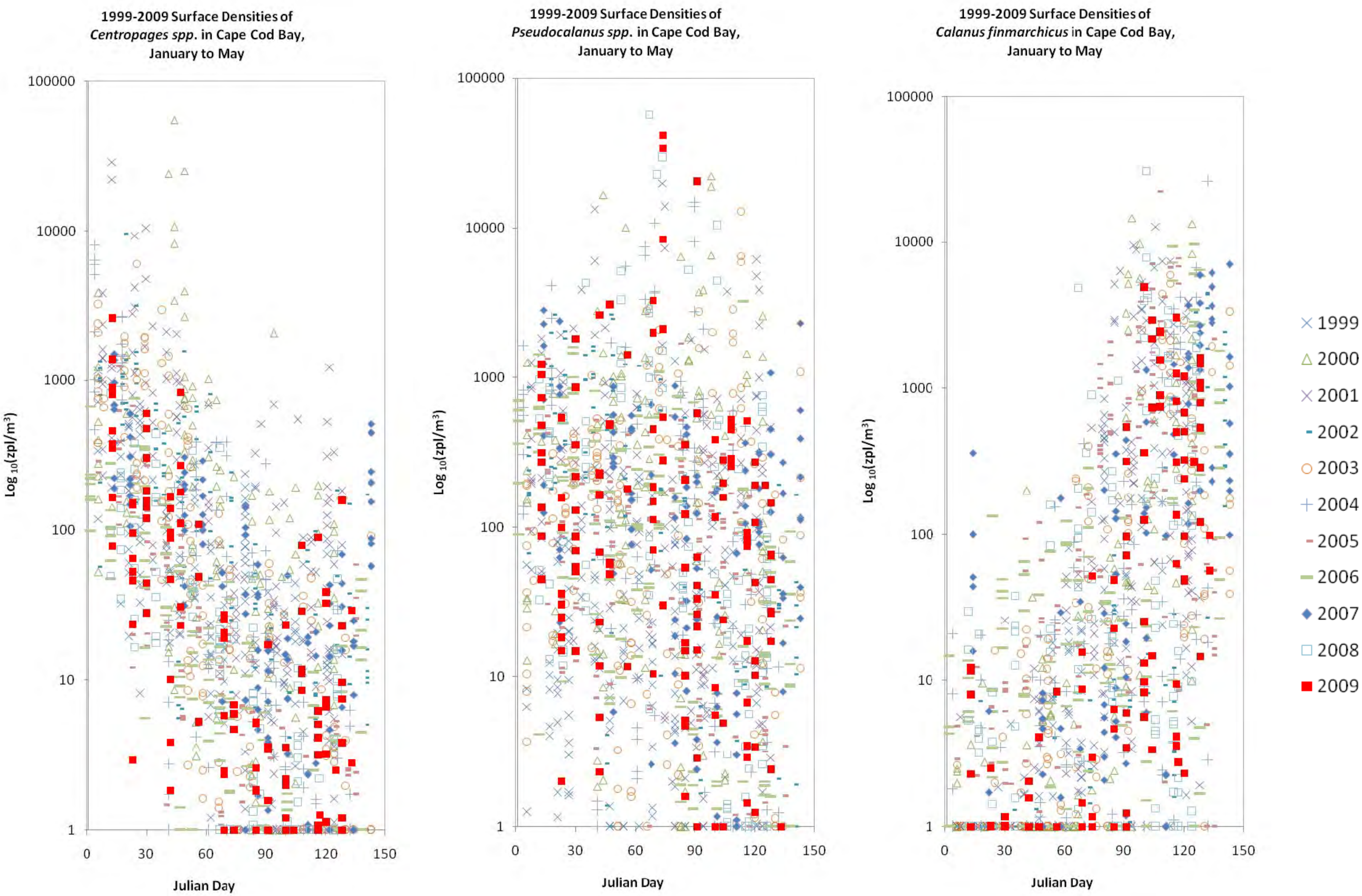



**Figure 3. Scatter plots showing temporal changes in surface densities of the three principal copepod taxa at Cape Cod Bay sampling stations in 2009: *Centropages* spp. (left plot), *Pseudocalanus* spp. (center plot) and *Calanus finmarchicus* (right plot). Note that all axes have identical scales.**

Density information for the three genera found in the water column is presented in Figure 4 and shows similar patterns of enrichment and decline of the three taxa compared to those found in the surface observations. The concentrations of *Centropages*, however, show a less distinct re-enrichment in the water column (Fig. 4, left plot) and water column *Pseudocalanus* does not have a distinct peak (Fig. 4, center plot) like that seen in the surface plots (Fig. 3, center plot).

Differences between the data for surface and water column densities demonstrate that historically, water column concentration tends to be more consistent, with a higher minimum than that for surface concentration, but also with a lower maximum (Fig. 3 and 4). This consistency found in the water column concentrations, and not in the surface concentrations, is explained by the aggregative nature of zooplankton. Physical forces such as upwelling, tidal currents and fronts, and active behavior of individual zooplankton can cause them to dramatically aggregate in surface waters, and then dissipate back into the water column; rich patch formation and dissipation accounts of the dramatic range of surface concentrations (Fig. 3) compared with water column concentrations (Fig.4).

*Pseudocalanus* was the most abundant copepod taxa until approximately the beginning of May, when *Calanus* became dominant; at that point the right whales had vacated the bay (section one), as is typical of past seasons. *Pseudocalanus* commonly forms dense bottom layers, on which the whales were observed feeding during the 2009 season. Based upon taxanomic data about the zooplankton resource (Fig. 3, 4, Appendix I), it appears that the right whales in Cape Cod Bay, during the 2009 season, were feeding primarily on *Pseudocalanus*.

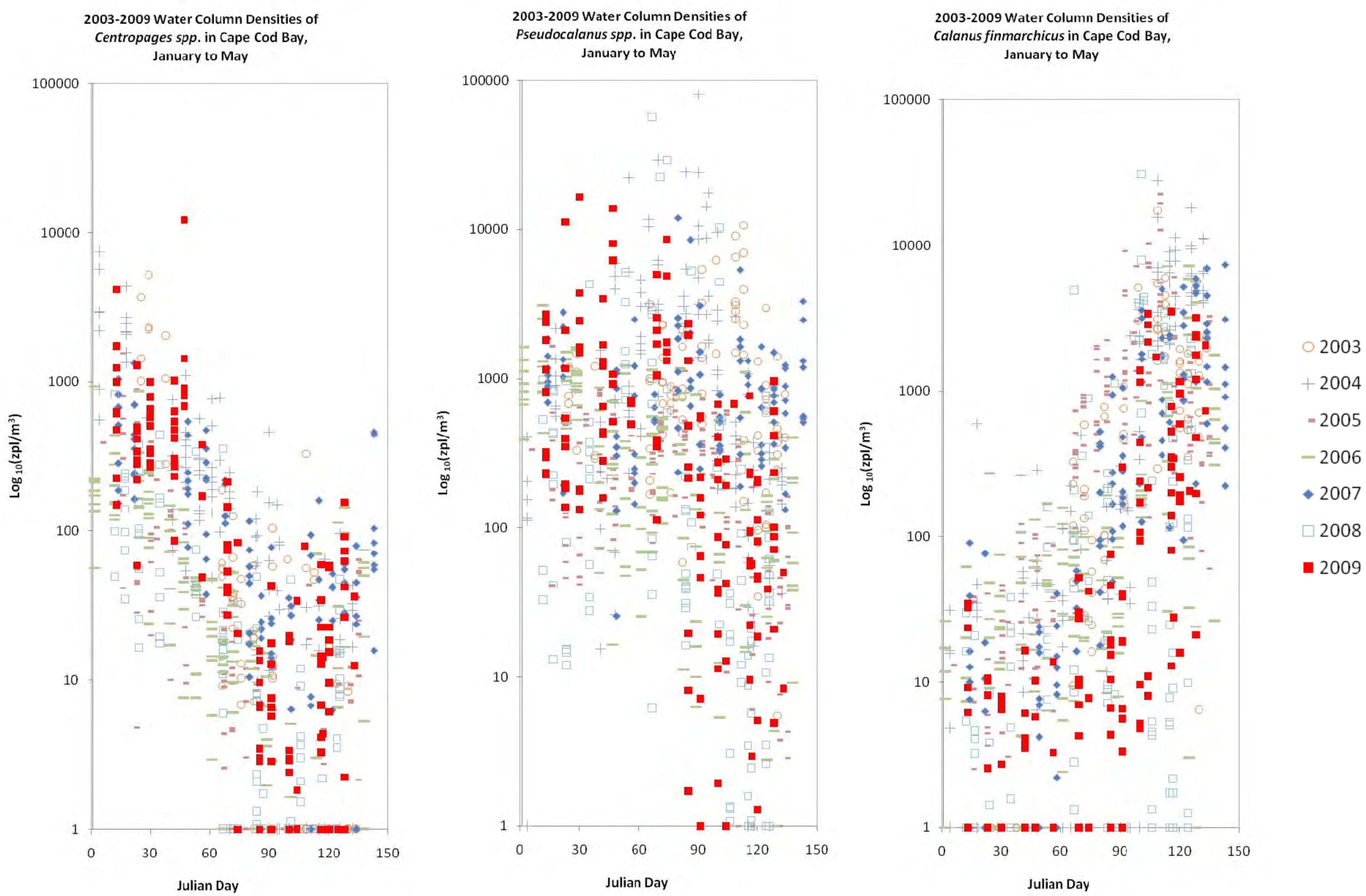



**Figure 4. Scatter plots showing temporal changes in water column densities of the three principal copepod taxa at Cape Cod Bay sampling stations: *Centropages* spp. (left plot), *Pseudocalanus* spp. (center plot) and *Calanus finmarchicus* (right plot). Note that all axes have identical scales.**

Figure 5 summarizes and compares the patterns of enrichment for the three principal copepod genera. The trend lines compare the 1999 through 2008 data with those for 2009, suggesting very broadly that similar patterns are found each year of the study. Differences between trends in surface water zooplankton for each genus are illustrated. *Centropages* spp. abundance was much lower in 2009 compared with the general trend over the previous nine years, though the pattern of late-winter enrichment left over from the previous season, followed by decline into the winter and fall, remains consistent. Also different from past years was the slight re-enrichment of surface waters by *Centropages*. The *Pseudocalanus* spp. trend shows a significantly higher abundance compared with the past trend. Finally, the surface *Calanus finmarchicus* shows a slightly higher than normal trend at the beginning of the season, and then a lower trend at the in May (Fig. 5). When looking at the trends of each year individually, one can see the same patterns (Fig. 7).

Figure 6 represents 2009's water column trends for the three primary genera compared with the average trend over 2003 through 2008. The *Centropages* spp. trend line shows a different pattern to that seen in the surface observations and in past years; a small enrichment occurs early in the season, then drops, and finally re-enriches in May. The trend indicates a lower abundance than past years as well (Fig. 6). As with surface water *Centropages*, this re-enrichment is lower and a different shape from past years. The *Pseudocalanus* trend in 2009 is also different from the trend over the last nine years, and from the 2009 *Pseudocalanus* surface water trend. Similar to the 2009 water column *Centropages* trend, the *Pseudocalanus* trend shows an increase in January and early February, a decrease in March, and a second increase in May. The *Pseudocalanus* trend, however, indicates a more abundant resource than past years (Fig. 6). Finally, 2009 water column concentrations of *Calanus finmarchicus* show a modest enrichment beginning in March, on into May (Fig. 6). The over-all abundance of *Calanus* is lower than the water column trend of past years and the pattern of enrichment is different from both the trend over 2003-2008, and the surface *Calanus* trend of 2009. The same patterns can be seen when the trend of each year is considered individually (Fig. 8).

The dependency of right whales upon the overlapping cycles of three genera of Gulf of Maine copepods suggests that a poor cohort of any one of the three could reduce the value of Cape Cod Bay to foraging right whales. In past years, the highest concentrations of whales are found at the end of the *Pseudocalanus* peak and throughout the period of *Calanus* enrichment, suggesting that right whales would be particularly sensitive to changes in the productivity of those two genera. It has recently been asserted that *Calanus finmarchicus* is not a significant resource for right whales in Cape Cod Bay, but rather, that *Centropages* and *Pseudocalanus* are the most important right whale resource (Pendleton et al., 2009). Contrary, our data show that *Calanus finmarchicus* is also a significant resource for right whales in Cape Cod bay, as their residency typically spans an enrichment of the surface waters with *Calanus*. Further, documentation by PCCS of 25 years of right whale-zooplankton interaction indicates that right whales frequently feed on *Calanus* in the bay. Data from 2009 indicate an unusually weak *Calanus* resource, coincident with an early departure of right whales from the bay (section one). Therefore, on the scale of right whales' foraging patterns, it appears that all three zooplankton taxa, especially *Pseudocalanus* and *Calanus*, are important to the nutrition of the North Atlantic right whale.

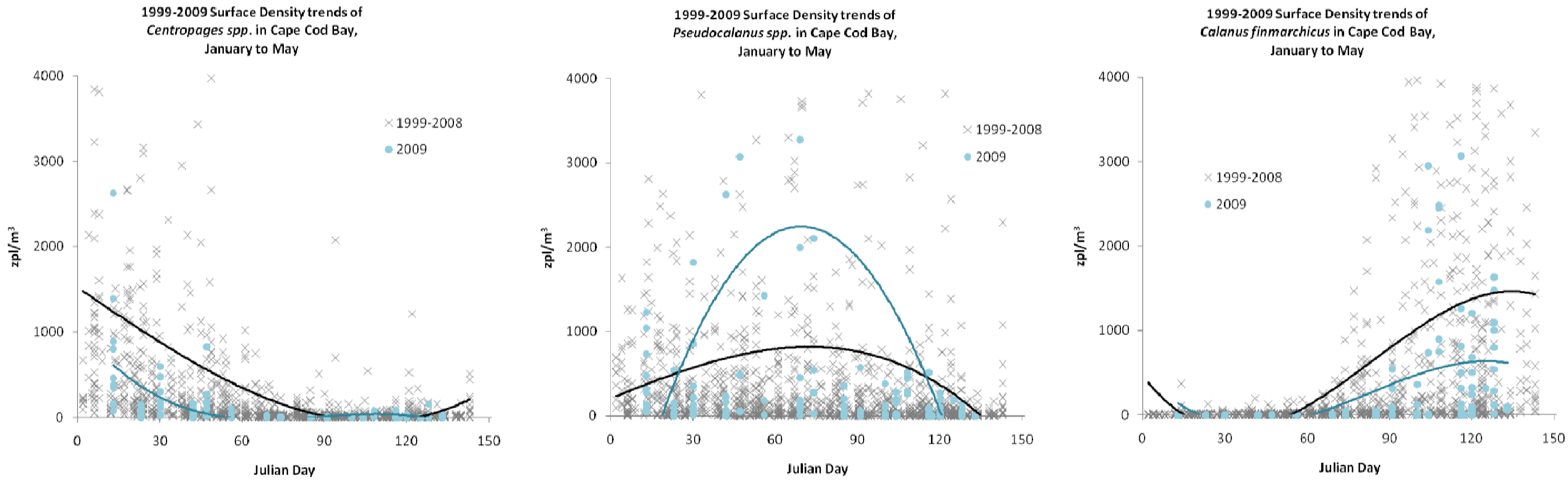



**Figure 5. Comparison of 2009 trend against 1999-2008 trends in the temporal progression of Cape Cod Bay surface densities of the three principal copepod taxa. All values of surface abundance for 1999-2008 are combined to illustrate the "typical" progression for the given taxa. Trend lines represent a 3rd-order polynomial regression treatment of the Cape Cod Bay surface density values for 2009 and for the period 1999-2008.**

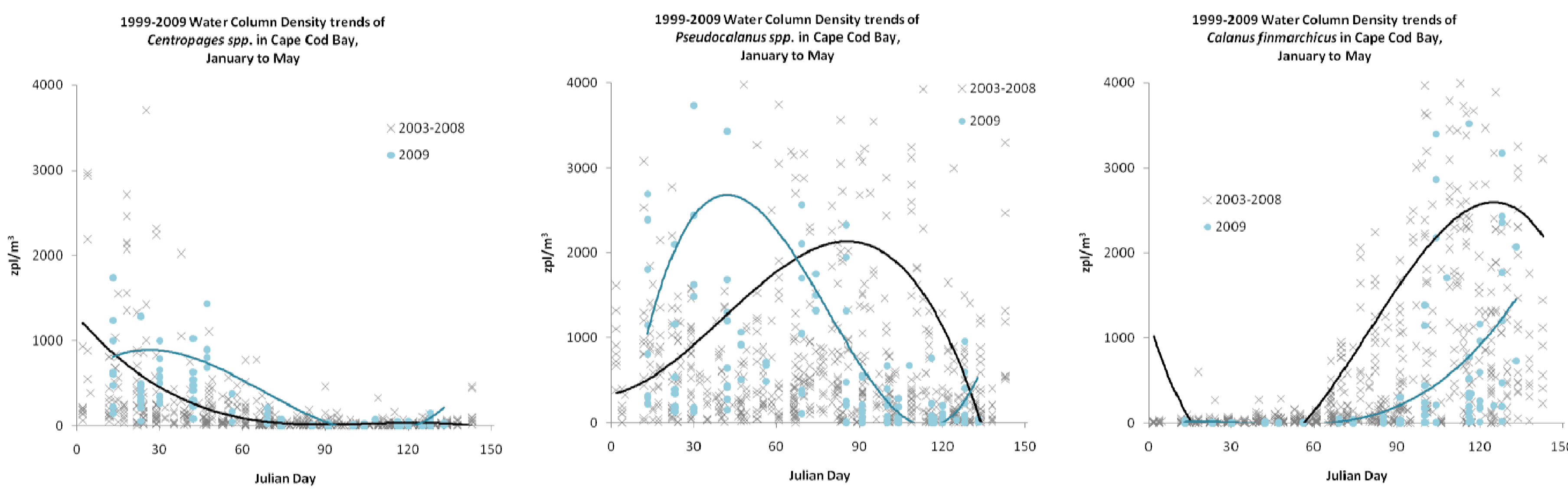



**Figure 6. Comparison of 2009 trend against 2003-2008 trends in the temporal progression of Cape Cod Bay water column densities of the three principal copepod taxa. All values of water column abundance for 2003-2008 are combined to illustrate the "typical" progression for the given taxa. Trend lines represent a 3rd-order polynomial regression treatment of the Cape Cod Bay water column density values for 2009 and for the period 2003-2008.**

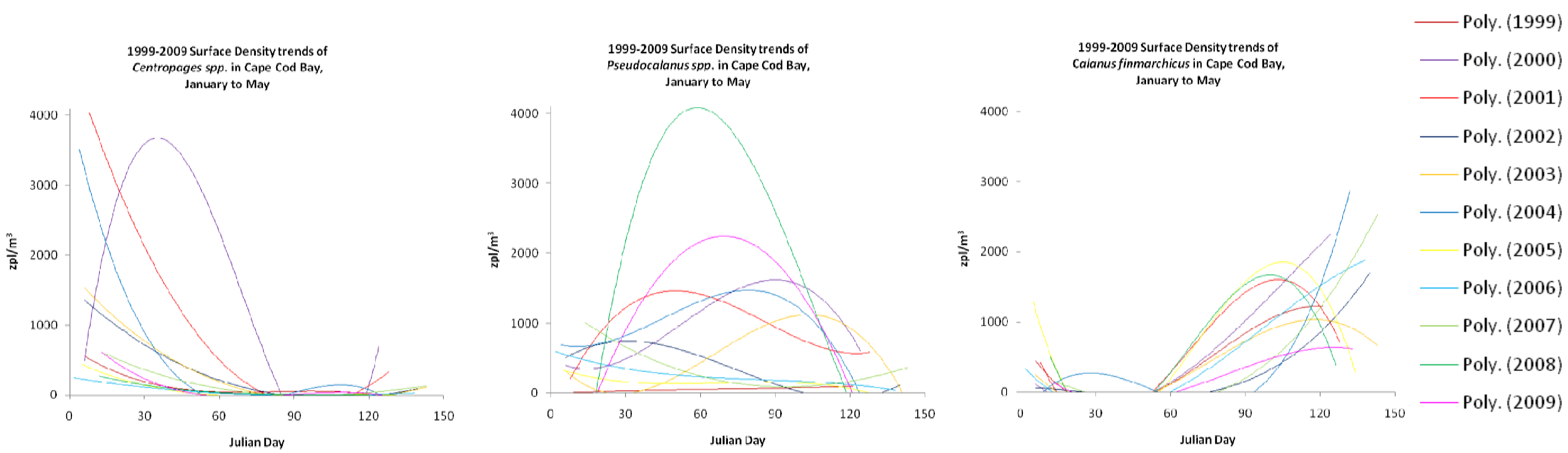



**Figure 7. Comparison of 2009 trend against 1999-2008 annual trends in the temporal progression of surface densities of the three principal copepod taxa in Cape Cod Bay. Individual yearly trends are presented for the period 1999-2009 to show historical inter-annual variations in the temporal trends. Each trend line represents a 3rd-order polynomial regression treatment of all surface density measurements from Cape Cod Bay station sampling for the specified year.**

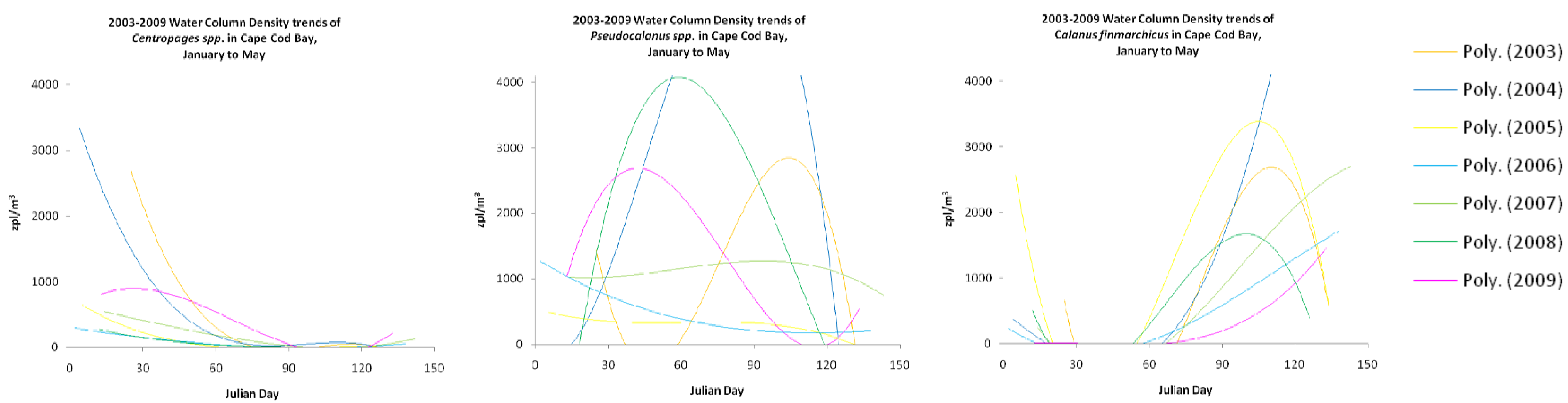



**Figure 8. Comparison of 2009 trend against 2003-2008 annual trends in the temporal progression of water column densities of the three principal copepod taxa in Cape Cod Bay. Individual yearly trends are presented for the period 2003-2009 to show historical inter-annual variations in the temporal trends. All trend lines represent a 3rd-order polynomial regression treatment of all water column density measurements from Cape Cod Bay station sampling for the specified year.**

### 2.4.2.3. The Zooplankton Resource and the Occurrence of Right Whales

When the density index for sightings of right whales (section one) is superimposed upon the densities of the three different taxa both at the surface and in the mid-waters (Figure 13) it is apparent that the late-season *Calanus* enrichment may, as it is believed to in other habitats, play a central role in the influx of more stable aggregations of right whales during the late winter and early spring. Interestingly, the greatest density of right whales enters Cape Cod Bay during most years at the time of the peak enrichment by *Pseudocalanus*. This time in the cycles of Cape Cod Bay, as mentioned above, precedes the increase in *Calanus* that will eventually dominate Cape Cod Bay's second trophic level productivity during the early to mid-spring.

The 2009 duration of right whale residency in the Bay followed a different pattern from most years: in 2009 the whales reached peak abundance in March, and then steeply dropped off in April (Fig. 9 and 10). Usually, right whales reach peak abundance in April, and then leave the bay during May (Jaquet *et al*. 2006; Jaquet *et al*. 2007; Leeney *et al*. 2008). This pattern of residency supports the resource-driven paradigm under which the right whale habitat studies have been conducted for 25 years. During the 2009 season of right whale residency in Cape Cod Bay, the most abundant zooplankton taxon was *Pseudocalanus*, which peaked in surface waters in March (Fig. 9). Water column *Centropages* and *Pseudocalanus* peaked simultaneously in February (Fig. 10). Both surface and water column *Calanus* peaked at the beginning of May, after most of the right whales had left the bay (Fig. 9 and 10). The right whales entered the bay to feed upon the rich *Pseudocalanus* and *Centropages* resources documented during the late winter and early spring, but did not stay in the bay to exploit the enriching, though relatively weak, *Calanus* resource in May. One explanation for this departure, despite modest *Calanus* enrichment relates to the stage of *Calanus* organisms found both the surface and water column. In both cases, early stage copepodites were consistently more abundant than late stage copepodites. Early stage copepods (CI-CIV) contain far fewer calories than those at a late developmental stage (CV-adult). Therefore, even with an enrichment of *Calanus*, the caloric value of this resource remained low.

In the past we have ascribed this pattern, a common feature of the end of the right whales season and Cape Cod Bay, to a “competition” between habitats. As detailed in the 2006 report to DMF (Jaquet *et al*. 2006), it seems likely that the departure of whales during a period when their primary food source is higher than when the whales enter the Bay a month or more before is due to attractions not measurable in the limited confines of Cape Cod Bay. The only clear explanation for this counterintuitive event in an environment that would otherwise support right whale forging is that other habitats have become super-enriched during early-to mid-May and that, queuing on the changes in the season, associated memories, or some undocumented far-field sense, the whales move to offshore areas that seasonally and predictably increase in resource value late in the Cape Cod Bay season. The importance of determining – and thereby developing the capability to predict – the departure of whales is important in our support of the DMF management program because the end of right whales season in the Bay marks the time when the risk of entanglement drops dramatically. This approximate date can be used to inform seasonal gear restrictions and seasonal vessel speed restrictions, because risk to the whales could increase if whales remained to feed on the remaining resource that may be found through May and June.

If this were the case, DMF would be adequately informed and modification to seasonal gear/vessel speed restrictions could be made to protect the right whales remaining in the Bay.

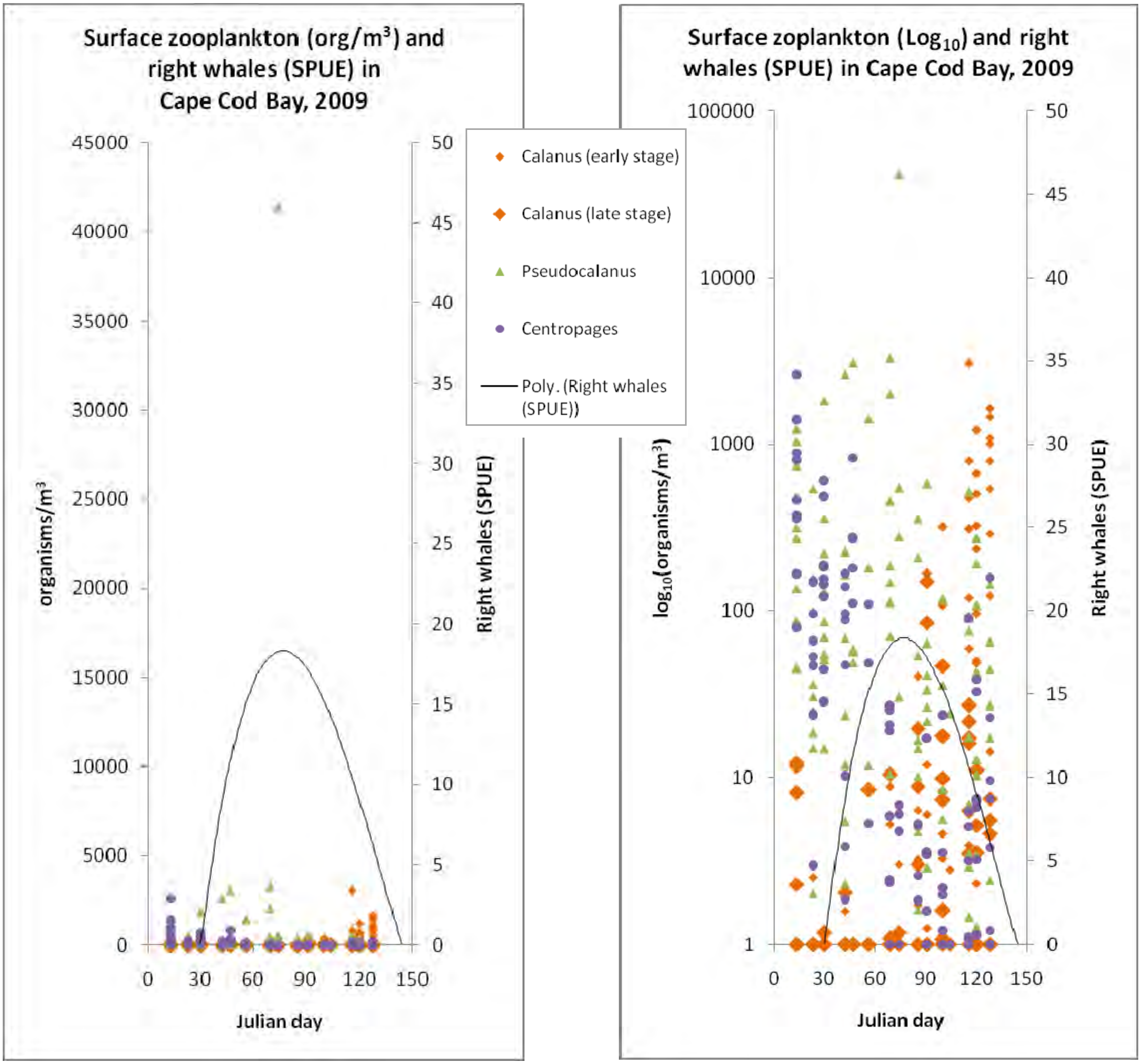



**Figure 9. 2009 comparison of right whale relative density index from aerial surveys with the densities of selected copepod taxa in Cape Cod Bay surface waters shown as organisms per cubic meter (right) and on a logarithmic scale (right). Right whale relative density index is displayed as a trend line, computed as a 3rd order regression of daily values of right-whales-per-nautical-mile of trackline from 2009 aerial surveys. Zooplankton species densities from on-station samples collected between January and mid-May 2009.**

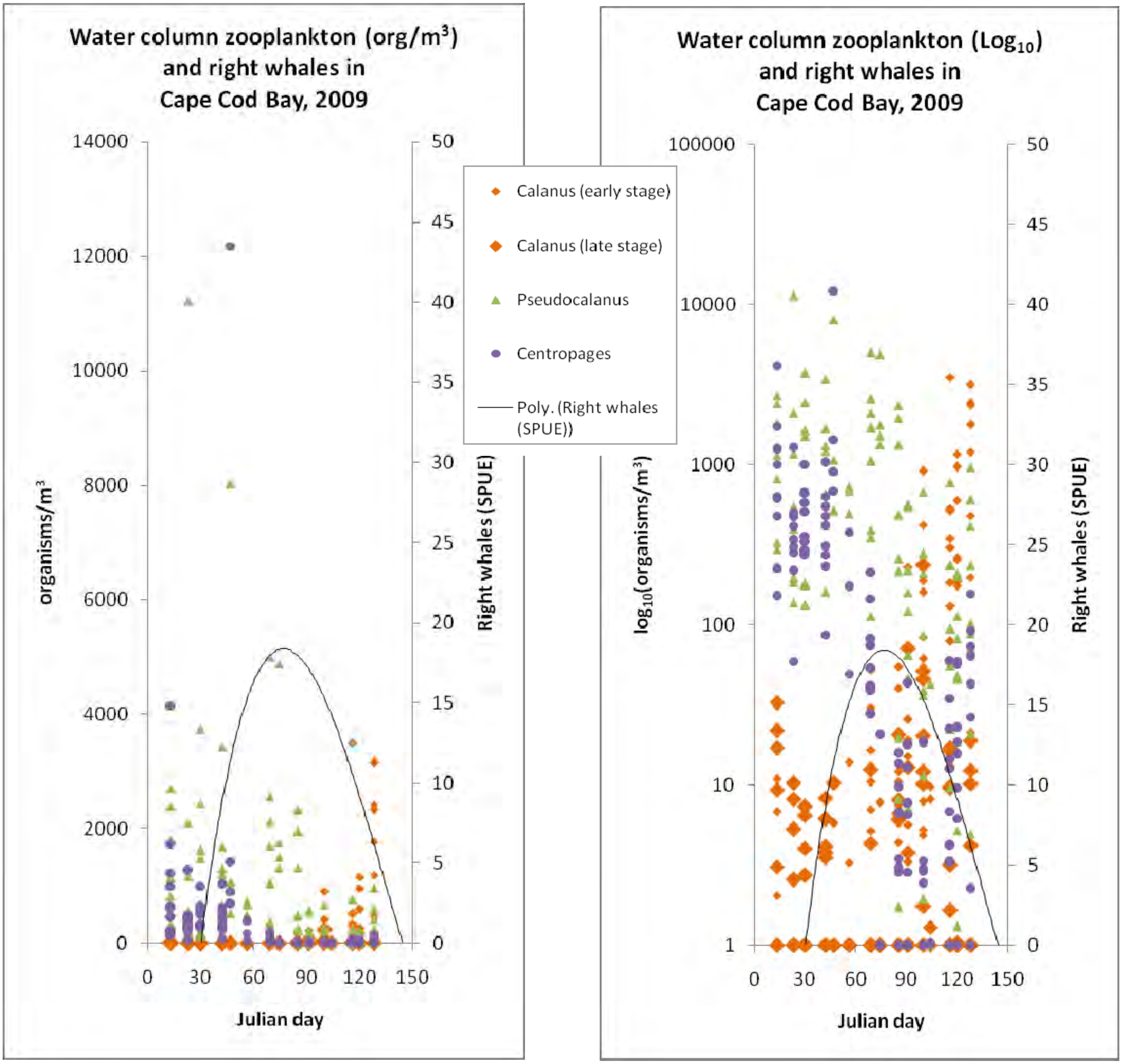



**Figure 10. 2009 comparison of right whale relative density index from aerial surveys with the densities of selected copepod taxa in the Cape Cod Bay water column shown as organisms per cubic meter (right) and on a logarithmic scale (right). Right whale relative density index is displayed as a trend line, computed as a 3rd order regression of daily values of right-whales-per-nautical-mile of trackline from 2009 aerial surveys. Zooplankton species densities from on-station samples collected between January and mid-May 2009.**

Comparing the right whale density index with total zooplankton density at the surface (Fig. 11a-11c, left) and in the water column (Fig. 11a-11c, right), the patterns of whale sightings in 2003 through 2009, *roughly* approximate the rise and fall in the bay- wide mean zooplankton concentrations, though not as well as one might think. This lack of direct relationship between zooplankton averaged over the entire bay and right whale abundance illustrates the need to understand the scale at which right whales interact with their habitat. By definition, averaging dampens the effect of outliers in a dataset. Right whale foraging strategy, however, depends on these outliers, which in this case, represent extremely rich patches or extremely impoverished areas of zooplankton (Mayo and Marx, 1990). The natural processes which aggregate zooplankton into patches rich enough to sustain a feeding right whale can occur on the order of meters, a much finer scale than is represented by a bay-wide zooplankton mean. Therefore, it is not surprising that the bay-wide mean zooplankton concentration does not correlate to right whale index.

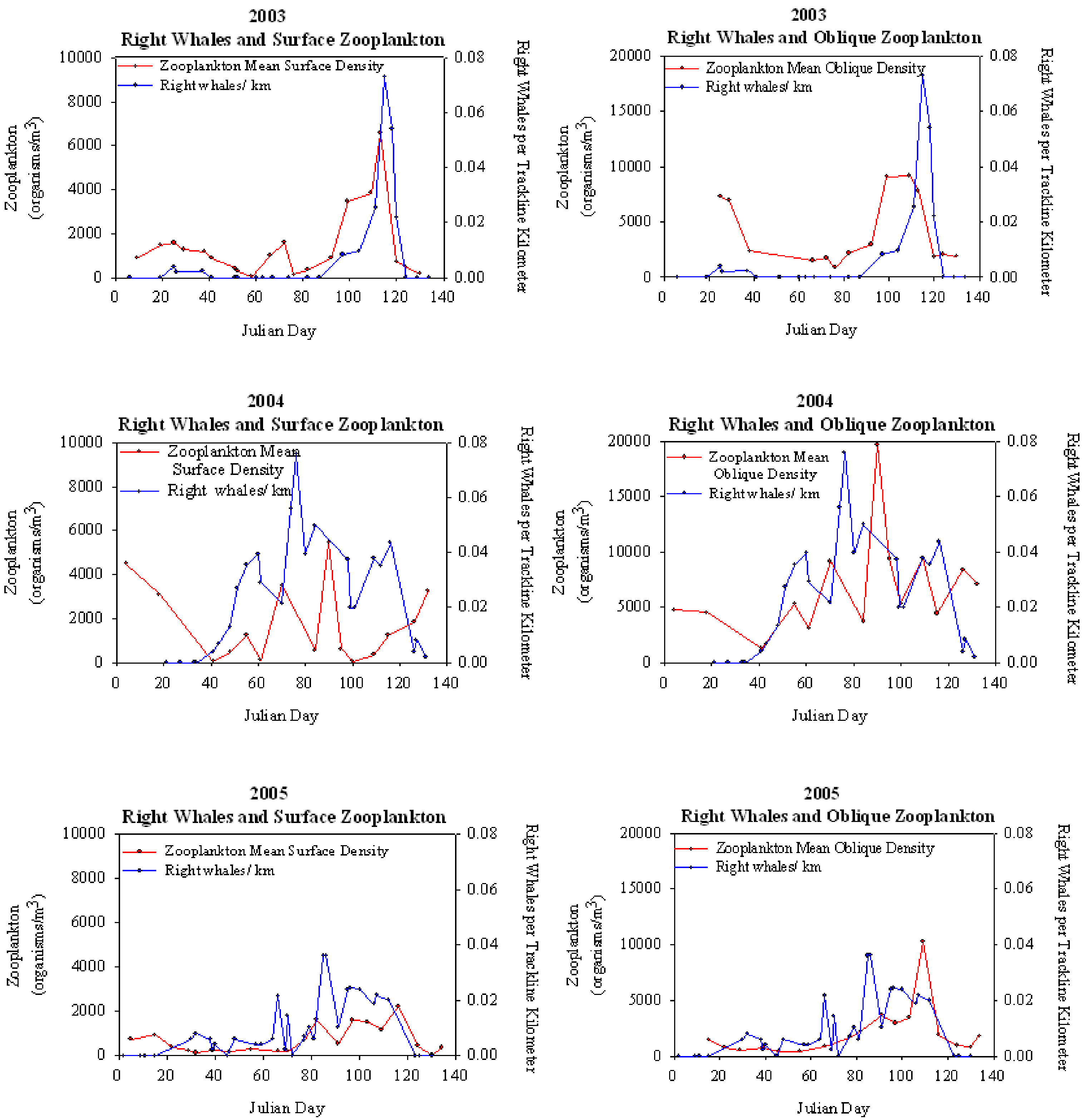



**Figure 11a. Comparison of right whale sightings and daily mean zooplankton densities in Cape Cod Bay, 2003- 2005; surface zooplankton is represented on the left and water column zooplankton is represented on the right. Please note differences in scale.**

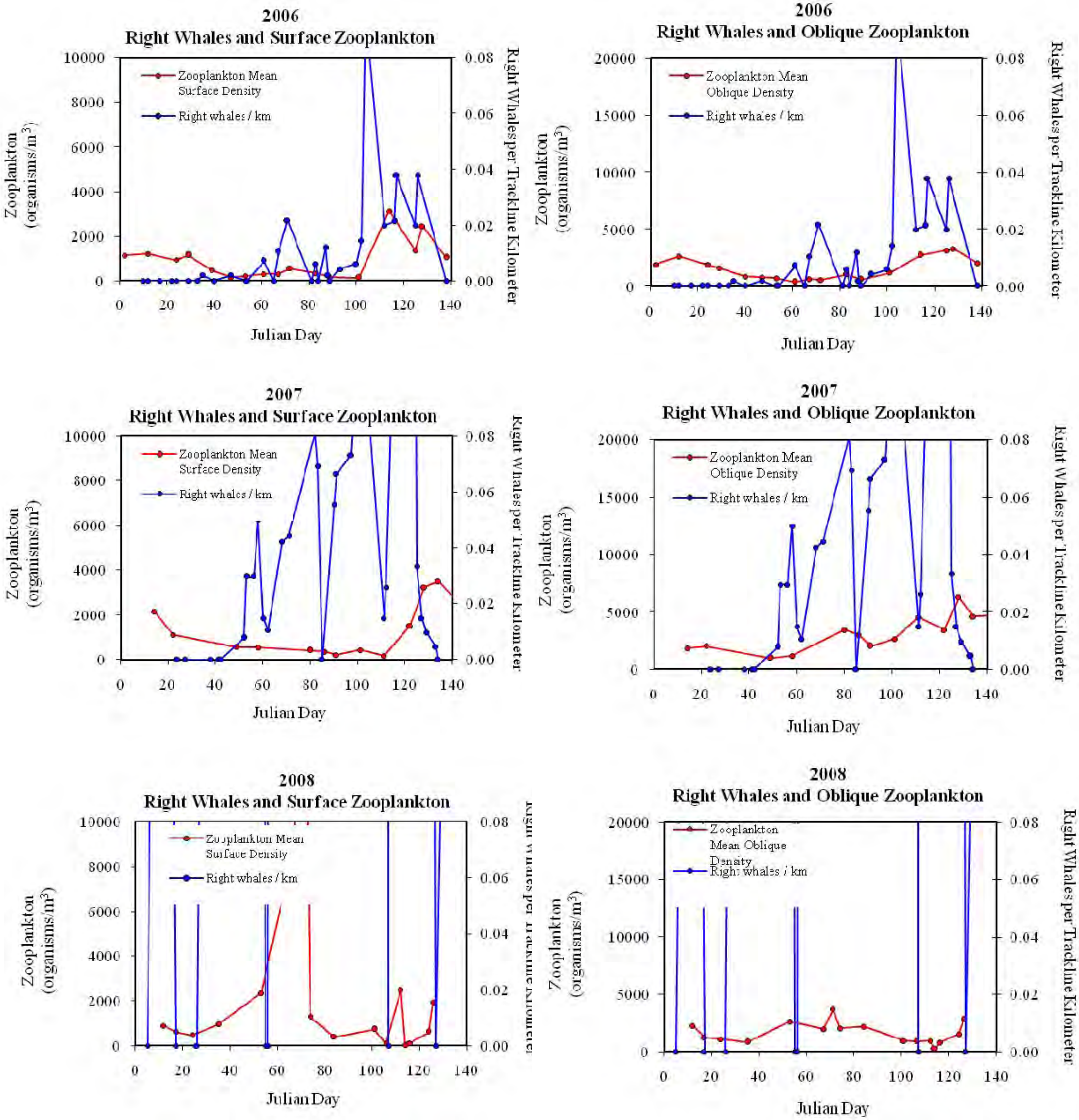
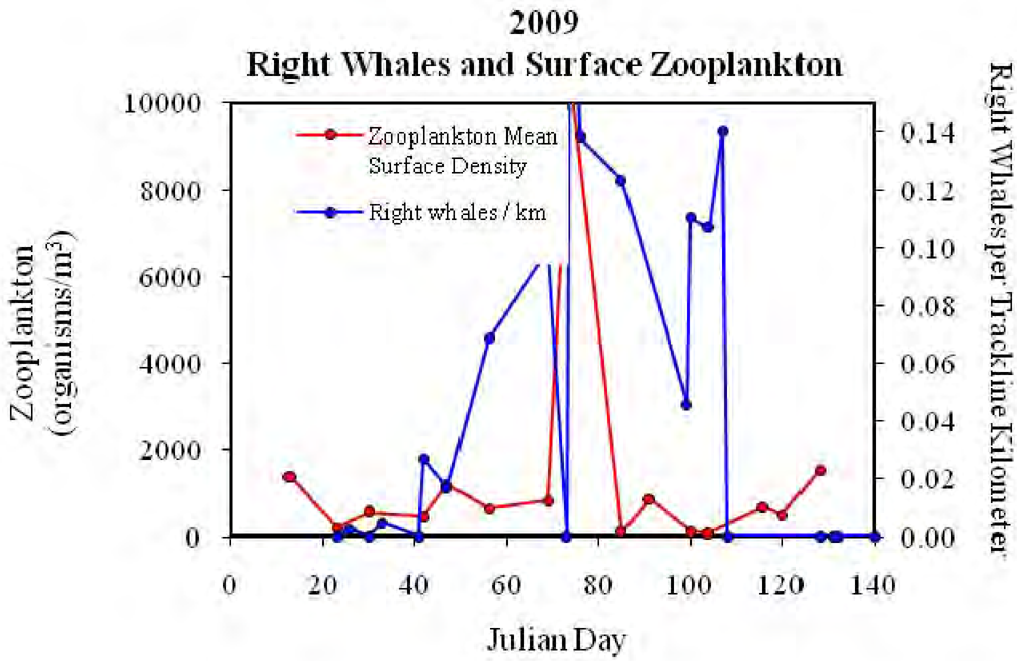



**Figure 11b. Comparison of right whale sightings and daily mean zooplankton densities in Cape Cod Bay, 2006- 2008; surface zooplankton is represented on the left and water column zooplankton is represented on the right. Please note differences in scale.**



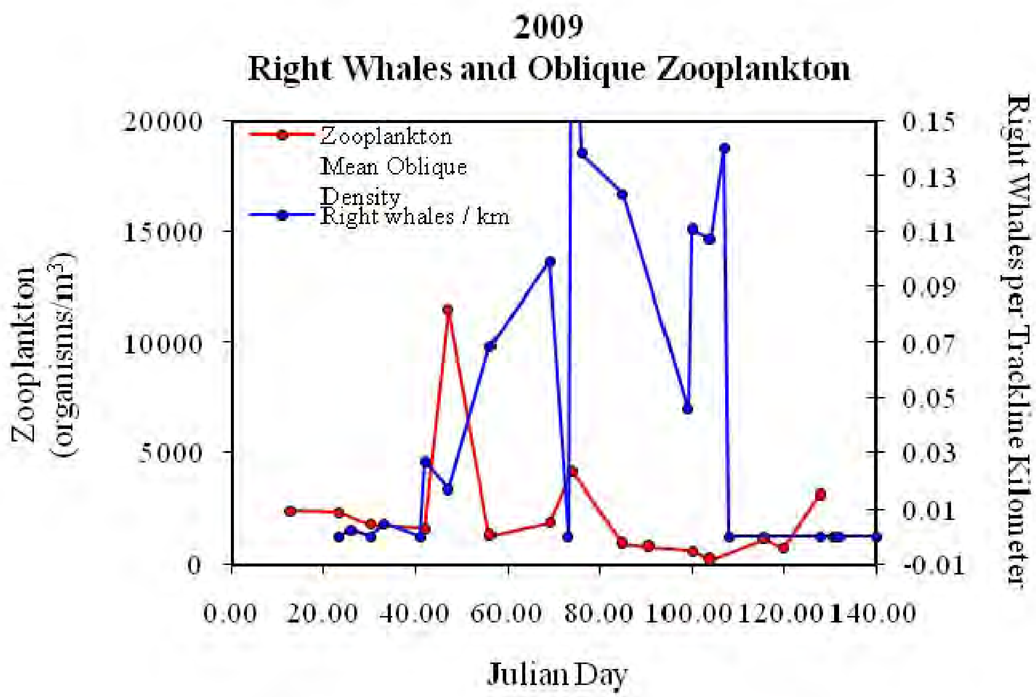




**Figure 11c. Comparison of right whale sightings and daily mean zooplankton densities in Cape Cod Bay, 2009; surface zooplankton is represented on the top and water column zooplankton is represented on the bottom. Please note differences in scale.**

Figure 12 illustrates zooplankton density by Cape Cod Bay quadrant. These quadrant views of the bay demonstrate several previously mentioned aspects of the zooplankton resource that control the right whales in the Bay. Generally, in 2009 the northwest quadrant was more impoverished than the other quadrants of the Bay, supporting the general pattern of resource distribution and the historic record of right whale distribution from the last 20 years. A distinct maximum at the end of the right whale season likely indicates an influx of organisms from elsewhere the Gulf of Maine, since the general Cape Cod Bay circulation is from the northwest. An additional spatial pattern apparent in the 2009 quadrant data is the difference between surface and water column stock of copepods (Fig. 12). As seen in all earlier referenced figures, the water column resource throughout all of the quadrants of the Bay, even during periods of low total resource, exceeded surface concentrations, except for a period at the end of March and mid-April in the southwest, and at the beginning of April in the Southeast. The northeastern quadrant remained consistently somewhat enriched in the water column, as is typical in the bay.

There were a number of noteworthy enrichment events during the 2009 season. In the northwestern part of the bay, enrichment in both the surface waters and water column was documented in mid-May, at the end of right whale season; the enrichment was more significant in the water column than the surface waters. Notable water column enrichment also occurs in mid-March, in the southeastern quadrant, as does a surface enrichment in early April. Most enrichment patterns can be explained by the 1) general counter-clockwise circulation pattern of the bay that starts in the northwest and 2) dominant wind direction. Copepods found in the bay are often advected from other parts of the Gulf of Maine, via this dominant circulation pattern. In May, when coastal waters are enriched with larval organisms and other zooplankton, such as copepods, it is expected to see an influx of planktonic biota in the northwest. Patterns of water column versus surface water enrichment are expected to generally follow those observed in 2009 (Fig. 12). Copepod taxa dominant in the earlier part of the season (February-March), particularly *Pseudocalanus* spp., are known to form bottom layers (Leeney *et al.* 2008; Stamieszkin *et al*. 2008); therefore any significant enrichment seen in the earlier part of the season would be expected to occur in the water column. Contrary, late-season copepods such as *Calanus* spp. are more likely to form surface and subsurface layers (Leeney *et al.* 2008; Stamieszkin *et al*. 2008); these are represented by surface water enrichment in late-March, April and May.

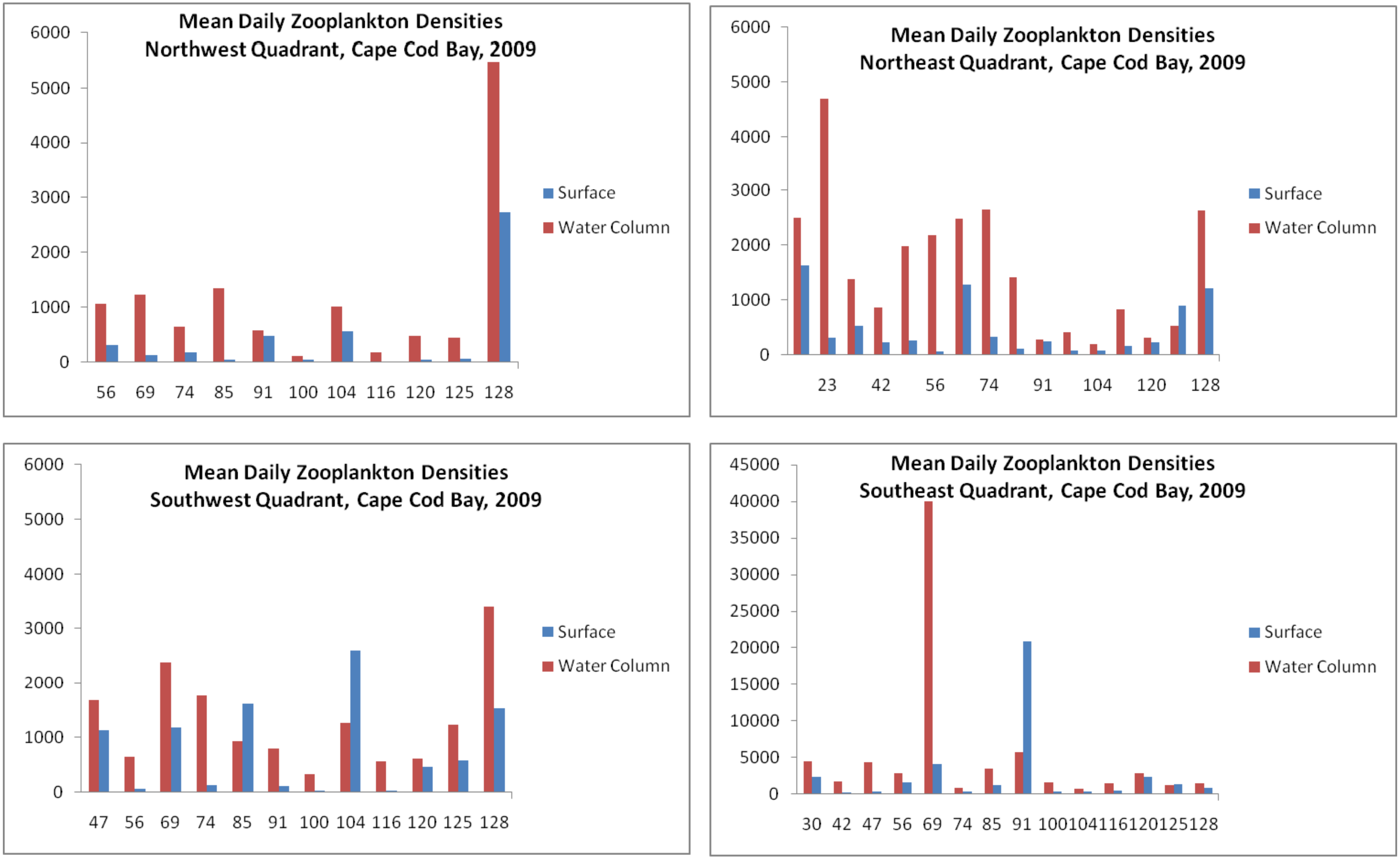



**Figure 12. Temporal progression of the daily mean density of surface and water column total zooplankton in each quadrant of Cape Cod Bay. Note scale difference for southeast quadrant.**

### 2.4.2.4. Zooplankton and Right Whale Distribution and Prediction

We include as part of our results a number of resource descriptions in Appendix I of this report. An interpolated estimation of the spatial density distribution of zooplankton through the 2009 season and the net change in density between any two cruises is found in Appendix I, Figures A1 through A25. These depictions play a central role in the assessment and prediction reports. The color scale was created to indicate, with color change (blue to yellow), when the zooplankton or caloric densities are rich enough to trigger feeding behavior of right whales. This was experimentally determined, but requires future refinement.

Unlike the 2008 season, observations beginning with 13 January 2009 indicated modest resource enrichment in the water column (Fig. A1); resource enrichment in 2008 was not observed until the beginning of February. This early zooplankton resource set a precedent for the displacement of the bay's enrichment cycles by approximately one month ahead of the patterns usually observed (Jaquet *et al*. 2006; Jaquet *et al*. 2007; Leeney *et al*. 2008). This enrichment in the eastern third of the bay does not exceed right whale feeding threshold in the surface waters, but does so in the water column. The lower caloric value seen in the area of organism density enrichment indicates that the organisms are likely small and low in oil content, though locally above caloric right whale feeding threshold at the eastern-middle edge of the survey area.

By 23 January 2009 the enriched water column patch had rotated to the northwest and declined (Fig. A2, A3); the patch no longer exceeded the caloric feeding threshold, though remained above organism threshold. The rotation from the eastern edge to the northwest is likely due to the general circulation pattern of Cape Cod Bay, from the northwest corner, down and around in a counter-clockwise gyre. Surface waters were extremely impoverished and uniform in zooplankton and caloric density at this time. By this time in the year, no right whales had been sighted by the R/V Shearwater.

The cruise on 30 January 2009 was the first during which right whales were documented by the boat-based survey effort; two to three were sighted. They were centered upon an enriched water column zooplankton resource (Fig. A4). While the resource appeared to be above the density-based feeding threshold throughout the southern third of the bay, caloric densities were only above threshold in a small patch, precisely where the whales were located. This suggests that the whales were cueing in on calories, rather than organism density. Surface waters remained relatively impoverished. The change in zooplankton distribution from 23 to 30 January 2009 indicated a strong decline in the resource previously documented in the northeastern quadrant of the bay, and the subtle enrichment of a resource in the southeastern portion of the bay (Fig. A5).

Nearly two weeks later, on 11 February 2009, neither the water column nor the surface water zooplankton resource was above feeding threshold in terms of organism density and caloric density (Fig. A6). Four right whales were sighted; they were not tightly aggregated, likely confirming the lack of exploitable prey patches in the bay. The water column resource remained stronger than the surface water resource, indicating that the whales documented in the bay during the cruise may have been feeding on a water column resource in the time between 30 January and 11 February.

On 16 February 2009 an extremely rich water column resource was documented during a partial cruise, which covered only the eastern half of the bay (Fig. A8). All surface water samples indicated a resource below density and caloric feeding threshold. The right whales were aggregated in small groups spread throughout the mid-eastern bay. The water column resource on which they were feeding was extremely dense and calorically rich. Noteworthy is the fact that the sample taken in the water column at station 6M was relatively impoverished, and that taken at the surface was relatively rich. This illustrates the mechanics of patch-formation; in order for zooplankton to aggregate in one area, it must be pulled away from another area. Likewise, the water column is, for the most part, highly enriched, and the surface is relatively impoverished. One would expect to see this impoverishment-enrichment pattern in both the vertical and horizontal planes when patches of zooplankton have formed. The changes in zooplankton density from 11 to 16 February 2009 confirm the extreme enrichment that occurred in the bay during this time period (A9).

The cruise on 25 February 2009 revealed that the aggregated and enriched resource documented on 16 February 2009 had dispersed (Fig. A10). Approximately seven right whales were sighted, spread throughout the mid to northeastern portion of the bay. The northwestern quadrant was not surveyed. No samples revealed a resource above feeding threshold in the surface waters or in the water column.

The zooplankton resource sampled on 10 March 2009 was characterized by weak surface water patches, concentrated in the northeastern quadrant, and a stronger localized water column patch in the southwest, which was above right whale feeding threshold both in terms of organism and caloric density (Fig. A11). Individual right whales were scattered into the northwestern quadrant and an aggregation of 10-12 whales was documented, presumably exploiting the water column resource near regular stations 6 and 7S, and special station A.

In the time between the cruises on 10 and 15 March 2009, an important shift occurred in the Cape Cod Bay zooplankton resource; the aggregation of zooplankton *generally* shifted from the water column to the surface waters (Fig. A12). This surface resource, which had attracted approximately 18 whales observed by the crew aboard the R/V Shearwater, was concentrated along the eastern margin of the survey area. It represented a highly dense, and extremely rich, resource. It is likely that the resource was advected in and concentrated along the eastern edge of the bay by winds and the bay's general circulation pattern. These changes represented a powerful increase in surface water zooplankton and calories and a small decrease in water column resources (Fig. A13).

By 26 March 2998, 11 days after the documentation of an exceedingly rich zooplankton resource, surface waters were uniformly impoverished, and the patches characterizing the water column were below right whale feeding threshold (Fig. A14). Despite the decreased levels of zooplankton found throughout the bay (Fig. A15), approximately 25-30 right whales were sighted from the R/V Shearwater. They were concentrated in the eastern half of the bay, coincident with the maximum densities of zooplankton; these maxima were still below both density and caloric feeding threshold. It is possible that these whales had been feeding on a rich resource prior to this cruise, and what we sampled was the dwindling remains of the previously rich zooplankton patches. Another explanation for the abundance of whales and lack of zooplankton is that there may have been bottom layers that were not sampled due to our standard surface and water column sampling techniques; no vertical pump samples were taken that would have confirmed the presence of bottom layers.

Sampling during the following two cruises, on 01 and 10 April 2009, revealed localized enriched surface patches of zooplankton (Fig. 16, 18); these patches were generally above both density and caloric feeding threshold. For the first time during the 2009 season, however, a patch that was below density threshold, but above caloric threshold, was observed; this was a water column resource (Fig. 18). It is likely that this change marks the influx of organisms containing more calories, specifically, the copepod *Calanus finmarchicus*. This will be discussed further in the next section. The plots illustrating changes between cruises on 01 and 10 April 2009 again demonstrate the circulation pattern of Cape Cod Bay, as the enriched resource rotates from the southwest to the northeast, in a counter-clockwise direction (Fig. 17, 19). Right whales were generally found throughout the bay, aggregated around the patches of concentrated zooplankton (Fig. 16, 18).

On 14 April 2009, following the development of the localized rich patches seen on 01 and 10 April 2009, a wide-spread patch that coved the southeastern quadrant in both surface waters and the water column was observed (Fig. A20); only the eastern half of the bay was surveyed. None of the resource sampled was considered dense enough to release right whale feeding behavior; however, the resource was above caloric feeding threshold. Indeed, 22 to 27 right whales were observed, primarily subsurface feeding.

During the next cruise on 26 April 2009, almost two weeks following the previous cruise, only a localized patch in the mid-eastern margin of the survey area was observed (Fig. A21). It was spread through both the surface waters and the water column. One whale was observed. Four days later, on 30 April 2009, two whales were observed at the northern edge of the bay, presumably exiting the survey area. No resource above density or caloric threshold was observed (Fig. A22). This universal decrease in zooplankton abundance left background levels low, leaving little possibility for the aggregation of a significant patch (Fig. A23).

On the last Cape Cod Bay survey of the season, no whales were sighted, but a moderate zooplankton resource was observed in the water column, in the northwest and, to a lesser extent, northeastern quadrants of the bay (Fig. A24). This influx of organisms and the coincident lack of whales are not unprecedented. Likely due to competition of other habitats that become enriched at this time, this situation, which contradicts the resource-driven paradigm of Cape Cod Bay, is regularly observed at the end of the right whale season of residency in Cape Cod Bay.

### 2.4.2.5. Zooplankton Summary by Station

The pairs of surface and water column descriptions from individual stations (Fig. A26-A43, Appendix I) reinforce previous comments that:

- The three genera of copepods that have been most implicated in feeding activities followed somewhat the same pattern of enrichment and impoverishment seen in previous years, with the exception of an unusually strong *Pseudocalanus* resource and a somewhat weaker *Calanus* resource than usual. This was observed also in 2008, and may represent a longer-term trend.
- Copepod resources in the southern portion of Cape Cod Bay are more abundant than in the west, particularly middle part of the season of right whale residence.
- Together with plots showing zooplankton density versus caloric density, it is clear that *Calanus* organisms, which tend to occur later in the season, are of higher caloric value, and therefore may represent a significant caloric resource, even when densities are lower than the right whale feeding threshold.
- Other zooplankton organisms besides copepods, such as nauplii, cyprids, molluscs, larvaceans and jellies, represent significant portions of the plankton community at particular times of year.

A side-by-side comparison of the composition of surface and water column samples at the eight stations in the study (Fig. A44-A52, Appendix I) present a different perspective with the same conclusions. Broadly the patterns of species composition tend to be similar, but comparisons between collections from individual stations on any given cruise often reveal intriguing anomalies, most notably when total zooplankton concentrations are impoverished. These treatments show again the consistent difference between surface and water column zooplankton densities are in many cases quite dramatic due to the processes that aggregate background concentrations of zooplankton, as noted earlier.

### Section 2.4.2.6. Fine-scale examination of complex resource patches

From years of observation in Cape Cod Bay, it has become apparent that right whales interact with their habitat at many different temporal and spatial scales. For example, it is likely that right whales use a homing sense of some kind to know when Cape Cod Bay is a suitable feeding habitat; this represents a very broad spatial and temporal scale. When the whales are in the bay, patches of zooplankton coalesce and disperse for biological (Daly and Smith, 1993; Folt and Burns, 1999) and physical reasons (Costa *et al*. 2006; Daly and Smith, 1993), they cue in on zooplankton density, or as we suggest in this report, caloric value; these processes occur at smaller spatial and shorter temporal scales. In continuation of the work begun in 2008 on small-scale vertical distribution processes of zooplankton (Leeney *et al*. 2008), activities were undertaken in 2009: 1) a study of zooplankton vertical distribution from daylight to dark, and 2) a statistical analysis of all complete vertical profiles sampled since the habitat studies program began taking vertical discrete depth pump samples, 15 years ago.

**2.4.2.6.1 Daylight to dark study**

On 25 February, three complete vertical zooplankton profiles were sampled: at 15:17 (A), 17:45 (B) and 19:02 (C); the top six meters of profile C were re-sampled at 20:10 (D). These samples spanned daylight to complete dark. In all samples, *Pseudocalanus* was the most abundant organism. The sampling stations were clustered in the middle-eastern part of the bay, in the vicinity of approximately ten feeding right whales. The goal of this study was to begin the exploration of diel vertical migration in Cape Cod Bay, its effect on right whales' use of the water column over day to night cycles, and the subsequent changes in anthropogenic risk over time.

During the course of sampling, the resource that was concentrated on the seafloor at the onset of the study spread throughout the water column during and after dusk, and continued to concentrate toward the surface at the night progressed; it appears that the *Pseudocalanus* resource exhibited the afternoon and early evening onset of classic diel vertical migration during this directed study. It is likely that the whales were foraging on the rich bottom layer before dusk, and then stopped when the layer dissipated as the zooplankton ascended in the water column, reflected by the change in the whales' dive intervals. Because the wind came up as the sun began to set, surface layers of zooplankton at dusk and after were mixed downward, and therefore not dense enough to release skim feeding activity. Earlier this year however, on a day coincident with our sampling of a dense bottom layer (11 February 2009), right whales were observed by Massachusetts Environmental Police skim feeding at dusk. We surmise that because there was little to no wind that day, a dense surface layer of zooplankton was able to form, whereas during the vertical sampling of cruise SW733 (25 February 2009), there was significant surface mixing as the resource reached the upper portion of the water column. In the future, we plan to continue sampling later into the night to determine whether the whales do feed as the surface zooplankton concentrates, and to document environmental/oceanographic mechanisms (wind, mixing) operating to concentrate or dissipate zooplankton at the surface.

These initial observations coupling whale behavior with the diel movement of the zooplankton resource, along with indications that DVM activity may vary by zooplankton species, open a new and important area for investigation with considerable management implications. Given that the horizontal distribution of zooplankton can be predicted and is directly linked to the distribution of right whales in Cape Cod Bay, we have come to understand that overlap of right whales and anthropogenic industrial activities, and hence risk of ship strike and entanglement, can be forecast on relatively small horizontal scales. Our DVM observations during cruise SW733 add another essential component to the evolving understanding of the risk posed to right whales by shipping and fishing activities. These and future efforts to document cyclic changes in the vertical profile of the zooplankton resource in Cape Cod Bay will allow us to examine the impact that such changes have on the vulnerability of whales to the principal anthropogenic causes of their mortality over time. Investigation of DVM and its influence on right whale behavior, particularly during the night, should provide substantial insights into the shifting risks of ship strike and entanglement in lines both in the water column and along the sea floor, by improving our understanding of the proximal conditions under which these grave events occur.

For more specific descriptions of this preliminary study, see Appendix IV, page 42.

#### 2.4.2.6.2 Statistical analysis of vertical profiles

The prediction of right whale behavior is essential to managing risks to these endangered whales. Quantifying the interaction between right whales and their habitat under a resource-driven paradigm provides the information necessary to determine environmental factors that are correlated to right whale behaviors, and associated risk. For fifteen years, between January 1994 and May 2009, vertical zooplankton profiles have been sampled during the time of right whale residency in Cape Cod Bay. Using 202 vertical profiles and associated metadata, we asked whether characteristics of zooplankton sampled in the vicinity (<100m) of right whales could be predictors of right whale behavior. Four categories of behavior were examined: skimming, sub-surface feeding, diving and a "social/other" category of non-feeding behaviors. We characterized vertical profiles by maximum zooplankton density, depth of that maximum, proportion of the three dominant copepod genera (*Calanus*, *Pseudocalanus*, *Centropages*) at the zooplankton maximum, evenness of the vertical distribution of zooplankton, and time of day at sampling. Several of these variables were correlated, so we used cluster and discriminant analyses rather than linear models. Cluster analysis classified most samples according to their associated whale behavior; discriminant analysis presented the coordinates of the four behavior groups in relation to the resource variables.

Results include: 1) Skimming and sub-surface feeding are positively related to the proportion of *Calanus* and negatively with depth of the zooplankton maximum; 2) Diving is positively related to depth of the maximum, while social behaviors are related to the proportion of *Centropages* at the maximum. 3) Skimming is positively related to time of day. The results show that the distribution and quality of food resource can be used as indicators of whale behavior, and of the types of risks to which they are exposed.

## 2.5 Other Habitat Studies Activities, 2009

### 2.5.1 Study of Caloric Capture by Right Whales

The right whale population is threatened not only by ship strike and entanglement, but also by low reproductive rates. A potential cause of this could be nutritional. Right whales need a certain amount of calories to reproduce. Therefore, it is necessary to understand how they attain calories from their environment. During the past two years, the habitat studies program conducted flume studies to simulate the function of right whale baleen in the lab, and to examine the caloric "capturability" of particular prey taxa. In order to estimate caloric availability, PCCS employed refined Mayo *et al.* (2001) techniques. These techniques documented the zooplankton filtering efficiency of the baleen of a North Atlantic right whale and defined their trophic requirements through a series of experiments designed to examine the food capture characteristics of the species (Mayo *et al.* 2001). The food filtering efficiency of the baleen of an immature right whale was tested in a flume using mixed samples of calanoid copepods (zooplankton). Water was pumped through the baleen at approximately the velocity of a feeding right whale (0.188m $sec^{1}$), various size fractions of mixed species of copepods were then injected into the flume (Mayo *et al*., 2001).

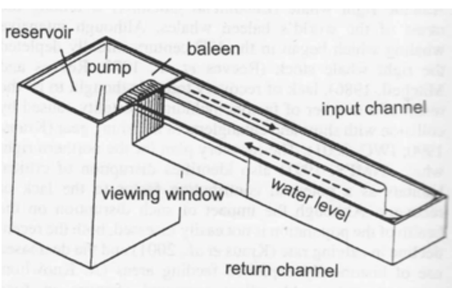


Figure 13. Baleen flume experiment

The zooplankton organisms that passed through the baleen represented those that the whale would not capture and were therefore a lost nutritional resource. Organisms that did not pass through the baleen represented a captured nutritional resource for the feeding whale. This study, however, did not define the filtering characteristics of specific species, taxa, life stages and sexes of zooplankton. In order to gain a fine scale understanding of what the whales are consuming, PCCS isolated the zooplankton samples by species, taxa, life stage and sex and then ran the samples through a refined flume experiment to estimate right whale prey consumption. The caloric availability of the zooplankton was then estimated by applying baleen filtration efficiency data, density and caloric value information. This process can be described with the following formula:

$$Ca = (Eb \times Ef\ O \times Cv)$$

Where:
E*b* is capture efficiency baleen
E*f* is capture efficiency refined flume experiment
O is number of organisms/$m^3$
C*v* is caloric value (Calanoid copepods based on DeLorenzo Costa *et al*., 2006)

The results of this experiment have allowed partial correction of historic data for caloric "capturability," however, further efforts are required to complete the study.

### 2.5.2 Modeling Zooplankton Patch Formation and Right Whale Foraging

Forecasting the co-occurrence of whales and the risk of ship strike and entanglement is the foundation of the conservation of right whales. The assessment and forecasting reports made available to DMF during the season of right whale residency are an example of a distribution forecasting method that combines an understanding of the foraging strategies of the whales with near-real-time collection of data on food resource. Using the foraging paradigm developed in previous years in Cape Cod Bay, we completed the construction and testing of a demonstration computer model that produces both graphic and numeric forecasts of whale distribution and demonstrates a method for forecasting the temporal and spatial potential for ship-strike and entanglement risk. The demonstration Distribution And Risk Simulator (DARS) subsumes the variety of information collected during the cruises reported here and combines such information with foraging strategy algorithms developed over the last 10 years to produce dynamic forecasts of whale movement in Cape Cod Bay along with an estimation of ship strike risk out to 3 weeks. The construction and validation of a refined and fully developed model built on the principals included in DARS will likely present new opportunities to advance a capacity to forecast and manage the principal risks to right whales in Cape Cod Bay.

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## SECTION 3: Recommendations for the 2010 right whale surveillance season, and future research efforts

### 3.1 Habitat Studies

The work done in 2009 by the right whale habitat studies program represents a number of preliminary projects that, if funded, could be fleshed out into complete independent studies: work on diel vertical migration (DVM) and associated patterns of right whale behavior, re-formatting and statistical analysis of historic data, continued work on right whale energetics, and continued efforts to model the dynamics between right whales and zooplankton, and their environment. Each is described in detail below.

The project conducted during cruise SW733, on 25 February 2009, to investigate whether zooplankton in the bay undergo DVM during daylight to dark periods, confirmed that more work must be done to understand this dynamic. There are many environmental factors effecting whether DVM occurs, including surface water mixing, tidal flow, wind patterns, and more (Costa *et al*. 2006; Daly and Smith, 1993). There are also biological factors; some copepod genera are more likely to migrate than others (Daly and Smith, 1993; Folt and Burns, 1999; Thorisson, 2006). In order to document DVM as it is affected by the factors above, daylight to dark studies must be completed under a number of different conditions, at different times throughout the season. In addition, the whales' behavior must be documented in more exact terms. Currently the ability to record whale behavior is limited to what can be observed at the sea-surface. New D-tag technology, however, allows scientists to collect a number of parameters regarding a whale's behavior, including depth, speed, tilt, etc; this has proven a successful technique for confirming whether right whales are feeding on a particular zooplankton layer or patch (Baumgartner and Mate, 2003). The potential for collaboration, in 2010, with a team that has D-tagging capacity is currently being explored. Funding for a complete DVM study is also currently being sought.

The database of information collected by the right whale habitat studies program contains data on right whales and zooplankton from the past 25 years. Due to the duration of the study and number of different people who have been responsible for the data, the information is not consistently formatted, is contained in multiple files, and therefore cannot be comparatively used across the entire timeframe of the study. Reformatting of the database into one useable entity is necessary. It is the hope of the program to attain funding to support these activities so that the database may be used to its full potential, for example to look at long-term ecosystem trends.

The work done on the historic log of vertical profiles and right whale behavior, described in section 2.4.2.6.2, is an example of what can be learned when historic data is stream-lined and statistically analyzed. Another important element of right whale foraging, which could be described best by statistical analysis of the entire database, is the question of right whale feeding threshold. To date, the feeding threshold used for right whales is based upon organism density, and is an estimate at best. If the 25-year old database were revised and analyzed, it would likely result in a number of findings, including a more accurate right whale feeding threshold. The importance of such a value lies in the prevention of ship strike and entanglement, as it has been asserted that right whales are at greatest risk when they are feeding (S. Mayo, pers. comm.).

Right whale population recovery depends not only on the reduction of ship strike and entanglement risk, but also that the whales' energetic requirements are met. Without enough food, right whales cannot reproduce. In a changing marine environment, it is important to know which zooplankton organisms provide most of the right whales' food, and how that may change over time. The long-term study of copepod taxanomic composition could aid in this question, as well as the study of right whales' ability to capture their food. Therefore, it is not only necessary that the right whale habitat studies program complete its database, but also that the flume studies begun during the last two seasons be completed; the habitat studies program is currently looking for funding to support this work. The information gleaned from the flume studies would enable scientists to know exactly how many calories right whales receive from different types of food, as well as how a change in that food might affect the whales' reproductive capacity, health and resilience.

### 3.2 Right whale aerial surveillance

Based upon efforts to combine and analyze datasets, the importance of coordination between the two right whale programs has become clear. In order to use aerial and habitat data to gain a more complete picture of right whales' and their environment, all efforts must be made so that a maximum number of cruises and flights occur simultaneously. Due to the mobile nature of right whales, and the ephemeral nature of their prey, comparative studies can be done best at fine scales, with spatially and temporally coincident data. During the 2009 season, efforts were made to increase the overlap between flights and cruises. These efforts will be continued in the future, so that the PCCS right whale studies may be as accurate as possible in describing the relationship between these whales and their habitat.

The CCB ecosystem is one of five known, seasonal high-use habitat areas for right whales in the western North Atlantic, the others being along the southeast coast of Florida and the Great South Channel in US waters, and the Bay of Fundy and Roseway Basin in Canadian waters. Over two-thirds of western North Atlantic right whales aggregate seasonally in one of these habitats (Kraus & Rolland 2007). However, right whales do not show strong site-fidelity to these identified habitats. Photo-identification and several satellite tagging studies (Baumgartner & Mate 2005) have shown that seasonal movements into, out of and around the critical habitat areas occur frequently. Right whales do not engage in a 'migration' in the way that many other species of large whale (such as humpback whale) do. Whilst pregnant female right whales migrate to the coastal waters of the southeast US with several non-calving females and juveniles, most of the population, including the vast majority of males, is absent from this region during the winter. Where these whales are located during winter months is unknown, despite comprehensive monitoring within Cape Cod Bay, the species calving grounds in the southeast, and areas of transit in between. The wintering grounds likely constitute the mating grounds for right whales, as current evidence suggests a mid-winter conception (Kraus & Rolland 2007). For over two decades, researchers have attempted to ascertain the location of these mating grounds.

Recently, surveys over Jeffrey's Ledge and Jordan Basin in early winter have detected concentrations of right whales in these areas (Weinrich *et al*. 2000). Cole *et al*. (2009) documented a high concentration of right whales in Jordan Basin during the winter in recent years (2004-2007). They suggest that sightings of females in this region, who were a year later sighted with calves, and the high proportion of known fathers in this region relative to other right whale habitats, indicates that this area may be mating ground. Identification and protection of mating grounds for this species is a key concern for the future. In collaboration with the Whale Center of New England (WCNE) and UMass Boston, a project has been initiated to investigate the use of both JL and CCB habitats by individual right whales, and the link between food resource and patterns of abundance in both areas. This study constitutes an important step towards further confirming the importance of Jeffrey's Ledge (JL) as a right whale habitat, and identifying its links with another critical habitat, that of Cape Cod Bay.

Questions:

1. *What proportion of right whales sighted on JL in any given year (Sep-Nov) are subsequently sighted in CCB (Jan-May)?* We are carrying out a joint analysis of the boat-based photo-identification data, collected by WCNE, on right whales on JL during the autumn and early winter, with data collected by the PCCS aerial survey team in CCB, to address this question.
2. *Can we link patterns of (a) presence/ abundance, and (b) behavior, with resource quality (i.e. plankton), in each habitat?* The above-mentioned collaboration with WCNE will also involve an assessment of the plankton data they collect during their surveys, and comparative analyses with the CCB plankton data collected by the PCCS habitat survey team.
3. *Can we ascertain whether right whales utilize CCB and JL simultaneously?* Since we often observe right whales moving in and out of CCB multiple times during our winter-spring field season, it is likely that they utilize other, nearby habitats during the time period; JL is one of the closest discrete habitat areas in this region. This could be best investigated by running fine-scale aerial surveys over JL during the same study period as for CCB, and is thus primarily funding-limited at present.

Further questions relating to behavior, such as whether SAG behavior on JL coincides with the winter conception timing, would also provide valuable information which would add to our understanding of the life cycle of North Atlantic right whales and the critical habitats for this species. In 2010, funding proposals will be prepared, targeting more flight hours or potentially an extended aerial survey season, in order to extend the study area covered by PCCS aerial surveys in order to address some of these exciting and pertinent questions. An extension of the availability of the aerial survey team and plane would also greatly assist other PCCS programs, especially the disentanglement team.

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