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Investigating the Role of an Understudied North Atlantic Right Whale Habitat: Right Whale Movement, Ecology, and Distribution in Jeffreys Ledge

Kathryn Longley
University of Massachusetts Boston

INVESTIGATING THE ROLE OF AN UNDERSTUDIED NORTH ATLANTIC RIGHT WHALE HABITAT: RIGHT WHALE MOVEMENT, ECOLOGY, AND DISTRIBUTION IN JEFFREYS LEDGE

A Thesis Presented

by

KATHRYN E. LONGLEY

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Approved as to style and content by:

____
Solange Brault, Associate Professor
Chairperson of Committee

____
Ruth H. Leeney, PhD, Muc Mhara Research & Conservation
Member

____
Michael Rex, Professor
Member

____
Alan Christian, Program Director
Biology Department

____
Rick Kesseli, Chairperson
Biology Department

ABSTRACT

INVESTIGATING THE ROLE OF AN UNDERSTUDIED NORTH ATLANTIC RIGHT WHALE HABITAT: RIGHT WHALE MOVEMENT, ECOLOGY, AND DISTRIBUTION IN JEFFREYS LEDGE

June 2012

Kathryn Longley, B.A., Wesleyan University
M.S., University of Massachusetts Boston

Directed by Professor Solange Brault

The critically endangered North Atlantic right whale (*Eubalaena glacialis*) consistently visits five major habitats throughout the year; however, they are known to visit additional habitats. This project examines the role of Jeffreys Ledge as an additional habitat of importance for this species by investigating three aspects of its distribution and ecology. I first addressed the relationship of Jeffreys Ledge to a known significant right whale feeding ground, Cape Cod Bay, by quantifying the movement of right whales between the two habitats and comparing demographic characteristics of right whales seen in these habitats. Secondly, I measured the quality of the zooplankton resource in Jeffreys Ledge and the relationship between plankton characteristics and whale sightings in this habitat. Thirdly, I examined the spatial distribution of right whales, and the relationship between right whale sightings and bathymetric characteristics in Jeffreys Ledge. While the populations of whales in these habitats do not appear to be demographically distinct, the results suggest that there is more movement between habitats by males than by females during the first few months of the year. Although there was no observed relationship between sightings per unit effort (SPUE) and energetic density of zooplankton prey resource in Jeffreys Ledge, low caloric density is a significant predictor of whale absence in the region. The lack of a relationship between SPUE and energetic density is likely the results of the zooplankton sampling methodology. Spatial analysis identifies a hot spot of high SPUE which changes in size, location and intensity throughout the study period, and both a binary logistic regression and a generalized linear model support a relationship between whale sightings and depth in the habitat. Results of this project highlight the need for more precise plankton sampling in the region as well as the need for concurrent survey efforts in multiple habitats. Assessing the importance the Jeffreys Ledge habitat to the right whale will help conservation managers to better allocate resources and mitigate the effects of anthropogenic threats to this highly endangered species in this region.

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TABLE OF CONTENTS

CHAPTER Page

APPENDIX

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

CHAPTER 1

INTRODUCTION

The North Atlantic right whale (*Eubalaena glacialis*) is a critically endangered species. At present, the global population is estimated at 490 individuals (Right Whale Consortium, 2011). Deemed the "right whale" to hunt, the population was severely reduced by whaling. Right whale catches were recorded as early as the year 1039 and the exploitation of this species continued until 1935 (Reeves et al., 2007). While the population appears to be slowly increasing since then, ship strikes and entanglement in fishing gear put the population at risk and remain the leading causes of death for these animals. The current potential biological removal (PBR) for right whales is 0.7 individuals per year (NMFS, 2010), meaning that a loss of .07 individuals per year due to anthropogenic sources will prevent the species from reaching its optimum sustainable population (MMPA, 1972). In other words, a loss of even one animal per year to non-natural causes threatens the survival of the species. The success of management strategies to prevent accidental right whale deaths will determine whether the species will persist and an understanding of how and why right whales use various habitats will enhance the ability of conservation efforts to assess and address anthropogenic risk.

Throughout the year, right whales consistently frequent five major habitats along the continental shelf from Eastern Canada to Florida: Cape Cod Bay from late winter to early spring, the Great South Channel from late spring to early summer, the Bay of Fundy and Roseway Basin during the summer months, and the coastal regions of the southeastern United States during the winter (Kenney et al., 2001; Kraus & Rolland, 2007). However, there are other less-studied habitats where right whale sightings also occur.

Jeffreys Ledge is one of these areas. This habitat is a relatively shallow glacial deposit approximately 54 km in length and is located off the coast of New Hampshire. It has recently been suggested that this area may qualify as an additional habitat of importance. Using a combination of platform of opportunistic surveys, sightings data from whale watching vessels, and dedicated survey efforts, Weinrich et al. (2000) suggested that right whales sightings occur here frequently and consistently. More importantly, feeding behavior is also regularly observed, particularly from October through December (Whale Center of New England (WCNE), 2008)

An analysis of sightings data from surveys in Jeffreys Ledge was undertaken to clarify whether Jeffreys Ledge might be considered an additional habitat of importance, or whether it is a marginal habitat, where right whales might visit on their way to more reliable feeding grounds or during periods of low productivity at other sites. Although the distinction between a marginal and significant habitat may seem trivial, such designations have the potential to dictate the extent to which management strategies are directed at various regions. One such strategy attempts to reduce the risk of lethal vessel strikes by designating Seasonal Management Areas (SMAs). SMAs are chosen to based on areas where right whales are likely to aggregate at a specific time of year, and during that time period, vessels over 65 feet must reduce their speed to 10 knots or less (Silber & Bettridge, 2010).

Cape Cod Bay is one such SMA, with restrictions in effect from January 1st to May 15th. Cape Cod Bay is federally designated as a critical habitat and is the focus of intense mitigation activities both at the State and Federal levels. During the right whale sighting season, aerial surveys monitor and report the positions of right whales to the Division of Marine Fisheries, the National Oceanographic and Atmospheric Administration (NOAA) and the National Marine Fisheries Service (NMFS), as well as mariners in the area. Acoustic buoys which detect specific right whale calls also serve as a warning that right whales are in the bay. By monitoring the quantity and taxonomic composition of plankton in Cape Cod Bay, researchers are able to forecast areas in which right whales are likely to be located (Provincetown Center for Coastal Studies (PCCS), 2010). Assessing the significance of lesser-studied habitats will help conservation managers better allocate resources and implement more intensive monitoring plans if necessary.

One component of this study (Chapter 2) will assess the connectivity of Jeffreys Ledge to a known significant habitat, Cape Cod Bay. Cape Cod Bay is the closest significant feeding ground to Jeffreys Ledge. The sighting season in Jeffreys Ledge also falls directly before the sighting season in Cape Cod Bay. This study examines two subsets of animals; those that are seen in Jeffreys Ledge in the late fall/early winter and subsequently in Cape Cod Bay in the late winter/early spring, and the animals that are known to visit both Cape Cod Bay and Jeffreys Ledge between January and May, a season in which a large segment of the population is expected to visit Cape Cod Bay.

Right whales show some degree of site fidelity. There are individual right whales that are never documented in Cape Cod Bay, despite being documented elsewhere. For example, there are individual right whales that are regularly seen in the Bay of Fundy despite never being seen in Cape Cod Bay (Kraus & Rolland, 2007). An implication of this finding is that alternative, possibly undocumented habitats exist for this species. Because right whales are known to enter and exit the Cape Cod Bay region throughout the sighting season (Baumgartner & Mate, 2005), a large amount of sighting overlap between the two sites would suggest that right whales may visit the Jeffreys Ledge region as an alternative destination during the typical Cape Cod Bay sighting season. Although tracking individual movements between the two sites is beyond the scope of this study, the calculation of transitional probabilities between the two sites will be indicative of the extent to which these two sites are connected.

While the characteristics of the sightings subset will provide researchers and conservation managers with valuable information, there are still unanswered questions about what these whales are doing in Jeffreys Ledge in the first place. With the exception of one subset of the population's migration to the southeastern calving grounds, right whale movement to these various habitats is thought to be motivated by food. It follows that attributing significance to a habitat would likely depend on the quality of the food resource in the region.

The right whale belongs to a group of baleen whales known as the "skim-feeders." This means that they feed by opening their mouths and swimming forward, filtering organisms through the fine bristles of the baleen plates on either side of their mouths. In doing so, their open mouths create an enormous amount of drag. It is believed that in order for it to be energetically worthwhile to open their mouth to feed, the density of plankton must reach a critical threshold of 3,750 organisms/m^3 (PCCS, 2003). Therefore, it is likely that for a right whale habitat to be recognized as significant, food availability and quality must be a primary concern. It is estimated that in order to survive, a right whale must consume between 407,000 and 4,140,000 calories (1,702,888 – 17,321,760 kilojoules) per day (Baumgartner et al., 2007). Considering this massive energetic requirement, it is not surprising that, with the exception of one subset of the population's migration to the southeastern calving grounds, right whale movement between and within its habitats is thought to be motivated by food. Deep dives in Jeffreys Ledge are often interpreted as foraging bouts, and skim-feeding is observed on occasion, however there is limited information on the relationship between right whales and their prey in this habitat. A second component of the study (Chapter 3) will address the quality of the plankton resource in Jeffreys Ledge.

A third component of the project (Chapter 4) is a spatial analysis of right whale sightings in Jeffreys Ledge. Spatial statistics methods in ArcGIS where used to investigate whether areas of high right whale sightings per unit effort are clustered in the habitat and whether right whale sightings are associated with bathymetric features.

While these analyses do little to make a case for habitat significance, they can be useful to focus management activities within a region and to make future surveys more efficient.

CHAPTER 2

EXAMINING THE RELATIONSHIP OF JEFFREYS LEDGE TO OTHER KNOWN RIGHT WHALE CRITICAL HABITATS

Introduction

Habitat overlap and transition probabilities

The North Atlantic right whale has been known to frequent five high-use habitats throughout the year: Coastal waters off the Southeastern United States are used primarily as a calving ground during the winter; Cape Cod Bay and Massachusetts Bay are primary feeding grounds during the late winter and early spring, with feeding activities taking place primarily in March and April; The Great South Channel is the primary feeding ground for right whales in the spring and early summer; The Bay of Fundy and the Scotian Shelf, specifically, Roseway Basin are two distinct summer and early fall feeding grounds in Canadian waters (Kenney et al., 2001).

These areas are geographically distinct and have been the focus of regular, seasonal survey effort since 1980, although survey efforts in Roseway Basin and Great South Channel have become less frequent (Brown et al., 2001). However, this set of regional habitats does not encompass the spatial and temporal complexity of right whale movement. For example, from 2003 – 2009, right whales were regularly documented in the Great South Channel in mid-winter, mainly February and March, before their expected peak in the spring (Right Whale Consortium, 2012). Further, satellite data from tagged right whales showed inconsistent site fidelity in a late summer feeding ground characterized by right whales moving out of the Bay of Fundy and moving extensively throughout the Western North Atlantic at an average speed of 79 km day^{-1} (Baumgartner & Mate, 2005). Finally, this description of overall habitat use says little about where right whales are found during the late fall and early winter. During this period, most of the whales seen in the Southeastern habitat are females giving birth to calves, as well as some juveniles (Kenney et al., 2001), while the location of the remainder of the population during this time period is often uncertain.

It is during this time period that right whales are frequently observed in Jeffreys Ledge. Weinrich et al. (2000) suggested that this area may a "habitat of unrecognized importance", with right whale sightings occurring during two different time periods: one in the spring and summer consisting mainly of mother/calf pairs, and a second between October and December. During this time all age classes were observed, with some individuals resighted in the area over the course of several weeks.

A goal of this study is to gain a more thorough understanding about whether Jeffreys Ledge is a more important habitat than previously thought by assessing the relative use of and individual exchange between Jeffreys Ledge and a known critical habitat, Cape Cod Bay. Critical habitats, as defined by the Endangered Species Act of 1973, refer to "(1) specific areas within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation." Cape Cod Bay is considered critical to the conservation of the North Atlantic right whale as it is a major feeding habitat for this species (NMFS 1994). Cape Cod Bay is, geographically, the closest critical habitat to Jeffreys Ledge, with the southern tip of Jeffreys Ledge located approximately 65km from the mouth of Cape Cod Bay. The sighting season in Jeffreys Ledge also falls directly before the sighting season in Cape Cod Bay. This study examines the importance of the movement by subset of animals that are seen in Jeffreys Ledge in the late fall/early winter, and then subsequently in Cape Cod Bay in the late winter/early spring.

Cape Cod Bay is known to be a significant feeding ground, with as much as 50% of the known population visiting the habitat within a given sighting season (PCCS, 2010). In contrast, as of the year 2000, it was estimated that approximately 13.9% of the known population frequents Jeffreys Ledge (Weinrich et al., 2001). Although this represents a much smaller segment of the population, this area is of interest due to the feeding and social behaviors, such as surface active groups (SAGs) that are regularly observed in the region (Whale Center of New England (WCNE), 2008). The fact that right whales are seen in these geographically adjacent habitats in temporally adjacent seasons leads to the following questions about habitat connectivity. Are there many whales which frequent both habitats, or do these seem to attract very different groups of individuals? Do sightings in Jeffreys Ledge in the fall mirror sightings in Cape Cod Bay in the following months? That these habitats are in close proximity spatially, but on opposite sides of a shipping lane (Ward-Geiger et al., 2005) also suggests important conservation implications for this type of investigation.

While it may be argued that study seasons and protected areas are, by nature, human-defined and cannot completely capture the complexity of animal movement within a continuous environment, these units of time and space are often the bases of management decisions involving this species. Currently, high-use areas such as the Great South Channel, Cape Cod Bay, and the Southeastern United States are considered critical habitats for right whales, meaning that at the times of year when right whales are expected to aggregate in these areas, a Seasonal Management Area management plan is enacted, (i.e there are restrictions on vessel speeds and commercial fishing activities in these habitat) (Merrick, 2005; NOAA, 1997). The conservation implication of the complexity of right whale movement suggests that the current method of seasonal management areas may be insufficient to protect animals that travel in and out of protected habitats, and that additional models of inter-habitat movement should be developed to predict when and where this species is at risk from anthropogenic threats.

In this study, I will measure the inter-habitat movement between Cape Cod Bay, Jeffreys Ledge, and a third habitat, the Great South Channel. Transition probabilities are estimates of the probability that an animal will move between habitats within a set time period. A method of estimation of these probabilities was developed by Whitehead

(2001) based on resightings of known individuals; this method appears robust even when survey efforts in different areas may be unequal or inconsistent.

The Great South Channel is examined as an additional habitat of interest in the section on transitional probabilities because right whales are regularly seen in this area before they are expected in Cape Cod Bay in large numbers (Right Whale Consortium, 2012). These areas are of interest particularly in the early part of the year as animals might be seen in any of these habitats, but when residence time in any one habitat is thought to be low. To date, there have not been simultaneous surveys of Jeffreys Ledge, the Great South Channel and Cape Cod Bay. Although surveys in these three areas employ similar methodology outlined by the Cetacean and Turtle Assessment Program (CeTAP, 1982), particularly with respect to photo-identification methods, the frequency of these surveys in all three areas has not been comparable. Therefore, the Whitehead (2001) method may be the best way of constructing a model of inter-habitat movement in this large-scale region which includes several known right whale habitats. Transitional probabilities can also be estimated over a variety of time scales to examine both large and fine-scale movements between habitats. Sightings data between 2003 and 2009 will be used. The goal of this section is to clarify inter-habitat movement patterns over the entire study period.

Sexual segregation and sex ratio differences

Another indication of how closely these habitats are connected is whether they are used by the same groups of animals. This section will examine whether these two habitats are used differently by animals of different sexes and reproductive status. Differences in habitat use by various sub-groups may provide insight into the reasons that whales visit Jeffreys Ledge and might also indicate disparate resources between the two habitats.

There are a number of potential reasons for sex-specific habitat selection in mammals. The forage-selection hypothesis suggests that females will choose a quality food source while males will opt for food sources with more biomass, as is the case in several species of ungulate (Ruckstahl & Neuhaus, 2002). In other species such as the Northern bottlenose whale, reproductively receptive females, rather than food, are thought to be the primary limiting resource for males. In these cases, males will prioritize habitats based on the presence of estrous females, leading to differential habitat choice between the sexes (Wimmer & Whitehead, 2004).

The presence of offspring may also lead to sexual segregation within a species. The predator-risk hypothesis predicts that females will be more risk averse when choosing habitats based on potential interaction with predators. For example, female belugas with calves in the Beaufort Sea tend to favor open water habitats where the risk of predation from polar bears and killer whales are lower (Loseto, L.L.L.L.L. et al., 2006). In other species, such as the gray whale, females with calves are the last to leave the winter calving grounds in Baja California, leading to skewed sex ratios in these habitats at certain times of year (Rice et al., 1984). Females accompanying offspring may also prioritize sheltered areas. For example, Southern right whales with calves off the coast of South Africa show a preference for sandy-bottomed bays that are protected from strong swells (Elwen & Best, 2004). The presence of sexual segregation in a habitat may be indicative of differences in food quality, safety and reproductive resources, or differences in time budgets between males and females of a species.

In a review of hypotheses on sexual segregation, Main et al. (1996) suggested differential energy requirements resulting from differential costs of reproduction or differences in metabolic requirements due to sexual dimorphisms may lead to differences in foraging behavior or habitat choices. For example, female Rocky Mountain mule deer select habitat cover types with higher species richness compared to the habitats favored by males (Main et al., 1996), and male sperm whales are thought to target a broader range of prey types than females (Teloni et al., 2008). However, because there is relatively little data on sex-specific foraging behavior in non- sexually dimorphic mammals, it is impossible to discern whether or not it is the cost of giving birth or merely the size differences themselves which account for these differential nutritional needs (Ruckstuhl & Neuhaus, 2000). Still, because a lack of adequate food availability has been implicated as a possible explanation for the depressed birth rates of North Atlantic right whales (Kraus et al. 2007), it is of interest to consider that the differential nutritional needs of females, particularly reproductive females, may influence habitat selection.

While there are no data on the differing nutritional and energetic needs of male and female right whales, the energetic costs of reproduction are thought to be high. The long lactation period (up to eleven months) followed by a long calving interval (>3 years) suggests that giving birth to a calf is energetically expensive for female right whales (Kraus et al. 2007), and Stevick et al. (2002) suggested that differences in reproductive statuses in marine mammals may lead to differences in habitat selections by sex. As female right whales may be reluctant to visit habitats that have less reliable food resources, it is expected that habitats with less reliable food resources be skewed towards males in comparison to habitats with more consistent food sources. In this section, we compare the sex ratio in Jeffreys Ledge to the sex ratio in a known reliable foraging habitat, Cape Cod Bay to test the idea that more males in Jeffreys Ledge is indicative of a less reliable food source there. The number of individuals returning to these two habitats over the course of the study period will also be compared to test the idea of habitat reliability.

An extension of this idea is that differing energetic requirements may prevent females from engaging in far-ranging behavior to visit habitats which may or may not have high-quality food. Indeed, an analysis on right whale sightings by Brown et al. (2001) indicates that female right whales show slightly more site fidelity than males. This is the case in other marine mammals such as the gray seal. Breed et al. (2009) demonstrated that female gray seals showed a preference for foraging locations that were smaller and closer to haul-out sites, and tended to spend less time traveling between foraging sites than males. This suggests that, at least in some marine mammals, males may have "nutritional flexibility", meaning that they may be able to spend more time traveling between habitats which may or may not yield an energetic payoff without a critical loss of energy reserves. If indeed males have more "nutritional flexibility" that would allow them to spend more time moving between potential foraging areas, we would expect to see a male-biased sex ratio in the group of whales seen in both habitats over the course of a single season. We will compare the sex ratio of this group to the sex ratio of the entire population thought to be alive during this time period to detect whether males exhibit greater inter-habitat movement.

Marine mammals select different habitats to meet different behavioral needs, such as rest, reproduction, socialization, foraging, and predator evasion, (Allen et al., 2001), which in turn may lead to demographic differences between habitats. For example, while female sperm whales are mostly restricted to lower latitudes and warmer waters, males disperse widely, and return to these warmer latitudes only to breed (Rice, 1989). Demographic information may be used to provide evidence that an animal is using a specific habitat to meet a specific requirement.

There is reason to believe that the Jeffreys Ledge may fall within a potential right whale mating area, as right whale sightings are frequently documented during the time period when conceptive mating is though to occur. Surface Active Groups (SAGs) are a commonly observed behavior thought to be sexual in nature. While SAGs occur throughout the year, and there is no indication that this behavior occurs more frequently at one time of year or one particularly habitat, calving only occurs at a specific time of year between December and March. Because most other large whales, including the Southern Right Whale, to which the North Atlantic right whale is closely related, have gestation periods lasting twelve to thirteen months, it is thought that mating occurs in the late fall and early winter. Although this has not been confirmed (Kraus et al., 2007), the timing suggests that mating activities could potentially be occurring in Jeffreys Ledge and the surrounding regions.

Further, demographic analysis of Jordan's Basin, located close to Jeffreys Ledge, showed that many known fathers tended to congregate in this area, implicating this region as a potential mating ground (T.V. Cole, personal communication, November 3, 2010). Demographic analysis of surrounding areas may also give insight into the location and extent of a right whale mating ground. From a conservation perspective, because the loss of reproductive females can have a profound impact on the persistence of this species (NMFS, 2010), it is important to understand how this group is using various habitats so that conservation efforts can be directed there. If reproductive females are using one habitat more than others, there is a case for directing increased management efforts to those habitats. If Jeffreys Ledge is also an area where mating takes place, we might expect a higher frequency of known reproductive females (that is, females who have given birth to a calf during their lifetime), to visit that area than an area where mating is not thought to occur. [The distinction of reproductive females is important because as of 2005, 12% of all adult females had never been sighted with a calf (Kraus et al., 2007).] To test this idea that a higher frequency of reproductive females in a habitat might be indicative of a mating ground, we compared the ratio of reproductive females to total individuals in Jeffreys Ledge during the study period to that in Cape Cod Bay. We also compared the ratio of reproductive females to total females in each habitat with the expectation that a mating ground will have a higher frequency of reproductive females.

Differences in foraging behavior due to the differential energetic requirements of reproduction may manifest themselves during the time when a female is pregnant or lactating. Mate & Baumgartner (2003) showed that female right whales who are either pregnant or with a calf spend longer time at the surface in between dives, while Nousek-McGregor (2010) found that positive buoyancy in right whales changes diving behavior, and that females had differences in duration of the ascent and descent phases of their dives that could be attributed to differences in blubber thickness. Lactating females, on average had thinner blubber layers, indicating that reproductive state has the potential to play a role in diving behavior. With the possibility that lactation can influence small-scale foraging behavior, it may also be expected to influence large-scale foraging behavior such as habitat selection. To test this, we compared the ratio of females who brought their calves to Jeffreys Ledge to the total number of reproductive females in the habitat to that in Cape Cod Bay during the study period. Because we expect that lactating females (i.e. those with calves) will have a need for a higher quality feeding ground, we expect to see more females with calves in Cape Cod Bay than in Jeffreys Ledge.

The subsequent chapter on the plankton resource in Jeffreys Ledge will provide additional information about the factors which may influence movement between habitats.

Methods

Jeffreys Ledge boat-based surveys

Between 2003 and 2009 the Whale Center of New England conducted boat-based surveys for right whales between 15 September and 30 December on Jeffreys Ledge using either a 21.3 or 30 m vessel following systematic track lines. In 2005, surveys were conducted through the month of January; however, no right whales were observed during that time. Both vessels were powered by twin diesel engines, and gave observers a height of eye of 5.5 m above the waterline. Surveys were conducted twice weekly on good weather days, with seas of Beaufort 4 or less. If seas became higher than that, survey effort was aborted.

On each cruise, two out of three pre-determined transect lines (Figure 2.1) were surveyed. Track # 1 was drawn over the shallow waters of the Ledge itself, while two parallel survey lines covered the deeper water on the eastern (Track # 3) and western (Track # 2) side of the Ledge. Two smaller V-shaped sections of trackline were included to account for survey effort on the way to and from plankton sampling stations (points A to D in Figure 2.1). Initially, protocol dictated that Track # 1 would be surveyed on every cruise, while alternating which deep water track would be covered on the same day. However, once it became apparent that the majority of sightings were taking place east of the Ledge, Track # 3 was surveyed on each cruise, and alternating Track # 2 and Track # 1. The Jeffreys Ledge study area was defined using these tracks as a guideline. Using ArcMap version 10, a 5km buffer was placed around these tracks, accounting for distance over which a trained observer could spot and record the presence of a right whale from a boat-based platform. The polygon encompassed by this buffer was used to define the Jeffreys Ledge survey area (Figure 2.1). Only effort and sightings that occurred within this polygon were included in analyses.

On several occasions, directed photo-identification surveys were conducted in which the vessel deviated from survey tracklines to target previously identified aggregations of right whales to maximize photo-identification opportunities. These surveys are not included in later calculations of sightings per unit effort; however, animals photographed during these surveys are included in demographic comparisons between habitats and in the calculations of transition probabilities.

On each cruise, three observers scanned for marine mammals. One observer faced towards the front of the vessel while the other scanned the areas to either side of the vessel. All observers were either Whale Center of New England staff or other personnel with extensive experience spotting and identifying whales to species. A principal investigator of the project was almost always assigned as spotting team leader. This person held the forward watch and was also responsible for recording human uses, such as fishing gear and vessels observed in the study area. In addition to the three observers, two additional staff, usually WCNE interns, acted as data collectors and, when necessary, relief observers.

When a cetacean or group of cetaceans was sighted, data collectors recorded the species, number of animals, time, location, distance, bearing from the vessel to the animal, behavior of the animal, whether the vessel broke track for the sightings, photos taken, and any additional notes for the sighting, such as the presence of calves. The observer also determined how sure he/she was of the species determination based on the sighting cues.

If uncertainty existed with the possibility that the animal was a right whale, the vessel slowed and remained on track until the animal was resighted, or the animal was approached for a closer sighting. If the animal was determined to be a right whale, the vessel approached it for identification photographs and behavioral observations. The time spent in the proximity of right whales was determined by the amount of time necessary to obtain quality photographs of all animals in the vicinity. A Canon 10D digital camera equipped with a 75-300 mm focal length lens was used to obtain identification photographs of each animal, ideally capturing the callosity pattern unique to each individual's head. The interval spent in proximity to these animals was usually between 20 and 30 minutes, but varied with surface behavior and dive time of the focal animals.

Behavioral data collected during sightings included respiration rates, dive times, and behavior sequences based on a modified version of an ethogram developed by The Whale Center of New England in its previous work on humpback whales. If insufficient time was spent observing the animal, or if behaviors were ambiguous, no behavior was recorded.

Data on vessel position were recorded every 10 minutes using a GPS interfaced with a laptop computer. Environmental parameters, such as visibility (as estimated by observers), sea state, wind speed and direction were recorded with every position record.

All photos were sent to the New England Aquarium for individual identification, confirmation, and archiving in their sightings database. Sightings were also reported in near-real time to the National Marine Fisheries Service. All approaches to right whales were done under permission of, and with the conditions noted in, marine mammal research permit 65-1607 issued by NOAA Fisheries (WCNE, 2008).

Jeffreys Ledge aircraft-based surveys

The Northeast Fisheries Science Center supplied additional confirmed individual sightings in Jeffreys Ledge between 2003 – 2009 during North Atlantic Right Whale Sightings Surveys. Only sightings that occurred within the area defined in Figure 2.1 were used as part of the analysis. From 2003 until 2007, random stratified broad scale surveys were flown along east-west tracklines bounded by the shoreline on the western end of the line and the Hague Line on the eastern end of the line (Cole et al., 2007). Lines are organized by blocks with 20 parallel lines spaced approximately 2.2 km apart within each block. A line number between 1 and 20 is chosen at random and that numbered line is flown in each survey block. On a survey day, the selected line number is flown eastbound in one block, and then westbound in an adjacent block. 40 of these lines from three different blocks (E, F, and G) pass through the Jeffreys Ledge study area defined previously Figure 2.2, and between 2003 and 2007 31 flights surveyed this region using this survey design .

In 2007, the survey scheme switched from broad scale to a random systematic sawtooth design, in order to maximize coverage over regions where right whales had been regularly seen during broad scale surveys. In this survey design, tracklines are straight, parallel lines, which zig-zag across the study block, ending at points spaced along the survey boundary. This survey scheme is often preferred because it eliminates the need for transit time between survey lines which can be costly in terms of time and money (Buckland et al., 2003). In this sampling scheme, a trackline number is chosen at random, and this trackline zig zags across the length of the survey area. When the boundary of the survey area is reached, a second line zig zags its way back across the survey area in the opposite direction (Figure 2.3). From 2007 – 2009, 12 flights surveyed the Jeffreys Ledge region using this survey design. In 2009, the sawtooth sampling design was modified slightly to the jump sawtooth sampling scheme. Unlike in the sawtooth scheme, there are transit legs between tracklines along the eastern and western edges of the survey (Figure 2.5). The lengths of these transit legs (3 km) between tracklines were not counted in the calculation of sightings per unit effort (SPUE). In 2009, 2 flights surveyed the Jeffreys Ledge region using this survey design.

On ten surveys during the study period, NEFSC conducted management flights to verify or monitor right whale aggregations for Dynamic Area Management (DAM) regulations. DAMs impose temporary commercial fishing restrictions when large aggregations of right whales were reported in an area not covered by Seasonal Area Management zones. During these surveys, parallel tracklines spaced 10 km apart were surveyed according to standard protocol (Figure 2.7). The number and location of these tracklines are dependent on the size and location of the aggregation that prompted the issuance of the DAM. Fourteen management flights took place over the Jeffreys Ledge region during the study period (2003 – 2010).

For all of these aforementioned survey schemes, a DeHavilland Twin Otter high-wing aircraft was used. The aircraft was equipped with a bubble window on each side of the plane to ensure that the observers had a full view both ahead and behind the aircraft. The crew consisted of two pilots, one observer on either side of the plane, and a data recorder. The surveys were conducted at a speed of 100 knots at an altitude of 230 m.

Sightings of all marine animals (except birds), including seals, turtles, sharks and large fish, as well as vessels and fishing gear were recorded using a custom program (VOR, designed by Lex Hiby & Phil Lovell and described in Hammond et al. 1995) which simultaneously logged the time and location of each sighting, as well as a survey waypoint every 5 seconds. Information on the species identification, the observer's confidence in his/her species identification, the number of animals, and the number of calves were recorded for each cetacean sighting. In the event that a right whale or potential right whale was sighted, the plane diverted from the trackline and circled the animal to record a more exact location and for a more accurate determination of behaviors and number of individuals. Photographs were also taken of the callosity pattern on the animal's head for individual identification. After enough photographs were obtained to determine the individual identity of all of the right whales in the aggregation, the plane returned to the trackline at the point where plane had originally diverted.

Throughout the survey, observers also reported environmental variables such as sea state, visibility, weather, cloud cover, and glare. Surveys were aborted if sea state consistently exceeded a Beaufort level of 6 or if visibility was obscured by rain, snow or fog. All photos were sent to the New England Aquarium for individual identification, confirmation, and archiving in their sightings database. Sightings information was also sent to Robert Kenney (University of Rhode Island) and to OBIS-SEAMAP (Duke University; http://seamap.env.duke.edu/). Data were also stored in an in-house Oracle database at the Northeast Fisheries Science Center. All aerial surveys were conducted under the permission of, and with the conditions noted in marine mammal research permit number 775-1875 issued by NOAA Fisheries .

Cape Cod Bay aircraft-based surveys

Sightings of individuals seen in Cape Cod Bay between 2004 and 2010 were obtained from the Provincetown Center for Coastal Studies' right whale aerial survey program. Right whale surveys were conducted between January and May. Surveys were flown along fourteen parallel east-west survey tracklines spaced 1.5 nm apart. Tracklines 3-15 covered the extent of Cape Cod Bay (Figure 2.8). The turn at the end of each survey line was initiated approximately 1.5nm from shore in order to observe any animals close to land. During these surveys, additional tracklines were routinely flown to the north of Cape Cod Bay, as well as to the east of Cape Cod Bay; however, only individuals seen within Cape Cod Bay are used in this analysis (PCCS, 2010).

For these surveys, a Cessna Skymaster high-wing twin engine aircraft was used. The crew consisted of two pilots and two observers. During the flight, a laptop synced to the plane's GPS system recorded a survey waypoint every 5 seconds, including information on altitude, speed, direction, geographic coordinates and time. The observer on the right side of the plane was designated as the data recorder, and would record sighting information into a voice recorder, along with the time of the sighting. The voice recordings were later transcribed into the database created by Logger (IFAW, 2000) for that survey so that each sighting is assigned to the nearest second. This protocol allowed data to be recorded without the data recorder looking away from the aircraft window (PCCS, 2007).

Data recorders logged sightings of all marine animals (except birds), including seals, turtles, sharks and large fish, as well as vessels and fishing gear. When a cetacean or group of cetaceans was sighted, information on the species identification, the likelihood of correctly identifying the species, the number of animals, and the number of calves were recorded. In the event that a right whale or potential right whale was sighted, the plane diverted from the trackline and circled the animal in order for the data logger to record a more exact position, and for a more accurate determination of behaviors and number of individuals. The observer on the left side of the plane was responsible for obtaining photographs were also taken of the callosity pattern on the animal's head in order for individual identification to occur. After enough photographs were obtained to determine the individual identity of all of the right whales in the aggregation, the plane returned to the trackline at the point where the trackline was originally broken (PCCS, 2007).

Throughout the survey, observers also reported environmental variables such as sea state, visibility, weather, cloud cover, and glare. Surveys were aborted if sea state consistently exceeded a Beaufort level of 4 or if visibility was consistently less than 2 nm due to rain, snow or fog. All photos were sent to the New England Aquarium for individual identification, confirmation, and archiving in their sightings database (PCCS, 2007).

All aerial surveys were conducted under the permission of, and with the conditions noted in marine mammal research permit number 633-1763-00, issued by NOAA Fisheries to Charles Mayo (Provincetown Center for Coastal Studies). Surveys of all habitats by year are summarized in Table 2.1. A complete list of surveys can be found in Appendix I.

Great South Channel confirmed sightings

Sightings from the Great South Channel were obtained via a data request to the New England Aquarium and consist of all confirmed individuals seen in this area (Figure 2.9) from either an aerial or boat-based survey or an opportunistic platform. See explanation of confirmed sightings in the following section. This approach for data acquisition was determined to be preferable to acquiring data from individual institutions due to the variety of platforms that have reported right whale sightings in this area during the study period.

Individual identifications

North Atlantic right whales have raised patches of cornified skin along their heads, near their blowholes, along their jawlines, on their chins, and next to their eyes. These patches of skin are known as callosities, and the callosity pattern is unique to every individual right whale. These callosities are inhabited by marine invertebrates known as cyamids. Ranging in color from cream-colored to orange, their bright colors highlight the individual callosity pattern enabling researchers to discern the identity of individual right whales in photographs. Other distinct physical markings such as scars may also be used in conjunction with the callosity pattern to determine the individual identity of a right whale.

Right whale observers are trained to distinguish individual right whales from one another, and matching right whales found in survey photographs to their identity using an online catalog curated by the New England Aquarium is a standard part of the data processing protocol. However, individual identifications are not said to be confirmed unless the match has been examined and approved by one or two researchers at the New England Aquarium. The sighting record then gets integrated into the North Atlantic Right Whale Catalog, along with the date, time, geographic coordinates, an observer code and any observed behaviors (Hamilton et al., 2007). At this point, the sighting is considered confirmed. It is only these confirmed sightings that are included in the following analyses.

Information on an individual's sex is also part of the North Atlantic Right Whale Catalog. Sex can be determined in the following ways. If a right whale is observed in close association with a calf at least 3 times during a season or a year it assumed that that animal is a female. Genetic analysis can also be performed in sloughed skin, biopsy or fecal samples. Quality photographs of the genital area can also be used to determine the sex of the individual (Hamilton et al., 2007).

Sightings per unit effort (SPUE) calculations

Because two different survey platforms were used in Jeffreys Ledge, the sightings per unit effort (SPUE) were calculated separately for each platform by dividing the number of individuals observed on a survey by the total km of tracklines covered on that survey. A monthly SPUE derived from boat-based surveys did not correspond to a monthly SPUE derived from aerial surveys (Figure 2.10), suggesting that it was inappropriate to combine the SPUE between the two platforms.

Unless otherwise stated, SPUE reported for Jeffreys Ledge refers to SPUE derived from the boat-based platform. The boat-based effort was chosen over the aerial effort as the more appropriate way to calculate SPUE for two reasons. One was due to the nature of right whale behavior in Jeffreys Ledge during the survey season. At this time of year, right whales are frequently engaging in long dives, sometimes exceeding 30 minutes. Therefore, observers on a slower moving vessel are thought to be more likely to observe a right whale than observers on a plane (WCNE, 2008). The second reason has to do with the greater frequency of boat-based surveys.

For both platforms in all habitats, SPUE was calculated for the portions of tracklines in which observers were said to be "on watch". Therefore, transit to and from the survey area, time spent off the trackline either searching for an animal, photographing an animal, or collecting plankton samples were not included in the calculation of effort. Additionally, time spent on the trackline when environmental conditions such as high sea state, fog, or precipitation may have prevented an observer from spotting a whale were not included in the calculation of effort. When SPUE for Jeffreys Ledge was calculated, only the whales that were sighted and the portions of the tracklines that occurred within the study area defined in Figure 2.1 were included in the calculation (See figures 2.2 – 2.7). When calculating SPUE, only individuals that were clearly photographed during the survey, even if they could not ultimately be matched, were included in the calculation; however, if the same individual was seen multiple times during a day, it was not included in the calculation of SPUE.

Transition probabilities

The method of calculating transition probabilities in SocProg employs maximum likelihood estimation to calculate the transition probabilities, and bootstrapping methods to estimate their standard errors. This method uses the population size as a known parameter and historical sighting data from the habitats of interest to calculate these probabilities. These transition probability models are considered to be robust even when survey efforts in different areas may be unequal or inconsistent (Whitehead, 2001). Individual identifications from all three habitats from September 2003 – December 2009 were entered into SocProg (Whitehead, 2009), along with the date seen, and the habitat associated with the sighting. Data from 2010 was omitted because at the time of writing, the New England Aquarium had not completed matching for 2010 (H. Pettis, personal communication, March 6, 2012). Only the sightings that occurred between October and May were selected to encompass the primary survey seasons for the Jeffreys Ledge and Cape Cod Bay habitats. The sampling period was set to one month, meaning that the program calculates the probability of transition between areas over the course of a month.

To calculate transition probabilities, the ‘Movement Between Areas’ tool was used. The population was set at 476 to reflect the number of identified individuals thought to be alive during this time period (Right Whale Consortium, 2011). This number differs slightly from the figure cited in the introduction, which was the most recent population estimate from 2011, while the number used in this analysis reflects the population estimate during the study period. The transition probability from Cape Cod Bay and Great South Channel to Jeffreys Ledge was set to zero as our primary focus is whales moving out of Jeffreys Ledge. Additionally, preliminary analysis using the program indicated that movement into Jeffreys Ledge during this time period was close to zero and had a large standard error. Extra areas were part of the estimation to account for the fact that these three areas are not the only three habitats where right whales can be sighted during this time period. The number of bootstrap replicates was set to 1000 so that standards of error could be calculated for this measure. This number of bootstrap replicates was recommended by Whitehead (2009) to obtain precise confidence intervals.

Definition of habitat categories

To compare the sex ratios between whales seen in Cape Cod Bay and Jeffreys Ledge, all confirmed sightings in the previously defined habitats during the study period were used. Individual whales were divided into eight habitat categories, described in Table 2.2. Note that some individuals fall into multiple categories.

To compare the number of reproductive females that visit each habitat, reproductive females were defined as any female right whale known to have given birth in her lifetime.

Statistical analysis

Sex ratios of the different demographic groups were compared to one another using Chi-square tests. A Fisher's Exact Test was used by SPSS when there were a relatively small number of observations, as determined by the program. We compared (1) the sex ratios of all whales seen in Cape Cod Bay to all whales seen in Jeffreys Ledge; (2) the sex ratios of the whales seen only in Cape Cod Bay to the whales seen only in Jeffreys Ledge; (3) the sex ratio of these groups to the sex ratio of the population assumed to be alive at this time; (4) the sex ratio of the population assumed alive to the "Within seasons" group as well as the "adjacent seasons" group.

A Fisher's Exact Test was used to compare the ratio of reproductive females to total individuals in Jeffreys Ledge during the study period to that in Cape Cod Bay. A Chi-square test was also used to compare the frequency of mother/calf pairs to total individuals visiting Jeffreys Ledge during the study period to that in Cape Cod Bay. Finally, a Chi-square test was used to compare repeat sightings in habitats on a yearly basis during the study period. Each individual seen in each habitat was coded as a repeat (seen in multiple years during the study period) or a non-repeat (only seen in one year during the study period). The ratio of repeats to non-repeats in Jeffreys Ledge was compared to the ratio of repeats to non-repeats in Cape Cod Bay. All tests were done using SPSS (PSAW Statistics 18.0).

Results

Habitat overlap

To assess the exchange between and relative use of the Jeffreys Ledge and Cape Cod Bay habitats, we calculated the number of individuals and sex ratios of the whales seen in each habitat and the whales seen in both habitats for each year (Figure 2.12). We also calculated the percentage of animals seen in Jeffreys Ledge and then Cape Cod Bay in the following season (Table 2.3). To address the question of whether the observed changes in adjacency over the study period could be attributed to survey effort, we compared the number of adjacent animals to yearly measures of effort by survey platform (Figure 2.13).

Although the number of individuals seen in Cape Cod Bay is consistently higher than the number of individuals seen in Cape Cod Bay, the number of whales travelling from Jeffreys Ledge in the late fall/early winter to Cape Cod Bay in late winter/early spring is not consistent throughout the years. The number of animals travelling between habitats does not appear to be correlated with effort.

To examine whether right whale sighting conditions in Jeffreys Ledge in one season were mirrored by right whale sighting conditions in Cape Cod Bay in the following season, we compared total sightings per unit effort (SPUE) and trackline effort by month between habitats, by season (Figure 2.14). Non-zero values of SPUE in Cape Cod Bay ranged from .002 individuals km^{-1} in January 2009 to 1.9 individuals km^{-1} in April 2008. Non-zero values of SPUE in Jeffreys Ledge ranged from .006 individuals km^{-1} in November of 2005 to .63 individuals km^{-1} in October of 2009. SPUE can only be directly compared between years in the same habitat because the surveys in different habitats were done on different platforms. SPUE cannot be compared between habitats because the surveys were done on different platforms.

General patterns of SPUE in Jeffreys Ledge in one season are sometimes, but not always echoed by general patterns of SPUE in Cape Cod Bay in the following season, as visualized in Figure 2.13.. The 2005/2006 season is one in which low SPUE values in Jeffreys Ledge were reflected by a similar pattern of low SPUE the following season in Cape Cod Bay in 2006. However, in other seasons such as 2007/2008, moderate SPUE values in Jeffreys Ledge in 2007 were followed by unusually high SPUE values in Cape Cod Bay in 2008. SPUE in Jeffreys Ledge in 2003 is higher than Cape Cod Bay SPUE in 2004, while peak SPUE values in Jeffreys Ledge in 2009 are similar to peak SPUE values in Cape Cod Bay in 2010. Months in which high SPUE values and low trackline effort values occur simultaneously reflect situations in which a large amount of time spent photographing aggregations of individuals prevents completion of the survey. There is no relationship between trackline effort and SPUE in either of the survey areas (Appendix II).

Transition probabilities

Estimated transition probabilities for movement between Cape Cod Bay (CCB), Great South Channel (GSC), Jeffreys Ledge (JL), and an external area are shown in Table 2.4. Within a month, animals are more likely to remain in the area in which they were first identified than to have traveled to a different habitat. Movement from Jeffreys Ledge to Great South Channel over the course of a month is more probable than movement to Cape Cod Bay, although when accounting standard errors these estimates are close. Both probabilities are relatively low. Right whales are more likely to move from the Great South Channel to Cape Cod Bay than to Jeffreys Ledge. The probability of movement from Cape Cod Bay to the Great South Channel is close to the probability of movement from Great South Channel to Cape Cod Bay. Movements in and out of outside areas are low, and have large standard errors.

Habitat reliability

To address the question of whether differences in sex ratios between the habitats could reflect differences in the reliability of the food source between the habitats we performed three tests. First, we compared the sex ratio of all the individuals seen in Jeffreys Ledge during the study period to all of the individuals seen in Cape Cod Bay during the study period using a Chi-square test (Tables 2.5, 2.6). This test showed no significant differences. Second, we compared the sex ratios of individuals seen exclusively in Jeffreys Ledge during the study period to the individuals seen exclusively in Cape Cod Bay during the study period using a Chi-square test (Tables 2.7, 2.8). No significant differences were found. Therefore, the null hypothesis that there is no difference in sex ratios of the right whales visiting Jeffreys Ledge compared to those visiting Cape Cod Bay cannot be rejected.

Third, habitat reliability was tested by comparing the number of repeat individuals (individuals who visited the habitat in multiple years during the study period) compared to the total number of individuals seen in each habitat using a Fisher's Exact Test (Tables 2.9, 2.10), which shows significant differences(χ^2 *(1, N=459) = 81.787, p<.001, Fisher's Exact Test*). This test demonstrated that right whales were likely to re-visit Cape Cod Bay more often than Jeffreys Ledge during the study period.

Nutritional flexibility and site fidelity

To test the idea that male right whales might be more likely to travel between habitats than female right whales, we compared the sex ratio of right whales in the "Within" habitat group (meaning those that were seen in both Jeffreys Ledge and Cape Cod Bay between January and May in a given sighting season), to the sex ratio of the population of right whales presumed alive during the study period using a Chi-square test (Tables 2.11, 2.12).

The results demonstrate that there is a greater male bias in the group of whales seen moving between habitats than would be expected by chance. The null hypothesis that the sex ratios of the "within" group compared to the total population group should be equal can be rejected (χ^2 *(2, N=459) = 6.901, p=.032)*.

Differences in habitat use by reproductive status

To test the idea that a mating area would have a higher frequency of reproductive females than a habitat where mating didn't take place, we performed two Fisher's Exact Tests. In the first test, we tested whether the frequency of reproductive females in Jeffreys Ledge compared to the total number of individuals in the habitat was different than that in Cape Cod Bay. (Tables 2.13, 2.14). In the second test, we tested whether the ratio of reproductive females to non-reproductive females was different than that in Cape Cod Bay. No differences were found in either test. Therefore, the null hypothesis that there was no difference in the frequency of reproductive females in either habitat was not rejected.

To further explore the possibility that animals with different reproductive statuses may be using different habitats, we used the frequency of females with calves compared to the total number of reproductive females, and compared those frequencies between Jeffreys Ledge and Cape Cod Bay using a Fisher's Exact Test (Tables 2.17, 2.18).

This test shows no significant difference. The null hypothesis that the frequency of females observed with calves to the total number of reproductive females is the same in both habitats cannot be rejected.

Discussion

Adjacent movement and transition probabilities

Every season some of the individual animals seen in Jeffreys Ledge during the late fall and early winter are seen in the subsequent sighting season in Cape Cod Bay; however, the percentage of whales seen on Jeffreys Ledge and subsequently in Cape Cod Bay is neither consistent, nor particularly high. Even in 2007/2008, the year where the largest proportion of Jeffreys Ledge whales was seen in Cape Cod Bay, during the subsequent sighting season, less than half of the individuals seen in Jeffreys Ledge during a sighting season were seen in Cape Cod Bay in the following months. This is somewhat surprising given that during some years, as many as 50% of the entire known right whale population visits Cape Cod Bay (PCCS, 2010) It is curious that, given the proximity of Jeffreys Ledge to Cape Cod Bay and the far-ranging behavior of right whales, it cannot be expected that most of the whales seen in Jeffreys Ledge will subsequently be seen in Cape Cod Bay. It is also notable that these inconsistencies in adjacent movement do not seem to be a function of inconsistent yearly effort. In fact, the years with the highest percentage of adjacent individuals occur during years when the number of yearly surveys and overall trackline effort are relatively low (Figure 2.13).

Adding the Great South Channel to the transition probability analysis lends more insight into the complexity of movement of right whales from the late fall through the early spring. Although the majority of right whales are expected in the Great South Channel in the late spring in early summer, after they have mostly left Cape Cod Bay

(Kenney et al., 2001), both the data set and the transitional probability analysis suggest that the Great South Channel might be a more important winter destination than previously expected, and provides further support that the currently accepted model of right whale movement between habitats is overly simplistic.

The transition probability of whales moving from Jeffreys Ledge to Cape Cod Bay over the study period also illustrates that this exchange is not as high as would be expected given the proximity of the habitats. The higher transition probability from Jeffreys Ledge to the Great South Channel compared to Cape Cod Bay suggests that right whales might be traveling to the Great South Channel in the early part of the year before heading to Cape Cod Bay, rather than moving directly from Jeffreys Ledge to Cape Cod Bay as previously expected.

There are several reasons why the results of the transition probability analysis must be interpreted with caution. One is the lack of survey effort in Cape Cod Bay from October – December during this study period. Although right whales are not generally expected in this area at that time of year (Kenney et al., 2001), the inconsistent site fidelity and far ranging behavior of right whales discussed in the introduction imply that right whales do not always follow an expected pattern of movement. Additionally, because the windows of time for effort in the different habitats restricted the analysis to months between October and May, the transition probability from Cape Cod Bay to the Great South Channel is likely to be an underestimate, as the Great South Channel is considered the primary late spring and early summer feeding area for right whales (Kenney et al., 2001). The choice of a month as a sampling period was a reflection of the lack of consistent, fine-scale, concurrent surveys in all habitats during the study period. Increasing the frequency of surveys and extending the survey seasons in these habitats would allow for finer scale transition probability analysis that might yield different results.

Sex ratios

As there was no significant difference between the sex ratio of Jeffreys Ledge whales compared to Cape Cod whales, it is not possible to draw conclusions about habitat reliability based on demographic patterns in habitat use. However, since Cape Cod Bay is more likely than Jeffreys Ledge to be visited by an individual in multiple years over the study period, it is likely that the reliability of resources in Cape Cod Bay compared to Jeffreys Ledge is equally important to both sexes.

The hypothesis that males have more flexibility than females in terms of their nutritional and energetic needs to travel between habitats is supported by a comparison of the "within seasons" group to the "all habitats group". There is a significantly higher number of males in the "within seasons" group that expected, given the sex ratio of the population thought to be alive at that time, suggesting that males are more likely to travel between Cape Cod Bay and Jeffreys Ledge. Most of the sightings of this "within seasons" group came from aerial surveys of Jeffreys Ledge in January and February. This is a time when many females can be expected in the Southeastern US calving habitats. Aerial surveys of Jeffreys Ledge in the winter occur infrequently, and the sample size of the within group is low, so these results must be interpreted with caution.

The lack of difference in the number of reproductive females visiting Jeffreys Ledge compared to the number of reproductive females visiting Cape Cod Bay does not allow us to draw conclusions about whether this habitat is used as a mating ground. Our study does not provide enough evidence to fully reject that idea, however. It is possible that the area covered by the study was too small to provide a significant dataset. More specific studies in the future might include sightings from the areas surrounding Jeffreys Ledge, as well as retrospective analyses which would use genetic analysis and photo ID data to determine whether the parents of right whale calves were documented in this region a year prior to the calf's birth.

Jeffreys Ledge also does not appear to play a different functional role than Cape Cod Bay for mothers with calves. The proportion of females seen with calves to reproductive females was not significantly different between habitats. This is somewhat surprising considering given that the food resource in Jeffreys Ledge is thought to be relatively poor compared to Cape Cod Bay, and one would expect lactating females to prefer habitats with higher food quality. However, there is not a great deal of background data on the quality of the food resource in Jeffreys Ledge. The topic of prey quality will be explored in the following section, including a discussion of technical problems that have prevented an in-depth analysis of the prey quality in this area. It is possible that the food resource in Jeffreys Ledge is not as poor as previously believed, which would explain the equal likelihood of lactating mothers to visit the area.

Data considerations

A major caveat of these analyses involves the disparate survey methodologies in these habitats. Aerial surveys are able to cover more trackline miles and may give a better vantage point for spotting whales, especially if they are just sub-surface. In habitats like Jeffreys Ledge, where both aerial and boat-based surveys take place, this means that sightings per unit effort data cannot be combined. It also means that any comparison of SPUE between survey platforms must be viewed cautiously.

Right whale behavior also has the potential to alter sighting probability. In Jeffreys Ledge, whales are often recorded on long, presumably deep dives with a typical dive interval lasting 8-12 minutes (WCNE, 2008). With long dive times like this, it is expected that some individuals will be missed, particularly on aerial surveys. Longer dives are typical in Cape Cod Bay towards the beginning of the sighting season; however, during late March and early April, right whales are typically skim feeding (PCCS, 2008; PCCS, 2010). This surface behavior makes them much more likely to be spotted, photographed, and identified.

Any surveys attempted in the Gulf of Maine, especially during the winter months are also subject to adverse weather conditions such as high seas, fog, and precipitation which can hinder an observer’s ability to spot whales or prevent surveys from taking place entirely. Long stretches of poor weather are not uncommon; in these conditions individuals visiting the areas are sure to be missed. The extent to which this affects the results of these analyses is unknown.

Although our definitions of habitat boundaries and sighting seasons represent an informed attempt to characterize areas important to right whales, they impose artificial limitations on time and space that are unlikely to completely account for the factors that right whales use to select their habitats and their movements between habitats. These human-imposed boundaries might also cause problems when comparing sightings in different habitats due to the differences in sizes of each habitat. For example, the area defined as the Great South Channel habitat covers an area of 24,734 km^2, compared to Cape Cod Bay which is 1,560 km^2 and Jeffreys Ledge which is 2,022 km^2, according to the study area defined for this project. A larger area might mean that there are more individuals present, but because larger areas require more effort than other areas to complete a survey, individuals using this habitat may be more likely to be undocumented.

Finally, although 2010 was left out of the transition probability analysis using SocProg, the other sections of interhabitat movement included 2010. The New England Aquarium has not completed matching and confirming all of the individuals seen in 2010. It is expected that all 2010 matches will be confirmed in the spring of 2012 (H. Pettis, personal communication, March 6, 2012). Therefore, any additional conclusions about movement from Jeffreys Ledge to Cape Cod Bay from 2009 to 2010 must be made with caution. The low overlap of individuals in the Jeffreys Ledge and Cape Cod Bay habitats from 2009 – 2010 may be a function of incomplete matching.

Conclusions

Despite our limited ability to monitor wide-ranging right whale movement on a fine temporal scale, photo-identification remains a useful tool in allowing us to examine the movements of a large number of individuals as well as to examine demographic patterns in habitat use. We have shown that less than half of the individuals seen on Jeffreys Ledge in the late fall and early winter can be expected in Cape Cod Bay in the late winter and early spring. Transitional probabilities indicate that the Great South Channel might be an alternate destination for right whales in the first few months of the year. We have also shown that while there are no differences in the sex ratios or reproductive status between the individuals using Jeffreys Ledge and Cape Cod Bay, there does seem to be a significant male bias in the number of individuals that travel between these habitats in the first few months of the year. Finally, our results indicate that during the study period, individuals were more likely to visit Cape Cod Bay with greater frequency than Jeffreys Ledge. These results clearly demonstrate the need for more frequent, concurrent survey effort in multiple areas so that the complexity of movements between areas can be described, and the role of the Jeffreys Ledge habitat can be clarified. These results also highlight the need for a management plan which accounts for the complexity of these movements.

TABLES

Table 2.1. Summary of survey effort in Jeffreys Ledge and Cape Cod Bay from 2003 – 2010. CCB refers to Cape Cod Bay and JL refers to Jeffreys Ledge. WCNE refers to Whale Center of New England; NEFSC refers to Northeast Fisheries Science Center; PCCS refers to Provincetown Center for Coastal Studies.

Season	**Org**	**Region**	**# surveys**	**#km surveyed**
2003/2004	WCNE	JL	23	3433.5
	NEFSC	JL	10	614.27
	PCCS	CCB	26	10102.66
2004/2005	WCNE	JL	26	3408
	NEFSC	JL	11	507.6
	PCCS	CCB	35	14021.492
2005/2006	WCNE	JL	24	3101
	NEFSC	JL	11	521.2
	PCCS	CCB	32	12188.012
2006/2007	WCNE	JL	13	1642
	NEFSC	JL	11	789.1
	PCCS	CCB	30	11286.088
2007/2008	WCNE	JL	11	1445
	NEFSC	JL	7	1141.4
	PCCS	CCB	25	7604.312
2008/2009	WCNE	JL	13	1527
	NEFSC	JL	6	1085.4
	PCCS	CCB	17	6596.824
2009/2010	WCNE	JL	9	831
	NEFSC	JL	7	997.4
	PCCS	CCB	25	9538.9112

Table 2.2. List of habitat categories and description of the individuals in each category.

Habitat Category	Definition	# Individuals
All Habitats	All members of the population presumed to be alive between 2003 - 2010	476
CCB and/or JL	Individuals seen in either habitat between 2003 – 2010	340
Both Habitats	Individuals seen in both habitats between 2003 – 2010	111
CCB	Individuals seen in Cape Cod Bay between 2004 – 2010	315
JL	Individuals seen in Jeffreys Ledge between 2003 – 2009	142
CCB Only	Individuals seen in Cape Cod Bay and not Jeffreys Ledge between 2003 - 2010	196
JL Only	Individuals seen in Jeffreys Ledge and not Cape Cod Bay between 2003 - 2010	34
Adjacent Seasons	Individuals seen in Jeffreys Ledge between September - December of one year and then Cape Cod Bay the following season (January - May).*	50
Within Seasons	Individuals seen in both Jeffreys Ledge and Cape Cod Bay within a single sighting season (January - May)	21

*For example, an individual seen in October 2007 in Jeffreys Ledge and then seen in March of 2008 in Cape Cod Bay would fall into this category.

Table 2.3. Number of individuals seen in each habitat by year. # Adjacent column reflects the number of individuals seen in Jeffreys Ledge during a sighting season (September – December) and subsequently in Cape Cod Bay the following season (January – May). % Adjacent column reflects the percentage of whales seen in Jeffreys Ledge during a sighting season that are subsequently seen in Cape Cod Bay the following season.

Season	**JL Individuals**	**CCB Individuals**	**# Adjacent**	**% Adjacent**
2003/2004	14	60	2	14.3
2004/2005	21	45	5	23.8
2005/2006	4	63	1	25.0
2006/2007	29	126	12	41.3
2007/2008	50	192	23	46.0
2008/2009	32	193	12	40.6
2009/2010	16	124	0	0.0

Table 2.4 Transition probabilities of individual right whales moving between study areas in one month from October 2003 – December 2009. Months were restricted from October – May. Numbers in parentheses are the standard errors estimated by bootstrap resampling.

	To CCB	**To GSC**	**To JL**	**Out**
From CCB	0.6523	.3476 (.111)	.000	.0000 (.050)
From GSC	.3323 (.082)	0.5268	.1186 (.063)	.0222 (.050)
From JL	.1232 (.077)	.2594 (.082)	0.6174	.0000 (.058)
Out	.0000 (.077)	.0006 (.078)	.0422 (.050)	0.9592

Table 2.5. Sex ratios of all individuals seen in Cape Cod Bay over the study period (AllCCB) and all individuals seen in Jeffreys Ledge during the study period (AllJL). "U" refers to individuals whose sex has not been determined at the time of the analysis.

			Category		Total
			AllCCB	AllJL	
Sex	F	Count	99	44	143
	M	Count	158	80	238
	U	Count	49	20	69
Total		Count	306	144	450

Table 2.6. Results of a Chi-square test comparing the sex ratios of all individuals seen in Cape Cod Bay to the sex ratios of all individuals seen in Jeffreys Ledge

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.672[a]	2	.714
Likelihood Ratio	.676	2	.713
N of Valid Cases	450		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 22.08.

Table 2.7. Sex ratios of all individuals seen only in Cape Cod Bay over the study period (CCBOnly) and all individuals seen in only in Jeffreys Ledge during the study period (JLOnly). "U" refers to individuals whose sex has not been determined at the time of the analysis.

Count

		Category		
		CCBOnly	JLOnly	Total
Sex	F	67	12	79
	M	94	17	111
	U	35	6	41
Total		196	35	231

Table 2.8. Results of a Chi-square test comparing the sex ratios of individuals seen only in Cape Cod Bay to the sex ratios of individuals seen only in Jeffreys Ledge.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.011[a]	2	.995
Likelihood Ratio	.011	2	.995
N of Valid Cases	231		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.21.

Table 2.9. Number of individuals visiting Jeffreys Ledge and Cape Cod Bay multiple times during the study period. Individuals in the Y category are considered repeat visitors.

		Repeats		
		N	Y	Total
Region	CCB	94	221	315
	JL	108	36	144
Total		202	257	459

Table 2.10. Results of a Chi-square test comparing the the frequency of repeat individuals compared to total individuals in Cape Cod Bay to that in Jeffreys Ledge.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	81.787[a]	1	.000		
Likelihood Ratio	83.757	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	459				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 63.37.

Table 2.11. Sex ratios of all individuals thought to be alive in the population during the study period (AllHab) compared to the sex ratio of individuals seen in both Jeffreys Ledge and Cape Cod Bay in a given sighting season (between January and May) (Within Season). See table 1.2 for further explanation of these categories

		Category		
		ALLHab	Within Season	Total
Sex	F	171	3	174
	M	224	16	240
	U	81	2	83
Total		476	21	497

Table 2.12. Results of a Chi-square test comparing the sex ratios of all individuals in the population presumed to be alive during the study period to the sex ratio of the individuals seen moving between habitats.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.901[a]	2	.032
Likelihood Ratio	7.260	2	.027
N of Valid Cases	497		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.51.

Table 2.13. Number of reproductive females compared to the total number of individuals seen in each habitat during the study period.

		Region		
		CCB	JL	Total
Calving	N	261	118	379
	Y	54	26	80
Total		315	144	459

Table 2.14. Results of a Fisher's Exact Test comparing the ratio of reproductive females to the total number of individuals between habitats.

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.057[a]	1	.811		
Likelihood Ratio	.057	1	.811		
Fisher's Exact Test				.793	.453
N of Valid Cases	459				

Table 2.15. Number of reproductive females in each habitat compared to the total number of females in each habitat.

		Region		Total
		CCB	JL	
Calving	N	49	19	68
	Y	54	26	80
Total		103	45	148

Table 2.16. Results of a Fisher's Exact Test comparing the ratio of reproductive females to the total number of females between habitats.

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.361[a]	1	.548		
Continuity Correction[b]	.178	1	.673		
Likelihood Ratio	.362	1	.547		
Fisher's Exact Test				.594	.337
McNemar Test				.	
N of Valid Cases	148				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 20.68.

b. Computed only for a 2x2 table

c. Both variables must have identical values of categories.

Table 2.17. Number of females seen with calves in each habitat compared to the total number of reproductive females seen in each habitat over the study period.

		Female Seen w/Calf		Total
		N	Y	
Region	CCB	39	15	54
	JL	16	10	26
Total		55	25	80

Table 2.18. Results of Chi-square test comparing the ratio of females seen with calves to the total number of reproductive females seen in each habitat.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.932[a]	1	.334		
Continuity Correction[b]	.501	1	.479		
Likelihood Ratio	.916	1	.338		
Fisher's Exact Test				.440	.238
N of Valid Cases	80				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.13.

b. Computed only for a 2x2 table

FIGURES

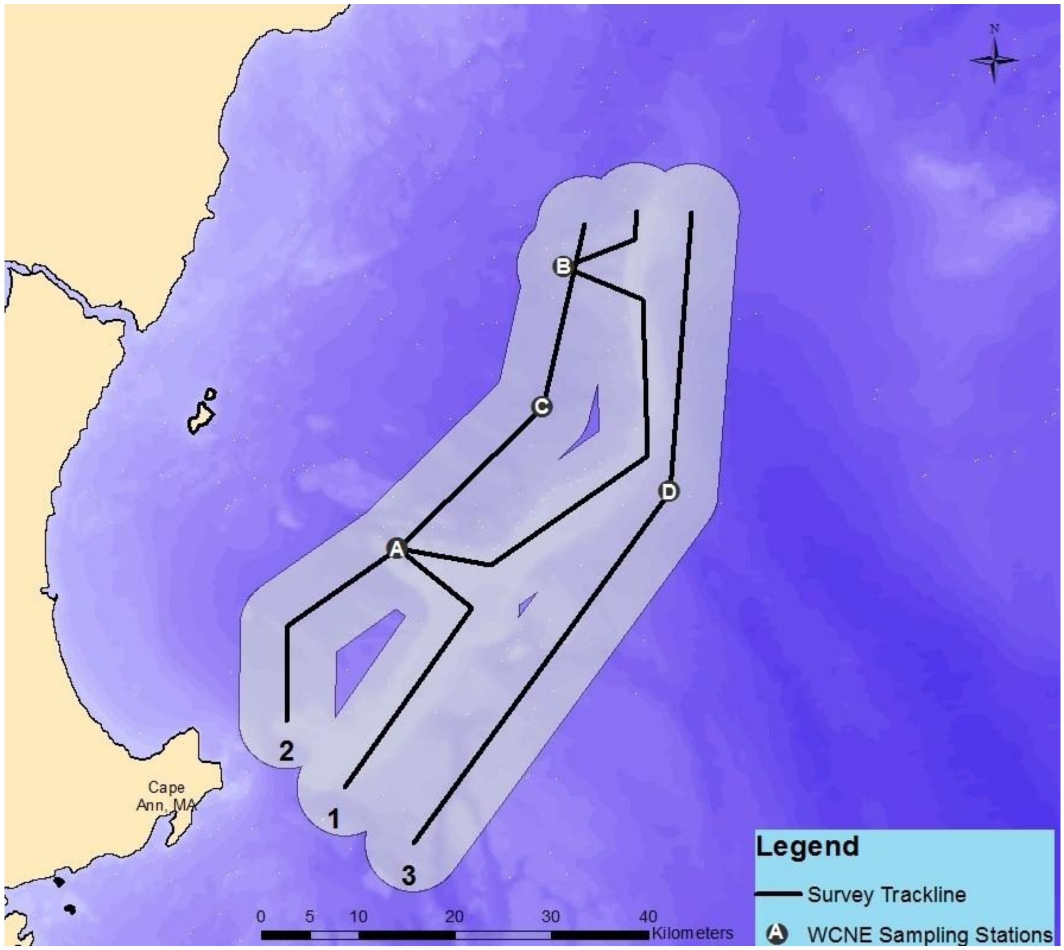


Figure 2.1 Whale Center of New England boat-based survey tracklines and plankton sampling stations in Jeffreys Ledge. Highlighted polygon defines Jeffreys Ledge study area, bounded by region within 5km of survey tracklines.

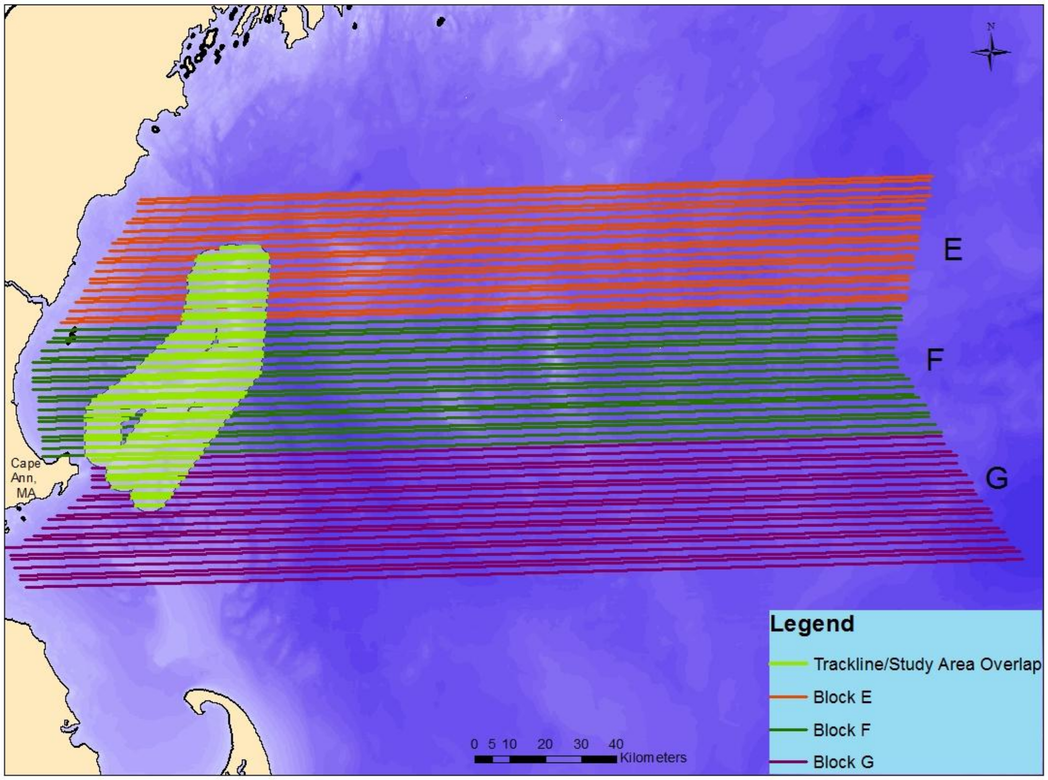


Figure 2.2. Broadscale survey lines flown by Northeast Fisheries Science Center. Segments of the trackline that overlap with the Jeffreys Ledge study area defined in Fig. 2.1 are highlighted in bright green.

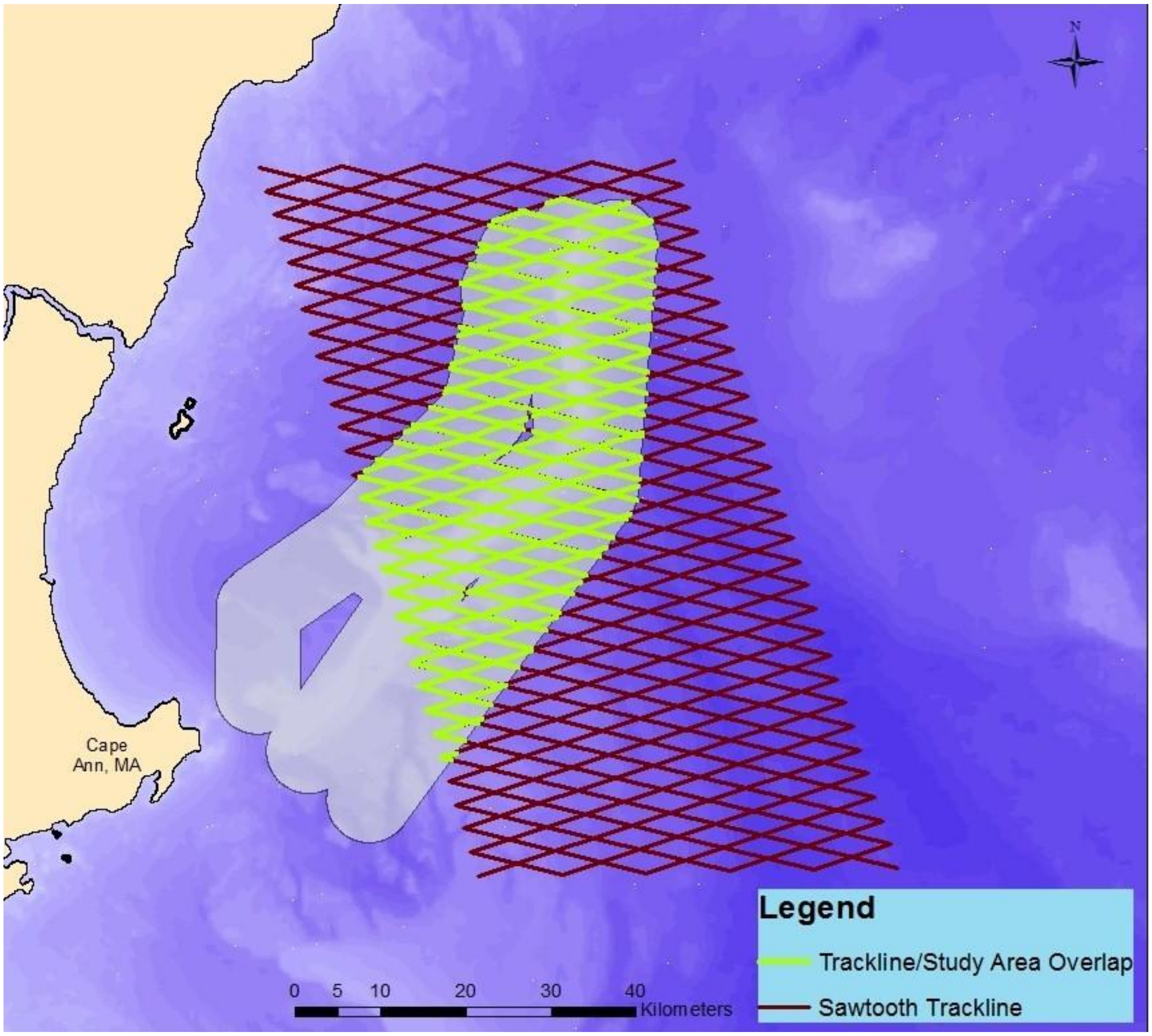


Figure 2.3. Sawtooth survey lines flown by Northeast Fisheries Science Center. Segments of the trackline that overlap with the Jeffreys Ledge study area defined in Fig. 1 are highlighted in bright green.

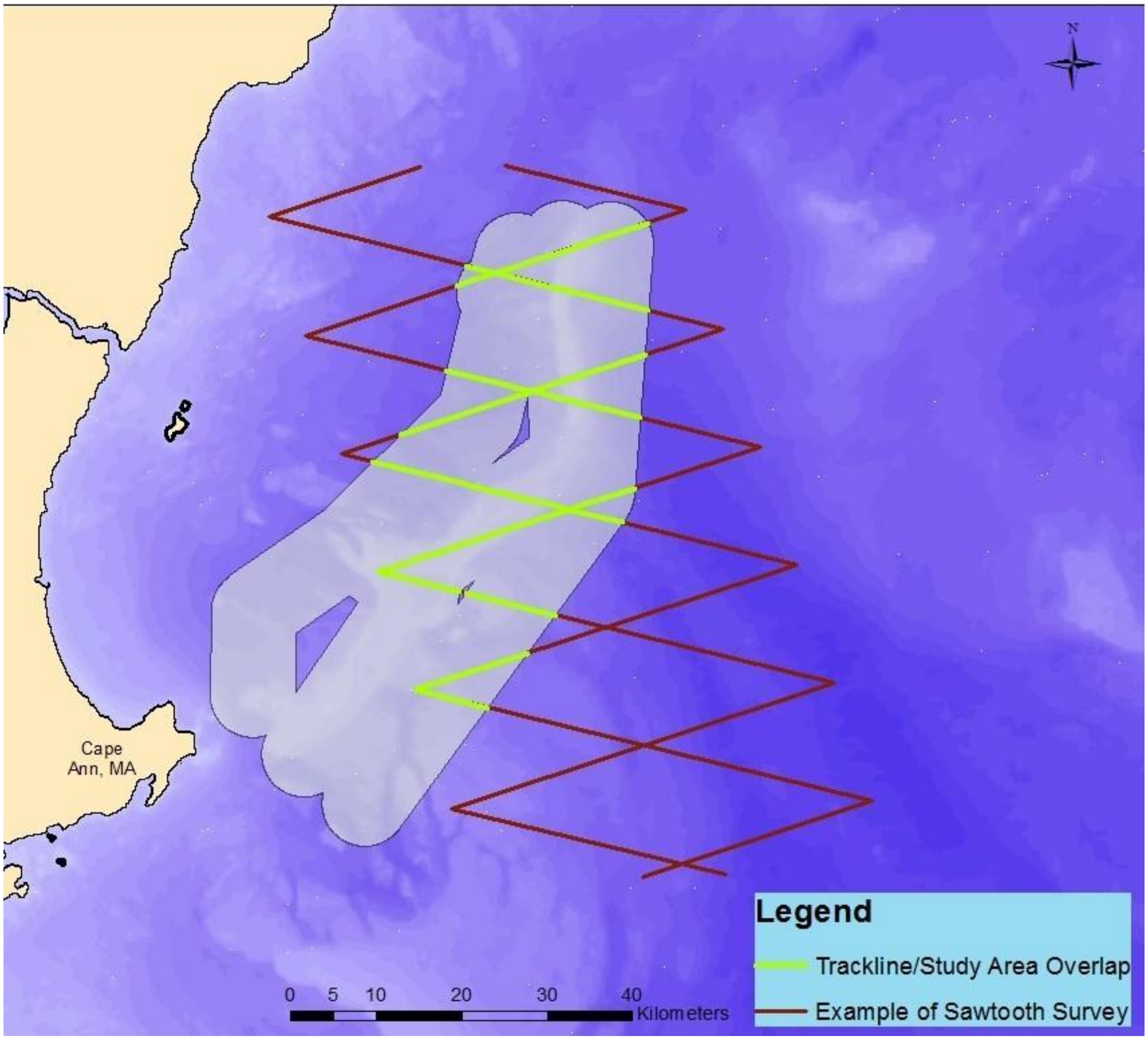


Figure 2.4 Example of an aerial survey flown by Northeast Fisheries Science Center using the Sawtooth sampling scheme. Segments of the trackline that overlap with the Jeffreys Ledge study area defined in Fig. 1 are highlighted in bright green.

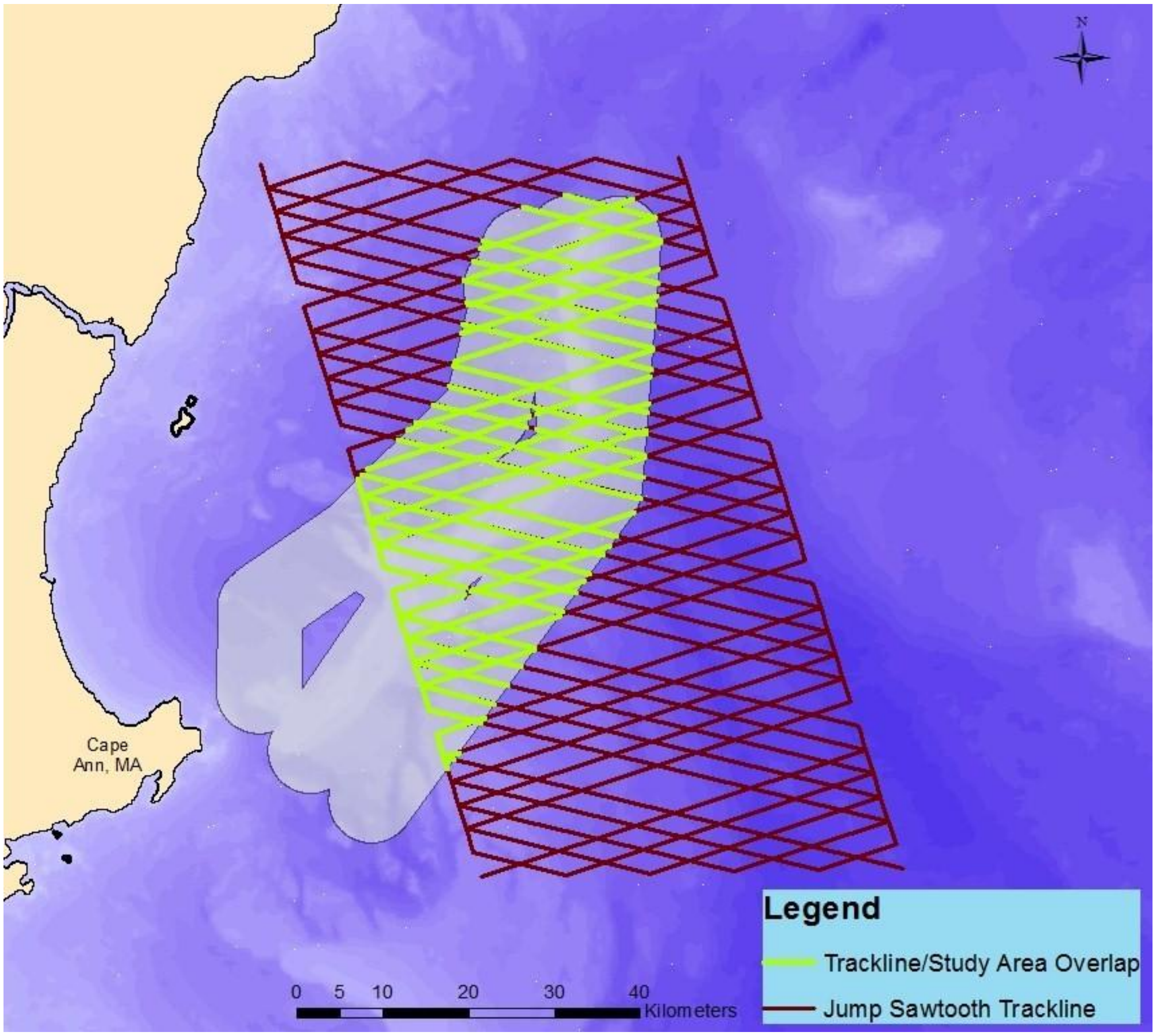


Figure 2.5. Jump Sawtooth survey lines flown by Northeast Fisheries Science Center. Segments of the trackline that overlap with the Jeffreys Ledge study area defined in Fig. 1 are highlighted in bright green.

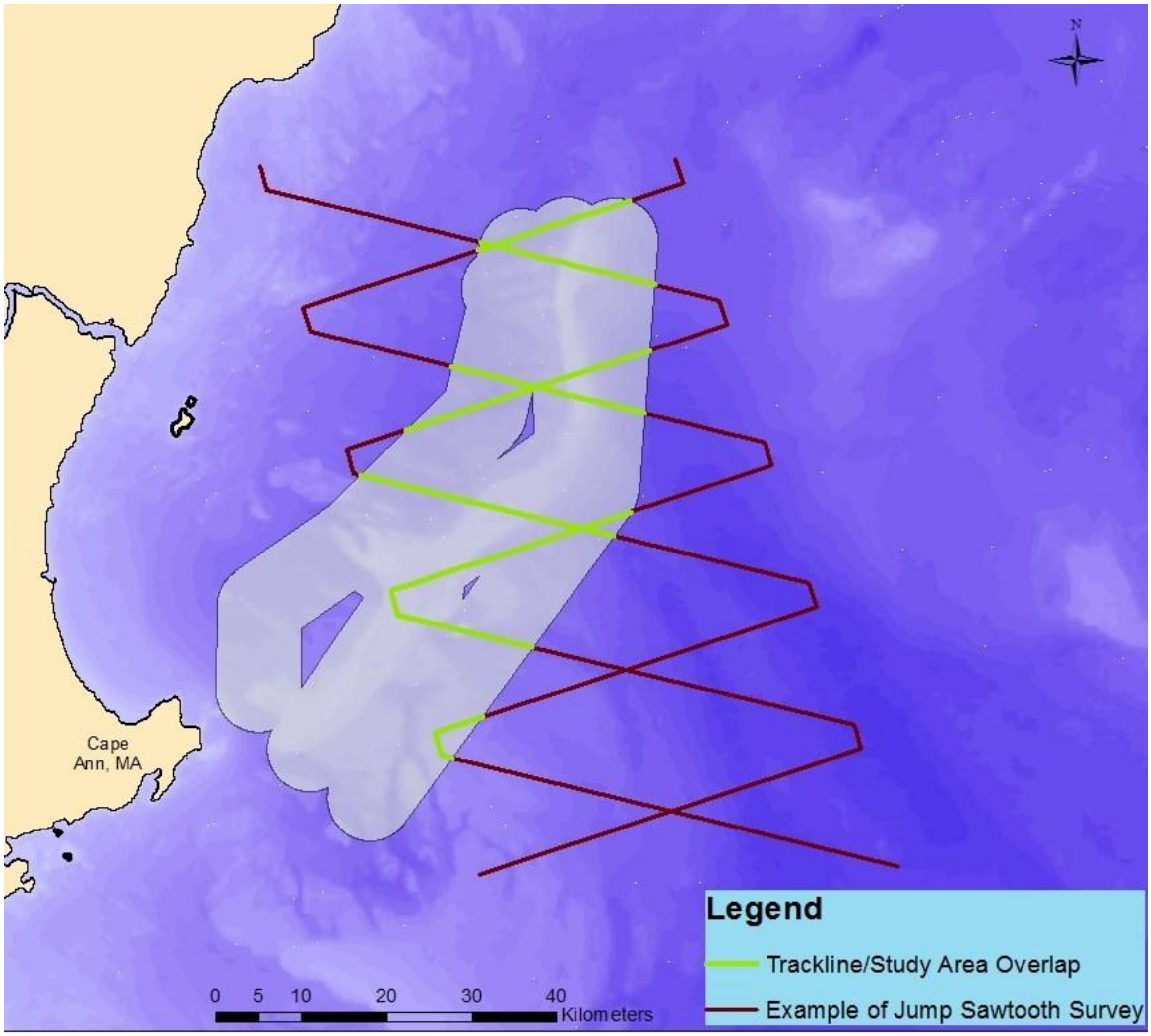


Figure 2.6. Example of an aerial survey flown by Northeast Fisheries Science Center using the Jump Sawtooth sampling scheme. Segments of the trackline that overlap with the Jeffreys Ledge study area defined in Fig. 1 are highlighted in bright green.

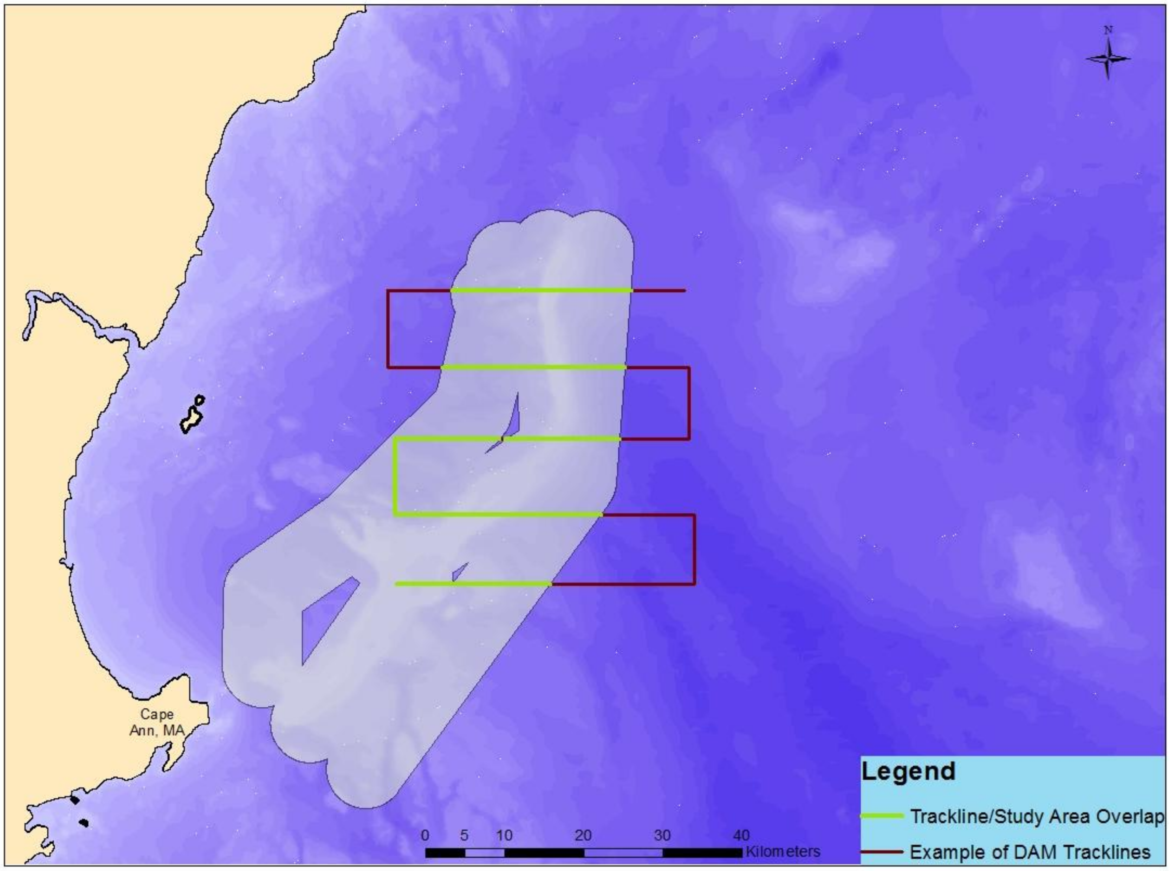


Figure 2.7. Example of a Dynamic Area Management Plan flight flown by NEFSC. Number and locations of tracklines are determined by right whale aggregations. Segments of the trackline that overlap with the Jeffreys Ledge study area defined in Fig. 1 are highlighted in bright green.

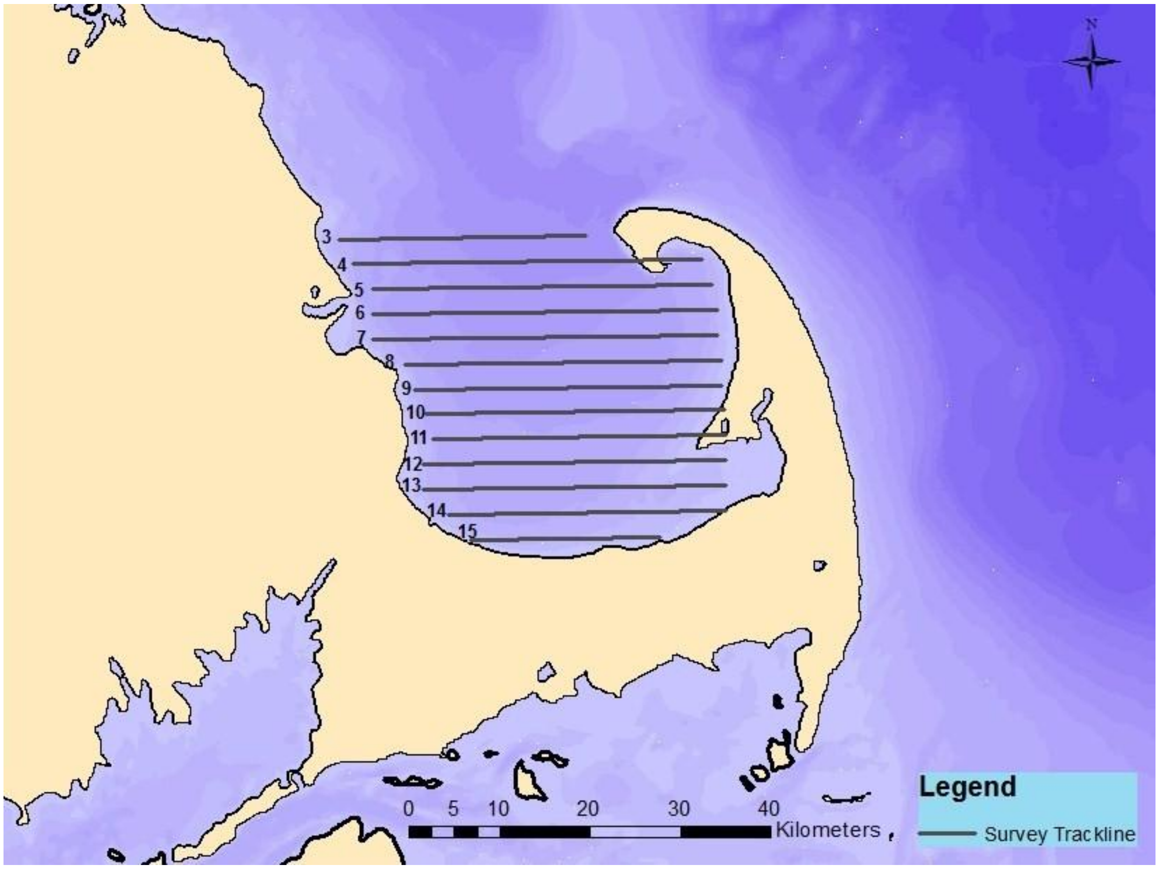


Figure 2.8. Provincetown Center for Coastal Studies aerial survey tracklines in Cape Cod Bay.

Figure 2.9. Habitat boundaries of the Great South Channel, Jeffreys Ledge and Cape Cod Bay, as used in analyses of habitat exchange and transitional probabilities.

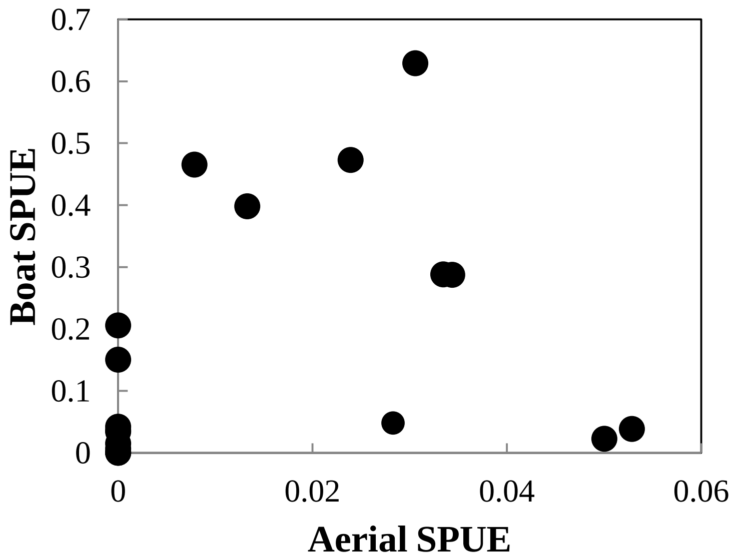


Figure 2.10. Aircraft-based sightings per unit effort (SPUE) compared to boat-based sightings per unit effort in Jeffreys Ledge. Each point represents a month in which both boat-based and aircraft-based effort occurred in Jeffreys Ledge.

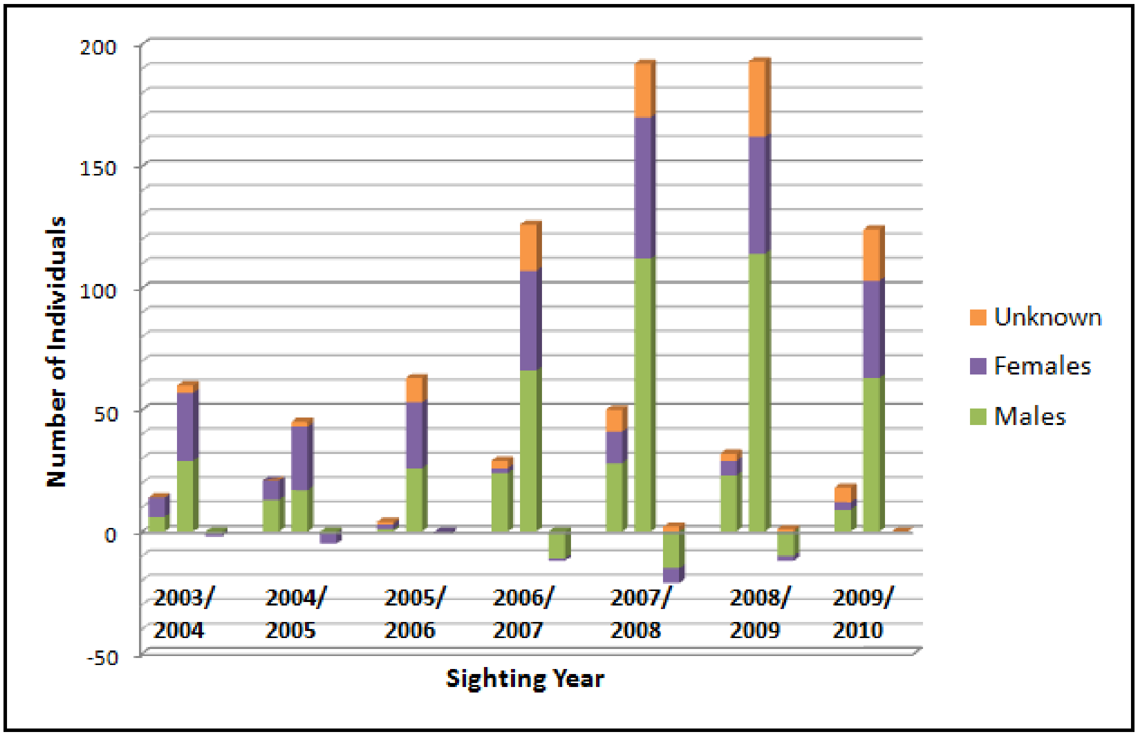


Figure 2.11 Breakdown of individuals by sex seen in Jeffreys Ledge, Cape Cod Bay, and in adjacent seasons by year. The leftmost column of every year represents whales seen in Jeffreys Ledge during a sighting season (September - December). The middle column represents the whales seen in Cape Cod Bay in the following season (January – May). The rightmost, negative column represents the adjacent animals –that is, the individuals seen in Jeffreys Ledge during one season and Cape Cod Bay in the subsequent season.

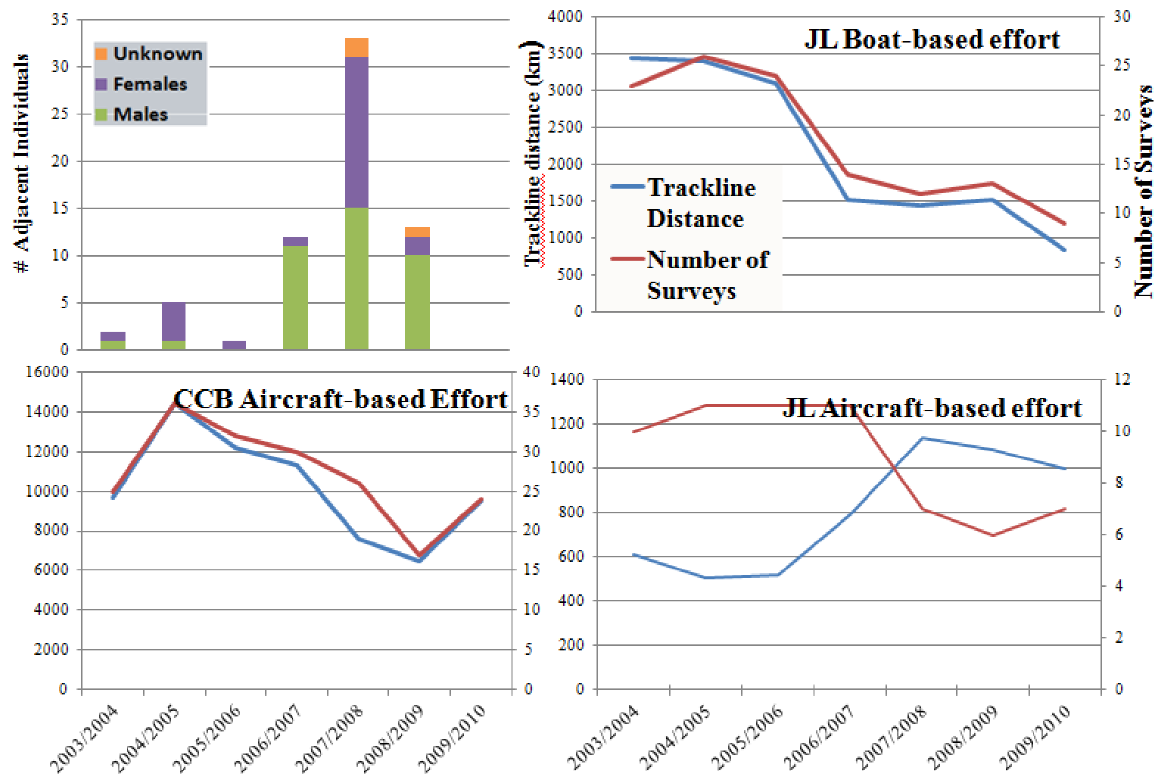


Figure 2.12. Number of individuals traveling between Jeffreys Ledge and Cape Cod Bay by season, compared to effort from each survey platform. JL refers to Jeffreys Ledge and CCB refers to Cape Cod Bay.

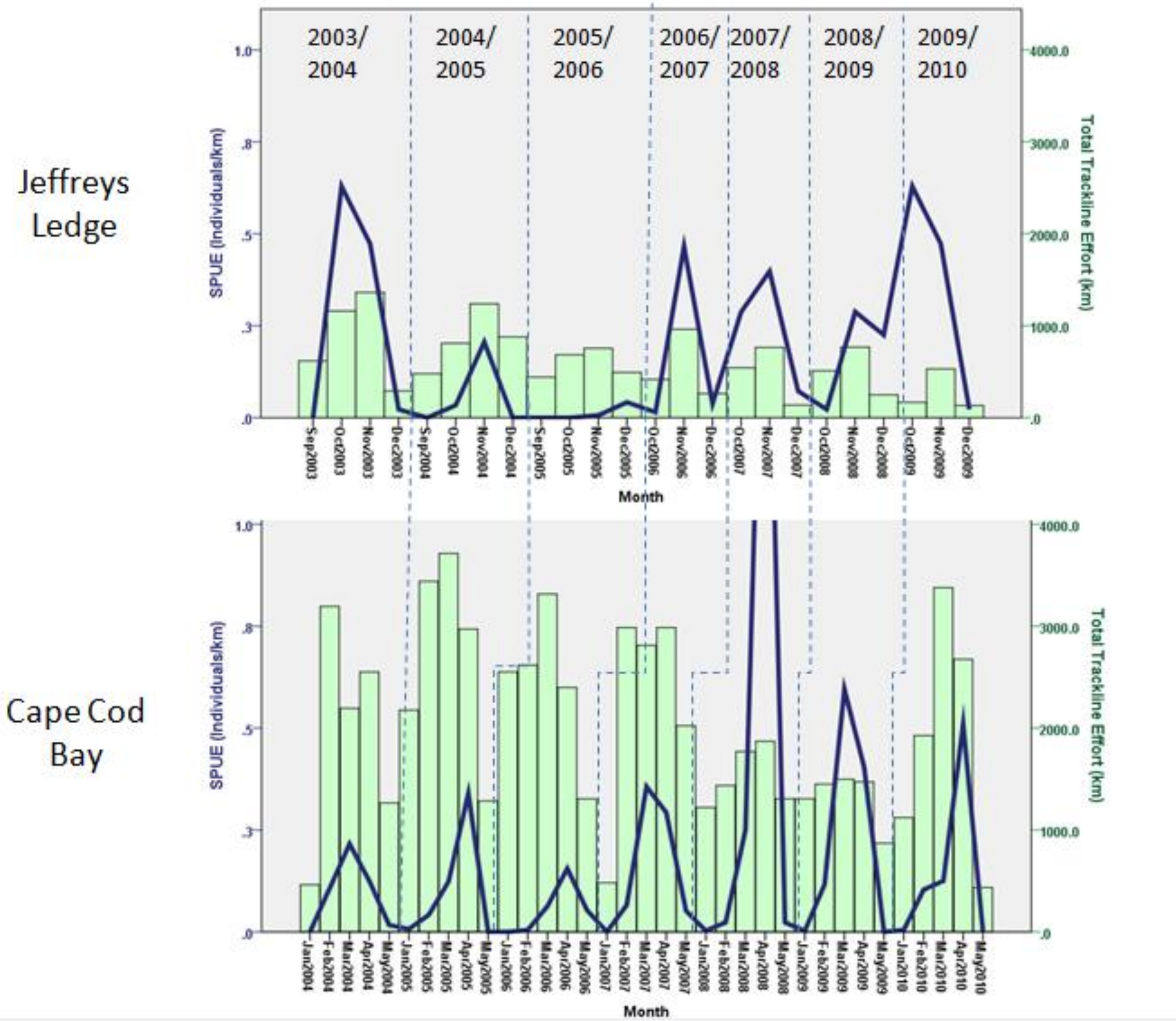


Figure 2.13. The total SPUE by month (shown in blue) compared to the total trackline effort by month (shown in green) in both habitats by season. The highest SPUE value (not shown) was 1.9 in April 2008.

CHAPTER 3

INVESTIGATING THE RELATIONSHIP BETWEEN PREY QUALITY AND RIGHT WHALE SIGHTINGS IN JEFFREYS LEDGE

Introduction

The North Atlantic right whale belongs to a sub-order of Cetacea known as the baleen whales, or Mysticetes. Unlike toothed whales, baleen whales use the bristles along the insides of the keratin plates which line their mouth to filter their prey. Right whales are further classified in the family Balaenidae which includes species which feed using a method known as ram filter feeding. This involves opening their mouths and swimming forward, constantly filtering water and zooplankton through their baleen. The fine bristles of right whale baleen are particularly efficient at capturing mesoplankton such as calanoid copepods. *Calanus finmarchicus* is the primary prey item of the North Atlantic right whale throughout their feeding grounds in the western North Atlantic. Late-stage *C. finmarchicus* are characterized by an energy-rich oil sac and have higher caloric content than other species of copepods found in the Gulf of Maine. However, right whales have also been known to feed on other copepod species including

Pseudocalanus spp. and *Centropages typicus*, particularly when abundance of *C. finmarchicus* is low (Mayo & Marx, 1990; Baumgartner et al., 2007).

While the ram filter feeding strategy allows right whales to capitalize on energy-rich species typical of lower trophic levels, in doing so, their open mouths create an enormous amount of drag. It is believed that in order for it to be energetically worthwhile to open their mouth to feed, the density of plankton must reach a critical threshold of 3,750 organisms m^{-3} (PCCS, 2008a). Estimates of daily caloric requirements for a right whale are thought to fall between 407,000 and 4,140,000 kilocalories (1,702,888 – 17,321,760 kilojoules) (Kenney et al., 1986).

An implication of this enormous energetic requirement is that a large portion of their life is dedicated to locating areas of dense and persistent plankton patches. Rather than occurring homogeneously throughout their habitats, the right whale's planktonic prey occurs in dense patches in the water column, their appearance and persistence dictated by oceanographic forces (Baumgartner et al., 2007). Zooplankton are also known to undergo diel vertical migration, in which plankton remain at depth during the day to avoid visual predators and migrate to the surface at night to feed (Johnson et al., 2005). The forces controlling the presence and size of plankton patches are so complex that, to date, researchers have not been able to precisely predict where or when these patches will occur on a fine scale (Baumgartner et al., 2007).

Although fine scale patch formation is difficult to predict, on a larger scale, patches of zooplankton, and by extension, feeding right whales, occur with some level of predictability. For example, in Cape Cod Bay, sightings of skim-feeding right whales generally increase in late winter and early spring as the energy-rich copepod *C. finmarchicus* reaches later stages of development. By contrast, on Jeffreys Ledge, sightings of feeding right whales are less predictable. In this habitat, right whales are seen skim-feeding only occasionally and are more frequently observed on long, presumably deep, dives. Both of these behaviors suggest that right whales use this habitat as a foraging ground to some extent (WCNE, 2008), if deep dives can, in fact, be interpreted as foraging bouts targeting deep-water plankton layers.

Although right whales sightings occur in Jeffreys Ledge with some degree of consistency, an investigation of right whale habitat quality and significance in Jeffreys Ledge took place between 2005 and 2006 in which the food resources were found to be rather poor. In a report to the Marine Mammal Commission (PCCS, 2008b), the Provincetown Center for Coastal Studies (PCCS) suggested three possible explanations for the observed results. One explanation was that the sampling scheme did not accurately reflect conditions on Jeffreys Ledge. The second was that the two years studied were anomalous, and that better conditions exist in other years. The third was that Jeffreys Ledge is not as significant as the other major described habitats, and is, instead, a "marginal" habitat, where right whales occasionally go to forage but which tends to provide a relatively unstable food resource. Ultimately, the report was inconclusive due to small sample sizes and inconsistent survey effort (PCCS, 2008b). By pooling Jeffreys Ledge plankton data collected between 2003 and 2009, this study seeks to further clarify whether or not foraging is likely to be the primary activity of right whales using this habitat.

While it is not known precisely how right whales locate their prey, it is believed that on a large scale, abiotic cues such as topography, currents, and sounds may direct right whales to their prey, while on a smaller scale, a combination of environmental factors and chemosensory cues might direct right whales to plankton patches (Kenney et al., 2001). The association between right whales and dense patches of zooplankton has been well-documented in several habitats including Cape Cod Bay (Mayo & Marx, 1990) and the Greath South Channel (Wishner et al., 1988). In the Bay of Fundy and the Scotian Shelf, Baumgartner & Mate (2003) documented right whale dives which corresponded to the depths at which peak abundance of stage V *C. finmarchicus* occurred, and Michaud & Taggart (2007) documented a significant positive relationship between sightings per unit effort and caloric density in this habitat. There has also been some success in modeling Gulf of Maine-wide *C. finmarchicus* abundance and right whale arrival times, frequency of right whale sightings, and mean SPUEs in the Great South Channel (Pendletown, 2009; Pershing et al., 2009), as well as a relationship between the abundance of other copepod species and right whale sightings in Cape Cod Bay (Pendleton, 2009). However, this relationship has never been adequately documented in Jeffreys Ledge.

In this study, the value of Jeffreys Ledge as a feeding site for right whales will be assessed by examining the relationship between plankton quality and whale sightings in Jeffreys Ledge. Specifically, I ask whether there is a relationship between the daily SPUE for a survey and the mean or maximum caloric density, as well as the relationship between daily SPUE and densities of specific copepod species. I also examine the relationship between the estimated caloric values at sampling stations and whale presence/absence at a station, as well as ask whether the type of sampling station (opportunistic vs. regular; whales present/absent) is a significant predictor of caloric density at a station.

In other known right whale feeding grounds, specifically Cape Cod Bay, habitat quality is successfully used as a predictor of where and when large aggregations of right whales will occur. This information is used by state agencies to make management decisions with the intent of lessening the risk of right whale mortality through vessel strikes and entanglement in fishing gear (PCCS, 2010). If it was confirmed that right whales were regularly using the Jeffreys Ledge habitat as a feeding ground, plankton quality in this area could ideally be used to make similar predictions.

Methods

Jeffreys Ledge tows

The Whale Center of New England conducted plankton tows during boat-based right whale surveys from 2003 – 2009. In 2003, two reference stations, A and B (Figure 2.1) were chosen on trackline 1 to be the sites of 5-minute surface plankton tows. In 2004, two additional reference stations, C and D were added on tracklines 2 and 3, respectively. Additionally, vertical tows were also conducted.

Following this modification, during each survey one vertical tow per trackline was taken. In the case of trackline 1, a coin flip determined which station would be sampled on that survey. A surface tow was also taken at one of those two stations. The station at which this tow occurred was also chosen randomly. If whales were seen skim feeding near the station tow, a surface tow would also be conducted.

Plankton tows were conducted opportunistically whenever possible when a right whale was observed. In some cases, the presence of sei whales (*Balaenoptera borealis*) prompted an opportunistic plankton tow due to the similarities in their diets (Mitchell 1974; Payne et al., 1990; Schilling et al., 1992). In this case, the whales' behavior determined whether or not a surface or a vertical tow was conducted. If the whale was observed feeding at or near the surface, a surface sample was taken. If no near-surface feeding was observed, a vertical tow was conducted. In these cases, the sample was taken as close to the whale, or, if possible, as close to the whales' mouth, as possible (WCNE, 2008). Samples were preserved immediately in a 6-8% formalin solution.

In 2005 and 2006, PCCS also conducted plankton sampling in the region at 8 additional stations in Jeffreys Ledge aboard the R/V Shearwater (Figure 3.1). To account for the fact that aboard WCNE cruises, photographing and identifying right whales was considered the primary priority of the survey, these additional stations provided greater spatial coverage for habitat sampling in Jeffreys Ledge. These additional tows were conducted according to the protocols outlined above, with the following exceptions:

1. Surface samples taken aboard the R/V Shearwater were collected by towing the net horizontally along a circular course. A circular course was chosen to permit the sampling to take place in water that was relative undisturbed by the vessel's wake.

2. Vertical samples were conducted to depths of 50m.
3. Samples were kept on ice in seawater aboard the vessel and fixed in formalin in the laboratory (PCCS, 2008b)

Surface tows were conducted using a 333 μm mesh net, equipped with a Digital Mechanical Flow-meter from General Oceanics, Inc. Tows were made approximately 15 m behind the vessel, while moving forward at a speed of 2 kts for five minutes.

Vertical tows were conducted using a 333 μm mesh net equipped with a Digital Mechanical Flow-meter from General Oceanics, Inc. In 2004, the net was extended 25m below the surface and raised vertically. In the remaining years, the depth of the tow was shortened to 19m.

Data collected along with each plankton tow included time, position, station (A, B, C, D, or near whale), flow-meter start and end, whale number and species in the vicinity, distance to whale(s) ((within 2km, within 100m or in path), behavior of focal whale(s), and any additional notes.

Plankton samples were analyzed under sub-contract to the Provincetown Center for Coastal Studies (WCNE, 2008).

Enumeration

To estimate the density and the taxonomic identities of the zooplankton in a sample, a sub-sample was taken from each tow. A minimum of 200 individuals was required in each subsample for an accurate representation of the taxa in the sample.

To obtain a subsample, the sample is strained through 333 μm mesh, rinsed of formalin, and the organisms are transferred to a beaker. Depending on the number of organisms in the sample, enough water is added to the beaker such that 5 ml of that sample volume contains at least 200 organisms. This volume of water is known as the sample volume and is used in the calculation of density.

The sample was then stirred gently until the organisms are even distributed in the volume of water. Using a Hensen-Stempel pipette, a 5 ml aliquot sample was taken from the overall sample and transferred to a watch glass. This aliquot volume was known as the counted volume and was also used in the calculation of density. In most cases, the counted volume was 5ml; however, if the number of organisms in the aliquot sample was less than 200, additional aliquot samples were taken and counted until the total number of organisms counted exceeded 200. In cases where the sample contained very few organisms, the entire sample was counted and the counted volume was considered equal to the sample volume (McCauley, 1984). In cases where the initial sample was very dense, a Folsom plankton splitter was used to dilute the sample. In these cases, the sample volume was multiplied by 2^n, where n=number of times the sample was split (McEwen et al., 1954).

Plankton samples were identified and enumerated using identification keys and descriptions by Wilson (1932), Todd et al. (1996) and Gerber (2000). All zooplankton were identified at least to the level of genus. *Pseudocalanus* spp. included species of *Pseudocalanus* spp. and *Paracalanus* spp were grouped due to the fact that their physical similarities make them very difficult to distinguish. *C. finmarchicus, Centropages* spp., and *Pseudocalanus* spp. and were identified to the level of stage and, in some cases, sex. These taxa are thought to be favored by the North Atlantic right whale, and in other habitats, such as Cape Cod Bay, appear to influence the occurrence and behavior of North Atlantic right whales (PCCSa, 2008). *C. finmarchicus*, and *Centropages* spp. were assigned to a life stage of <IV, V and adult. All adults were identified as male or female (Gerber, 2000). *Pseudocalanus* spp. were classified as either early (<IV) or late stage, but no sex was identified.

Calculation of density and energetic density

Zooplankton density was expressed in # of organisms m^{-3} and was calculated separately for surface and vertical tows. A faulty flow meter on the net used for vertical tows necessitated that the volume of water that passed through the net was calculated using the diameter of the net and the depth to which the net was dropped. Zooplankton density was then calculated using the following equation:

$$Total\ zooplankton\ \cdot m^{-3} = Total\ Zooplankton\ \cdot \frac{sample\ volume}{counted\ volume} \cdot \frac{1}{2\ \cdot sample\ depth\ \cdot 0.26}$$

Here, .26 represents the area of the net opening (m^2). The sample depth is multiplied by two to account for the fact that water passes through the net opening as the net is lowered and as the net is raised.

This method is not ideal as the drift of the boat is likely to increase the amount of water moving through the net, so these values should be seen as a conservative estimate

(Sameoto et al., 2000); however, in the absence of a functional flow meter this was the only way to estimate density.

Following damage to the net normally used for vertical tows, the net used for surface tows was used for vertical tows on 11/13/2008 and 11/21/2008. On these occasions, the equation was adjusted to account for the different diameter of the surface tow net.

For surface tows, a flow meter was used to calculate the volume of water passing through the net during a tow. As water flows through the net, numbers advance on the flow meter, while a flow meter constant is added to the equation which measures how much water flows through the net with every tick of the meter. The flow meter constant takes the diameter of the net into account. In this case, the flow meter constant was determined through calibration to be .0014 and the equation used to calculate the density of the surface sample is as follows (Sameoto et al., 2000):

$$Total\ zooplankton\ \cdot m^3 = Total\ Zooplankton\ \cdot \frac{sample\ volume}{counted\ volume} \cdot \frac{1}{(meter\ end - meter\ start) \cdot 0.0014}$$

Energetic density was calculated using copepods only and therefore represent a conservative estimate of caloric density at each sampling station. The caloric values (expressed in kilocalories) for each copepod are from DeLorenzo Costa et al. (2006) and are summarized in Table 3.1, along with their equivalent in kilojoules. These values were used to estimate the energetic of the copepods found at each sampling station by calculating the total number of kilojoules per sub-sample and entering them into the previous equations in place of the "Total Zooplankton" variable.

Sightings per unit effort and plankton characteristics

To examine the relationship between SPUE (sightings per unit effort) and plankton characteristics, we compared SPUE to energetic density and proportions of *C. finmarchicus* at vertical sampling stations. Only surveys from October – December were included so that yearly plots had similar temporal extents. Only data from vertical plankton tows were used, as these represented the majority of plankton tows during the study period. Additionally, right whales were observed surface feeding on very few occasional throughout the study period, suggesting that sub-surface plankton samples were more likely to be representative of the whale's target prey. However, this restriction meant that 2003 was excluded from these plots due to the paucity of vertical tows from that year.

Statistical analysis

All statistical analyses were performed using SPSS. To test for a difference in caloric values between vertical and surface plankton tows, a univariate analysis of variance (ANOVA) was carried out. The results of this test were used to justify separating analyses by tow type in the following statistical tests. A binary logistic regression was used to test the predictive value of caloric density of a station on whale presence/absence at a station. Two tests were performed: one on vertical samples and one on surface samples. A generalized linear model was used to test whether the station type was a significant predictor of caloric density at the station. Here, caloric value was the dependent variable and station type was the random factor. Station types included Rn (Regular sampling station at which no whale was present in the vicinity), Rd (Regular sampling station at which at least one right whale was present in the vicinity) and Sd (Opportunistic sampling station chosen due to the presence of a right whale). Two tests were performed: one on vertical samples and one on surface samples. Samples were separated because a Levene's (homogeneity of variance) test revealed that surface samples had a different distribution than vertical samples.

Results

The effect of tow type (vertical or surface) on caloric value was found to be significant (*ANOVA*, *p=.015*) with vertical tows having significantly smaller caloric densities than surface tows (Table 3.2). In analysis of plankton characteristics in Jeffreys Ledge, vertical and surface samples were analyzed separately, and in certain cases, surface samples were omitted completely for reasons discussed in the methods section.

Sightings per unit effort and plankton characteristics

To examine the relationship between SPUE (sightings per unit effort) and energetic density in Jeffreys Ledge, SPUE and mean energetic density (expressed in kilojoules m^{-3}) from vertical tows were plotted against survey day on the same graph (Figure 3.2). Plots were separated by survey season.

In some years, such as 2005, low overall SPUE was associated with low energetic density in the study area. In 2004, overall SPUE values were relatively low, despite high energetic density at some stations, while in 2007, the peak in SPUE was concurrent with very low energetic density. 2006 was the only year in which peak SPUE corresponded with high energetic density at some stations (Figure 3.2). A scatter plot of energetic density and SPUE revealed no relationship between the two variables when all the years were combined (Figure 3.3).

To examine the relationship between SPUE and species composition, SPUE and the proportions of *C. finmarchicus* (Figure 3.4), *Centropages spp.* (Figure 3.6), and *Pseudocalanus spp.*(Figure 3.8) in each sample were plotted against day of season. SPUE was plotted on the same graphs. Plots were separated by survey season (Figures 3.4, 3.6, 3.8).

There appeared to be no relationship between the proportion of *C. finmarchicus* at a station and the SPUE (Figures 3.4, 3.5). In 2005, SPUE was low throughout the season despite high proportions of *C.finmarchicus* at many survey stations throughout the season, whereas relative low proportions of *C. finmarchicus* in 2007 were measured concurrently with peak SPUE values for that year. In most years, there was a large variation in the proportions of *C. finmarchicus* observed at different sampling stations on the same survey date.

There were no observable trends in the proportions of *Centropages spp.* during the study period (Figures 3.6, 3.7). Except for 2004 and early 2005 when most stations exhibited low proportions of *Centropages spp*., there was large variation in proportions of

Centropages spp. within and between survey dates and between years. There were no observable changes in SPUE associated with changes in the proportion of *Centropages spp*., although the small spike in SPUE in 2005 did coincide with a peak measurement of *Centropages spp*. proportion for that year. Similar variation within and between years existed in the proportions of *Pseudocalanus spp.*(Figure 3.8). Wide variation existed within a survey date, throughout seasons and across the study period.

The proportion of *C. finmarchicus, Centropages spp.,* and *Pseudocalanus spp.* showed no trend against SPUE when all years in the study period were combined (Figures 3.5, 3.7, 3.9).

Energetic density and whale presence/absence

A binary logistic regression was used to test the predictive value of the energetic density of surface samples on whale presence/absence. While there was a significant relationship between energetic density and whale presence/absence (*p=.001*)(Table 3.4), energetic density correctly predicted whale absence 97.5% of the time but correctly predicted whale presence only 25.6% of the time (Table 3.3).

Results were similar when vertical samples were tested. There was a significant relationship between energetic density and whale presence absence (*p=.028*) (Table 3.6). Energetic density could correctly predict whale absence 98.8% of the time, but the model was not powerful in predicting whale presence (Table 3.5).

In both vertical and surface tows, low energetic density was a good predictor of whale absence, but high energetic density was a poor predictor of whale presence.

Energetic density and station types

A generalized linear model was used to test whether the station type (Regular station with no whales (Rn), Regular station with whales (Rd), Opportunistic station with whales (Sd)) was a significant predictor of caloric density at the station. Testing surface samples only, we found that both the Rd and the Rn stations have significantly less energetic density than the opportunistic stations ($p=.03; p<.001$) (Table 3.7).

In a second generalized linear model testing only vertical samples (Table 3.8), Rd and Sd stations were not significantly different, although there was a large standard error for the Rd effect estimate. However, the Rn stations were found to have significantly smaller caloric densities (B= -156.104) compared to the Sd stations (p=.003). In this case, the station type could accurately predict the difference in caloric values between Sd stations and Rn stations 85.1% of the time (Table 3.8).

Discussion

Sightings per unit effort and plankton characteristics

The finding that energetic density was significantly smaller in vertical samples compared to surface samples was probably a result of the sampling methodology. In most of the vertical samples, the net was dropped to a depth of 19 m, although in some cases the net was dropped to 25 m or 50 m. Station A was the shallowest sampling station, with an average depth of about 50 m; however, the remaining samples were taken at locations where depths were far greater. Station C had an average depth of 180m, and many opportunistic stations were in depths of 180 – 200 m. This means that vertical tows were only sampling a small fraction of the water column. This is especially problematic because from the late summer to mid-winter, stage V *C. finmarchicus* is known to go into diapause, a dormant state that conserves energy during times of low food availability. During these times of dormancy, diapausing *C. finmarchicus* settle at the bottom of the water column (Hirche, 1996). In other habitats, such as the Bay of Fundy, right whales are thought to target these energy-rich diapausing copepods, diving to depths exceeding 90 m (Baumgartner & Mate, 2003). Therefore, it is possible that vertical samples taken in Jeffreys Ledge did not capture the layer of zooplankton that the whales were targeting.

The absence of a flow meter on the vertical net also likely caused an underestimation of the plankton density, and by extension, the energetic density of the vertical samples. As discussed in the methods, drift from the boat is likely to occur while a vertical sample is being dropped, causing more water to flow through the net than is captured by the equation (Sameoto et al., 2000).

These issues in sampling methodology also likely contributed to the lack of correlation between sightings per unit effort, energetic density, and species composition. It is possible that deep layers of diapausing copepods are what draw right whales to the area, but that the lack of sampling range and precision do not allow us to measure the relationship between SPUE and plankton characteristics. It is also possible that factors which skew the calculation of SPUE contribute to this lack of correlation. Because SPUE is calculated based on how many kilometers of trackline are surveyed , unusually high SPUE values sometimes occur when a large amount of survey time is spent photographing large aggregations of individuals, and a relatively small amount of time is spent on the trackline.

It is also possible that food is not the primary factor drawing right whales to the area. As discussed in section 1, Jeffreys Ledge and the surrounding areas have been identified as a possible mating ground for right whales, so the lack of a relationship between plankton characteristics and whale sightings might indicate that right whales are using this habitat for purposes other than feeding.

Some patterns between energetic density and whale presence were observed from the binary logistic regressions. However, while low energetic density appeared to be a good predictor of whale absence, high energetic density was not powerful in predicting whale presence. The lack of power of high energetic density at a station to predict whale presence is most likely caused by the small sample size of stations at which whales were present.

A generalized linear model also gave some support of a relationship between whale presence and caloric density. Opportunistic stations had significantly higher energetic density than both types of regular sampling stations (whale present vs. whale absent) when surface tows were tested. In vertical samples, regular stations with no whales had significantly lower energetic density than opportunistic stations. The distinction between opportunistic samples and both types of regular sampling stations is likely because opportunistic surface samples were most likely to be taken near whales which were surface feeding, meaning that the researchers could more precisely target the area where the plankton layer was likely to be dense by sampling as close to the whale as possible.

The weak relationship between plankton characteristics and whale sightings is likely due to one of two factors. Either the sampling methodology failed to capture the layer of prey targeted by the whale, or the prey quality is not, in fact, the primary factor drawing whales to the study area. Future studies should focus on targeting deeper layers of plankton to characterize the quality of zooplankton for the entirety of the water column. While net tows are the least technologically-advanced methods of evaluating zooplankton density in a region, they are valuable in that they permit detailed analysis of taxa, life stage, and gender of individual copepods at a specific location; however, they are not able precisely target plankton layers concentrated at a specific depth, and samples taken at deeper depths require winches and cables to retrieve the net. Future studies of the plankton resource in Jeffreys Ledge should focus on targeting the depths in the water column at which whales are likely to be feeding. An optical plankton counter (OPC) might be useful in identifying the depths at which large concentrations of zooplankton might be occurring in order to decide the depth to which the net will be dropped (Sameoto et al., 2000)

Determining that food is not the primary reason drawing whales to the area would be of equal value, lending further support to the idea that this habitat might be part of a mating area for the species. As discussed in Chapter 2, the timing of right whale occurrences in Jeffreys Ledge coincides with the time period during which conceptive mating is thought to take place (Kraus et al., 2007). If more thorough plankton sampling techniques were to continue to yield low values of energetic density in the study area, that would provide support for the idea that right whales are using this habitat for reasons other than foraging.

Alternately, this habitat could be a habitat with marginal food quality where right whales occasionally stop and forage on their way to better feeding areas. It may be that the occasional energy-rich plankton patch in Jeffreys Ledge might make it worthwhile for right whales to forage in this region during times of year when plankton quality in other habitats is also poor. Updating the plankton sampling regime to include more sampling stations and to target specific depth would clarify which of these scenarios is the most likely. Assessing the relationship between whale sightings and plankton quality could potentially allow for predictions of whale aggregations, allowing conservation managers to lower the risk of ship strikes and entanglement in fishing gear.

Conclusions

Technical facets of the plankton sampling methodology made it difficult to establish a positive correlation between right whale SPUE and prey quality in Jeffreys Ledge. However, we have shown a weak relationship between low energetic density and right whale absence, as well as a significant difference in caloric densities at different plankton sampling station types. These results suggest that more comprehensive plankton sampling would be of value in determining the quality of the prey resource in this region.

TABLES

Table 3.1. Estimate of species, stage and stage-specific energy density of copepods (From DeLorenzo Costa et al., 2006).

Species/Stage/Sex	**Caloric Value(kCal)**	**Caloric Value (kJ)**
C. finmarchicus ≤IV	0.2644	1.1062496
C. finmarchicus ≥V	1.8623	7.7918632
C. finmarchicus Female	1.6346	6.8391664
C. finmarchicus Male	2.0977	8.7767768
Pseudocalanus spp. ≤IV	0.03	0.12552
Pseudocalanus spp. ≥V	0.1991	0.8330344
Centropages spp. ≤IV	0.08	0.33472
Centropages spp. V	0.0704	0.2945536
Centropages spp. Female	0.1562	0.6535408
Centropages spp. Male	0.1331	0.5568904
Acartia hudsonica	0.04	0.16736
Temora longicornus	0.12	0.50208
Tortanus discaudatus	0.2	0.8368
Oithona spp.	0.02	0.08368
Other	0.02	0.08368

Table 3.2. Results of a univariate analysis of variance testing the effect of tow type on energetic density at a sampling station**.**

Parameter	**B**	**SE**	**T**	**Sig.**	**Observed Power***
Intercept	386.447	62.962	6.138	0	1.000
Vertical tow	-196.354	80.165	-2.449	0.015	0.686
Surface tow	0**				
	*Computed using alpha=.05				
	**Parameter set to zero because it is redundant				

Table 3.3. Logistic model from a Binary Logistic Regression measuring predictive power of effect of energetic density of surface samples on whale presence/absence.

Observed		Predicted: Whale Presence		Predicted: Percentage Correct
		Absent	Present	
Step 1	Absent	117	3	97.5
	Present	29	10	25.6
	Overall Percentage			79.9

Table 3.4. Results of a binary logistic regression testing the effect of energetic density of surface samples on whale presence/absence

		B	SE	Wald	df	Sig.	Exp(B)
Step 1	Energetic Density	.001	.000	11.396	1	.001	1.001
	Constant	-1.582	.230	47.473	1	.000	.206

Table 3.5. Logistic model from a binary logistic regression measuring predictive power of effect of energetic density of vertical samples on whale presence/absence.

Observed		Predicted: Whale Presence		Predicted: Percentage Correct
		Absent	Present	
Step 1	Absent	163	2	98.8
	Present	84	7	7.7
	Overall Percentage			66.4

Table 3.6. Results of a binary logistic regression testing the effect of energetic density of vertical samples on whale presence/absence

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1	Energetic Density	.001	.000	4.798	1	.028	1.001
	Constant	-.788	.156	25.632	1	.000	.455

Table 3.7. Results of a Generalized Linear Model testing the effect of station type on the energetic density of surface samples. (Rd = Regular sampling station with whales present; Rn=Regular sampling station with no whales present; Sd = Opportunistic sampling station with whales present).

Parameter	B	SE	t	Sig.	Observed Power*
Intercept	1192.892	181.872	6.559	0	1.000
Rd	-1067.18	486.884	-2.192	0.03	0.586
Rn	-1050.19	208.874	-5.028	0	0.999
Sd	0**	.	.	.	.

*Computed using alpha=.05

**Parameter set to zero because it is redundant

Table 3.8. Results of a generalized linear model testing the effect of station type on the energetic density of vertical samples. (Rd = Regular sampling station with whales present; Rn = Regular sampling station with no whales present; Sd = Opportunistic sampling station with whales present).

Parameter	**B**	**SE**	**t**	**Sig.**	**Observed Power***
Intercept	299.604	42.531	7.044	0	1
Rd	-207.086	122.328	-1.693	0.092	0.392
Rn	-156.104	51.825	-3.012	0.003	0.851
Sd	0**	.	.	.	.

*Computed using alpha=.05

**Parameter set to zero because it is redundant

FIGURES

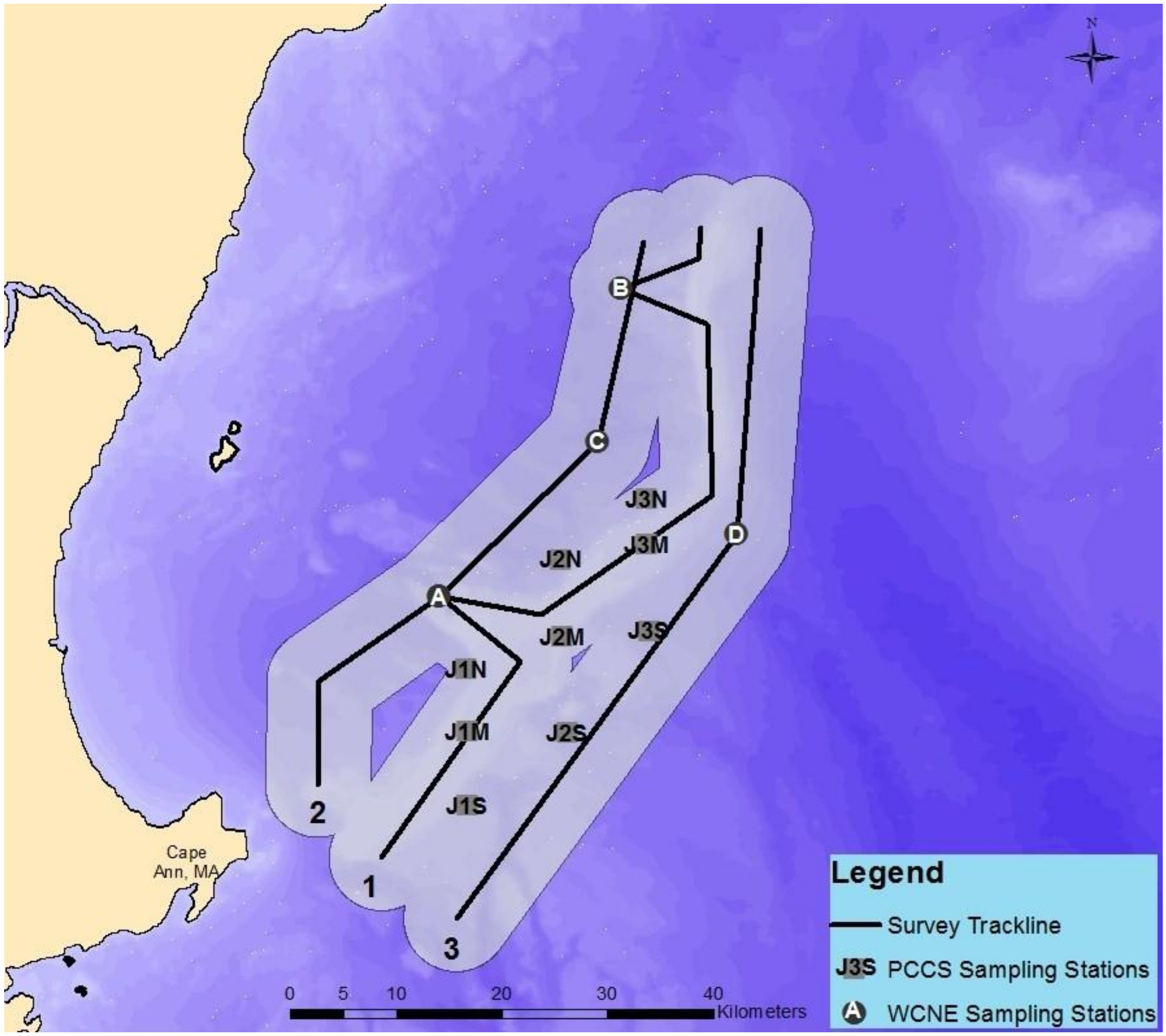


Figure 3.1. Jeffreys Ledge survey area tracklines and regular sampling stations with additional stations sampled by Provincetown Center for Coastal Studies (PCCS) in 2005 – 2006.

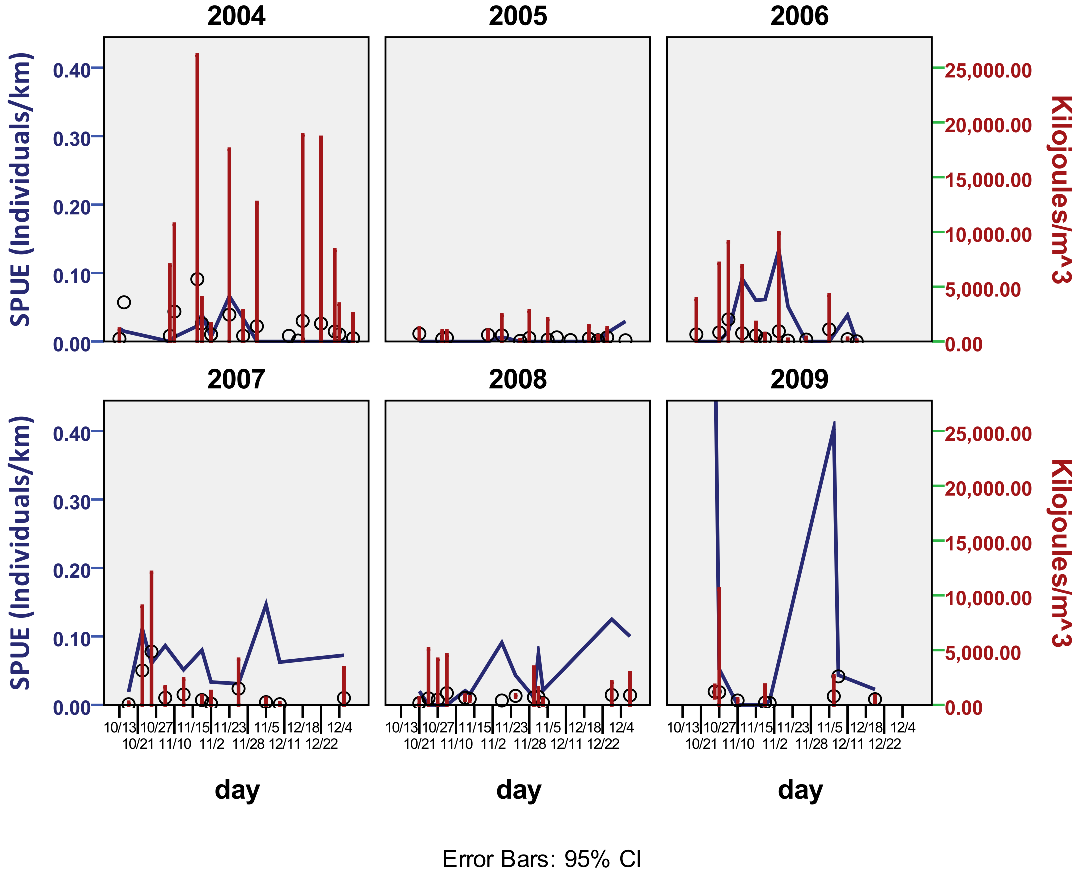


Figure 3.2. Sightings per unit effort (SPUE) expressed in the number of individuals per kilometer of trackline and mean energetic density of vertical plankton samples, expressed in Kilojoules m^{-3}. The peak SPUE in 2009 was .58 km^{-1}(cut off).

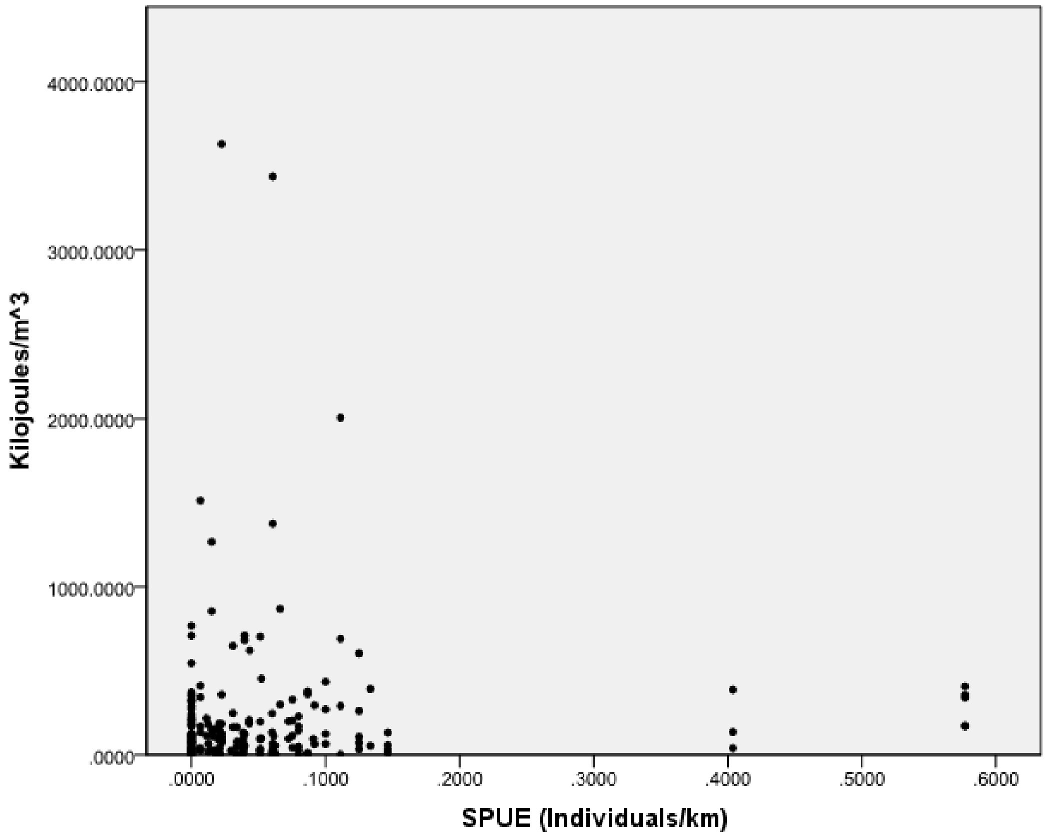


Figure 3.3. Scatter plot of energetic density (expressed in kilojoules m^{-3}) at a sampling station and SPUE (expressed in number of individuals km^{-1}) for a survey date.

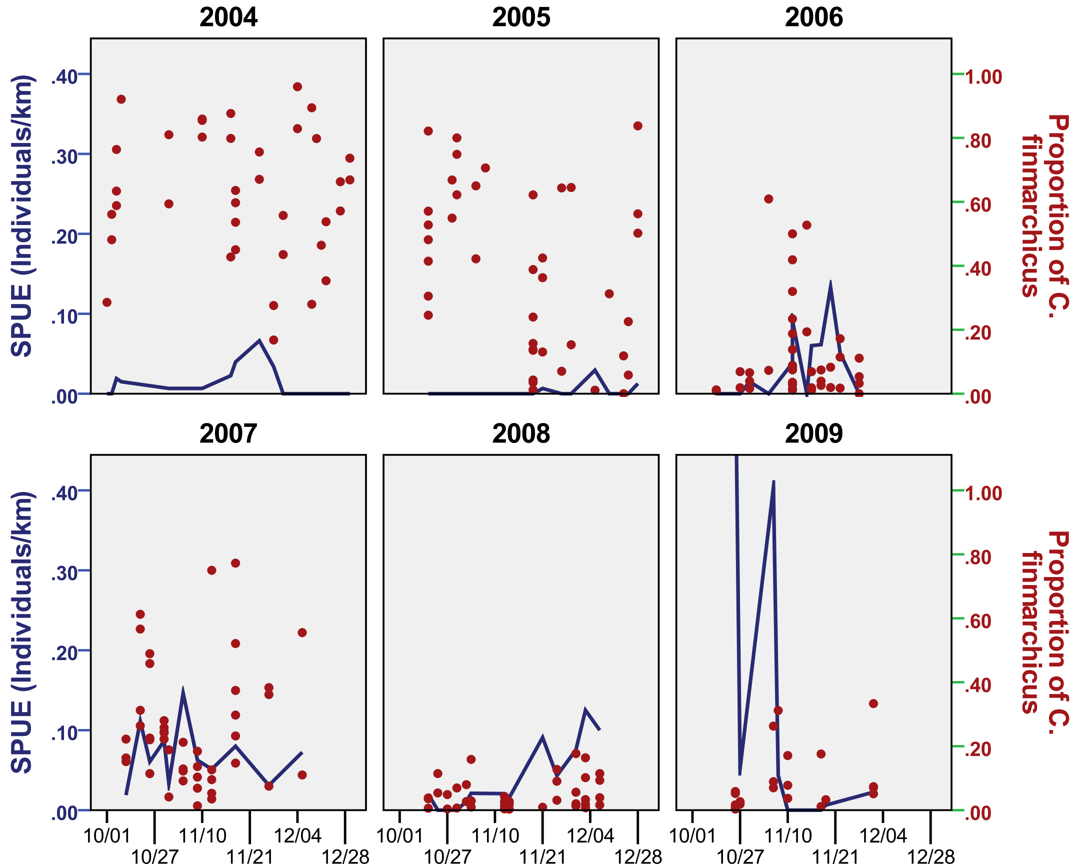


Figure 3.4. Sightings per unit effort (SPUE) expressed in the number of individuals per kilometer of trackline and the proportion of *C. finmarchicus* in vertical samples. Each point represents an individual vertical sample. The peak SPUE in 2009 was .58 individuals km^{-1} (cut off).

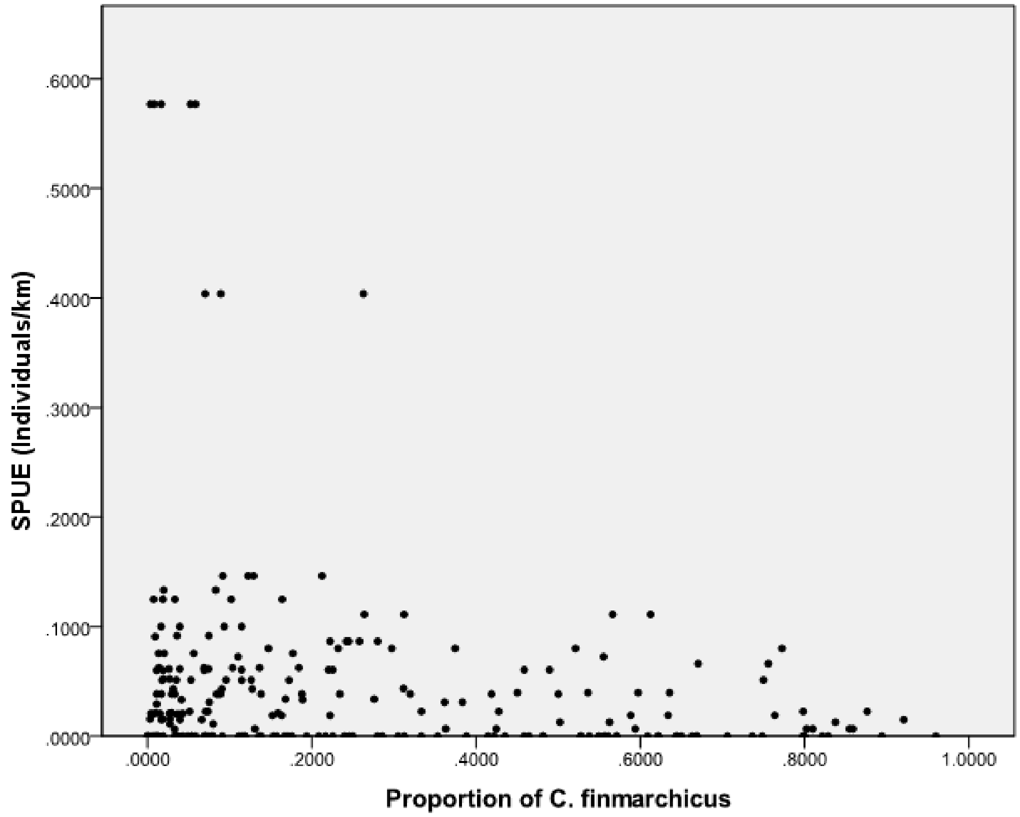


Figure 3.5. Scatter plot of the proportion of *C. finmarchicus* at a sampling station and SPUE (expressed in number of individuals km^{-1}) for a survey date.

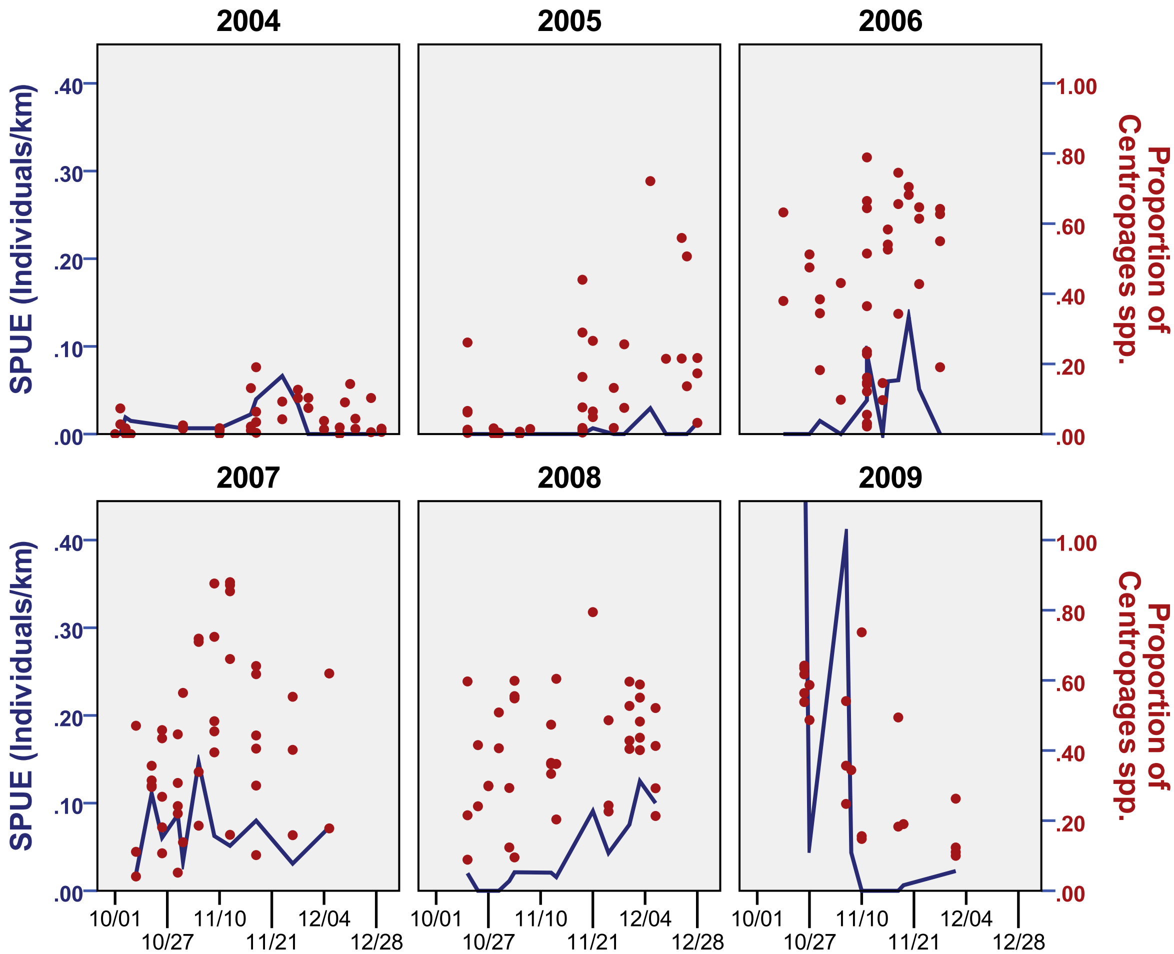


Figure 3.6. Sightings per unit effort (SPUE) expressed in the number of individuals per kilometer of trackline and the proportion of *Centropages spp*. in vertical samples. Each point represents an individual vertical sample. The peak SPUE in 2009 was .58 individuals km $^{-1}$ (cut off).

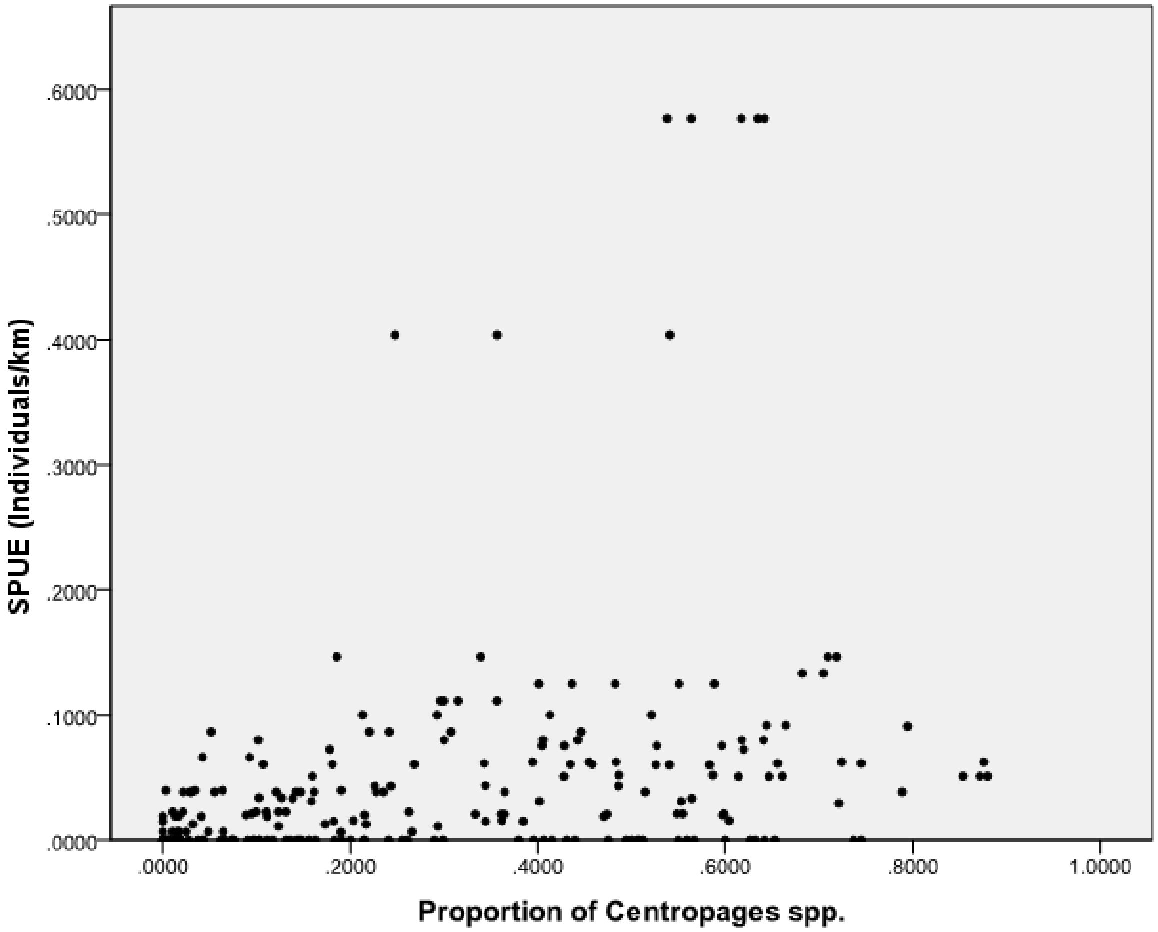


Figure 3.7. Scatter plot of the proportion of *Centropages spp.* at a sampling station and SPUE (expressed in number of individuals km^{-1}) for a survey date.

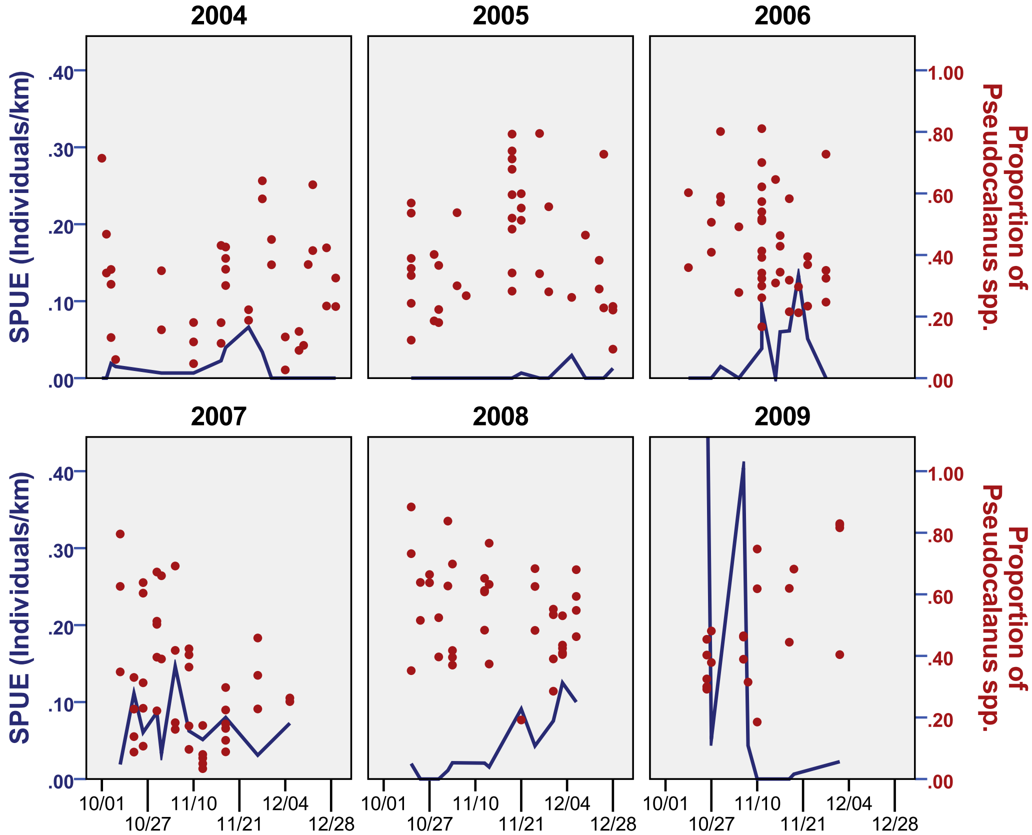


Figure 3.8. Sightings per unit effort (SPUE) expressed in the number of individuals per kilometer of trackline and the proportion of *Pseudocalanus spp.* in vertical samples. Each point represents an individual vertical sample. The peak SPUE in 2009 was .58 individuals km^{-1} (cut off).

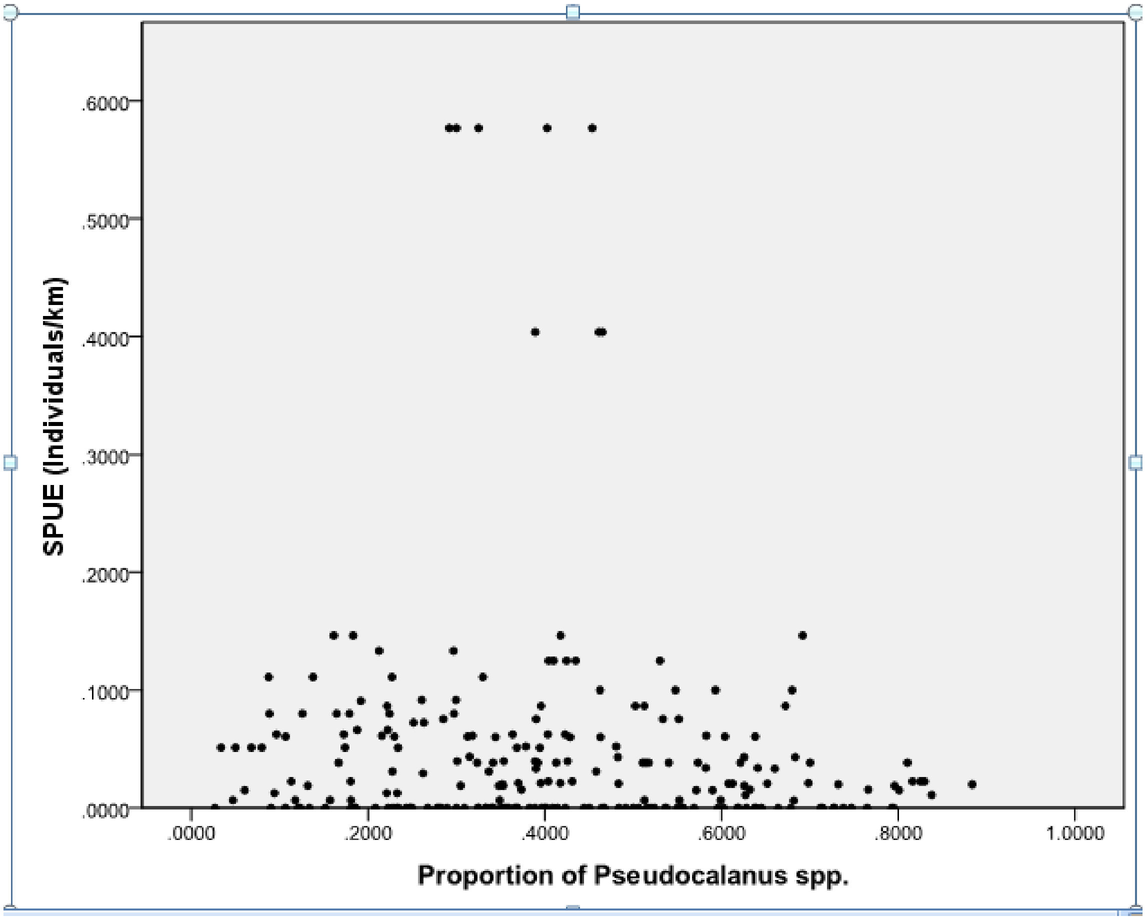


Figure 3.9. Scatter plot of the proportion of *Pseudocalanus spp.* at a sampling station and SPUE (expressed in number of individuals km^{-1}) for a survey date.

CHAPTER 4

RIGHT WHALE DISTRIBUTION IN JEFFREYS LEDGE: IDENTIFYING HOT SPOTS AND ASSESSING THE EFFECT OF BATHYMETRIC FEATURES ON RIGHT WHALE SIGHTINGS

Introduction

Jeffreys Ledge is approximately 54km long and is considered a complex glacial deposit. The shallowest part of Jeffreys Ledge is characterized by depths of 45 – 61 m, while the east and west sides of the ledge slope steeply to depth of up to 150 m (Weinrich et al., 2000). The Jeffreys Ledge study area covers 2,022 km^2, but right whale sightings do not occur uniformly throughout the study area. Initial visualization of the sightings data indicate that right whale sightings are most likely to occur off the northwest side of the ledge (Figure 4.1). In this section, spatial statistics tools in ArcMap 10 will be used to examine whether this clustering pattern is significantly different than what might be expected from a random distribution of sightings, and hot and cold spots within the region will be identified.

Hot spots refer to areas where features with high values cluster spatially, and cold spots refer to areas where features of low values cluster spatially (ESRI, 2011).

Identifying hot and cold spots is a helpful research tool because by looking at where features of high and low values cluster, there is the potential to identify the underlying cause of that clustering pattern, based on location. Hot spot analysis is often used to set conservation priorities by identifying areas of exceptionally high ecological importance or vulnerability (Myers et al., 2000). In the case of the right whale, identifying such hot spots can also be helpful to focus research and conservation efforts in the understudied habitat of Jeffreys Ledge, and may provide insight into the factors affecting fine-scale distribution of right whales. This analysis will also identify how hot and cold spots change in size and location throughout the study period. Determining whether these hot spot patterns are stable is important if future conservation decisions are to be informed by these hot spots.

A second question that will be addressed is whether whale sightings are influenced by bathymetric factors such as depth and slope. In some habitats, large numbers of right whale sightings are often correlated with dense aggregations of zooplankton, particularly calanoid copepods (Baumgartner et al., 2007). As discussed in Chapter 2, attempts to correlate plankton densities with right whale sightings in Jeffreys Ledge have been inconclusive (PCCS, 2008b; WCNE, 2008), possibly due to the fact that the plankton layer that the whales are targeting may be too deep to be targeted by traditional plankton tow methodologies employed .

Because a biological variable which can accurately predict right whale presence has not yet been identified for this area, abiotic bathymetric features have the potential to affect right whale sightings due to their role in influencing oceanographic patterns. The bathymetry of the Gulf of Maine plays a role in the distribution of chlorophyll in the water column (Fong et al., 1997). Oceanographic forces which affect primary productivity can also, in turn, affect zooplankton population dynamics (Durbin, 1996). Calanoid copepods are often found in areas of coastal upwelling where the interaction between deep layers of nutrient rich water and coastal features leads to areas of high productivity (Pinet, 2006; Miller, 2008).

Both depth and slope have been shown to affect the distribution of cetacean species in various habitats. In many cetacean species including the sperm whale, dwarf sperm whale, and several types of dolphins, depth and slope have been identified as factors linked to species aggregations (Baumgartner et al., 2001; De Stephanis et al, 2008). In the shelf waters off the Western Antarctic Peninsula, areas of increasingly slope are associated with both areas of increasing krill aggregation and whale distribution (Friedlander et al., 2006). In other cetacean species such as the sperm whale, pygmy sperm whale, In shelf-edge and deeper waters off the Northeastern United States, mean sighting rates of both sperm and beaked whales are associated with canyon features, and that association is thought to be a result of the interplay between both ephemeral and non-ephemeral hydrographic features at the location resulting in the establishment of foraging sites (Waring et al., 2001). Further, Southern right whales appear to show preferences for areas of specific depths and sometimes slope on a fine scale. Elwen (2004) suggests that the apparent preference by Southern right whale females with calves for slopes that are neither very shallow nor very deep may reflect a preference for calmer waters. Calmer waters are likely to deposit sediment in such a way that creates a gentle, but not too shallow slope. This section will investigate whether such habitat preferences exist in the Jeffreys Ledge habitat.

Methods

Only boat-based sightings of right whales collected by the Whale Center of New England from 2003 - 2009 were used for these analyses. For details on data collection, refer to the methods section of Chapter 2. All spatial analyses were performed in ArcMap v. 10 and all regressions and generalized linear models were performed in SPSS.

Base map

Using ArcMap version 10.0, a vector-based bathymetry layer of the Gulf of Maine from MassGIS was reprojected to the NAD_1983_Stateplane_Massachusetts_Mainland_FIPS projection, which is a Lambert Conformal Conical projection. Projections are used in cartography to address the problem of working with a three-dimensional surface (the Earth's surface) in two-dimensional space by transforming a latitude and longitudinal position on the Earth's surface to a set of Cartesian coordinates (Longley et al., 2011). This projection is appropriate for the mapping of states in the middle latitudes, and is used for areas that are smaller than 30 degrees latitude. It preserves shape and provides minimal distortion of area, and distance is preserved along parallels (Price, 2010).

To define the survey area, a polygon grid was created over the extent of the survey area defined in Chapter 1. The grid was set so that each cell had an area of 2 km^2. This grid size was chosen because every effort was made to obtain a right whale location that was a close to the right whale itself, but when the location of a right whale is recorded, that whale is within a 2 km radius of the recorded location.

To derive the sightings per unit effort (SPUE) value for each grid cell, a point layer was imported where each point represented the number of whales seen at that location on that survey date, divided by the total number of trackline kilometers surveyed on that date. Using a spatial join, all of the points from the duration of the study period were aggregated by each 2 km^2 grid cell such that each grid cell contained the sum of the SPUE in that particular 2 km^2 area.

Hot spot analysis

The Hot Spot tool in ArcMap 10 uses the Getis-Ord Gi* statistic to identify hot and cold spots within a region. The Gi* statistic returns a Z-score based on the value of a feature and the values of neighboring features. In this case, each feature is a 2 km^2 grid cell with an associated summed SPUE value. A feature with a high value in close proximity to cells of other high values will have a high positive Z-score, while a feature with a low value in close proximity to other features with low values with have a low, negative Z-score. Z-scores represent standard deviations associated with a normal distribution. Z-scores with very high positive values or very low negative values are associated with low p-values. A high positive Z-score and a low p-value indicate a hotspot –a non-random clustering of high values, while a small Z score and a low p-value indicate a cold spot—a non-random clustering of low values (ESRI, 2011).

To test the null hypothesis that there are no hot spots, only grid cells that contained SPUE values greater than zero were selected. Inverse Distance was used as the spatial characterization. This implies that every feature is potentially a neighbor of every other feature, and was chosen as no physical boundaries prevent these kinds of relationships in this environment. The distance band was set to the default, which is the minimum distance needed so that each point has at least one neighbor (ESRI, 2011). Each grid cell was weighted by the total SPUE in the cell.

The analysis was performed over the whole study period (2003 – 2009) as well as on three year data intervals. Three year intervals were chosen because they contained enough sightings data for meaningful analysis while allowing us to examine hot spots on a finer temporal scale to see whether they changed over time. The tool requires a variety of values in the variable to be analyzed (ESRI, 2011), and three years was the smallest time interval over which a variety of values could be observed. In this analysis, the sum of SPUE in each grid cell can be considered the independent variable and the resulting Gi* score or Z-score in each grid cell is the dependent variable, as the analysis uses the summed SPUE value per $2km^2$ grid cell as a weighting factor.

Regression analysis

To test whether or not right whale sightings were associated with bathymetric features two types of regressions were performed on the data. An ordinary least squares regression was performed to analyze the relationship between bathymetric features and whale presence/absence, while a Generalized Linear Model was used to analyze the relationship between bathymetric features and SPUE. For the binary logistic regression, a Wald statistic was generated to test the significance of each individual parameter {{103 Sokal, R.R. 1995;}} and an exponentiation of the B coefficient (Exp(B)) was generated because it is easier to interpret than the B coefficient (UCLA, 2007).

To prepare the data for these regressions, average values for depth and slope were assigned to each grid cell. To accomplish this, separate rasters for both slope and depth were created. To create a depth raster, an attribute was added to the polygon-based bathymetry layer which averaged the high and low values for each depth range category. Then, a raster was created using the average depth as the value for every cell. The cell size was set to 350 m^2, which was the finest-scale value allowed by the program, given the complexity of the vector layer. To create a slope raster, the Slope tool in spatial analyst was used to create a raster using the average depth raster as an input. The cell size is also 350 m^2 and each cell has a value for the average slope in degrees.

A point was placed in the center of each 2 km^2 grid cell. Using the Extract Multi Values to Point tool in the Extraction toolbox, depth and slope values from the depth and slope from the 350 m^2 rasters were extracted to the points at the center of each 2 km^2 grid cell such that each 2 km^2 grid cell had an associated slope and depth values defined by that center point. The option to allow interpolation to the point was used so that the slope and depth values across each cell were averaged for each center point. After this tool was run, every 2km^2 grid cell had 3 three values associated with it: average depth, average slope and total SPUE. A table containing this information was imported into SPSS where an additional field was added. For each grid cell, a value of 0 was assigned if no whales were ever seen in the cell and a value of 1 was assigned if there had ever been a whale observed in the cell.

Before attempting the regression analyses, a statistical test for multicollinearity was performed in SPSS to confirm that slope and depth do not co-vary, as multicollinearity can skew regression analyses. A Pearson's Correlation Score of -.003 and a p-value of .94 suggested that covariance between slope and depth would not be problematic in the following analyses.

A binary logistic regression was performed in SPSS to determine whether average depth and slope in a 2km^2 grid cell affected the probability of seeing a whale in that cell. All cells within the study area were tested. A generalized linear model using a gamma distribution with log link in SPSS was used to determine whether there was a relationship between depth or slope and SPUE. Only grid cells in which whales were seen were included in this analysis. This model was chosen due to the non-normality of the SPUE data.

Results

Hot spot analysis

The Getis-Ord Gi* Hot Spot Analysis reveals a large hotspot located on the northwestern edge of the ledge, and well a cold spot off the southeastern corner of the ledge (Figure 4.2) Grid cells with high positive Z-scores and low p-values are considered hot spots, meaning that they have high SPUE values and are in close proximity other cells with high SPUE values. Grid cells with low negative Z-scores and low p-values are considered cold spots, meaning that they have low SPUE values and are in close proximity to other cells with low SPUE values.

Analysis over three-year intervals reveals a hot spot which changes in size, location and intensity from 2003 – 2009. Cold spots are sparse in some years (Figures 4.3, 4.5 – 4.7) and non-existent in others (Figure 4.4), and in all years are lacking in intensity, having only slightly negative Z-scores. The presence and location of a cold spot in the map containing the entire study area is likely due to a larger sample size. In the earlier years of the study period, the hotspot is small, and located off the southwestern edge of the Ledge. As the years progress, the hotspot expands and moves towards the northeast. The last three-year interval most closely resembles the hot spot present in the hotspot analysis containing all seven years of data.

Regressions

Results of a binary logistic regression indicate that the probability of seeing a whale within a given grid cell increases significantly with the average depth ($p<.001$), but not slope in a cell (Table 4.1). Similarly, in areas where whales are present, a generalized linear model reveals that SPUE is significantly higher with increasing cell depth ($p<.001$), but not with slope or the interaction term (Table 4.2). The Wald statistic value of 16.588 for that parameter also supports the significance of increasing depth with slope. In the context of this analysis, the negative intercept or constant is meaningless because a negative SPUE value is not possible. Negative intercepts and constants can occur when the regression line moves farther away from the center of data (Freedman et al., 2007).

Discussion

Hot spot analysis

The clustering and hot spot analysis showed statistically significant clustering and hot spots off the northwest edge of Jeffreys Ledge where high sightings per unit effort (SPUE) have occurred. The results of the hot spot analysis suggest that the null hypothesis, that right whale SPUE is random throughout the study area, can be rejected. The hot spot analysis identifies both hot spots, which are areas where high values (in this case, high SPUE values) are spatially clustered, and cold spots, where low values of

SPUE are spatially clustered. Looking at the results of the Hot Spot analysis over three-year intervals allowed us to see how hot spots changed over time.

An initial examination of the results shows a hot spot which changes in size as well as location between 2003 and 2009. Between 2003 and 2005, only two grid cells show a slightly significant hotspot, and these cells are much further to the southwest of the large hotspot in the aggregated data. By the 2007 – 2009 interval, the hot spot was larger, having more grid-cells with higher z-scores, and had shifted to the northeast.

Interestingly, the 2006 – 2008 interval shows several slightly significant cold spots, while the aggregated data shows a much larger and more significant cold spot on the other side of the ledge than the hotspot. This suggests that a survey is more likely to observe high numbers of right whales off the northwest side of the ledge, to the west of the westernmost trackline, while it is sightings are likely to be less frequent off the northeast side of the ledge, to the east of the easternmost trackline.

Sightings of right whales were normalized by survey trackline effort due to account for inconsistent survey effort between and within seasons. Because a primary focus of these surveys was identifications data, one survey trackline (Track #3) was surveyed more frequently than others to maximize the number of identification photos obtained. Surprisingly, although this trackline was surveyed more than others because it was believed that most sightings were occurring east of Jeffreys Ledge, this hot spot analysis reveals that the highest sightings per unit effort occurred west of the ledge between tracks 1 and 2.

Correcting sightings for effort alleviates some of the bias inherent in this survey methodology. High SPUE values can occur when a large group of whales is seen after spending very little time on the trackline and a long time capturing photos of each whale. Very high SPUE values were characteristic of the 2009 season in which a large number of surface active groups (SAGs) were observed and surveys were not completed due to the time spent photographing individuals within these groups. It is possible that these large values can at least partially account for the large hot spot seen towards the end of the study period.

While the presence of a hot spot in this habitat can be useful in making future survey effort more efficient; however, the changes in hot spot characteristics over shorter time periods suggest that Jeffreys Ledge might be a more important habitat in some years rather than others. Before restricting conservation efforts to a smaller segment of the study area, more years of data should be included in the analysis to determine the long-term stability of the hot spot.

Bathymetry

Both a binary logistic regression and a generalized linear model suggest that depth, but not slope is a statistically significant predictor of the number of right whales in an area. Bathymetric features were chosen as potential predictive factors because of the characteristics of the right whales' food source. It has been well-documented that many species of zooplankton, including the copepod, vertically migrate throughout the day, feeding at the surface during the night and migrating to deeper waters during the day to avoid predators. Tarrant et al. (2008) sampled copepods in the Gulf of Maine in the spring and found that the copepods sampled at depth were diapausing and had a larger oil sac compared to copepods sampled at the surface. Similarly, studies by Baumgartner et al. (2011) revealed that non-migrating copepods that remained in deep waters in the Great South Channel had larger oil sac volumes, indicative of higher energetic content, than migrating copepods and non-migrating copepods found at the surface. Right whales have been documented feeding at depths of up to 200 meters in the Bay of Fundy (Baumgartner & Mate, 2003), and it is possible that the correlations between right whale sightings and increasing depths are related to the distribution of the planktonic resource in deeper waters. However, many other factors not included in the model tested here, including current speed and direction, sunlight, sea surface temperature, and nutrient load may also play major roles in where plankton and right whales can be found in large numbers.

Other facets of the methodology might also have influenced the results of both the hot spot and the regression analyses. For example, although right whale sightings are entered into the database as point features, their locations are not exact. The location is determined by a GPS unit from a boat-based platform. As a result, the documented right whale can be anywhere within an approximately 2 km radius of the documented location. This is why 2 km was chosen as the grid size, however, that does not fully account for the lack of precision in the whale's location. Additionally, right whales generally do not stay in the same location. Right whales in other foraging areas moved at an average of 1.1 km/h, and at greater speeds outside the foraging area (Mate, 1997). As their locations are generally reported only once over the course of a survey, it is not possible to say whether the whale is associated with a particular depth or slope for the duration of the observation.

Finally, it is possible that the behavior of right whales causes the data to be skewed. On Jeffreys Ledge, right whales are often observed on long (and presumably deep) dives, which can exceed 30 minutes (Weinrich et al, 2000; WCNE, 2008). Because they are detected visually, it is assumed that surveys underestimate the total number of whales in any given area, as whales which may be on a long dive as the boat passes along the trackline will remain undetected. It is possible that foraging behavior like long dives may make a whale less likely to be detected than a whale that is engaging in surface behavior such as surface feeding, surface social behavior, or travel. Future analyses which incorporate observed behavior into a predictive model based on bathymetric features may play a role in addressing this issue.

Future work must be done to confirm that deep basins play a role in zooplankton, and by extension, right whale aggregation; however, depth appears to be a useful proxy in predicting where right whales are likely to occur in the Jeffreys Ledge region. Information on bathymetric preferences of right whales, used in conjunction with hot spot visualization, can be helpful in focusing future conservation and research effort in this region in order to further assess the importance of this habitat to the right whale.

Conclusions

Spatial analysis and spatial statistics tools are helpful in identifying patterns of right whale habitat use in Jeffreys Ledge. We have identified a statistically significant hot spot in the northwestern part of the study area which changed in size, location, and intensity throughout the study period. Increasing the number of years involved in this analysis could be useful in identifying long-term patterns of use in this habitat. We have also used spatial data derived from a bathymetric layer of the Gulf of Maine to identify a positive relationship between depth and right whale sightings in the region. In the absence of a biological variable that can accurately predict right whale sightings, depth is a useful and widely available predictive variable. Although the mechanism driving this relationship is not certain, it further stresses the need for plankton sampling in this area which targets the water column in its entirety.

TABLES

Table 4.1. Results of a binary logistic regression of the whale presence/absence in relation to slope, depth and an interaction termin a 2km^2 grid cell.

Parameter	B	SE	Wald	df	Sig.	Exp (B)
Constant	-2.99	0.448	44.599	1	.000	0.05
Depth	0.014	0.003	16.588	1	.000	1.014
Slope	0.204	0.386	0.279	1	0.597	1.226
Depth* Slope	-0.002	0.003	0.294	1	.588	0.998

Table 4.2. Results of a generalized linear model of SPUE value in relation to slope, depth and an interaction term in a 2km^2 grid cell.

Parameter	B	SE	Wald	df	Sig.
Constant	-5.025	.3982	159.281	1	.000
Depth	.011	.0029	15.100	1	.000
Slope	.317	.3329	.909	1	.340
Depth*Slope	-.002	.0026	.932	1	.334

FIGURES

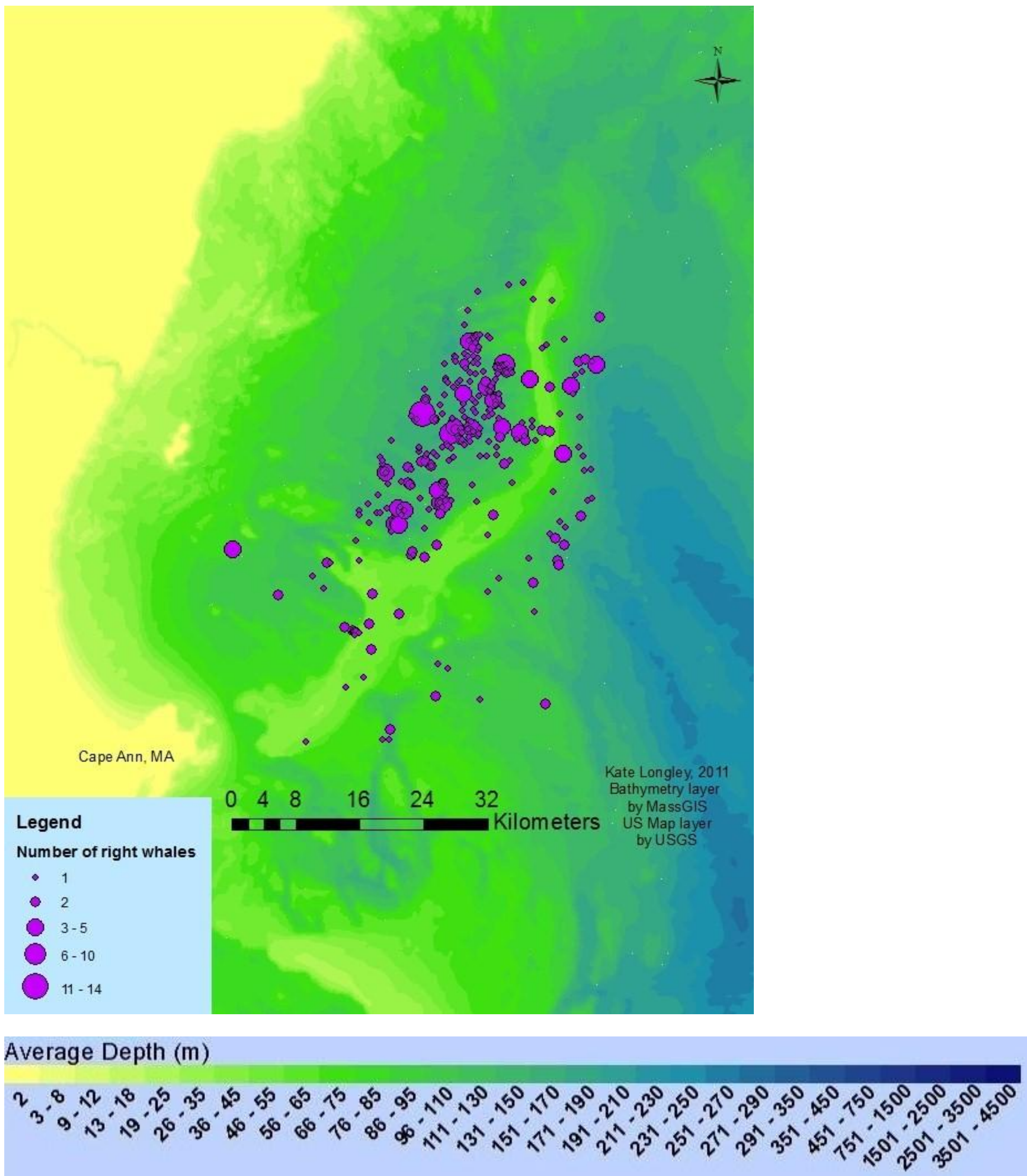


Figure 4.1. Bathymetry of Jeffreys Ledge with boat-based whale sightings September 2003 – December 2009.

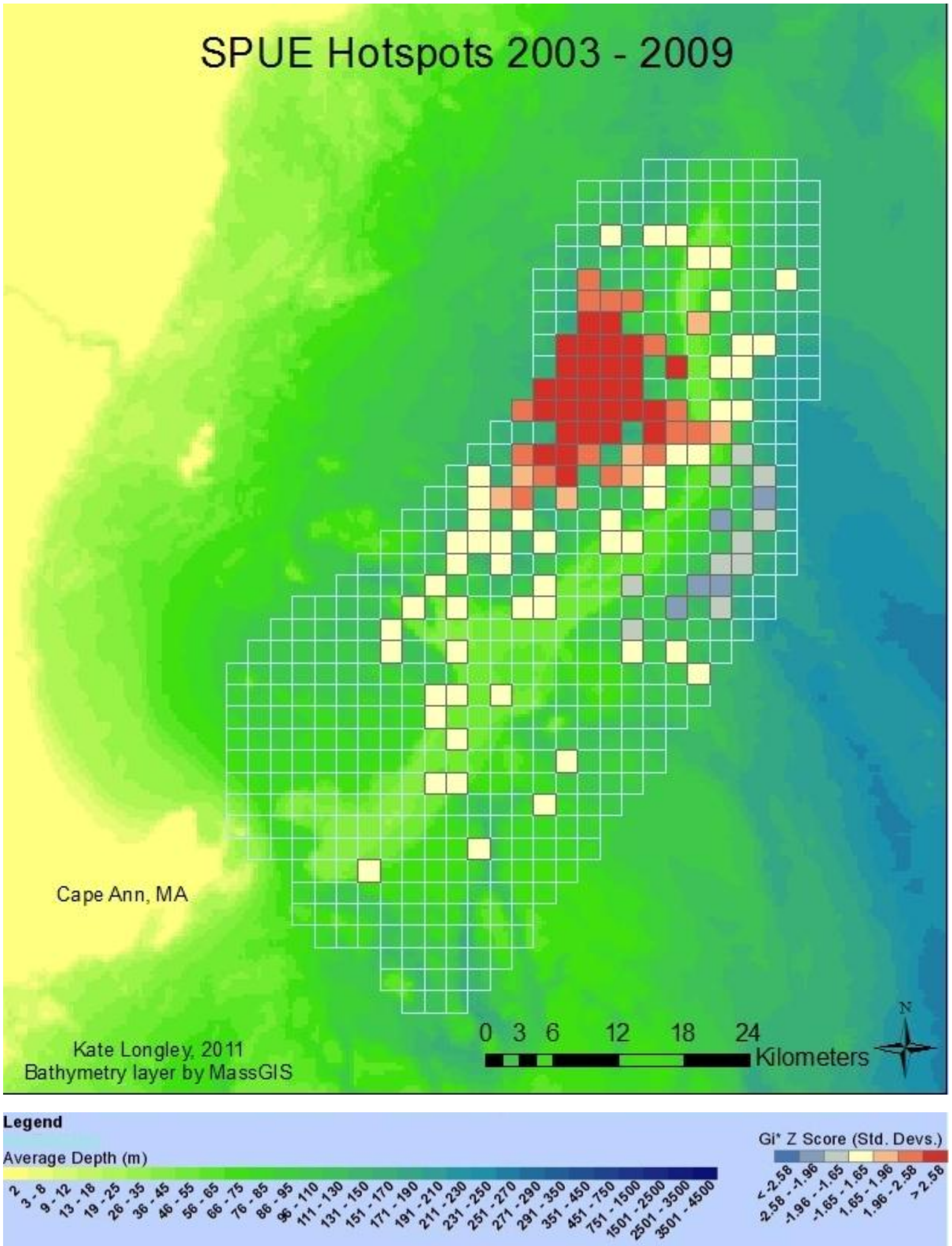


Figure 4.2. Results of Getis-Ord Gi* Hot Spot analysis of 2003 - 2009 SPUE. Cells with high positive Z-scores are considered hotspots and cells with low negative Z-scores are considered cold spots**.**

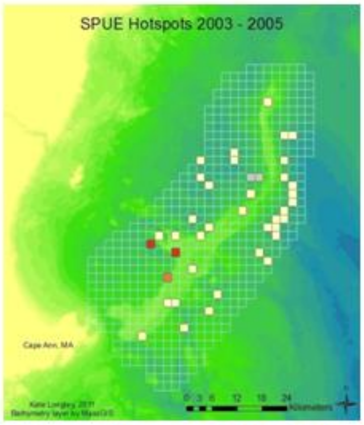


Figure 4.3. Results of Getis-Ord Gi* Hot Spot analysis of 2003 – 2005 SPUE

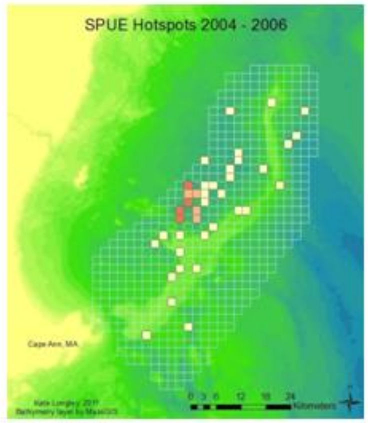


Figure 4.4 Results of Getis-Ord Gi* Hot Spot analysis of 2004 - 2006 SPUE

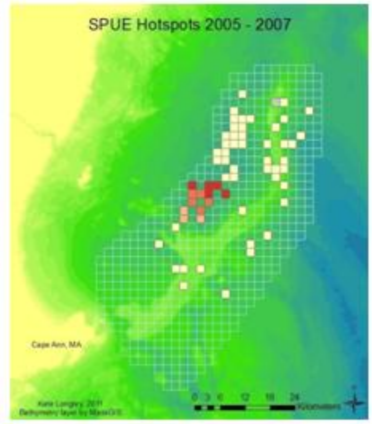


Figure 4.5 Results of Getis-Ord Gi* Hot Spot analysis of 2005 - 2007 SPUE

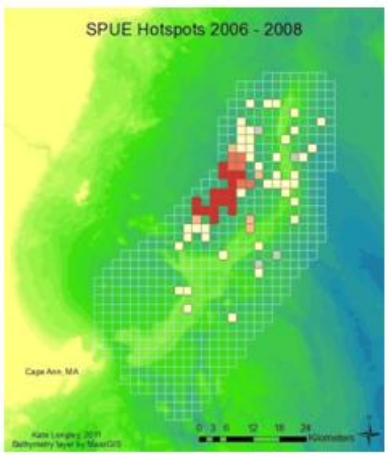


Figure 4.6 Results of Getis-Ord Gi* Hot Spot analysis of 2006 - 2008 SPUE

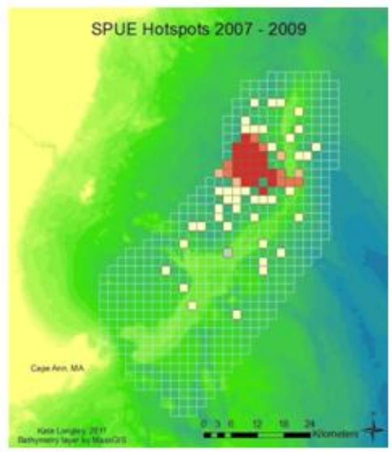


Figure 4.7 Results of Getis-Ord Gi* Hot Spot analysis of 2007 - 2009 SPUE

APPENDIX I

LIST OF ALL SURVEYS OF JEFFREYS LEDGE (JL) AND CAPE COD BAY (CCB) DURING THE STUDY PERIOD BY THE WHALE CENTER OF NEW ENGLAND (WCNE), NORTHEAST FISHERIES SCIENCE CENTER (NEFSC), AND PROVINCETOWN CENTER FOR COASTAL STUDIES (PCCS)

Date	**Organization**	**Platform**	**Area**	**Survey Completed?**	**Flight Type***	**Trackline km in survey area covered**
9/30/2003	NEFSC	Aerial	JL	Y	Broadscale	22.3
10/9/2003	NEFSC	Aerial	JL	N	Broadscale	36.3
10/18/2003	NEFSC	Aerial	JL	Y	Broadscale	44.2
12/4/2003	NEFSC	Aerial	JL	Y	Focused (DAM)	70.72
2/12/2004	NEFSC	Aerial	JL	Y	Focused (DAM)	59.6
3/10/2004	NEFSC	Aerial	JL	Y	Focused (DAM)	256.25
3/30/2004	NEFSC	Aerial	JL	Y	Broadscale	38.2
4/17/2004	NEFSC	Aerial	JL	Y	Broadscale	10.7
4/25/2004	NEFSC	Aerial	JL	Y	Broadscale	34.3
5/12/2004	NEFSC	Aerial	JL	Y	Broadscale	41.7
10/14/2004	NEFSC	Aerial	JL	N	Focused (DAM)	22.6
10/26/2004	NEFSC	Aerial	JL	Y	Focused (DAM)	92.4
11/17/2004	NEFSC	Aerial	JL	Y	Broadscale	50.3
11/30/2004	NEFSC	Aerial	JL	Y	Broadscale	34.3
1/9/2005	NEFSC	Aerial	JL	Y	Broadscale	36.4
1/15/2005	NEFSC	Aerial	JL	Y	Broadscale	22.3
2/8/2005	NEFSC	Aerial	JL	Y	Broadscale	50.1
3/31/2005	NEFSC	Aerial	JL	Y	Broadscale	50.3
4/13/2005	NEFSC	Aerial	JL	Y	Broadscale	45
4/26/2005	NEFSC	Aerial	JL	Y	Broadscale	50.1
5/14/2005	NEFSC	Aerial	JL	Y	Broadscale	53.8
9/19/2005	NEFSC	Aerial	JL	Y	Broadscale	147.1
9/28/2005	NEFSC	Aerial	JL	Y	Broadscale	20.4
10/21/2005	NEFSC	Aerial	JL	N	Broadscale	26.9
10/28/2005	NEFSC	Aerial	JL	Y	Broadscale	53.8
11/18/2005	NEFSC	Aerial	JL	Y	Broadscale	10.7
11/19/2005	NEFSC	Aerial	JL	Y	Broadscale	38.2
12/21/2005	NEFSC	Aerial	JL	Y	Broadscale	34.3
1/29/2006	NEFSC	Aerial	JL	Y	Broadscale	49.4
2/21/2006	NEFSC	Aerial	JL	Y	Broadscale	67.9

3/19/2006	NEFSC	Aerial	JL	Y	Broadscale	38.2
4/26/2006	NEFSC	Aerial	JL	Y	Broadscale	34.3
10/3/2006	NEFSC	Aerial	JL	Y	Broadscale	34.3
10/17/2006	NEFSC	Aerial	JL	Y	Broadscale	50.3
11/25/2006	NEFSC	Aerial	JL	Y	Broadscale	34.2
11/27/2006	NEFSC	Aerial	JL	Y	Directed	127.3
12/11/2006	NEFSC	Aerial	JL	Y	Directed	132.4
1/4/2007	NEFSC	Aerial	JL	Y	Directed	16
1/22/2007	NEFSC	Aerial	JL	N	Directed	16
1/24/2007	NEFSC	Aerial	JL	Y	Directed	112.3
2/21/2007	NEFSC	Aerial	JL	Y	Directed	112.3
2/27/2007	NEFSC	Aerial	JL	Y	Broadscale	41.7
3/21/2007	NEFSC	Aerial	JL	Y	Directed	112.3
10/16/2007	NEFSC	Aerial	JL	Y	Sawtooth	203.6
11/5/2007	NEFSC	Aerial	JL	Y	Sawtooth	150.5
12/18/2007	NEFSC	Aerial	JL	N	Directed	0
1/13/2008	NEFSC	Aerial	JL	Y	Sawtooth	192.7
2/3/2008	NEFSC	Aerial	JL	Y	Sawtooth	192.7
2/29/2008	NEFSC	Aerial	JL	Y	Directed	209.2
2/29/2008	NEFSC	Aerial	JL	Y	Sawtooth	192.7
10/5/2008	NEFSC	Aerial	JL	Y	Sawtooth	99.7
10/21/2008	NEFSC	Aerial	JL	Y	Sawtooth	201.7
11/24/2008	NEFSC	Aerial	JL	Y	Sawtooth	209.2
1/26/2009	NEFSC	Aerial	JL	N	Sawtooth	176
2/10/2009	NEFSC	Aerial	JL	Y	Sawtooth	202.5
3/5/2009	NEFSC	Aerial	JL	Y	Sawtooth	196.3
10/27/2009	NEFSC	Aerial	JL	Y	Sawtooth	163.5
11/19/2009	NEFSC	Aerial	JL	Y	Sawtooth	167.2
1/5/2010	NEFSC	Aerial	JL	Y	Sawtooth	167.2
1/13/2010	NEFSC	Aerial	JL	Y	Sawtooth	83
1/28/2010	NEFSC	Aerial	JL	N	Sawtooth	88.4
2/28/2010	NEFSC	Aerial	JL	N	Jump Sawtooth	151.1
5/5/2010	NEFSC	Aerial	JL	Y	Jump Sawtooth	177
1/21/2004	PCCS	Aerial	CCB	N		66.672
1/27/2004	PCCS	Aerial	CCB	N		396.328
2/2/2004	PCCS	Aerial	CCB	N		374.104
2/3/2004	PCCS	Aerial	CCB	N		364.844
2/10/2004	PCCS	Aerial	CCB	N		433.368
2/12/2004	PCCS	Aerial	CCB	N		388.92
2/17/2004	PCCS	Aerial	CCB	N		392.624

2/20/2004	PCCS	Aerial	CCB	N	411.144
2/24/2004	PCCS	Aerial	CCB	N	414.848
2/29/2004	PCCS	Aerial	CCB	N	414.848
3/1/2004	PCCS	Aerial	CCB	N	414.848
3/10/2004	PCCS	Aerial	CCB	N	350.028
3/14/2004	PCCS	Aerial	CCB	N	414.848
3/16/2004	PCCS	Aerial	CCB	N	185.2
3/20/2004	PCCS	Aerial	CCB	N	414.848
3/24/2004	PCCS	Aerial	CCB	N	414.848
4/7/2004	PCCS	Aerial	CCB	N	414.848
4/8/2004	PCCS	Aerial	CCB	Y	435.22
4/10/2004	PCCS	Aerial	CCB	Y	435.22
4/18/2004	PCCS	Aerial	CCB	Y	435.22
4/21/2004	PCCS	Aerial	CCB	N	414.848
4/25/2004	PCCS	Aerial	CCB	N	414.848
5/5/2004	PCCS	Aerial	CCB	Y	435.22
5/6/2004	PCCS	Aerial	CCB	N	414.848
5/8/2004	PCCS	Aerial	CCB	Y	435.22
5/10/2004	PCCS	Aerial	CCB	N	414.848
1/2/2005	PCCS	Aerial	CCB	Y	435.22
1/9/2005	PCCS	Aerial	CCB	Y	435.22
1/11/2005	PCCS	Aerial	CCB	Y	435.22
1/15/2005	PCCS	Aerial	CCB	Y	435.22
1/30/2005	PCCS	Aerial	CCB	Y	435.22
2/1/2005	PCCS	Aerial	CCB	Y	435.22
2/2/2005	PCCS	Aerial	CCB	N	435.22
2/7/2005	PCCS	Aerial	CCB	Y	435.22
2/8/2005	PCCS	Aerial	CCB	N	414.848
2/9/2005	PCCS	Aerial	CCB	Y	435.22
2/14/2005	PCCS	Aerial	CCB	N	414.848
2/17/2005	PCCS	Aerial	CCB	Y	435.22
2/26/2005	PCCS	Aerial	CCB	Y	435.22
2/28/2005	PCCS	Aerial	CCB	Y	435.22
3/5/2005	PCCS	Aerial	CCB	Y	435.22
3/7/2005	PCCS	Aerial	CCB	Y	435.22
3/10/2005	PCCS	Aerial	CCB	N	414.848
3/11/2005	PCCS	Aerial	CCB	N	175.94
3/13/2005	PCCS	Aerial	CCB	N	414.848
3/18/2005	PCCS	Aerial	CCB	N	222.24
3/20/2005	PCCS	Aerial	CCB	N	414.848

3/22/2005	PCCS	Aerial	CCB	Y	435.22
3/26/2005	PCCS	Aerial	CCB	N	350.028
3/27/2005	PCCS	Aerial	CCB	N	414.848
4/1/2005	PCCS	Aerial	CCB	N	414.848
4/5/2005	PCCS	Aerial	CCB	Y	435.22
4/6/2005	PCCS	Aerial	CCB	N	368.548
4/10/2005	PCCS	Aerial	CCB	Y	435.22
4/16/2005	PCCS	Aerial	CCB	N	414.848
4/17/2005	PCCS	Aerial	CCB	Y	435.22
4/22/2005	PCCS	Aerial	CCB	Y	435.22
4/26/2005	PCCS	Aerial	CCB	N	31.484
5/3/2005	PCCS	Aerial	CCB	N	414.848
5/5/2005	PCCS	Aerial	CCB	Y	435.22
5/10/2005	PCCS	Aerial	CCB	Y	435.22
1/10/2006	PCCS	Aerial	CCB	Y	435.22
1/12/2006	PCCS	Aerial	CCB	Y	435.22
1/17/2006	PCCS	Aerial	CCB	N	414.848
1/22/2006	PCCS	Aerial	CCB	N	414.848
1/24/2006	PCCS	Aerial	CCB	N	414.848
1/29/2006	PCCS	Aerial	CCB	Y	435.22
2/2/2006	PCCS	Aerial	CCB	Y	435.22
2/4/2006	PCCS	Aerial	CCB	Y	435.22
2/9/2006	PCCS	Aerial	CCB	Y	437.072
2/16/2006	PCCS	Aerial	CCB	Y	437.072
2/22/2006	PCCS	Aerial	CCB	Y	437.072
2/23/2006	PCCS	Aerial	CCB	Y	437.072
3/2/2006	PCCS	Aerial	CCB	N	216.684
3/6/2006	PCCS	Aerial	CCB	N	66.672
3/8/2006	PCCS	Aerial	CCB	N	414.848
3/12/2006	PCCS	Aerial	CCB	N	368.548
3/22/2006	PCCS	Aerial	CCB	N	64.82
3/24/2006	PCCS	Aerial	CCB	Y	435.22
3/25/2006	PCCS	Aerial	CCB	Y	437.072
3/28/2006	PCCS	Aerial	CCB	Y	437.072
3/29/2006	PCCS	Aerial	CCB	Y	437.072
3/30/2006	PCCS	Aerial	CCB	Y	437.072
4/3/2006	PCCS	Aerial	CCB	N	414.848
4/10/2006	PCCS	Aerial	CCB	Y	437.072
4/12/2006	PCCS	Aerial	CCB	N	142.604
4/14/2006	PCCS	Aerial	CCB	N	316.692

4/22/2006	PCCS	Aerial	CCB	Y	435.22
4/26/2006	PCCS	Aerial	CCB	N	216.684
4/27/2006	PCCS	Aerial	CCB	Y	435.22
5/5/2006	PCCS	Aerial	CCB	Y	435.22
5/6/2006	PCCS	Aerial	CCB	Y	435.22
5/18/2006	PCCS	Aerial	CCB	Y	435.22
1/24/2007	PCCS	Aerial	CCB	N	414.848
1/27/2007	PCCS	Aerial	CCB	N	66.672
2/7/2007	PCCS	Aerial	CCB	N	414.848
2/10/2007	PCCS	Aerial	CCB	Y	435.22
2/11/2007	PCCS	Aerial	CCB	Y	435.22
2/21/2007	PCCS	Aerial	CCB	N	414.848
2/22/2007	PCCS	Aerial	CCB	Y	435.22
2/25/2007	PCCS	Aerial	CCB	Y	435.22
2/27/2007	PCCS	Aerial	CCB	N	414.848
3/1/2007	PCCS	Aerial	CCB	Y	435.22
3/3/2007	PCCS	Aerial	CCB	N	283.356
3/9/2007	PCCS	Aerial	CCB	N	283.356
3/12/2007	PCCS	Aerial	CCB	N	350.028
3/21/2007	PCCS	Aerial	CCB	N	51.856
3/23/2007	PCCS	Aerial	CCB	N	414.848
3/24/2007	PCCS	Aerial	CCB	N	414.848
3/26/2007	PCCS	Aerial	CCB	N	142.604
3/31/2007	PCCS	Aerial	CCB	Y	435.22
4/1/2007	PCCS	Aerial	CCB	Y	435.22
4/7/2007	PCCS	Aerial	CCB	N	414.848
4/11/2007	PCCS	Aerial	CCB	N	414.848
4/21/2007	PCCS	Aerial	CCB	Y	435.22
4/22/2007	PCCS	Aerial	CCB	Y	435.22
4/25/2007	PCCS	Aerial	CCB	Y	435.22
4/26/2007	PCCS	Aerial	CCB	N	414.848
5/5/2007	PCCS	Aerial	CCB	N	414.848
5/7/2007	PCCS	Aerial	CCB	Y	435.22
5/9/2007	PCCS	Aerial	CCB	N	387.068
5/13/2007	PCCS	Aerial	CCB	N	350.028
5/14/2007	PCCS	Aerial	CCB	Y	435.22
1/5/2008	PCCS	Aerial	CCB	Y	435.22
1/12/2008	PCCS	Aerial	CCB	N	350.028
1/26/2008	PCCS	Aerial	CCB	Y	435.22
2/3/2008	PCCS	Aerial	CCB	Y	435.22

2/21/2008	PCCS	Aerial	CCB	N	151.864
2/24/2008	PCCS	Aerial	CCB	Y	435.22
2/29/2008	PCCS	Aerial	CCB	N	414.848
3/6/2008	PCCS	Aerial	CCB	N	225.944
3/11/2008	PCCS	Aerial	CCB	N	233.352
3/14/2008	PCCS	Aerial	CCB	N	194.46
3/18/2008	PCCS	Aerial	CCB	Y	435.22
3/24/2008	PCCS	Aerial	CCB	Y	435.22
3/27/2008	PCCS	Aerial	CCB	N	246.316
4/8/2008	PCCS	Aerial	CCB	N	137.048
4/9/2008	PCCS	Aerial	CCB	N	174.088
4/10/2008	PCCS	Aerial	CCB	N	66.672
4/11/2008	PCCS	Aerial	CCB	N	151.864
4/14/2008	PCCS	Aerial	CCB	N	166.68
4/15/2008	PCCS	Aerial	CCB	N	292.616
4/19/2008	PCCS	Aerial	CCB	N	357.436
4/21/2008	PCCS	Aerial	CCB	N	350.028
4/23/2008	PCCS	Aerial	CCB	N	174.088
5/1/2008	PCCS	Aerial	CCB	Y	435.22
5/6/2008	PCCS	Aerial	CCB	Y	435.22
5/15/2008	PCCS	Aerial	CCB	Y	435.22
1/23/2009	PCCS	Aerial	CCB	Y	435.22
1/26/2009	PCCS	Aerial	CCB	Y	435.22
1/30/2009	PCCS	Aerial	CCB	Y	435.22
2/2/2009	PCCS	Aerial	CCB	Y	435.22
2/11/2009	PCCS	Aerial	CCB	N	337.064
2/16/2009	PCCS	Aerial	CCB	N	414.848
2/25/2009	PCCS	Aerial	CCB	N	262.984
3/10/2009	PCCS	Aerial	CCB	N	414.848
3/15/2009	PCCS	Aerial	CCB	N	311.136
3/17/2009	PCCS	Aerial	CCB	N	383.364
3/26/2009	PCCS	Aerial	CCB	N	388.92
4/9/2009	PCCS	Aerial	CCB	N	218.536
4/10/2009	PCCS	Aerial	CCB	Y	435.22
4/14/2009	PCCS	Aerial	CCB	N	383.364
4/17/2009	PCCS	Aerial	CCB	Y	435.22
5/8/2009	PCCS	Aerial	CCB	Y	435.22
5/11/2009	PCCS	Aerial	CCB	Y	435.22
1/13/2010	PCCS	Aerial	CCB	N	77.784
1/16/2010	PCCS	Aerial	CCB	N	396.328

1/21/2010	PCCS	Aerial	CCB	Y	435.22
1/28/2010	PCCS	Aerial	CCB	N	212.98
2/2/2010	PCCS	Aerial	CCB	Y	435.22
2/13/2010	PCCS	Aerial	CCB	Y	435.22
2/21/2010	PCCS	Aerial	CCB	N	206.6832
2/22/2010	PCCS	Aerial	CCB	N	414.848
2/28/2010	PCCS	Aerial	CCB	Y	435.22
3/2/2010	PCCS	Aerial	CCB	Y	435.22
3/7/2010	PCCS	Aerial	CCB	Y	435.22
3/10/2010	PCCS	Aerial	CCB	Y	435.22
3/12/2010	PCCS	Aerial	CCB	Y	435.22
3/19/2010	PCCS	Aerial	CCB	Y	435.22
3/21/2010	PCCS	Aerial	CCB	Y	435.22
3/25/2010	PCCS	Aerial	CCB	N	331.508
3/28/2010	PCCS	Aerial	CCB	Y	435.22
4/2/2010	PCCS	Aerial	CCB	N	414.848
4/5/2010	PCCS	Aerial	CCB	Y	435.22
4/8/2010	PCCS	Aerial	CCB	N	85.192
4/12/2010	PCCS	Aerial	CCB	Y	435.22
4/13/2010	PCCS	Aerial	CCB	Y	435.22
4/18/2010	PCCS	Aerial	CCB	Y	435.22
4/20/2010	PCCS	Aerial	CCB	Y	435.22
5/5/2010	PCCS	Aerial	CCB	Y	435.22
9/15/2003	WCNE	Boat	JL	Y	151
9/22/2003	WCNE	Boat	JL	Y	158
9/26/2003	WCNE	Boat	JL	Y	151
9/29/2003	WCNE	Boat	JL	Y	158
10/1/2003	WCNE	Boat	JL	N	133.5
10/6/2003	WCNE	Boat	JL	Y	158
10/9/2003	WCNE	Boat	JL	N	132.5
10/14/2003	WCNE	Boat	JL	Y	158
10/17/2003	WCNE	Boat	JL	Y	158
10/20/2003	WCNE	Boat	JL	Y	151
10/25/2003	WCNE	Boat	JL	N	119
10/31/2003	WCNE	Boat	JL	Y	151
11/2/2003	WCNE	Boat	JL	Y	158
11/6/2003	WCNE	Boat	JL	Y	151
11/7/2003	WCNE	Boat	JL	Y	158
11/10/2003	WCNE	Boat	JL	Y	158
11/11/2003	WCNE	Boat	JL	Y	133

11/17/2003	WCNE	Boat	JL	Y	158
11/18/2003	WCNE	Boat	JL	Y	158
11/24/2003	WCNE	Boat	JL	N	138.5
11/26/2003	WCNE	Boat	JL	Y	151
12/5/2003	WCNE	Boat	JL	Y	133
12/10/2003	WCNE	Boat	JL	Y	158
9/15/04	WCNE	Boat	JL	Y	158
9/21/04	WCNE	Boat	JL	Y	151
9/24/04	WCNE	Boat	JL	Y	133
9/27/04	WCNE	Boat	JL	N	37
10/1/04	WCNE	Boat	JL	N	103
10/4/04	WCNE	Boat	JL	Y	151
10/8/04	WCNE	Boat	JL	Y	133
10/13/04	WCNE	Boat	JL	Y	158
10/14/04	WCNE	Boat	JL	Y	133
10/29/04	WCNE	Boat	JL	Y	133
11/2/04	WCNE	Boat	JL	Y	151
11/4/04	WCNE	Boat	JL	Y	133
11/10/04	WCNE	Boat	JL	Y	151
11/16/04	WCNE	Boat	JL	Y	133
11/18/04	WCNE	Boat	JL	Y	151
11/19/04	WCNE	Boat	JL	N	100
11/23/04	WCNE	Boat	JL	N	151
11/27/04	WCNE	Boat	JL	N	118
11/30/04	WCNE	Boat	JL	Y	151
12/4/04	WCNE	Boat	JL	Y	133
12/9/04	WCNE	Boat	JL	Y	151
12/12/04	WCNE	Boat	JL	N	44
12/16/04	WCNE	Boat	JL	N	84
12/18/04	WCNE	Boat	JL	Y	151
12/22/04	WCNE	Boat	JL	Y	158
12/30/04	WCNE	Boat	JL	Y	158
9/19/2005	WCNE	Boat	JL	Y	151
9/23/2005	WCNE	Boat	JL	Y	133
9/28/2005	WCNE	Boat	JL	Y	158
10/3/2005	WCNE	Boat	JL	N	84
10/18/2005	WCNE	Boat	JL	Y	158
10/21/2005	WCNE	Boat	JL	Y	133
10/28/2005	WCNE	Boat	JL	Y	151
10/31/2005	WCNE	Boat	JL	Y	158

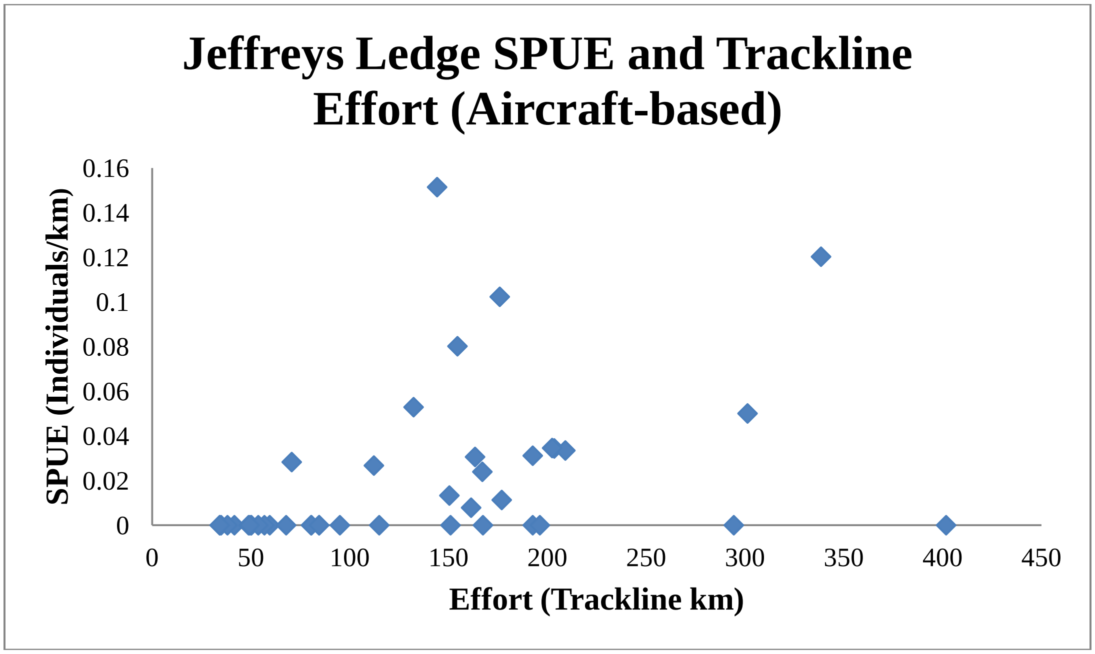
11/5/2005	WCNE	Boat	JL	N	55
11/8/2005	WCNE	Boat	JL	N	125
11/19/2005	WCNE	Boat	JL	Y	133
11/21/2005	WCNE	Boat	JL	Y	151
11/26/2005	WCNE	Boat	JL	Y	133
11/28/2005	WCNE	Boat	JL	Y	158
12/5/2005	WCNE	Boat	JL	N	34
12/12/2005	WCNE	Boat	JL	Y	133
12/19/2005	WCNE	Boat	JL	N	36
12/21/2005	WCNE	Boat	JL	Y	133
12/28/2005	WCNE	Boat	JL	Y	158
1/6/2006	WCNE	Boat	JL	Y	133
1/10/2006	WCNE	Boat	JL	Y	151
1/13/2006	WCNE	Boat	JL	Y	158
1/17/2006	WCNE	Boat	JL	Y	133
1/24/2006	WCNE	Boat	JL	Y	151
10/19/06	WCNE	Boat	JL	Y	133
10/27/06	WCNE	Boat	JL	Y	151
10/31/06	WCNE	Boat	JL	Y	133
11/5/06	WCNE	Boat	JL	Y	158
11/6/06	WCNE	Boat	JL	Y	133
11/11/06	WCNE	Boat	JL	N	109
11/15/06	WCNE	Boat	JL	Y	133
11/18/06	WCNE	Boat	JL	N	114
11/20/06	WCNE	Boat	JL	N	45
11/22/06	WCNE	Boat	JL	N	137
11/27/06	WCNE	Boat	JL	Y	133
12/11/06	WCNE	Boat	JL	N	130
12/14/06	WCNE	Boat	JL	Y	133
10/18/2007	WCNE	Boat	JL	Y	151
10/22/2007	WCNE	Boat	JL	Y	133
10/26/2007	WCNE	Boat	JL	N	132
10/31/2007	WCNE	Boat	JL	N	127
11/2/2007	WCNE	Boat	JL	Y	151
11/5/2007	WCNE	Boat	JL	N	82
11/9/2007	WCNE	Boat	JL	N	144
11/12/2007	WCNE	Boat	JL	Y	133
11/18/2007	WCNE	Boat	JL	N	125
11/26/2007	WCNE	Boat	JL	N	129
12/5/2007	WCNE	Boat	JL	N	138

10/21/2008	WCNE	Boat	JL	Y		133
10/24/2008	WCNE	Boat	JL	Y		151
10/27/2008	WCNE	Boat	JL	Y		133
10/31/2008	WCNE	Boat	JL	N		94
11/3/2008	WCNE	Boat	JL	N		90
11/4/2008	WCNE	Boat	JL	Y		151
11/12/2008	WCNE	Boat	JL	Y		133
11/13/2008	WCNE	Boat	JL	N		128
11/21/2008	WCNE	Boat	JL	N		44
11/24/2008	WCNE	Boat	JL	N		116
11/30/2008	WCNE	Boat	JL	N		106
12/3/2008	WCNE	Boat	JL	N		128
12/6/2008	WCNE	Boat	JL	N		120
10/21/2009	WCNE	Boat	JL	N/A	Directed	0
10/26/2009	WCNE	Boat	JL	N		52
10/27/2009	WCNE	Boat	JL	N		115
11/7/2009	WCNE	Boat	JL	N		52
11/8/2009	WCNE	Boat	JL	N		138
11/10/2009	WCNE	Boat	JL	N		50
11/18/2009	WCNE	Boat	JL	Y		133
11/19/2009	WCNE	Boat	JL	Y		158
12/2/2009	WCNE	Boat	JL	Y		133

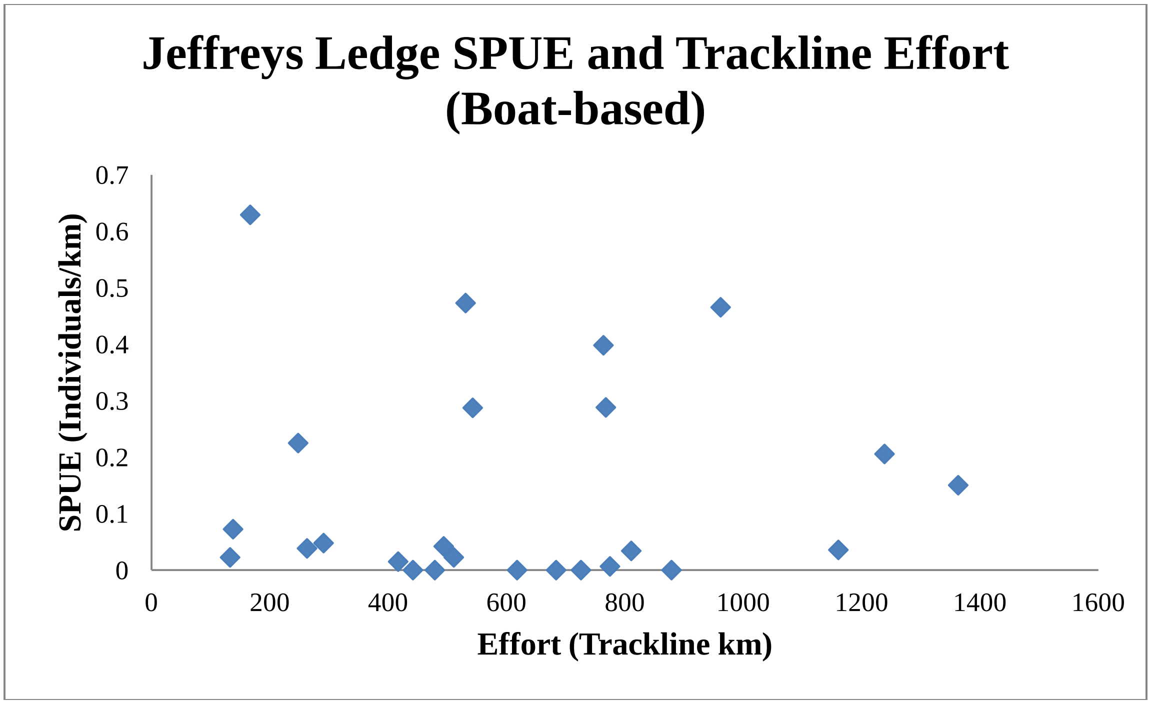
*For NEFSC surveys only. All other surveys are the same throughout the study period.

APPENDIX II

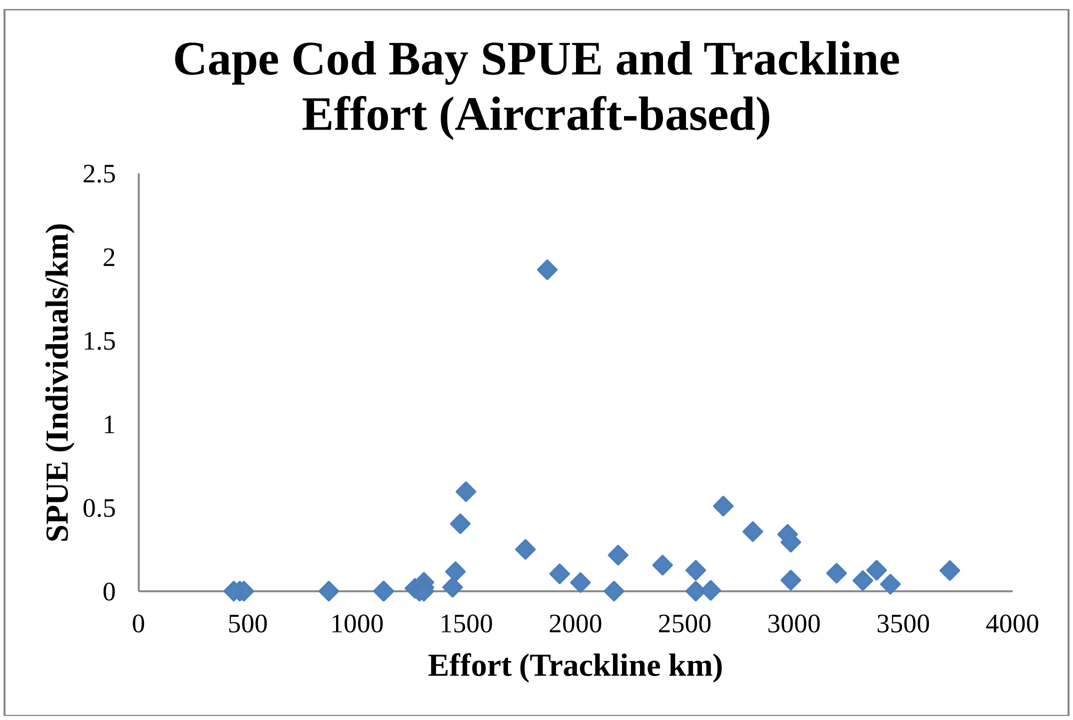
RELATIONSHIPS BETWEEN SIGHTINGS PER UNIT EFFORT (SPUE) AND EFFORT



Relationship between SPUE (sightings per unit effort) and total trackline effort for Northeast Fisheries Science Center (NEFSC) aircraft-based surveys.



Relationship between SPUE (sightings per unit effort) and total trackline effort for Whale Center of New England (WCNE) boat-based surveys.



Relationship between SPUE (sightings per unit effort) and total trackline effort for Provincetown Center for Coastal Studies (PCCS) aircraft-based surveys.

APPENDIX III

LIST OF ALL PLANKTON SAMPLES WITH STATION, STATION TYPE, TOW TYPE, PROPORTIONS OF THREE MAJOR SPECIES, ORGANISM DENSITY AND ENERGETIC DENSITY

Date	**Station**	**Station Type**	**Tow Type**	**Prop. *C.finmarchicus.***	**Proportion *Centropages spp.***	**Proportion *Pseudocalanus spp.***	**Organisms m^{-3}**	**Energetic Density (kJ m^{-3})**
10/9/2003	B	Rn	surface	0.00	0.41	0.11	184.14	64.60
10/9/2003	Z	Rn	surface	0.03	0.62	0.17	4155.69	2765.12
10/9/2003	A	Rn	surface	0.10	0.62	0.18	138.73	120.07
10/9/2003	B	Rn	vertical	0.08	0.75	0.12	3971.65	3841.00
10/14/2003	A	Rn	surface	0.00	0.72	0.12	180.20	86.11
10/14/2003	B	Rn	surface	0.04	0.31	0.60	479.13	64.70
10/14/2003	W1	Sd	surface	0.00	0.73	0.15	268.73	249.40
10/14/2003	W2	Sd	surface	0.02	0.75	0.21	5340.97	7506.99
10/17/2003	B	Rn	surface	0.00	0.63	0.36	2114.87	2898.18
10/17/2003	A	Rn	surface	0.03	0.66	0.28	527.43	761.56
10/20/2003	A	Rn	surface	0.03	0.44	0.38	162.96	141.61
10/20/2003	B	Rn	surface	0.00	0.62	0.35	414.12	93.94
10/25/2003	A	Rn	surface	0.08	0.07	0.80	29.03	17.12
10/25/2003	B	Rn	surface	0.03	0.52	0.44	599.21	191.61
10/25/2003	W1	Sd	surface	0.01	0.88	0.12	3426.90	2322.98
10/31/2003	A	Rn	surface	0.03	0.25	0.69	1018.60	202.27
10/31/2003	B	Rn	surface	0.10	0.08	0.75	57.77	11.99
11/2/2003	B	Rn	surface	0.02	0.63	0.35	1611.39	1676.18
11/2/2003	A	Rn	surface	0.16	0.18	0.57	337.15	430.74
11/2/2003	W1	Sd	surface	0.06	0.80	0.14	3871.70	6775.20
11/6/2003	W1	Sd	surface	0.99	0.00	0.00	1302.53	9547.44
11/6/2003	A	Rn	surface	0.31	0.20	0.46	592.41	1286.86
11/7/2003	A	Rn	surface	0.45	0.22	0.32	245.26	789.81
11/7/2003	B	Rn	surface	0.13	0.59	0.27	530.81	1550.99
11/7/2003	W1	Sd	surface	0.44	0.15	0.41	2779.72	4163.61
11/7/2003	W2	Sd	surface	0.58	0.12	0.22	63.48	97.09
11/10/2003	B	Rn	surface	0.03	0.34	0.62	533.64	245.57
11/10/2003	W1	Sd	surface	0.06	0.26	0.68	221.44	128.96
11/10/2003	A	Rn	surface	0.20	0.18	0.62	1461.45	1744.13
11/10/2003	W2	Sd	surface	0.08	0.06	0.71	16.19	6.50
11/11/2003	W1	Sd	surface	0.09	0.35	0.54	175.58	60.68
11/11/2003	W2	Sd	surface	0.52	0.15	0.31	854.90	631.66
11/11/2003	W3	Sd	surface	0.61	0.17	0.21	913.31	1750.92
11/17/2003	B	Rn	surface	0.22	0.44	0.22	0.52	0.51
11/17/2003	W1	Sd	surface	0.90	0.03	0.04	8.09	49.38
11/17/2003	W2	Sd	surface	1.00	0.00	0.00	0.34	2.09

11/17/2003	W3	Sd	surface	0.05	0.39	0.54	131.18	68.67
11/18/2003	W1	Sd	surface	0.17	0.29	0.52	324.14	337.02
11/18/2003	A	Rn	surface	0.06	0.47	0.46	939.75	597.14
11/24/2003	A	Rn	surface	0.06	0.50	0.44	1423.55	694.96
11/24/2003	B	Rd	surface	0.07	0.49	0.43	149.32	113.35
11/24/2003	W1	Sd	surface	0.15	0.40	0.41	19.01	25.12
11/26/2003	A	Rn	surface	0.09	0.50	0.39	740.94	1388.11
11/26/2003	B	Rn	surface	0.02	0.35	0.62	1042.12	671.94
11/26/2003	W1	Sd	surface	0.08	0.30	0.61	341.74	160.58
12/5/2003	B	Rn	surface	0.04	0.26	0.68	81.51	30.83
12/5/2003	W1	Sd	surface	0.01	0.18	0.76	18825.49	4729.64
12/5/2003	W2	Sd	surface	0.00	0.16	0.84	5227.85	1698.74
12/10/2003	B	Rn	surface	0.10	0.27	0.54	31.45	19.34
12/10/2003	W1	Sd	surface	0.55	0.15	0.28	20.14	67.63
12/10/2003	A	Rn	surface	0.04	0.43	0.48	984.16	530.87
12/10/2003	W2	Sd	surface	0.00	0.66	0.30	969.67	1033.64
9/15/2004	A	Rn	surface	0.00	0.50	0.50	0.62	0.06
9/15/2004	B	Rn	vertical	0.33	0.11	0.56	0.98	0.61
9/15/2004	A	Rn	vertical	0.21	0.40	0.35	5.53	2.57
9/21/2004	B	Rn	surface	0.47	0.06	0.35	4.04	0.94
9/21/2004	A	Rn	vertical	0.00	0.60	0.40	0.45	0.27
9/21/2004	B	Rn	vertical	0.25	0.20	0.55	1.74	2.28
9/24/2004	W1	Sd	vertical	0.56	0.00	0.33	0.76	0.62
9/27/2004	W1	Sd	vertical	0.46	0.04	0.50	9.92	3.74
9/27/2004	A	Rn	vertical	0.12	0.12	0.76	1.89	1.05
9/27/2004	A	Rn	surface	0.34	0.43	0.20	2.73	1.21
9/27/2004	W1	Sd	surface	0.66	0.06	0.28	427.74	104.92
10/1/2004	A	Rn	vertical	0.29	0.00	0.71	0.61	0.48
10/1/2004	A	Rn	surface	0.77	0.06	0.16	8.23	4.27
10/4/2004	B	Rn	vertical	0.48	0.03	0.47	508.69	1020.55
10/4/2004	A	Rn	vertical	0.56	0.07	0.34	3.41	3.41
10/13/2004	A	Rn	vertical	0.59	0.00	0.35	42.58	51.50
10/13/2004	B	Rn	vertical	0.76	0.02	0.13	580.35	655.29
10/13/2004	W1	Sd	vertical	0.63	0.01	0.30	38.30	28.99
10/14/2004	W1	Sd	vertical	0.92	0.00	0.06	2526.42	3576.95
11/2/2004	W1	Sd	vertical	0.81	0.02	0.16	295.22	715.13
11/2/2004	B	Rn	vertical	0.59	0.02	0.35	304.31	565.34
11/2/2004	A	Rn	surface	0.37	0.09	0.09	87.13	63.23
11/10/2004	W1	Sd	vertical	0.80	0.02	0.18	2252.01	6327.06
11/10/2004	B	Rn	vertical	0.85	0.01	0.12	656.30	1723.11
11/10/2004	A	Rn	vertical	0.86	0.00	0.05	86.11	148.06
11/10/2004	B	Rn	surface	0.91	0.00	0.03	99.58	323.16
11/16/2004	C	Rn	vertical	0.43	0.13	0.43	1315.88	1504.39
11/16/2004	W1	Sd	vertical	0.80	0.02	0.18	160.78	373.48
11/16/2004	W2	Sd	surface	0.86	0.00	0.12	2046.78	9357.17
11/16/2004	W2	Sd	vertical	0.88	0.01	0.11	3583.04	15188.14

11/18/2004	W4	Sd	vertical	0.60	0.00	0.39	1090.05	2858.61
11/18/2004	W4	Sd	surface	0.81	0.00	0.18	7795.23	34557.35
11/18/2004	W2	Sd	surface	0.93	0.00	0.07	2426.85	12243.25
11/18/2004	B	Rn	surface	0.57	0.31	0.07	1455.48	2344.57
11/18/2004	B	Rn	vertical	0.45	0.19	0.35	1755.25	2975.89
11/18/2004	W3	Sd	surface	0.93	0.00	0.07	535.36	2617.99
11/18/2004	W1	Sd	vertical	0.64	0.06	0.30	111.28	231.99
11/18/2004	C	Rn	vertical	0.54	0.03	0.43	302.03	518.78
11/23/2004	A	Rn	vertical	0.67	0.09	0.22	1067.34	3635.26
11/23/2004	D	Rn	vertical	0.76	0.04	0.19	268.73	1257.40
11/23/2004	W3	Sd	surface	0.81	0.01	0.15	1964.96	2511.09
11/23/2004	W2	Sd	surface	0.97	0.01	0.02	5948.30	34095.74
11/23/2004	W1	Sd	surface	0.83	0.03	0.14	6970.34	32187.38
11/23/2004	A	Rn	surface	0.74	0.04	0.22	368.38	1376.43
11/27/2004	A	Sd	vertical	0.17	0.10	0.64	821.32	697.30
11/27/2004	W1	Sd	vertical	0.28	0.13	0.58	429.96	336.07
11/27/2004	A	Sd	surface	0.26	0.08	0.61	124.83	79.86
11/30/2004	B	Rn	surface	0.50	0.10	0.13	4.39	3.96
11/30/2004	B	Rn	vertical	0.44	0.10	0.45	254.53	506.22
11/30/2004	C	Rn	vertical	0.56	0.07	0.37	1400.41	2284.28
12/4/2004	D	Rn	surface	0.65	0.03	0.29	9.42	27.39
12/4/2004	C	Rn	vertical	0.96	0.01	0.03	171.83	869.68
12/4/2004	D	Rn	vertical	0.83	0.04	0.13	89.42	435.67
12/9/2004	A	Rn	vertical	0.28	0.02	0.15	133.10	124.39
12/9/2004	C	Rn	vertical	0.89	0.00	0.09	160.86	474.52
12/9/2004	C	Rn	surface	0.25	0.25	0.25	0.29	0.60
12/12/2004	D	Rn	surface	0.55	0.02	0.41	16.16	44.06
12/12/2004	D	Rn	vertical	0.80	0.09	0.11	120.49	515.43
12/16/2004	D	Rn	vertical	0.46	0.14	0.37	33.31	86.20
12/18/2004	B	Rn	vertical	0.54	0.04	0.41	957.58	3214.15
12/18/2004	C	Rn	vertical	0.35	0.01	0.63	254.53	537.30
12/18/2004	C	Rn	surface	0.45	0.17	0.24	2.52	5.89
12/22/2004	D	Rn	vertical	0.66	0.10	0.23	82.79	291.98
12/22/2004	A	Rn	vertical	0.57	0.01	0.42	715.35	2968.52
12/22/2004	A	Rn	surface	0.87	0.00	0.13	1025.57	5804.73
12/30/2004	A	Rn	surface	0.70	0.04	0.24	56.19	249.92
12/30/2004	C	Rn	vertical	0.67	0.01	0.33	308.47	1498.16
12/30/2004	A	Rn	vertical	0.74	0.02	0.23	61.50	327.40
9/19/2005	C	Rn	vertical	0.09	0.65	0.25	12.85	9.71
9/19/2005	A	Rn	vertical	0.22	0.57	0.21	12.85	12.72
9/19/2005	C	Rn	surface	1.00	0.00	0.00	0.92	0.20
9/23/2005	C	Rn	surface	0.00	0.00	0.00	0.59	0.01
9/23/2005	D	Rn	vertical	0.17	0.50	0.25	3.29	1.42
9/28/2005	D	Rn	surface	0.02	0.93	0.03	80.90	37.38
9/28/2005	B	Rn	surface	0.00	1.00	0.00	3.78	0.77
10/3/2005	A	Rn	surface	0.50	0.50	0.00	1.61	0.27

10/18/2005	C	Rn	surface	0.64	0.09	0.27	124.83	79.86
10/18/2005	A	Rn	surface	0.34	0.05	0.57	243.75	73.30
10/21/2005	J1N	Rn	surface	0.18	0.69	0.11	16.16	44.06
10/21/2005	J3N	Rn	vertical	0.53	0.01	0.24	90.36	123.43
10/21/2005	J3M	Rn	vertical	0.82	0.00	0.12	399.94	1392.30
10/21/2005	J2N	Rn	vertical	0.48	0.06	0.39	280.08	269.06
10/21/2005	J1S	Rn	vertical	0.25	0.07	0.57	698.79	739.10
10/21/2005	J1N	Rn	vertical	0.31	0.26	0.36	1419.34	1218.53
10/21/2005	J3N	Rn	surface	0.36	0.02	0.61	0.92	0.20
10/21/2005	J3M	Rn	surface	0.55	0.00	0.44	56.19	249.92
10/21/2005	J3S	Rn	vertical	0.41	0.01	0.54	78.63	87.21
10/21/2005	J1S	Rn	surface	0.52	0.04	0.34	2.52	5.89
10/21/2005	J1M	Rn	surface	0.57	0.04	0.35	0.29	0.60
10/21/2005	D	Rn	surface	0.31	0.02	0.58	9.42	27.39
10/21/2005	C	Rn	surface	0.51	0.04	0.22	4.39	3.96
10/21/2005	J3S	Rn	surface	0.70	0.01	0.27	0.59	0.01
10/21/2005	J2N	Rn	surface	0.55	0.04	0.40	1025.57	5804.73
10/21/2005	J1M	Rn	vertical	0.57	0.01	0.33	524.21	1150.99
10/28/2005	B	Rn	surface	0.45	0.01	0.25	3.78	0.77
10/28/2005	B	Rn	vertical	0.55	0.02	0.40	74.70	166.48
10/28/2005	C	Rn	vertical	0.67	0.00	0.19	119.52	286.20
10/31/2005	W1	Sd	vertical	0.62	0.00	0.37	42.83	55.23
10/31/2005	D	Rn	surface	0.86	0.00	0.11	80.90	37.38
10/31/2005	A	Rn	vertical	0.75	0.00	0.22	186.01	431.32
10/31/2005	D	Rn	vertical	0.80	0.00	0.18	191.24	537.75
11/5/2005	D	Rn	vertical	0.65	0.00	0.30	26.20	15.31
11/5/2005	C	Rn	vertical	0.42	0.01	0.54	109.81	312.71
11/5/2005	C	Rn	surface	0.63	0.02	0.31	1.61	0.27
11/8/2005	B	Rn	surface	0.76	0.02	0.15	243.75	73.30
11/8/2005	B	Rn	vertical	0.71	0.01	0.27	77.29	375.35
11/19/2005	J3M	Rn	surface	0.87	0.04	0.02	20.42	132.40
11/19/2005	J3N	Rn	vertical	0.24	0.01	0.60	86.30	164.48
11/19/2005	J3M	Rn	vertical	0.39	0.02	0.34	162.50	510.80
11/19/2005	J2S	Rn	vertical	0.16	0.00	0.74	107.74	139.34
11/19/2005	J2M	Rn	vertical	0.62	0.02	0.28	349.16	1478.76
11/19/2005	J1N	Rn	vertical	0.04	0.29	0.52	584.77	469.64
11/19/2005	J1M	Rn	vertical	0.04	0.16	0.68	893.24	729.34
11/19/2005	J3S	Rn	vertical	0.14	0.01	0.79	142.50	205.27
11/19/2005	J3N	Rn	surface	0.48	0.30	0.20	15.20	49.59
11/19/2005	J2N	Rn	vertical	0.14	0.08	0.71	119.22	164.79
11/19/2005	J2S	Rn	surface	0.72	0.08	0.10	25.50	48.71
11/19/2005	J2N	Rn	surface	0.13	0.71	0.15	28.79	30.50
11/19/2005	J2M	Rn	surface	0.50	0.28	0.10	28.84	101.45
11/19/2005	J1S	Rn	surface	0.23	0.55	0.10	544.86	990.77
11/19/2005	J1N	Rn	surface	0.53	0.35	0.03	161.19	636.58
11/19/2005	J1M	Rn	surface	0.56	0.24	0.07	135.63	520.49

11/19/2005	C	Rn	surface	1.00	0.00	0.00	0.17	1.30
11/19/2005	J3S	Rn	surface	0.39	0.21	0.31	4.49	9.11
11/19/2005	J1S	Rn	vertical	0.01	0.44	0.48	2441.26	1562.71
11/21/2005	A	Rn	vertical	0.13	0.27	0.60	1115.55	1440.37
11/21/2005	W1	Sd	vertical	0.36	0.06	0.55	49.70	144.37
11/21/2005	C	Rn	vertical	0.42	0.05	0.51	35.76	117.61
11/21/2005	C	Rn	surface	0.26	0.13	0.50	5.08	8.53
11/26/2005	D	Rd	vertical	0.64	0.02	0.34	11.75	51.34
11/26/2005	C	Rn	vertical	0.07	0.13	0.79	56.87	63.87
11/26/2005	C	Rn	surface	0.13	0.28	0.56	9.62	6.15
11/28/2005	D	Rn	vertical	0.64	0.07	0.28	106.57	517.52
11/28/2005	A	Rn	vertical	0.15	0.26	0.56	76.59	126.53
11/28/2005	D	Rn	surface	0.36	0.12	0.51	32.58	78.89
12/5/2005	W1	Sd	vertical	0.01	0.72	0.26	159.65	108.76
12/12/2005	C	Rn	vertical	0.31	0.21	0.46	48.51	126.62
12/12/2005	C	Rn	surface	0.18	0.10	0.62	6.34	5.56
12/19/2005	A	Rn	surface	0.37	0.51	0.09	57.57	200.04
12/19/2005	W1	Sd	vertical	0.00	0.22	0.38	624.51	367.65
12/19/2005	A	Rn	vertical	0.12	0.56	0.29	132.33	183.79
12/21/2005	C	Rn	surface	0.06	0.31	0.07	7.22	4.60
12/21/2005	D	Rn	vertical	0.23	0.51	0.23	37.65	76.93
12/21/2005	C	Rn	vertical	0.06	0.14	0.73	130.31	142.60
12/28/2005	D	Rn	vertical	0.50	0.22	0.23	198.41	765.16
12/28/2005	W1	Sd	vertical	0.84	0.03	0.09	48.51	282.40
12/28/2005	B	Rn	surface	0.08	0.41	0.08	29.77	28.85
12/28/2005	B	Rn	vertical	0.56	0.17	0.22	20.82	87.68
10/19/2006	D	Rn	vertical	0.01	0.38	0.60	525.90	397.68
10/19/2006	C	Rn	vertical	0.01	0.63	0.36	1354.59	904.67
10/19/2006	C	Rn	surface	0.00	0.77	0.15	160.11	269.22
10/27/2006	B	Rn	surface	0.03	0.38	0.55	26.87	9.67
10/27/2006	B	Rn	vertical	0.02	0.48	0.51	1603.60	1326.46
10/27/2006	C	Rn	vertical	0.07	0.51	0.41	303.29	334.61
10/31/2006	C	Rn	surface	0.04	0.43	0.53	23.59	8.61
10/31/2006	D	Rn	vertical	0.02	0.18	0.80	741.04	637.46
10/31/2006	C	Rn	vertical	0.04	0.38	0.57	153.14	128.29
10/31/2006	W1	Sd	vertical	0.07	0.34	0.59	4581.72	5301.23
11/5/2006	A	Rn	surface	0.91	0.02	0.05	387.68	2350.92
11/5/2006	A	Rn	vertical	0.61	0.10	0.28	219.62	862.09
11/5/2006	B	Rn	vertical	0.07	0.43	0.49	1275.91	1358.13
11/6/2006	C	Rn	surface	0.23	0.25	0.52	56.17	22.39
11/6/2006	D	Rn	surface	0.03	0.47	0.47	13.26	1.09
11/6/2006	W1	Sd	surface	0.02	0.55	0.40	519.47	98.29
11/6/2006	W2	Sd	surface	0.01	0.79	0.20	283.92	205.84
11/11/2006	W1	Sd	vertical	0.04	0.64	0.30	1607.59	1238.29
11/11/2006	W1	Sd	surface	0.09	0.54	0.34	497.12	408.90
11/11/2006	C	Rn	vertical	0.07	0.66	0.26	248.01	273.28

11/15/2006	W1	Sd	vertical	0.01	0.53	0.46	1462.17	1034.51
11/15/2006	C	Rd	vertical	0.02	0.54	0.43	129.23	86.68
11/15/2006	D	Rd	vertical				0.00	0.00
11/15/2006	W2	Sd	vertical	0.07	0.58	0.34	565.74	564.70
11/18/2006	W1	Sd	vertical	0.03	0.66	0.32	613.55	472.14
11/18/2006	B	Rn	surface	0.00	0.92	0.08	309.96	508.99
11/18/2006	B	Rn	vertical	0.04	0.75	0.22	228.59	197.00
11/18/2006	C	Rn	vertical	0.07	0.34	0.58	87.65	102.39
11/20/2006	W1	Sd	vertical	0.02	0.68	0.30	2262.97	1644.65
11/20/2006	C	Rn	surface	0.03	0.82	0.11	47.53	117.25
11/20/2006	C	Rn	vertical	0.08	0.70	0.21	194.23	228.83
11/22/2006	D	Rn	vertical	0.11	0.65	0.23	20.32	26.76
11/22/2006	W2	Sd	vertical	0.17	0.43	0.39	68.35	120.04
11/22/2006	W3	Sd	vertical	0.02	0.61	0.37	130.73	98.27
11/22/2006	D	Rn	surface	0.00	0.89	0.11	66.02	217.18
11/27/2006	C	Rn	surface	0.01	0.59	0.34	17.26	26.08
11/27/2006	W1	Sd	vertical	0.00	0.55	0.35	119.52	76.32
11/27/2006	C	Rn	vertical	0.03	0.63	0.32	276.40	228.04
11/27/2006	W2	Sd	vertical	0.11	0.64	0.25	243.53	333.04
11/27/2006	D	Rn	vertical	0.05	0.19	0.73	59.96	66.87
12/11/2006	W1	Sd	vertical	0.23	0.36	0.39	105.98	116.67
12/11/2006	W2	Sd	vertical	0.03	0.14	0.81	491.54	263.87
12/11/2006	J1M	Rn	vertical	0.02	0.06	0.51	274.03	159.32
12/11/2006	D	Rn	vertical	0.42	0.23	0.34	24.70	84.99
12/11/2006	J3N	Rn	vertical	0.50	0.02	0.41	139.28	559.76
12/11/2006	W3	Sd	vertical	0.14	0.12	0.70	316.74	317.23
12/11/2006	J3M	Rn	vertical	0.19	0.03	0.51	108.34	170.41
12/11/2006	J2S	Rn	vertical	0.01	0.79	0.17	102.19	54.01
12/11/2006	J2N	Rn	vertical	0.32	0.03	0.52	65.10	161.59
12/11/2006	J2M	Rn	vertical	0.09	0.16	0.54	35.20	37.33
12/11/2006	J1S	Rn	vertical	0.08	0.15	0.57	432.99	399.54
12/11/2006	J1N	Rn	vertical	0.03	0.51	0.32	257.37	168.78
12/11/2006	J3S	Rn	vertical	0.09	0.24	0.62	105.98	116.67
12/14/2006	D	Rn	vertical	0.53	0.15	0.31	3.09	6.34
12/14/2006	C	Rn	vertical	0.19	0.10	0.65	123.31	202.87
10/18/2007	W1	Sd	surface	0.10	0.88	0.02	3796.23	3150.92
10/18/2007	A	Rn	surface	0.25	0.43	0.32	50.53	11.71
10/18/2007	W2	Sd	surface	0.50	0.34	0.16	3142.38	5122.51
10/18/2007	A	Rn	vertical	0.16	0.04	0.80	5.68	22.26
10/18/2007	W3	Sd	vertical	0.15	0.47	0.35	13.05	10.84
10/18/2007	W4	Sd	vertical	0.22	0.11	0.63	218.13	143.28
10/22/2007	W1	Sd	vertical	0.61	0.30	0.09	849.11	1223.37
10/22/2007	W2	Sd	vertical	0.57	0.30	0.14	3466.17	8388.44
10/22/2007	D	Rn	vertical	0.31	0.36	0.23	20.32	14.58
10/22/2007	D	Rn	surface	0.31	0.57	0.10	2874.96	4673.93
10/22/2007	W3	Sd	vertical	0.26	0.31	0.33	2121.53	2893.92

10/26/2007	A	Rn	vertical	0.11	0.18	0.64	91.63	62.03
10/26/2007	W4	Sd	vertical	0.22	0.11	0.60	199.21	163.96
10/26/2007	W2	Sd	vertical	0.46	0.43	0.11	5059.81	14381.27
10/26/2007	W1	Sd	vertical	0.49	0.27	0.23	1928.31	5754.48
10/26/2007	C	Rn	vertical	0.23	0.46	0.31	273.71	285.97
10/26/2007	W3	Sd	surface	0.52	0.33	0.12	2731.11	6514.04
10/26/2007	C	Rn	surface	0.02	0.82	0.14	1996.51	3320.58
10/31/2007	C	Rn	vertical	0.24	0.05	0.67	38.25	40.02
10/31/2007	D	Rn	vertical	0.28	0.45	0.22	883.97	1516.77
10/31/2007	D	Rd	surface	0.02	0.80	0.09	947.36	1681.53
10/31/2007	W1	Sd	vertical	0.26	0.31	0.40	932.28	1584.23
10/31/2007	W2	Sd	vertical	0.24	0.22	0.51	33.17	51.07
10/31/2007	W3	Sd	vertical	0.22	0.24	0.50	26.39	28.69
11/2/2007	C	Rn	vertical	0.19	0.14	0.66	19.52	23.41
11/2/2007	B	Rd	vertical	0.04	0.56	0.39	352.19	198.30
11/2/2007	B	Rd	surface	0.04	0.83	0.12	438.83	250.20
11/5/2007	C	Rd	surface	0.06	0.90	0.03	949.67	545.08
11/5/2007	D	Rn	vertical	0.12	0.19	0.69	122.01	137.08
11/5/2007	W3	Sd	vertical	0.09	0.72	0.18	71.71	51.72
11/5/2007	C	Rd	vertical	0.13	0.71	0.16	301.80	247.84
11/5/2007	W2	Sd	vertical	0.21	0.34	0.42	448.21	558.32
11/9/2007	W3	Sd	vertical	0.14	0.45	0.36	2.99	2.81
11/9/2007	W2	Sd	vertical	0.10	0.72	0.17	3.29	3.29
11/9/2007	W1	Sd	vertical	0.01	0.88	0.10	370.19	236.23
11/9/2007	C	Rn	vertical	0.18	0.39	0.40	17.53	18.13
11/9/2007	B	Rn	vertical	0.07	0.48	0.42	37.75	37.22
11/9/2007	B	Rn	surface	0.10	0.44	0.36	37.93	15.26
11/12/2007	W2	Sd	vertical	0.04	0.88	0.05	502.99	390.64
11/12/2007	D	Rn	vertical	0.75	0.16	0.08	768.93	2946.46
11/12/2007	W1	Sd	vertical	0.13	0.66	0.17	141.04	155.88
11/12/2007	W3	Sd	vertical	0.10	0.85	0.03	737.06	830.03
11/12/2007	C	Rn	vertical	0.05	0.87	0.07	443.23	421.29
11/18/2007	B	Rn	surface	0.06	0.73	0.11	88.75	152.19
11/18/2007	B	Rn	vertical	0.23	0.64	0.09	372.51	719.04
11/18/2007	C	Rd	vertical	0.30	0.41	0.30	4.08	8.19
11/18/2007	W1	Sd	vertical	0.77	0.10	0.13	207.17	962.32
11/18/2007	W2	Sd	vertical	0.52	0.30	0.18	162.10	613.24
11/18/2007	W3	Sd	vertical	0.15	0.62	0.22	88.45	114.75
11/18/2007	W4	Sd	vertical	0.37	0.44	0.16	75.70	212.14
11/26/2007	C	Rn	vertical	0.08	0.55	0.34	1157.38	1042.76
11/26/2007	D	Rn	surface	0.55	0.03	0.03	93.53	346.99
11/26/2007	D	Rn	vertical	0.38	0.16	0.46	912.36	2714.94
11/26/2007	W1	Sd	vertical	0.36	0.40	0.23	223.11	697.42
12/5/2007	C	Rn	vertical	0.11	0.62	0.26	337.06	406.98
12/5/2007	W1	Sd	vertical	0.56	0.18	0.25	195.42	840.44
12/5/2007	B	Rn	surface	0.08	0.37	0.38	0.72	0.62

10/21/2008	C	Rn	vertical	0.04	0.60	0.35	123.71	92.26
10/21/2008	D	Rn	vertical	0.04	0.22	0.73	470.12	388.42
10/21/2008	W1	Sd	vertical	0.01	0.09	0.88	39.04	25.73
10/24/2008	B	Rn	surface	0.01	0.13	0.11	5.61	1.62
10/24/2008	B	Rn	vertical	0.05	0.42	0.52	287.85	242.58
10/24/2008	C	Rd	vertical	0.11	0.24	0.64	709.17	953.35
10/27/2008	D	Rn	surface	0.00	0.37	0.07	23.34	15.80
10/27/2008	D	Rn	vertical	0.05	0.30	0.64	231.58	175.31
10/27/2008	C	Rn	vertical	0.00	0.30	0.66	1095.63	757.35
10/31/2008	C	Rd	vertical	0.07	0.41	0.52	1117.54	800.27
10/31/2008	A	Rn	surface	0.00	0.36	0.63	109.08	75.67
10/31/2008	A	Rn	vertical	0.01	0.51	0.40	2438.27	1350.24
11/3/2008	C	Rd	vertical	0.08	0.29	0.63	1081.68	913.37
11/3/2008	D	Rn	vertical	0.03	0.12	0.84	531.88	480.95
11/3/2008	C	Rd	surface	0.12	0.39	0.49	449.87	511.86
11/4/2008	A	Rn	vertical	0.16	0.10	0.70	8.77	5.16
11/4/2008	C	Rn	vertical	0.03	0.60	0.37	287.45	167.95
11/4/2008	W1	Sd	vertical	0.01	0.55	0.42	739.05	490.65
11/4/2008	A	Rn	surface	0.00	0.01	0.71	209.36	56.93
11/4/2008	W2	Sd	vertical	0.03	0.55	0.40	57.27	41.31
11/12/2008	W1	Sd	vertical	0.03	0.36	0.61	613.55	455.29
11/12/2008	W2	Sd	vertical	0.00	0.36	0.61	892.44	610.67
11/12/2008	D	Rn	vertical	0.04	0.47	0.48	935.27	741.16
11/12/2008	C	Rn	vertical	0.01	0.33	0.65	1075.71	785.66
11/12/2008	D	Rd	surface	0.01	0.44	0.44	107.98	53.76
11/13/2008	C	Rn	vertical	0.00	0.36	0.63	671.32	463.79
11/13/2008	C	Rn	surface	0.00	0.30	0.70	16887.23	12993.02
11/13/2008	W2	Sd	vertical	0.02	0.60	0.37	827.70	546.56
11/13/2008	W1	Sd	vertical	0.03	0.20	0.77	742.04	626.74
11/21/2008	W1	Sd	vertical	0.01	0.79	0.19	654.39	400.85
11/24/2008	D	Rn	surface	0.36	0.30	0.34	70.39	130.19
11/24/2008	C	Rd	vertical	0.03	0.49	0.48	1010.97	815.42
11/24/2008	W1	Sd	vertical	0.09	0.23	0.68	693.73	872.26
11/24/2008	D	Rn	vertical	0.13	0.24	0.63	523.91	783.03
11/30/2008	B	Rn	surface	0.16	0.66	0.17	361.30	661.78
11/30/2008	W2	Sd	vertical	0.02	0.43	0.55	1048.82	857.07
11/30/2008	W1	Sd	vertical	0.06	0.40	0.53	453.19	483.87
11/30/2008	C	Rd	vertical	0.01	0.60	0.39	266.54	183.30
11/30/2008	B	Rn	vertical	0.18	0.53	0.29	833.67	1379.62
12/3/2008	W4	Sd	vertical	0.16	0.40	0.44	1414.36	2529.24
12/3/2008	W3	Sd	vertical	0.02	0.55	0.42	194.82	149.25
12/3/2008	W2	Sd	vertical	0.03	0.44	0.53	368.53	304.68
12/3/2008	W1	Sd	vertical	0.01	0.59	0.40	679.79	455.78
12/3/2008	W5	Sd	vertical	0.10	0.48	0.41	856.58	1099.16
12/6/2008	D	Rn	vertical	0.02	0.52	0.46	2446.24	1822.45
12/6/2008	W2	Sd	vertical	0.09	0.21	0.68	224.11	277.56

12/6/2008	C	Rn	vertical	0.04	0.41	0.55	687.26	1137.36
12/6/2008	W1	Sd	vertical	0.11	0.29	0.59	355.58	524.97
10/26/2009	W2	Sd	vertical	0.06	0.64	0.29	756.98	715.80
10/26/2009	W1	Sd	vertical	0.01	0.54	0.45	2143.45	1425.85
10/26/2009	A	Rn	vertical	0.05	0.63	0.30	1840.66	1706.56
10/26/2009	W3	Sd	vertical	0.00	0.56	0.40	1195.23	736.54
10/26/2009	C	Rn	vertical	0.02	0.62	0.33	2267.95	1498.59
10/27/2009	C	Rn	surface	0.00	0.67	0.30	2337.06	4367.13
10/27/2009	C	Rn	vertical	0.02	0.59	0.38	653.39	418.52
10/27/2009	W1	Sd	vertical	0.03	0.49	0.48	2717.16	1899.94
11/7/2009	C	Rn	surface	0.09	0.13	0.18	44.87	19.28
11/7/2009	W1	Sd	vertical	0.26	0.25	0.47	331.68	576.52
11/7/2009	C	Rn	vertical	0.09	0.36	0.46	170.32	171.96
11/7/2009	A	Rn	vertical	0.07	0.54	0.39	1715.16	1624.84
11/8/2009	C	Rn	surface	0.01	0.18	0.10	18.42	6.17
11/8/2009	C	Rn	vertical	0.31	0.34	0.31	1073.72	2602.75
11/10/2009	A	Rn	surface	0.13	0.20	0.21	92.79	24.39
11/10/2009	C	Rn	vertical	0.04	0.74	0.19	547.81	329.01
11/10/2009	A	Rn	vertical	0.17	0.16	0.62	329.88	458.26
11/10/2009	B	Rn	vertical	0.08	0.15	0.75	394.43	416.53
11/18/2009	C	Rn	surface	0.01	0.54	0.16	145.23	148.99
11/18/2009	D	Rn	vertical	0.18	0.18	0.62	54.08	81.73
11/18/2009	C	Rn	vertical	0.01	0.49	0.44	549.81	333.04
11/19/2009	B	Rn	surface	0.00	0.23	0.25	5.31	1.73
11/19/2009	B	Rn	vertical	0.03	0.19	0.68	232.32	174.89
12/2/2009	W1	Sd	vertical	0.05	0.12	0.83	330.68	312.48
12/2/2009	D	Rn	vertical	0.33	0.26	0.40	315.54	777.55
12/2/2009	C	Rn	vertical	0.07	0.11	0.82	541.84	448.99
12/2/2009	B	Rn	vertical	0.07	0.10	0.83	492.44	536.12

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