Surveillance, Monitoring and Management of North Atlantic Right Whales in Cape Cod Bay and Adjacent Waters - 2006

Final Report

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EXECUTIVE SUMMARY

In 2006, the right whale surveillance program supported by the Commonwealth of Massachusetts Division of Marine Fisheries (DMF) was conducted in Cape Cod Bay and adjacent waters from 1 January through 18 May by the right whale research team at the Provincetown Center for Coastal Studies (PCCS). The program included bi-weekly aerial surveys and weekly habitat sampling. Upon completion of each survey, all sightings were reported to the NOAA Fisheries Sighting Advisory System (SAS) and the US Army Corps of Engineers Cape Cod Canal Field Station.

During the 2006 winter and spring season, PCCS observers performed 36 aerial surveys totaling 170 hours of flight time covering Cape Cod Bay and the near-shore of the outer shore of the cape.

Right whales were observed in Cape Cod Bay for 91 days, from 29 January through 8 May. This period of occupation of the Bay is only slightly longer than in 2004 (90 days) and 2005 (86 days). In 2006, a total of 305 right whale sightings were recorded from all platforms, of which 290 were photographed representing 99 different individuals. Although most identification photographs have already been matched to the existing right whale catalogue by two independent experienced researchers, most of the matches are still awaiting final confirmation by the New England Aquarium, and the results outlined in the present report may change slightly once confirmation is obtained.

In 2005, more right whales than average visited CCB (78 individuals versus an average from 1998 to 2004 of 60) but their average individual residency time (excluding gaps when not sighted during three or more surveys) was substantially shorter ($\bar{x}$=5 days) than the project average (11 days). This shorter individual residency time was likely related to the somewhat low zooplankton density throughout the season. It is therefore interesting to note that despite lower food resources in 2006 and shorter residency time, a larger number of individual whales visited CCB and the adjacent waters. In 2006, a large number of individuals were observed on the two tracks just north of CCB (39), and in adjacent waters (32), therefore showing a similar pattern of distribution than in 2005.

Six mother and calf pairs were sighted in CCB and adjacent waters. The residency time of mother and calf pairs was substantially longer than of single females and the residency time of single females was also substantially longer than that of single males. This result was consistent with that of all previous years (1998-2005) suggesting that CCB is an important nursery area and that the habitat is more intensively used by females than by males. In 2006, the highest proportion of mother/calf pairs (31%) since the beginning of the project were recorded in CCB, and there was a significant trend in the last four years for an increase in proportion of mother/calf pairs visiting CCB. This result may suggest that CCB is becoming more and more important as a nursery area for very young calves.

In 2006, a large proportion of right whales were observed in the south-west corner of the Bay and around Race Point. This is in contrast to 2004 and 2005 when most sightings were more to the east. The west part of the Bay is subjected to intense boat traffic and thus a residency in this part of the Bay renders the whales more susceptible to ship strikes.

Results from analyzing the data for the entire project (1998-2006) reveals that part of the right whale population shows significant preference for CCB, and demonstrate the frequent whale movements in and out of CCB, movements during which individual right whales may be particularly at risk of collision with ships as they may be crossing the Boston shipping lanes and are traveling in areas devoid of protection. Furthermore, our results suggest that the individuals that are observed in large numbers east of CCB during some years are usually not observed in CCB and seem to be transiting to or from another area. In general, right whale abundance increases slowly during January and February with an average of 3 and 6 individuals per survey/day respectively, peaks in March and April with just over 10 individuals sighted during each survey, and drops dramatically in early May, with only 1.5 individual sighted per survey. This study also demonstrates that individuals stay in the Bay for an average of 10-20 days and that during this time they move on average 13 km from the beginning to the end of their residency period.

Three previously entangled whales were sighted during the 2006 season; an updated assessment on the condition of these three whales (#s 3346, 1167 and 2320) is presented. Piper (#2320) had also been sighted in CCB in 2004 and 2005, she is presently gear-free.

The habitat sampling program in 2006 focused on further developing the method for assessing the quality of the Cape Cod Bay food resources, building on previously developed methods for assessing and reporting on the quality of the feeding environment. A total of 288 zooplankton samples were collected from the eight regular and additional directed stations in support of the habitat assessment effort. During the 2006 season we developed a new "Preliminary Assessment and Alert of Right Whale Risk" report to rapidly inform DMF of potential conflicts with shipping or fishing activities as forecast by analysis of movements and activities of whales associated with zooplankton patches. Examples of the close association between the habitat assessment activities of the surveillance program and management actions taken by DMF are presented. The close interaction and rapid response of the assessment studies and the DMF managers resulted in several advisories intended reduce the risk to whales forecast to enter and remain in areas where high vessel traffic places whales at risk of ship strike.

During the 2006 season, the increasing sophistication of habitat assessment techniques resulted in a refined examination of the relationship between whales and food patches and encouraged the advancement of new concepts of the interaction of zooplankton composition with whale behavior, concepts that have important implications for managing the threats to whales. In particular, the different vertical distribution of various taxa of copepods that are found in Cape Cod Bay suggest that the greatest risk of mouth entanglement in fishing ground lines above the bottom is likely during the mid winter and early spring when *Pseudocalanus* dominates the resource, while the greatest threat of large-vessel ship strike probably occurs in early spring through summer when *Calanus,* a taxon that forms mid water layers, predominates. While there are exceptions to the depth of layering that we perceive, it is likely that natural cycles of zooplankton dominance detailed in the report have significant implications for the kind, location, and seasonality of various threats to right whales.

During the 2006 assessment period specific changes in the composition of the zooplankton resource are hypothesized to have influenced the location and occurrence of whales. Throughout the first 100 days of the 2006 season the zooplankton resource was impoverished, largely because the two taxa of copepods that usually form the mid-winter food patches, *Centropages* and *Pseudocalanus,* did not appear in the abundance usually found in mid winter. However, despite this low resource, whale density in March was almost as high as during the peak density in 2005, but residency time in the Bay was lower than average during the entire season, including during late April when resources were high. During the entire winter throughout the bay all four zooplankton measures used in the assessment instrument remained below that of previous years, similar only to the general pattern documented in 2004 when a deep valley in the mean zooplankton density in February and weak productivity of the two winter taxa was documented.

Dramatic changes in the food resource occurred in late April and were coincident with the influx of whales reported by vessel and aircraft surveillance teams. The zooplankton resource was apparently enriched by resources entering the bay, probably from regions northeast of Cape Cod. During the period from April through the first week of May two aggregations of whales mapped over dense mid-water and surface concentrations of zooplankton dominated by the usual late season copepod taxon *Calanus finmarchicus*, a resource dominated by the energy-rich 5^{th} copepodite stage. Both areas of aggregation were subject of Alerts sent to DMF that triggered management advisories to federal and state agencies warning of a risk of ship strike and the need to exercise caution in the areas of high food resources. The area west of the critical habitat identified in the PCCS Alerts is occasionally occupied by right whales, however this pattern was also seen in 2005 and could, if persisting over several years, present new problem for management of both shipping and fishing in the area west of the federally designated Cape Cod Bay Right Whale Critical Habitat.

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GENERAL INTRODUCTION

The Cape Cod Bay ecosystem is one of five known seasonal high-use habitat areas used by right whales (*Eubalaena glacialis*) in the western North Atlantic. The Critical Habitat for the North Atlantic right whale in Cape Cod Bay was federally designated in 1994 (Federal Register 59 FR 28793) in recognition of the seasonal importance of the Bay as an important feeding, socializing, and nursery area for the species (Watkins and Schevill 1979, Schevill *et al.* 1986, Hamilton and Mayo 1990, Mayo and Marx 1990, Kraus and Kenney 1991), and a habitat seasonally visited by a number of cows that are rarely seen in the other three northern habitat areas (Knowlton *et al*. 1992, Brown 1994). Cape Cod Bay has a long history as an important habitat area for right whales. Photographic identifications date from 1959 (Hamilton *et al*. 1997) to the present, and whaling records provide evidence of right whales in this area 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).

Since the 1980s, right whales have been known to occur in Cape Cod Bay and adjacent waters[*] in all months of the year, with the peak of occurrence from February through April (Schevill *et al.* 1986, Winn *et al.* 1986, Hamilton and Mayo 1990, Payne *et al.* 1990, Brown 1994). Survey data collected in the last two decades suggest annual variation in the numbers of whales visiting the Bay. 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). Expanded surveillance and monitoring efforts in the winter and spring over the last nine years (1998 – 2006) have confirmed that Cape Cod Bay and adjacent waters are usually important feeding, nursing and socializing areas from late December through early May for as many as 95 individuals during some years, almost a third of the known catalogued population (Brown and Marx 1998, 1999, 2000, Brown *et al*. 2001b, 2002, 2003, Mayo *et al.* 2004, Jaquet *et al.* 2005).

Range-Wide Concerns

Despite international protection from commercial hunting since 1935, the North Atlantic right whale is the most endangered large whale in the world. No more than 350 remain (CeTAP 1982, Brownell *et al*. 1986, Kraus *et al*. 1988, NMFS 1991, Knowlton *et al*. 1994, IWC 2001, Kraus *et al*., 2005). In the United States, the northern right whale is listed as "endangered" under the Endangered Species Act (ESA) of 1973. Scientists and conservationists have long been concerned about the status of the North Atlantic right whale population and its slow rate of growth (about 2.5% per year in the 1980s, Knowlton *et al*. 1994). Furthermore, recent analyses showing a decrease in the reproductive rate (fewer calves per mature female per year), an increase in the calving interval (Kraus *et al*. 2001, Kraus 2002), and a decline in the survival rate (Caswell *et al*. 1999, Fujiwara and Caswell 2001, Kraus *et al.,* 2005) suggest we should view the present situation with increasing concern.

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[*] Adjacent waters include those state waters outside of the Cape Cod Bay Critical Habitat and federal waters over Stellwagen Bank/Wildcat Knoll in Massachusetts Bay, as well as those east of Cape Cod.

The apparent failure of the North Atlantic population to recover has also been attributed to anthropogenic factors including mortality from collisions with ships and entanglements in fixed fishing gear (Kraus 1990, Kenney and Kraus 1993, Knowlton and Kraus 2001, Kraus *et al.*, 2005). A total of 73 right whale deaths were documented from 1970 through September 2006 (Knowlton and Kraus 2001; New England Aquarium unpublished data). Of those 73 mortalities, 27 (37%) were attributed to ship strikes, eight (11%) were a result of entanglement in fixed fishing gear, 21 (29%) were adult and juveniles that died of unknown causes, and 17 (23%) were calves that died of neonatal or unknown causes. In 2006, the toll on right whales was high with at least four calves dying in the first few months of their life and two adult females being hit by ships. Ship collisions kill more right whales than any other documented causes of mortality and more than half of the ship collision mortalities have been recorded since 1990. Entanglements, however, can result in long-term deterioration of health and may be responsible for more deaths than previously thought (Knowlton and Kraus 2001), so that entanglement may be equally responsible for right whale deaths as ship collisions (Kraus 2002). In addition, many animals disappear from the population (The New England Aquarium uses the metric “presumed dead” when a whale is not photographically identified for more than 6 years; this number stands at 121 in August 2006, Hamilton *et al*. 2004, Philip Hamilton pers. com), and it is obvious that not all deaths are seen on the beach (Knowlton and Kraus 2001). Based on the aforementioned information Caswell *et al*. (1999) estimated that if human - caused mortality is not reduced, the North Atlantic right whale population could become extinct in less than 200 years. Upon further analysis, Fujiwara and Caswell (2001) suggested that preventing the death of only two female right whales per year could increase the population growth rate to replacement level.

Right Whales in Cape Cod Bay and Adjacent Waters

The use of the Cape Cod Bay ecosystem by right whales has occurred for hundreds of years (Reeves *et al*. 1999, Reeves *et al*. 2002). Since the cessation of whaling in the late 1800s, other relatively recent human activities have affected the right whales using the area. Right whales are slow moving (particularly when accompanied by a calf) and very difficult for vessel-based observers to see when the whales are feeding at or just below the surface. 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 Critical Habitat with the Cape Cod Canal one of three entrances into the Port of Boston. There are about 550 transits annually by inbound and outbound vessels through the canal and along the western portion of the Bay (Kite-Powell and Hoagland 2002). The habits of the whales and the moderate level of ship traffic in the region make the right whale vulnerable to collisions with vessels in Massachusetts waters. Knowlton and Kraus (2001) documented two right whales that were likely killed by collisions with ships near this area, one in 1986 (found off Provincetown), the second in 1996 (found near Wellfleet). A third right whale was found dead in Cape Cod Bay in April 1999. A necropsy showed that the cause of death was blunt trauma, likely the result of a collision with a ship (Brown and Marx 1999). In all three events, the location of the collision between vessel and whale was not known. Modeling work using data collected during previous years of this project has been performed to identify areas of potential risk to right whales from shipping traffic in the Bay (Nichols and Kite-Powell 2005). The model has shown that an average of seven large (>65’) vessels transited Cape Cod Bay each day to and from the Cape Cod Canal, the highest volume of which is bound to or from Boston (four/day) and ports in the northern Gulf of Maine (two/day). Furthermore, the results of the simple two-dimensional model suggest that there are approximately 1.5 expected ship/whale encounters (assuming whales are always at the surface and no avoidance behavior is attempted by whales or vessels) in Cape Cod Bay each year; Boston traffic contributing about 46% of this risk, and Gulf of Maine traffic ~35%. Large commercial fishing vessel transits contribute an additional 0.4 expected encounters in Cape Cod Bay each year if assumed to follow the same route as Gulf of Maine traffic, generating a combined total of 1.9 encounters per year (Nichols and Kite-Powell 2005).

Right whales are at risk of entanglement in fixed fishing gear in the area. In response to this risk, the Division of Marine Fisheries, Commonwealth of Massachusetts (DMF) has taken management action to mitigate the threat to right whales. Under DMF management gill nets have been prohibited and the use of modified gear is required in the Cape Cod Bay Critical Habitat area. These gear modifications include sinking or neutrally buoyant ground line between lobster pots, traps set in trawls of four pots or more with vertical buoy lines on each end or in "doubles" where two pots are strung together with only one buoy line, and a 500-pound break away link in all buoy lines (322 CMR 12.05 Critical Habitat gear restrictions during January 1 to May 15). The modified gear is marked with twin orange flags on the buoy stick. Most of the fixed fishing gear set in the Cape Cod Bay Critical Habitat area during the survey period is located in the northern margins in depths greater than 30 fathoms. Fixed fishing gear is also set to the west of the western margin (070° 30' W) of the Critical Habitat in state waters where only a few right whales have been reported west of the critical habitat area in the past (Brown *et al.* 2003, Mayo *et al.*, 2004). Until recently fisheries in the western bay were not subject to the above gear restrictions because the area is outside the federally designated critical habitat area. Gear in the western portion of the bay was included in the above restrictive regulations as of January 2003. In addition to the above conservation measures, a Division of Marine Fisheries "ghost gear removal program" is carried out in the winter months in order to further reduce entanglement risk.

Over the last twenty years, more than 70% of the catalogued population of right whales has been photo-documented in Cape Cod and Massachusetts Bays at some time during their lives (PCCS and NEAq, unpublished data). These photographic data have been collected by various means. Recent survey efforts include twice-weekly aerial surveillance flights and weekly vessel-based habitat monitoring cruises conducted annually from January to mid-May during 1998 to 2006 as part of the program described in this report (Brown and Marx 1998, 1999, 2000, Brown *et al*. 2001b, 2002, 2003, Mayo *et al.,* 2004, Jaquet *et al.*, 2005). Prior to 1998, there were weekly vessel surveys and limited aerial surveys in the winter and spring in 1997 (Hamilton *et al*. 1997, Mayo 1997) and annual studies on foraging of right whales in the winter and spring since 1984 (Mayo and Marx, 1990). Researchers gathered opportunistic sightings from whale watching vessels from April through October from the late 1970s until 1996. The latter platform, which yielded many valuable sightings of right whales (including some rarely seen mothers with calves) in the spring, summer and fall (NEAq unpublished data), and reports of entanglements, is no longer available due to a state- and federally-mandated 500-yard exclusion zone around right whales for non-permitted vessels.

Program Objectives – 2006

To gain a better understanding of both the spatial and temporal distribution of individually identified right whales in Cape Cod Bay, an extensive surveillance and monitoring research program that was begun in the winter and spring of 1998 and has continued for the past nine years (Brown and Marx 1998, 1999, 2000, Brown *et al*. 2001b, 2002, 2003, Mayo *et al*. 2004, Jaquet *et al*., 2005, this report). 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 in the federal Atlantic Large Whale Take Reduction Plan, the Right Whale Recovery Plan (NMFS 1991), and the ESA. This report consists of the results of the research activities conducted in 2006 as described below. The objectives of the 2006 surveillance, monitoring, and management program in Cape Cod Bay and adjacent waters were:

I) 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 age, sex, reproduction, distribution, abundance and patterns of habitat use (residency) of right whales in Cape Cod Bay and help refine long-term, range-wide analyses on presumed mortality, incidence of scarring, demographics and predictability of occurrence. Photographic and sighting data are integrated into the right whale photo-identification catalogue at the New England Aquarium and the sighting database at the University of Rhode Island.

II) To provide sighting data to the National Marine Fisheries Sighting Advisory System. Sighting locations of right whales are reported promptly to NMFS/SAS at the completion of each survey. The goal is to ultimately 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 these surveys provide almost all of the data for the NMFS advisory system in the northeast, there are no other surveys being conducted by other states or federal agencies during the winter months (January through March).

III) To monitor right whales in the study area for evidence of entanglement. Each right whale encountered is examined visually for any evidence of attached gear. The disentanglement team is on standby, ready for immediate dispatch in the event an entangled whale is reported.

IV) To collect food resource information on weekly vessel cruises, from January to mid-May, designed to develop an understanding of the characteristics of the habitat to which right whales respond. These data, combined with data from past habitat studies in Cape Cod Bay by the Provincetown Center for Coastal Studies, provide additional information on the conditions that are believed to cue the movements and activities of right whales in Cape Cod Bay and adjacent waters. Management agencies (e.g. MA DMF, NMFS) have used these data to forecast whale movements and residency times within the study area and have issued vessel speed advisories and amended seasonal gear restrictions on a real-time basis in response to right whale distribution predictions based on controlling characteristics of the food resource in the bay and adjacent waters.

V) To describe the distribution and abundance of any other marine mammals and shipping activity in Cape Cod Bay and adjacent waters from January through mid-May.

Objectives I through III and V are the focus of the first section of this report; Objective IV is discussed in the second and third sections.

SECTION 1: SURVEILLANCE, RESIDENCY AND DEMOGRAPHICS OF NORTH ATLANTIC RIGHT WHALES IN CAPE COD BAY AND ADJACENT WATERS - 2006

1.1. Introduction

The following section addresses Objectives I through III and V of the PCCS/DMF right whale surveillance and monitoring program. Objective IV is discussed in section 2.

During March through mid-May, an additional study was jointly funded by National Fish and Wildlife Foundation and DMF to gain preliminary data on right whale surface/dive behavior, small-scale movements and vocalization rates in relation to demographic group and food resources. Although in the last 20 years, survey data and opportunistic sightings have greatly improved our understanding of the right whale population, individual whales were seldom followed and thus little data is available on variability in behavior and small-scale movements in relation to food resources. An understanding of this aspect of the ecology of right whales would greatly increase our understanding of right whale vulnerability to ship strikes and thus is crucial in the conservation scheme of the species. Furthermore, the power of passive acoustics monitoring programs has been demonstrated for several species of cetaceans and could potentially be very useful for monitoring the presence/absence of right whales in hard-to-reach areas. However, to date, there are little data on the variation in vocalization rates in relation to demographic group, number of animals present, behavior and/or amount of food resources. It is clear that, before passive acoustics can be used as a monitoring tool, it is critical to gain a better understanding of the behaviors during which individuals may be silent as well as an understanding of the proportion of time that various demographic components of the population of right whales are emitting sounds.

1.2. Methods

1.2.1 Aerial Surveys

Aerial surveys were conducted regularly from 1 January 2006 through mid-May 2006 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 (Fig. 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 (Figure 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 (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. Additional track lines were established and flown at various times during the season to respond to reports of right whales in adjacent waters or to search for right whales in nearby locations when they were not being seen in the Bay (Table 1b, Figure 1b).

The surveys were flown under visual flight rules conditions 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 (N700AM), 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).

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 left 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 10-second intervals as well as at a keystroke by an observer. At each event, latitude, longitude, time, altitude, and heading were obtained through an interface with the aircraft GPS. At manually entered events, the observers recorded additional data using a digital voice recorder (Sony ICD-ST10). A distinct voice file was created for each manually entered event. The file name of each voice file included date, time, and a sequentially assigned number that corresponded to the record number of the event entered in Logger 2000 to facilitate accurate post-flight transcription (see section on Data Management, Analysis, and Interpretation). The clocks of the logger computer and voice recorder were synchronized prior to each flight to aid transcription in the event of a mismatch between filenames and event record numbers. 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 at a right angle to the sighting 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 research protocols followed by the North Atlantic Right Whale Consortium and approved by NOAA Fisheries.

1.2.2. Shipboard Data Collection

The Provincetown Center for Coastal Studies (PCCS) maintains a 40' (12m) long, twin diesel engine research vessel the "R/V *Shearwater"*. The R/V *Shearwater* has been used successfully for habitat sampling and photo-identification in the winter and spring surveillance program in Cape Cod Bay from 1997 through 2005 (Mayo 1997, 1998, Mayo *et al*. 1999, 2000, 2001a, 2001b, 2004, Mayo and Bessinger 2002, Bessinger *et al.* 2003, Jaquet *et al*., 2005). The results of this part of the program are reported in sections 2 and 3 of this report.

Although the primary objective of the vessel cruises was habitat sampling, sightings of marine mammals were recorded on an opportunistic basis. Observers were on watch as often as weather and available personnel permitted, however observers did not follow a strict survey protocol. An observer from the aerial survey team was present on board R/V *Shearwater* whenever possible to aid in opportunistic data collection. Photographs of right whales obtained during habitat cruises were integrated with the photographs collected during aerial surveillance. These vessel-based sightings were also included in the analyses of residency, demographics, and life history. Sighting data from the daily vessel logs were entered into the Right Whale Initiative DBase program as opportunistic sightings.

Data on right whale distribution and identity were also taken during the "acoustic/behavior" study and included in the aerial surveillance database.

1.2.3. Right whale focal follows and acoustic behavior

To investigate right whale surface and diving behavior, small-scale movements, and vocalization rates in relation to demographic group and food resources, we closely followed one or several individuals continuously for up to 10 hours. During the focal follows, the track of the research vessel as well as the positions of all right whale sightings were recorded using custom-written software on a Hewlett Packard 200LX palmtop computer linked to a Garmin 12XL GPS. The times of surfacing and diving, the behavior of the focal animal, whether it showed its fluke or not, the number of other individuals within 0.5 nautical miles (n.miles) of the research vessel, the general behavior of the other individuals as well as their approximate distance and position were recorded in a Sony digital voice recorder. Recordings of vocalizations were performed through a 2-element tow hydrophone array with an element separation of 8 meters linked to a Magrec amplifier and a Casio D7 Digital Audio Tape Recorder. While in visual contact with right whales, underwater noise and right whale vocalizations were recorded continuously. Identification photographs were taken for each individual encountered following the standard protocol described below.

1.2.4. Photo-Identification Techniques

i) Identification Photographs

During aerial and shipboard surveys, photographs were taken using hand-held 35-mm Canon digital cameras 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. 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.

ii) Photo-Analysis and Matching

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). NEAq has curated the 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 resightings of known individuals, to monitor the animals' reproductive status, births, deaths, scarring, distribution and migrations. Since 1980, a total of 34,432 sightings of 459 individual right whales have been archived, of which 330 were thought to be alive as of 31 August 2006 (Hamilton *et al.* 2004, Philip Hamilton, pers. com).

The matching process consists of separating photographs of right whales into individuals and inter-matching between days within the season. To match different sightings of the same whale, composite drawings and photographs of the callosity patterns of individual right whales are compared to a limited subset of the catalogue that includes animals with a similar appearance. For whales that look alike in the first sort, 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.

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 (Marx *et al.* 1998) and health assessment (Pettis *et al.* 2004).

<u>iii) Photographic Data Archiving</u>

Original digital images are kept on file at PCCS on CD-R and an external hard drive. As digital photography has only been used for the last two 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. In the future, DIGITS will be available for use by those outside of NEAq, and similar software will likely be used to manage digital images at PCCS. All PCCS digital images from the 2006 season have been archived at NEAq and are available for access by collaborators per North Atlantic Right Whale Consortium protocols.

1.2.5. Data Management

At the end of each aerial survey and focal follow, data from the voice recorder were downloaded and backed up on CD-R along with the digital voice recordings. 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 and opportunistic sightings were submitted to Dr. Robert D. Kenney, curator of the Consortium Database maintained at the University of Rhode Island.

1.2.6. Data Analyses

All sightings were incorporated and integrated into the right whale catalogue and Consortium database with existing data on life histories for each individual identified by PCCS. 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 2006. Sighting 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. 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).

Number of different individuals identified in an area may not accurately reflect the utilization of the area by right whales, as one whale visiting an area for six day would be similar to six whales visiting the area for one day each. Therefore, it is also important to take into account the residency time of individuals and a variable “whale*day” (=the number of different individuals time the number of day each had been identified) was created. Although meaningful, this new variable will be negatively biased by long period of bad weather. Furthermore, the number of different individuals is also important to obtain an understanding of the number of whales that may be threatened by entanglements or ship strike in a particular area. Therefore, in this report, both variables are used to describe habitat utilization of right whales.

For ease of reading and avoid confusion, the details of each particular analysis is given together with its result (see result section). Standard statistical tests were used to determined trends in the data and significant differences between means, and thus t-tests, Chi-square tests, G goodness of fit tests, Pearson correlations, Kruskall Wallis tests etc were widely used in this report (Zar, 1996, Fowler et al., 1998). Significance was accepted at the 5% level and standard deviations (SD) were usually given with means except when standard errors (SE) were more appropriate (see Zar, 1996). To analyze movement patterns and overall individual residency time in CCB, we used the “movement module” of the SOCPROG version 2.2 suit of Matlab programs (written by H. Whitehead and available from http://myweb.dal.ca/~hwhitehe/social.htm).

1.2.7. Notification of Agencies

Prior to and following an aerial survey, both US Coast Guard Group Woods Hole and Air Station Cape Cod at Otis Air National Guard Base were notified of our planned survey, departure time, estimated return and a verbal summary of what was seen. 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. Prior to reporting to the NOAA Fisheries/SAS, on days when any other whale research vessels were operating in Cape Cod Bay and adjacent waters, additional sightings, if any, were added to the report if from an area not already included in the PCCS report. A daily summary of the location and number of right whale sightings was faxed to DMF. 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 Surveys

In 2006, the PCCS/DMF aerial survey team was in position to survey for 135 days from 1 January through 15 May. Thirty-six full and partial surveys were flown during these 4.5 months: 32 were flown in Cape Cod Bay including two surveys that also completed 15 to 81 nautical miles of track northeast of CCB (Table 1b; Table 2), two surveys were flown exclusively along the northeast tracks (adjacent waters, Table 1b), and two surveys only completed track 16 (eastern shore of Cape Cod, Fig. 1, Table 1) due to very rapidly deteriorating weather. Out of these 36 surveys, six were aborted due to inclement weather, one was not completed due to the large number of right whale sightings (37 sightings, 8.8 hours of flight time) and four did not include track 15 due to low tide (Figure 1, Table 2). These represented 9,219 miles flown and 170.3 hours of flight. The weather in winter and spring of 2006 was substantially worse for aerial surveys than in 2005, especially during the month of March, where only one full survey could be completed before the 24th (Table 5). However, despite the inclement weather in 2006, we flew an average of 1.7 surveys per week in CCB (excluding the surveys in adjacent waters) compared to 2.0 surveys per week planned, 1.9 surveys per week flown in 2005 and 1.3 per week in 2004 (Table I).

Table I **Summary of aerial survey effort in 2004, 2005 and 2006**

	Number of surveys in CCB (include track 16)	Number of surveys in adjacent waters	Total number of nautical miles flown	Total number of hours flown
2004	25	3	7,164	139
2005	37	4	10,855	175
2006	32	4	9,219	170

The first flight of 2005 was conducted on the 10th of January, first good weather day since the 2nd of January. There was a long stretch of windy weather during the month of March that explains the number of surveys that had to be aborted (Table 5). There was also a long stretch of bad weather at the end of the season that prevented pinpointing the approximate date at which the whales left CCB. The first right whale was sighted in the Bay by the aerial team on the 4th of February (compared to the 30th of January in 2005) and the last ones on the 6th of May (compared to the 26th of April in 2005). However, the shipboard team spotted one right whale on the 29th of January and four individuals on the 8th of May. Therefore, the approximate timing for the arrival of the first individual was similar in 2006 than in 2005. However, the whales left the Bay later in 2006 than in 2005.

The average duration of the standard Cape Cod Bay survey was approximately 4.9 hours for surveys that were not aborted early due to an increase in wind speed, sea state (above Beaufort 4) or decrease in sighting conditions (to visibility less than two nm). This duration was about 0.3 hr longer than the mean for 2005, 0.7 hr shorter than the mean for 2004 and 1 hr longer than the mean survey length for 1998 through 2003. The longer survey length in comparison to surveys prior to 2004 is attributable to the longer time required to adequately photograph individual right whales with only one photographer in a rear seat, as opposed to earlier surveys flown with one pilot and a photographer in the copilot position and a secondary photographer in the rear (Mayo *et al.* 2004). The rear seat offers a smaller viewing area and less opportunity for photographing whales; consequently, more passes over an animal were required to obtain photographs of sufficient quality for matching. The increase in average CCB survey duration between 2005 and 2006 was due to the higher number of right whales present in the Bay during any one day (up to 37 photographed sightings in a single day in 2006, versus a maximum of 22 in 2005 (Table 2, Jaquet *et al.* 2005), and the decrease in average CCB survey duration between 2004 and 2006 was due to the observers being used to taking identification photographs from the rear seat and being more experienced than in 2004.

The standard Cape Cod Bay survey includes track 16 and thus encompasses about 35 nautical miles of survey outside the Bay (Fig. 1). However, as it has been shown in the previous report (Jaquet *et al*., 2005) that right whales seen on track 16 are seldom observed within the Bay and as the residency time of individual on track 16 suggests that these whales are transiting through the area, all the analyses below differentiate between Cape Cod Bay and adjacent waters (outside 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 track 3 to 15. However, in previous reports, CCB also included the two tracks just north of CCB (track 1 and 2), therefore, in the present report, it is always stated whether the analysis are for CCB exclusively (track 3 to 15) or whether they also include the water just north of CCB (track 1 to 15). This differentiation allows comparisons with previous years and previous reports (using track 1 to 15), and allows analyses that are compatible with the definitions of the New England Aquarium and also that make more sense as track 1 and 2 are outside CCB.

Most of the aerial survey effort was concentrated within CCB and the two tracks just north of CCB and 7,652 miles of transects were flown in CCB (track 1-15) while only 1,567 miles were flown in adjacent waters.

1.3.2. Shipboard Data Collection

The R/V *Shearwater* completed a total of 18 habitat sampling cruises between 2 January and 18 May 2006 (Table 3). The primary purpose of these cruises was to collect oceanographic data in the Cape Cod Bay Critical Habitat area on a weekly basis to compare distribution and abundance of right whales from aerial surveys with that of the food resource as determined from plankton samples obtained at sea. See sections 2 and 3 of this report for the results and discussion of this portion of the program. Whenever conditions and numbers of personnel permitted, sightings of marine mammals were recorded on an opportunistic basis. The vessel crew documented the first right whales in Cape Cod Bay on 29 January, but right whales were not seen again by the R/V *Shearwater* during February, and their next sighting happened on the 2nd of March. Many of the shipboard sightings were initially recorded by the aerial survey team and radioed to the vessel to facilitate collection of photo-identification and behavioral data and oceanographic sampling in the location of feeding whales. Sightings of other species were recorded on an opportunistic basis. The right whale habitat team spent 104 hours at sea in 2006. In addition to the work described above, 15 cruises were conducted to collect data on behavior and vocalizations of individual right whales (focal follows), amounting to over 90 hours at sea.

In addition to habitat sampling and recording opportunistic sighting data, the habitat team also photographed 15 right whale sightings during the habitat cruises and the focal follow team 66 individual right whales (Table 3 and Table II).

Shipboard photographs are the best means of documenting lip ridges and chin callosities of calves, which are particularly important for matching sightings in subsequent years (Hamilton and Martin 1999). All of the shipboard photographs have been compared to those obtained from the aircraft and were included in the same matching process as described in the methods, the results of which are detailed in the following analyses.

1.3.3. Sightings and Photo-Identification

In 2006, a total of 305 right whale sightings were recorded from all platforms, of which 290 were photographed and analyzed in this report (Tables 2 and 3). From these 290 photographed sightings, 99 different individuals were identified including 6 first year calves. Another 59 right whale sightings have not yet been matched to known individuals as the individuals may be new whales or yearlings from last year and thus may not yet have a good record in the catalogue. From these 59 unidentified photographed sightings, 41 were in adjacent waters and 18 in CCB.

The number of photographed sightings and different individuals identified by platform and location are outlined in Table II.

Table II Number of photographed sightings and individual right whales identified by platform and location in 2006.

Platform and Location	Photographed sightings	Number of different individuals	Sightings not yet matched	Number of miles flown or number of days on the water
Aerial – CCB (track 3 to 15)	116	52	13	6581 miles
Aerial – Adjacent waters (track 1,2, 16 and other 2 surveys)	93	55	22	2638 miles
Habitat Cruises - CCB	15	11	2	18 days
Focal Follow Cruises	66	35	22	15 days
Total	**290**	**99**	**59**	

The total number of different individuals identified is lower than the sum of individuals per platforms and locations as 20 identified individuals were sighted both in CCB and adjacent waters, and as most of the identified individuals that were sighted from cruises were also identified from the aerial surveys. Despite a much lower overall aerial survey effort and a much smaller area surveyed in adjacent waters than in Cape Cod Bay, as much as 55 individuals were identified in adjacent waters while 52 were identified within CCB by the aerial surveys.

At the time of this writing, 99 individual right whales have been identified from all platforms combined and from all areas (CCB and adjacent waters). This is substantially larger than the total number of individual right whales identified in 2004 (54 individuals, Mayo *et al.,* 2004, Right Whale NEAq data base), and also larger than the total number of individuals identified in 2005 (82 individuals, Jaquet *et al.,* 2005).

Out of these 99 individuals, 33 were seen exclusively in CCB (track 3-15), 46 were seen exclusively in adjacent waters (include the 2 tracks just north of CCB) and 20 individuals were observed in both areas. For the sake of comparison, if we include track 1 and 2 into the CCB area (as it had been done in previous reports), it means that only 21 individuals were seen exclusively in adjacent water (track 16 and eastern tracks) while 78 individuals were seen in CCB and/or just north of CCB (track 1 and 2). Therefore the number of individual whales observed in CCB and just north of CCB in 2006 (78 ind) was substantially larger than in 2004 (53 ind) and substantially larger than in 2005 (45 ind, Fig. I). Although more individuals were identified in CCB and just north of it during the first 4 years of the project in relation to the last 5 years (Fig. I), the slope of the fitted regression line was not significantly different from 0 (P=0.2105, NS), suggesting that there is no trend towards a lesser number of individuals visiting the Bay every year. The number of individuals observed exclusively in adjacent waters (as defined in previous reports, so only track 16 and eastern tracks) was substantially smaller in 2006 (21 ind) than in 2005 (33 ind.) but larger than in 2004 (1 ind). This result suggests that the number of individual whales observed on track 16 and on tracks east of CCB is highly variable between years. Transect 16 only covers a strip of water about five nm wide east of Cape Cod Bay. Therefore, the variability in right whale abundance on this transect is possibly due to whales transiting at slightly different distances from shore between years, and thus more or less easily spotted.

During the nine years of the project, an average of 62.4 individuals (SD=25.98, range 20 to 89, Fig. I) were present each year in CCB and just north of CCB (track 1-2) representing 16% of the individuals believed to be currently alive (392 ind, Philip Hamilton pers. com).

Figure II show the number of different right whale identified in adjacent waters (track 16 and all tracks east and north east of CCB) over the course of the project (1999-2006), no data could be found for 1998 and thus this year is not represented on Fig. II. As the amount of survey effort in adjacent waters was very variable over the years (min of 1,071 n.miles in 2004, max of 2,234 n.miles in 2002, mean=1754 n.miles, SD=392.6), the total number of individual identified is meaningless and thus only the number of individuals per 100 n.miles of survey effort is presented. The shipboard effort in adjacent waters has been negligible for all years and thus is not taken into account. It is evident from Fig. II that the abundance of right whales in adjacent waters is even more variable than in CCB.

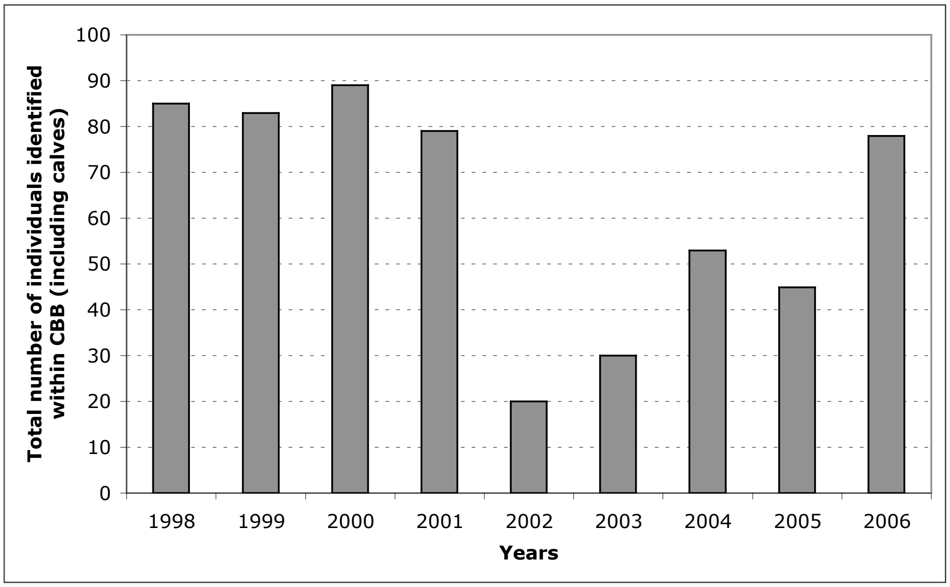


Figure I **Total number of individual right whales identified within CCB each year. For comparison purposes, in this figure, CCB means track 1 to 15.**

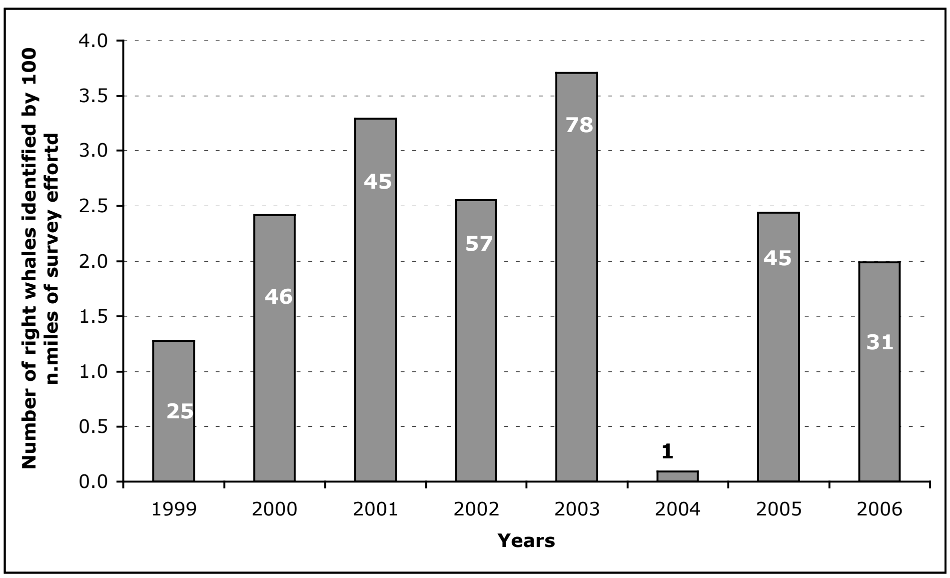


Figure II **Number of right whales identified per 100 nm of survey effort in adjacent waters. For comparison purposes, in this figure, adjacent waters means track 16 and all tracks flown NE, E or SE of CCB. The number in each column represent the number of different individual identified.**

As individual right whales have different residency times within CCB (see section 1.3.7), and as the individual residency time may also depend on the amount of food resources (untested to date), the total number of different individuals identified within CCB each year may not reflect the yearly utilization of the Bay. Therefore, to take some proxy of the residency time into consideration, for each year, the number of individuals identified have been multiplied by the number of days they have been observed in CCB, providing a new variable called "whale*day" (Figure III, see also methods section).

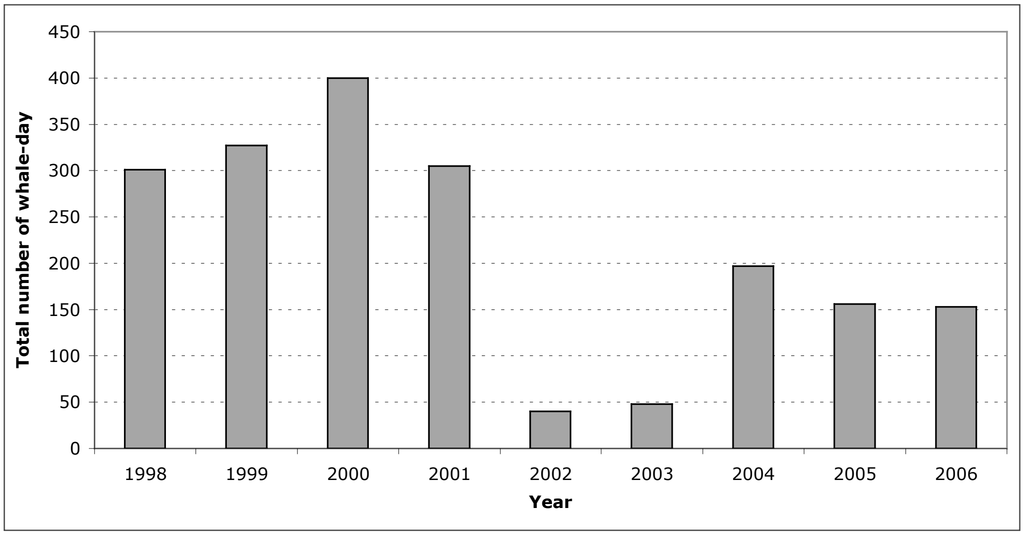


Figure III **Total number of whale*day in relation to years (see text for explanations of the variable "whale*day). For comparison purposes, in this figure, CCB means track 1 to 15.**

Figure III suggests that, although a high number of different individuals were observed within CCB in 2006 (78), their residency time was shorter than usual as the number of whale*day (153) is smaller than for 2005 and 2004. However, despite large variability in residency time, the two variables "number of different individuals" and "whale*day" were well correlated ($r=0.901$, $df=8$, $P=0.0003$), suggesting that, on average, both variables are an acceptable proxy to estimate the yearly utilization of CCB by right whales.

Since 1998, 197 different individuals have been identified in CCB (tracks 3 to 15) by all observers and all platforms, and thus over 50% of the right whale population has been sighted in CCB. The discovery curve showing the rate at which "new" individuals are identified within CCB for the duration of the project is shown in Figure IV. As the curve is showing sign of a plateau for the last couple of years, and as 197 individuals have been identified so far in relation to a total population of about 392 individuals (Hamilton et al. 2004, Phil Hamilton, Pers. Com.), this result suggests that a part of the population may never or very rarely enter CCB. The small increase in the number of new individuals each year is likely to represent the new recruitment into the population (i.e. calves).

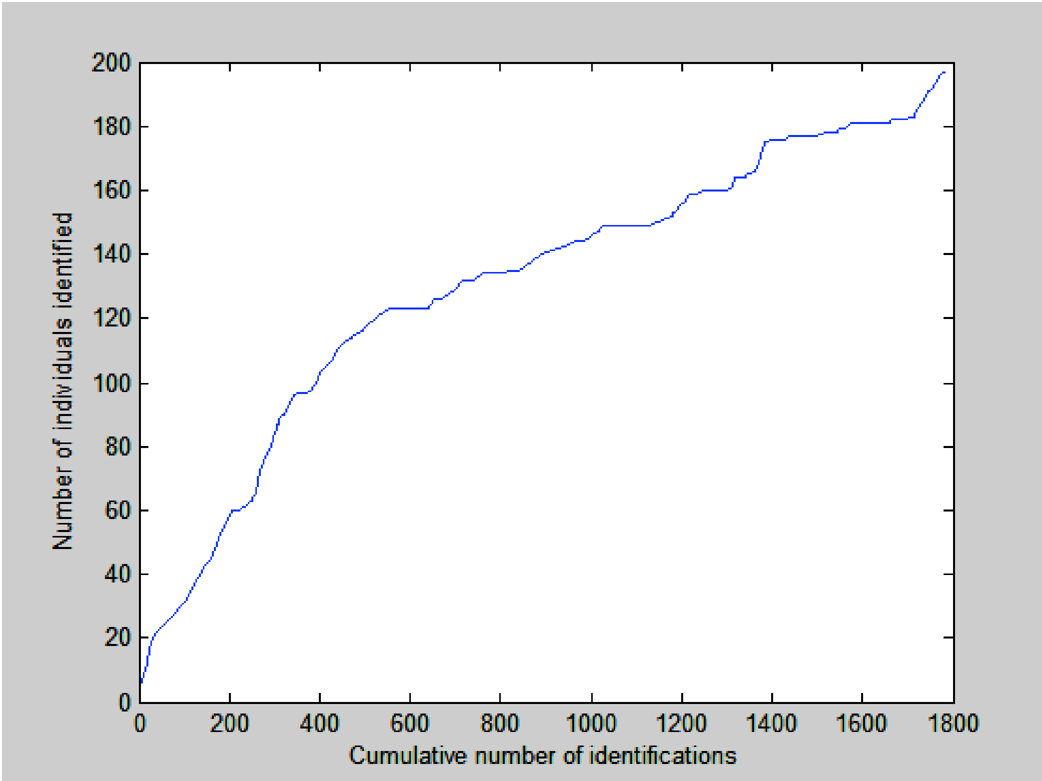


Figure IV **Discovery curve for individual right whales identified within CCB (track 3-15) by all observers, but excluding all adjacent waters (track 1, 2, 16 and eastern tracks) for the duration of the project (1998-2006).**

To investigate whether some individual right whales were preferentially seen in CCB while others were preferentially seen in other areas, the expected frequency of identifying an individual only in CCB or only in other areas or in both were calculated. For these analyses, as two sightings of the same individual during the same day are not independent, only the first sighting of the day for each whale was taken into account. The analyses were also corrected for differences in effort between CCB and other areas (15% of all identification photographs were taken within CCB and 85% in other areas) and for differences in the number of days a whale was sighted (min 2 days, max 108 days). Individuals identified only on one day during the entire time period were not taken into account, as we could not calculate a probability of being re-sighted in any area. A log-likelihood ratio test of goodness of fit between observed and expected frequencies was then calculated (*H*o = no preferences for either CCB or other areas). Of the 357 individuals that were seen on more than one day between 1998 and 2006, four were seen only in CCB, 175 were seen only in other areas and 178 were seen both in CCB and in other areas. These observed frequencies did differ significantly from what would be expected if each right whale showed no preference for a particular area (*G* test, $G = 374.3$, df = 2, $P < 0.00001$; Table III), suggesting that individual right whales show strong preferences for CCB while other tend to avoid CCB.

Table III **Results of *G* test of goodness of fit for right whales seen only in CCB, those seen only in other areas, and those seen in both.**

	Observed frequencies	Expected frequencies	G test
CCB only	4	0.2	
Other areas only	175	35.4	
CCB + other areas	178	321.4	
Total	357	357	G=374.33, df=2, P<0.0001

1.3.4. Distribution, Abundance and Seasonality of Right Whales within CCB

Right whales recorded during aerial surveys of Cape Cod Bay and adjacent waters are plotted by two-week periods in Figure 2. Sightings recorded from vessels were not collected according to systematic survey protocols and thus were not plotted; however, the distribution of the opportunistic sightings mirrors that of the aerial survey sightings as indicated in Figure 2. The habitat team spotted the first right whale of the year within CCB on January 29, and the aerial team on February 4. Right whales were then observed within the Bay in every 2-week period until they left sometimes between May 8 and May 18. However, only one individual was sighted in each 2-week period in February (Fig 2c and 2d) and only seven individuals during the period of March 26 to April 8 (Fig 2g). Right whales were more abundant during the month of March than during the first week of April, but high wind and persistent bad weather prevented full surveys of the Bay and thus the number of sightings shown in Figures 2e and 2f are likely underestimated. Right whales were most abundant in CCB between April 14 and May 6, and up to 22 different individuals were photographed in a single day. Therefore, unlike other years, right whale abundance did not increase steadily during the course of the season. In 2006, right whale residency in CCB extended from January 29 to May 8 without any large time gap where no whales were observed (the residency period includes shipboard sightings).

Figure V shows the number of different individual right whale identified per unit effort within CCB (track 3-15) in 2006. Due to the high number of individuals on April 14, it seems that there was a low abundance of whales in March. However, in 2005, the maximum abundance of whales during a single day was five individuals per 100 nautical miles (nm) of survey effort, only slightly more than some of the sightings per 100 nm observed in March 2006. Figure V illustrates high variability in abundance during February and March and a peak in abundance between 14 April and 8 May. The fact that the survey on April 26 had to be aborted due to deteriorating weather may explain why no right whales were sighted on this day. However, more than half the Bay was surveyed and only track 9 to 15 were not surveyed. If right whales were present on this day, they had to be confined to the southern portion of the Bay.

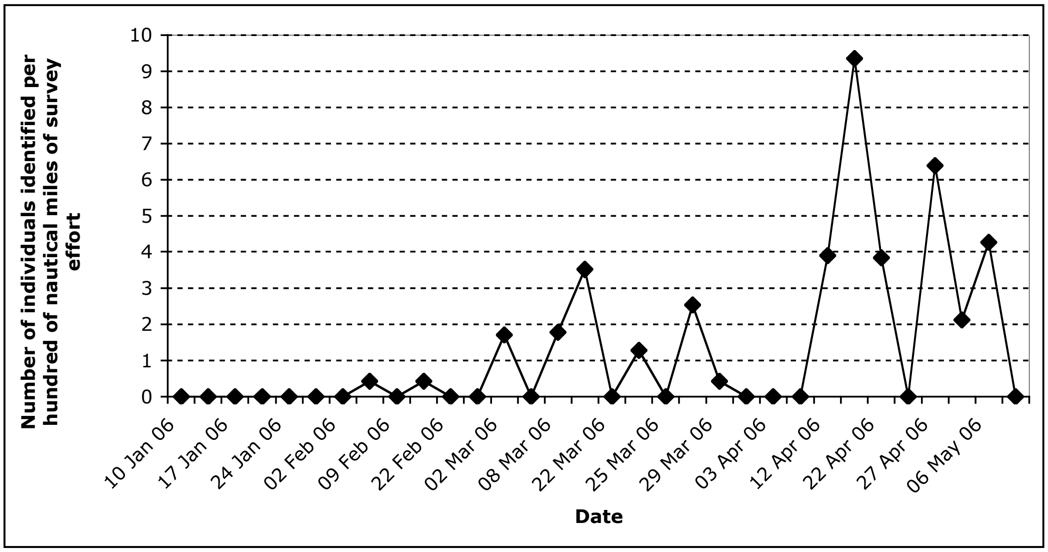


Figure V **Number of individual right whales identified within CCB (only track 3-15) in 2006 per 100 nautical miles of aerial survey effort.**

No consistent pattern emerges when number of individual right whales per 100 miles of survey effort is plotted for adjacent waters in 2006 (Fig. VI). No right whales were sighted in adjacent waters until March 24. From March 30 to the end of April, there was a high variability in right whales abundance with abundance sometimes reaching 16 individuals per 100 nm of effort (Fig. VI, Table 5).

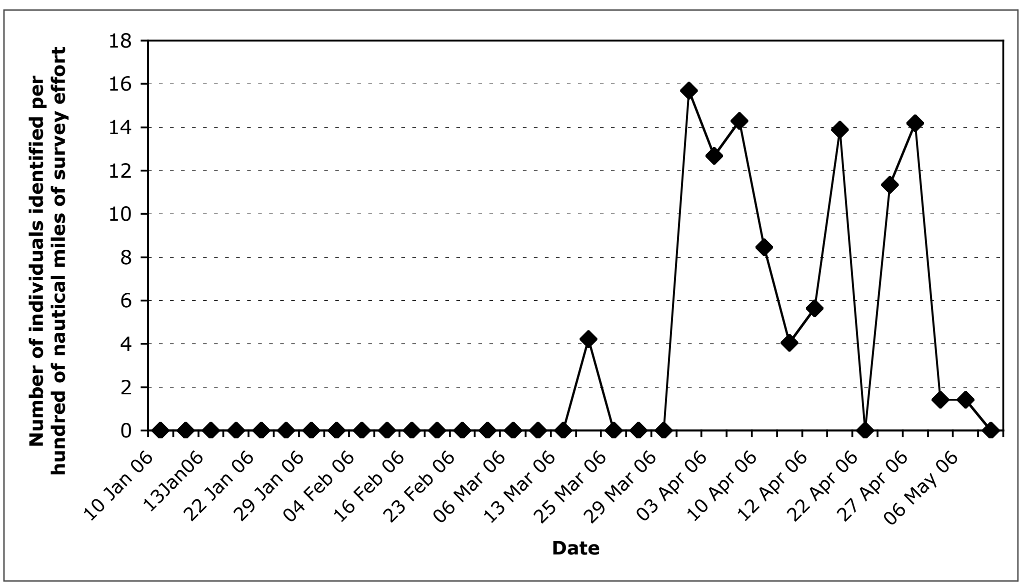


Figure VI **Number of individual right whales identified in adjacent waters (include tracks 1-2, 16 and all north-eastern tracks) in 2006 per 100 nautical miles of aerial survey effort.**

Table IV shows the date right whales were first and last sighted within CCB. During the nine years of this study, right whales were present for the longest period during the 1999 season

(Table IV). The value of 95 days indicated for 2003 is misleading because there was a period of 46 days between 10 February and 28 March during which no right whales were seen in the Bay. Furthermore, the timing of the first survey varied greatly between years (from 9 December for the 2005 season to 21 January for the 2004 season) and therefore it is possible that, during some years, the time period during which right whales were present was longer than the one described in Table IV. On average, right whales are observed to be present in CCB for about 96 days (SD=30.7 days) each year; and thus the time period that right whales was present in CCB in 2006 (91 days, Table IV), is similar to the yearly average. If shipboard sightings are included, the total residency period for right whale in 2006 was 99 days and thus only three days above the project average.

Table IV **Time period when right whales are present in Cape Cod Bay over the 9 years of the project. 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. For comparison purposes CCB means track 1 to 15 (and thus includes the 2 tracks just north of CCB).**

Year	Date of 1st aerial survey	Date of 1st aerial survey right whales were sighted within CCB	Date of last aerial survey right whales were sighted within CCB	Minimum # of days when right whales were present in CCB
1998	04 Jan 1998 (9)	04 Jan 1998 (9)	21 April 1998 (1)	108 [75]
1999	13 Dec 1998 (5)	13 Dec 1998 (5)	02 May 1999 (1)	140 [86]
2000	20 Jan 2000 (1)	20 Jan 2000 (1)	11 April 2000 (3)	82 [86]
2001	19 Dec 2000 (5)	19 Dec 2000 (5)	29 April 2001 (2)	132 [87]
2002	06 Jan 2002 (0)	7 Feb 2002 (1)	15 March 2002 (3)	36 [24]
2003	10 Dec 2002 (0)	25 Jan 2003 (5)	30 April 2003 (8)	95 [26]
2004	21 Jan 2004 (0)	10 Feb 2004 (2)	10 May 2004 (1)	90 [54]
2005	09 Dec 2004 (0)	30 Jan 2005 (3)	26 April 2005 (6)	86 [45]
2006	10 Jan 06 (0)	4 Feb 2006 (1)	6 May 2006 (12)	91 [59]

Except for 2002 when few right whales were sighted within the Bay, the whales seem to enter CCB for the first time between late December and early February and leave the Bay between late April and early May. Therefore there seems to be large variation in the time right whales enter CCB, but little variation in the time they leave it. Furthermore, during all years, whale abundance seemed to increase slowly during the first two months of their residency period, then reached a peak for a couple of weeks to a month, followed by a seemingly abrupt departure.

The average number of individual right whales identified per 100 nm of survey effort during each month between 1998 and 2006 is plotted on Figure VII, the error bars represent 1 standard deviation. The figure shows the same pattern of slow increase in whale number in January and February, a peak in March and April and a sudden decrease in early May. The large standard deviations are an indication of the large variability in the number of right whales per 100 nm of survey effort within a month. However, despite this high variability, the mean number of individuals per 100 nm of survey effort was significantly smaller in January than in February (t-test: t=3.121, df=104, P=0.0023), and significantly smaller in February than in March (t-test: t=2.818, df=130, P=0.0056). There were no differences between the mean number of individuals in March and in April (t-test: t=-0.240, df=131, P=0.8104, NS), suggesting that the peak in whale abundance is as likely to occur in March as in April. The mean number of right whale per 100 nm of survey effort in May was much smaller than in March-April consistent with a rapid decline in right whale abundance in late April-early May.

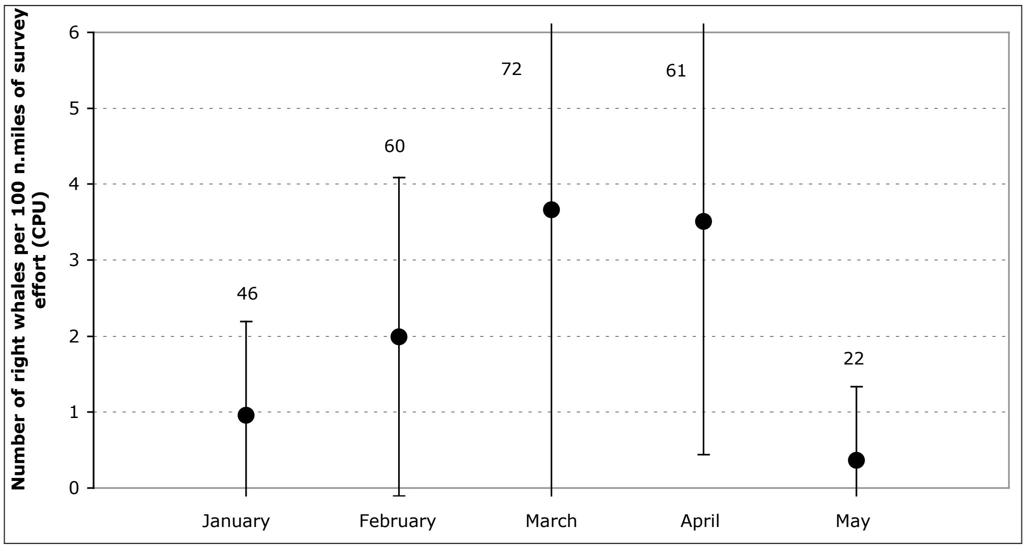


Figure VII Average number of individual right whales identified in CCB (track 1-15 for across years comparison) per 100 nautical miles of aerial survey effort during each month between 1998 and 2006. Error bars represent 1 standard deviation. The number above each month represents the total number of surveys conducted during the month.

Out of the 215 sightings in 2006 (Table 2), 76 (35%) occurred outside the Critical Habitat. This is significantly more than what was observed in 2004 when only 1% of the sightings occurred in waters outside the Critical Habitat, and also substantially more than in 2005 when 28% of the sightings occurred in waters outside the Critical Habitat. Within the Bay, several right whales were observed close to the western edge of the Critical Habitat (Fig. 2g, 2h), and many were observed outside the boundaries close to Plymouth (Fig. 2h, 2i). Most of the whales were sighted in the southwestern part of the Bay (Fig. 3a) in close proximity to the Cape Cod Canal and thus on a major shipping route. This overall distribution of sightings is quite different from the 2005 distribution (Jaquet *et al*., 2005, Fig. 3b). In 2005 the sightings were mainly concentrated in the southern central part of the Bay. This distribution is also quite different from the 2004 distribution (Jaquet *et al*., 2005; Mayo *et al.,* 2004) suggesting that right whale small-scale habitat utilization is highly variable between years.

1.3.5. Mother/Calf Pairs

Six mother/calf pairs were photographed in Cape Cod Bay and adjacent waters in 2006 (Table V). Table V shows that three of the mothers that brought their calf into CCB were first time mothers.

Table V **Identities, calving histories and residency of the 2006 mothers sighted in CCB and adjacent waters.**

Identification numbers	Number of known calves that the mother had before 2006	Area seen	Number of days seen	Time span in days between first and last sighting
1281	5	CCB	3	15
1503	2	Just north of CCB (track 1-2)	1	1
2029	0	CCB + Just north of CCB	2	5
2123	1	Adjacent waters	2	14
2320	0	CCB + Adjacent waters	4	13
2660	0	Adjacent waters	1	1

In 2006, 19 mother and calf pairs were observed in the southeastern United States (SEUS), a substantially smaller number than in 2005 (28) and 2001 (31), but similar to what has been observed in the three years previous to 2005 (16, 19 and 22 respectively). However three of these calves died in the first few months of their life and thus only 16 could have been coming into CCB. A fourth calf died during the summer, but as it was after the possible residency in CCB, this mother/calf pair is included in the analyses. Six (37.5%) out of these 16 mother and calves pairs identified in the SEUS were also observed in CCB and adjacent waters (Fig. VIII) in spring 2006, and four of them (25%) were identified in CCB and just north of CCB (Fig. IX). For comparisons between years, in the two following figures, CCB means track 1 to 15 and thus include the two track lines just north of CCB.

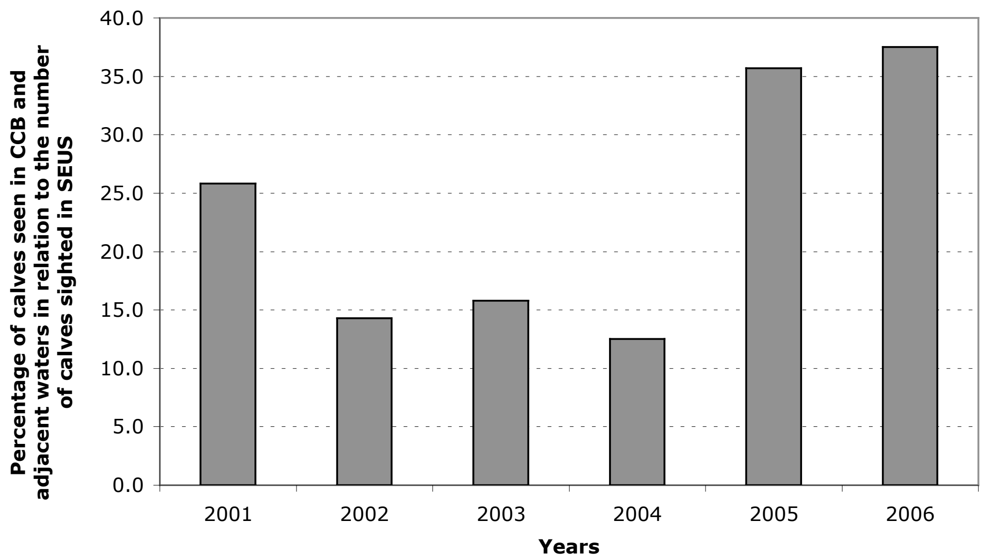


Figure VIII **Proportion of calves seen in CCB and adjacent waters in recent years in relation to the total number of calves born in the SEUS.**

Although a higher percentage of mother and calf pairs were observed in CCB and adjacent waters in 2006 and 2005 than in previous years (Fig. VIII), the difference was not statistically significant (χ^2=202, df=5, P>0.05). The years from 1998 to 2000 are not shown as no calves were sighted in CCB or adjacent waters during these years despite a similar aerial survey effort. However, because few calves were sighted in the SEUS during these years, 6 in 1998, 4 in 1999 and only 1 in 2000 (New England Aquarium unpublished data), it is not surprising that none were observed in CCB.

When only CCB (including the two tracks just north of CCB) is taken into account, the proportion of calves sighted in CCB in relation to the number of calves seen in the SEUS is shown in Figure IX.

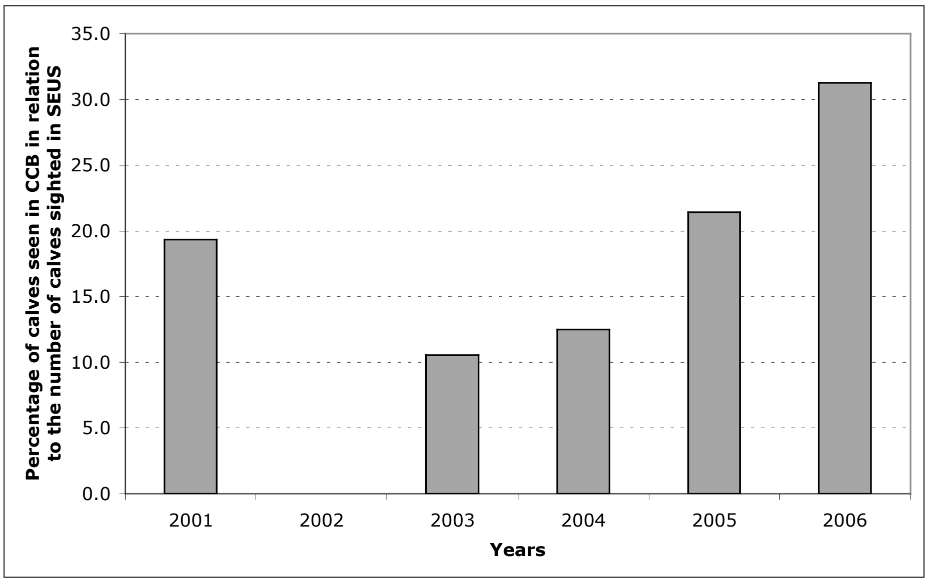


Figure IX Proportion of calves seen in CCB and just north of CCB (track 1-15) in recent years in relation to the total number of calves born in the SEUS.

Since 2001, on average, 14.8% of the calves seen in the SEUS were also sighted within CCB (tracks 1-15), and this percentage reached 31.3% in 2006. This is the highest percentage of mother and calf pairs observed in CCB since the beginning of this project 9 years ago. Due to the high variability in the proportion of mother/calf pairs visiting the Bay every year, the higher proportion in 2006 was not statistically significant (χ^2=7.097, df=5, P>0.05). However, Fig. IX shows the suggestion of a trend towards a higher proportion of mother/calf pairs utilizing CCB with years. This may suggest that CCB is becoming more important an habitat for mother/calf pairs, and as calves are most at risk during the first year of their life and are the hope for the survival of the species, this observation emphasizes the importance of Cape Cod Bay for right whales. However, the slope of the trend line was not significantly different from zero (P=0.1808, NS) and thus more data in coming years will be needed before we can conclude whether a higher proportion of calves are visiting the Bay with years or not.

1.3.6. Demographics

Overall, a slightly larger number of males (41.1%) than females (33.3%) were seen in Cape Cod Bay and adjacent waters in 2006 (exactly the reverse to what was observed in 2005 and in 2004), and 25.5% of the individuals identified were of unknown sex. However, this sex ratio was not significantly different from the expected ratio of 1:1 (χ^2=0.8177, df=1, p>0.05). When only the individuals of known sex are taken into account, and our study area is divided into CCB (track 3-15) and adjacent waters, more females (57.1%) than males (42.9%) were observed within CCB (χ^2=2.016, df=1, p>0.05), while significantly more males than females were identified in adjacent waters (71.9% versus 28.1%, χ^2=19.18, df=1, p<<0.05). Therefore, despite the fact that more males were overall observed, there was a higher percentage of females within the Bay. This result suggests that, from 2004 to 2006 CCB was more important a habitat for females than for males.

Out of the 197 individuals ever identified in CCB (Track 3-15) between 1998 and 2006, 72 (36.5%) were females, 97 (49.2%) were males and 28 (14.2%) were of unknown sex. This sex ratio was not significantly different from the expected 50%-50% ratio (χ^2=2.1904, df=1, p>0.05), suggesting that overall, when the nine years are averaged, the same proportion of males and females visit CCB during winter/spring. However, there are large variability in the proportion of males and females visiting the Bay and the water just north of it every year (Fig. X). In 2001 and 2003 significantly more males than females were identified in CCB and just north of it (tracks 1-15), while in 2002 and 2005, significantly more females than males were identified. The absence of any trend or pattern on Fig X suggests high variability in the number of males and females that visit the Bay every year, but does not suggest any steady increase in the proportion of females observed in CCB to the detriment of males.

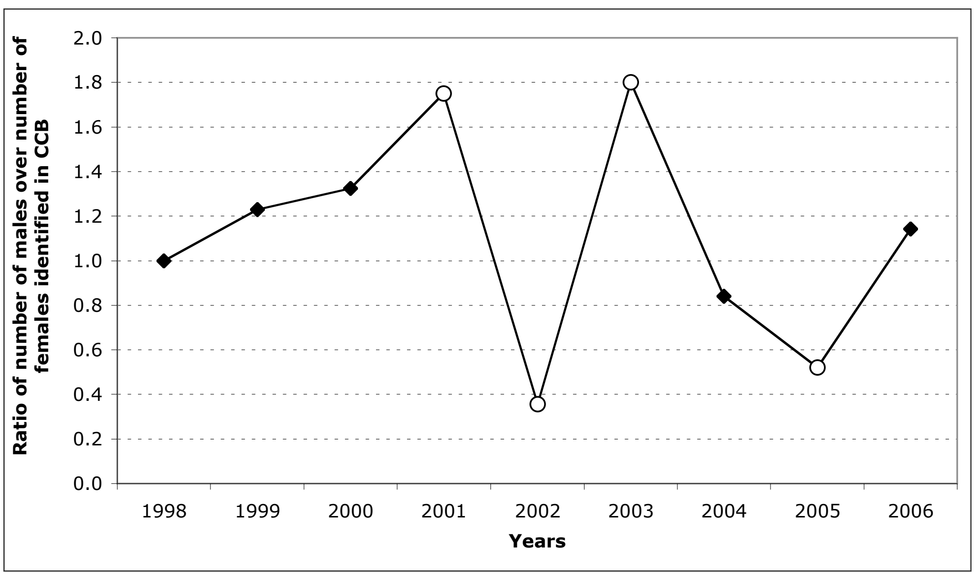


Figure X **Ratio of number of males over number of females identified in CCB and waters just north of it (track 1-15) during the nine years of the project. Open dots mean that the ratio was significantly different from 1.**

Although slightly fewer individual females than males visited CCB (track 3-15) during these nine years, females were observed on a significantly larger number of days than males ($\bar{x}$=15.8 days, SD=13.56 and $\bar{x}$=9.4 days, SD=8.00 respectively, t=3.840, df=167, P=0.002). These results suggest that females are utilizing CCB more than males. Figure XI shows the number of days each of the 197 individual right whales were sighted within CCB. Except for one male, all whales that were observed on 30 days or more were females (n=15).

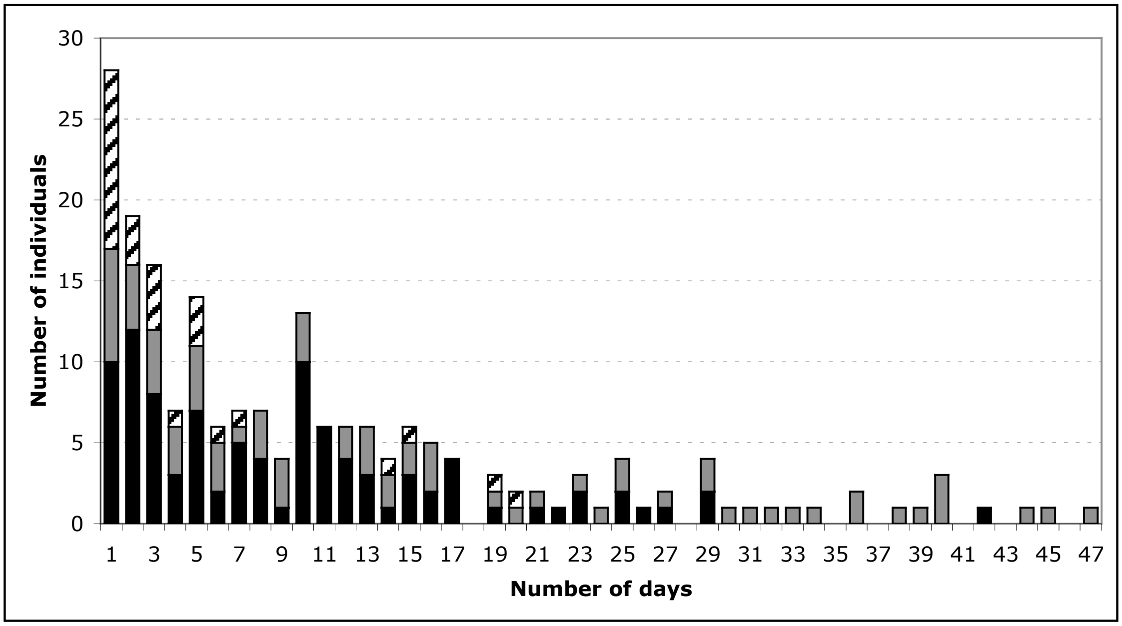


Figure XI **Number of days each of the 197 individuals was sighted in CCB (Track 3 to 15) between 1998 and 2006. Males are in black, females in grey and unknown sex in stripe.**

In 2006 CCB was frequented mainly by adults and by mother and calf pairs as only 10 individuals between 2 and 9 years of age were identified in CCB and adjacent waters (Fig. XII and Table VI). The age structure of animals of known age class (criteria defined in Hamilton *et al*. 1998) in the catalogued right whale population consists of approximately 84% adults and 16% juveniles, excluding calves (as of December 2003; Hamilton *et al*. 2004). Therefore, in 2006, out of the animals of known age class and excluding calves, we had 73 adults and 10 juveniles (excluding calves), and thus a proportion of 87.9% of adults versus 12.1% of juveniles. This age structure is not significantly different from the right whale catalogue (Hamilton *et al.* 2004; χ^2=1.1317, p>0.05). However, this proportion is significantly different from the approximately 75%/25% adult/juvenile ratio observed by Hamilton *et al.* (1998) for the entire catalogue through 1996 and by Brown *et al.* (2001b) in Cape Cod Bay during the first four years of this study (χ^2=8.8752, p<0.001. On the other hand, this proportion is very similar to that found in 2004 and 2005 (Mayo *et al*., 2004; Jaquet *et al*., 2005) when respectively 94% and 93% of the individuals of known age class (excluding calves) were adults and 6% and 7% were juveniles. Comparisons between all years from 1998 to 2006 are outlined in Table VI.

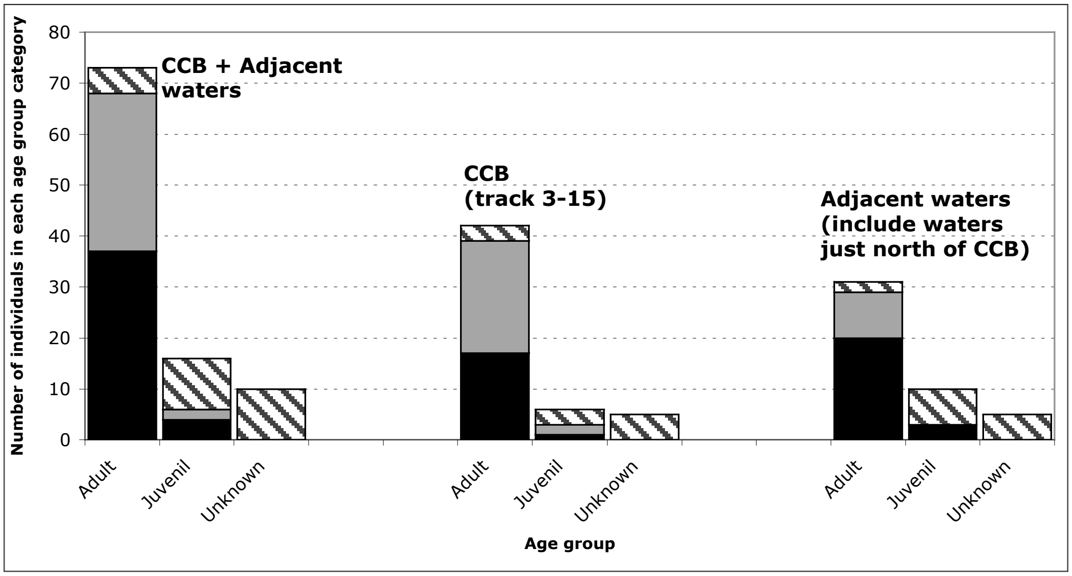


Figure XII **Number of males (black), females (grey) and whales of unknown sex (stripes) in relation to age groups and areas for 2006. A whale is considered a juvenile from its birth until age nine, and thus the 6 calves identified in 2006 are considered in the "Juvenile" category and were still of unknown sex at the time of writing.**

Table VI **Proportion of age groups and sex over the duration of the project (1998 to 2006) in CCB and adjacent waters.**

Year	Minimum # individuals	Adult : Juvenile (excluding calves)	# of Calves	# Unknown age	Males : Females	# Unknown sex
1998	75	58 : 15	0	2	28 : 38	9
1999	86	55 : 23	0	8	37 : 35	14
2000	86	64 : 15	0	7	42 : 36	8
2001	87	57 : 05	8	17	40 : 30	10
2002	19	10 : 06	3	0	02 : 12	5
2003	27	21 : 02	3	1	14 : 10	3
2004	54	47 : 03	2	2	22 : 27	5
2005	82	59 : 05	10	8	27 : 35	20
2006	69	73 : 10	6	10	41 : 33	25

A timeline depicting the demographic composition of right whales identified in Cape Cod Bay in 2006 and separated into two-week periods by age and sex is presented in Table 4. Within the Bay, all the individuals identified during the first month of sighting (from January 29 to March 8) were females. The first male was sighted within the Bay on March 12 and was seen only once. The second male was sighted on March 28, despite two complete and two partial surveys between these two dates (Table 5). The first male observed in adjacent waters was on March 24. This result is similar to what was observed in 2004 where all but two of the individuals seen in the first month of sightings were females, and similar to the 2005 results where most males started appearing in March.

Between 1959 and 2005, 288 individual right whales (excluding calves) have been identified in CCB (tracks 3-15). In 2006, seven whales that had never been identified in CCB (track 3-15) were observed; one of them was a male, three of them females, and three of unknown sex. During this project (1998-2006), 197 individuals (72 females, 97 males and 28 of unknown sex) have been identified within CCB (track 3-15), 71 individuals (36%) only during one year while four individuals (2%) were identified during eight years; no individuals have been identified during every year of the project (Figure X). Females tended to have a greater site fidelity than males, and a large proportion of males came to the Bay only once during the course of the project, while females tended to return more often (Fig. XIII). In addition, between 1998 and 2006, none of the 97 males that visited Cape Cod Bay during this period are known to have died, while seven of the 72 females have died (confirmed death), and thus less females were available to return in CCB in 2006. This result suggests that CCB is an important habitat for females and that they tend to come back there repetitively.

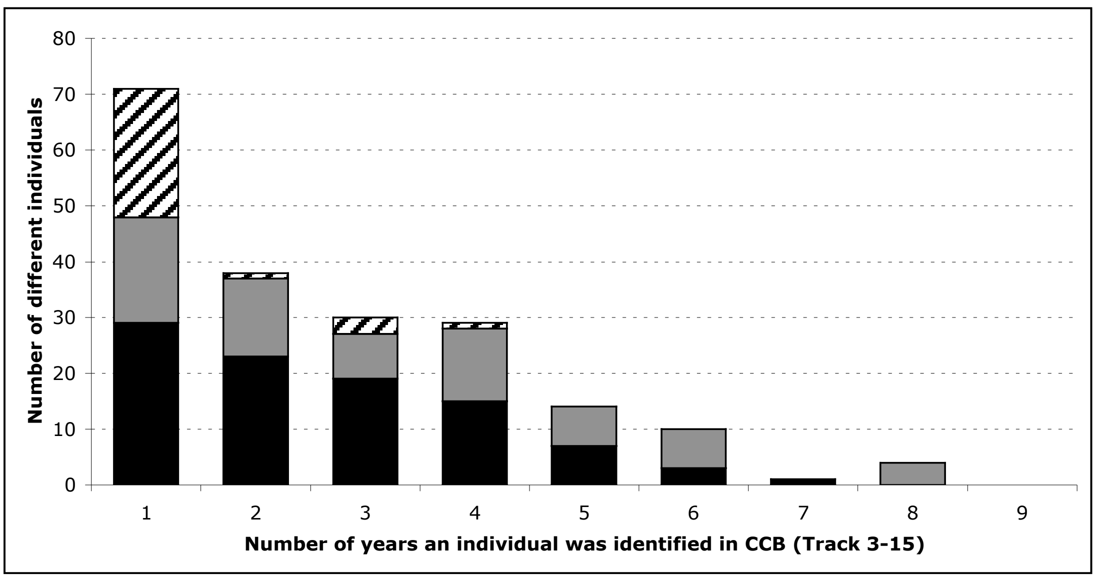


Figure XIII **Numbers of year individual right whales (males in black, female in grey and unknown sex in stripes) were sighted within CCB (Track 3-15) during the duration of the project (1998-2006).**

1.3.7. Individual Residency

As aerial surveys were not conducted every day, we have no way of knowing whether a whale was present in the Bay between two surveys or whether it had left the Bay and re-entered it at a later date. Therefore we define individual residency time as the time span between the first and the last sighting of an individual whale.

Right whales are often seen multiple times in Cape Cod Bay over a four-and-a-half month field season. Table 5 shows the sighting history for each of the 99 individuals identified in 2006 in CCB and adjacent waters. Right whales were present in CCB and adjacent waters for 99 days in 2006 (29 Jan to 8 May) in comparison to only 89 days in 2005 (Jan 30 to April 29). The longest time span between first and last sighting for a single individual was 71 days ($\bar{x}$=7.4 days; SD=13.31, n=93), these numbers are very similar to 2005 (see Jaquet *et al.*

2005). Calves were not included in the analyses as their residency time is not independent of their mother's. There were differences in the number of days seen and time span from first and last sighting between individuals seen in CCB and individuals seen only in adjacent waters.

Of the 50 right whales identified in Cape Cod Bay (only track 3-15) in 2006 (excluding calves), 28 (56%) were seen only once (Table VII). The greatest number of days on which individual right whales were identified in CCB was 7 (one adult female; Table 5). On the other hand, 84.2% of the individuals sighted exclusively in adjacent waters (track 16 and eastern tracks) were identified on a single occasion and only three individuals (15.8%) were identified on two different days (Table VII), no individuals were sighted on more than two occasions in adjacent waters. This pattern is similar when we include the two tracks just north of CCB into the adjacent waters (track 1, 2, 16 and eastern tracks): 79.1% of the individuals were seen only once, 20.9% were seen on two different days, and no individuals were seen on more than two days.

Table VII Number of days individuals (calves excluded) were identified in CCB (track 3-15) and in adjacent waters (include water just north of CCB)

Number of days an individual was photographed in 2006	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of individuals photographed **in CCB** (n=50)	17	20	3	7	1	1	0	1
Number of individuals photographed **exclusively in adjacent waters** (n=43)	34	9	0	0	0	0	0	0

Therefore, the individuals sighted in CCB were seen on a significantly larger number of days than those identified only in adjacent waters ($\bar{x}$=2.3 days, SD=1.47 days versus $\bar{x}$=1.2, SD=0.41; t-test: P<<0.001). This result suggests that the individuals identified in CCB were staying or returning in the area over a period of a few days to a few weeks while the individuals identified in adjacent waters must have been transiting to another area. This is confirmed by the time span in days between first and last sighting. In CCB (track 3-15) there was an average of 12.4 days between first and last sighting (SD=16.55 days, median=5 days, range= 1 to 71 days, Figure XIV), while in adjacent waters there was an average of 2.2 days between first and last sighting (SD=3.56, median=1 day, range= 1 to 17, Figure XV). Altogether 61 individuals (excluding calves) were sighted in adjacent waters (tracks 1,2, 16 and ES tracks), 50 in CCB (tracks 3-15) and only 18 were observed in both areas. This result confirms the suggestion outlined above that most whales sighted in adjacent waters are transiting to another area and only few enter CCB.

Similarly to single individuals, mother and calf pairs sighted within CCB were identified on multiple occasions (2 to 4 days), while mother and calf pairs identified exclusively in adjacent waters were sighted only on one or two days (Table V).

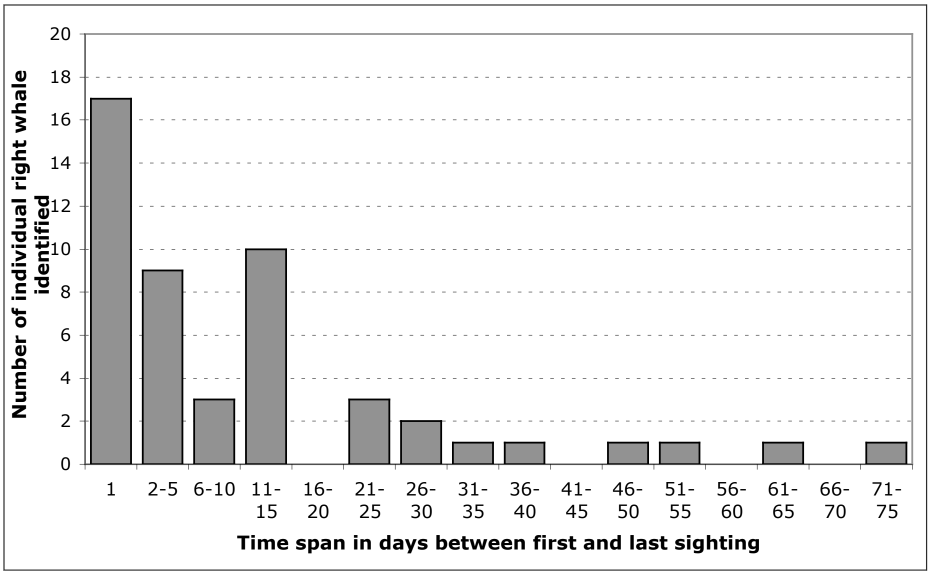


Figure XIV Time span between first and last sightings for right whales identified in CCB (tracks 3-15).

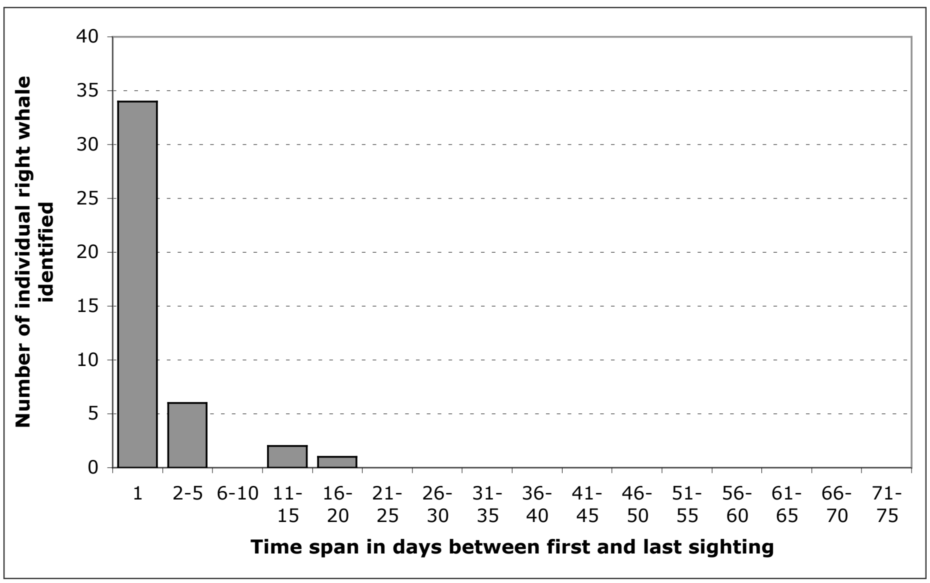


Figure XV Time span between first and last sightings for right whales identified exclusively in adjacent waters. Note the difference of scale for the Y axis between Figure XIV and XV.

Due to little photo-identification effort in areas other than CCB and the SEUS during winter/early spring, and due to the fact that most of the 2006 sightings from teams other than the PCCS team are still awaiting identification, it is not possible to assess whether the time span between first and last sighting in CCB represents the real residency within CCB or whether there are extensive movements in and out of the Bay between sightings. However, it seems clear that some individuals exited the Bay and re-entered it at a later date.

For example, right whale #1310 was observed in CCB on two consecutive surveys in March 8 and 12, observed again on April 14, and again on April 27 (Table 5). It is therefore much more likely that this individual made two to three different visits to the Bay rather than had a residency time of 51 days (Table 5). Table 5 also shows that, except for a few individuals, right whales were seldom observed during several consecutive surveys, suggesting extensive movements in and out of the Bay in 2006. However, the large number of windy days in March and April meant that eight surveys had to be aborted due to deteriorating weather and thus there were often long time gaps between consecutive full surveys (up to 16 days in March). Therefore, it is likely that the residency time of individual whales were underestimated in 2006. Furthermore, on the 14th of April the survey could not be completed due to the large amount of right whale sightings (37) and the lack of daylight hours to complete the entire survey. If we assume that an individual whale has left CCB when not sighted during three or more consecutive surveys, then, in 2006, 39.4% of the individuals seen more than once left and re-entered CCB one to three times during their residency period.

When only the residency time within CCB (track 3-15) was considered (and not the gaps in between), right whales had a mean residency time of 5.0 days (SD=5.26). Although shorter than in 2005 ($\bar{x}$=8.0 days, SD=9.72), the difference was not significant (t-test: t=1.878, df=87, P=0.0637, NS), suggesting that CCB was more utilized in 2006 than in 2005.

In CCB and adjacent waters, there were differences in residency time between demographic groups. Fifty-eight percent of the males were seen on only one day, and only one male was observed on more than four different days (average number of days identified=1.6, SD=1.03, n=40). Furthermore, the time span between first and last sighting for males was short (average=5.9 days, SD=9.62). In contrast, individual females were identified on a slightly larger number of days ($\bar{x}$=2.0 days, SD=1.57 n=33) and the time span between first and last sighting was considerably larger ($\bar{x}$=11.8 days, SD=18.72). Mother and calf pairs were identified on average on the highest number of days ($\bar{x}$=2.2, n=6), and had a time span between first and last sighting in between males and single females ($\bar{x}$=8.2 days, median=2 days, SD=6.59).

Within CCB only, there were differences in time span between first and last sightings between males and females, and the mean residency time was longer for females than for males (Table VII). As for all areas and all years, mother and calves pairs had the longest residency time (Table VII).

Table VII **Time span (between first and last sighting) and residency time (excluding gaps when not sighted during ≥3 consecutive surveys) for individuals sighted within CCB (track 3-15) in 2006. Calves are excluded from this analysis.**

	Sample size	**Mean Time Span in days (SD)**	**Median Time Span in days**	**Mean residency, no gaps ≥ 3 surveys (SD)**	**Median residency, no gaps ≥ 3 surveys**
All (including unknown sex)	50	12.4 (16.55)	5	5.0 (5.26)	2
Males	17	10.5 (12.86)	5	3.6 (4.27)	1
Females	24	15.2 (20.90)	5	5.1 (5.96)	1
Mother/calf pairs	3	11.0 (5.29)	13	11.0 (5.29)	13

Table VIII Time span (between first and last sighting) and residency time (excluding gaps when not sighted during ≥3 consecutive surveys) for individuals sighted within CCB during the entire project (1998-2006).

	Sample size	Mean Time Span in days (SD)	Median Time Span in days	Mean residency, no gaps ≥ 3 surveys (SD)	Median residency, no gaps ≥ 3 surveys
All	518	20.5 (24.9)	12	10.4 (11.69)	6
Males	248	19.0 (25.89)	9	9.3 (10.56)	5
Females	215	24.0 (24.38)	18	12.0 (13.19)	7
Mother/calf pairs	21	15.6 (11.31)	15	15.6 (11.31)	15

Overall (1998-2006) there were significant differences in residency time between mother/calf pairs, single females, males and unknown sex (Kruskal Wallis: K=11.372, df=3, p=0.0099), suggesting that mother/calf pairs stay in CCB the longest, than single females and then males (fig. XVI). Mother and calf pairs were the only demographic group that didn't show movements in and out of the Bay between first and last sighting and thus the mean time span was equal to the mean residency time. This discrepancy in residency time between demographic groups suggests that, although as many males as females are visiting the Bay, CCB is a more important habitat for females than for males.

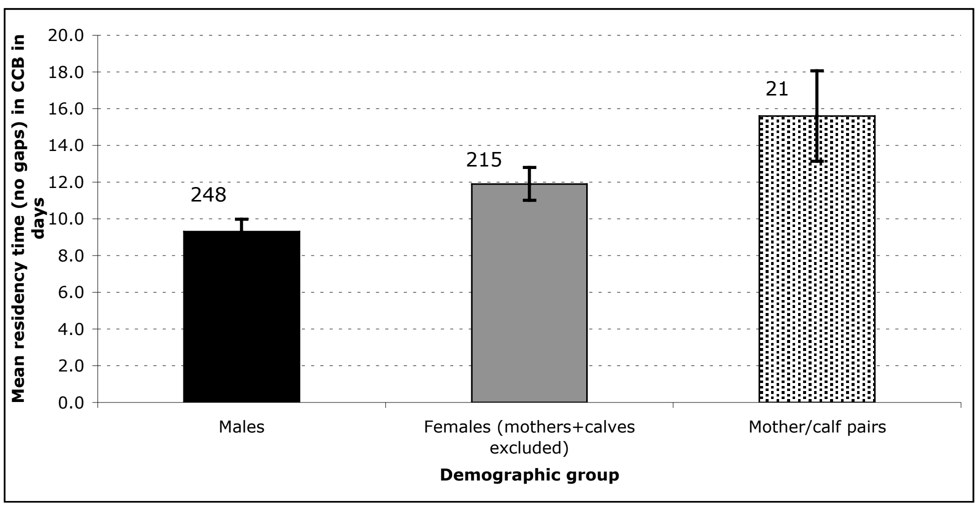


Figure XVI Mean residency time (excluding all gaps) for males, females and mother/calves pairs in CCB, all 9 years combined (1998-2006). Error bars are one Standard Error and the number above is the sample size.

The mean residency time of 10.5 days (SD=11.696) for all individuals (including the ones of unknown sex) in CCB all years combined (1998-2006), is further confirmed by the results of the lagged identification rate analyses (using SOCPROG 2.2, Whitehead, 2001). The lagged identification rate is the probability that if an individual is identified in CCB at any time, it will be identified during any single identification made in CCB after a certain time lag (Whitehead, 2001). For this analysis we used all identification photographs from 1998 to 2006. The maximum time lag was set at 135 days (length of a field season), as we were interested in the number of days individuals stay in CCB within a field season. Standard errors were calculated using 1,000 bootstraps. Several models were fitted to the curve, but the best fitted model (using the Quasi Akaike Information Criterion) was an "emigration + reimmigration" model suggesting that individuals enter CCB, leave it and re-enter it at a later date. These results are consistent with observations, and thus provide confidence in all results and interpretations.

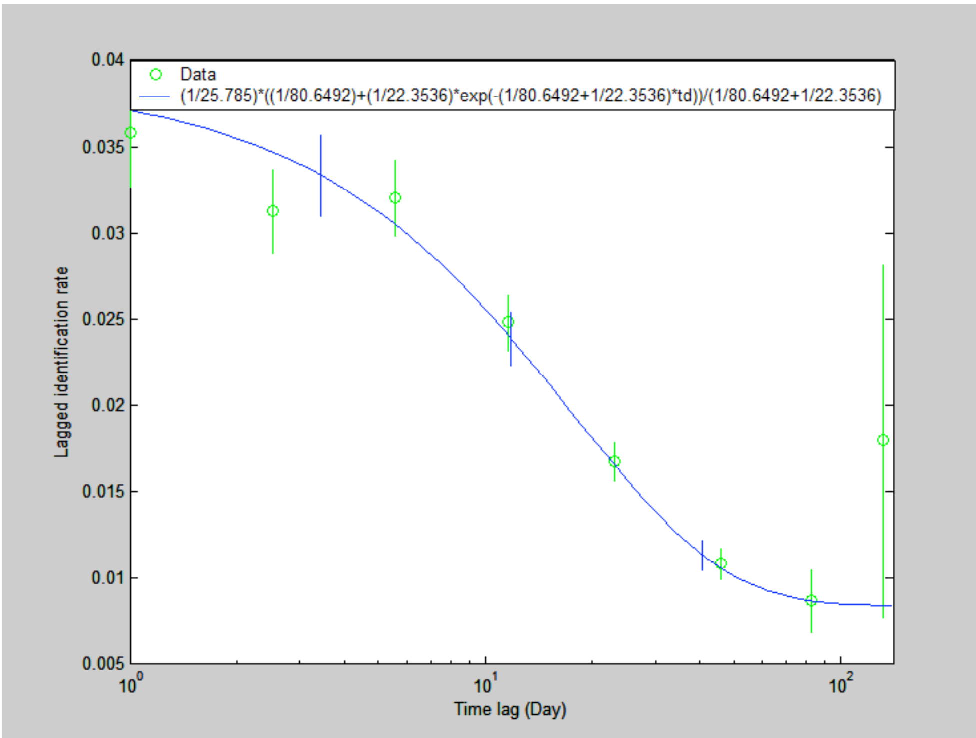


Figure XVII Lagged Identification Rates for CCB 1998-2006. Error bars represent standard errors, and the blue line is the fitted model

Figure XVII suggest that individuals use CCB for about 10 to 20 days before leaving the Bay for the season. The fitted model suggests that the average residency time in CCB is 22 days. This is longer than what was calculated using observations of individuals and deleting any gaps of two or more surveys when individuals were not seen (average of 10.5 days, see above). However, both calculations measure something slightly different, the mean residency time without gaps provide the average time that an individual stay in the Bay at any one time, while the results of the above model provide the total time an individual is likely to be in the Bay and thus suggest that, on average, each individual will come and go twice during the course of the field season.

1.3.8. Movement patterns and daily displacement of right whales

Knowledge of movement patterns is critical in order to understand how an animal relates to its environment, and data on movements of individual right whales can provide information on spatial use, residency and profitability of foraging. Furthermore, the levels of threat posed by entanglement in fishing gear and by collision with ships highly depend on the distribution and movements of right whales. Therefore, an understanding of movement patterns over a range of temporal scales is crucial for the conservation of this species, and should be a significant component of management and conservation policies. Using photo-identification data collected systematically during the last nine years, the movement and diffusion rate (Turchin, 1998) of right whales in CCB were calculated using the SOCPROG suite of Matlab programs (Whitehead, 2001). As aerial surveys almost always covered the entire Bay, the probability of re-identifying an individual within CCB was independent on its movement within the Bay, and therefore the standard method of calculating diffusion rates (Turchin, 1998) was appropriate (Whitehead, 2001; Hooker et al., 2002). Standard errors were obtained by jackknifing, omitting consecutive 20-day periods in turn (Efron and Gong, 1983).

Figure XVIII shows the root mean square (rms) displacement of individual right whales within CCB. Although rms displacement is less theoretically justifiable than mean squared displacement, it is more easily interpretable and has been shown to provide meaningful approximations (Whitehead, 2001). The results indicate that on average right whales have a daily displacement of about 9 km, and that this displacement increases slightly during the 10 days or so of their residency within the Bay. Displacement over time lags shorter than one day could not be investigated using the aerial survey data as individuals were very seldom sighted more than once during a single day. Displacement over time lags longer than 20 days were meaningless as individual right whales have a mean residency in the Bay of 10 to 20 days (see section 1.3.8). This result suggests that, during its residency in the Bay, an individual will stay in an area about 12-13 km in diameter, and will not, on average, move extensively throughout the entire Bay. However, these results represent the average movement of individual right whales over a nine-year study period and do not mean that extensive movement covering the entire Bay does not occur at time.

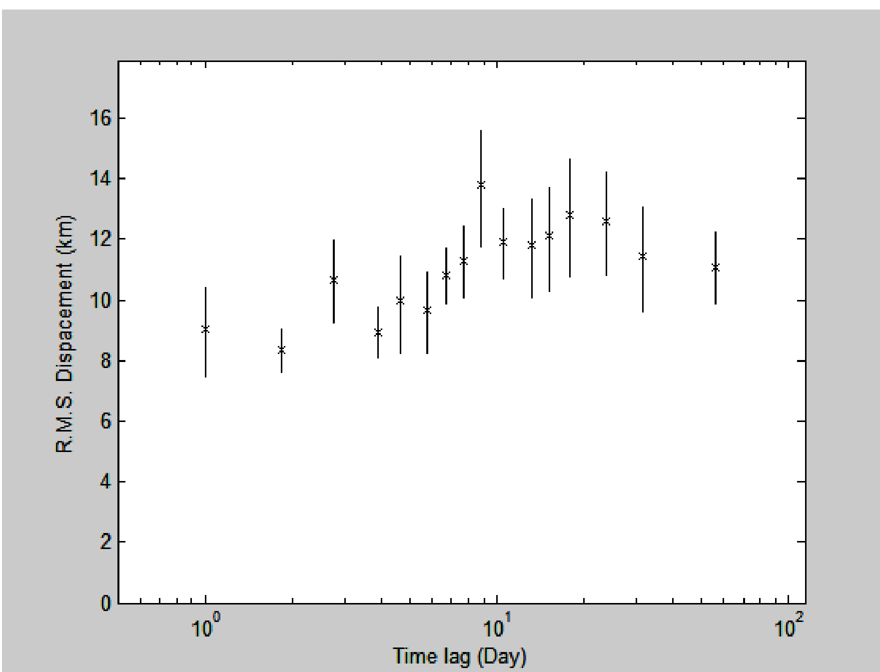


Figure XVIII Root mean square displacement (in km) for right whales within CCB. The maximum time lag of 135 days corresponds to the length of a field season. The error bars represent 1 standard error.

Over time scale of less than a day, movements were investigated by following single individuals for as long as possible. In the morning of the 27th of April, whale # 2540 (adult male) was followed closely for 4 hours and in the afternoon whale #2530 (adult male) was followed for 3.5 hours, both these whales were sub-surface feeding. On the 5th of May, whale #1317 (a 23 year old male) was followed closely for 9h05 while skim feeding. Furthermore, a cluster of 10 whales were followed on the 6th of May, these whales were skim feeding. However, as the individuals were moving independently (unlike the cluster of two whales in 2005), we cannot calculate the details of their small-scale movement patterns. During the 2005 pilot study (acoustic behavior and focal follow), a cluster of two traveling whales (1 adult male and 1 adult female) was followed closely for 3 hours on the 5th of April, and a mother and calf pair was followed for 5.1 hours on the 17th of April while subsurface feeding. The focal follow on the 17th of April did not keep a consistent distance between whales and research vessel and therefore the details of the small-scale movement patterns were not analyzed. The results of the small-scale movement patterns for all of these individuals are summarized in Table VIII.

Table VIII Summary of small-scale movement patterns for 2005 and 2006. The straight-line distance represents the net displacement of the individual between the time it was first seen to the time it was last seen. The total distance represents the distance traveled by the individual including all zigzags and back-tracking. The zigzag index is the total distance over the straight-line distance. Numbers between brackets represent standard deviations.

Date and Whale #	Straight-line distance km	Total distance in km	Zigzag Index	Speed in km/hr	Time followed in hours
5 Apr 05 - #1267 + #1122	11.3	16.4	1.45	5.5	3
17 April 05 - #1310+calf	2.5				5.1
27 April 2006 - #2540	10.9	21.0	1.94	5.3	4
27 April 2006 - #2530	0.6	15.9	27.74	4.5	3.5
5 May 2006 - #1317	9.1	35.9	3.95	3.9	9
6 May 2006 – 10 whales	2.0				9.45
Average	**6.1 (4.87)**	**22.3 (9.33)**	**8.8 (12.69)**	**4.8 (0.68)**	**5.7 (2.84)**

The zigzag index represents an index of how much back-tracking an individual is doing, a zigzag index of 1 mean that an individual is traveling in a perfectly straight line, the higher the zigzag index, the more back-tracking an individual is performing. Despite large differences in net displacement between individuals, the speed for all of these whales was very consistent and was on average 4.8 km/h (similar to the walking speed of human). This means that right whales are mostly moving at the same speed and that the speed is unrelated to behavior. On the other hand, the net displacement (or area used by an individual) was highly related to behavior, and while feeding whales had substantially smaller net displacement than when traveling. The cluster of traveling whales had a net displacement of 11.3 km in just 3 hours, while feeding whales had an average net displacement of 5 km over an average of 6.2 hours.

Root mean square displacements were then calculated for the individuals for which we had detailed small-scale movements patterns and show that the average hourly displacement was about 3 km/hr, 4.8 km for two hours, 5.6 km for three hours, and 6.1 km for 6 hours (Fig. XIX). These results are consistent with the average daily displacement calculated using all sighting data in CCB from 1998-2006 (see above). Figure XIX indicates that, already after 6 hours, the net displacement seems to be reaching a plateau at just above 6 km. Therefore, although we do not yet have average data to calculate root mean square displacement for time lag between 6 and 23 hours, this result suggests that an average net displacement of 9 km over 24 hours is appropriate.

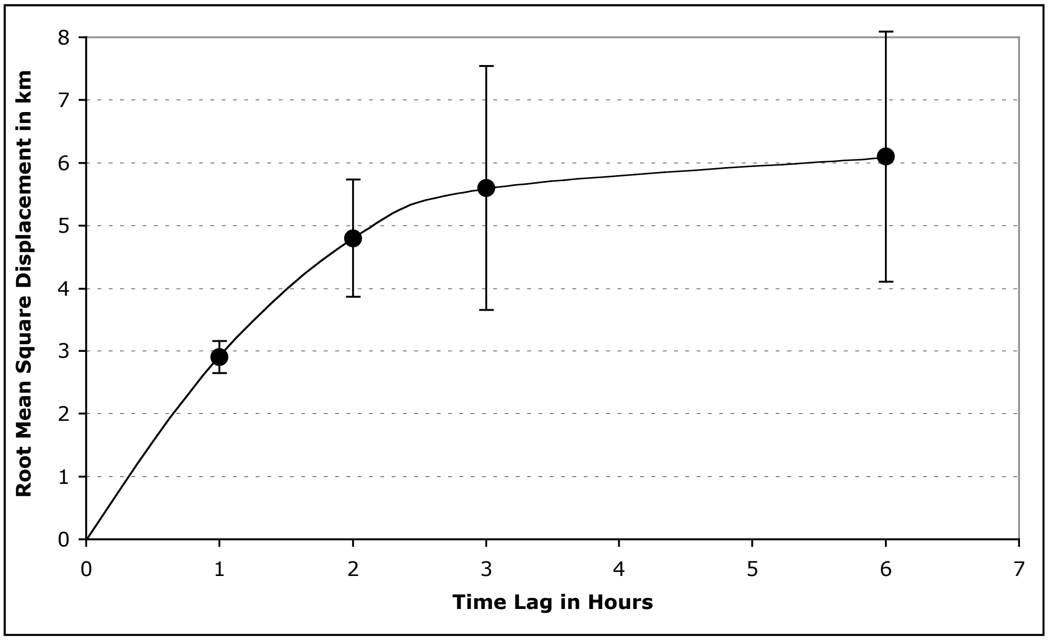


Figure XIX Root mean square displacement (in km) for right whales within CCB calculated using focal follows data. The error bars represent 1 standard error.

Figure XX shows the path of whale #1317 that was followed for 9 hours on the 5th of May. The focal follow started at 8h30 (start on Fig. XX), was lost between 12h15 and 13h55 and was left at 17h30 (finish on Fig. XX). Although the whale covered a bit of ground, mainly during the 1h45 minute that it was lost, there was only 9 km between start to finish. During the 1h45 minutes that the whale was lost, it covered 6.4 km and thus if done in straight line, would have been moving at a speed of 3.7 km. This suggests that the patch of food the whale was first feeding on became depleted (or diffuse) and the whale decided to move elsewhere in a more or less straight line. The details of the small-scale movement patterns of this skim-feeding individual are shown on Fig XXI. This Figure shows a large amount of zigzags (likely indicative of dense patches of food, Mayo and Marx 1990, Jaquet and Whitehead, 1999) during the second part of the follow.

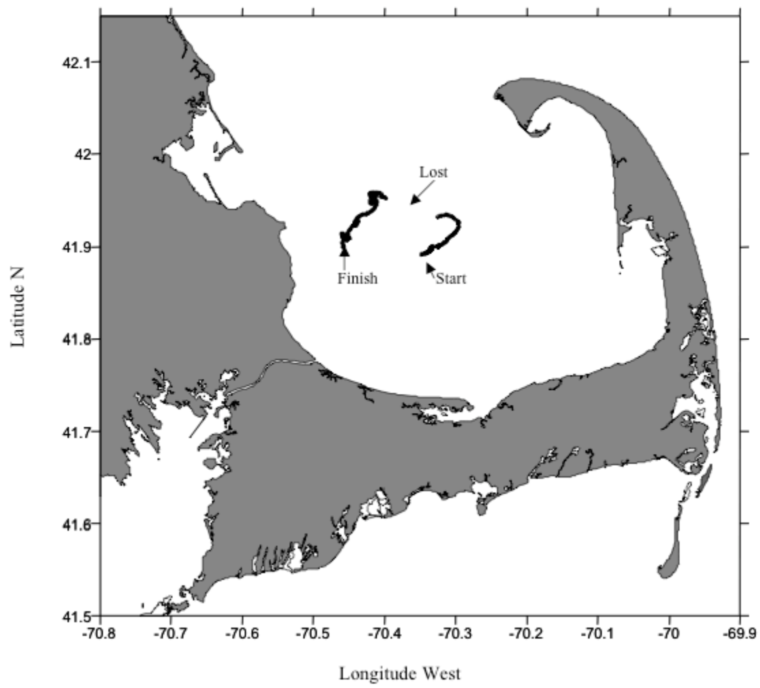


Figure XX Path of whale #1317 followed closely on May 5, 2006.

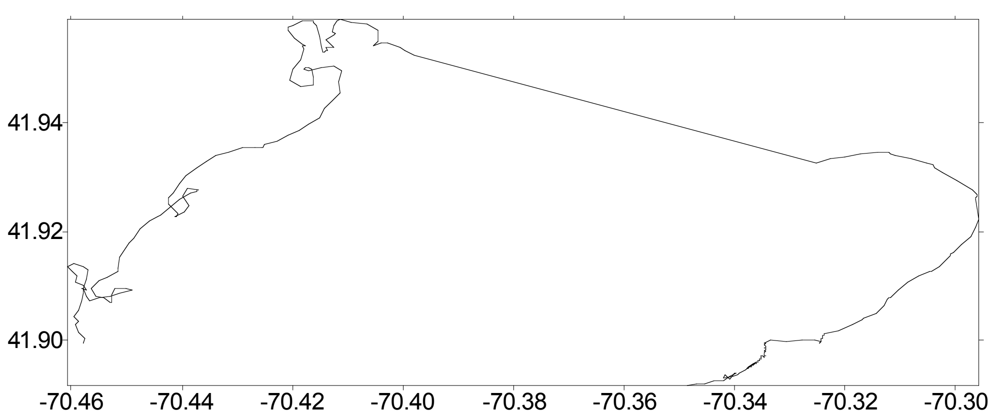


Figure XXI Details of the small scale movement pattern of whale #1317 followed for 9 hours on May 5, 2006, while skim feeding.

1.3.9. Sightings Between Habitats and Transit Time

At the time of writing, most of the identification photographs of the South East US (SEUS) have not been matched to the catalog, and thus an analysis of the number of individuals seen both in SEUS and in CCB as well as of the transit time between these areas in 2006 is not possible, and therefore the results have not changed from what was outlined in the 2005 report (Jaquet *et al*., 2005).

To investigate movements between CCB and the Great South Channel (GSC) and between CCB and the Massachusetts Bay (MB), we plotted the lagged identification rates for both areas (Figure XXII and Fig. XXIII). For these graphs the maximum time lag was 150 days and the error bars were calculated using 100 bootstraps. Figure XXII suggests that in general there are about 10 to 30 days between identifying an individual in CCB and re-identifying it in GSC. However, these results also suggest movements at smaller time scales and some individual whales were re-identified in GSC only a day after having been seen in CCB. It is likely that the time between being observed in CCB and the time being observed in GSC is over-estimated as little survey effort is dedicated in the GSC in late winter/early spring and as the weather conditions prevent the completion of many surveys during May and June.

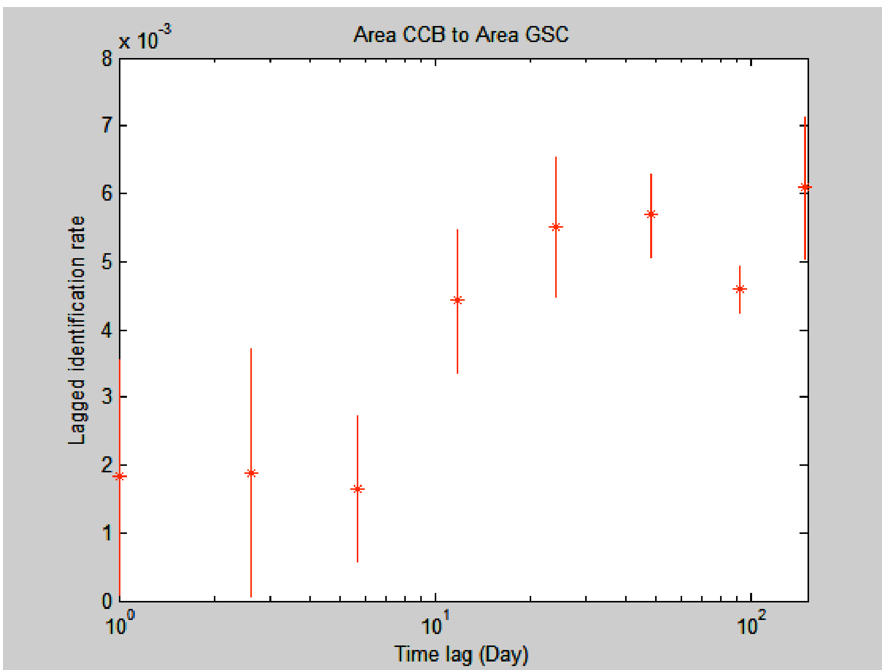


Figure XXII Lagged Identification Rates for CCB to GSC (1998-2006). This corresponds to the probability of re-identifying an individual in GSC at time lag t after having identified it in CCB. Error bars are calculated using 100 Bootstraps.

Figure XXIII suggests that most of the movements between CCB and MB occur over a short time scale of a few days, and thus the higher probability of re-identifying an individual in MB after having identified it in CCB is after 1 to 3 days, and then this probability decrease and become very small after 40-50 days. This is consistent with the idea of individual right whales going in and out of the Bay several times during a season and then leaving the area all together.

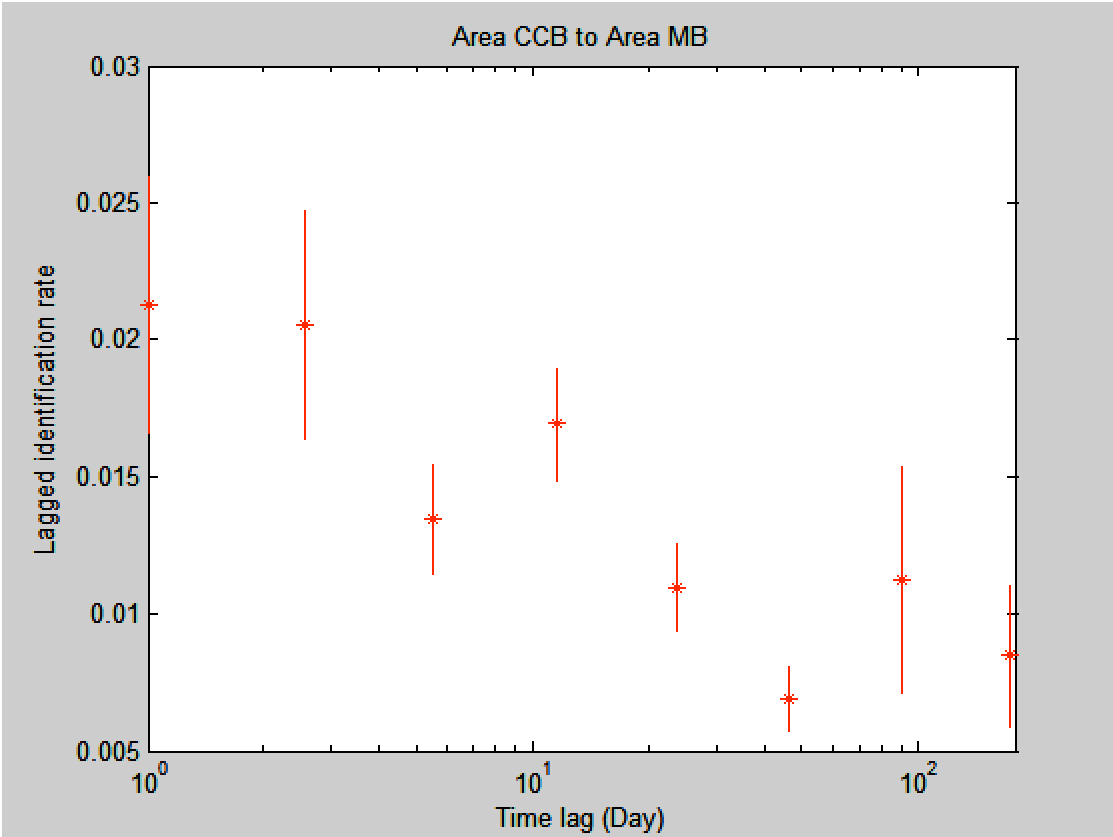


Figure XXIII Lagged Identification Rates for CCB to MB (1998-2006). This corresponds to the probability of re-identifying an individual in MB at time lag t after having identified it in CCB. Error bars are calculated using 100 Bootstraps.

1.3.10. Acoustic behavior of right whales

Recordings of individual right whales were conducted during seven days between late March and early May 2006, and right whales vocalizations were recorded continuously amounting to about 40 hours of recordings. Behavior and vocalization rates were highly variables between days but as not all the data have been analyzed to date, the following only describes very preliminary observations. On May 5 and May 6, four and 10 right whales respectively were observed skim feeding within one nm of the research vessel. The observations and recordings lasted for 9 hours each day. On both days, there were no vocalizations during the first eight hours of recordings and about 10 to 15 up-calls were heard during the last hour. This observation suggests that right whales may stay mostly silent when skim feeding. This observation also suggests that more vocal activity may take place in late afternoon and early evening than during the day. As skim feeding whales spend over 95% of their time at or near the surface, it is one of the times that they are most vulnerable to ship strike and the lack of vocalizations may render them difficult to detect by passive acoustic. However, more data will be needed before any conclusion can be reached.

Preliminary observations suggest little correlation between number of whales and vocalization rates, but high correlation between behavior and vocalization rates. When in Surface Active

Groups (SAGs), even when the SAG involves only three to four individuals, up-calls and tonal sounds are heard almost continuously. On the other hand, when exclusively feeding, no calls were usually heard even when 10 individuals were present in close proximity.

1.3.11. Monitoring of Entangled Whales

On 12 April 2006, entangled whale # 3346 (juvenile male, "Kingfisher") was observed north of Cape Cod Bay. He has been entangled since 2004. This whale was not re-sighted during the field season. The photographs of #3346 have been examined by members of the PCCS disentanglement team and the New England Aquarium right whale research team. The images show the entanglement on the right flipper and the apparent lack of entanglement on the left. The remaining entanglement appears to be limited to the tight wraps around the middle portion of the right flipper and a short section of trailing line extending down the right side of the body, which is what was observed earlier in the year in the southeast US, and in summer 2005 in the Bay of Fundy.

Previously entangled right whale #1167 (adult male), first seen entangled in June 2005, was sighted in Cape Cod Bay during an aerial survey on 27 April and was sighted on several more occasions from both the aircraft and vessels. No gear was visible, although the nature of the entanglement makes it impossible to conclusively declare the whale free of gear from the images taken to date. The whale's apparent condition has improved since its last sighting in September 2005 in Roseway Basin.

Right whale #2320 (adult female, "Piper"), subject of numerous disentanglement attempts and documentation efforts since first being reported entangled on August 4, 2002, was confirmed gear-free using photographs taken during an aerial survey on 14 April 2006, one half mile west of Race Point. Previous sightings in the southeast US, including documentation with a calf in January, had suggested that at least some of the rope that entangled this whale for the past four years was gone, but the images from 14 April were the first to document the absence of rope where it once was woven in the whale's baleen. She was first seen in Cape Cod Bay on 12 April, along with her calf, and the pair was documented several more times from vessels and the aircraft.

1.3.12. Distribution of Vessel Traffic

The distribution of vessels by type as recorded during aerial surveys during the 2006 season is plotted in Figure 4. No direct whale/vessel interactions were documented.

1.3.13. Notification of Agencies and Management Measures

At the completion of each survey and cruise, the information on the number of right whales and their locations was sent to the coordinator at the SAS office at NOAA Fisheries, Northeast Fisheries Science Center in Woods Hole. Sightings in Cape Cod Bay were reported to the USACE Cape Cod Canal Field Office at the end of each aerial survey. USACE marine traffic controllers transmitted sighting locations to vessel traffic exiting the Canal into the Bay. In order to expedite the distribution of the information to the maritime community, the number and location of right whales was relayed to SAS and USACE by cell phone at the completion of each survey. During surveys and cruises in Cape Cod Bay, the USACE Field Office was contacted directly by VHF radio or cell phone at the time of a sighting in close proximity to traffic exiting or entering the Cape Cod Canal. A total of 54 faxes were sent to the DMF offices in Boston and Gloucester (one fax for each aerial survey and habitat sampling cruise in Cape Cod Bay and adjacent waters). Sightings from R/V *Shearwater* were noted, but not plotted, on the faxes. The DMF/PCCS surveys are the principal source of right whale sighting information in the northeast region (north of latitude 41° N) for the NOAA Fisheries/SAS program in the months of January through March.

On 15 April, DMF issued an advisory to the maritime community due to the high number of right whales sighted by aerial surveys in close proximity to areas of high vessel traffic off Provincetown (Race Point). NOAA Fisheries issued a similar advisory on 21 April based on this data. Both advisories recommended that vessels transiting the bay reduce speed to 12 knots, post lookouts, and proceed with caution. Vessel operators were reminded that it is against the law to approach right whales within 500 yards. An expanded advisory was issued for western Cape Cod Bay and Race Point on 25 April based on aerial survey sightings and zooplankton concentrations. The advisory was extended on 8 May, with the western Cape Cod Bay high-risk area moved further west to reflect sightings and zooplankton densities. DMF lifted the 8 May advisory on 19 May, following the 18 May aerial survey and habitat sampling cruise.

1.3.14. Sightings of Other Species

In addition to right whales, seven other species of cetaceans and two pinniped species were sighted during aerial surveys in 2006 (Table 2). Fin whales (*Balaenoptera physalus*, 158 sightings) and humpback whales (*Megaptera novaeangliae,* 89 sightings) were the most numerous of the large whales sighted in Cape Cod Bay and adjacent waters. In addition, 34 minke whales (*Balaenoptera acutorostrata*) were sighted. The spatial distribution of the above three species of balaenopterids is plotted in Figure 5a. Fin and humpback whale sightings were largely concentrated toward the northeastern portion of Cape Cod Bay. Of the toothed whales sighted and identified by species, common dolphins, *Delphinus delphis*, were the most common species recorded in Cape Cod Bay (Table 2). A large proportion of toothed whale sightings were recorded as “unidentified dolphin” as the species could not be determined without circling to allow examination of morphological features to facilitate identification. The spatial distribution of toothed whales from aerial surveys is indicated in Figure 5b. Sightings of species other than right whales were also recorded opportunistically during vessel cruises (Table 3).

1.4. Discussion

1.4.1. CCB Right Whale Population: Characteristics, Abundance and Seasonality

Results of this study suggest that the right whales that visit CCB in winter/early spring is not a random subset of the population but that these individuals have a statistically higher probability to be observed in CCB than in all other areas. Similarly, there is a part of the right whale population that has a lower probability to be observed in CCB than in all other areas. It is thus possible to call the individuals that come into CCB a “CCB population”. This is consistent with the idea that not all individual right whales are seen in all areas and that individuals show preferences for offshore or inshore areas for example. It is also consistent with Malik et al (1999) who showed that some reproductive females show site fidelity for the Bay of Fundy and that other reproductive females are almost never seen in this area.

Over the last nine years, there was no trend in CCB being more and more or less and less utilized by right whales. However, there was high variability in utilization amongst years, with only 20 different individuals coming into the Bay in 2002, while 89 individuals were identified in the Bay in 2000. This yearly variability is unlikely to be due to differences in effort, as effort has stayed relatively constant for the past nine years. This variability is more likely due to yearly differences in food resources, but statistical tests still need to be performed to elucidate the spatial and temporal relationship between zooplankton abundance and right whale abundance.

In general, over the last nine years, there was a significant correlation between the number of individuals that were observed in CCB and the number of whale-day (=number of different individuals time the number of days they were observed). This result suggests that during years of high right whale abundance, individuals also tend to have a longer residency time within the Bay, and that in years of low right whale abundance, individuals tend to be observed on a smaller number of days. However, this was not the case for 2006 when 78 different individuals were identified in CCB amounting to just over 150 whale-day, while a similar number of individuals were observed in 2001 but amounting to about twice as many whale-day. It is possible that the long stretch of bad weather during the month of March 2006 substantially biased the results as few surveys were completed during March, reducing the probability of re-identifying an individual several times over a time period of about 10 days and thus negatively biasing the residency time.

On average, right whales are present into CCB for just over three months every year, and although there is large variability in the time they first enter the Bay, the emerging pattern after the nine years of survey suggests that there is more variability between months than within months. Our results suggest that, on average there are already about three right whales per survey day in January, that this number doubles in February, reaches a peak in March and April with just over 10 individuals on each survey day and drops drastically in early May with only about 1.5 individuals on average on each survey day. This is consistent with the pattern that has been observed during most years of the study: a slow increase in right whale abundance in January and February, a peak during March and April and an “en masse” departure in early May. This result is somewhat puzzling as there are usually more food resources available to right whales in early May then there is in January, but yearly trends in zooplankton abundance still need to be formally quantified. It is possible that, in January, there is little food available for right whales anywhere within their range and thus, that it is still worthwhile for them to forage in CCB even if the number of copepods per m^3 rarely reaches the threshold in January or February (see section 2 of this report for details on feeding threshold). It is also possible that, as monthly copepods abundance shows large yearly variations, right whales come into the Bay early in the season to investigate the state of the resources regardless of the amount of resources. In early May, copepod abundance starts increasing in many areas and large amounts of food resources are usually available for right whales in the Great South Channel. It is therefore possible that right whales leave CCB in early May regardless of the resource present in CCB knowing that better patches could be found elsewhere. However, what seems clear is that the peak in right whale abundance in March and April coincides with the peak of copepod abundance (see section 2 for details).

1.4.2. Right Whales in Adjacent Waters

Right whales are also often observed outside CCB, either just north of the entrance, along the Atlantic side of the Cape (also called “backside”) or on the track-lines that are occasionally flown north-east, or east of CCB. However, it is more difficult to characterize these individuals either in term of population or yearly abundance as the effort varies widely among years. Therefore the probability of seeing a particular individual in what we called “adjacent waters” is highly dependent on effort, and not only on the presence or absence of this individual in these waters. Despite this short-coming, the results of this study to date (after nine years of data) strongly suggest that the waters adjacent to Cape Cod Bay are an important area for migrating whales and that a large number of them transit close to CCB to reach different areas. Our results also suggest that most of the whales transiting through the adjacent waters do so in late March, April and early May. To increase our understanding of the utilization of adjacent waters by right whales, it would be interesting in later years to compare the proportion of feeding whales in CCB versus in adjacent waters, to investigate movement patterns, as well as to collect zooplankton samples in these waters.

The yearly abundance of right whales in adjacent waters is more variable (even after correction for effort) than for CCB. It is likely that this high variability is the result of the small strip of waters that is surveyed by plane as part of the bi-weekly survey (a strip of only about five nm wide). It means that if on some days, right whales are transiting only slightly further offshore they would be missed by the survey. Furthermore, it is more difficult to detect transiting individuals by bi-weekly surveys than to detect them in an area where they tend to stay for about 10 days or so, and thus it is likely that many individuals are missed in adjacent waters.

1.4.3. Demographics

Between 1998 and 2005, 126 calves were born in the SEUS and thus assuming that none died in their first few years of life (which we know to be untrue), 126 juveniles (aged 2 to 8 years) would have been available to come into CCB and adjacent waters in 2006. In 2006, 99 different individuals were observed in CCB and adjacent waters representing 25.3% of the entire population presumed to be alive (New England Aquarium, unpublished data). Therefore, if all of the 126 calves born between 98 and 2006 were alive, and if juveniles had the same probability than adults to be observed in CCB and adjacent waters in winter/spring 2006, we should have seen 32 juveniles instead of 10. It is most unlikely that all calves born in the last nine years were still alive in winter/spring 2006, however, even if only 50% of them survived, we would still have expected that 16 were observed in the Bay and adjacent waters in 2006. However, first year calves are very difficult to identify and thus juveniles are difficult to match to individuals that were first identified as calves. Therefore a large proportion of the individuals that have not yet been matched to the catalogue is likely to be juveniles, accounting, at least partly, for the deficiency in juveniles seen in recent years. As soon as all the back-logged identification photographs will be matched to the catalogue, it will be possible to re-visit this issue. If the deficiency in juveniles persists after all identifications has been match, it may suggest that a very large proportion of calves die before they reach adulthood, but a formal investigation of survival rate should be performed before conclusions could be reached. However, such a large difference between the number of expected and observed juveniles is unlikely to be explained solely by mortality (as it would mean that 70% of juveniles died before reaching adulthood), and thus this difference may also suggests that juveniles are less likely than adults to visit CCB and adjacent waters.

In 2006, we recorded the highest percentage of mother and calf pairs in CCB and just north of CCB, and if we only take the last four years into account, there is a significant upward trend in the proportion of mother/calf pairs visiting the area (P=0.0326) suggesting that, during the last four years more and more mother/calf pairs have been utilizing the Bay. On average, about 16% of the entire right whale population is identified in CCB and just north of CCB, and therefore, a proportion of 31% of mother/calf pairs as observed in 2006 suggests that mother/calf pairs showed a substantial preference for CCB confirming that CCB is an important nursery area. As calves are the future of the population, it will be important to monitor this trend during the next few years. It will also be crucial to identify the other early spring nursery areas, as to date there are no information as to where 60-70% of the population spends the late winter/early spring.

On average, more females than males are observed within CCB (tracks 3-15), individual females have a higher site fidelity than males (meaning they are more likely to come back year after year) and have a significantly longer residency time than males. This is consistent with the work of Brown et al. (2001a) who showed strong evidence for geographical segregation by age and sex (in adults). Furthermore, all these observations establish that CCB is a more important habitat for adult females than for adult males. As the death of a female is considered substantially more detrimental to the survival of the species than the death of a male (Fujiwara and Caswell, 2001), it means that CCB, as far as management is concerned, is even more important a habitat than previously thought.

1.4.4. Individual Residency of Right Whales in CCB

Analyses of individual residency time have outlined substantial differences between CCB and adjacent waters, with individuals having a significantly longer residency time in CCB (tracks 3-15) than in adjacent waters (tracks 1, 2, 16 and NE, and E tracks). This result suggests that the boundary line for CCB as defined in the Right Whale Consortium photo-identification database (42.0666°N) is also meaningful in terms of right whale distribution and residency and not only in geographic terms. Therefore, it makes sense to analyze data from CCB and adjacent waters separately as trends could be obscured if all data were combined.

During the entire season there is a substantial turn-over of individuals; on average, right whales are present in the Bay for about 96 days, but the individual residency is of only 10-20 days. Furthermore, an average of about 27% of the individuals that visit CCB, leave the Bay and come back at least once during their residency period. These results suggest that individual right whales come into CCB, stay for about 10 days, and after that some of them leave for good and some of them leave and return for another residency in the Bay. Therefore, even during the peak of food resources (most often in March or April, see section 2) not all the "CCB right whale population" is present in the Bay at the same time and none of them stay for the duration of the entire peak. This is most likely due to the per whale profitability of foraging. Obviously, when the number of right whales in CCB increases beyond a certain point, individuals experience diminishing returns (Hooker et al. 2002). Therefore, even if CCB is much richer in terms of copepod abundance in late winter/early spring than most other areas, if too many whales are present, an individual would do better by leaving the Bay and feeding in a poorer patch. An Ideal Free Distribution (IFD, Fretwell and Lucas, 1970) would be the result of such movements. However, IFD assumes that right whales would have perfect knowledge of the relative availability of food resources, which is most unlikely to be the case. Therefore movements between patches and areas are likely to occur even after an equilibrium has been reached (Hugie and Grand, 1998). Right whales enter and leave CCB at variable intervals (average 10-20 days) and therefore potentially fit such a model.

1.4.5. Movement patterns

Independently of their behavior, right whales moved at a mean speed of about 4.8 km/h, and thus traveling whales were not moving any faster than feeding whales. Such a consistent swimming speed that is unrelated to behavior has been observed in other species (i.e. sperm whales, *Physeter macrocephalus*, Whitehead, 2003). This speed presumably represents an optimum largely determined by energetic factors. However, over time periods of a few hours, movement patterns differed substantially between traveling whales and skim-feeding whales, traveling whales tended to move in a straight line while skim-feeding whales were zigzagging over a small area. A variety of creatures from bacteria to vertebrates have a tendency to turn more often and in tighter semi-circles when in favorable than when in non-favorable patches of food, and this behavior will tend to maintain them within profitable patches (Giraldeau 1996). Such typical movement patterns have also been demonstrated for sperm whales (Whitehead, 1996; Jaquet and Whitehead, 1999). Therefore, the extent of the displacement of feeding right whales over a few hours may give us some insight into the size of the copepod patch (Mayo and Marx, 1990).

This result shows that depending on their behavior, there are large variations in movement patterns between individual right whales. Furthermore, due to the IFD (see 1.4.4), individual right whales may be traveling in or out of the Bay even during periods of high food resources. Therefore, it is usually impractical to determine the likely movement of a particular whale at a particular time to be able to advise management about how far this particular individual is likely to move, and average displacements are needed to predict likely movements. The results of the root mean squared displacement using the last nine years of data suggested that, over 24 hour, an individual will move on average 9 km from start to finish (straight line distance, so excluding all zigzags), and that this distance does not increase substantially during the next 10-20 days. During their residency period into CCB, individual right whales tend to (on average) stay in an area that is about 13 km in diameter, and thus they tend to use only 1/8th of the Bay. Such small displacement is not uncommon amongst coastal species and even smaller net daily movements were found for a pelagic species bottlenose whales (*Hyperoodon ampullatus*) in the Gully (~4-5km/24h, Hooker et al., 2002). The high consistency in net daily displacement calculated using two completely different techniques (root-mean squared displacement using data from 1998-2006, and focal follows using data from 2005-2006) gave us great confidence in the validity of our results. Furthermore, these results are very consistent with the finding of Kenney (1997) who investigated movements of right whales in CCB using a different data set (1979-1996), and different techniques (regression analyses) and showed that individual right whales have a net daily displacement of about 8 km and that this displacement increase of ~500m per day. Therefore, in Kenney's (1997) analyses, after 10 days, an individual whale would have travel ~12.5 km from start to finish.

This net daily displacement in CCB (9 km) is substantially larger than what was found in the Bay of Fundy (~2 km, New England Aquarium and Jaquet, unpublished results) and substantially smaller than what was found in the South East US (~45 km, New England Aquarium and Jaquet, unpublished results). In late summer and early Fall, the Bay of Fundy (BoF) is characterized with very high copepod *Calanus finmarchicus* density forming very dense patches (Baumgartner et al., 2003) and thus it makes total sense that individuals have a very small net daily displacement. On the other hand, no feeding takes place in the SEUS, and thus one would expect from the theory that individuals will have much larger daily displacements than in feeding areas. These preliminary results confirm this statement.

1.4.6. Vocal behavior

Very few of the recordings have been analyzed at the time of this writing and thus only very preliminary suggestions are presented here. Furthermore, the sample size of this study is still very small and more recordings will need to be collected before the vocal behavior of right whales in Cape Cod Bay can be elucidated.

However, despite these shortcomings, our preliminary data suggest that the vocal behavior of right whales in CCB is similar to that in the BoF (S. Parks, unpublished data). In CCB, no vocalizations were heard for at least eight hours of continuous recording in the presence of four to 10 skim feeding whales, suggesting that, like in BoF, right whales are mainly quiet when feeding. A very large amount of vocalizations (including upcalls, tonals and gunshots) were heard when whales were in a Surface Active Group which is similar to what was observed in other areas, but contradict previous beliefs that a very low proportion of gunshots are ever heard in CCB. Furthermore, the few calls that were heard during days when only feeding whales were within visual range of the research vessels were recorded in the late afternoon, suggesting a diel pattern in right whale vocalizations. A similar diel pattern has been detected in BoF (S. Parks, unpublished data).

Much more data on vocalization rates in relation to behavior and time of day will need to be collected in the future in all high use areas to be able to obtain an understanding of right whale vocal behavior as well as of the temporal and spatial scale at which they could be detected by "real-time" passive acoustic devices. The determination of the distance at which an average right whale upcall can be heard from a hydrophone in a large spectrum of ambient noise should be one of the first priorities.

1.5. Conclusion

The results of the 2006 field season continue to support the view that CCB is an important habitat for right whales during winter and early spring, and that this habitat is especially important for adult females and for mother/calf pairs. Although some patterns are beginning to be unraveled thanks to a long-term systematic study, many questions are still unanswered. Adequate protection to right whales can only be provided if sound scientific knowledge of the species exists, and there are many examples all over the world of "conservation measures" that were in fact detrimental to a species as they were implemented before enough knowledge was gathered. As so few right whales are still alive and as the species is so close to extinction, no such mistakes can be made with right whales without tipping the balance the wrong way. It is therefore crucial to try to answer the many remaining questions regarding their distribution, movements (small and large-scales), vocal behavior, reaction to sounds etc, and to thus increase our understanding of the species.

Table 1A. **Aerial survey track lines flown over Cape Cod Bay, January to mid-May 2006. For location of track lines, cross-reference by track line number with Figure 1. Cross-leg mileage (between track lines) are not listed for the standard Cape Cod Bay survey (track 1 to 16), as tracks are spaced 1.5 nm apart and the aircraft is turning during at least half of the cross-leg.**

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
2	42 05.0	70 36.3	70 15.8	15
3	42 03.5	70 36.8	70 17.0	15
4	42 02.0	70 35.7	70 07.7	21
5	42 00.5	70 34.2	70 07.0	20
6	41 59.0	70 34.2	70 06.6	21
7	41 57.5	70 34.2	70 06.6	21
8	41 56.0	70 31.6	70 06.3	19
9	41 54.5	70 30.9	70 06.3	18
10	41 53.0	70 30.0	70 06.1	18
11	41 51.5	70 29.5	70 06.1	18
12	41 50.0	70 30.3	70 06.1	18
13	41 48.5	70 30.2	70 06.1	18
14	41 47.0	70 28.3	70 06.1	17
15	41 45.5	70 26.5	70 11.4	11
Subtotal track line miles in Cape Cod Bay				**271**
16*	41 40.0		69 52.0	35
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).

Table 1B. **Aerial survey track lines flown north east of Cape Cod. Cross-reference this table with Figure 1b. Date/tracks flown: 13 Jan/tracks 2-11, 23 Feb/tracks 1-5, 30 Mar/eastern portion track 1, 11 Apr/tracks 1-6. Cross-leg mileage is listed as the track lines are spaced ≥3 nm apart.**

Track line Number	Latitude	Longitude West End	Longitude East End	Track line Length (nm)
1	42 17.0	70 10.0	69 40.0	22
2	42 14.0	70 10.0	69 40.0	22
3	42 11.0	70 10.0	69 40.0	22
4	42 08.0	70 10.0	69 40.0	22
5	42 05.0	70 00.0	69 40.0	15
6	42 02.0	70 00.0	69 40.0	15
7	41 59.0	69 55.0	69 40.0	11
8	41 56.0	69 55.0	69 35.0	15
9	41 53.0	69 55.0	69 35.0	15
10	41 50.0	69 55.0	69 35.0	15
11	41 47.0	69 55.0	69 35.0	15
Total survey with transits and cross-legs				**189**

Table 1C. **Legend of abbreviations and common names for marine mammals and shark species listed in report tables**

Species Abbreviation	Common Name
Eg	Right Whale
Ba	Minke Whale
Bp	Fin Whale
Mn	Humpback Whale
UNBA	Unidentified Balaenoptera
UNLW	Unidentified Large Whale
La	Atlantic White-Sided Dolphin
Dd	Common Dolphin
Gm	Pilot whales
Pp	Harbor Porpoise
UNDO	Unidentified Dolphin/ Porpoise
Hg	Gray Seal
Pv	Harbor Seal
UNSE	Unidentified Seal

Table 2a. **Number of marine mammals and other animals seen, hours and track line miles surveyed during aerial surveillance of Cape Cod Bay and adjacent waters during the 2006 season. ES=Eastern Shore of Cape Cod; NE=North East of Cape Cod; GSC=Great South Channel. Species abbreviation are explained in Table 1C.**

Survey#	Date	Eg Sighted	Eg Photo'd	Ba	Bp	Mn	UNBA	UNMW	UNLW	La	Dd	Gm	Pp	UNDO	UNSE	Pv	Hours Flown	Distance Flown (nm)	Tracks Completed
CCS387	10Jan06	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3.6	306	1-15,16
CCS388	12Jan06	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3.8	306	1-15,16
CCS389	13Jan06	0	0	0	10	3	0	0	0	0	0	0	0	0	0	0	3.6	233	ES
CCS390	17Jan06	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3.4	295	1-14,16
CCS391	22Jan06	0	0	0	0	0	0	0	0	0	3	0	1	2	0	0	3.4	295	1-14,16
CCS392	24Jan06	0	0	0	0	0	0	0	0	0	26	0	0	79	6	0	3.2	295	1-14,16
CCS393	29Jan06	0	0	1	0	0	0	0	0	1	2	0	2	55	1	0	3.9	306	1-15,16
CCS394	02Feb06	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	4.1	306	1-15,16
CCS395	04Feb06	1	1	0	1	0	0	0	0	38	0	0	1	16	11	0	4.4	306	1-15,16
CCS396	09 Feb06	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3.6	306	1-15,16
CCS397	16Feb06	1	1	0	1	0	0	0	0	0	0	0	4	4	8	0	5.3	306	1-15,16
CCS398	22Feb06	0	0	0	0	0	0	0	0	0	0	0	0	2	5	0	3.8	306	1-15,16
CCS399	23Feb06	1	0	0	2	0	0	0	0	0	0	0	4	0	2	0	5.9	377	1-15, part of 16 + ES
CCS400	02Mar06	2	2	0	0	0	0	0	0	1	0	0	0	0	1	0	3.4	188	1-8,16
CCS401	06Mar06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7	107	1-4,16
CCS402	08Mar06	5	5	0	0	0	0	0	0	0	0	0	0	0	2	0	5.4	295	1-14,16
CCS403	12Mar06	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	4.6	199	5-15
CCS404	13Mar06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	35	Track 16
CCS405	22Mar06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	35	13-14
CCS406	24Mar06	8	8	0	0	0	0	0	0	0	0	0	0	1	0	0	6.4	306	1-15,16
CCS407	25Mar06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.0	306	1-15,16
CCS408	28Mar06	6	6	0	0	0	2	0	0	0	0	0	0	0	2	0	5.7	306	1-15,16

Table 2a. Continued

Survey#	Date	Eg Sighted	Eg Photo'd	Ba	Bp	Mn	UNBA	UNMW	UNLW	La	Dd	Gm	Pp	UNDO	UNSE	Pv	Hours Flown	Distance Flown (nm)	Tracks Completed
CCS409	29Mar06	1	1	0	0	3	0	0	0	1	0	0	4	0	9	0	5.6	306	1-15,16
CCS410	30Mar06	16	16	2	0	0	0	0	0	0	16	0	5	4	3	0	6.9	286	1-15 and ES
CCS411	03Apr06	16	16	3	0	0	2	0	0	0	12	0	2	0	7	0	6.5	295	1-14,16
CCS412	05Apr06	5	5	0	10	1	1	0	0	0	0	0	1	3	0	0	1.9	35	Track 16
CCS413	10Apr06	7	7	3	13	6	2	0	0	0	7	0	5	33	1	0	6.9	306	1-15,16
CCS414	11Apr06	8	8	0	7	8	0	0	0	0	0	0	5	12	1	0	7.4	198	ES
CCS415	12Apr06	11	7	1	11	14	2	0	0	0	4	0	2	13	0	0	5.6	148	1-6,16
CCS416	14Apr06	37	37	5	19	18	0	0	0	0	9	0	2	60	0	0	8.8	207	1-11
CCS417	22Apr06	10	10	1	18	2	1	0	0	0	0	0	2	5	0	0	7.1	306	1-15,16
CCS418	26Apr06	10	10	3	26	11	0	0	0	0	0	0	10	72	3	0	5.2	188	1-8,16
CCS419	27Apr06	33	32	6	28	19	1	0	0	0	0	0	0	35	1	0	7.8	306	1-15,16
CCS420	05May06	10	10	2	4	0	0	0	0	0	0	0	21	25	5	0	6.2	306	1-15,16
CCS421	06May06	19	19	6	6	2	1	0	0	0	0	0	0	5	1	0	6.5	306	1-15,16
CCS422	18May06	0	0	0	1	2	0	0	0	0	0	0	0	0	1	0	3.1	306	1-15,16
Total All Surveys		**215**	**209**	**34**	**158**	**89**	**12**	**0**	**0**	**41**	**79**	**0**	**73**	**426**	**77**	**0**	**170.3**	**9219**	

Table 2b. **Number of right whale sightings and photographed, hours and track line miles surveyed during aerial surveillance of Cape Cod Bay (only track 3 to 15). Crossed referenced with Fig. 1 for track numbers.**

Survey#	Date	Eg Sighted	Eg Photo'd	Distance Flown (nm)	Tracks Completed
CCS387	10Jan06	0	0	235	3-15
CCS388	12Jan06	0	0	235	3-15
CCS390	17Jan06	0	0	224	3-14
CCS391	22Jan06	0	0	224	3-14
CCS392	24Jan06	0	0	224	3-14
CCS393	29Jan06	0	0	235	3-15
CCS394	02Feb06	0	0	235	3-15
CCS395	04Feb06	1	1	235	3-15
CCS396	09Feb06	0	0	236	3-15
CCS397	16Feb06	1	1	236	3-15
CCS398	22Feb06	0	0	236	3-15
CCS399	23Feb06	0	0	236	3-15
CCS400	02Mar06	2	2	117	3-8
CCS401	06Mar06	0	0	36	3-4
CCS402	08Mar06	5	5	224	3-14
CCS403	12Mar06	8	8	199	5-15
CCS405	22Mar06	0	0	35	12-13
CCS406	24Mar06	3	3	235	3-15
CCS407	25Mar06	0	0	236	3-15
CCS408	28Mar06	6	6	236	3-15
CCS409	29Mar06	1	1	236	3-15
CCS410	30Mar06	0	0	236	3-15
CCS411	03Apr06	0	0	224	3-14
CCS413	10Apr06	0	0	236	3-15
CCS415	12Apr06	6	3	77	3-6
CCS416	14Apr06	31	31	171	3-11
CCS417	22Apr06	10	10	235	3-15
CCS418	26Apr06	1	1	117	3-8
CCS419	27Apr06	19	19	235	3-15
CCS420	05May06	9	9	235	3-15
CCS421	06May06	16	16	235	3-15
CCS422	18May06	0	0	235	3-15
Total All Surveys		**119**	**116**	**6581**	

Table 2c. **Number of right whale sightings and photographed, hours and track line miles surveyed during aerial surveillance of Adjacent Waters (tracks 1-2, track 16 and Eastern Tracklines). Crossed referenced with Fig. 1 for track numbers.**

Survey#	Date	Eg Sighted	Eg Photo'd	Distance Flown (nm)	Tracks Completed
CCS387	10Jan06	0	0	71	1-2,16
CCS388	12Jan06	0	0	71	1-2,16
CCS389	13Jan06	0	0	233	ES
CCS390	17Jan06	0	0	71	1-2,16
CCS391	22Jan06	0	0	71	1-2,16
CCS392	24Jan06	0	0	71	1-2,16
CCS393	29Jan06	0	0	71	1-2,16
CCS394	02Feb06	0	0	71	1-2,16
CCS395	04Feb06	0	0	71	1-2,16
CCS396	09Feb06	0	0	71	1-2,16
CCS397	16Feb06	0	0	71	1-2,16
CCS398	22Feb06	0	0	71	1-2,16
CCS399	23Feb06	1	0	142	1-2,part of 16 + ES
CCS400	02Mar06	0	0	71	1-2,16
CSS401	06Mar06	0	0	71	1-2,16
CCS402	08Mar06	0	0	71	1-2,16
CCS404	13Mar06	0	0	35	16
CCS406	24Mar06	5	5	71	1-2,16
CCS407	25Mar06	0	0	71	1-2,16
CCS408	28Mar06	0	0	71	1-2,16
CCS409	29Mar06	0	0	71	1-2,16
CCS410	30Mar06	16	16	51	1-2,ES
CCS411	03Apr06	16	16	71	1-2,16
CCS412	05Apr06	5	5	35	Track 16
CCS413	10Apr06	7	7	71	1-2,16
CCS414	11Apr06	8	8	198	ES
CCS415	12Apr06	5	4	71	1-2,16
CCS416	14Apr06	6	6	36	1-2
CCS417	22Apr06	0	0	71	1-2,16
CCS418	26Apr06	9	9	71	1-2,16
CCS419	27Apr06	14	13	71	1-2,16
CCS420	05May06	1	1	71	1-2,16
CCS421	06May06	3	3	71	1-2,16
CCS422	18May06	0	0	71	1-2,16
Total All Surveys		**96**	**93**	**2638**	

Table 3a. **Number of opportunistic marine mammal sightings and hours at sea during vessel-based habitat sampling cruises of Cape Cod Bay, January to mid-May 2006. Species abbreviation are explained in Table 1C.**

Cruise	Date 2004	Eg Sighted	Eg Photo'd	Ba	Bp	Mn	UNBA	UNLW	La	Dd	Pp	UNDO	Pv	UNSE	Hours At Sea
SW586	02Jan06	0	0	0	0	0	0	0	0	0	0	0	0	0	6.5
SW587	12Jan06	0	0	0	0	0	0	0	0	0	0	0	0	0	6
SW588	24Jan06	0	0	0	0	0	0	0	51	0	2	0	5	0	6.25
SW589	29Jan06	1	1	0	0	0	0	0	0	20-35	0	0	0	3	5.9
SW590	09Feb06	0	0	0	0	0	0	0	0	0	0	0	0	0	6
SW591	16Feb06	0	0	0	1	0	0	0	0	0	0	0	0	8	5.75
SW592	22Feb06	0	0	0	0	0	0	0	0	0	0	0	0	0	5.75
SW594	02Mar06	1	1	0	0	0	0	0	0	0	0	0	0	0	7
SW595	08Mar06	2	2	0	0	0	0	0	0	0	0	0	0	0	6.4
SW596	13Mar06	0	0	0	0	0	0	0	0	0	3	0	1	14	5.8
SW597	22Mar06	0	0	0	0	0	0	0	0	0	0	0	0	0	3.4
SW598	24Mar06	1	0	0	0	0	0	0	0	0	0	0	0	6	4.75
SW600	30Mar06	0	0	1	1	0	1	0	0	0	6	0	11	32	5.5
SW602	11Apr06	0	0	0	0	0	0	0	0	0	2	0	3	0	5.75
SW604	24Apr06	3	2	1	12	8	0	3	0	0	3	0	1	0	7.4
SW606	05May06	3	2	0	8	2	0	0	0	0	10	0	0	5	7.2
SW607	08May06	11	7	1	4	0	0	0	0	0	16	0	0	0	8.8
SW 608	18May06	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Total All habitat cruises		**22**	**15**	**3**	**26**	**10**	**1**	**3**	**51**	**20-35**	**42**	**0**	**21**	**68**	**104.15**

Table 3b. **Number of opportunistic marine mammal sightings and hours at sea during vessel-based focal follow cruises in Cape Cod Bay, March to mid-May 2006. Species abbreviation are explained in Table 1C.**

Cruise	Date 2004	Eg Sighted	Eg Photo'd	Ba	Bp	Mn	UNBA	UNLW	La	Dd	Pp	UNDO	Pv	UNSE	Hours At Sea
Shackleton	12Mar06	0	0	0	0	0	0	0	0	0	0	0	0	0	3.5
Shackleton	13Mar06	1	1	0	0	0	0	0	0	0	1	0	0	0	4
Shackleton	24Mar06	2	2	0	0	0	0	0	0	0	0	0	0	0	7.5
Shackleton	28Mar06	6	6	0	0	0	0	0	0	0	2	0	0	0	6.8
Shackleton	29Mar06	1	0	0	0	0	0	0	0	0	2	0	0	0	5
Shackleton	30Mar06	0	0	1	0	0	0	0	0	0	1	0	0	0	5
Shackleton	03Apr06	0	0	0	1	0	0	0	0	0	0	0	2	0	3.8
Shackleton	05Apr06	0	0	0	1	0	0	0	0	0	0	0	1	0	1.7
Shackleton	10Apr06	1	0	0	0	0	0	0	0	0	0	9	0	0	5
Shackleton	14Apr06	4	4	0	5	3	0	0	0	0	10	0	0	0	6.5
Shackleton	15Apr06	34	34	0	0	0	0	0	0	0	2	0	0	0	8.5
Shackleton	22Apr06	0	0	0	2	1	0	0	0	0	0	0	0	0	2.3
Ezyduzit	27Apr06	4	4	1	2	4	0	0	50	0	0	0	1	0	9.9
Ezyduzit	05May06	5	5	1	1	0	0	0	0	0	0	0	0	0	10.4
Ezyduzit	06May06	10	10	0	0	0	0	0	0	0	0	0	0	0	10.3
Total focal follow cruises		**68**	**66**	**3**	**12**	**8**	**0**	**0**	**50**	**0**	**18**	**9**	**4**	**0**	**90.2**

Table 4. **Number of survey days, demographic composition and number of right whales identified in all areas (A), in Cape Cod Bay (B) and in adjacent waters (C) from aerial surveys and all cruises (from R/V Shearwater, R/V *Shakelton* and R/V *Ezyduzit*) in two-week periods from January 1 through May 18 2006. The values in this table represent the minimum number of whales, as photo-analysis has not been finalized. The total is lower than the sum of each line as many whales were seen during several 2-week periods. The shaded areas represent 2-week intervals when right whales were observed. The last interval (*) represent only 1 week. Numbers between brackets are the survey days where there was no aerial survey effort (exclusively shipboard effort).**

A) All Areas:

Two week intervals	1-14Jan	15-28Jan	29Jan-11Feb	12-25Feb	26Feb-11Mar	12-25Mar	26Mar-8Apr	9-22Apr	23Apr-6May	7-18May*	Total
Surveys (all platforms)											
Number of survey days	4 (1)	3 (0)	4 (0)	3 (0)	3 (0)	5 (0)	5 (0)	6 (1)	5 (1)	2 (1)	40
Number of individuals identified	0	0	2	1	6	12	23	53	37	5	139
Demographics											
Male	0	0	0	0	0	3	11	20	17	3	54
Female	0	0	2	1	6	7	8	19	8	1	52
Unknown Sex	0	0	0	0	0	2	4	14	12	1	33
Calf	0	0	0	0	0	0	1	5	4	0	10
Juvenile	0	0	0	0	0	1	0	8	1	0	10
Adult	0	0	2	1	6	10	19	37	27	4	106
Unknown Age	0	0	0	0	0	1	3	3	5	1	13

B) Cape Cod Bay track 3 to 15:

Two week intervals	1-14Jan	15-28Jan	29Jan-11Feb	12-25Feb	26Feb-11Mar	12-25Mar	26Mar-8Apr	9-22Apr	23Apr-6May	7-18May*	Total
Surveys (all platforms)											
Number of survey days	3 (1)	3 (0)	4 (0)	3 (0)	3 (0)	5 (1)	4 (0)	6 (2)	5 (1)	2 (1)	38
Number of individuals identified	0	0	2	1	6	9	6	26	24	4	78
Demographics											
Male	0	0	0	0	0	1	2	6	11	3	23
Female	0	0	2	1	6	7	4	14	4	0	38
Unknown Sex	0	0	0	0	0	1	0	6	9	1	17
Calf	0	0	0	0	0	0	0	3	2	0	5
Juvenile	0	0	0	0	0	1	0	2	0	0	3
Adult	0	0	2	1	6	8	6	19	18	3	63
Unknown Age	0	0	0	0	0	0	0	2	4	1	7

C) Adjacent waters (tracks 1-2, track 16 and all eastern tracklines):

Two week intervals	1-14Jan	15-28Jan	29Jan-11Feb	12-25Feb	26Feb-11Mar	12-25Mar	26Mar-8Apr	9-22Apr	23Apr-6May	7-18May*	Total
Surveys (all platforms)											
Number of survey days	3 (0)	3 (0)	4 (0)	3 (0)	3 (0)	3 (0)	5 (0)	6 (1)	5 (1)	2 (1)	38
Number of individuals identified	0	0	0	0	0	3	18	31	17	1	70
Demographics											
Male	0	0	0	0	0	2	6	13	8	0	29
Female	0	0	0	0	0	0	8	9	4	1	22
Unknown Sex	0	0	0	0	0	1	4	9	5	0	19
Calf	0	0	0	0	0	0	1	3	2	0	6
Juvenile	0	0	0	0	0	0	0	7	1	0	8
Adult	0	0	0	0	0	2	16	20	11	1	50
Unknown Age	0	0	0	0	0	1	3	1	3	0	8

Table 5: **Sighting records of identified right whales seen in CCB and adjacent waters, January to mid May 2006. F=female, M=male, J=juvenile, C=calf, U=unknown. "X" denotes the sighting date in CCB (track 3-15), bold "Y" just north of CCB (tracks 1-2) and bold "X" in adjacent waters (track 16 and Eastern track lines). Yellow are survey dates flown exclusively over the eastern track lines. Light blue represents incomplete surveys due to deteriorating weather. Pink represent dates of only shipboard effort. Light green represents incomplete surveys due to too many right whale sightings and not enough day light hours.**

Id #	Sex	Age category	2-Jan-06	10-Jan-06	12-Jan-06	13-Jan-06	17-Jan-06	22-Jan-06	24-Jan-06	29-Jan-06	2-Feb-06	4-Feb-06	9-Feb-06	16-Feb-06	22-Feb-06	23-Feb-06	2-Mar-06	6-Mar-06	8-Mar-06	12-Mar-06	13-Mar-06	22-Mar-06	24-Mar-06	25-Mar-06	28-Mar-06	29-Mar-06	30-Mar-06	3-Apr-06	5-Apr-06	10-Apr-06	11-Apr-06	12-Apr-06	14-Apr-06	15-Apr-06	22-Apr-06	24-Apr-06	26-Apr-06	27-Apr-06	5-May-06	6-May-06	8-May-06	18-May-06	# of days sighted	Time span 1st to last sighting
1245	F	A								X																																			1	1
1027	F	A										X								X																							2	37
2223	F	A												X																**Y**			X				**Y**	**Y**					5	71
1267	F	A															X								X		**X**				**X**												4	29
1812	F	A															X																										1	1
2460	F	A																	X	X																							2	5
1310	F	A																	X	X													X					X					4	51
1703	F	A																	X						X	X									X			X	X	X	**X**		8	62
1039	F	A																	X																								1	1
1140	F	A																		X			X																				2	13
2145	F	A																		X												X											2	32
1980	M	A																		X																							1	1
Yearlingof1303	U	J																		X			X																				2	13
1303	F	A																			X																						1	1
2614	F	A																					X																				1	1
1207	M	A																					**X**										X										2	22
2530	M	A																					**X**		X													X	X	X	X		6	46
3050	U	U																					**X**																				1	1
1706	F	A																							X																		1	1
1241	M	A																							X																		1	1
1507	M	A																							X																		1	1
1152	M	A																									**X**	**X**															2	5
1153	F	A																									**X**																1	1
1315	F	A																									**X**																1	1
1425	F	A																									**X**																1	1
1813	M	A																									**X**							**Y**									2	17
SE06CT10	U	U																									**X**																1	1
2608	M	A																										**X**	**X**														2	3
2750	M	A																										**X**	**X**														2	3
1603	M	A																										**X**															1	1
2048	M	A																										**X**															1	1
1409	M	A																										**X**										X					2	25

Table 5 continued

Id #	Sex	Age category	2-Jan-06	10-Jan-06	12-Jan-06	13-Jan-06	17-Jan-06	22-Jan-06	24-Jan-06	29-Jan-06	2-Feb-06	4-Feb-06	9-Feb-06	16-Feb-06	22-Feb-06	23-Feb-06	2-Mar-06	6-Mar-06	8-Mar-06	12-Mar-06	13-Mar-06	22-Mar-06	24-Mar-06	25-Mar-06	28-Mar-06	29-Mar-06	30-Mar-06	3-Apr-06	5-Apr-06	10-Apr-06	11-Apr-06	12-Apr-06	14-Apr-06	15-Apr-06	22-Apr-06	24-Apr-06	26-Apr-06	27-Apr-06	5-May-06	6-May-06	8-May-06	18-May-06	# of days sighted	Time span 1st to last sighting
BK25	U	U																										**X**															1	1
1503	F	A																										**Y**															1	1
Calfof1503	U	C																										**Y**															1	1
1408	F	A																											**X**														1	1
1052	M	A																											**X**														1	1
2720	U	A																											**X**														1	1
1821	M	A																												**X**										X			2	27
3110	M	J																												**X**													1	1
C8YG	U	U																												**X**													1	1
1301	F	A																												**Y**		**Y**											2	3
1327	M	A																												**Y**			X										2	5
3108	F	J																													**X**	X											2	2
3180	F	J																													**X**	X	X	**Y**									4	5
3346	M	J																													**X**	**Y**											2	2
2660	F	A																													**X**												1	1
Calfof2660	U	C																													**X**												1	1
3120	M	J																													**X**												1	1
2005CALFOF2223	U	J																													**X**												1	1
2320	F	A																														**X**	X	**Y**		X							4	13
Calfof2320	U	C																														**X**	X	**Y**		X							4	13
3190	U	U																															X	**Y**									2	2
1911	F	A																															X					**Y**					2	14
1158	F	A																															X										1	1
1711	F	A																															X										1	1
1802	F	A																															X										1	1
2430	F	A																															X										1	1
1716	M	A																															X										1	1
2540	M	A																															X					X					2	14
CT50	U	U																															X					**X**	X	X			4	23
2123	F	A																															**Y**					**Y**					2	14
1170	M	A																															**Y**										1	1
1250	M	A																															**Y**										1	1
Calfof2123	U	C																															**Y**					**Y**					2	14
3302	U	J																															**Y**										1	1

Table 5 continued

Id #	Sex	Age category	2-Jan-06	10-Jan-06	12-Jan-06	13-Jan-06	17-Jan-06	22-Jan-06	24-Jan-06	29-Jan-06	2-Feb-06	4-Feb-06	9-Feb-06	16-Feb-06	22-Feb-06	23-Feb-06	2-Mar-06	6-Mar-06	8-Mar-06	12-Mar-06	13-Mar-06	22-Mar-06	24-Mar-06	25-Mar-06	28-Mar-06	29-Mar-06	30-Mar-06	3-Apr-06	5-Apr-06	10-Apr-06	11-Apr-06	12-Apr-06	14-Apr-06	15-Apr-06	22-Apr-06	24-Apr-06	26-Apr-06	27-Apr-06	5-May-06	6-May-06	8-May-06	18-May-06	# of days sighted	Time span 1st to last sighting
2005Calfof1140	U	J																													Y										1	1
1209	F	A																														Y									1	1
1032	M	A																														Y									1	1
1122	M	A																														Y									1	1
1427	M	A																														Y									1	1
1429	M	A																														Y									1	1
2010	M	A																														Y									1	1
2140	M	A																														Y									1	1
1804	M	A																														Y				Y					2	13
1423	U	A																														Y									1	1
1513	U	A																														Y				X					2	13
2029	F	A																															X		Y						2	5
1281	F	A																															X			X		X			3	15
2310	M	A																															X			X					2	6
1042	U	A																															X			X					2	6
1280	U	A																															X			X					2	6
Calfof2029	M	C																															X		Y						2	5
Calfof1281	U	C																															X			X		X			3	15
CT39	U	U																																	Y	X		Y			3	11
1306	M	A																																	Y	Y					2	2
1627	M	A																																	Y						1	1
BKMX01	U	U																																	Y						1	1
1167	M	A																																		X	Y	X	X		4	12
1036	M	A																																		X					1	1
1328	M	A																																		X					1	1
1514	M	A																																		X					1	1
1960	M	A																																		Y					1	1
2209	M	A																																		Y					1	1
1317	M	A																																		Y	X	X	X		4	12
3308	U	J																																		Y					1	1
BK52	U	U																																			X	X	X		3	4
2740	M	A																																			X	X			2	2
CT42	U	U																																			X	X			2	2

Figure 1a. Cape Cod Bay study area including aerial survey tracks, Critical Habitat and state waters boundaries, shipping lanes, and CCB analysis boundary.

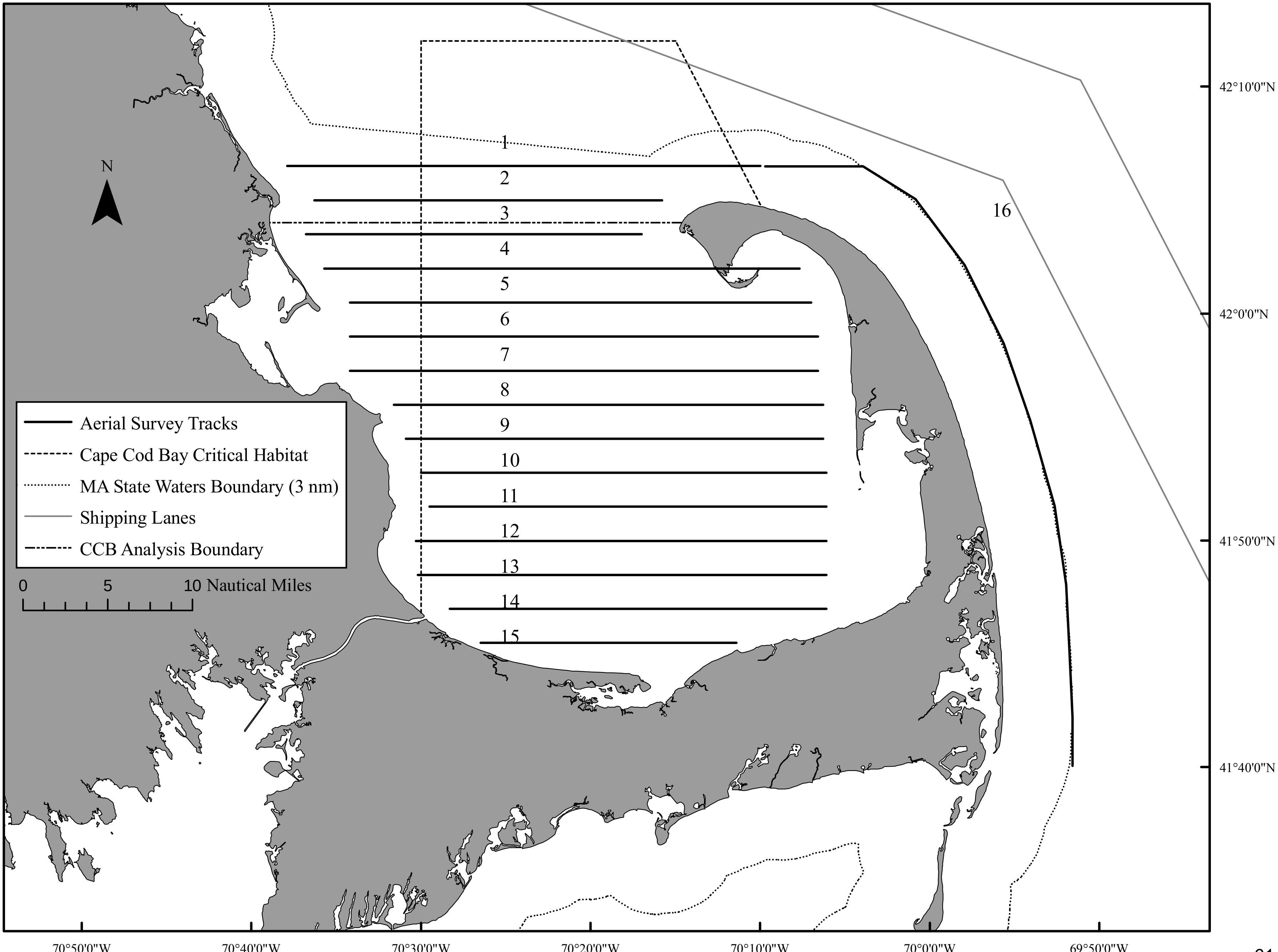


Figure 1b. Aerial survey track lines flown north and east of Cape Cod.

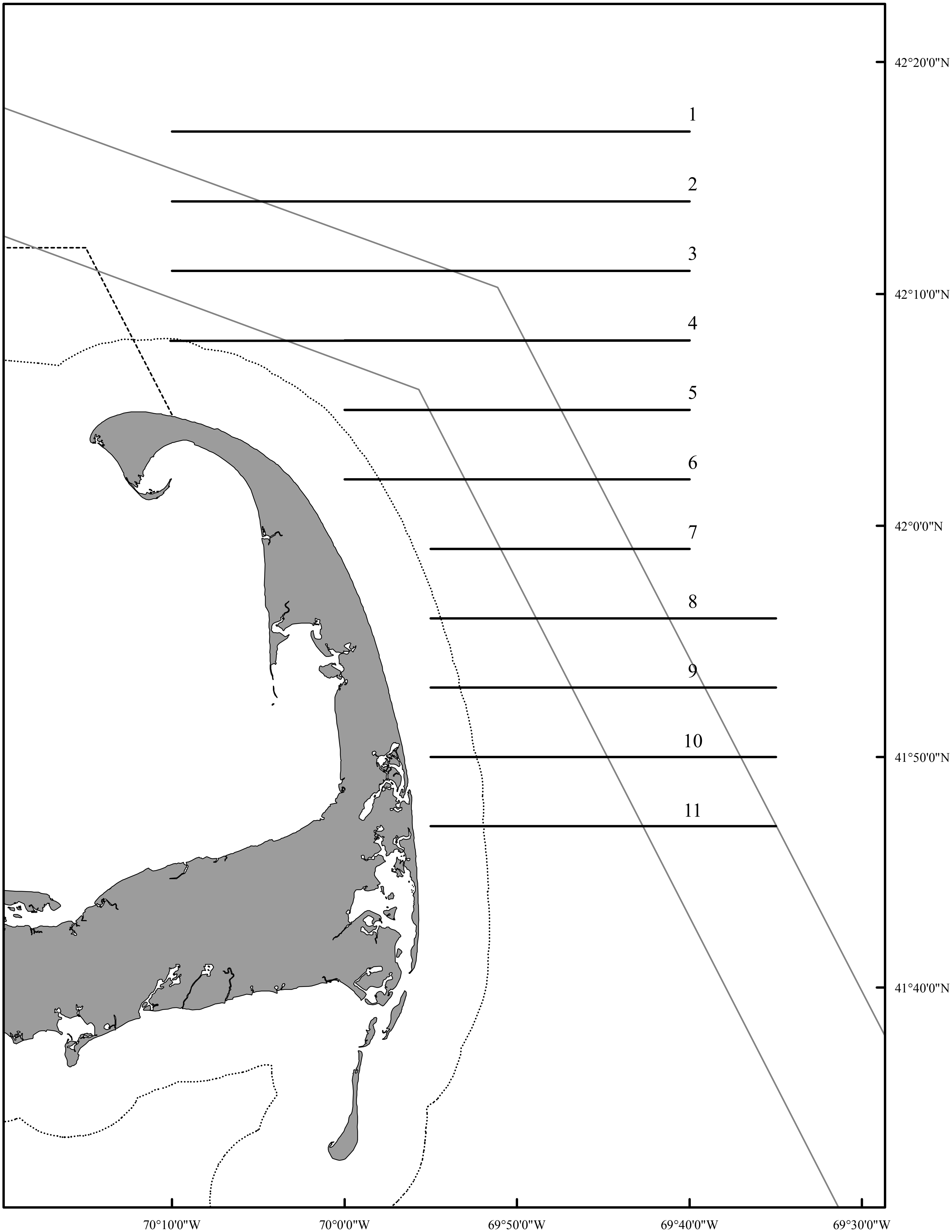


Figure 2a - d. Sightings of right whales from aerial surveys of Cape Cod Bay and adjacent waters, 1 January - 25 February 2006.

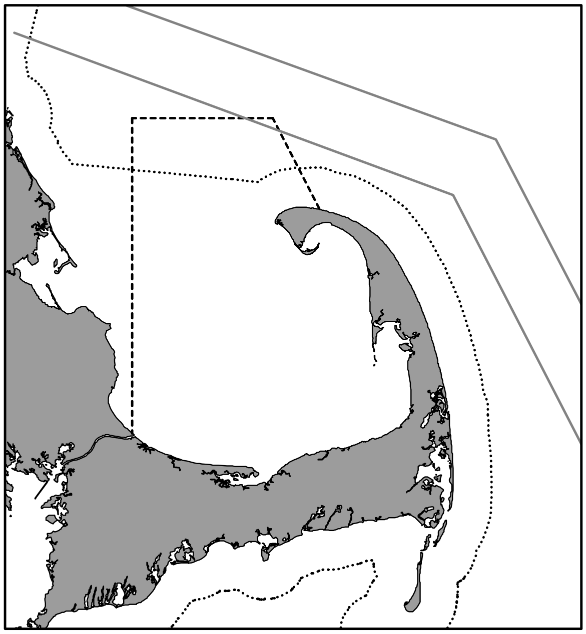


Figure 2a. 1 - 14 January

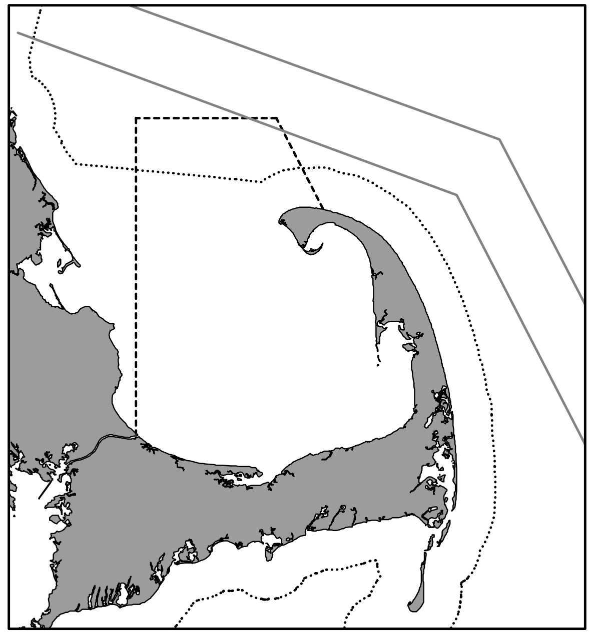


Figure 2b. 15 - 28 January

Cape Cod Bay Critical Habitat
MA State Waters Boundary (3 nm)
Shipping Lanes

0 10 20 Nautical Miles

Right Whales
animals
1
2
3 - 7
8 - 10

N

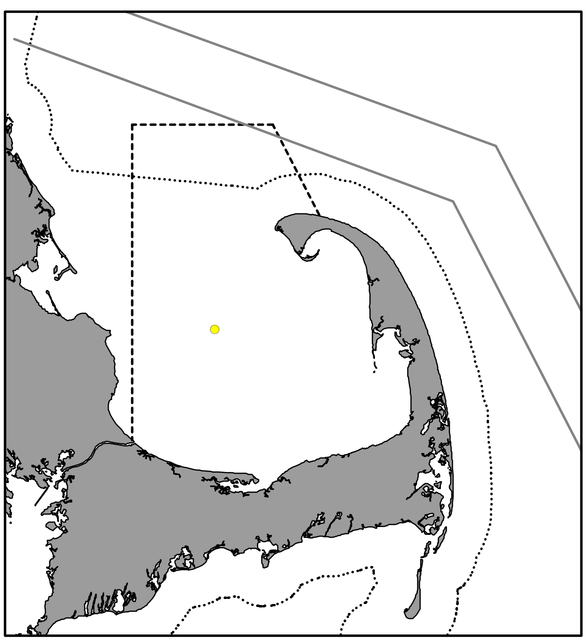


Figure 2c. 29 January - 11 February

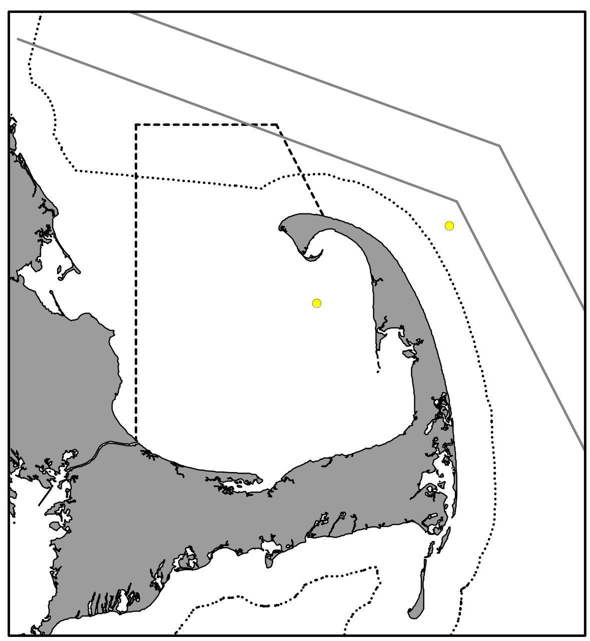


Figure 2d. 12 - 25 February

Figure 2e - h. Sightings of right whales from aerial surveys of Cape Cod Bay and adjacent waters, 26 February - 22 April 2006.

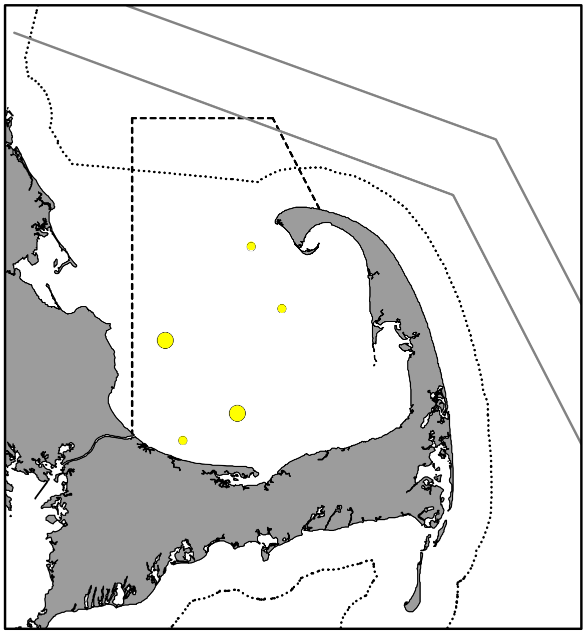


Figure 2e. 26 February - 11 March

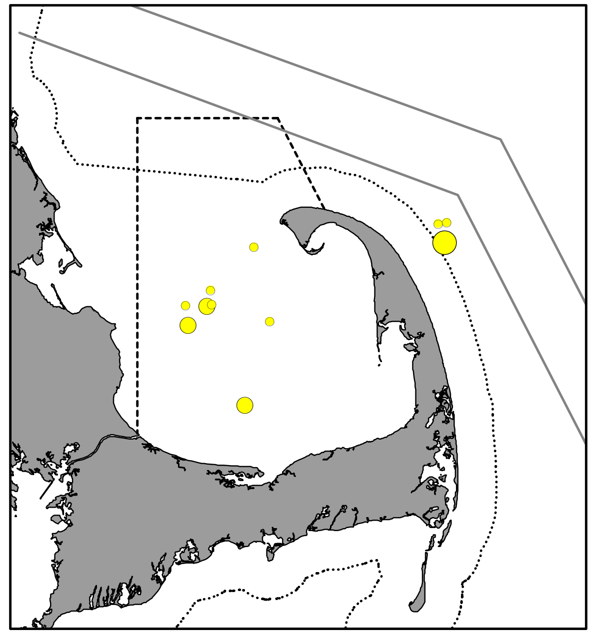
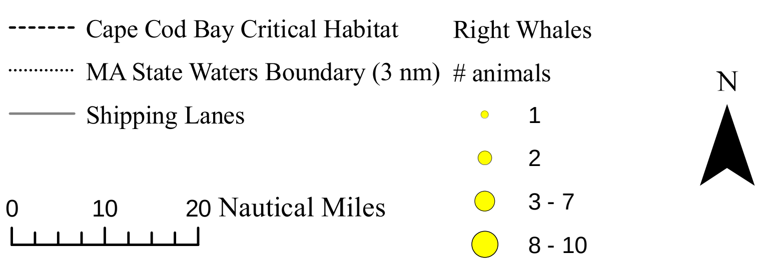


Figure 2f. 12 - 25 March



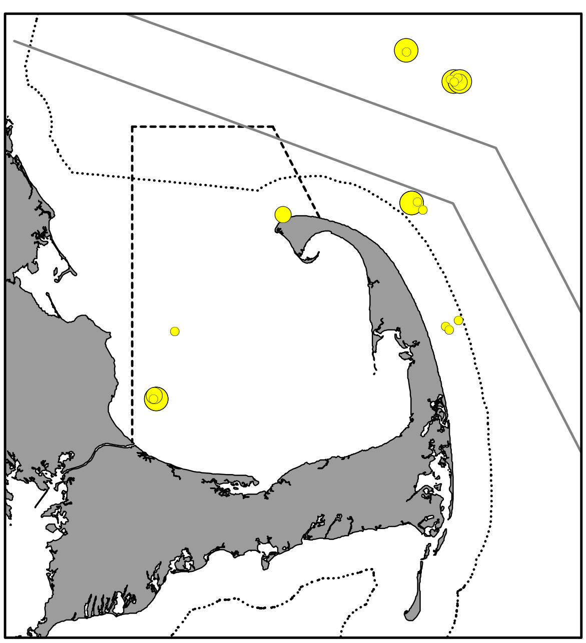


Figure 2g. 26 March - 8 April

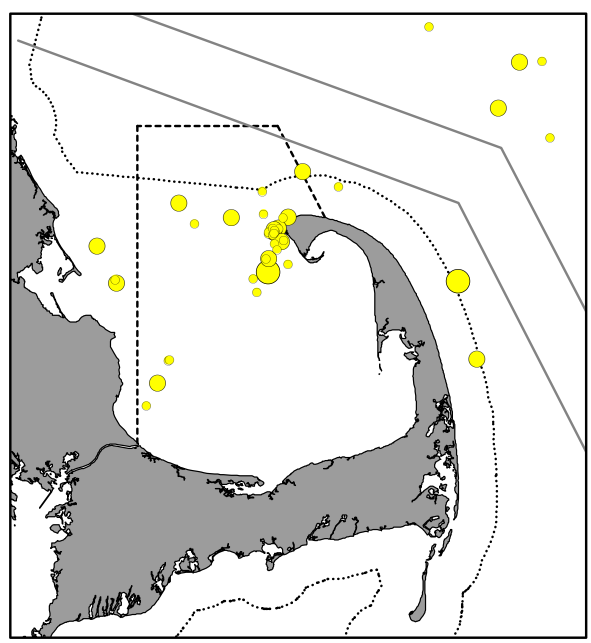


Figure 2h. 9 - 22 April

Figure 2i - j. Sightings of right whales from aerial surveys of Cape Cod Bay and adjacent waters, 23 April - 18 May 2006.

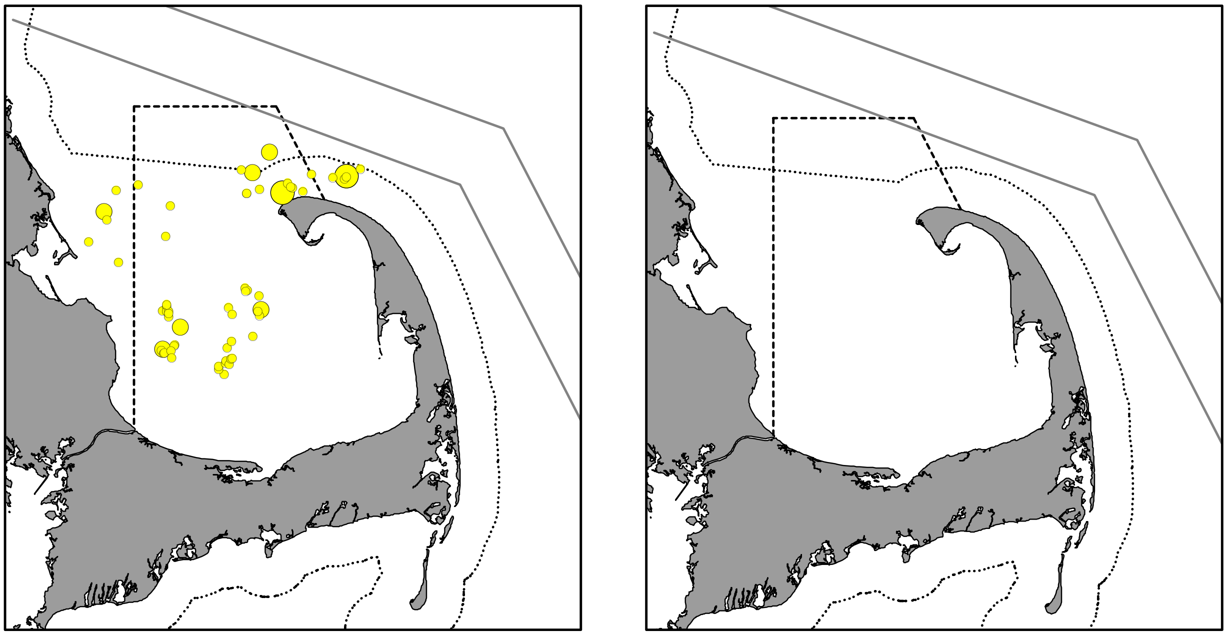


Figure 2i. 23 April - 6 May

Figure 2j. 7 - 18 May

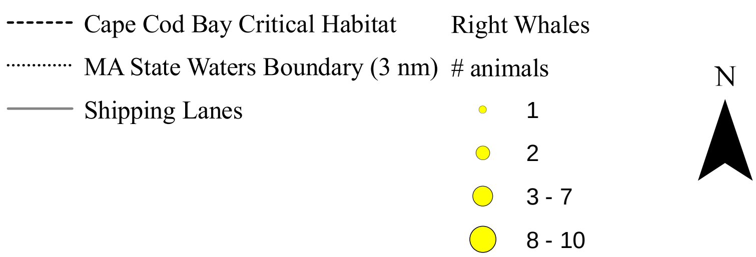
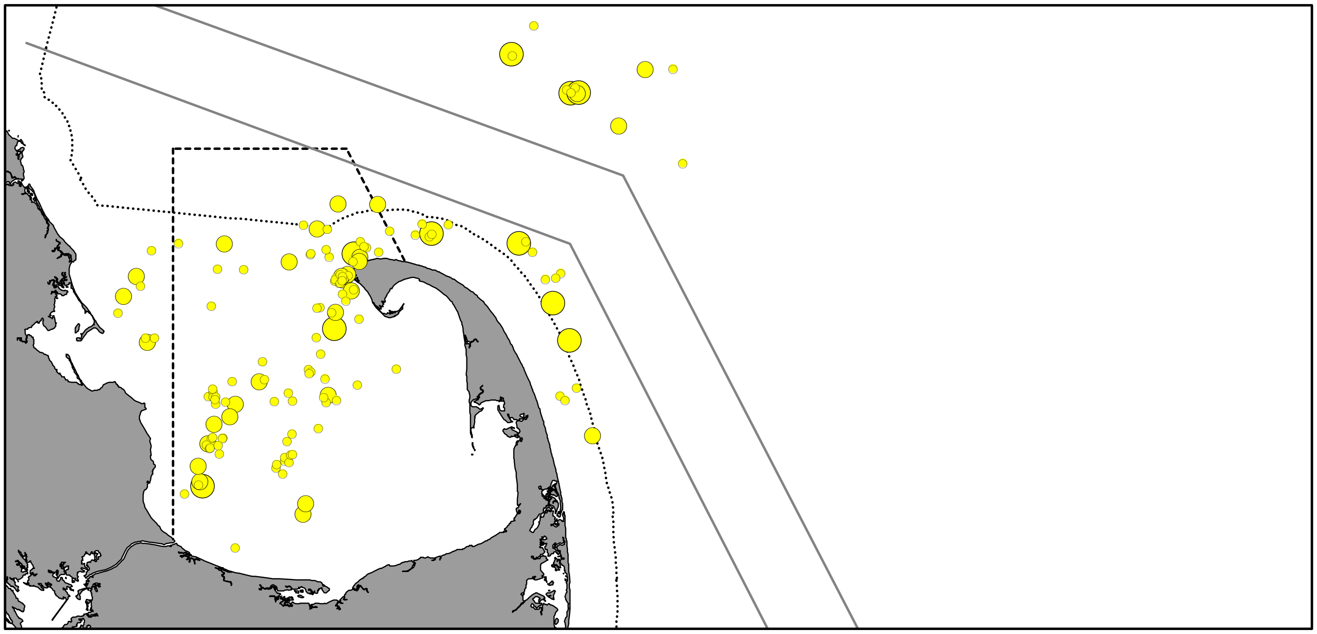


Figure 3a. Sightings of right whales from aerial surveys of Cape Cod Bay and adjacent waters, 1 January - 18 May 2006.



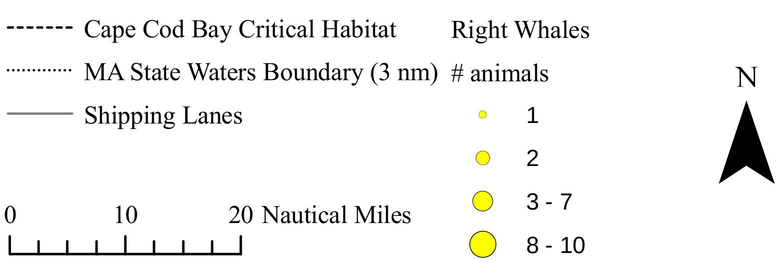


Figure 3b. Sightings of right whales from 2005 season (shown in red) over 2006 season sightings.

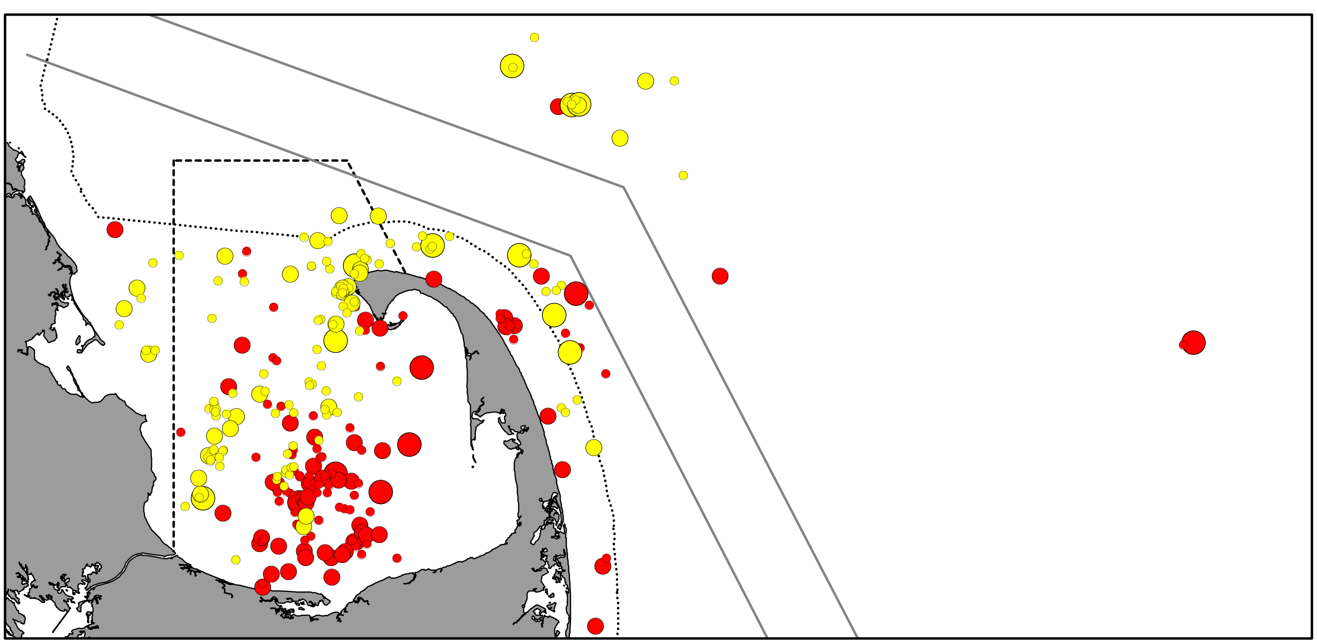


Figure 4. Sightings of vessels from aerial surveys of Cape Cod Bay and adjacent waters, 1 January - 18 May 2006.

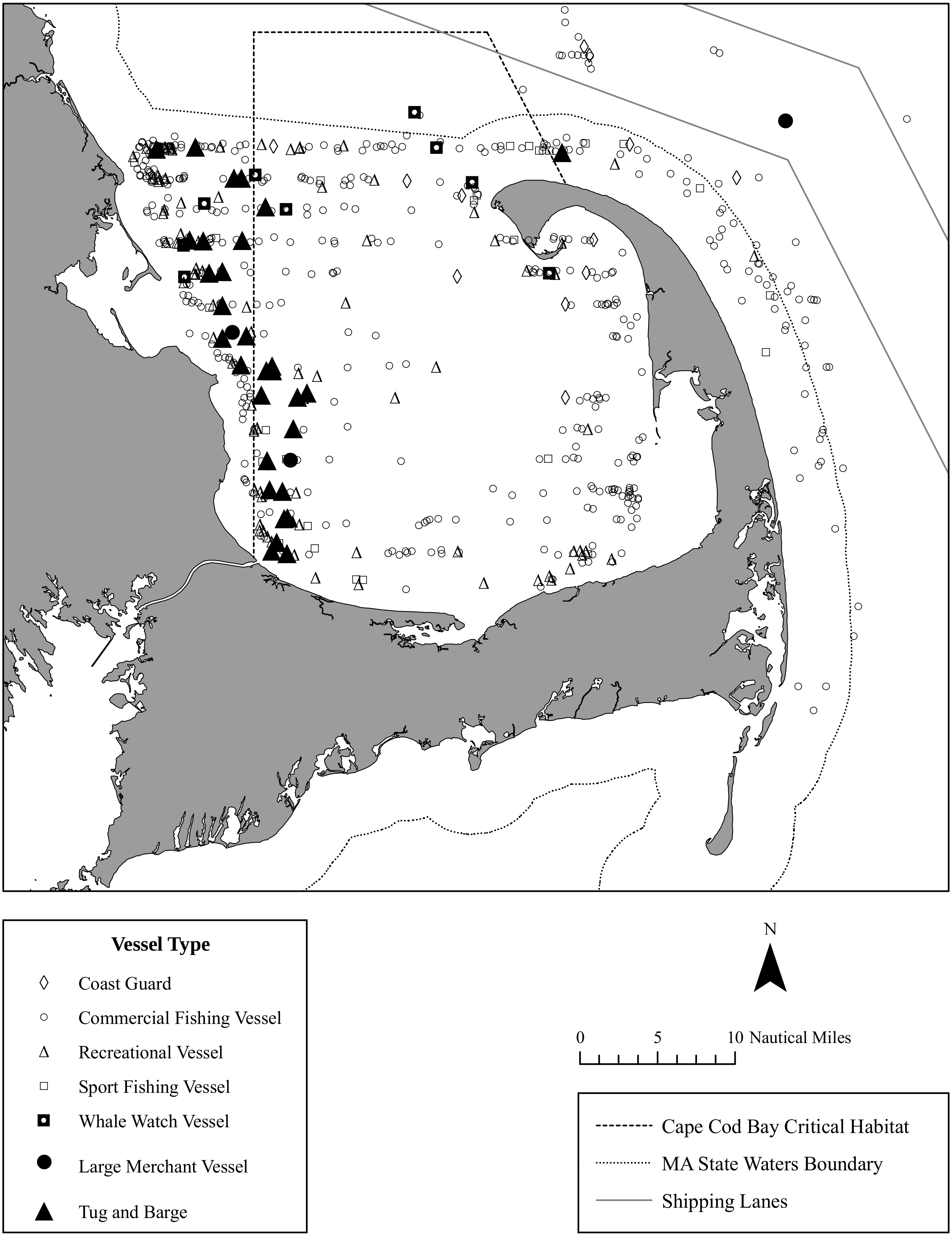
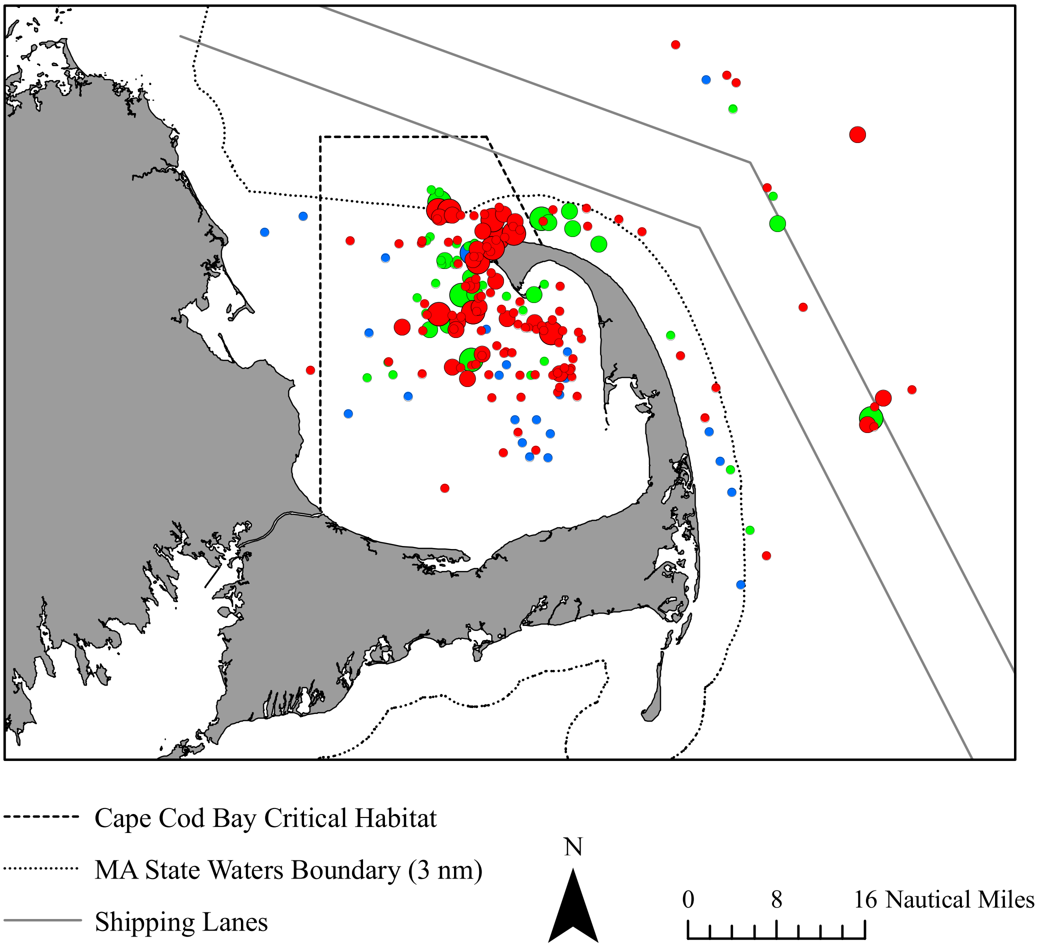


Figure 5a. Sightings of balaenopterid whales from aerial surveys of Cape Cod Bay and adjacent waters, 1 January - 18 May 2006.



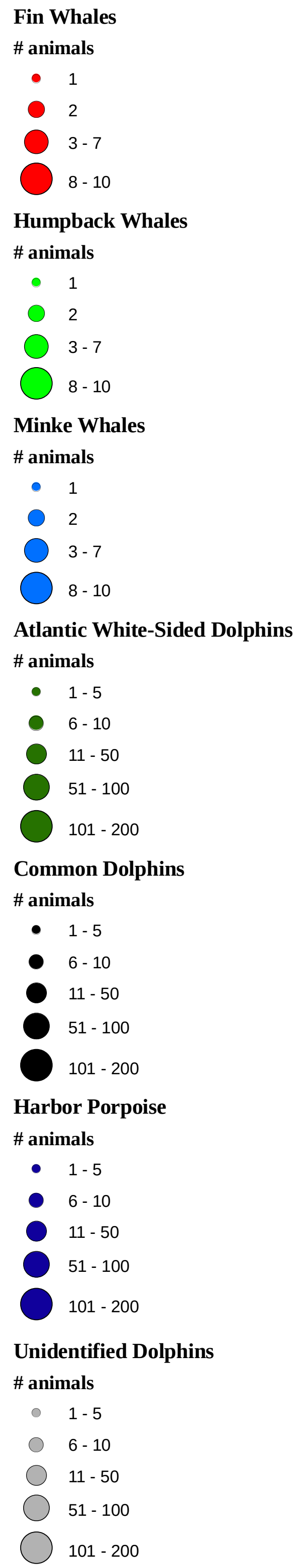
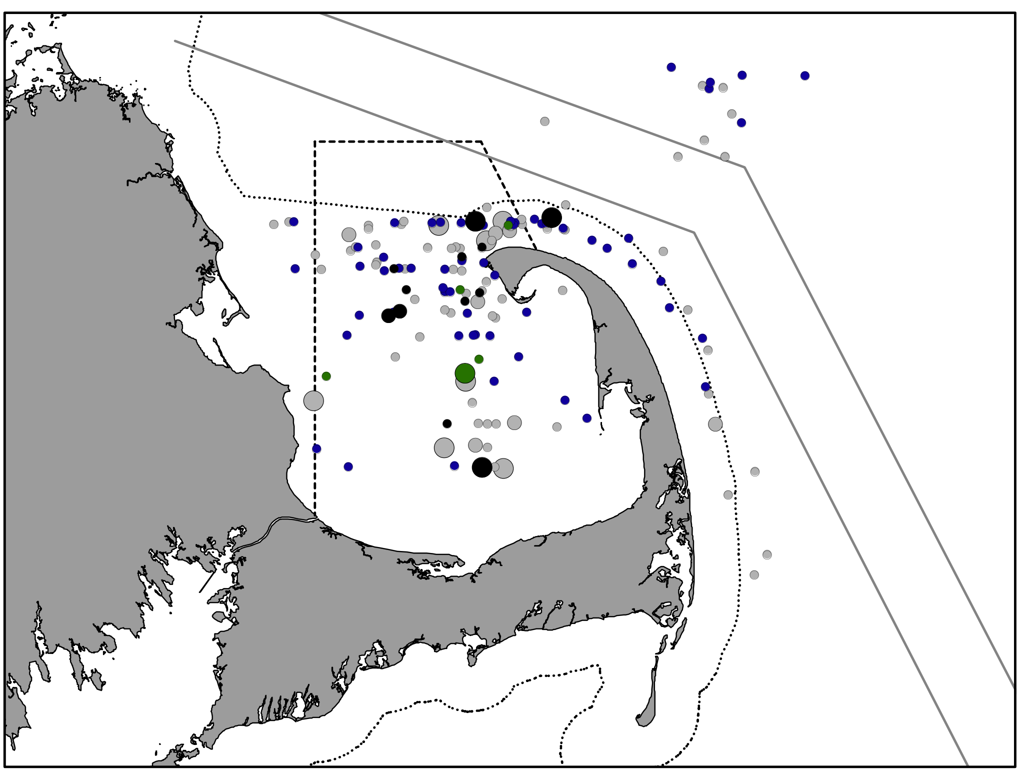


Figure 5b. Sightings of toothed whales from aerial surveys of Cape Cod Bay and adjacent waters, 1 January - 18 May 2006.



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

2.1. Introduction

Habitat studies in Cape Cod Bay (CCB) were directed in 2006, as in previous years, to monitor the distribution of right whales in relation to that of food resources in the Critical Habitat in an attempt to advance our understanding of the habitat characteristics to which right whales respond. In accordance with the goals set forth in Objective IV by PCCS/DMF (see General Introduction), surveillance and monitoring activities also aimed to assist management agencies in time-critical decisions (e.g., amendments to seasonal gear restrictions or the issuance of vessel speed restrictions) that directly affect right whales. As such, the reporting strategy of electronically disseminating post-cruise "Habitat Assessments" to interested managers and colleagues was continued and further developed in 2006, providing detailed descriptions, analyses and forecasts concerning the interaction of right whales, habitat conditions and potential risks. The evolution of the habitat assessment instrument this year to more thoroughly integrate zooplankton distribution and trend data with right whale sightings and behavioral observations was attended by a proportional increase in data processing time, which led to an unfortunate decline in the speed at which assessments were distributed. To address the need to rapidly alert DMF to conditions in Cape Cod Bay deserving their immediate attention, in March 2006 we developed a rapid reporting system, a "Preliminary Assessment and Alert of Right Whale Risk," to support the more time-consuming assessment analysis.

In this section we summarize and discuss some of the principal spatial and temporal dynamics that were observed in the Cape Cod Bay habitat in 2006, integrating detailed analyses of the zooplankton resource with the right whale distributional information. We also present a foundation paradigm that describes the relationship between right whales and their prey, the dynamics of the prey fields, and the strategies and movement of whales that result in the predictive parts of the assessment analysis and risk alert warnings.

2.2. Management Process: the Application of Habitat Studies

The investigation of the habitat conditions in Cape Cod Bay during the winter is an integral part of the ongoing surveillance studies used to manage human activities that may threaten right whales. Because right whales respond to the food resource, the distribution of zooplankton may be seen to "control" the distribution and occurrence of the whales within the 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 action.

In order to assess the conditions controlling the occurrence of right whales within Cape Cod Bay, the habitat work of the surveillance program has been tasked to explore the processes that influence the movement of right whales and to develop a forecast of movement and occurrence patterns of the whales. The food resource, the "zooplankton", is composed of a rich and complex assemblage of many forms of macroscopic organisms that drift within the mid-waters of the Gulf of Maine. Right whales, the largest of all marine filter-feeders, use baleen plates adapted to catch the extremely small prey on which they feed throughout much of the Gulf of Maine. Although the zooplankton concentrations over most of the whales' range are far too low to maintain the whales, the zooplankton resource, in response to physical and biological processes, occasionally coalesces into "patches" of exceedingly dense layers of organisms rich enough to be harvested by right whales. Because of the intimate relationship between zooplankton and right whales, the whales have evolved a variety of forging behaviors that cause them to find and aggregate in the areas where food patches are abundant. It is upon the forging behavior of right whales that their tendency to aggregate depends, and it is in areas where aggregations develop that risk of interaction between human/industrial activities and whales may occur. By understanding the fundamental characteristics of the relationship between the zooplankton patches and the strategies used by right whales, in some cases it is possible to predict the distribution patterns of the whales. If such distribution patterns are accurately portrayed, human activities can be managed to avoid the co-occurrence of anthropogenic risks and whales.

At the foundation of the forging behavior of right whales are specific decision-making processes that result in the aggregations of whales in the areas rich in the patches of plankton. Because right whales must optimize their food intake and, further, because they must feed throughout much of the year in order to make a living, right whales may be seen in two dominant behavioral modes within Cape Cod Bay: feeding and searching. These two modes are based upon simple decision-making processes that dictate very different spatial and temporal distribution patterns. While the searching behavior of the right whale is coarse in spatial scale, critical feeding behaviors are based on very small scale decision-making that is responsive to the shape and structure of the food patches. Clearly, the aggregations of right whales forming over patches of zooplankton are the direct result of broad-scale searching patterns combined with very small scale feeding behavior, and it is upon this relationship that our predictions, assessments, and alerts to DMF are based.

Using the emerging searching/feeding paradigm, our reporting system is aimed at identifying locations where whales may occur as a reflection of zooplankton patch formation and movement. Weekly habitat cruises characterize the zooplankton resource throughout Cape Cod Bay, providing information (e.g., zooplankton abundance, spatial distribution, and species composition) on which short- to medium-term movement and aggregation of whales may be forecast. Upon rapidly analyzing the collected samples, we author and electronically disseminate a "Habitat Assessment Report" to inform the DMF and interested agencies about times and locations where whales and human activities that place whales at risk are likely to co-occur. For several years these Assessments have been developed and refined, contributing significantly to the management of the Cape Cod Bay Critical Habitat. In 2006, in response to the need to more rapidly address time-critical management issues (e.g., fisheries or shipping conflicts), our reporting evolved to include a “Preliminary Assessment and Alert of Right Whale Risk” report that was delivered to DMF *immediately* following a cruise, if conditions warranted. This rapid reporting method, while slowing the reporting of the detailed Habitat Assessment analyses, added an essential component to the documentation and prediction portion of the Cape Cod Bay surveillance program. Six such Risk Alerts were distributed in 2006 (see Appendix II), identifying distributions of the food resource that were likely to result in aggregation of right whales in locations where ship strike risk was particularly high, and resulting in direct action by DMF in several cases. Examples of Risk Alerts, as well as the subsequent DMF formal management Advisories and notification to government agencies and the shipping community, is given in Figures 1 through 4. These exchanges demonstrate the rapidly-evolving interaction between the PCCS surveillance program and state agencies leading to management action triggered by the habitat assessment studies. Indeed, the new Risk Alert reports permit a responsiveness that had not been formerly part of previous assessment strategies, and have added an important component to the reactivity of the program.

The sentinel role played by habitat assessment and reporting and supported by aircraft survey underpins the capacity of DMF to respond with management action to forecasted changes in whale distribution and occurrence. It is upon the interaction between the assessment teams in the field and the managers charged with protection of right whales within the critical habitat that determines the effectiveness of many aspects of the assessment program. Hence, in 2006, we sought to identify those conditions deserving of alert to the DMF. As the exchanges between DMF and PCCS demonstrate, it has proven possible to translate field observations into predictions and those into alerts, which are received by DMF and which the agency quickly converts into advisories that apply to various user groups. The forecasting of right whale presence and subsequent management action and advisories are unique in the management of threats to whales. Thus, the collection and integration of resource information continues to permit the development of a broad-based program for the management and forecasting of right whale distribution which, when combined with rapid assessment methods, permits the management of human activities in the vicinity of right whales in ways not previously contemplated.

Right Whale High Risk Alert and Preliminary Assessment Report: SW607
8 May 2006

Cruise SW607 was mounted in calm conditions and excellent visibility in response to DMF/PCCS aircraft survey reports from 6 May indicating that right whales continue to move into the western portions of Cape Cod Bay. On cruise SW607 eight right whales were recorded, all confined to the western bay. All whales were feeding at or very near the surface. Zooplankton sampling using pump and surface nets along with surface in-path net tows in the vicinity of feeding whales were used to document the distribution of the controlling prey field. Fifty-one zooplankton samples were collected to better define the conditions and to permit prediction. A strong zooplankton signal well in excess of the estimated feeding threshold was found at stations both in the vicinity of whales and at regular stations in the western margins of the western quadrants of Cape Cod Bay. The calanoid resource that was disjunct on cruise SW606 on 5 May has apparently filled in and now appears continuous and extremely rich along the western margin of the bay. Furthermore, a gradual movement of the resource associated with clearly defined surface slicks toward the west has occurred in the last several days. As a result we predict that whales will continue to aggregate and feed within the western warning area originally identified in the alert of 24 April that includes the Boston to Cape Cod Canal shipping lanes. The eastern quadrants of the bay as well as the eastern margins of the western quadrants remain impoverished at all depths and will not support either feeding or aggregation of right whales. Absent strong changes in the present advective characteristics of the western bay we predict that the right whales will be resident along the western margin of the bay, occasionally west of the federally defined Critical Habitat, for as much as one more week. We anticipate only a very slow movement to the south and east unless strong storm winds disrupt the resource distribution. Departure of the right whales from Cape Cod Bay, usually seen by this date, is not likely for a week or more; however, surface feeding and aggregation in the near future in the eastern bay including the area around Provincetown is not likely.

The region Cape Cod Bay west of 70^{o}22' remains rich in surface zooplankton resources that are resulting in an aggregation of 10 to 20 right whales, possibly including mothers and calves. We forecast that this will remain an area of high risk of potential ship strike and entanglement. The rich near-surface resources will continue to attract right whales and elicit sub-surface and skimming behaviors making whales particularly vulnerable to collision with fast moving large vessels. The controlling zooplankton resource continues to be strong enough to warrant particular caution by ships transiting between the Cape Cod Canal and Boston. Shipping interests should continue to remain vigilant and vessel speeds should be reduced within the identified area and the shipping lanes. We anticipate that zooplankton resources will remain high within the near-surface waters in area. We forecast that this area of high risk will continue for several days with no immediate movement, barring strong winds, for as much as a week.

* * * * * * * * * *

These observations are considered preliminary pending detailed analysis and final assessment reporting. The assessment and prediction reports are a product of the Right Whale Surveillance Program at the Provincetown Center for Coastal Studies – a management study supported by the Division of Marine Fisheries of the Commonwealth of Massachusetts and funded by the National Marine Fisheries Service, NOAA, Department of Commerce. (study conducted under NMFS research permit #633-1483-06)

Figure 1. Example of a "Preliminary Assessment and Alert of Right Whale Risk" that was delivered immediately following the completion of cruise SW607 on 8 May 2006, alerting DMF of resource and right whale distribution conditions that place the whales at a significantly elevated risk ship strike.

Commonwealth of Massachusetts

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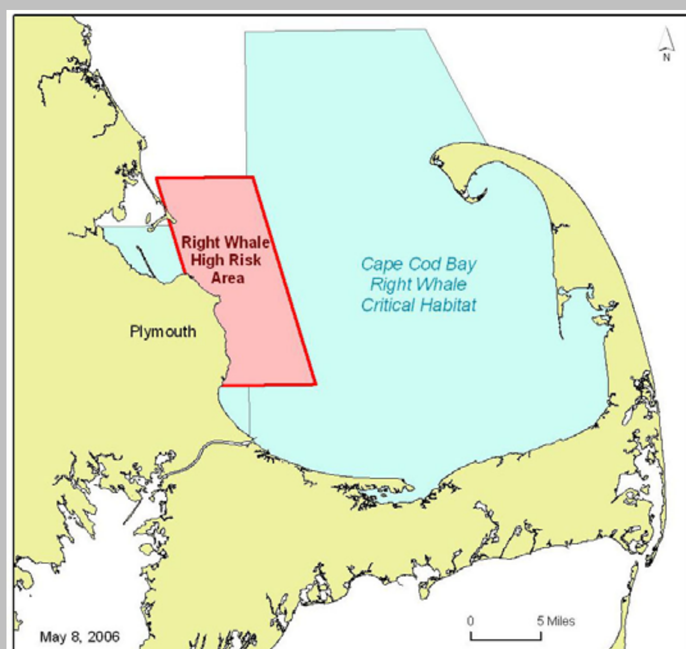
Paul J. Diodati
Director

ADVISORY TO MARINERS

RIGHT WHALES CONTINUE TO AGGREGATE IN WESTERN CAPE COD BAY

Right whales continue to aggregate and feed in western Cape Cod Bay. The extremely dense zooplankton resource in this area places feeding right whales at an elevated risk of ship strike. *MarineFisheries* issued an initial advisory for this area on April 25, however, the current High Risk Area has been shifted to the west. This corresponds with a change in distribution of the whales and the zooplankton resource, now overlapping with the Cape Cod Canal shipping lanes. Zooplankton surveys indicate that right whales will continue feeding in this area for several days.

MarineFisheries recommends that vessel operators use extreme caution in this area. Reduce speeds (as slow as 12 knots) and post lookouts to avoid colliding with this highly endangered whale. It is recommended that ships transiting between Cape Cod Canal and Boston use extreme caution. The Massachusetts Environmental Police and the Coast Guard have been notified.



OTHER RIGHT WHALE UPDATES

The High Risk Area off Race Point has been suspended. Zooplankton densities are not high enough to support right whale foraging. Thus the risk of ship strike in this area is expected to be low.

An Agency of the Department of Fisheries, Wildlife & Environmental Law Enforcement
David M. Peters, *Commissioner*

Figure 2. Example of a DMF Advisory that was disseminated to government agencies and the shipping community as a direct response to the Risk Alert put out by PCCS in Figure 1.

Termination of Right Whale High Risk Alert and Preliminary Assessment Report: SW609
18 May 2006

After a 10 day period of strong easterly winds preventing cruises and aircraft surveys, Cruise SW609 was mounted in moderate conditions and ended in Beaufort 3 sea state. During the cruise surface and oblique zooplankton samples were collected from eight stations in Cape Cod Bay in order to forecast the locations where right whales would aggregate and feed. No whales were sighted from either the DMF/PCCS aircraft or from R/V Shearwater on 18 May. The prolonged period of windy weather following the alert of 8 May 2006 apparently resulted in dispersion of the very strong zooplankton signal that had persisted for several weeks and controlled the location and behavior of the right whales. Zooplankton densities at all stations and all depths during SW609 were estimated as far below the feeding threshold that leads to aggregation of whales; therefore, no part of Cape Cod Bay will support feeding and aggregation of right whales for the foreseeable future.

Near-surface, high-density zooplankton patches identified in the western third of Cape Cod Bay on 8 May 2006, the subject of the previous right whale ship-strike risk alert, have dispersed and the food resource in all quadrants of Cape Cod Bay is now below feeding threshold. **Low concentration of the controlling zooplankton resource in the bay indicates that the high risk of ship-strike throughout Cape Cod Bay has ended and that aggregation of right whales will not occur. Therefore, the previous ship-strike alerts for western Cape Cod Bay may be lifted.**

* * * * * * * * * *

These observations are considered preliminary pending detailed analysis and final assessment reporting. The assessment and prediction reports are a product of the Right Whale Surveillance Program at the Provincetown Center for Coastal Studies – a management study supported by the Division of Marine Fisheries of the Commonwealth of Massachusetts and funded by the National Marine Fisheries Service, NOAA, Department of Commerce. (study conducted under NMFS research permit #633-1483-06)

Figure 3. Example of a later Risk Alert that was issued by PCCS immediately following the completion of cruise SW609 on 18 May 2006, notifying DMF that degraded resource conditions and the absence of right whales warrant the termination of the previously-issued DMF Advisory.

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FOR IMMEDIATE RELEASE
May 19, 2006

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RIGHT WHALE AGGREGATION DEPARTS CAPE COD BAY

ADVISORY LIFTED

Recent survey and monitoring efforts by the Center for Coastal Studies and the Division of Marine Fisheries have determined that the large aggregation of right whales observed in western Cape Cod Bay has departed. The recent period of poor weather conditions prohibited observations of right whales in the Bay; however, the aerial and vessel-based surveillance teams were able to complete surveys on May 18. No right whales were sighted from the aircraft or boat, and habitat monitoring revealed a sharp decline in the zooplankton resource, suggesting that right whale aggregations are not likely to return in the near future.

With the departure of these animals the Commonwealth is lifting the May 9th advisory to mariners in Cape Cod Bay. *MarineFisheries* would like to thank fishermen, whale watch companies, and other mariners for their assistance and compliance with measures designed to protect this highly endangered animal. During the past month, large aggregations of right whales have been seen feeding in high traffic areas such as Race Point and the Cape Cod Canal Shipping Lanes. *MarineFisheries* monitors the presence of right whales in Cape Cod Bay through aerial surveys, habitat sampling, and acoustic monitoring. Sightings observed through these efforts allow *MarineFisheries* to address threats to right whales on a real-time basis. We greatly appreciate the diligence and alertness of mariners and our surveillance team during the 2006 season.

An Agency of the Department of Fisheries, Wildlife & Environmental Law Enforcement
David M. Peters, *Commissioner*

Figure 4. Example of a DMF notification, subsequent to the updated Risk Alert of Figure 3, that lifted their right whale risk Advisory.

2.3. Methods

2.3.1. Data Collection and General Protocols

Observations reported here are based upon collections and field notes made during Cape Cod Bay habitat surveys and directed sampling on board the R/V *Shearwater* in 2006. R/V *Shearwater* is a 40 ft (12m) twin diesel engine research vessel equipped with plankton nets, a vertical plankton pump, and a CTD (Conductivity-Temperature-Depth profiler) to satisfy the needs of 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 eight fixed ("regular") stations in Cape Cod Bay. The stations, many of which have been sampled by PCCS annually for more than two decades, are located throughout the Bay (see Figure 5) and provide spatial coverage of the entire system, allowing characterization of zooplankton distributions and dynamics during the season of right whale residency in the Bay. From 1 January through mid-May, weekly habitat cruises visited the regular stations to collect zooplankton from the surface waters and from the water column. Samples were collected using standard 333-micrometer (μm) mesh conical nets fitted with a General Oceanics helical flow meter. At each station, surface sampling involved towing a 30cm-diameter net in a circle horizontally for 5

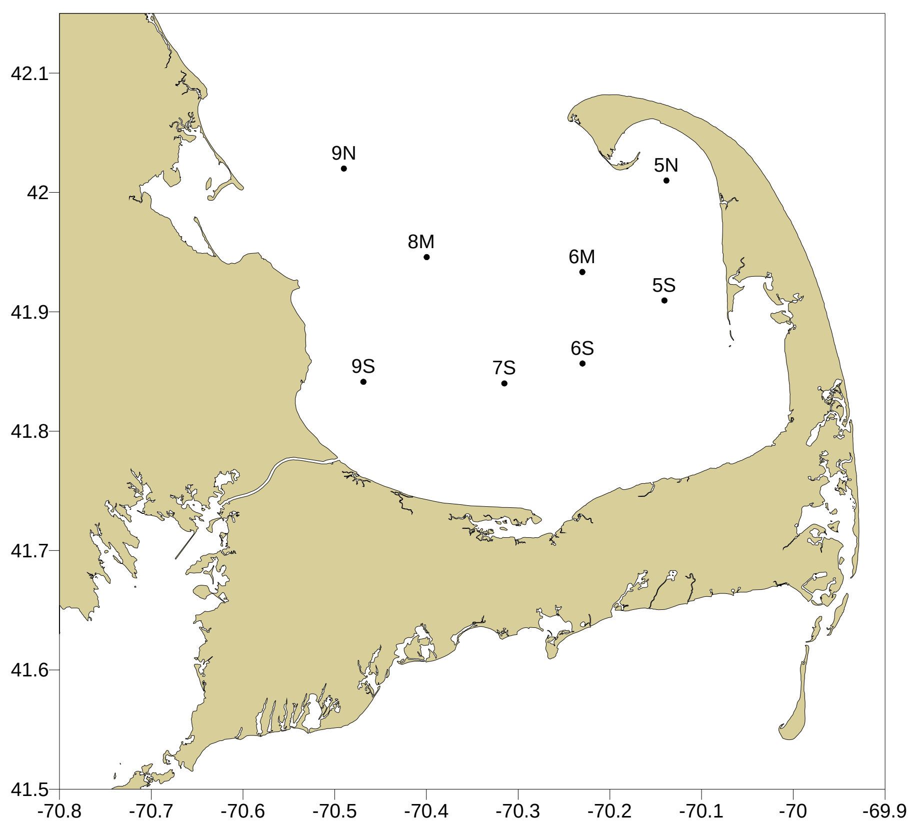


Figure 5. Map of "regular" sampling stations in Cape Cod Bay that were visited approximately weekly between 1 January and mid-May of 2006.

minutes. Water column collections were made by vertically dropping a 60cm-diameter net on-station and then hauling it in obliquely through the upper 20 meters of the water column. These net collection techniques have been employed since 1984 and therefore provide the most useful comparative measure of the conditions that support the feeding activities of right whales in Cape Cod Bay. Furthermore, zooplankton samples were occasionally obtained at targeted depths using a pump sampler deployed on a CTD frame. All samples were concentrated by filtering through a 333 μm mesh and the volume of the water sampled by the net or pump system was recorded. Field samples were kept in seawater on ice on board the vessel. In the laboratory, the zooplankton samples were preserved in 6-8% formalin and settled overnight in graduated cylinders. Zooplankton were identified and counted within 12-24 hours of collection and the results of the zooplankton observations were expressed in organisms per cubic meter (organisms/m^3). The settled volume was recorded and estimates of the caloric content were made from the zooplankton density estimated from enumeration.

Beyond the regular station sampling regime, directed sampling near feeding right whales was opportunistically conducted to characterize the abundance, species composition, and spatial extent of the zooplankton resource on which the animals were feeding. Such information was used to characterize the durability of the resource and to forecast the likelihood of continued whale aggregation and residency. These analyses were 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, as detailed in Figures 1 through 4 of Section 2.2.

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, when possible, photographed by observers aboard *Shearwater*. This vessel-based opportunistic information, including identifying photographs and location information, was integrated within the residency, demographic, and life history analyses contained in Section 1, as well as in subsequent plots of whale locations presented in this section of the report. However, because R/V *Shearwater* surveys were non-systematic, such opportunistically collected data were not included as part of analyses which require right whale density estimates. The photographic information collected from *Shearwater* was handled in much the same fashion as that collected from the aerial surveillance effort, and ultimately all vessel-collected ID information was pooled to permit the development of a more complete view of right whale presence in Cape Cod Bay.

Using the computer data logging system, the System Data Logger developed by PCCS, information on other species of marine mammals and on a variety of human activities in Cape Cod Bay was collected on all cruises in 2006. In particular, because of the interest of DMF in fixed fishing gear and shipping, special note was made of the types and locations of fixed fishing gear which might pose a risk to right whales. Observations of potentially threatening conditions were relayed to DMF via cell phone and in post-cruise Risk Alert reports. 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 2006 surveillance season.

2.3.2. Habitat Cruises and Reporting, 2006

R/V *Shearwater* completed 19 habitat sampling cruises in the Cape Cod Bay Right Whale Critical Habitat between 1 January and 18 May 2006. On every cruise the data logging computer was used to record all information on sample collections, right whale observations, information on other marine mammals, and a wide variety of physical, biological and human activity information that forms the underpinning of the study. During the 2006 cruises, a total of 288 zooplankton samples were collected using surface and oblique sampling techniques (Table 1). With the exception of a few January cruises, CTD profiles were also conducted on-station throughout the sampling season.

Table 1. Summary of 2006 Cape Cod Bay habitat cruises and collected zooplankton samples.

		ZOOPLANKTON SAMPLES					
Cruise	**Date**	**On Station Surface Tows**	**Off Station Surface Tows**	**On Station Oblique Tows**	**Off Station Oblique Tows**	**Horizontal Transect Samples***	**Total**
SW585	2-Jan	8	.	8	.	.	**16**
SW587	12-Jan	8	.	8	.	.	**16**
SW588	24-Jan	8	.	8	.	.	**16**
SW589	29-Jan	8	1	8	3	.	**20**
SW590	9-Feb	8	.	8	.	.	**16**
SW591	16-Feb	8	.	8	.	.	**16**
SW592	22-Feb	8	.	8	.		**16**
SW594	2-Mar	8	.	8	.	.	**16**
SW595	8-Mar	8	.	7	1	.	**16**
SW596	13-Mar	8	.	8	.	.	**16**
SW597	22-Mar	4	.	4	.	.	**8**
SW598	24-Mar	4	.	4	.	.	**8**
SW600	30-Mar	8	.	8	.	.	**16**
SW602	11-Apr	8	.	8	.	.	**16**
SW603****	14-Apr	.	3	.	.	32	**35**
SW604	24-Apr	8	1	8	1	.	**18**
SW606	5-May	8	2	8	.	.	**18**
SW607	8-May	8	5	8	.	22	**43**
SW609	18-May	8	.	8	.	.	**16**
	Totals	**136**	**12**	**135**	**5**	**54**	**342**

* collected by filtering a pumped volume of surface water as the vessel steamed along a horizontal transect
****** designates a non-assessment, opportunistic sampling cruise

During the 2006 season, 27 right whales were sighted and 15 photographed opportunistically for inclusion in the analysis of individual whales. The photographs collected permit detailed, close-up analysis of callosity patterns, enriching the photographic database that underpins the demographic analysis of the 2006 whales. The techniques used for the identification of whales from photographs taken opportunistically onboard *Shearwater* are identical to those used for the identification of whales from aerial photographs; however, shipboard photographs are particularly valuable in the analysis of individual whales because they provide a profile of the individually-distinctive lipped bridges that may offer the only method for individual identification of some whales.

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. The regular “Habitat Assessment” reports were typically circulated within several days following the completion of each cruise, while the newly-developed “Preliminary Assessment and Alert of Right Whale Risk” reports were distributed immediately following six of the late-season cruises when right whale aggregation and feeding in the Bay’s surface waters placed them at a significant risk to ship strike. As in previous years, the Habitat Assessment analyses focused on evaluating the quantity and quality of the zooplankton resource in the Bay, both in terms of spatial distribution and temporal dynamics. A new addition to the reports this year was the inclusion of spatial plots to simplify presentation of zooplankton density distributions and trends throughout the Bay. These analyses gave us an important perspective on the dynamics of zooplankton richness within the bay ecosystem and improved our capacity for predicting changes in right whale distribution (see Figure 6 for examples).

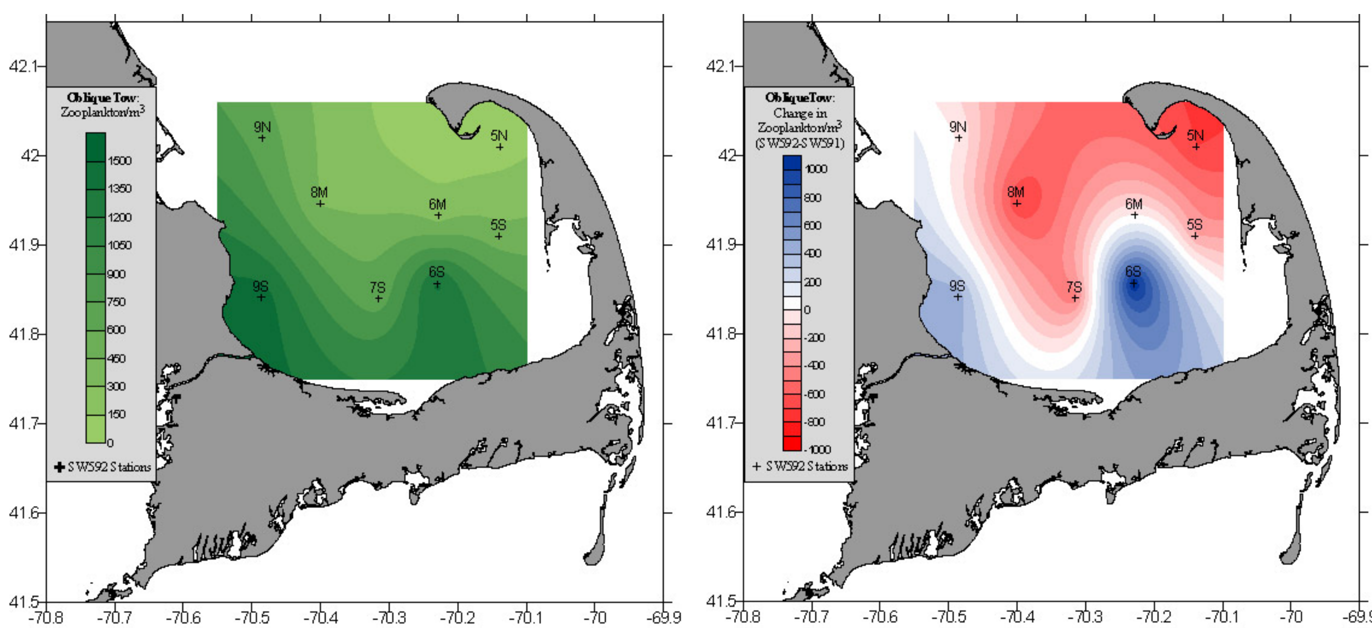


Figure 6. Examples of spatial plots, new this year to the Habitat Assessment reports. The left plot shows zooplankton density distributions determined from water column samples, while the right plot presents changes in zooplankton densities since the previous week’s sampling cruise.

2.4. Results and Discussion

Summary information and supporting analyses are included in the body of the text of Section 2, in the supplementary figures compiled at the end of this section, and in the Habitat Assessment reports bound in Appendix II. Any data not reproduced in this section or in the Appendices of this report are available to DMF upon request.

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 Habitat Assessment and Risk Alert documents that were regularly sent via email after analysis of the material collected during each cruise. In this section we also evaluate the season as a whole in light of the paradigm used to predict the occurrence of right whales in Cape Cod Bay. As a foundation for this discussion, we here summarize the resource conditions that influenced right whale distribution and activity during the 2006 season and revisit our forecasts of whale movements. As in past years, our field information continues to amplify the value of resource sampling in the critical process of predicting right whale movements and aggregation in Cape Cod Bay.

2.4.1. A Resource-Based Paradigm for Understanding Right Whale Movements

The habitat studies that underpin both the alert and assessment portions of the Cape Cod Bay surveillance program have been founded upon an emerging understanding of the importance of food resources in determining the distribution of right whales and the attendant risk of entanglement and ship strike. While this resource-based paradigm is the foundation of all aspects of the habitat work reported here, with the exception of the general paper presented by Kenny et al. (2001) and information on foraging movement patterns described by Mayo and Marx (1990), a detailed description of this relationship has not heretofore been presented. Thus it is useful to begin our evaluation of this year's sampling and surveillance by first discussing the basic elements of the whale-resource interaction that underpin the prediction and assessment processes used in the DMF/PCCS management studies of Cape Cod Bay.

For some years it has been clear that right whales are often distributed where their zooplanktonic food is located, and this fact has been repeatedly reported over several years to DMF – the only exception to this observation being right whales' activities in the calving grounds of the southeastern United States. In the higher latitudes of their range, right whales appear by all accounts to spend as much as 18 hours a day feeding or searching for food (Kenney et al. 1986). While this view may be an overly simplified vision of any mammal's lifestyle, there is little doubt that within Cape Cod Bay right whales spend much of their time feeding in sometimes-dense whale aggregations. Indeed, because right whales are grazing animals, the relationship of rich food to whale presence is more strictly applicable than in many other species. In response to the need to understand the distribution of whales in order to reduce their co-occurrence with the anthropogenic threats to them, considerable attention has been paid by researchers studying the distribution of the planktonic food of the right whales in order to develop a better understanding of the movements of whales. This effort has largely been focused by the management needs of various federal and state agencies. Thus the foundation of those strategies intended to manage the human activities that result in death and injury of right whales have been driven by the broad understanding that right whale distribution usually maps over its food resources.

Given this relationship and the importance of understanding the co-occurrence of right whales and the anthropogenic threats to the population – threats which are unevenly distributed through the coastal waters of the northeastern United States – a particular management focus has been placed upon describing the distribution of the whales' primary foods. To support this effort within Cape Cod Bay, field work and laboratory analysis over the last two decades has concentrated on developing an understanding of the dynamic relationship between the very-small-scale structure of zooplanktonic food resources and the whales in order to better define, and in some cases predict, whales' occurrence patterns.

2.4.2. Right Whale Distribution in the Context of the Paradigm

Given these considerations, an understanding of the basic interaction between food and whales has been and continues to be essential to the resource-based management plan that has evolved within Cape Cod Bay. The unique advantage of utilizing the relationship between food and whale occurrence is that prediction of the movements, behavior, aggregation, and dispersion of right whales is achievable. While it has long been possible to locate whales using survey techniques, an essential part of the management system for the species, prediction, even on the short term, has eluded managers. By developing a detailed understanding of the relationship between whales and the food patches that they seek, a prediction of movement and occurrence patterns for several days or weeks into the future is possible.

Habitat studies at PCCS have been focused on developing an understanding of the food requirements of right whales and of the distribution and quality of the foods that control right whale distribution within Cape Cod Bay. With an understanding of the zooplanktonic food resources it is possible to place empirically derived boundaries around the forging requirements of right whales within the Bay and then to assess any set of observations relative to the conditions described by those boundaries. The results of these studies, using information on the requirements of right whales when foraging, has permitted an increasingly refined understanding of the influence that food has upon the distribution of whales. Thus the emerging paradigm offers an increasingly important foundation on which the management of the co-occurrence of whales and several of the anthropogenic causes of mortality may be based.

2.4.3. Potential Influence of Zooplankton Taxonomic Composition on Right Whale Distribution and Risk

The principal taxa of zooplanktonic resources that support right whales, *Centropages* spp., *Pseudocalanus* spp. and *Calanus finmarchicus*, go through annual periods of enrichment and impoverishment that ultimately govern the entry and exit of right whales to and from Cape Cod Bay (see Figures 7-10). On very small temporal and spatial scales, the changes within the taxonomic composition of the mid-water zooplanktonic resource have profound effects upon the formation of patches and therefore upon the response of whales. Even seen at a coarse scale, the early winter zooplankton that occasionally supports right whales during their entry into the Bay is dominated by *Centropages* spp. There is every indication, as shown by the 1999-2005 trend line in Panel A of Figure 9 and the 2003-2005 trend line in Panel A of Figure 10, that the *Centropages* resource observed during cruises in January is usually in a state of decline during the early winter, dropping from a peak that likely occurs sometime in the autumn. In contrast to early-winter dominance of *Centropages*, the typical mid-winter food resource is dominated by dense concentrations of *Pseudocalanus* (Panel B in Figures 7-10), which appear to fluctuate less throughout the season than the other two primary taxa. The uniformity of *Pseudocalanus* resources (see the pre-2006 trend line in Panel B of Figures 9 and 10) during many years may be seen as a stabilizing influence upon the winter occurrence of right whales. During most years within Cape Cod Bay the early entry of right whales is supported almost exclusively by the early- and mid-season calanoid copepods consisting of smaller taxa and not, as often hypothesized, by *Calanus finmarchicus*. That *Pseudocalanus* and *Centropages* are central controlling influences on early- and mid-winter right whale distribution is at an important variance from the commonly held view that the principal controlling food resource is late stage *Calanus*.

Calanus does play a critical role in the occurrence and distribution of right whales during the late winter and early- to mid-spring of most years (Panel C of Figures 7-10), as *Calanus* increases from very low densities during the early- and mid-winter to a rapidly enriching resource in the period of March and April. The importance of the late winter rise in *Calanus* is amplified because by the later part of the right whales' season *Centropages* has sharply declined in density and *Pseudocalanus* has started its slow decline (Panel B of Figures 9 and 10). Thus, the rich *Calanus* impulse appears to be a critical element in support of late season right whale occurrence when the other two calanoid copepods have dropped to low densities. By the end of the surveillance season, during the last zooplankton sampling cruises of each year, it appears that a sometimes steep decline in the *Calanus* resource begins. The importance of the timing and severity of the decline in the *Calanus* resource should not be underestimated. It is possible that in many years this decline cues the departure of right whales, a departure that is particularly important in the development of management strategies for late-season shipping and fisheries management strategies. In Cape Cod Bay, as fixed fishing gear is increasingly common during May and June, it is possible that the presence of *Calanus* throughout the region may be used as an indicator of the timing of management actions. In fact, supporting this view are many observations by PCCS from the last 30 years that suggest that occasional late spring and summer right whale occurrence is also closely associated with occasions of high *Calanus* density and moreover that in some years the influence of the summer *Calanus* resource may stretch the season for strict management of human activities. Under any circumstances, the composition of the food resources of right whales appears to have a profound effect on the timing of right whale occurrence within Cape Cod Bay.

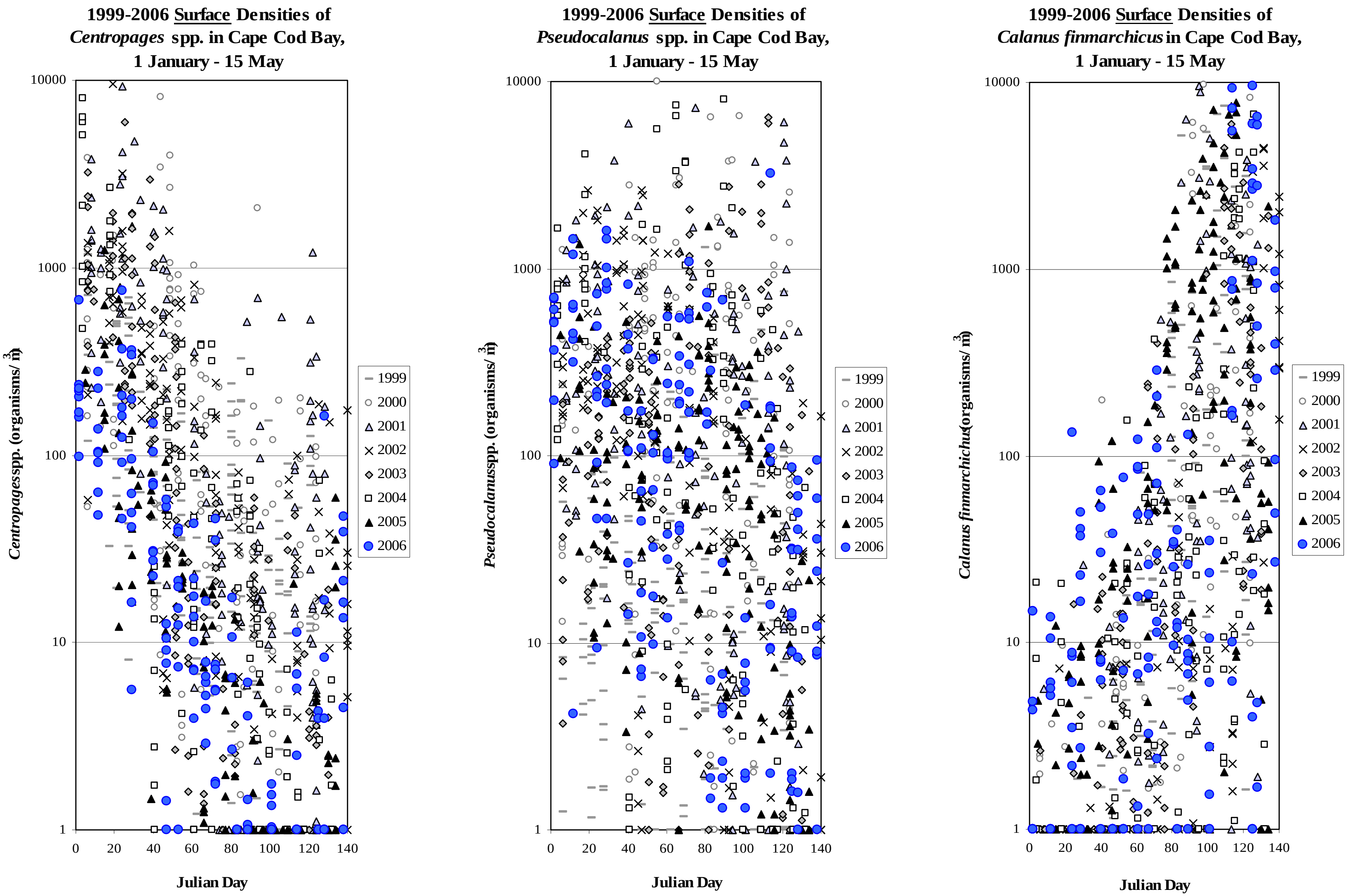


Figure 7. Scatter plots showing temporal changes in the bay-wide mean surface densities of the three principal copepod taxa: *Centropages* spp. (left plot, "Panel A"), *Pseudocalanus* spp. (center plot, "Panel B") and *Calanus finmarchicus* (right plot, "Panel C"). Note that all axes have identical scales.

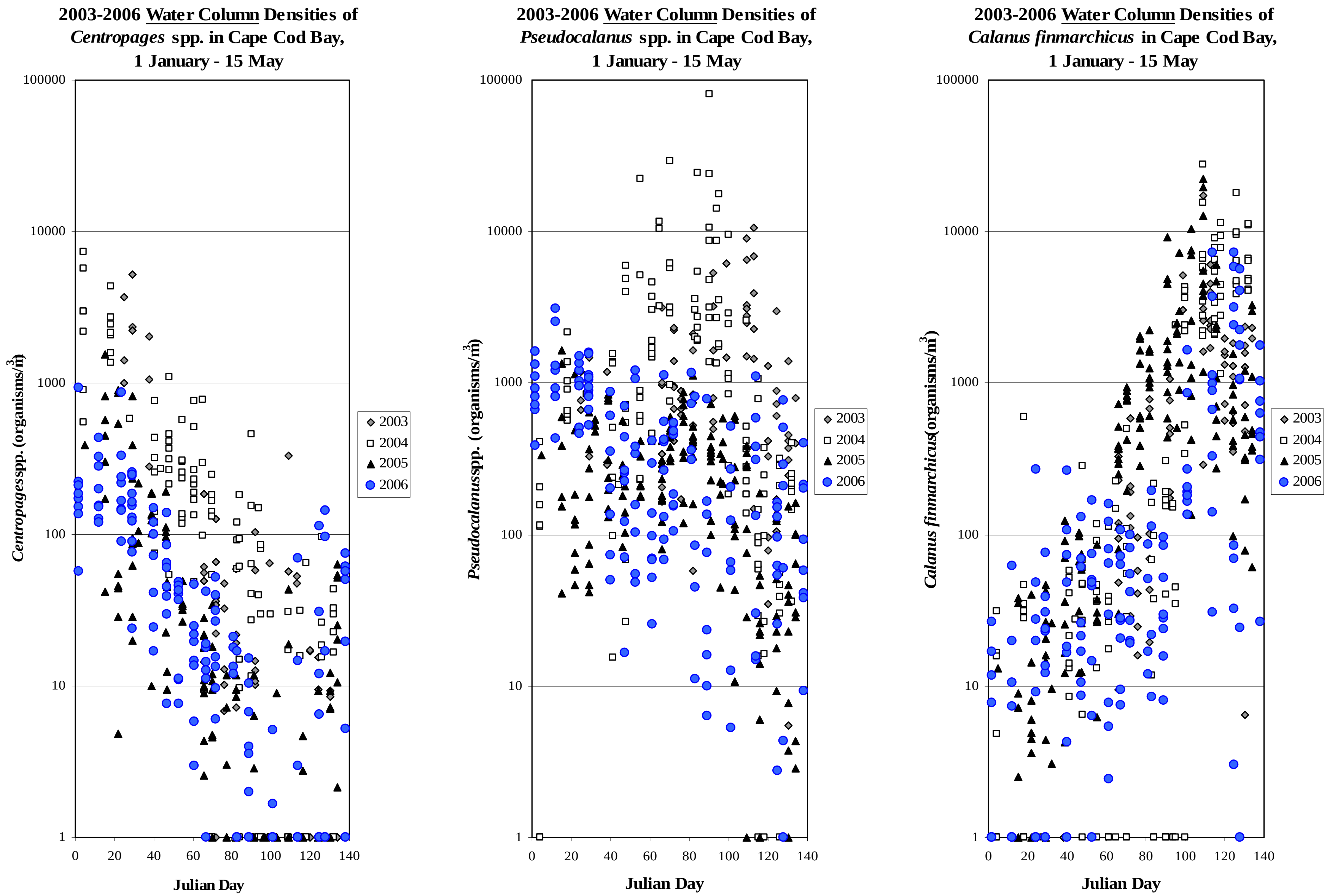


Figure 8. Scatter plots showing temporal changes in the bay-wide mean water column densities of the three principal copepod taxa: *Centropages* spp. (left plot, "Panel A"), *Pseudocalanus* spp. (center plot, "Panel B") and *Calanus finmarchicus* (right plot, "Panel C"). Note that all axes have identical scales.

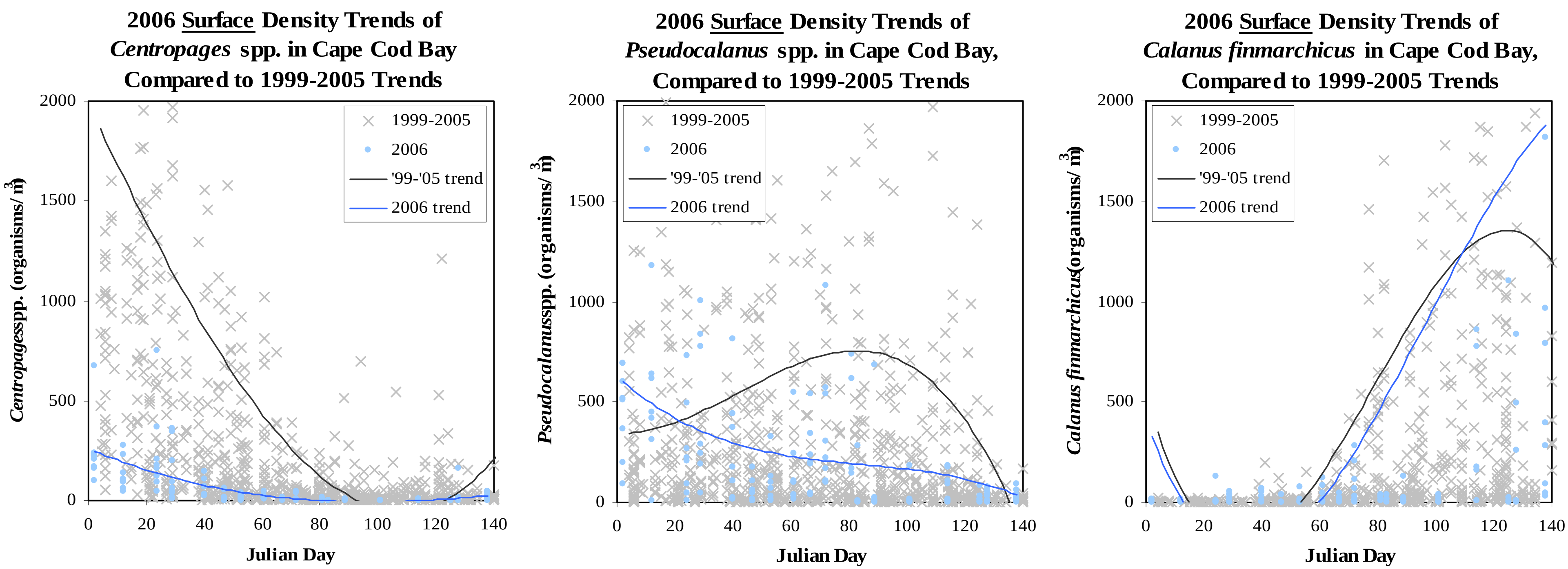


Figure 9. Comparison of 2006 trend against 1999-2005 trends in the temporal progression of bay-wide mean surface densities of the three principal copepod taxa – *Centropages* spp. (left, "Panel A"), *Pseudocalanus* spp. (center, "Panel B"), and *Calanus finmarchicus* (right, "Panel C"). All daily values of bay-wide mean surface abundance for 1999-2005 are combined to illustrate the "typical" progression for the given taxa. Trend lines represent a 3rd-order polynomial regression treatment of the daily values of Cape Cod Bay mean surface density for 2006 and for the period 1999-2005.

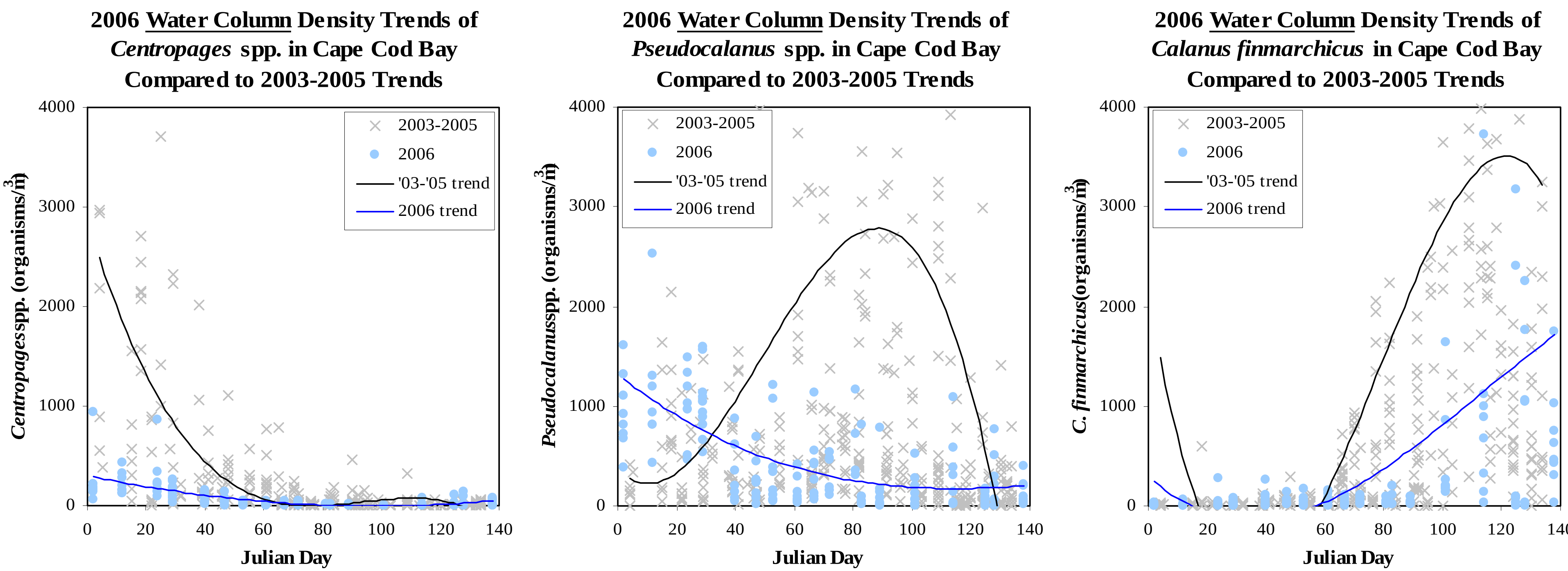


Figure 10. Comparison of 2006 trend against 1999-2005 trends in the temporal progression of bay-wide mean water column densities of the three principal copepod taxa – *Centropages* spp. (left, "Panel A"), *Pseudocalanus* spp. (center, "Panel B"), and *Calanus finmarchicus* (right, "Panel C"). All daily values of bay-wide mean surface abundance for 1999-2005 are combined to illustrate the "typical" progression for the given taxa. Trend lines represent a 3rd-order polynomial regression treatment of the daily values of Cape Cod Bay mean surface density for 2006 and for the period 1999-2005.

As for the influence of taxonomic composition on the aggregation and residency of right whales, there are also indications based on several observations that differences in the swarming behavior among the different taxa that control whale distribution also play a role in the acceptability of the resource. Generally the richest surface layer food concentrations, those that cause dense aggregation of whales and release behaviors that present the greatest risk of ship strike, are *Centropages* and *Pseudocalanus*. *Calanus*, in contrast, more often forms dense layers at the depth of the thermocline, which during the late spring forms at three to 5 m deep. Should these differences in Cape Cod Bay and the surrounding waters be supported by focused studies it may be possible to identify different risk potentials related to the taxonomic composition of high-density patches. Applying this developing hypothesis to Cape Cod Bay, the greatest large-vessel ship strike potential may arise from swarming of all three species of copepods since the draft of large vessels impinges on the thermocline that develops in the early spring. Ship strike by smaller vessels with comparatively shallow draft may be greater where the primary resource is composed of *Centropages* or *Pseudocalanus* than where it is dominated by *Calanus*. Because of the depth of layering of *Calanus* in the late winter when the thermocline has formed, the risk of ship strike from smaller vessels may be reduced. With the seasonal development of high densities of the three taxa and the differences in layering depth, the aforementioned tendencies would suggest greater ship strike potential from larger vessels during the late winter and early spring, and an elevated potential for ship strike by shallow draft vessels as well as from larger ships during the winter. To date the rare but occasional events of summertime right whale occurrence are apparently the result of rich layers of late-stage *Calanus* formed at the depth of the thermocline, suggesting that large-vessel ship strike is likely during summer as well as during the winter. These foregoing observations are based on a variety of sources of information spread over three decades which will require more detailed confirmatory work. However, it may be that even the taxonomic composition of the zooplankton resource could be used to manage aspects of the vessel speed and traffic lanes during certain seasons of the year.

The subtle differences between the swarming behavior and timing of the three dominant taxa of calanoid copepods that support right whale feeding may also have implications for management of fishing gear. Although generally included in the fishing methods permitted within the southern Gulf of Maine, clearly any horizontal, floating lines deployed in areas where right whales are surface feeding threatens mouth entanglement. Such a high-risk of entanglement would likely be associated with both high-density calanoid copepod resources and particularly with the most common surface-swarming taxa, *Centropages* and *Pseudocalanus*. Conversely, resources dominated by *Calanus* may present a reduced tendency for surface swarming, thus reducing the potential, all things being equal, for whales to become entangled in the mouth during surface foraging behavior when lines may be floating in an orientation that is most easily tangled in the mouth.

Feeding activities at the bottom of the water column, observed during previous DMF surveillance studies, are associated with dense swarms of calanoid copepods found in the engybenthic layer. We have observed that floating bottom lines deployed within this layer may present a particularly high risk of mouth entanglement if copepods swarm close to the bottom. As with differences in surface swarming behavior among the three taxa, more study would be needed to confirm the general observations that we have made. Nevertheless, our limited data on such bottom-layer formation strongly suggests that resource layering in the engybenthos results in active feeding within 3 m of the bottom. Our information further suggests that these layers are typically composed primarily of *Pseudocalanus*. Therefore, within Cape Cod Bay and other habitats where right whales aggregate it is possible that near-bottom feeding activities and associated mouth-entanglement risks may be most common where the dominant food resource is composed of *Pseudocalanus*. Without further study, it is difficult to define the management implications of such observations; however, among the considerations within Cape Cod Bay these observations suggest potential of subtle modifications in present management plans. The conservative strategies presently being considered by the Atlantic Large Whale Take Reduction Team to require all bottom lines be sinking is wise; nevertheless, as details of the taxonomic differences in the swarming behavior that elicits feeding and causes right whale aggregation become better understood, modifications in the measures used to mitigate the effects of both ship strike and fisheries entanglement may be possible.

2.4.4. Multi-Scale Influences of Food on Whale Occurrence.

The distribution of zooplanktonic patches that control right whale occurrence within Cape Cod Bay is dependent upon a variety of conditions understood to varying degrees. Within Cape Cod Bay, our data show that the general background of calanoid copepod densities during the winter ranges between tens of organisms upwards to several hundreds of organisms per cubic meter. Forming out of that background resource are dense patches usually organized into horizontal layers at the surface or bottom of the water column, layers of enriched densities several centimeters to several meters thick. Within these layers densities may exceed several million organisms per cubic meter. The horizontal dimension of the layers, often referred to as “patches”, may range from tens of meters to several kilometers in extent. The structure of the patches and their depth are governed by a variety of oceanographic characteristics including the strength and stability of the thermocline, or the absence thereof, incident light intensity, water temperature, turbulence, and transport mechanisms. Biological mechanisms that influence the formation of layers and the extent of the patches are not well understood but are thought to have a significant influence on the development and structure of the resource patches. Among the biological parameters that may influence patch structure are: taxonomic composition, swarming characteristics of the individual taxa of calanoid copepods, stage composition of the resource, and the physiological condition of the individuals (satiation, demographics, and reproductive state). Though not well understood, together these physical and biological parameters conspire to develop out of the existing background concentrations of zooplankton the patches that are the actual resource sought by right whales.

It should be noted that the complex interactions among the physical processes and the biological demands of a variety of different taxa of zooplanktonic organisms result in an extremely dynamic and largely cryptic process that ultimately defines the occurrence and distribution of right whales within the southern Gulf of Maine. The tendency for organisms to aggregate to form patches occurs at many scales so that great variation in density and composition may be found within the individual patch. Indeed, a review of the data in any year demonstrates that Cape Cod Bay is occupied by an extremely variable and highly heterogeneous zooplankton resource. At many scales and in three dimensions, the ever changing zooplankton community, which so influences right whales, is in a state of dynamic flux that sometimes defies description. As part of our efforts to understand and report on the influences included in the paradigm presented here, we have come to understand that coarse patterns within the processes of enrichment and dispersion of zooplankton patches and of the general zooplankton background may be used to most effectively describe the potential for aggregation and occurrence of right whales within Cape Cod Bay. By reviewing the 2006 observations that are presented in this report one may see complex patchwork of dynamic interactions across all established station locations. However, when viewed as a process description, documentation of the coarse patterns of occurrence may become apparent in the seasonal and station comparisons.

In the context of the management efforts in Cape Cod Bay, one of the important contributors to the development of medium- to short-term predictions is the advective character of the Bay system. Because the movement of whales responds to drifting patches of zooplankton, the advective transport processes also define the movement of whales. Generally, circulation within Cape Cod Bay in the upper layers of the water column is counterclockwise, leading to a general movement of resources along the central and western shore of Cape Cod Bay into the southern region along Barnstable, and then sweeping to the east along the Dennis shore and thence northward to Provincetown, before exiting near Race Point. The fine details of this circulation pattern are not clear; further, turbulence and the vertical migration of calanoid copepods may substantially confuse the results of the advective processes, with slow and small-scale vertical migratory excursions potentially bringing patches into circulation patterns that differ from the general transport model. In addition to these general circulation tendencies, there are strong indications that the eastern and southeastern portions of Cape Cod Bay are less influenced by the large scale transport processes, such that the eastern part of the Bay is influenced by a less energetic circulation pattern; hence, resources that are entrained in the eastern portion of the bay may be more stable over time. We hypothesize that the eastern and southeastern portions of the Bay that, during some years, are rich in plankton productivity may entrain zooplankton resources and permit the formation of rich patches that are durable enough to permit relatively stable aggregations of whales. Nevertheless, as a consequence of advective processes, whales entering Cape Cod Bay and foraging on patches of plankton generally move through the Bay system from west and south west to the east and then to the north as the season progresses. The period of residency of right whales in the eastern Bay is considerably greater then that in the west, which we hypothesize to be due to the entrainment of zooplankton in areas of lower current flux along the eastern side of the Bay, leading to more stable and durable patch formation. It is also likely that special conditions in the eastern Bay, including particularly enriched phytoplankton communities, may encourage the patch formation and swarming of calanoid copepods. Though influenced by considerable interannual variability in transport mechanisms and by a number of factors that affect the quality of patch formation, the distribution of right whales observed during the last 5 years of DMF/PCCS air survey supports the general view that right whales are found more often in the eastern and southeastern half of Cape Cod Bay in late winter and early spring. The management implications of such a distribution, established by the higher density and more stable patches documented in the east, is that during many years the risk of anthropogenic injury or mortality in the western Bay are substantially less than those in the east, despite greater shipping and fishing activity along the western side of the Bay. Our observations over the last seven years clearly indicate that the reasons underlying the concentration of whales in the eastern bay, and hence the reduced risk in the western portions, arise from differences in the zooplankton concentrations in the two halves of the embayment.

The movement of whales into Cape Cod Bay probably arises as a response to the enrichment of the ecosystem in the early- and mid-winter. Conversely, departure is in part a reaction to changes in the food resources in the Bay. While several hypotheses may explain the entry and exit of whales to and from the Cape Cod Bay, in our efforts to predict right whale occurrence we have paid attention primarily to general food concentrations within the system.

The entry and exit of whales into and out of Cape Cod Bay appears to be based on relatively simple and easily demonstrated rules. Although the mechanisms by which whales find patches remains poorly understood, within Cape Cod Bay the movement patterns that we observe appear to be simple reactions to resource distribution. In order to predict right whale distribution, therefore, it is necessary only to understand in some detail the small-scale foraging strategies employed by right whales as they react to the ephemeral and heterogeneous patches.

The movement patterns of right whales associated with patches at the surface in Cape Cod Bay were described by Mayo and Marx (1990) as involving simple area-restricted movement within patches and straight line searching patterns when food density is below a feeding threshold. In Cape Cod Bay, even at the peak feeding season, less than 10% of the surface area encompasses patches of copepods rich enough to elicit feeding behavior (Mayo and Goldman 1998). Thus right whales, in order to optimize food intake, must apply searching and foraging strategies in order to respond to the dynamic conditions that influenced patches. A simple combination of highly angular movement within a patch and the comparatively straight movement pattern when feeding conditions are poor appears to be the central cause for the aggregative patterns of distribution that have been observed during the Cape Cod Bay surveillance program. The angularity of the area-restricted movement pattern maintains foraging whales in areas of high food density, allowing them to optimize their intake, while the straight line movement of searching results in whales discovering patches. In the limited habitat of Cape Cod Bay, the result of those movement strategies is the aggregation of whales in areas of high food resource. It is likely that many yet-to-be-understood behavioral strategies subtly influence the tendency of whales to aggregate, yet the broad conditions of zooplankton patch formation combined with the movement strategies employed by searching and foraging whales clearly underpins the general paradigm for aggregation and dispersion of whales in the Gulf of Maine. It is by using this part of the paradigm that prediction of the movement of whales within Cape Cod Bay is possible.

In a practical sense we assess the distribution of the zooplanktonic resource in several ways to arrive at the assessments and predictions made available to DMF. Combined with air survey data and looking at the absolute densities of food, the taxonomic composition of the zooplankton, and the physical processes, we judge the likely direction of movement of the resource that controls the aggregation of whales while we evaluate the overall density field and quality of resource. The quality of the resource is measured against zooplankton requirements and feeding thresholds of feeding whales established by earlier studies. Presently, the feeding threshold is estimated as a particle count of 3,750 organisms/m^3 and the energy minimum requirement 0.69 kcal/m^3 of water filtered.

2.4.5. Analysis and Management: the Relationship between Whales and Food Resources in 2006

In 2006, observations of the food resource and the associated whale distribution generally fit well within the resource-based paradigm described above. The zooplankton conditions and whale distribution patterns observed during the 2006 season are presented in the detailed Habitat Assessment analyses in Appendix II. While exemplary plots will be offered in the text to demonstrate general principles and trends, the complete suite of graphic summaries of seasonal taxonomic trends are presented in supplementary figures (Figures S1-S27) compiled at the conclusion of Section 2.

As a graphic summary of the combined information from the air survey studies, and the habitat assessment and prediction part of the DMF/PCCS program, Figure 11 shows the average surface zooplankton concentrations over which are mapped all of the sightings of 2006. A very similar summary emerges when 2006 sightings are mapped over water column zooplankton resources in Figure 12. While such graphics display the distribution of whales in a meaningful form, the central influence of the zooplankton resources on whale distribution is not clear when zooplankton densities are averaged seasonally in this manner due to the mobility, spatial variation and small-scale structure of the resource patches. For example, as seen in these two figures, the average zooplankton resource appears to be relatively uniform and low throughout the entire bay, a condition that if it occurred at any one time would likely result in no right whale residency.

Figure 13 presents more detail, showing the average food density throughout Cape Cod Bay, separating water column and surface samples and displaying a broad pattern of very low density in all quadrants until the beginning of April (JD92). It is apparent from the paired bars of Figure 13 that one uniform characteristic of the 2006 zooplankton resource was that the mean water column zooplankton densities during any one cruise exceeded near-surface densities. Furthermore, there is a clear indication that, contrary to the aforementioned pattern of enrichment, during 2006 as in 2005 in the eastern and southeastern Bay, a late-season enrichment did not appear. Instead, sightings in 2006

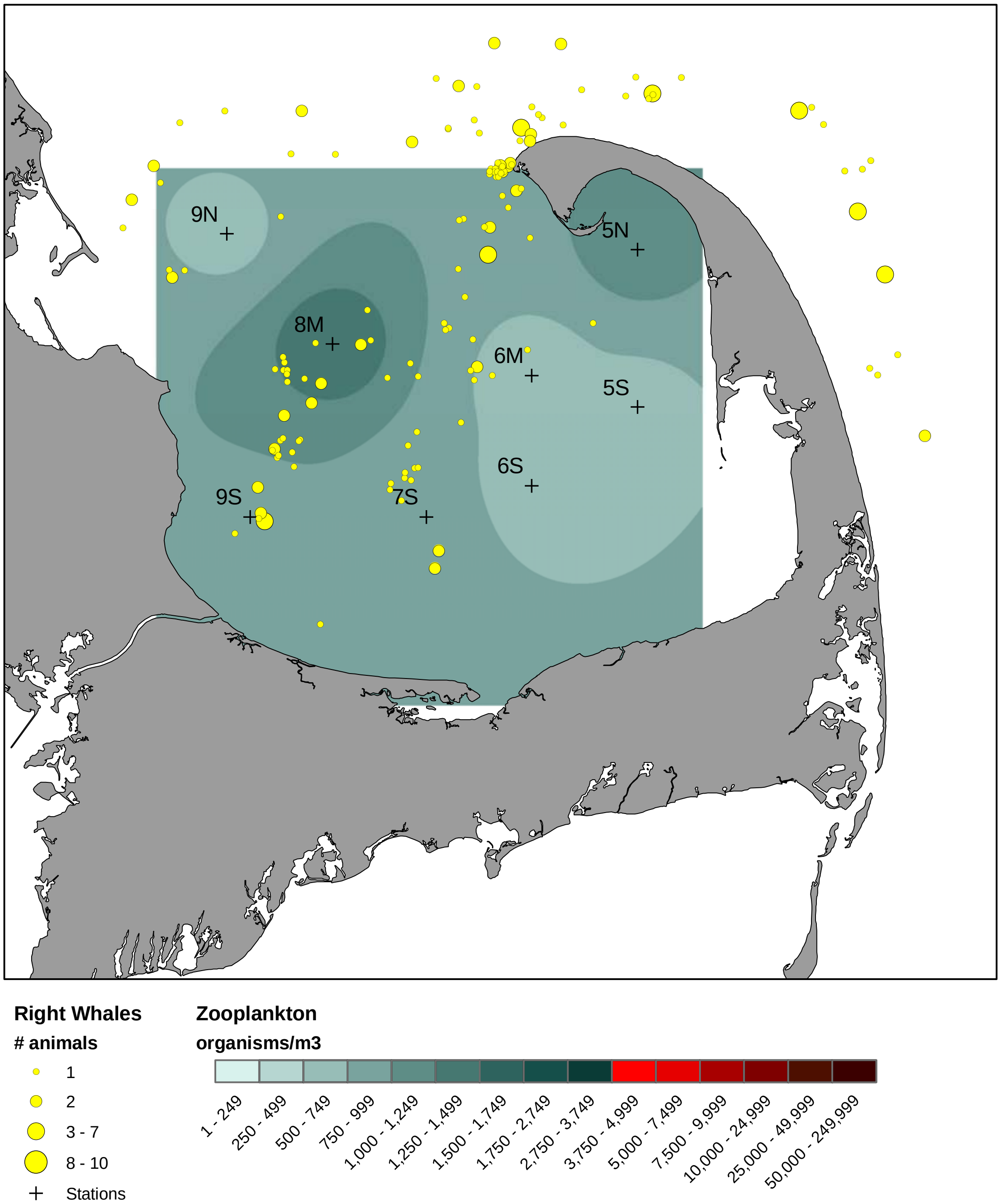


Figure 11. Right whale sightings from aerial surveys, and the spatial distribution of <u>surface</u> zooplankton density in Cape Cod Bay during the period from 1 January to 15 May 2006. The eight fixed sampling stations are marked by +. The legend shows densities exceeding the estimated right whale feeding threshold (3750 organisms/m^3) in red. The spatial zooplankton distribution was generated using an inverse distance weighted (IDW) interpolation method in ArcGIS.

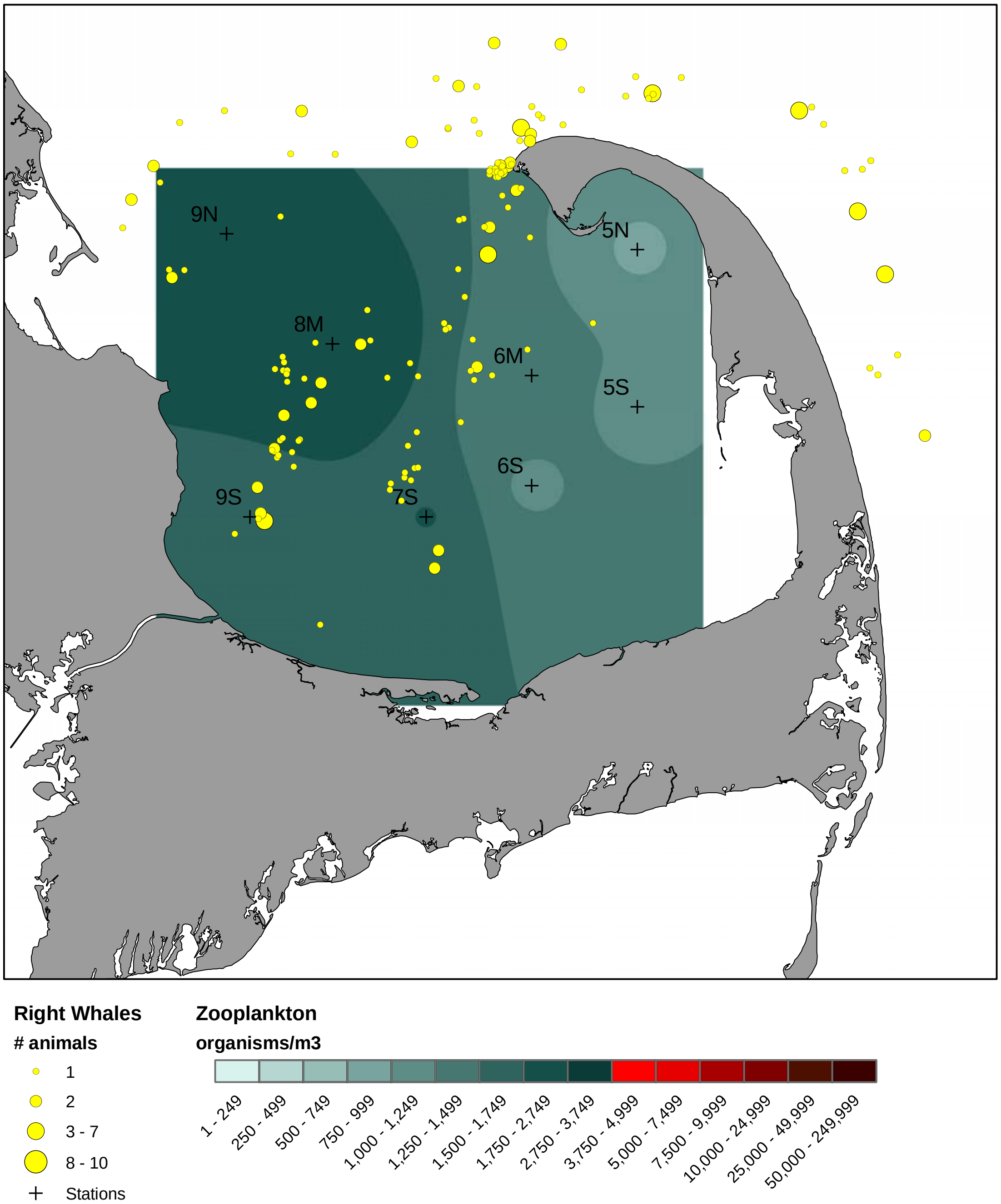


Figure 12. Right whale sightings from aerial surveys, and the spatial distribution of water column zooplankton density in Cape Cod Bay during the period from 1 January to 15 May 2006. The eight fixed sampling stations are marked by +. The legend shows densities exceeding the estimated right whale feeding threshold (3750 organisms/m^3) in red. The spatial zooplankton distribution was generated using an inverse distance weighted (IDW) interpolation method in ArcGIS.

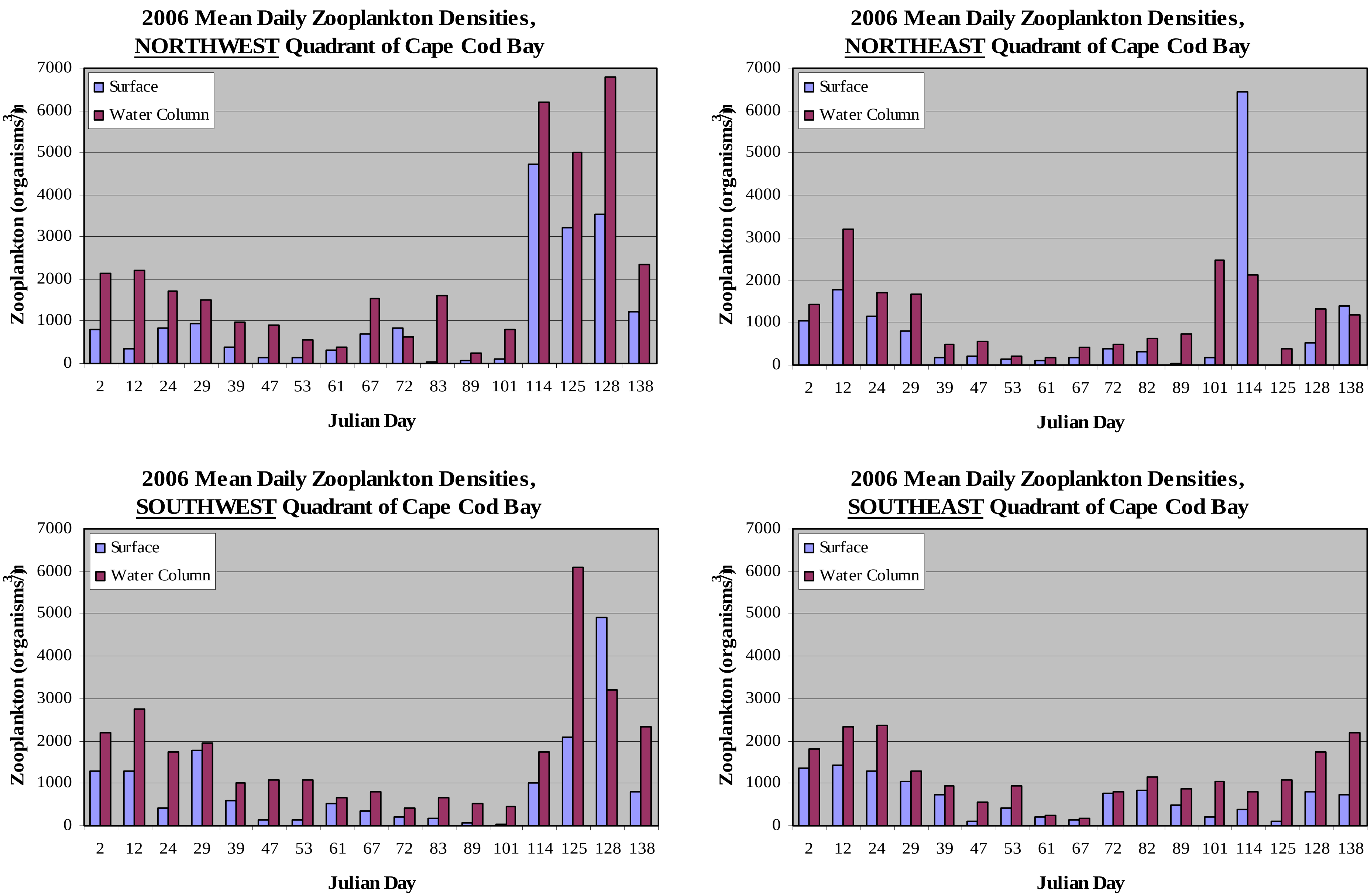


Figure 13. Temporal progression (2006) of the daily mean density of surface and water column total zooplankton in each quadrant of Cape Cod Bay. Note that axes in all graphs have identical scales.

were mapped over rich mid-water zooplankton resources along the western side of Cape Cod Bay. Although the pattern of enrichment of the western margin of Cape Cod Bay is not unique, should the pattern of the last two years become more commonplace, active management of the intense human activities along the western shore of the bay may be warranted.

Another summary and comparison tool is shown in Figures 14 and 15, in which the last four years of mean zooplankton density recorded for each cruise is compared with the estimated whale density per air survey track kilometer. The summaries in these figures show the similarity in trends of zooplankton concentration in surface and water column samples. Furthermore, the general pattern of whale occurrence and mean zooplankton concentration followed approximately the same broad pattern of zooplankton enrichment in 2003 and 2004, with relatively high mean concentrations of zooplankton apparently eliciting right whale aggregation within the Bay. The 2005 and 2006 seasons, while differing dramatically from those in 2003 and 2004, were also similar in that they showed a slight increase in zooplankton concentration during the period of April and May, coupled with an overall weakness in zooplankton productivity from January through late March. The response of whales to these latter conditions apparently manifests as considerable variability in the density of whales observed during the air survey. Indeed, it seems likely from these observations that when zooplankton resources are low whales' searching activities – and hence their movements – may prevail over the more stabilizing and aggregative behavior of area-restricted foraging.

Because the broad-scale view of the zooplankton resource and the traditional methods of seasonally-averaging conditions within the zooplankton community do not capture the scale of change and movement observed in the plankton resource, for the assessment and prediction aspects of the study we depend on analyses of the smallest scales of time and space. As demonstrated above (i.e., Figures 11 and 12), averaging methods over periods greater than a week mask the very detail that is essential in understanding and responding to right whale movements and residency.

An overview of the general patterns of productivity, comparing the 2006 season with the previous three years (Figure 16), demonstrates relatively impoverished zooplankton resources in both the surface and mid-water environments throughout the entire winter and early spring season. The general trends in the density of the three principal taxa of calanoid copepods compared to an index of right whale density within Cape Cod Bay (shown as right whales per kilometer of the aircraft survey tracks) shows that during 2006 densities of zooplankton remained well below the estimated feeding threshold of 3750 organisms per cubic meter until a dramatic, late-season increase in *Calanus* density. Figure 17 suggests a close relationship between a high density of *Calanus* and the increase in observed right whale density, apparently the usual cause of the late season immigration of right whales into Cape Cod Bay suggested in Figures 14 and 15. These general observations illustrate clearly the view that right whale density and presence within Cape Cod Bay, as we suggest in our proposed paradigm, are closely associated with the general richness of the calanoid copepods populations, as illustrated in the seasonal patterns shown in Figures 16 and 17. For the purposes of managing human

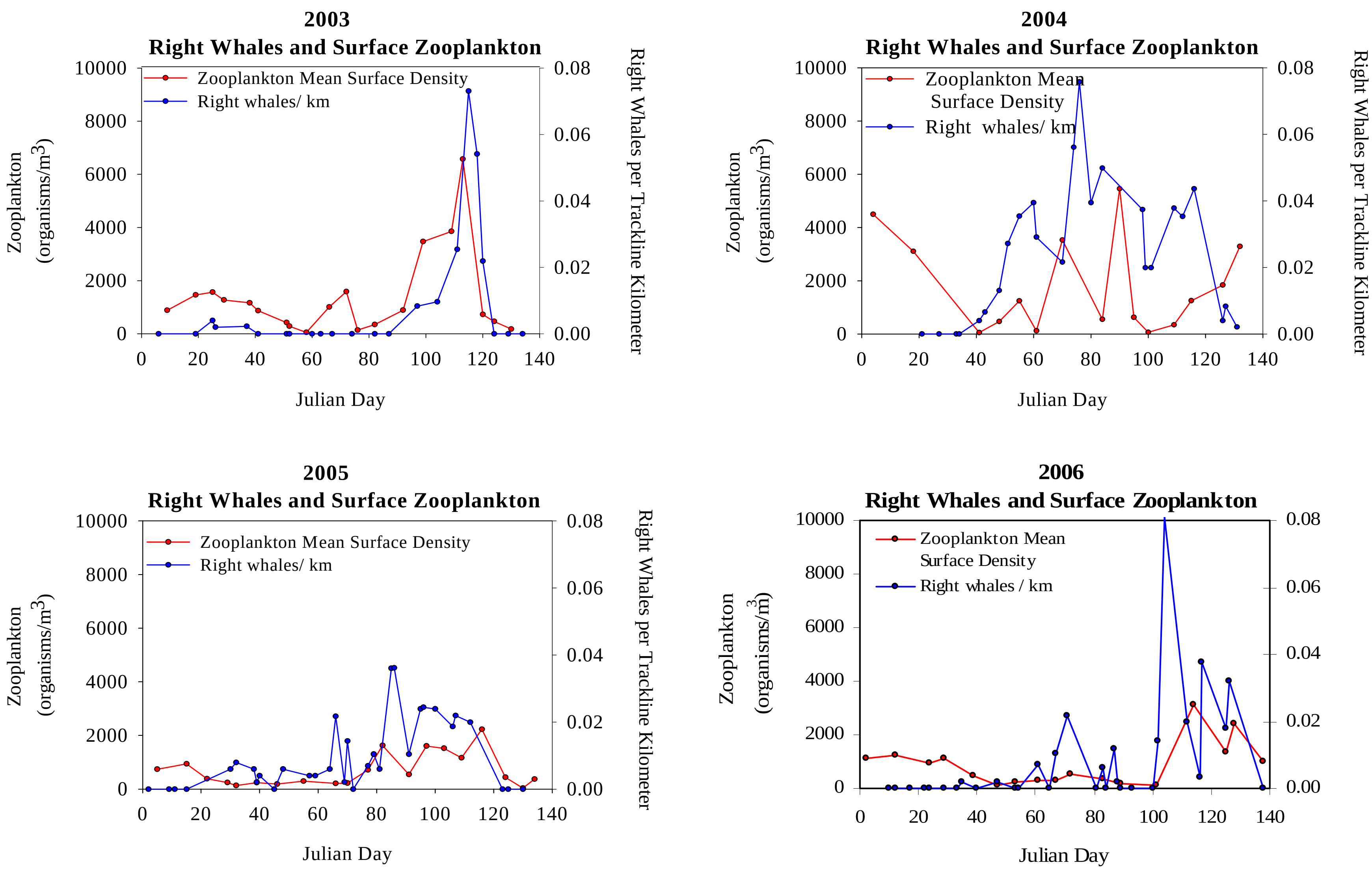


Figure 14. Comparison of right whale sightings and daily mean surface zooplankton densities in Cape Cod Bay, 2003-2006.

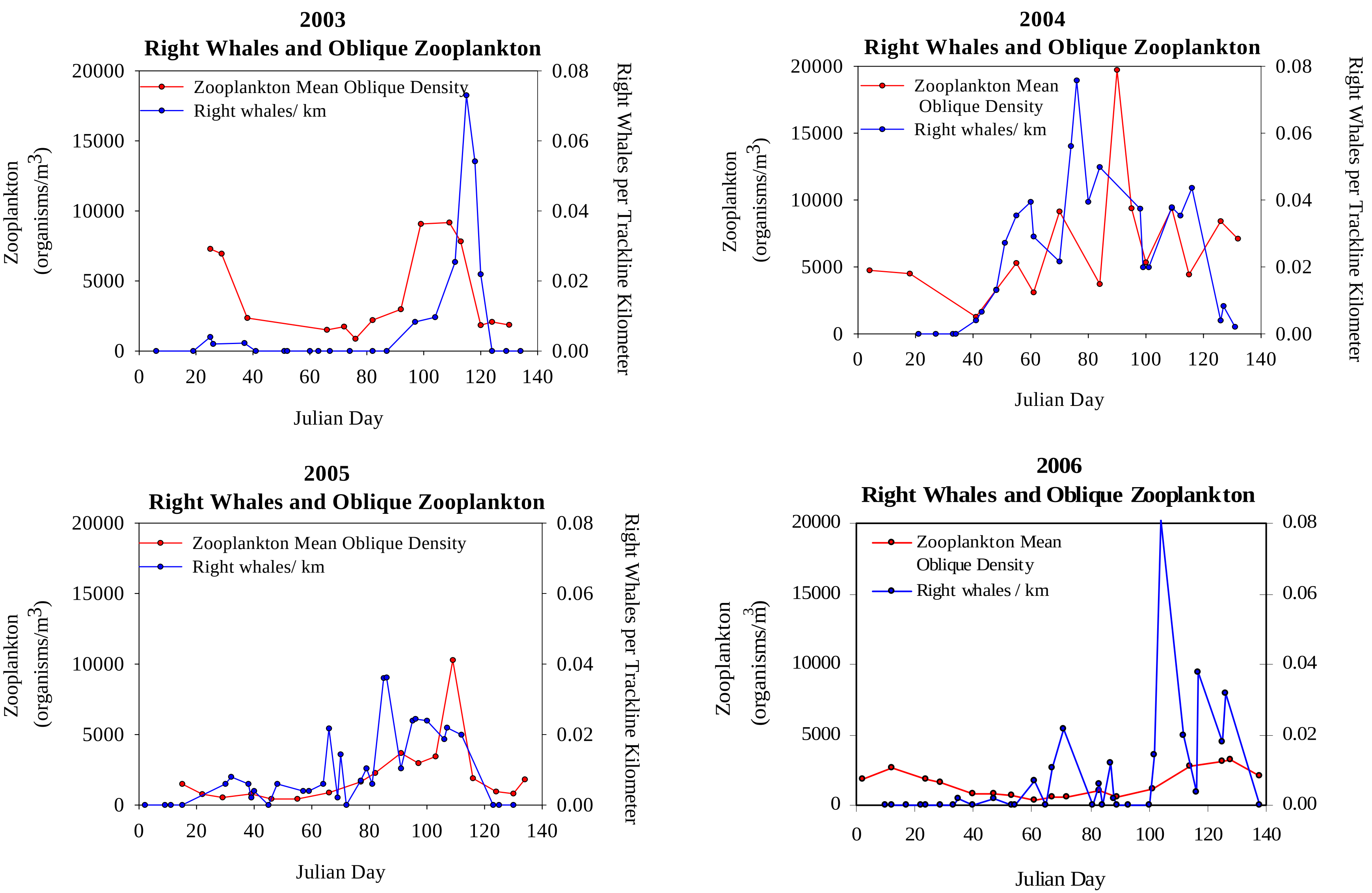
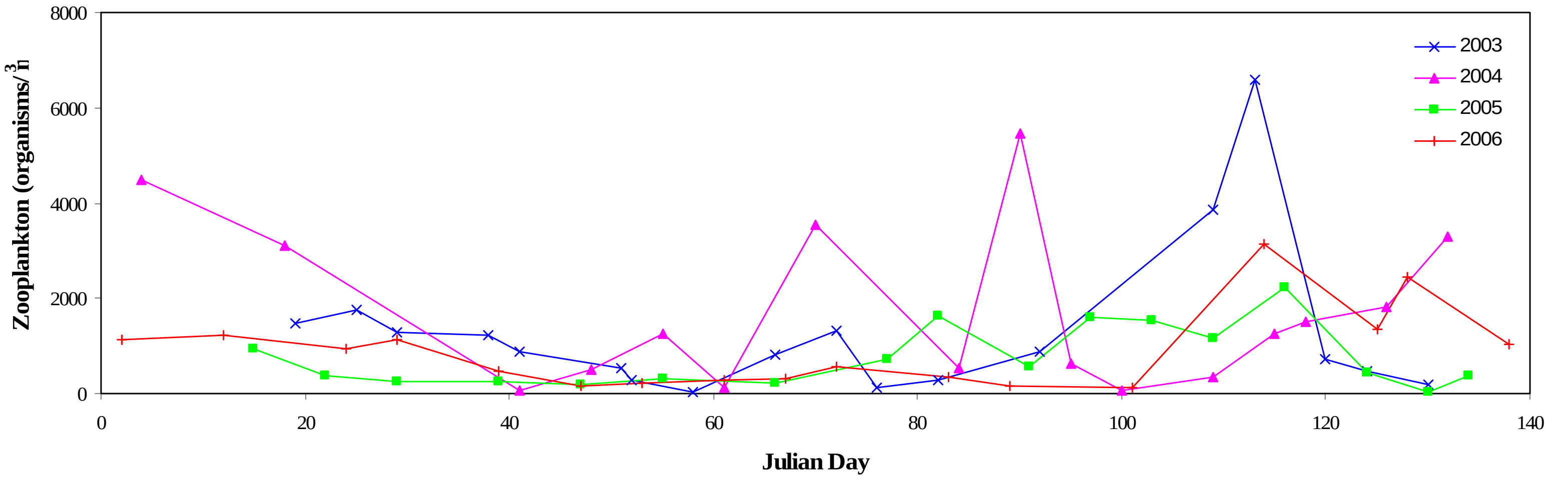


Figure 15. Comparison of right whale sightings and daily mean <u>water column</u> zooplankton densities in Cape Cod Bay, 2003-2006.

Cape Cod Bay Daily Mean Total Zooplankton Densities
from Surface Tow Collections, 2003-2006



Cape Cod Bay Daily Mean Total Zooplankton Densities
from Oblique Tow (Water Column) Collections, 2003-2006

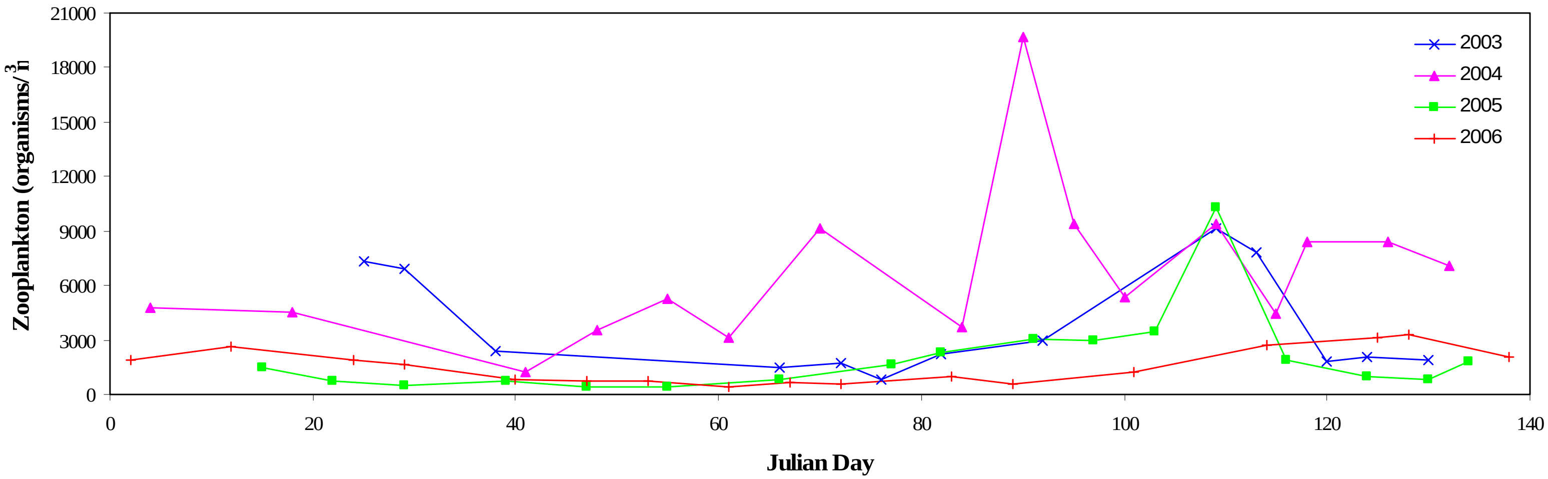


Figure 16. Temporal progression of the daily mean total zooplankton density in Cape Cod Bay surface waters (upper graph) and in the water column (lower graph), January to mid-May for each year 2003-2006.

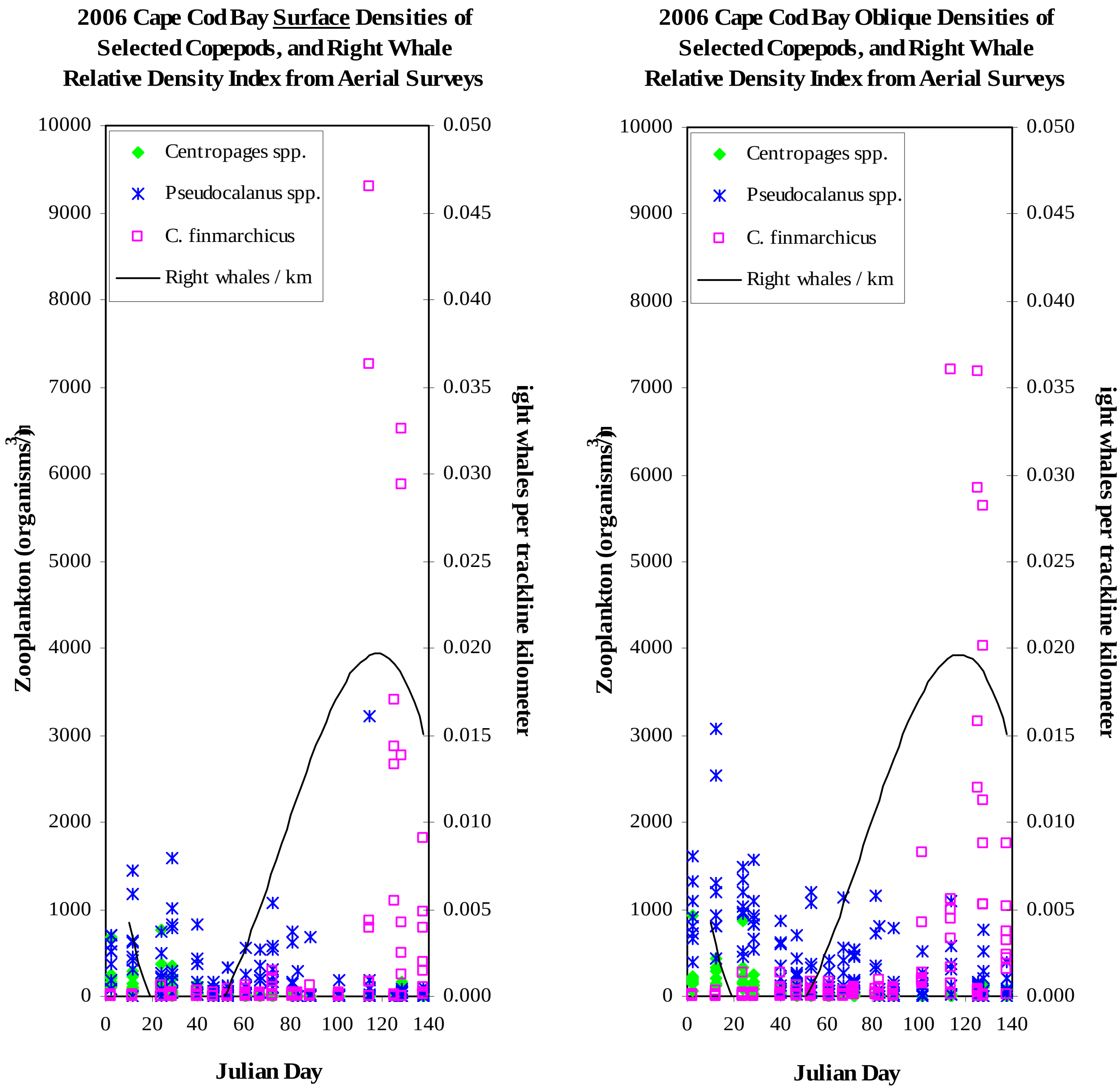


Figure 17. 2006 comparison of right whale relative density index from aerial surveys with the densities of selected copepod taxa in Cape Cod Bay surface waters (left graph) and the water column (right). Right whale relative density index is displayed as a trend line computed as a 3rd-order regression of 32 daily values of right-whales-per-trackline-kilometer from 2006 aerial surveys.

activities within Cape Cod Bay during the early part of the season, the close relationship between the influx of whales and dramatic increases in estimated zooplankton richness offers an important benchmark for the prediction of whale entry into Cape Cod Bay. It seems likely that departure from the Bay may be a balanced response to bay-wide decreases in zooplankton density, as well as a decline in patch-forming tendencies of the zooplankton resource.

The information collected during the 2006 season and incorporated in the assessment forms and summary graphics presents yet another valuable insight into the complex relationship between the ecosystem and the zooplankton resources and ultimately the distribution of right whales. Summarized by station and by depth stratum are several different season-long perspectives on the controlling resources in Cape Cod Bay (Supplementary Figures S1-S16). These individual station views support the general contention that the 2006 season was characterized by low zooplankton densities at all depths and locations, particularly from mid February through to early April. In previous years, as indicated in Figure 16, occasional periods of strong calanoid copepods resource were seen, particularly beginning in early to mid March. However, Figure 16 and the summary by station of the season-long zooplankton observations (Figures S1-S16) support the contention that the bay in 2006 supplied both a weak and a variable quality zooplankton resource. Clearly throughout the winter and into the third week of March a valley is seen in the total zooplankton densities, as shown in Figure 18 for example (compare to similar temporal trends apparent in Panel B of Figures S1-S16). Throughout all of the zooplankton collections of the early and mid-winter of 2006 it is clear that the significant decline in resources was due to a weakness in the productivity of the standing stock of the calanoid copepods *Centropages* and *Pseudocalanus*. Usually present in higher concentrations than observed in 2006, the failure of these two taxa probably had a profound impact on the entry, residency, and behavior of whales in Cape Cod Bay, substantially impacting the need for management action and reducing the early- and mid-season potential risk of human-caused mortality.

The assessment analyses for early- and mid-January offer a detailed description of the condition of the resources throughout the Bay, supporting the view that zooplankton densities were well below the feeding threshold estimated for right whales (see Appendix II, cruises SW585 and SW587). Not unexpectedly, right whales were largely absent from the Bay during this early winter period. The limited copepod resource that was available was dominated by *Pseudocalanus* and not by the usual early winter taxon *Centropages*. A review of the station summary data (e.g., Figure 18 below, and Figures S1-S16 for all regular stations) suggests uniformly low zooplankton densities throughout the entire

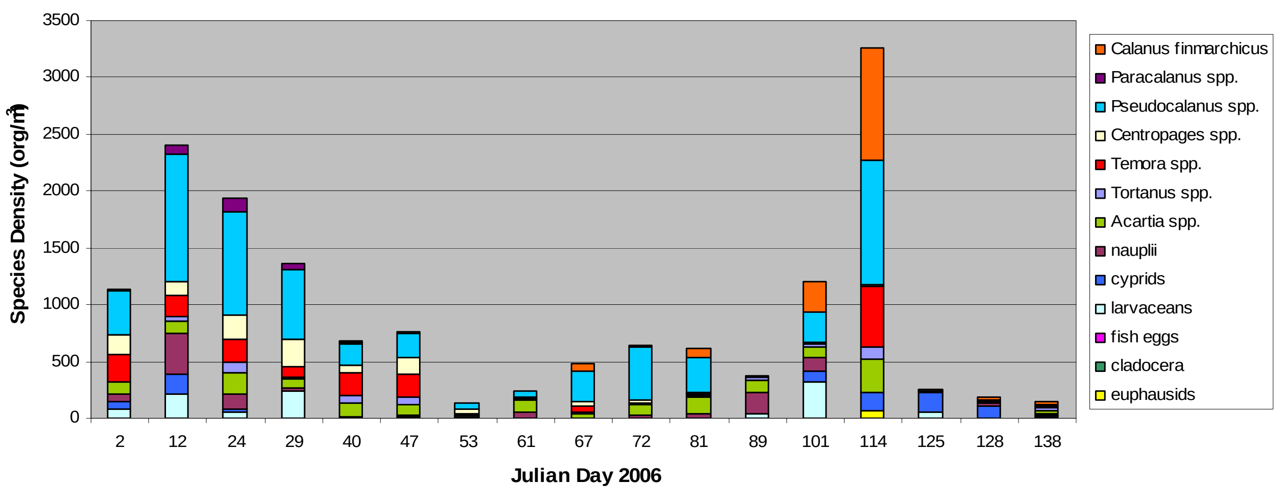


Figure 18. Temporal trends in water column zooplankton composition and density at station 5N, showing the extended impoverishment that occurred until late March that was typical of most Cape Cod Bay stations (see Supplementary Figures S1-S16 for comparison).

region. During this season, although some quantitative and qualitative variation may be found throughout the system, the copepod resource appeared somewhat richer in oblique collections than in surface samples (Figure 19). The resulting spatial density distribution plots from SW585 and SW587 (see Appendix II) confirm the low density of food throughout the Bay system. The most obvious exception to these early-season analyses is the indication of a modest enrichment at stations 9S and 6M on 12 January. Nevertheless, the generally low zooplankton densities and the declining or flat gradient of the four measures of zooplankton richness reported in the assessment analyses suggested that the lack of whales observed in two flights during this period would continue.

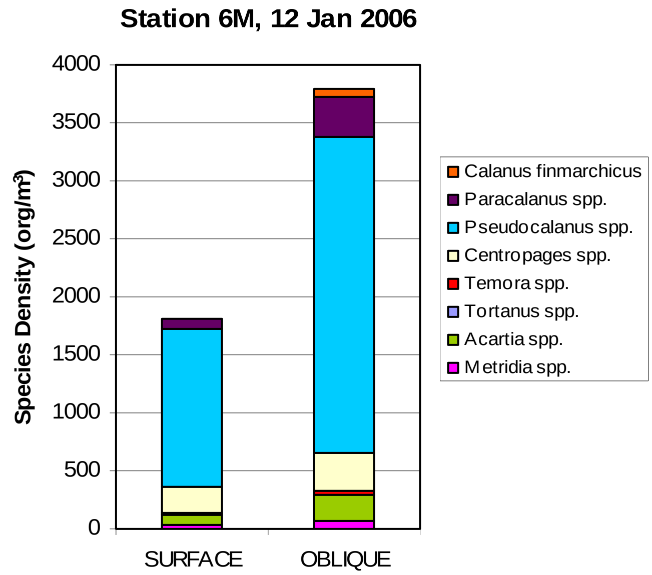


Figure 19. Comparison of mid-January surface and oblique zooplankton collections, showing elevated water column densities.

Interestingly, by 24 January zooplankton densities had declined further throughout much of the Bay and right whales remained absent from air survey observations. A review of previously reported seasons 2004 and 2005 suggests that during some seasons low *Centropages* productivity coupled with a lack of *Pseudocalanus* (because in most years the latter taxon is associated with February and March enrichment) can lead to depression of the available food resource, as illustrated through most years in Figure 16 (Julian Days 20-40). The beginning of what was to become a deep mid-season depression in the trend of available food resulting in the general absence of right whale aggregations from Cape Cod Bay during most of the 2006 season appeared to start during this period in late January. The spatial density contour plots from the assessments of SW588 show very low zooplankton concentrations throughout the Bay, particularly at the surface, and the plots of zooplankton density changes since the previous cruise suggested that on the 24th of January the already-low zooplankton concentration was in a state of further decline (the surface plots from SW588 are reproduced in Figure 20). The observation that the zooplankton resource was low and declining as indicated by all measures reported in the full assessment analysis of cruise SW588 (Appendix II) led to the continued prediction that right whales were not likely to enter Cape Cod Bay until dramatic increases in zooplankton density occurred. In summary, the "resource change" contour plots and trends in measures of resource quality, zooplankton density, settled volume, caloric density, and dry weight reported in January assessments displayed changes in zooplankton concentrations between cruises indicating that throughout much of the Bay during January low concentrations of food resources continued to drop making right

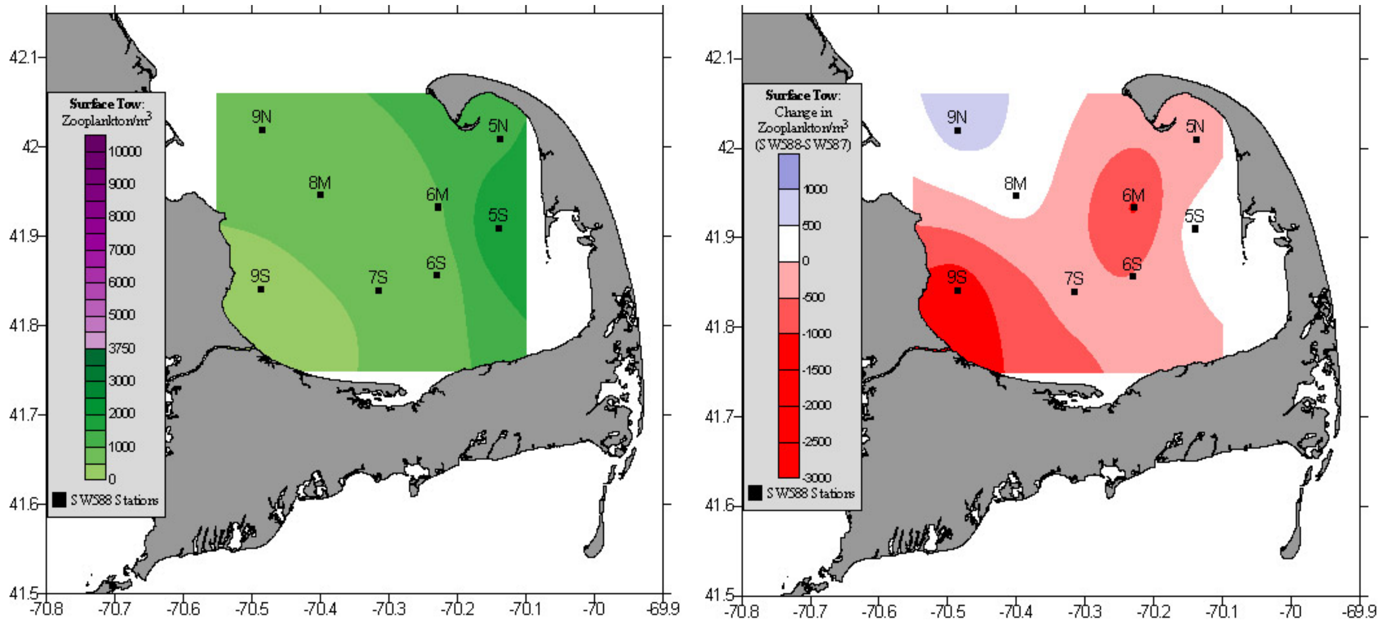


Figure 20. Spatial plots from surface samples collected on cruise SW588 (24 January) showing zooplankton abundance (left plot) and the changes thereof since the previous cruise (SW587 on 12 January; right plot). The observed declines in zooplankton densities created very low density conditions bay-wide that would persist through late spring.

whale aggregation unlikely. During January, *Pseudocalanus* dominated the available calanoid copepod resource, while *Centropages* dropped well below the average trends for the genus (see Figure 21 for example, and compare Panels A&B in Figures 22 and 23).

By 29 January (SW589), total zooplankton densities at some stations showed a modest increase in zooplankton concentration, principally in several collections made east of station 6M (see supplemental assessment SW589 in Appendix II) associated with the first right whale observed during the 2006 season. The elevated richness associated with the observed right whale appears to have caused the modest increase in the mean bay-wide zooplankton density and was apparently the result of combined increases in *Centropages* and *Acartia*. The zooplankton density observed in the

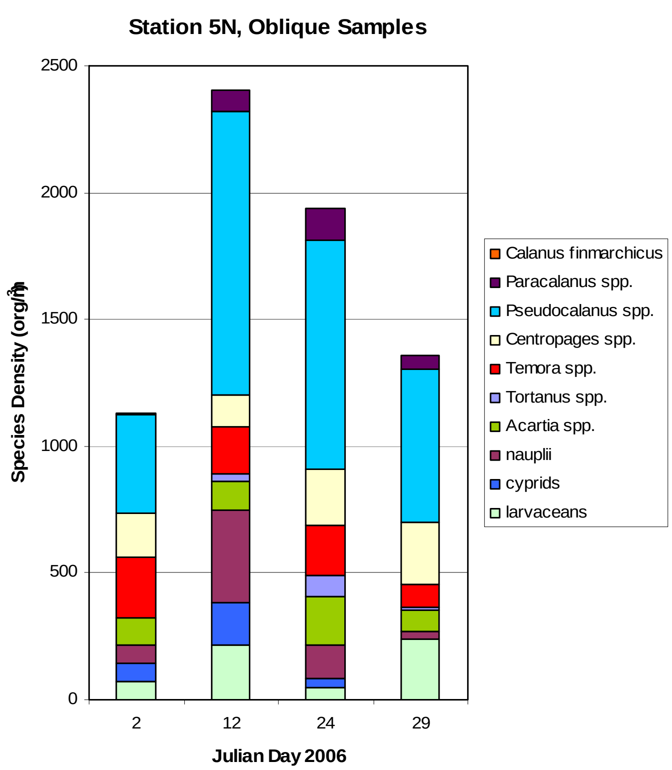


Figure 21. An example of the anomalous January dominance of *Pseudocalanus* over *Centropages* in 2006 zooplankton samples.

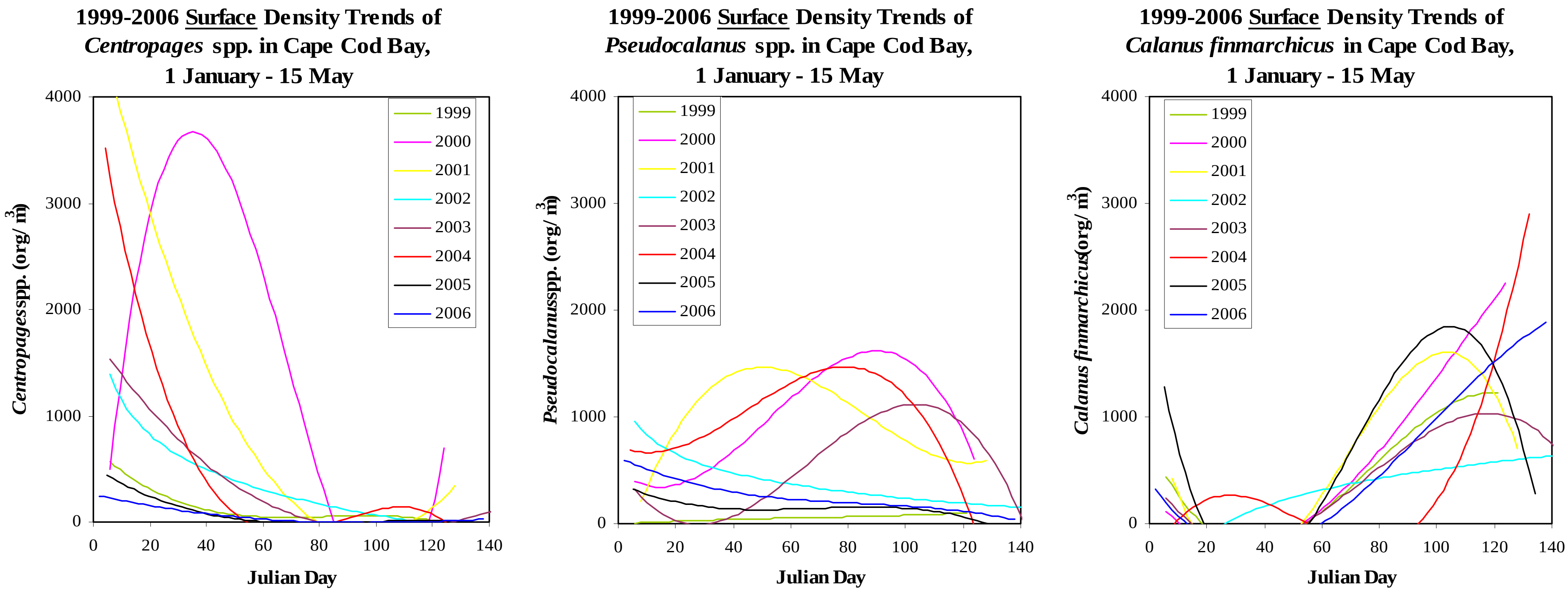


Figure 22. Comparison of 2006 trend against 2003-2005 annual trends in the temporal progression of bay-wide mean surface densities of the three principal copepod taxa. Individual yearly trends are shown for the period 2003-2005 to show inter-annual variations in the temporal trends. All trend lines represent a 3rd-order polynomial regression treatment of each individual year's daily values of Cape Cod Bay average surface density.

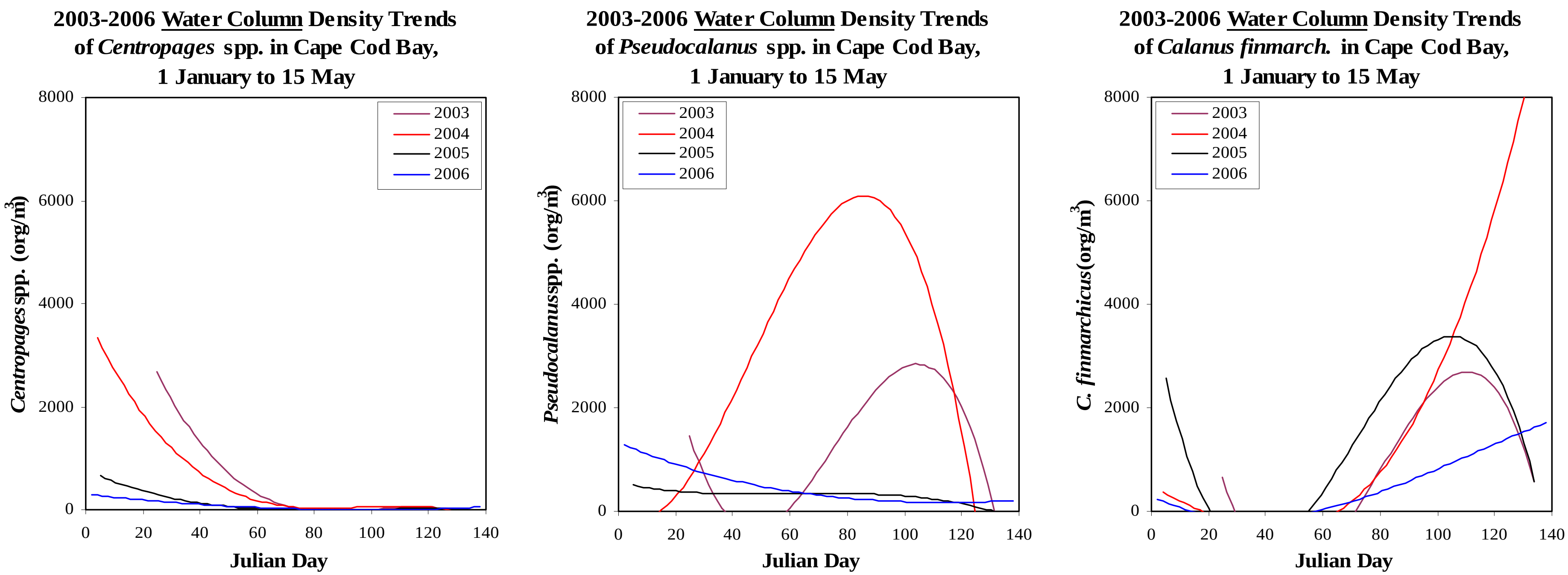


Figure 23. Comparison of 2006 trend against 2003-2005 annual trends in the temporal progression of bay-wide mean water column densities of the three principal copepod taxa. Individual yearly trends are shown for the period 2003-2005 to show inter-annual variations in the temporal trends. All trend lines represent a 3rd-order polynomial regression treatment of each individual year's daily values of Cape Cod Bay average water column density.

central part of the Bay at the special stations in the vicinity of the right whale was also increased, particularly in surface samples, as were samples from the southwestern corner of the Bay. The resources of the Bay, influenced by samples near the right whale, appeared to be changing and a slightly elevated potential for right whale aggregation, particularly in the southwest corner of the Bay, was predicted despite generally low resource densities at all depths throughout the remainder of the Bay as shown in Figure 16 and in individual station descriptions (refer to Panel B, JD29, of Figures S1-S16).

From 9 February (SW590) through 16 February (SW591) the overall zooplankton density once again declined throughout the Bay and the potential for aggregation and residency of right whales was again judged to be low or very low in all quadrants. The two air survey sightings of right whales reported in the assessment reports were likely of animals searching the region, thus with all measures of resource quality in decline in all quadrants and contoured plot of spatial changes in zooplankton density confirming a general decline from low densities to very low densities, our prediction was that right whales would not remain in any region of the Bay. During this time, between JD 40 and 47, the measures of food resource quality at all depths showed some of the lowest densities reported during the early- to mid-winter (see Figure 16 and refer to Panel B of Figures S1-S16 for this time period). Indeed, continued low *Centropages* productivity coincident with a weak *Pseudocalanus* resource resulted in a feeding habitat that could not elicit right whale foraging. During this period the usual sub-dominant genera *Acartia* and *Temora* became more prominent in many areas of the Bay; still, *Pseudocalanus* continued to be the most prevalent genera in the zooplankton assemblage, assuming its usual place of dominance among the mid-winter taxa controlling right whale occurrence despite low densities reminiscent of those observed during the 2005 season (see Figures 22 and 23). Total zooplankton densities bay-wide were depressed far below the feeding threshold of 3,750 organisms/m^3, as the temporal plots in Panel B of Figures S1-S16 (Julian Days 40 and 47) make strikingly clear. The departure from the typical annual mean density trends for *Pseudocalanus* (Figures 9 and 10) appeared at all depths and profoundly controlled both the presence of right whales and our predictions. Clearly foraging whales, which usually depended upon the *Pseudocalanus* resource in most years preceding 2005, encountered an environment poor in calanoid copepods, where usable patches were neither found nor likely to occur.

During the later half of the winter surveillance period, from Julian day 50 through 90, the zooplankton resource began a recovery that never reached the densities observed in the previous 3 years. During the period of 22 February (JD 53; cruise SW592) through 2 March (JD 61; cruise SW594) a weak impulse of *Pseudocalanus* allowed that genera to achieve super dominance because of the lack of other competing taxa. Although modest increases in zooplankton density were occasionally observed at some stations, all samples remained well below the feeding threshold at this time, as exemplified by the spatial plots of density distribution and change from the March 2nd cruise (Figure 24). Clearly during January and February of 2006 the normally rich resources of *Centropages* and *Pseudocalanus* did not appear. Interestingly, right whales were observed in Cape Cod Bay and reported during air survey efforts on 2 March (see assessment report for SW594 in Appendix II); however, the food resource quality was so low as to suggest no

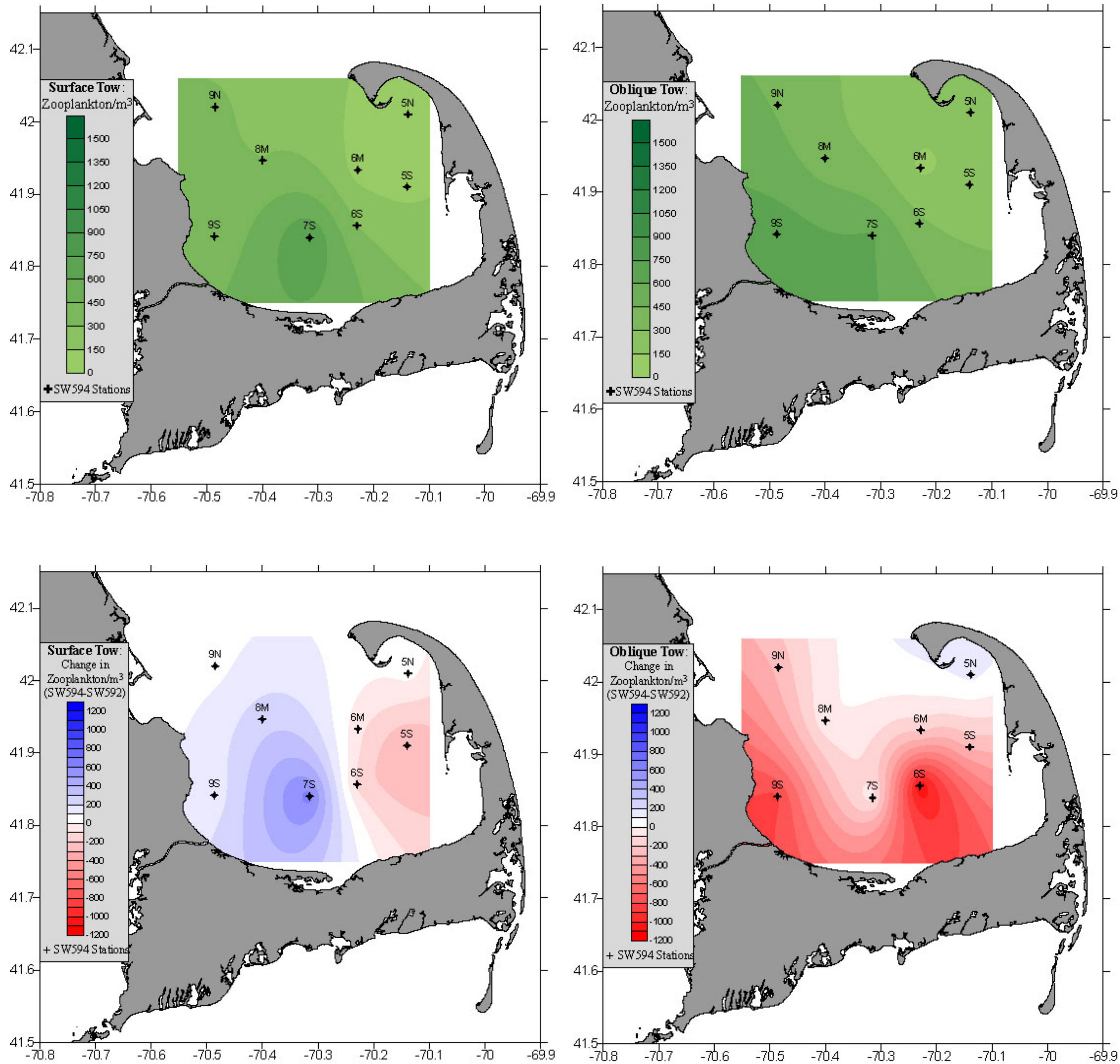


Figure 24. Zooplankton density distribution from surface (top left) and water column (top right) samples collected on 2 March 2006 (cruise SW594), showing the extremely low densities – bay-wide and at all depths – that characterized the zooplankton of late winter. The lower plots present changes in density since the previous cruise, revealing declines at most stations.

possibility that these animals would remain within the system for any significant period of time, and so we predicted a very low potential for right whale aggregation and residency in all quadrants of the Bay (see assessment report for SW594 in Appendix II). Furthermore, the low zooplankton densities suggested that the most risky behaviors displayed by right whales, mouth open feeding, would likely not soon occur within the Cape Cod Bay system.

Coincident with the first observations of significant increases in zooplankton density in limited areas of Cape Cod Bay during the period encompassed by cruise SW595 (JD67 on 8 March) through SW596, SW597, and SW598 on 13, 22, and 24 March (JD 72, 81, 83) respectively was a small number of right whales observed by the air survey team to be aggregating in the west-central part of the Bay. The bay-wide average zooplankton density during the period showed signs of increase in the west-central part of the Bay during the early part of March, with considerable fluctuation in the area around station 9S as suggested by comparisons of both surface and mid-water collections reported on in the assessments SW595 through SW598. Despite indications that an aggregation of whales was forming in the west-central part of the Bay, we continued to predict low potential for aggregation and residency because zooplankton densities remained relatively low. Samples from station 8M near the vicinity of the whale aggregations observed on 12 March (JD 67, SW595) showed very low densities at the surface, but moderately high concentrations of copepods in mid-water samples, with *Pseudocalanus* dominating the assemblage at that location. The zooplankton samples of widely-varying density collected during the period of aggregation near station 8M, along with the generally moderate to low concentration of zooplankton throughout the remainder of the Bay, strongly suggested that the observed aggregation of whales was concentrated on a limited food resource. Indeed, on review of the seasonal observations it seems that the whales located during the air survey were very likely feeding on an ephemeral and declining patch of limited dimensions. Under any circumstances, by 24 March only 3 right whales, none feeding, were sighted widely distributed through the Bay. On 25 March aircraft surveys in poor sighting conditions located no right whales. As with the months leading up to this first observed aggregation, the zooplankton resource in the Bay appeared both weak and highly partitioned – conditions of low enough quality that the usual late-March influx of right whales continued to be unlikely. Certainly, forging whales, according to the proposed paradigm, cannot optimize their feeding when foraging on ephemeral, small, and weak patches of their foods. A review of Figure 16 combined with the *Calanus* trends in Panel C of Figures 9, 10, 22 and 23 suggests that by the third week of March a rapid increase in *Calanus* ought to have started to support and attract right whales into the Bay. The first evidence of the advective delivery of *Calanus* to the Bay would typically become apparent in the far northwest, but as Figure 25 clearly shows, that area remained impoverished and no *Calanus* influx was detected. We propose that the continuing weakness of the *Calanus* resource was the fundamental reason why right whales were not present in Cape Cod Bay during the usual peak of their residency in mid- to late-March.

The assessment of zooplankton densities from SW600 on 30 March 2006 (JD 89) continued to show the predominant pattern of the 2006 season, with low densities found

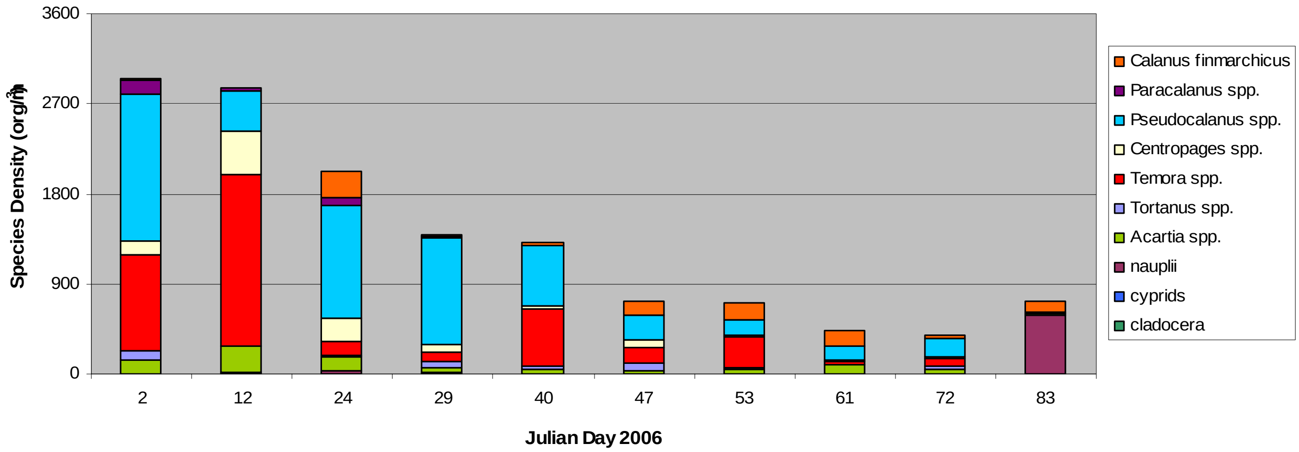


Figure 25. Zooplankton species densities through 24 March (JD83) from water column samples collected at station 9N in the far northwest of Cape Cod Bay. Total zooplankton densities throughout the Bay showed similar decreasing trends, and the onset of advective delivery of *Calanus* was still not apparent.

throughout the entire Bay and a particularly steep drop in midwater zooplankton concentrations at the location where right whales had been seen two weeks earlier. With all measures of zooplankton quality low and relatively unchanging throughout the Bay, it was clear that the rich zooplankton resource that usually supports right whales in late March and April had not developed. The composition of the zooplankton collected during SW600 continued to show a weak *Pseudocalanus* dominating an assemblage that in typical years would consist principally of a rich *Calanus* resource. Because of the low absolute densities of the zooplankton, poorly represented taxa such as crustacean nauplii and the calanoid copepod *Acartia* appeared prominently in composition diagrams. In past years, by the end of March *Pseudocalanus* had often reached its peak (see Panel B of Figures 9 and 10) and species composition diagrams (e.g., Panel C of Figures S1-S16) indeed show that in 2006 the relatively weak *Pseudocalanus* resource was in fact beginning to decline at that time throughout most of the Bay. The result of this decline may be seen in the continuing low mean zooplankton resource density summarized in Figure 16. Obviously the original paradigm put forth at the beginning of this section hypothesizes that patch formation requires a substantial background resource from which, through physical and biological processes, are formed the patches that control the distribution of right whales within Cape Cod Bay. During the 2006 season, and similarly during the 2005 season, failures particularly in the development of the *Pseudocalanus* resource resulted in a weak aggregative response by whales. The interannual bay-wide comparison in the assessment analysis of SW600 shows that in 2005 and 2006 surface zooplankton densities were far below the feeding threshold for right whales, while in 2004 by the end of March the concentration of organisms in the surface were well in excess of feeding threshold. Adding to the complexity of the picture are the interannual comparisons for mid-water density contained within the SW600 assessment analysis: While 2004 samples at the surface and within the water column were on average well above the feeding threshold for right whales, surface zooplankton concentrations in 2005 were below the threshold and water column concentrations were marginally above the threshold. These observations are contrasted dramatically with the summary information for surface and oblique samples collected during SW600, in which case zooplankton

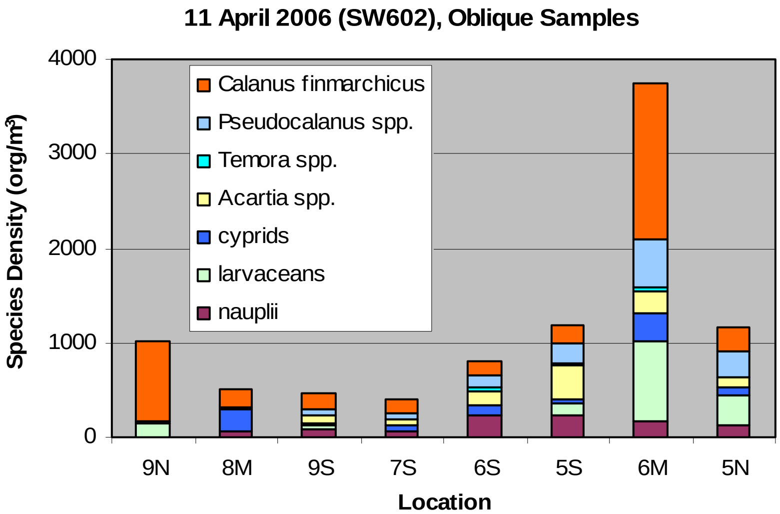


Figure 26. The zooplankton assemblage from water column samples collected on 11 April 2006, showing the first evidence of an influx of *Calanus finmarchicus* to the northeastern region of the Bay at station 6M.

concentrations, both in the surface and in the water column were far below acceptable levels. Ultimately, management of potential causes of right whale injury and mortality during the first three months of the surveillance studies of 2006 was controlled by the success of the calanoid copepod *Pseudocalanus*.

Approaching mid-April, conditions within Cape Cod Bay remained highly variable, while *Pseudocalanus* continued to decline in relative importance. The first indications of an increasing *Calanus* resource were seen in collections made in the northeast region of the Bay on 11 April (JD 101), when various stages of that important copepod became dominant (Figure 26). This *Calanus* enrichment is particularly noticeable in the spatial plot displaying changes in zooplankton density since the previous cruise (Figure 27), in which the dark blue region in the northeast represent zooplankton density increases in excess of 3000 organisms/m^3. The interannual quantitative comparisons contained within the assessment reports also confirm an increase in the mean zooplankton density collected in the mid waters. Though not yet approaching the levels found in 2004 and 2005, the increase in midwater *Calanus* resources and the air survey sighting of right whales dispersed in the area northeast of Cape Cod Bay suggested that while aggregation and feeding within the Bay were unlikely, conditions might be changing enough to improve the potential for right whale aggregation in the near future.

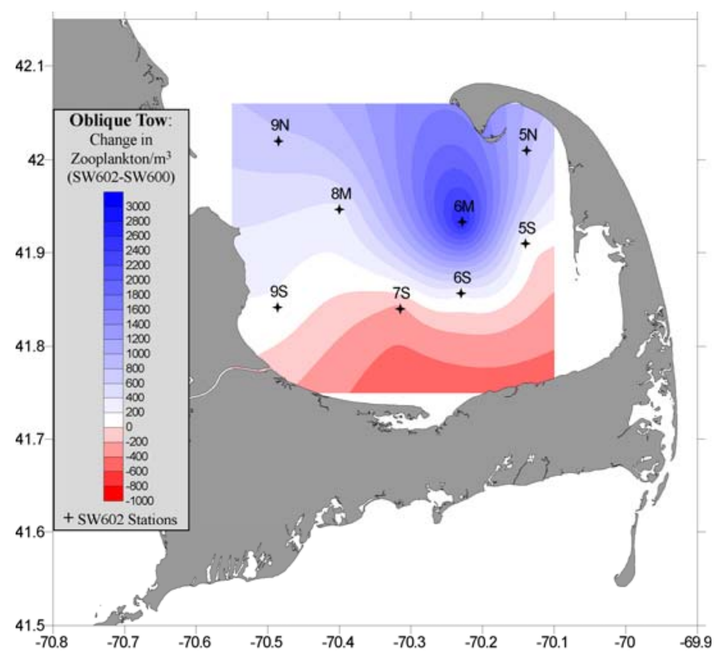


Figure 27. Changes in zooplankton abundance between 30 March (SW600) and 11 April (SW602), showing significant enrichment at station 6M.

Very dramatic changes in the zooplankton resources occurred in the brief period between SW602 and SW603 on 14 April (JD 104) when directed sampling encompassing aggregations of whales apparently entering Cape Cod Bay in the vicinity of Race Point, Provincetown, showed a strong resource signal in the surface layers. It is likely that the right whales recorded by the air survey team 2 to 3 miles outside Cape Cod Bay on 11 April moved into the northeast quadrant due to advection of a rich copepod resource from an area outside of the Bay, northeast of Race Point. Sampling during SW603 demonstrated high concentrations of late stage *Calanus* exceeding feeding threshold by several times. The richness of this localized *Calanus* resource suggested the need for an immediate preliminary assessment to warn of potential ship strike in the inbound shipping lanes between Race Point and Long Point. The risk alert was issued within several hours of the cruise based upon a strong indication that the resource was extensive and rich and likely to cause right whale aggregation and potentially risky near-surface feeding behavior. Because the collections taken during SW603 were specifically directed at determining the durability and location of the zooplankton patch attracting the right whales into the Bay, a bay-wide sampling cruise was not possible. Nevertheless, by comparison the resource collected at Race Point and resulting in the risk of ship strike was dominated by several late stages of *Calanus* much more dense and higher in all resource quality measures than any single sample collected in the previous 104 days of 2006. The observations from SW603 provide an excellent example of the impact of physical processes upon the management of right whales; indeed, sampling throughout Cape Cod Bay prior to 14 April indicated that the raw materials (a rich *Calanus* resource) was not available within the Bay. The only explanation for the rapid appearance of a strong *Calanus* signal was an advective process moving the resource from beyond Cape Cod Bay into the northeastern quadrant, likely not following the predicted counterclockwise circulation hypothesized earlier.

Resource sampling for the purpose of full habitat assessment was resumed on 24 April (JD 114) when Cape Cod Bay was undergoing the first significant bay-wide enrichment of the season (see Figures 16 and note the major increases apparent in Panel B plots of Figures S1-S16). The principal cause of this late season enrichment was the long-awaited arrival of *Calanus*. From the relatively small area off of Race Point observed during SW603 it appears that the *Calanus* resource spread throughout the Bay. The timing of the *Calanus* influx was at some variance from the typical annual trends shown in Panel C of Figures 9 and 10, beginning approximately 20 days later than the 2003-2005 average rise of *Calanus* in the water column and therefore not reaching a peak until at least 25 days later than was usually the case. In fact, the offset of timing during 2006 was greater than 35 days when compared with 2005 (Panel C of Figures 22 and 23). The significant lag in the influx of *Calanus*, coupled with the weakness of the midseason *Pseudocalanus* resource had a profound effect upon the habitat use patterns of the right whales entering the Bay in late winter and early spring. During late April 2006, whales began to aggregate and feed in response to the strong zooplankton signals in the northeast and northwest quadrants of the Bay (see assessment report for cruise SW604 in Appendix II) particularly in the vicinity of station 8M, where zooplankton concentrations exceeded the feeding threshold by three times. Thus on 24 April PCCS issued another ship strike warning both for the area close to Provincetown and for a box on the west side of Cape Cod Bay. The spatial plots of zooplankton densities dynamics from this date (Figure 28) support the general view that a rich copepod resource dominated by *Calanus* was advected from the north into Cape Cod Bay, triggering the movement of right whales

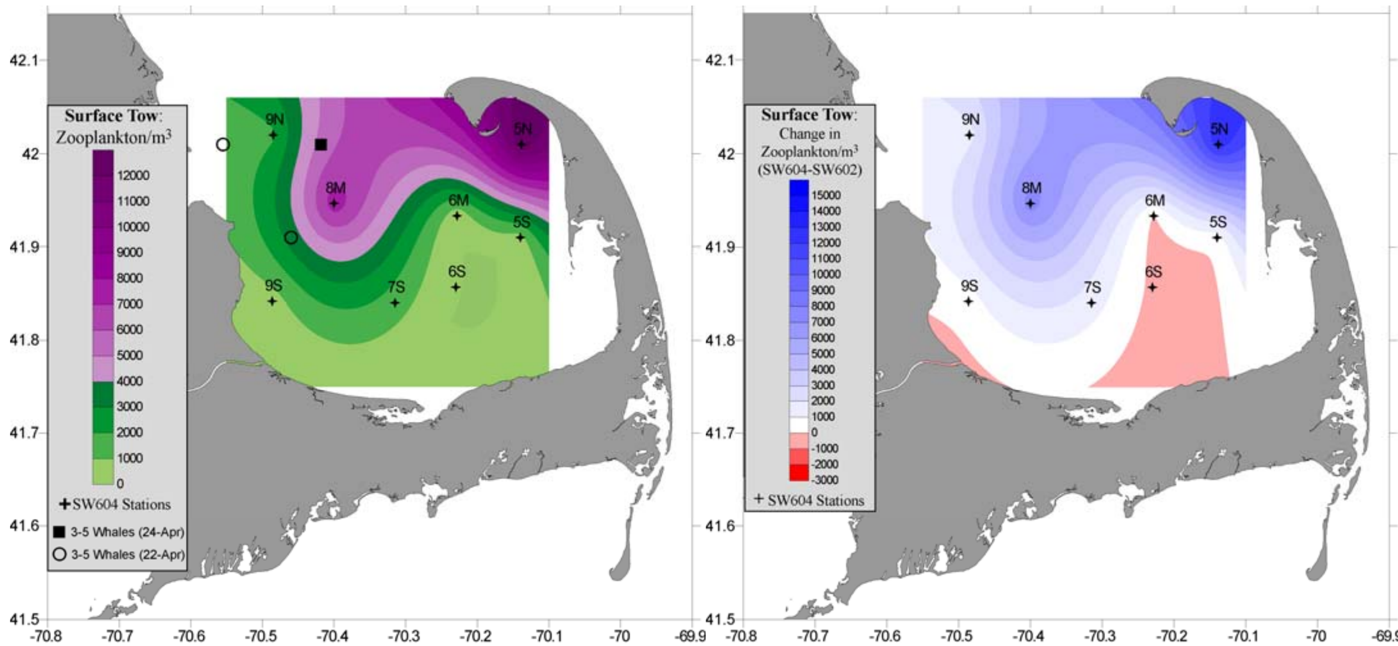


Figure 28. Spatial plots of zooplankton densities (left) in the surface samples collected on 24 April (SW604) and the changes thereof since the previous cruise (right). A similar pattern of enrichment was observed in water column samples (see assessment report for SW604 in Appendix II). Observed whale positions are marked with the symbol ○ (aircraft sightings) and the symbol ■ (vessel-based sightings).

toward the southwest into the vicinity of the Boston shipping lanes. Throughout the Bay at all depths the species composition was dominated by *Calanus* while the quadrant characterizations clearly pointed to the importance of the resource controlling the location of right whales in both the northeast and northwest quadrants. Although the 2006 *Calanus* resource was relatively weak compared to those observed during the last 5 years of our surveillance and monitoring studies, Figures 16 and 17 nonetheless show the importance of the *Calanus* signal on right whale density. Interestingly, the *Calanus* enrichment was short-lived at all eastern stations (as can be seen in Panel C of Figures S1-S8), yet at all stations in the western Bay (Panel C of Figures S9-S16) both the richness and the persistence of *Calanus* were notable. The lingering *Calanus* resource in those areas of the Bay resulted in the issuance of continued right whale high risk alerts through 8 May 2006. Coincident with the alerts, directed sampling in the northeast quadrant where collections had previously been highly enriched indicated a sharp drop in the zooplankton resource at all depths to levels below the feeding threshold; consequently, the warnings previously issued for the northeastern quadrant of the Bay were suspended on 5 May. On 18 May 2006 the final cruise of the 2006 season, SW609, was directed at the area of previous alerts in the northwestern and southwestern quadrants of the Bay. No whales were sighted by aircraft- or vessel-based observers on this date, and zooplankton samples indicated that the likelihood of whale aggregation and feeding was low; thus, the high risk alert was terminated for those western areas.

Supplemental Figures

for Section 2

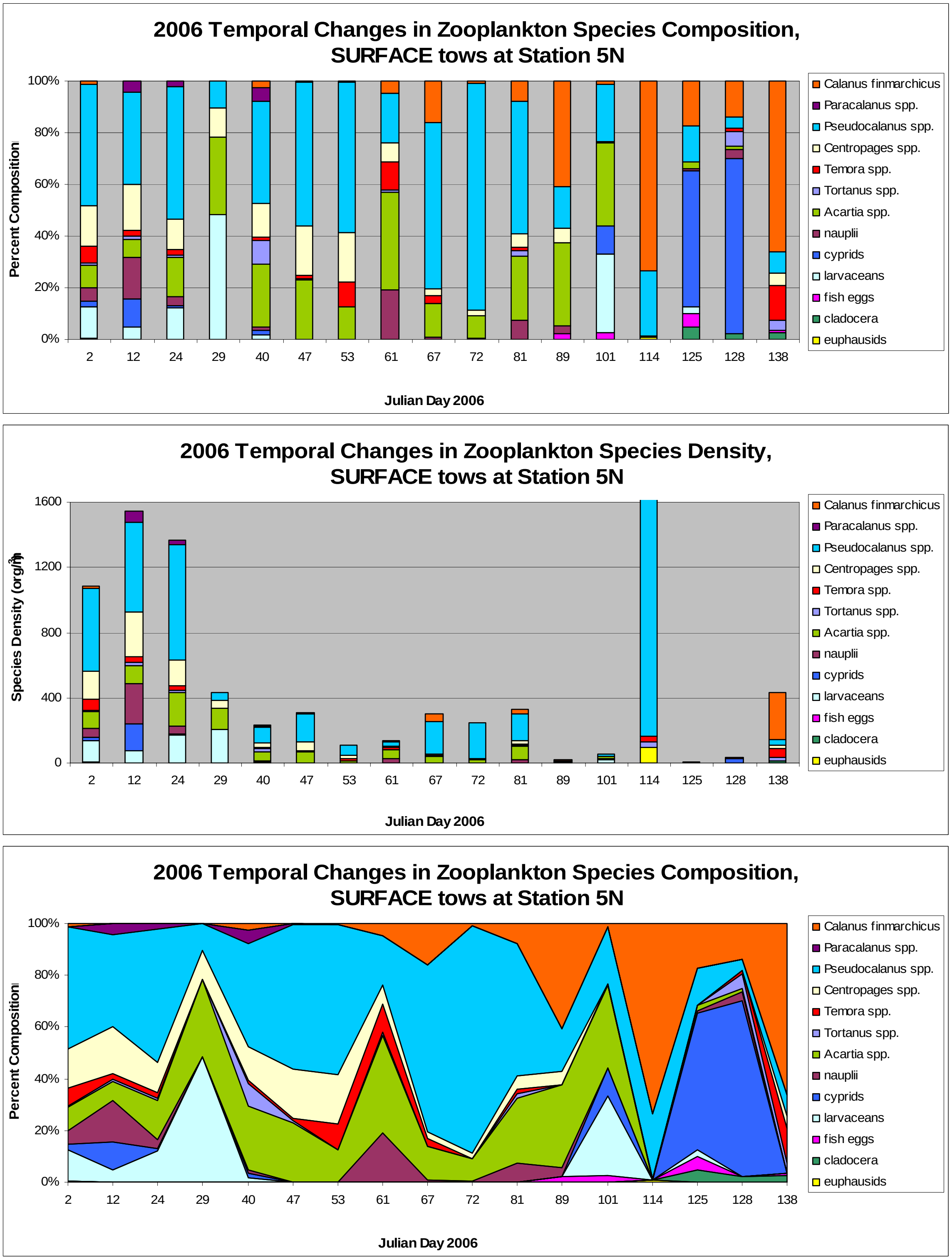


Figure S1. Temporal progression of surface zooplankton species at Station 5N in 2006;
Panel A (top) – Zooplankton species composition through time
Panel B (middle) – Zooplankton species densities through time
Panel C (bottom) – Zooplankton species composition (alternate visualization)

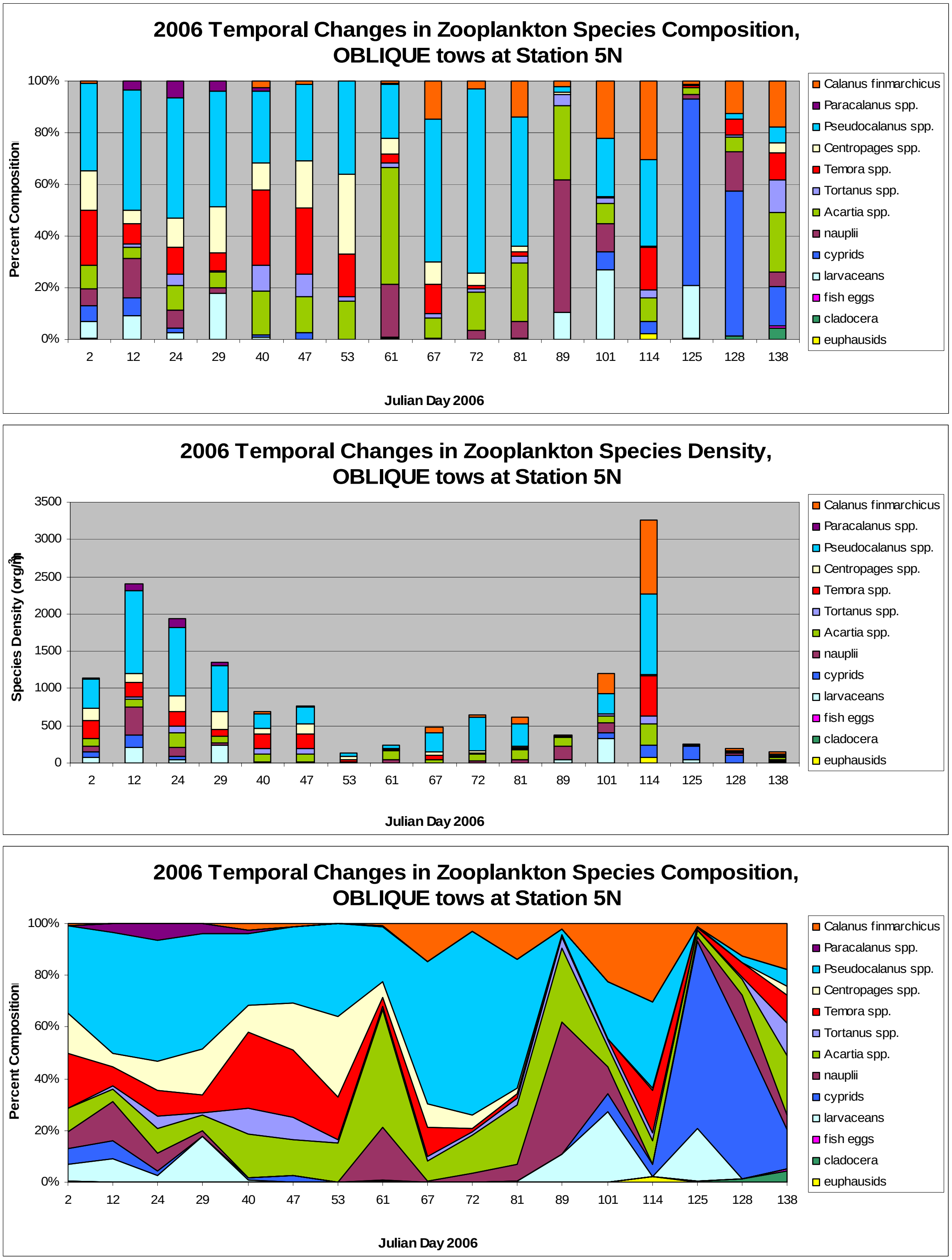


Figure S2. Temporal progression of oblique zooplankton species at Station 5N in 2006;
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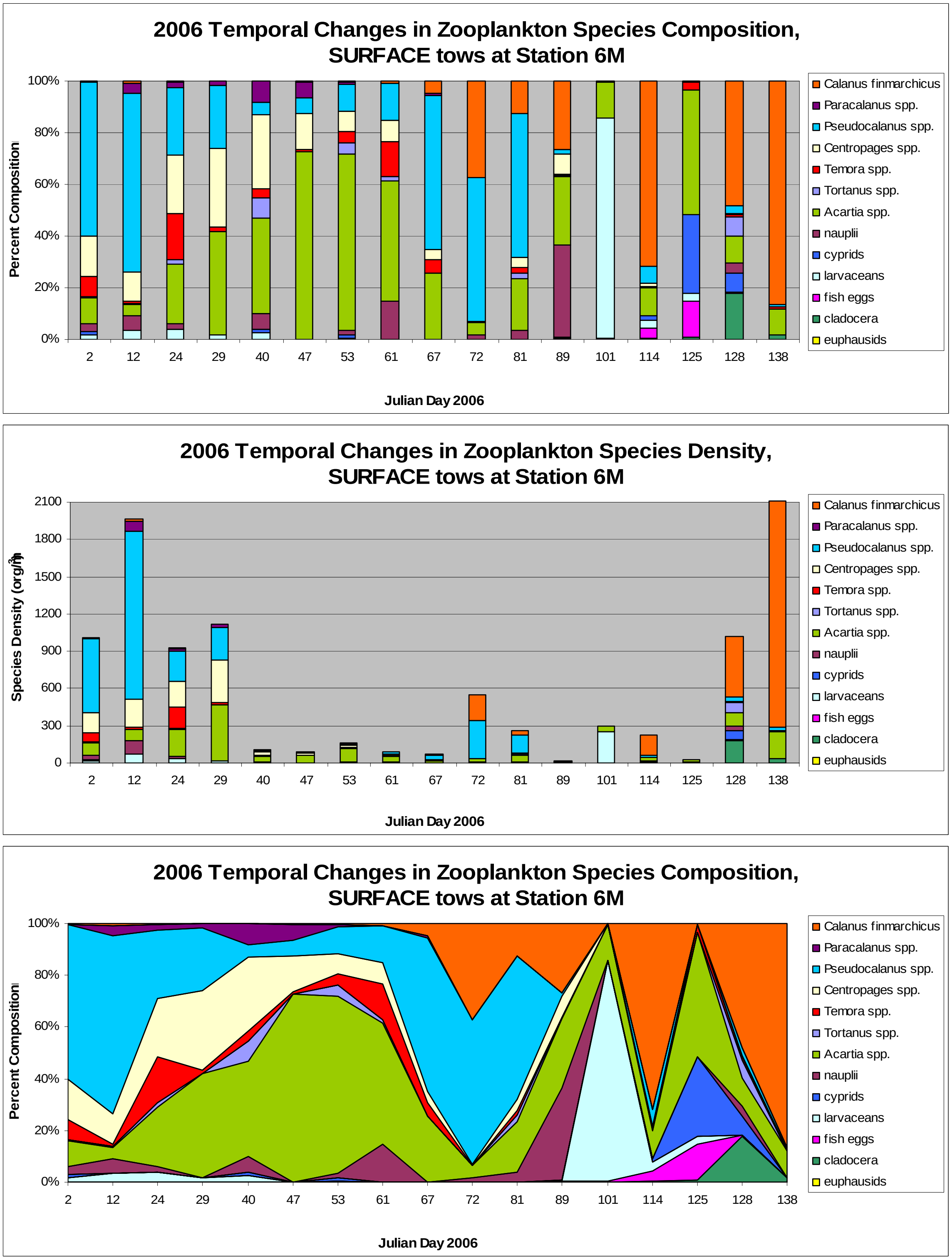

Figure S3. Temporal progression of <u>surface</u> zooplankton species at Station 6M in 2006;
Panel A (top) – Zooplankton species composition through time
Panel B (middle) – Zooplankton species densities through time
Panel C (bottom) – Zooplankton species composition (alternate visualization)

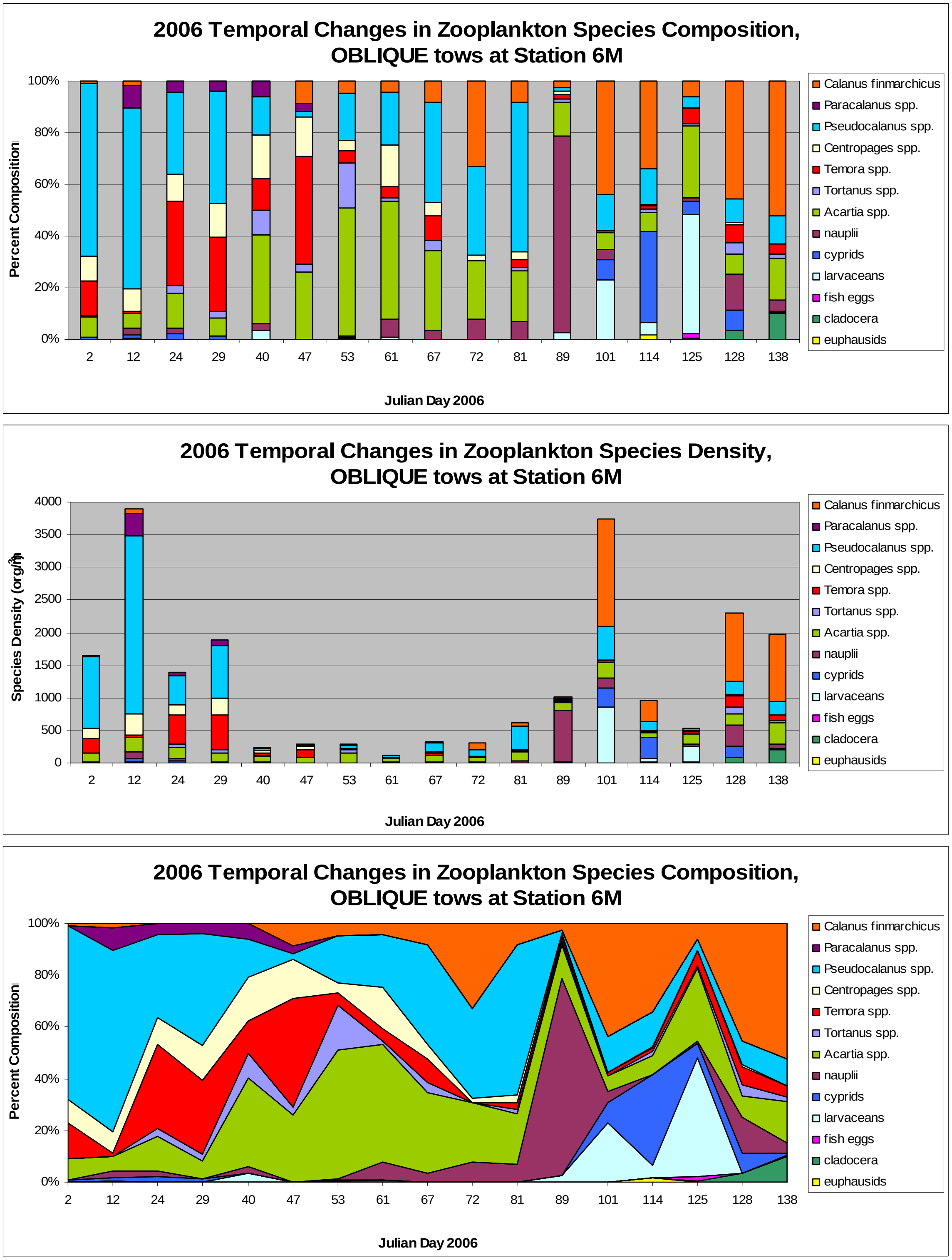

Figure S4. Temporal progression of oblique zooplankton species at Station 6M in 2006;
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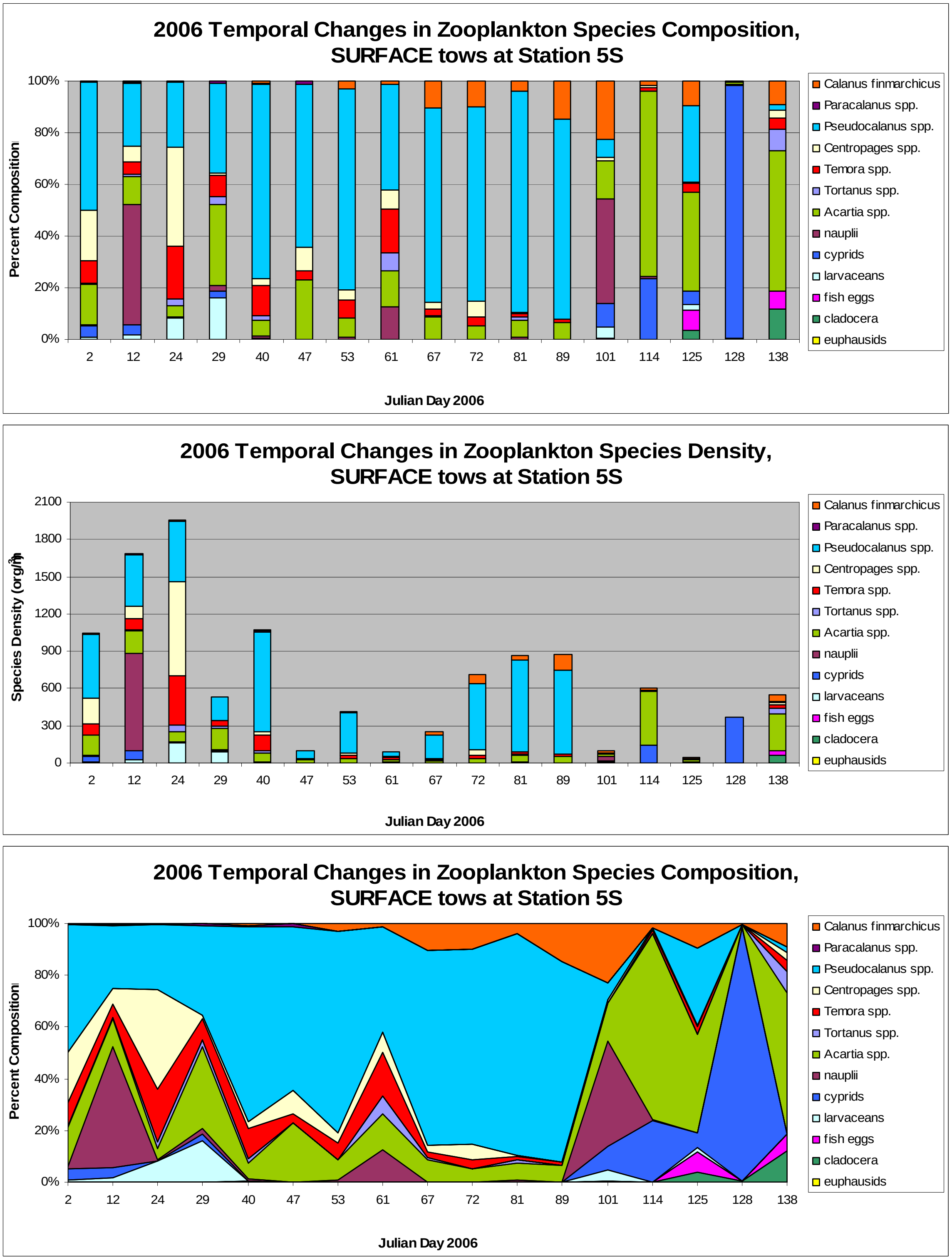

Figure S5. Temporal progression of <u>surface</u> zooplankton species at Station 5S in 2006;
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Panel B (middle) – Zooplankton species densities through time
Panel C (bottom) – Zooplankton species composition (alternate visualization)

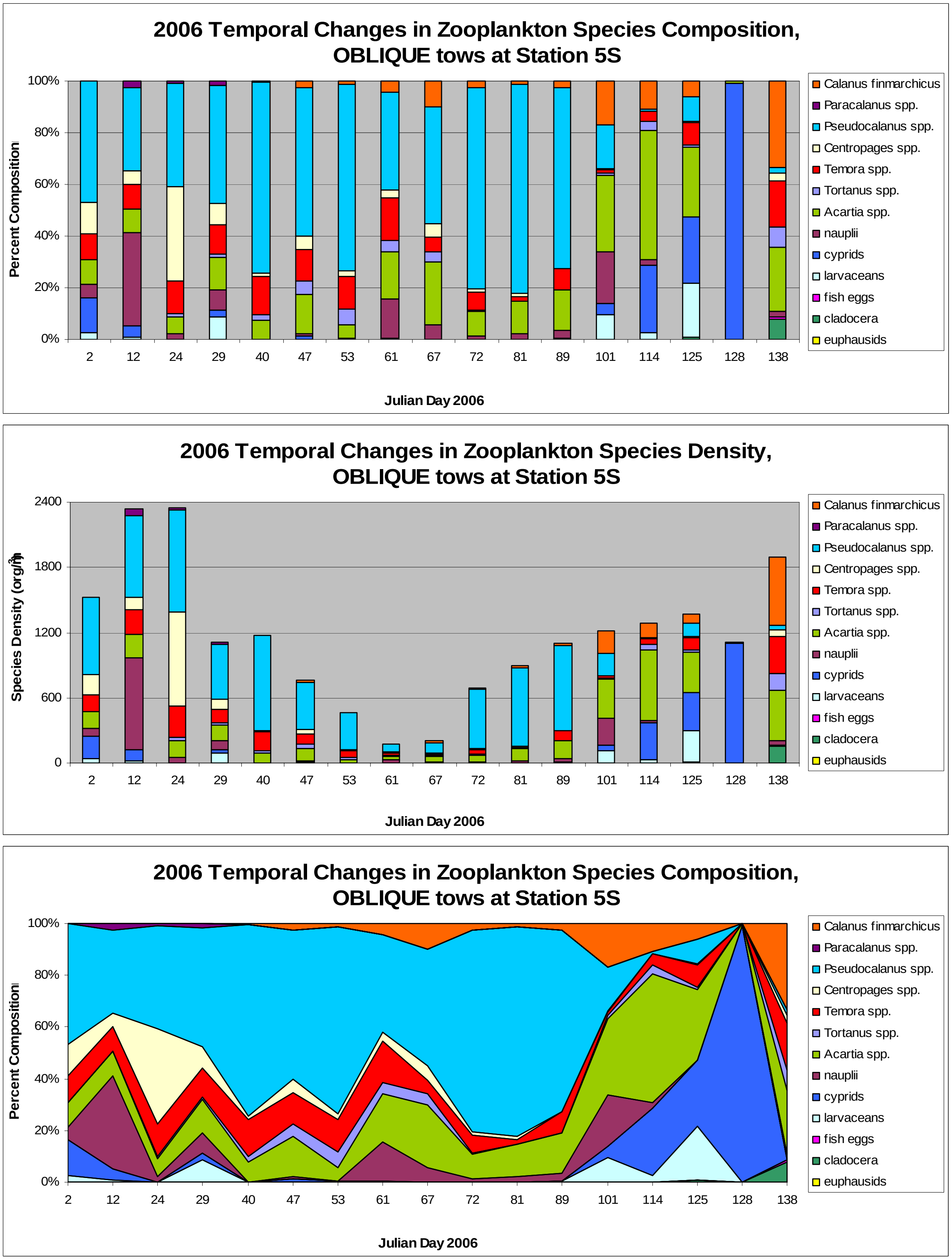

Figure S6. Temporal progression of oblique zooplankton species at Station 5S in 2006;
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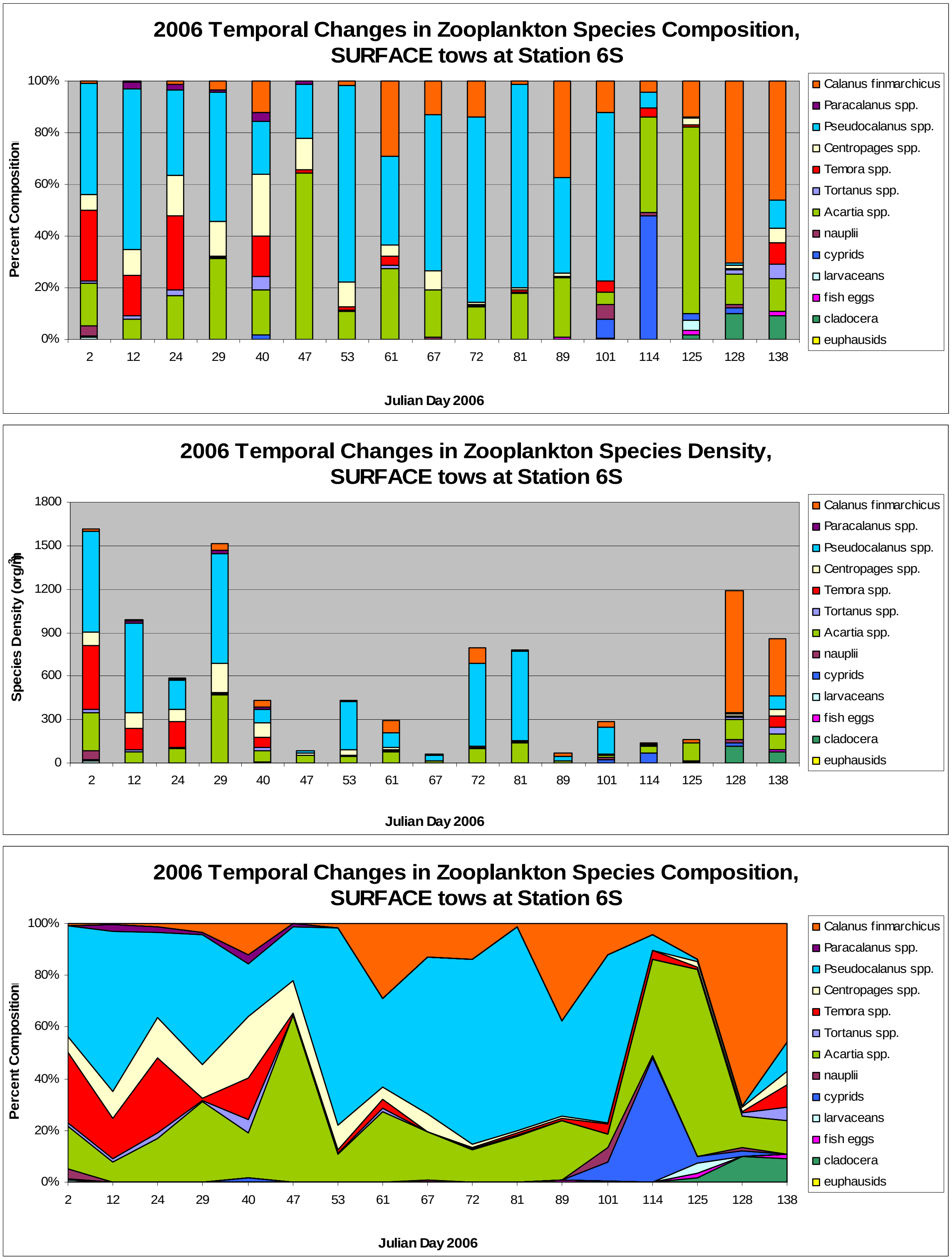

Figure S7. Temporal progression of <u>surface</u> zooplankton species at Station 6S in 2006;
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Panel C (bottom) – Zooplankton species composition (alternate visualization)

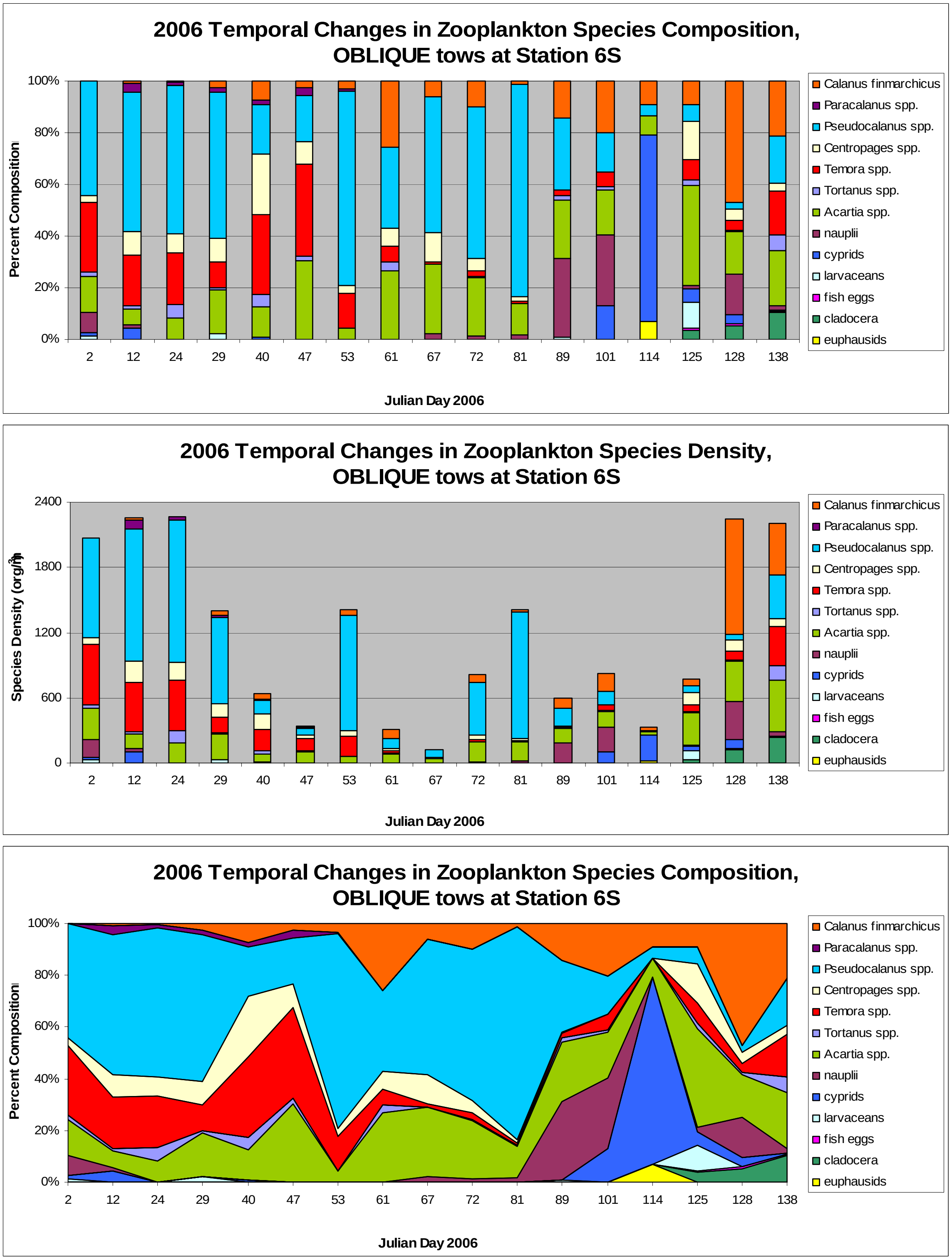

Figure S8. Temporal progression of <u>oblique</u> zooplankton species at Station 6S in 2006;
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Panel C (bottom) – Zooplankton species composition (alternate visualization)

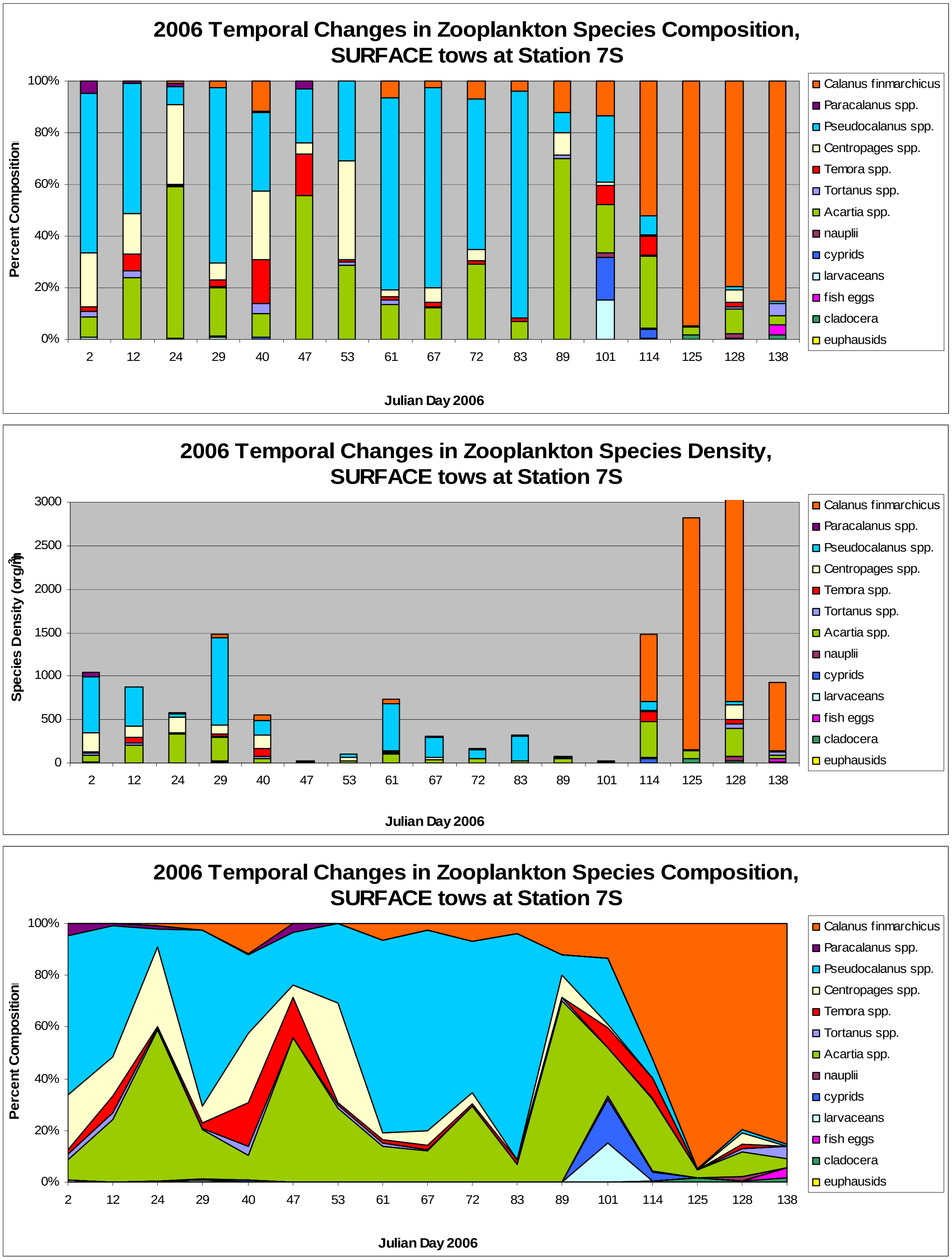

Figure S9. Temporal progression of surface zooplankton species at Station 7S in 2006;
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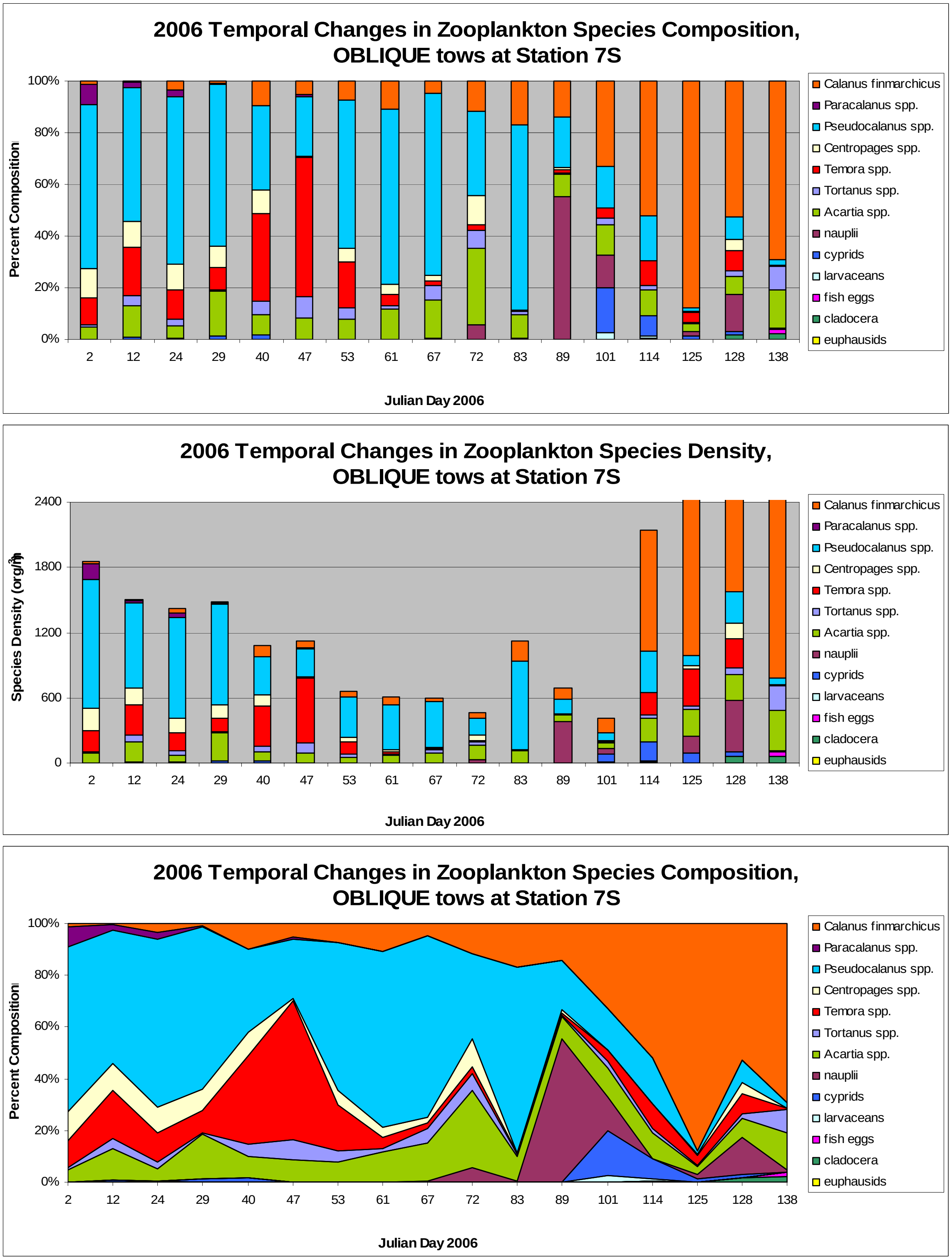

Figure S10. Temporal progression of oblique zooplankton species at Station 7S in 2006;
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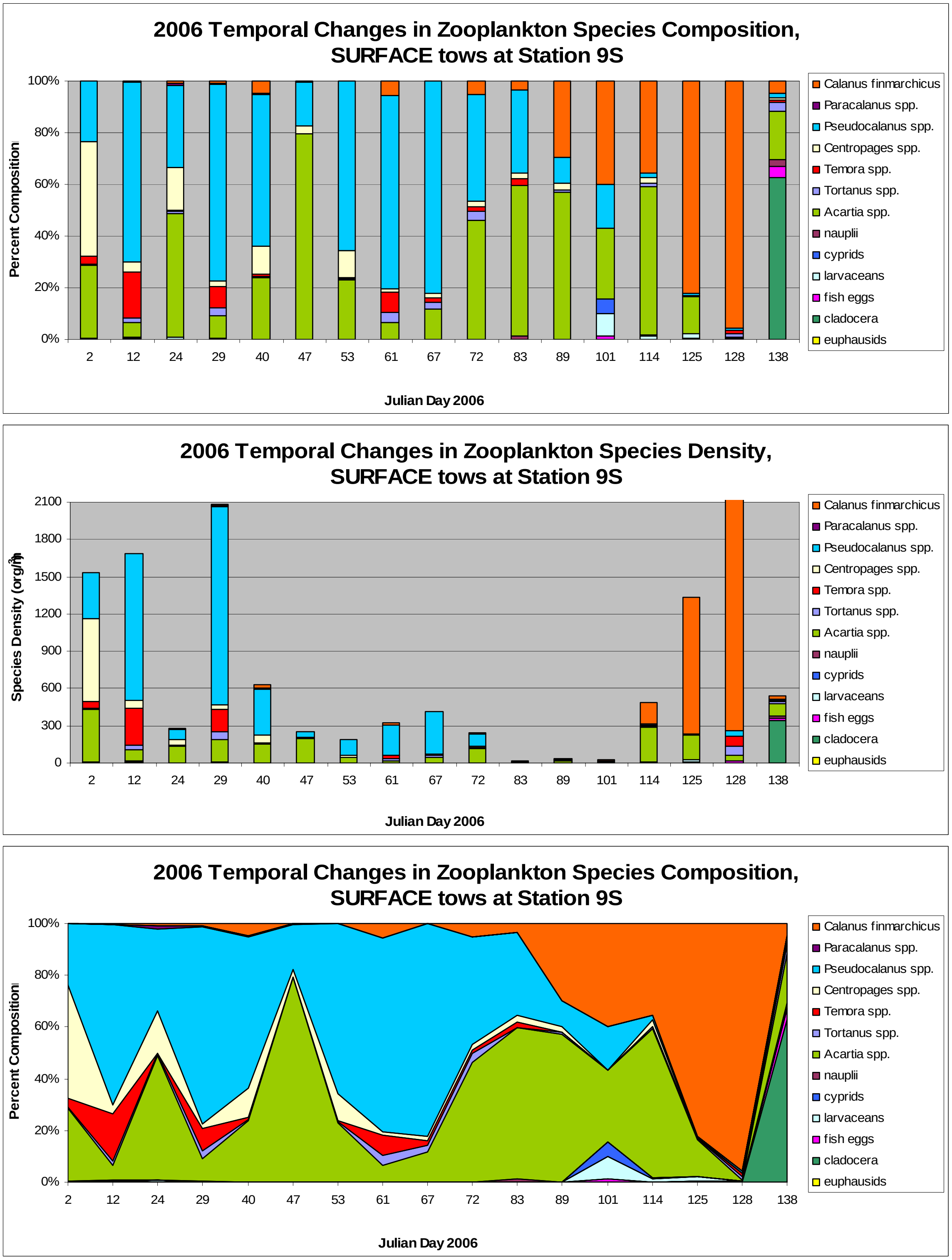

Figure S11. Temporal progression of <u>surface</u> zooplankton species at Station 9S in 2006;
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Panel C (bottom) – Zooplankton species composition (alternate visualization)

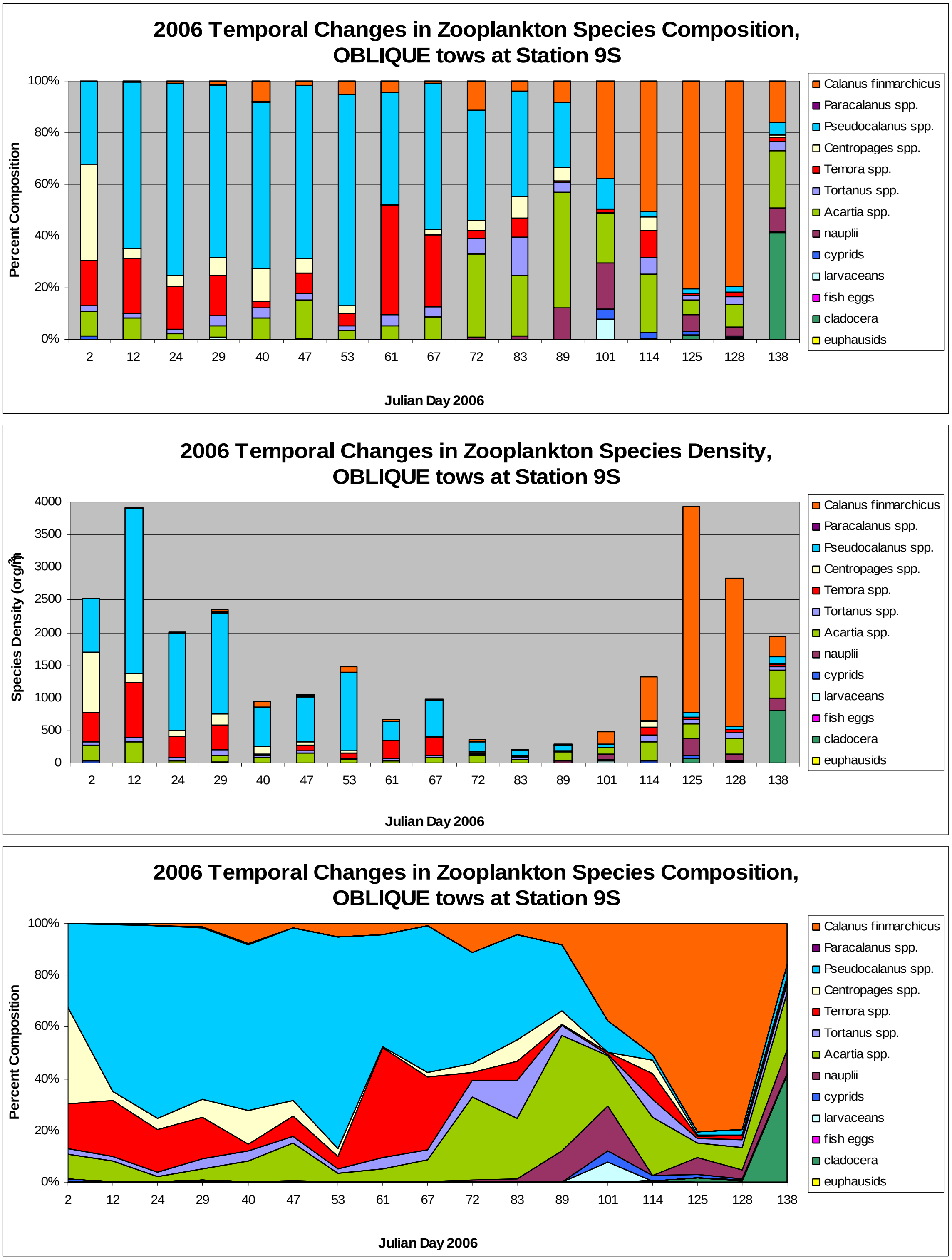

Figure S12. Temporal progression of oblique zooplankton species at Station 9S in 2006;
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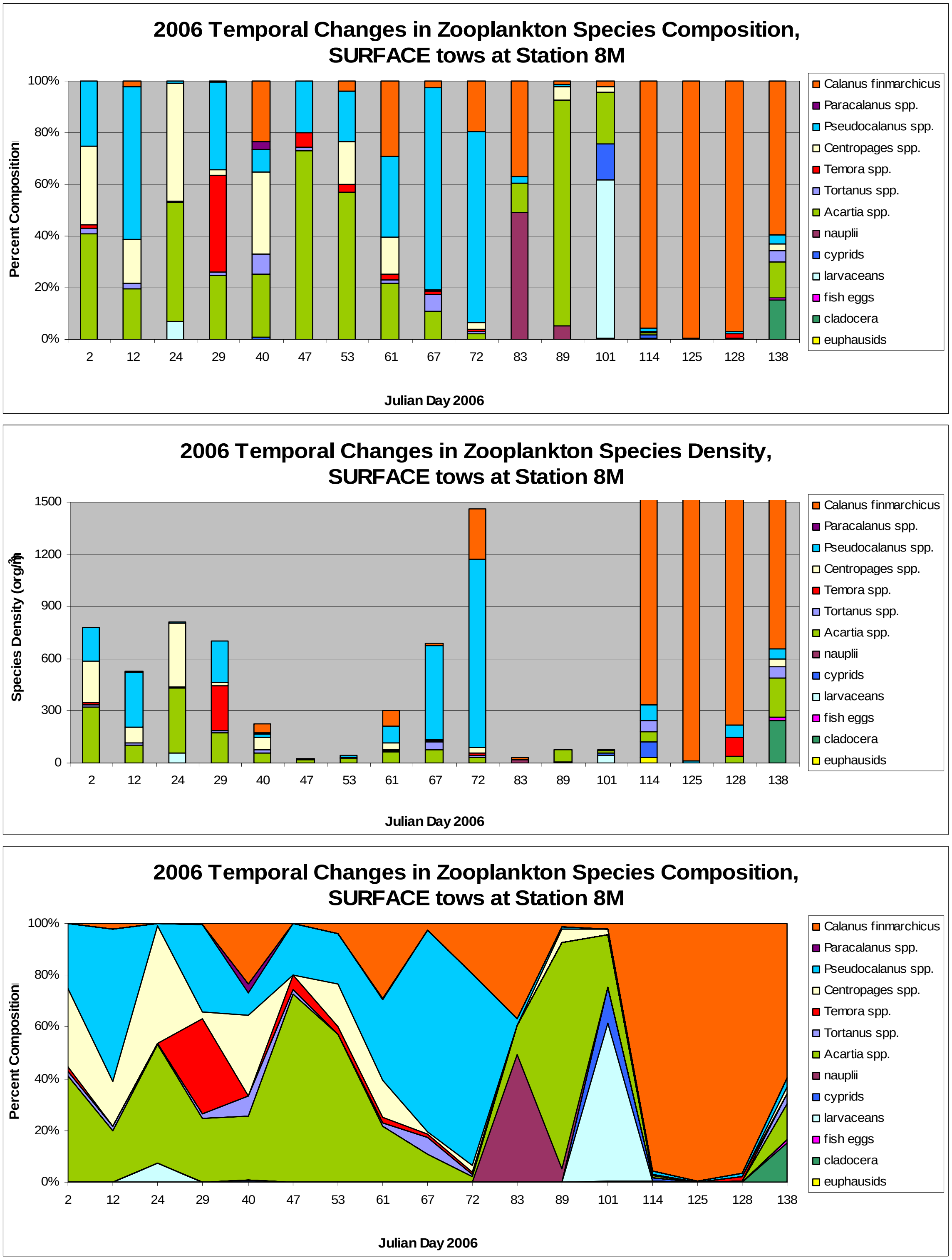

Figure S13. Temporal progression of <u>surface</u> zooplankton species at Station 8M in 2006;
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Panel C (bottom) – Zooplankton species composition (alternate visualization)

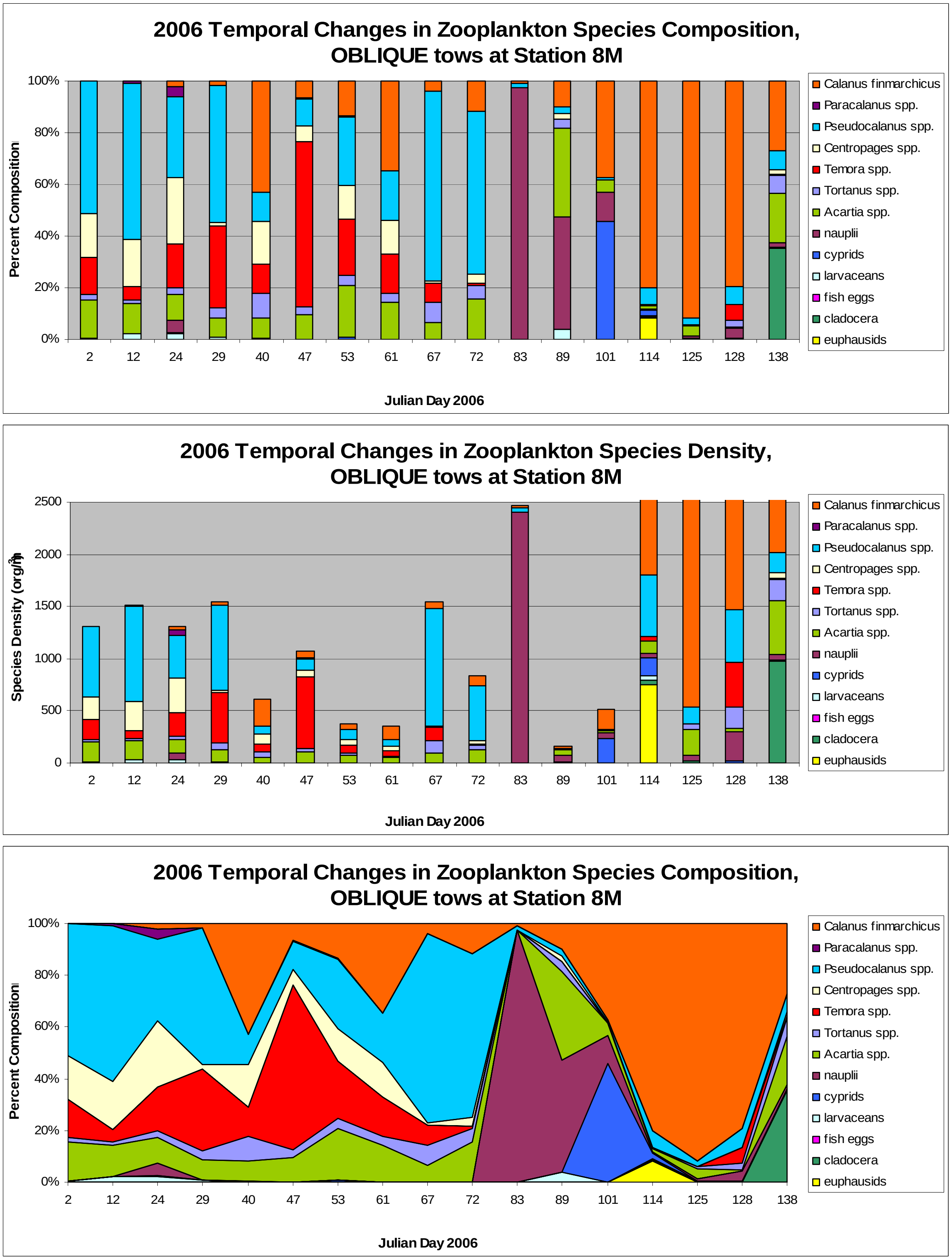

Figure S14. Temporal progression of oblique zooplankton species at Station 8M in 2006;
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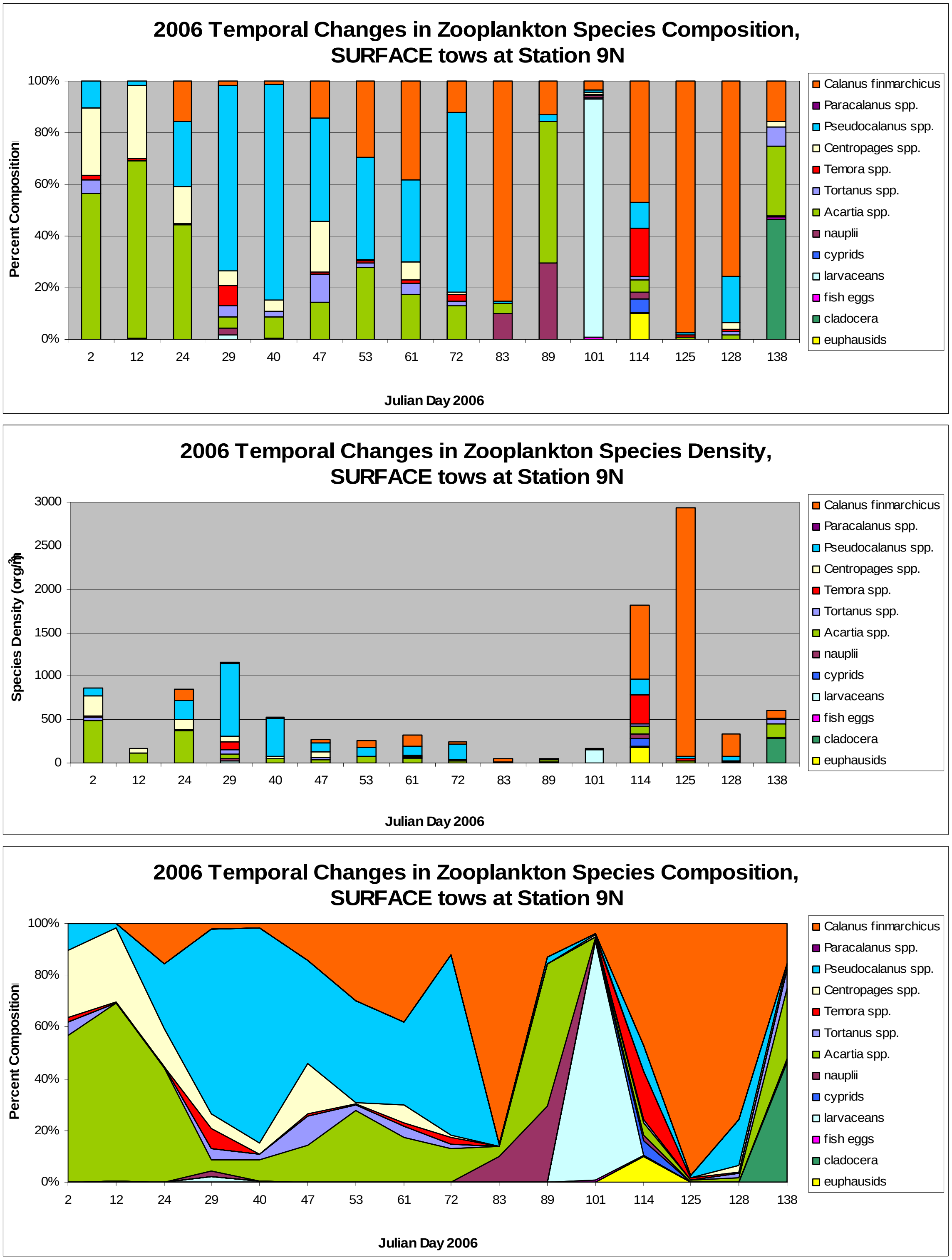

Figure S15. Temporal progression of surface zooplankton species at Station 9N in 2006;
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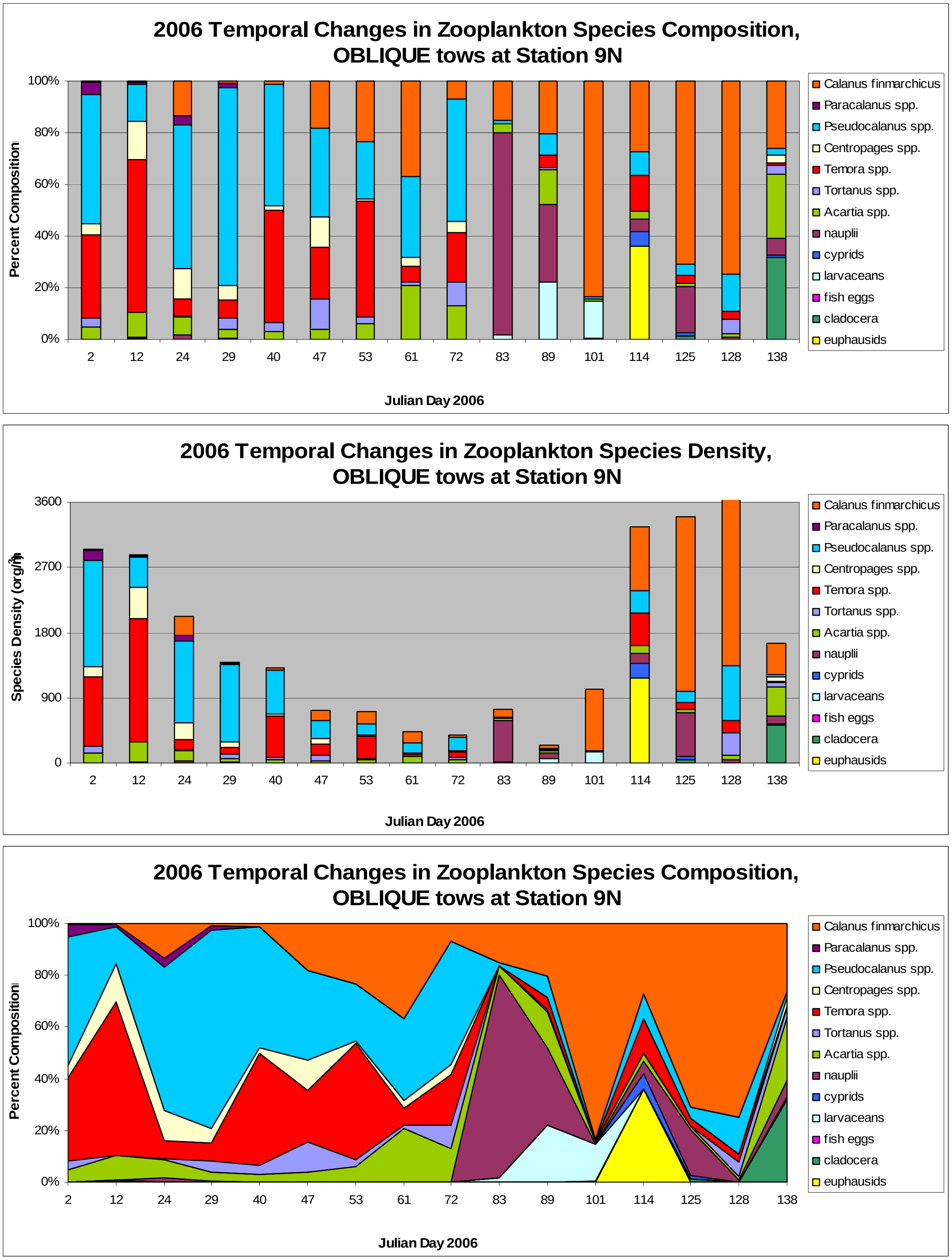

Figure S16. Temporal progression of oblique zooplankton species at Station 9N in 2006;
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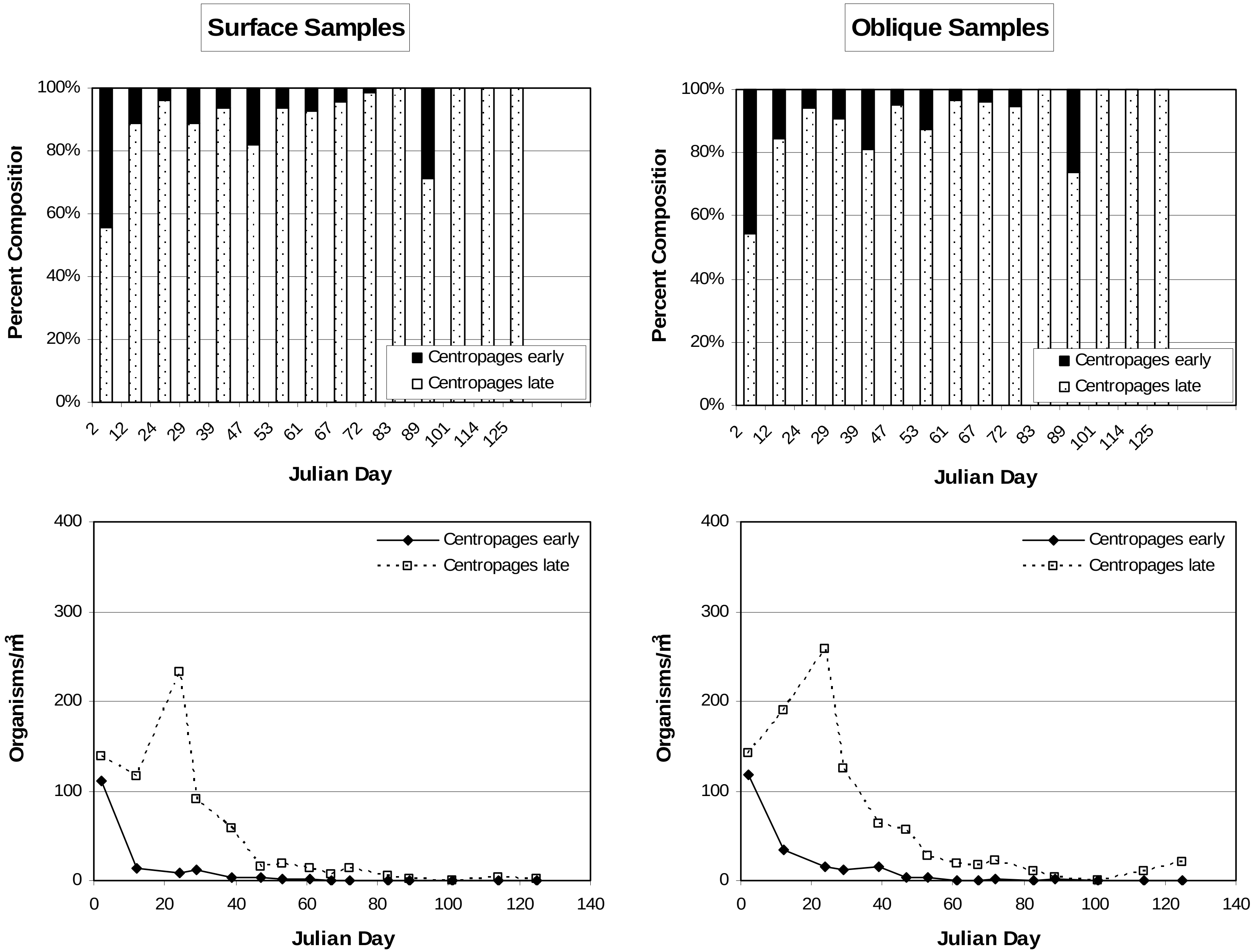


Figure S17. 2006 temporal progression of *Centropages* spp. early- vs. late-stage composition (upper plots: surface samples displayed at left, oblique water column collections at right) and daily average early- vs. late-stage densities in Cape Cod Bay (lower plots: surface at left, water column at right). Enumeration of samples from JD 128 and 138 did not include stage analysis.

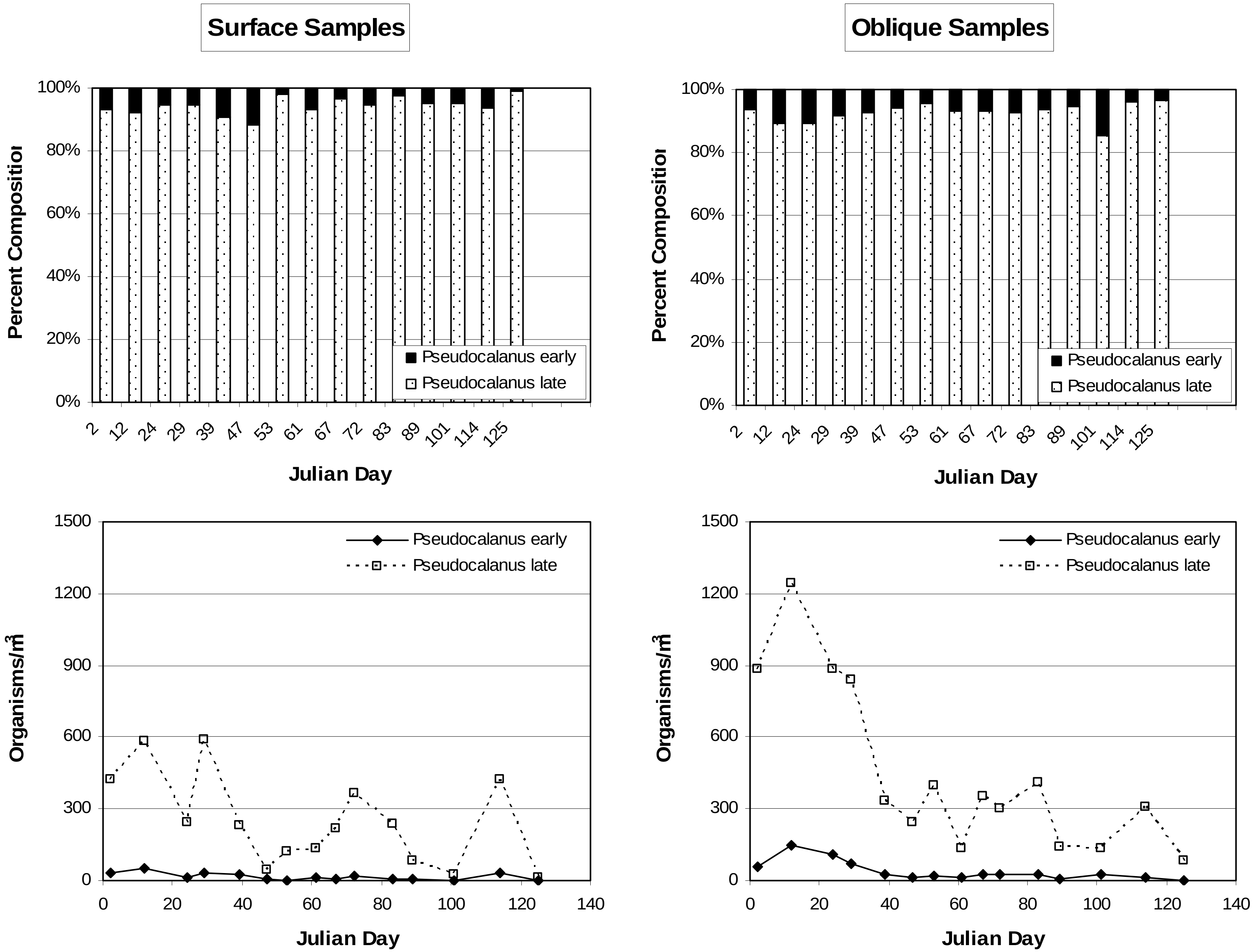


Figure S18. 2006 temporal progression of *Pseudocalanus* spp. early- vs. late-stage composition (upper plots: surface samples displayed at left, oblique water column collections at right) and daily average early- vs. late-stage densities in Cape Cod Bay (lower plots: surface at left, water column at right). Enumeration of samples from JD 128 and 138 did not include stage analysis.

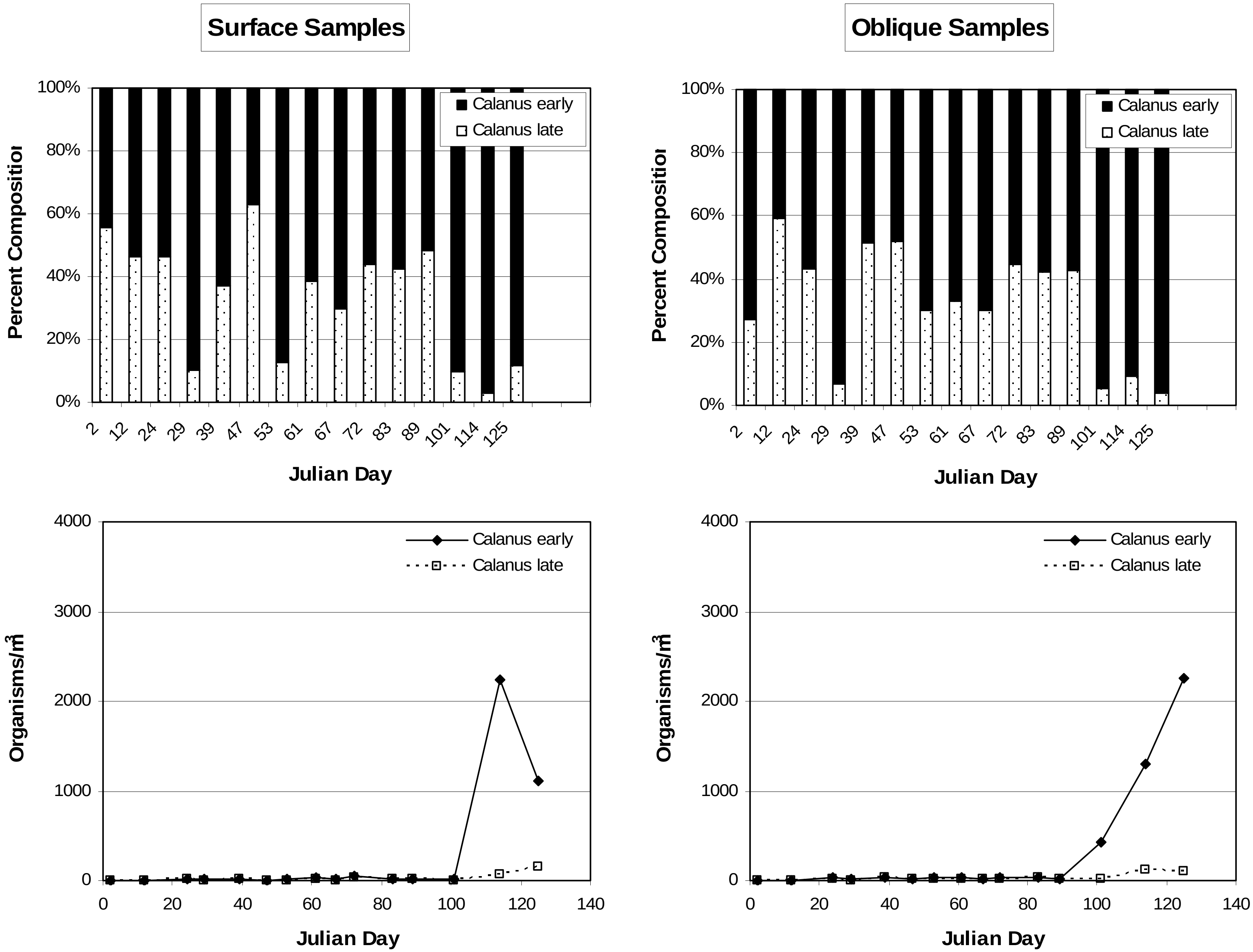
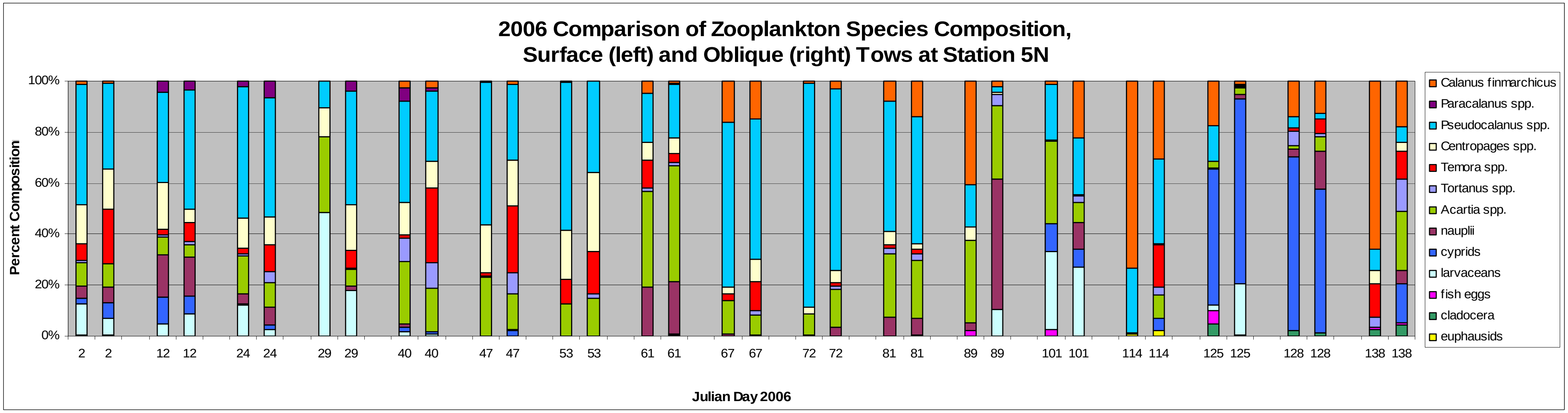


Figure S19. 2006 temporal progression of *Calanus finmarchicus* early- vs. late-stage composition (upper plots: surface samples displayed at left, oblique water column collections at right) and daily average early- vs. late-stage densities in Cape Cod Bay (lower plots: surface at left, water column at right). Enumeration of samples from JD 128 and 138 did not include stage analysis.



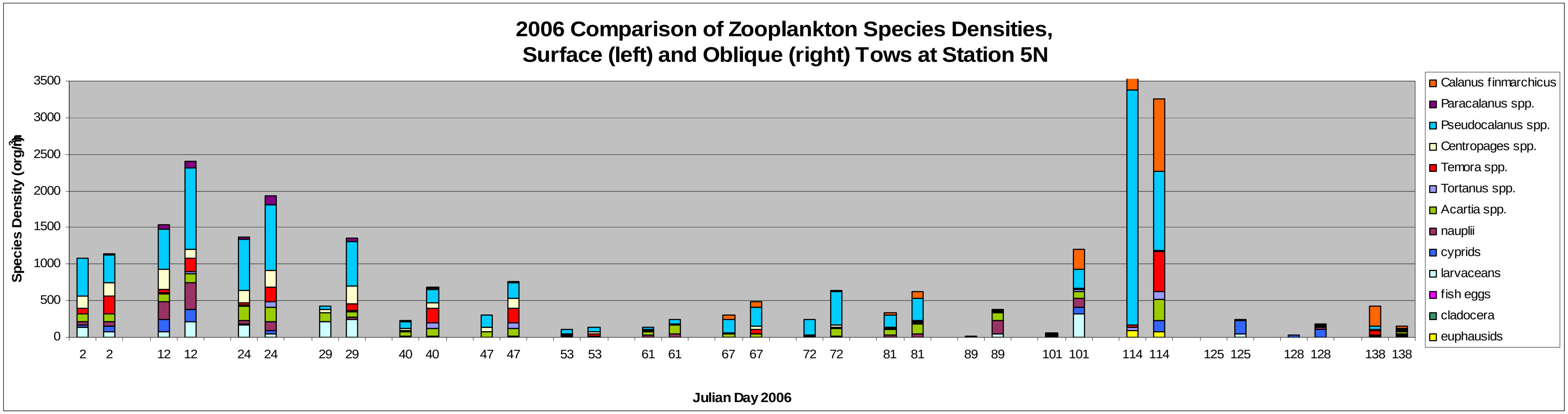
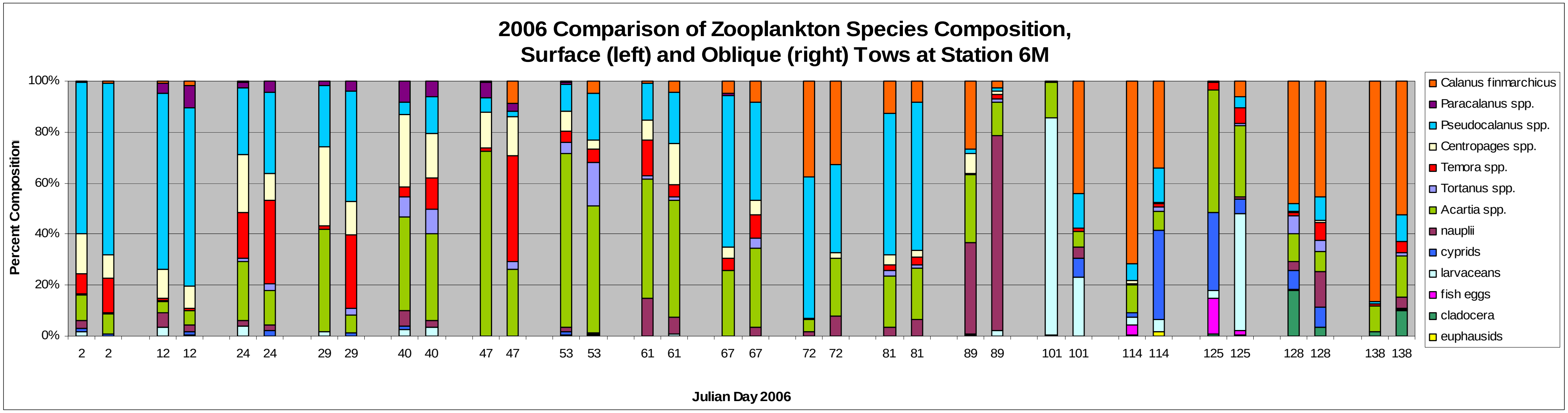


Figure S20. Comparison of surface and oblique zooplankton collections at Station 5N in 2006:
Panel A (top) – Zooplankton species composition through time
Panel B (bottom) – Zooplankton species densities through time



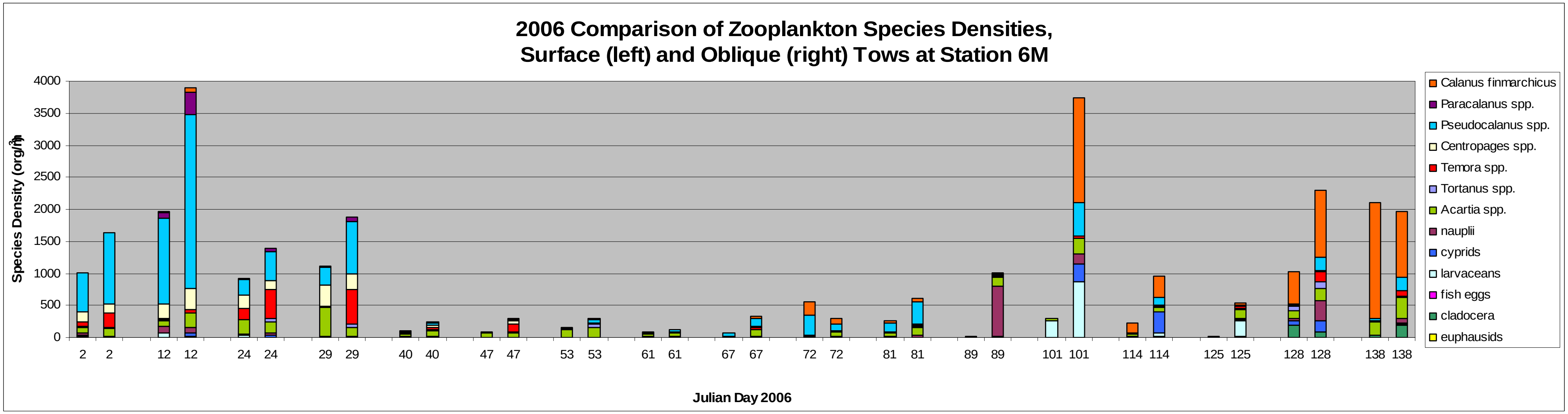


Figure S21. Comparison of surface and oblique zooplankton collections at Station 6M in 2006:
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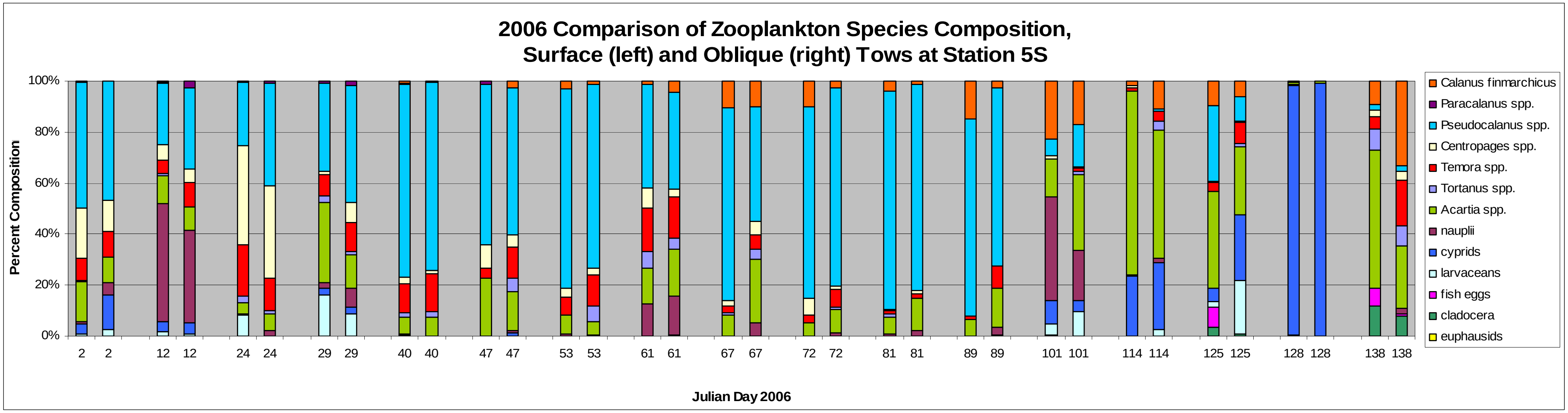

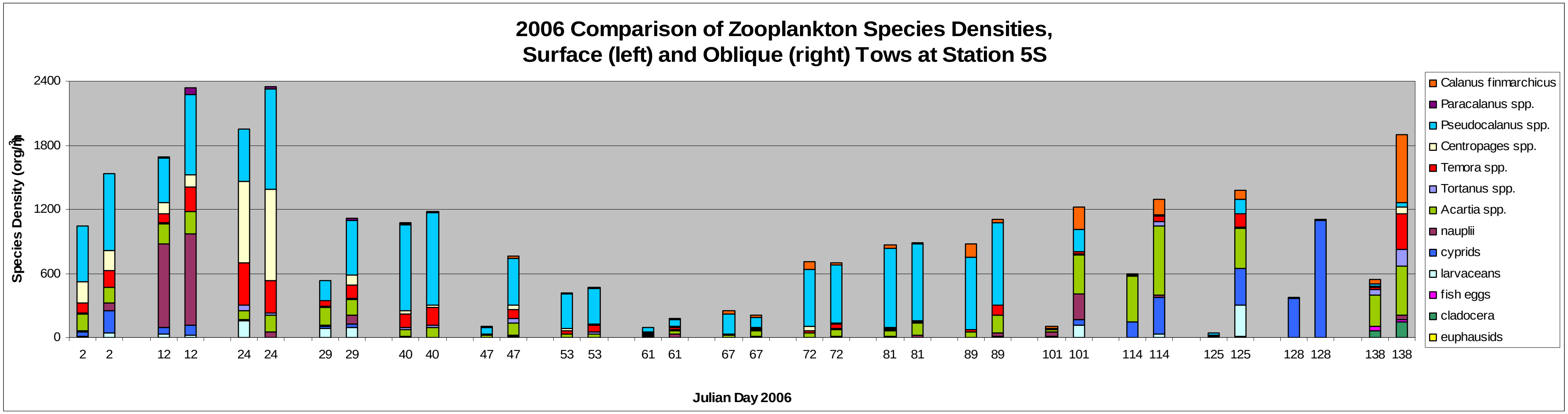

Figure S22. Comparison of surface and oblique zooplankton collections at Station 5S in 2006:
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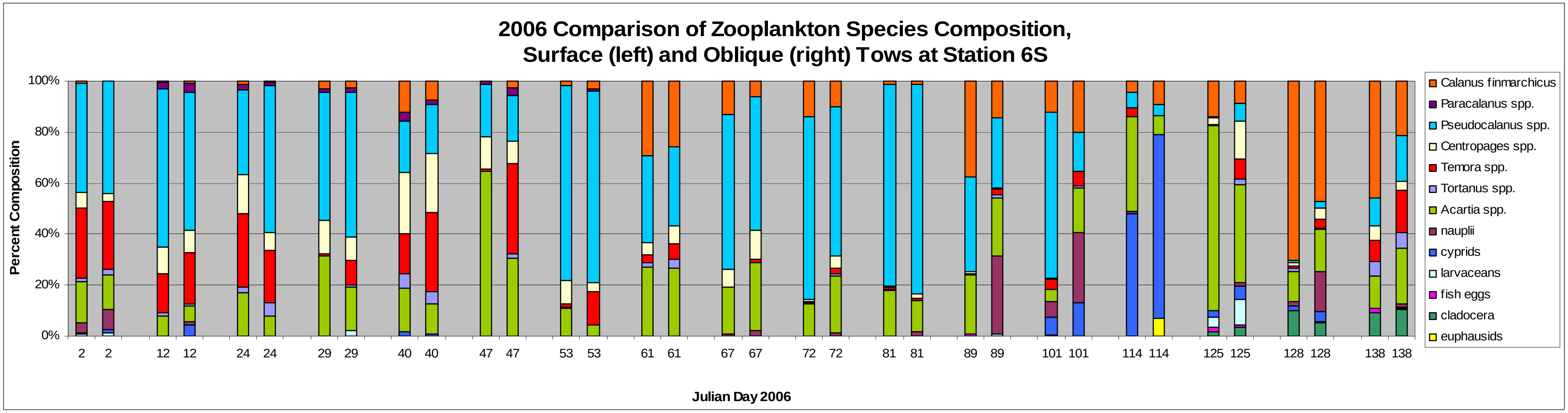
Panel B (bottom) – Zooplankton species densities through time



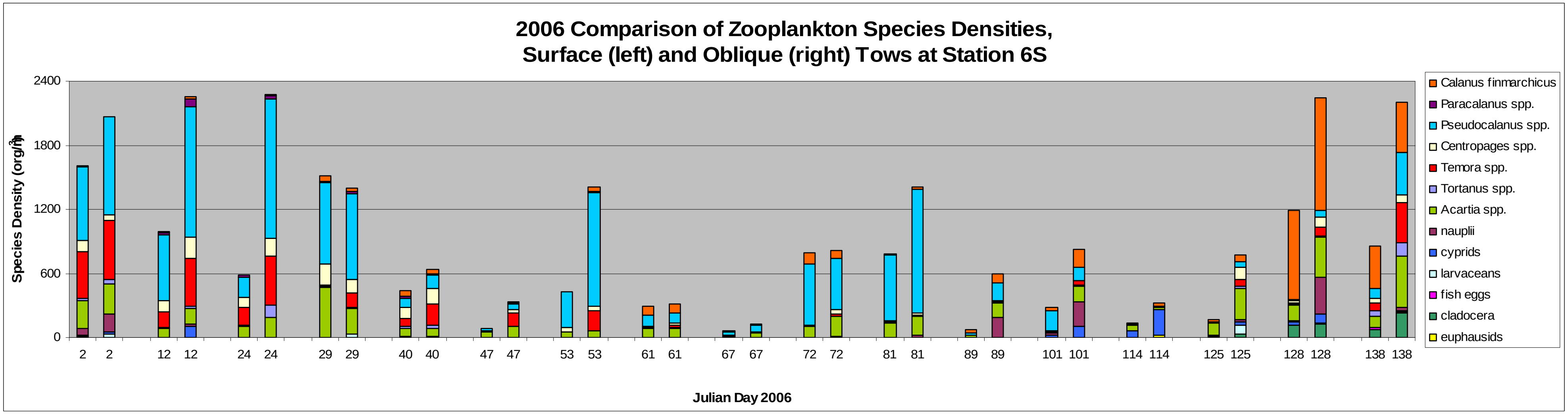


Figure S23. Comparison of surface and oblique zooplankton collections at Station 6S in 2006:
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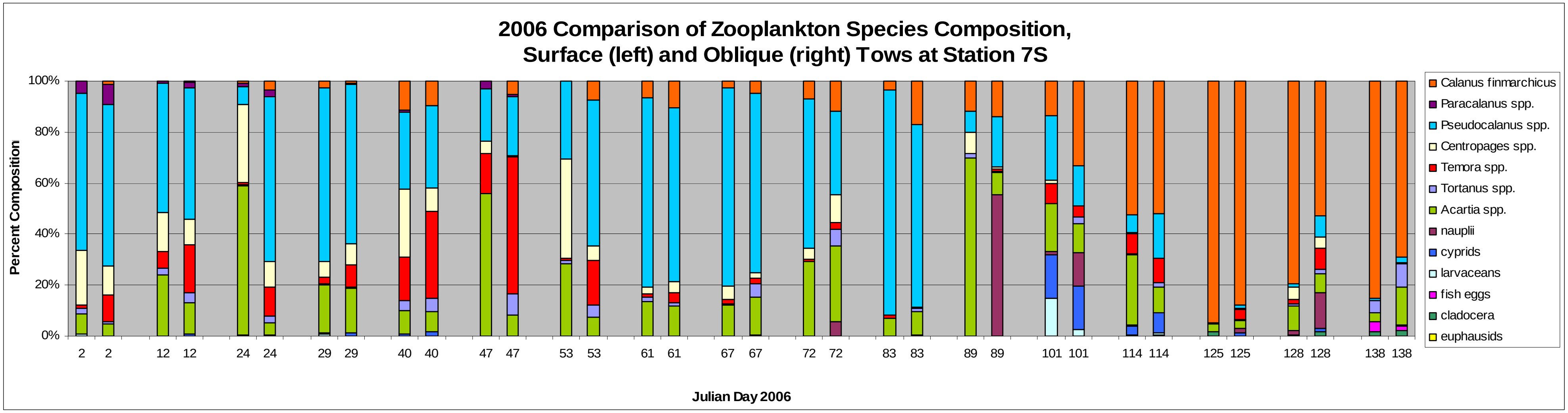
Panel B (bottom) – Zooplankton species densities through time



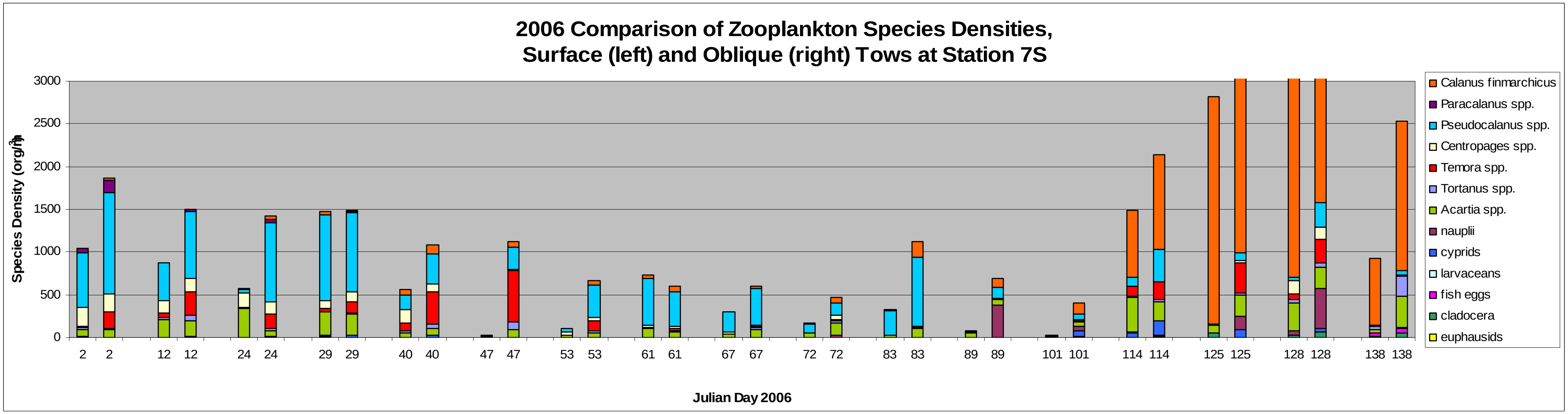


Figure S24. Comparison of surface and oblique zooplankton collections at Station 7S in 2006:
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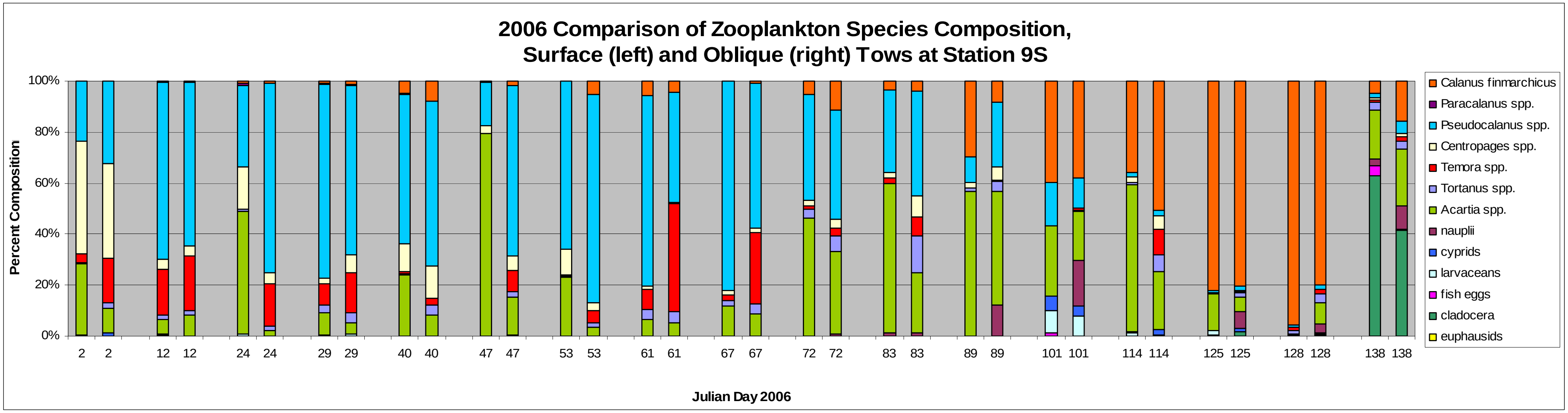
Panel B (bottom) – Zooplankton species densities through time



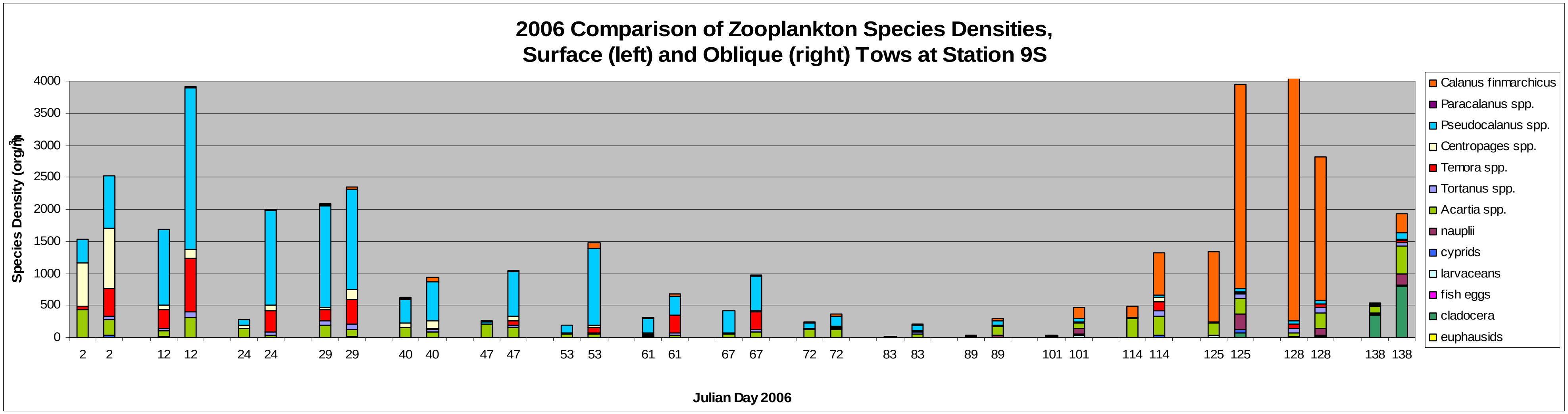
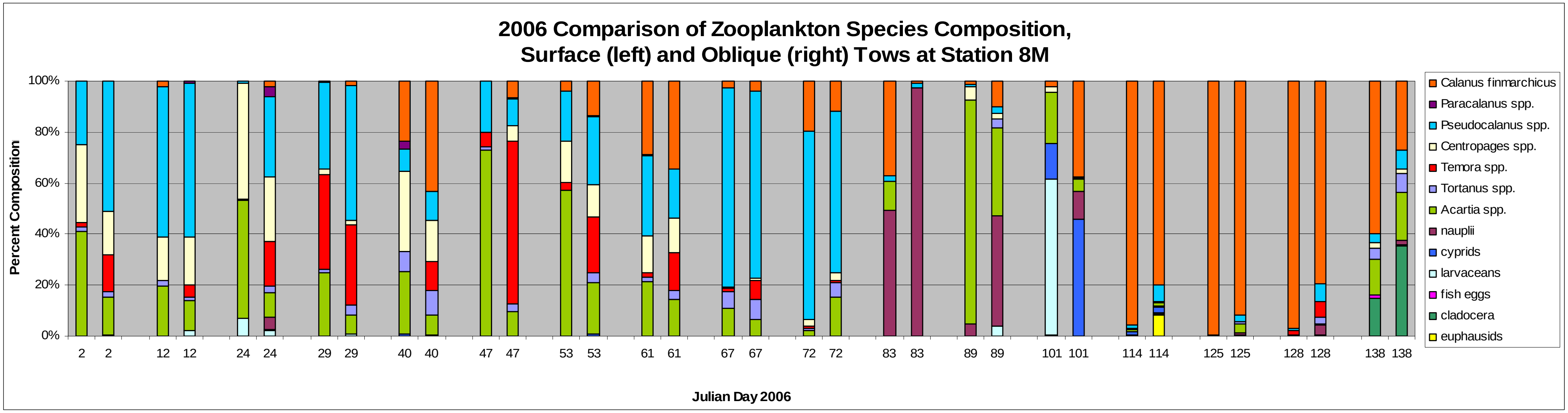


Figure S25. Comparison of surface and oblique zooplankton collections at Station 9S in 2006:
Panel A (top) – Zooplankton species composition through time
Panel B (bottom) – Zooplankton species densities through time



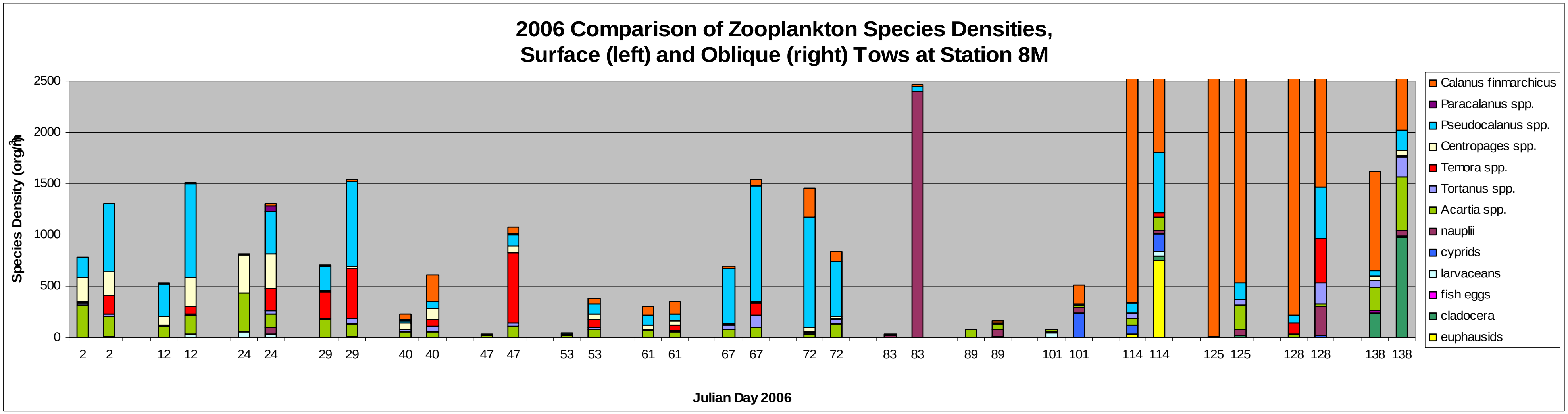
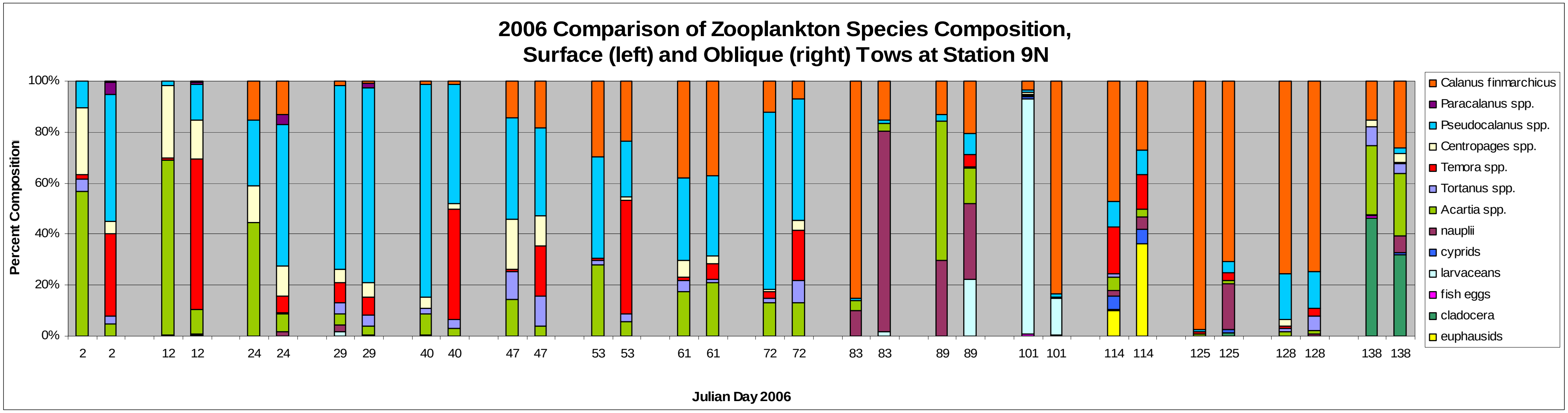


Figure S26. Comparison of surface and oblique zooplankton collections at Station 8M in 2006:
Panel A (top) – Zooplankton species composition through time
Panel B (bottom) – Zooplankton species densities through time



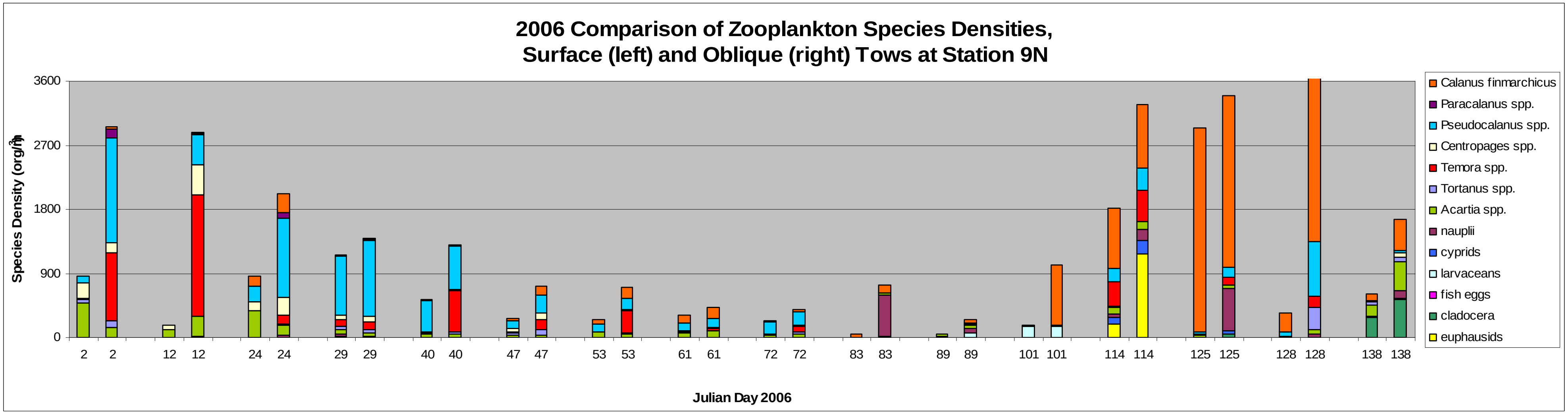


Figure S27. Comparison of surface and oblique zooplankton collections at Station 9N in 2006:
Panel A (top) – Zooplankton species composition through time
Panel B (bottom) – Zooplankton species densities through time

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