Long term passive acoustic monitoring of the distribution and movement patterns of North Atlantic right whales (*Eubalaena glacialis*) in Stellwagen Bank National Marine Sanctuary

by

Sarah Elizabeth Mussoline

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Thesis Committee:
Dr. Paul Webb, Faculty Advisor
Dr. Sofie Van Parijs, Reader*

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ABSTRACT

The North Atlantic right whale (*Eubalaena glacialis*) is considered the most endangered large whale species as a result of historic whaling, modern ship collisions, and fishing entanglements. To monitor the distribution and movement patterns of the right whales within Stellwagen Bank National Marine Sanctuary (SBNMS), a critical feeding area at the mouth of the Massachusetts Bay, passive acoustic techniques were used. Passive acoustic recordings were made at between 7 and 9 locations throughout the SBNMS from January to May 2006, July to December 2006, and January to February 2007 (366 days). Recordings were made using Automated Recording Units (ARUs), produced by Cornell University, recording at frequencies between 0 and 1000 hertz. Right whale up-calls, a type of vocalization, are the dominant call type occurring within the study area. An automated detection program (Urazghildiiev and Clark 2006) detected over 22,522 up-calls in 89,280 hours of data. Up-calls were present throughout the sanctuary for 11 out of the 13 months, and were present throughout the 24 hour cycle, with a pronounced peak in activity in the late evening. These results show that right whales use the sanctuary to a greater extent than previously thought, particularly during the winter months. The Right Whale Sightings Advisory System (RWSAS) includes visual sightings of right whales from a variety of platforms. During the 366 recording days the RWSAS had 33 sightings of 311 right whales that could have fallen within the acoustic range (8 nautical miles radius) of the ARUs. Sightings from the RWSAS did not account for all the acoustic

behavior present throughout the sanctuary. These results suggest that passive acoustics is an effective tool for monitoring right whale activity and distribution, and can significantly augment management efficacy during months when other techniques are severely limited. The present results will help to direct further management decisions towards reducing ship-whale collisions and fishing entanglements with the right whales.

INTRODUCTION

Historical Background

The North Atlantic right whale, *Eubalaena glacialis*, is the most endangered species of large whale (Clapham et al .1999). Historically the right whale population ranged from 12,000 to 15,000 in the eastern and western regions of the North Atlantic Ocean (Gaskin 1991), but fewer than 350 whales exist today in the western Atlantic (IWC 2001; Clapham et al. 1999). The name, right whale, derives from the whale-hunting era, as for nearly 900 years this species was considered the "right" whale to hunt. It floats when killed as a result of thick blubber stores, yields high quantities of oil, and is often associated with the continental shelf (Reeves and Mitchell 1986; Aguilar 1986). Due to over exploitation, commercial harvest became unsustainable and stocks were reduced to a possible low of 58 animals in 1935 (Kenney et al. 1995). Consequently in that year, the right whale became the first baleen whale to receive international protection as an endangered species, originally under the League of Nations and later by the International Whaling

Commission in 1946 (Katona and Kraus 1999; Best et al. 2001). Demographic modeling indicates the right whale population is still declining despite efforts to reduce anthropogenic mortalities and in spite of recent increases in calving (Caswell et al. 1999; Fujiwara and Caswell 2001).

The two major anthropogenic activities threatening the right whale population today are collision with vessels and entanglement in fishing gear (Knowlton and Kraus 2001). A global database of ship collisions (a total of 292 records) from 1975 to 2002 for eleven large whale species indicates that the right whale is the third most frequently hit species (38 records) (Silber and Bettridge 2006). Reproductively mature and/or pregnant females and juveniles and young calves are especially susceptible to ship collisions during their migrations (Fujiwara and Caswell 2001; Ward-Geiger et al. 2005), and juveniles and young calves represent 50% of the carcasses from all confirmed right whale deaths in the western North Atlantic between 1970 and 1999 (Knowlton and Kraus 2001).

Losses of whales are undoubtedly associated with direct morality, as well as indirect effects on animal health. Among indirect effects, whales are susceptible to deterioration of their acoustic environment because of increasing anthropogenic activities. Given the urgency for right whale protection and the importance of vocalizations in their communication, better understanding of whale-human interactions is essential when planning further coastal development along the Atlantic seaboard. For example, the U.S. Coast Guard has approved a proposal to build a liquefied natural gas port two miles from the western boundary of the Stellwagen Bank National Marine Sanctuary, and a second one is still under consideration (NAOO 2006). The construction and operation of these ports will undoubtedly increase vessel traffic, and consequently introduce noise and contamination into the waters.

The introduced noise is problematic since right whales use sound to communicate with conspecifics (Clark and Clark, 1980; Parks, 2003b). An increase in background noise (i.e. from shipping, trawling, dredging, and sonar use) fragments their acoustic habitat by “masking”, where whale vocalizations are obscured by interfering sounds. Parks and Clark (2007) showed that right whales modify their behavior in response to masking by increasing the frequency of their calls and decreasing their calling rates. The strategy of shifting frequencies comes at a cost because higher-frequency calls do not travel as far. The overall effect of increasing background sound and the whales’ frequency shift in response is a reduction in the range of communication between whales. It is also possible that whales decrease their call rate because it is energetically taxing to call in higher noise or they may be waiting for a reduction in noise. Increased background noise is expected to have critical effects on communication, reproduction, foraging, navigation, and hence ultimately whale survival. Thus in addition to ship collisions, noise pollution is also recognized as a potential limiting factor in sustaining the yearly whale population in Stellwagen Bank National Marine Sanctuary, especially if ship traffic increases as expected.

Direct causes of mortality are primarily associated with ship strikes and entanglement in fishing gear. Between 1986 and 2005, 50 right whales deaths were documented in global waters. Ship strikes contributed to 38% (19 of 50) of these fatalities, and 12% were due to entanglement in fishing gear (6/50). The causes of death were unknown for the remaining 25 individuals either because the carcasses were not retrieved, they were too decomposed to identify, or the necropsy did not produce conclusive results, overall suggesting the number of known ship kills are underreported (Kraus et al. 2005). Knowlton and Kraus (2001) indicate vessel collision as the leading cause of mortality for the North Atlantic right whales. Slow swimming and skim feeding near the surface are characteristics that make this species particularly vulnerable to ship collisions and gear entanglement (Kraus et al. 1988). In addition most right whale habitats and migratory corridors coincide with major shipping lanes in the eastern North Atlantic, where large vessels and fast speeds contribute to lethal collisions (Knowlton 1997; Knowlton and Kraus 2001). Documented ship injuries include severed tailstocks, shattered skulls, and large bruises (Knowlton and Kraus 2001). In regards to entanglement injuries, 75% of all right whales display net scars, a strong indication that these coastal whales frequently encounter fishing gear (Knowlton et al. 2005).

Existing Management and Mitigation Strategies

As a result of their declining population, comprehensive right whales studies have taken place in the western North Atlantic for more than 25 years.

To keep track of numbers and status of the population, the New England Aquarium (began in 1980) and the North Atlantic Right Whale Consortium (began in 2001) has compiled an online database of identified individuals, referred to as The North Atlantic Right Whale Catalog (The North Atlantic Right Whale Catalog 2008). The archived data includes updated biographies and photographs on identified right whales that are submitted by non-governmental and governmental organizations, as well as individuals, in an effort to monitor and understand the entire population (Crone and Kraus 1990; Hamilton & Martin 1999).

Currently all northern right whale populations are listed as a top priority for marine mammal conservation efforts (IWC 2001). Models indicate that protecting only two right whale females per year will help stop and reverse the declining trend in the population (Caswell et al. 1999). Achieving even this minimum goal requires immediate and proactive measures. One occurred in 1999, when The National Oceanic and Atmospheric Administration’s National Marine Fisheries Service and the U.S. Coast Guard established the Mandatory Ship Reporting System (MSRS) that advises mariners of the possibility of right whales throughout the east coast of the United States, particularly around Massachusetts, Georgia, and Florida. When vessels greater than 300 gross tons enter these areas they must report to the U.S. Coast Guard to receive current sighting information about the right whale (Ward-Geiger et al. 2005). To extend the warming system to smaller vessels, the U.S. Coast Guard has developed another system, called the Automatic

Identification System (AIS). This system is an improvement from the MSRS because it tracks a multitude of vessel types and sizes, and reports position accuracy and vessel attribute information. The AIS also provides real time tracking and the data are transmitted as often as every two seconds, and can be received 40 nautical miles from the shore-based stations (Moller et al. 2005). This information enables careful monitoring of vessel movement through restricted areas where whales are present, while enforcing proposed regulations.

In addition, the Northeast Right Whale Sighting Advisory System was created in 1996 to monitor the populations for the northeast United States. This system provides real time sighting information from aerial and shipboard surveys to commercial ships and mariners. The RWSAS reports are compiled from numerous groups and individuals, such as: Northeast Fisheries Science Center's North Atlantic Right Whale Sighting Survey (NARWSS), the U.S. Coast Guard, the Center for Coastal Studies, the Massachusetts's Division of Marine Fisheries, Woods Hole Oceanographic Institution, the International Wildlife Coalition, the Whale Center of New England, whale watch companies, the ferry company, and verified opportunistic sightings. When weather permits the northeast region is surveyed aerially by NARWSS, and more intensive surveys are conducted throughout Cape Cod Bay by the Center for Coastal Studies during the spring migration period. After a survey, the sightings are plotted in an ARCINFO based Geographic Information System (GIS) program and encircled with a 5 kilometer buffer zone (Appendix A,

Figure 1). The positions and maps of right whale sightings are then distributed through various means: faxes and verbal updates to commercial vessels, 24-hour radio broadcasts, and online postings to several web pages (Northeast U.S. RWSAS 2008). Due to logistical and weather constraints however, it is estimated that only 33% of whales are detected by an observer on a given day (Colborn et al. 1998, Hain et al. 1999). This poses significant constraints for aerial surveys, and additional measures must be developed to complement and improve these population studies.

Passive Acoustics and Right Whale Calling Behavior

All of these protective measures rely upon visual sightings, which can be limited by daylight and weather conditions. Acoustic techniques are another effort that will increase data on the spatial distribution and identify high-risk areas where concentrations of whales are present. Bioacoustics is not limited by availability of light and/or weather conditions, and eliminates human injuries due to plane crashes that can occur in aerial surveys.

The noise in the ocean can be monitored in the form of passive and active acoustics. Active acoustics broadcasts an acoustic signal through the water and then listens to the return echo reflected back from objects in the path. The device interprets the characteristics of the echo to provide information about the detected object. Passive acoustics, as the name implies, only listens to and records the sounds heard around the device, but can collect data continuously from remote and independent locations (Rouseff et al.

2001). In this project buoys were deployed throughout the study area to record passive acoustics.

In the past, acoustic projects have studied several species of whales, researching migration patterns (Ljungbland et al. 1982; Crane and Lashkari 1994; Norris et al. 2001), population sizes (Clark and Ellison 1989; Clark et al. 1996; McDonald and Fox 1999), and habitat use in the northwest Atlantic (Hazen and Desharnais 1997). The right whales were studied in the early 1960's, when Schevill and Watkins (1962) researched the sounds of the Southern right whales (*Eubalaena australis*). Right whales are especially appropriate for acoustic studies because they have distinct acoustic characteristics that can be quantified and monitored (Vanderlaan et al. 2003), and individuals are estimated to vocalize 10 times per hour and groups at a rate of 60 times per hour (Matthews et al. 2001). For the same reasons, passive acoustic monitoring for whale positions is expected to effectively reduce collisions with right whales.

Several studies have used passive acoustic techniques to investigate the vocal characteristics of the North Atlantic right whale, including the call rate, frequency range, and source level of its sound production (Clark 1999; Mathews et al. 2001; Vanderlaan et al. 2003). The repertoire of the right whale is grouped into three main calls based on similar categories described for Southern right whales: 1) tonal call types, 2) broadband impulsive sounds, and 3) blow sounds (Appendix A, Figure 2), and research has shown correlations between particular call types and right whale behavioral activities

(Parks 2003; Parks and Clark 2005; Parks et al. 2005). The up-call is a characteristic tonal call that sweeps from low to high frequencies in a whoop, and is the most dominant type of call detected in the Massachusetts Bay area (Appendix A, Figure 3). Noted by Clark as a contact call, the up-call contains most of its energy in the 80 to 250 hertz range (Clark 1999) and is used in social contact situations (Clark 1983). The call may allow the right whales to announce their presence in relation to others and/or help mothers and calves reunite if they ever get separated. The up-call is capable of traveling long distances, suggesting it is a powerful communication tool among whales. Acoustic detections from a 2002 to 2003 study in Cape Cod Bay revealed that two whales are capable of communicating between 32 and 48 km under ideal conditions (Clark et al. 2007).

Another tonal call, the scream, may serve multiple purposes and has been observed during reproduction and in mother-calf interactions (Parks and Tyack 2005). Among the broadband sounds is the gunshot. These calls are predominately produced by males and are short, impulsive sounds related to reproduction and often produced near the surface. Gunshots are typically heard near mating grounds (i.e. Bay of Fundy and Browns Bank), where courting occurs in the late summer and early fall (Parks et al. 2005). The third category is blow sounds and coincides with a whale's exhalation. Depending on their intensity, these blows can be heard over greater distances than normal exhalations (Wursig and Clark 1993).

This project continuously monitored and recorded right whale up-calls because this is most frequently detected call in Cape Cod Bay and the Great South Channel, which are close to Stellwagen Bank National Marine Sanctuary (Parks et al. 2005). In conjunction with acoustic detections, visual surveys also took place. These sightings corroborated the acoustic data and thus the persistence of an aggregation of whales within an area.

Right Whale Movement Patterns

Right whales migrate over 1,400 miles along the Atlantic coast from Georgia and Florida to the northwestern Atlantic, remaining largely confined to United States and Canadian waters (Appendix A, Figure 4 and 5) (Kenney et al. 2001). Most right whales are solitary travelers and do not form large groups as they migrate between productive northern waters in the summer and warmer southern waters in the winter (Winn et al. 1986; Dobson et al. 1999), and in many cases they travel the same route as cargo vessels and passenger ships. A majority of the whales follow this pattern, but there are portions of the population, specifically males and non-pregnant females, where the migrations are unknown. This is especially true in winter months, in part because the adverse weather conditions can make visual surveys challenging (Brown et al. 2001). There is a strong possibility that a large proportion of the population is remaining around the northeast U.S., expanding from the Stellwagen Bank National Marine Sanctuary to the northern Scotian Shelf (Mellinger et al. 2007).

In the winter, pregnant females reside in the warm waters off the coasts of Georgia and Florida that serve as calving grounds to give birth (Winn et al. 1986; Kenney 2001). After the calves are born and spring arrives, mothers accompanied by their calves migrate north to the Cape Cod area and Stellwagen Bank National Marine Sanctuary (Mayo and Marx 1990; Brown et al. 2002). The whales temporally rest inside the protected waters and in spring move out to feed on dense copepod patches (small crustaceans that serve as their primary prey) in the Great South Channel, a deep water passage between the tip of Cape Cod and the Georges Bank to the east (Kenney et al. 1995; Beardsley et al. 1996). The right whales then continue north to the Bay of Fundy and the Scotian Shelf where they will reside for the summer and early fall months (Kraus et al. 1982; Woodley and Gaskin 1996). In this area strong tidal currents mix cold and nutrient waters to provide large numbers of copepods, and serve as reliable nursery and breeding habitat for the right whales (Mate et al. 1997). In addition to the North Atlantic migration, the Southern right whale migrates to their mating and calving grounds off the southern coasts of Africa, South America, the Great Australian Bight, and the coast of New Zealand during the winter and spring. The Southern right whales then migrate to colder water rich in food near Antarctica for the summer (Best et al. 1993).

Stellwagen Bank National Marine Sanctuary

Ships and right whales co-occur throughout their entire migratory range. Collisions damaging to whales are likely to increase because the United

States has grown dependent on international trade and ship sizes have increased over the past half century (Hershman 1999; Waters et al. 2000). The eastern seaboard of the United States and Canada is exposed to one of the highest levels of shipping traffic worldwide (Endreson et al. 2003). Laist et al. (2001) analyzed global whale-ship collision accounts and found that 40 of the 43 (98%) ships reported never seeing the whale before it was struck (n=17) or seeing it too late to avoid (n=23).

The Stellwagen area is recognized as a hot spot for ship collisions along the eastern United States coast (Anon 2004), with approximately 10% of the worldwide collision data being reported for the SBNMS, Cape Cad Bay, and the Boston Harbor (Appendix A, Figure 6). Every winter and springtime SBNMS serves as a seasonal feeding area for approximately one-third of the right whale population (National Marine Sanctuary Condition Report 2007). The 842 square mile Gerry E. Studds Stellwagen Bank National Marine Sanctuary is located on the eastern edge of the mouth of the Massachusetts Bay, comprising a portion of the right whale's migration track (National Marine Sanctuary Condition Report 2007; Hatch et al.2006). Depths range from 20 meters to over 182 meters, and the most prominent feature of SBNMS is an underwater plateau of sand and gravel that was created 1,400 years ago by the last major ice age (Hatch et al. 2006; National Marine Sanctuary Condition Report 2007) (Appendix A, Figure 7). The sanctuary is geologically and biologically diverse. It contains five of the major seafloor habitats (rocky outcrop, piled boulder, gravel, sand, and mud), every major taxonomic group of invertebrates present in global oceans, and is frequently visited by seventeen species of cetaceans (National Marine Sanctuary Condition Report 2007).

SBNMS is also surrounded by a large coastal human population, with nearly 4.8 million people. It is described as the “gateway to maritime commerce of Massachusetts” and is exposed to 200 large, commercial vessels per month that enter the Port of Boston (State of the Sanctuary Report 2002). In addition, upwelling along the SBNMS has made the area a popular fishing ground for centuries, with an estimated 440 commercial fishing vessels using mobile and fixed gear each year (Hatch et al. 2006). Whale watching also contributes to the local boat traffic. Twenty-four whale watching boats visit the sanctuary in Massachusetts, completing 1 to 3 trips daily, and hosting over a million annual visitors (National Marine Sanctuary Condition Report 2007).

The reputation of the Stellwagen area as a hot spot for ship-whale collisions reflects the large whale populations, heavy boat traffic, and high fishing activity. Reducing ship-whale collisions is a priority within the sanctuary, and requires information on whale occurrence and behavior, their associated habitats, and maritime traffic. Towards this end, the National Oceanic and Atmospheric Administration (NOAA) proposed a 12 degree northward shift in the Boston shipping lane as a reduction tool for ship collisions starting in July 2007 (Appendix A, Figure 8). Part of the Traffic Separation Scheme approved by the International Maritime Organization the new lane still transverses the lower section of the Stellwagen Bank National

Marine Sanctuary, but has been placed over seafloor habitat that is unfavorable to the right whale (Shifting the Boston TSS 2007). Hence the new shipping lane is intended to minimize disruption to the whale's primary feeding areas (Appendix A, Figure 9). Thus a total of 61,742 sightings of different species of whales were observed in the old land from a 25 year database, while observation s from the new lane recorded 11,922 sightings over a 1 year period (Smrcina 2006). The shift was expected to reduce ship strikes on large whale species by 81% and for right whales by 58% (Silber & Bettridge 2006). Ongoing whale surveys will seek to evaluate this goal.

Current Management and Mitigation Strategies

Despite international and federal protection over the past sixty years, the right whale has not recovered to a sustainable level. At current mortality rates, the extinction time for the population is estimated between 191 to 245 years (Caswell et al. 1999; Fujiwara & Caswell 2001). The three main approaches to reduce ship collisions with right whales are: 1) educate mariners about when and where right whales are found; 2) implement technological techniques, like passive acoustics, to detect right whales; and 3) impose routing and speed restrictions for vessels within critical right whale habitats (IWC 2001), with the potential for steps 2 and 3 being combined in real time to divert ships from whale concentrations.

These approaches are consistent with The National Marine Sanctuaries Act, originally passed in 1972, recommending a research focus for the National Oceanic and Atmospheric Administration of evaluating impacts of anthropogenic activities to designated marine areas. Furthermore, when such anthropogenic activities are likely to "destroy, cause the loss of, or injure a sanctuary resource," the National Marine Sanctuary Program may propose alternatives to protect the sanctuary and its resource (National Marine Sanctuaries Act 2000).

Given the frequency of anthropogenic disturbances and the presence of right whales within the SBNMS, the Northeast Fisheries Science Center/National Marine Fisheries Service (NEFSC/NMFS), Stellwagen Bank National Marine Sanctuary Office and National Ocean Service (SBNMS/NOS), and Cornell University are working together on the passive acoustic monitoring project. The NEFSC/NMFS research component focuses on biological sounds (i.e. cetacean and fish), while SBNMS/NOS research focuses on analyzing sound data from different vessel types and quantifying the anthropogenic noise field. Lastly, Cornell University supplies the technology, software, and conceptual support. This group installed an array of 9 Autonomous Recording Units to monitor underwater sounds throughout SBNMS waters, and recently the project has been approved to continue for another three years as part of a National Oceanographic Partnership Program grant (NOPP 2007).

Together the group hopes to build a case study that can provide a benchmark to scientifically evaluate the impacts and interactions between various anthropogenic activities and marine mammals. While other aspects of the project are studying how right whales respond to human generated noise, this portion focuses on determining right whale acoustic activity and hence whale occurrence within Stellwagen Bank National Marine Sanctuary. The distribution and movements of right whales are critical for devising mitigation measures, and the study seeks to understand how to identify and diminish ship collisions and fishing entanglements within the sanctuary, while creating a portrait of localized right whale populations throughout the year.

METHODOLOGY

Passive Acoustics

Passive acoustic recordings were made of ocean noise throughout the SBNMS from January to May 2006, July to December 2006, and January to February 2007. Seven to 9 Autonomous Recording Units were deployed at roughly the same locations for a total of 5 successive 2 to 3 month periods. The ARUs are weather independent and continuously record underwater sounds and times. ARUs are small, round pop-up buoys developed by the Cornell Laboratory of Ornithology's (CLO) Bioacoustics Research Program. They are easy to deploy and retrieve at sea. Each ARU contains batteries, a microphone, and a computer hard drive all encased inside a 17-inch pressurized sphere (Appendix B, Figure 1). The ARUs are anchored to the bottom of the ocean with sandbags, and are remotely triggered to release to the surface for retrieval (Cornell Lab of Ornithology 2006; Clark et al. 2002). Each ARU unit record sounds within 5 to 10 nautical miles from the buoy location between 0 and 1000 hertz, the frequency of noise signals from both shipping and whale vocalizations (Frady 2006).The ARU locations within SBNMS were selected based on water depth and coverage area, and to minimize losses to bottom trawling activity. Five to 7 ARUs were deployed for each 2 or 3 month periods, depending on the number retrieved each period. Although the number of ARUs deployed varied, the ARUs were arranged in a triad with 8 nautical mile equilateral triangular separation and a 5 nautical mile radius to acoustically cover 80 to 85% of the sanctuary (Appendix B, Figure 2).

After retrieval, the acoustic data from the ARUs were merged and analyzed for right whale sounds using custom-built software at the CLO Bioacoustics Research Program. The resulting 89,280 hours of continuous acoustic recordings were analyzed using an automated call detected algorithm, which functions as a generalized likelihood ratio test (Urazghildiiev & Clark 2006). The automated call detector was programmed to identify the up-calls of the right whale because it is the most dominant call heard in the SBNMS (Parks et al. 2005). The detector is highly efficient, detecting 80 to 85% of the up-calls in high ambient noise conditions **(**Van Parijs pers. comm.). Since biological and anthropogenic noises are also recorded on the ARUs, it is possible for the detector to confuse boat noise and/or humpback whale calls for a right whale up-call. Therefore in order to validate the results the detections were hand browsed and checked for accuracy through an Extensible BioAcoustic Tool known as XBAT. This sound analysis tool enables viewing of multi channels and continuous scrolling through sound files and is a platform written to operate in MATLAB, a numerical computing environment (Extensible Bioacoustic Tool 2007; MATLAB 2008). In this program audible sounds are converted to visual information in the form of multi spectrograms which enabled measurement of sounds frequency, duration, and intensity (Appendix B, Figure 3).

After the up-call detections were verified by a human operator through these platforms, the end product was a catalog of the number of right whale calls heard at each day at each Automated Recording Unit from January to May 2006, July to December 2006, and January to February 2007. These data were analyzed to calculate the number of calls by day, month, hour, and ARU location. The densities of up-calls at each ARU were calculated (mean number of up-calls) in order to view spatial patterns of data, and the monthly data were effort corrected to compensate for the different number of ARUs present per month. To compare acoustic and visual data, ARCINFO based Geographic Information System maps were created.

Aerial Surveys

In order to validate the efficacy of acoustic methods for identification of right whale locations, acoustic data were compared with direct observations from aerial and shipboard surveys collected as part of the Right Whale Sighting Advisory System (RWSAS) when available. The RWSAS provides real time sighting information from aerial and shipboard surveys to commercial ships and mariners in the northeastern United States. The RWSAS reports are compiled from a variety of sources including the North

Atlantic Right Whale Sighting Survey, research organizations, whale watch vessels, the U.S. Coast Guard, fishing vessels, commercial ships, ferry companies, and the general public.

North Atlantic Right Whale Sighting Survey (NARWSS) is a NOAA Fisheries Service program which focuses on locating and recording the seasonal distribution of the right whales in the northeastern United States when weather permits (Niemeyer et al. 2007). The crew consists of two pilots, a data recorder, and two observers that are positioned on either side of the plane. During 2006 and 2007, the NARWSS completed standardized surveys that covered waters from Long Island, New York, to the northern Gulf of Maine out to the Exclusive Economic Zone (EEZ) marine boundary, the edge of the sea zone over which the United States has special rights for the exploration and use of marine resources. The flights were performed at 185 km/hr (100 knots) and an altitude of 230 meters (750 feet), using the high-wing aircraft DeHavilland Twin Otter. The average flight duration was six hours and predominately occurred between the times of 8 AM to 5 PM. The plane was equipped with bubble windows on each side which provided the observers with a good view ahead and abeam of the aircraft. On all survey flights, sighting condition variables (i.e. sea state, cloud cover, glare intensity) that could affect the probability of detecting whales along track lines were logged (Cole et al. 2007). Once a whale was sighted it was identified to species and the number of individuals present was recorded. In addition, observers took photographs and made observations of appearance or behavior.

The plane then flew over the whale to determine its exact location by a Geographic Positioning System equipped on the plane (Cole et al. 2007).

Statistical Analyses

Data were analyzed to determine if there were differences in number of up-calls among months. Tests for homogeneity of variance indicated that there were significant differences in variance between numbers of up-calls over the 13 months; thus non-parametric methods were used in this analysis. One factor analysis was conducted using a Kruskal-Wallis test to evaluate heterogeneity among different months.

Chi-square goodness-of-fit tests were used to test if the number of right whale up-calls occurred with equal frequency over the 24 hour day. A significance level of 0.05 was selected.

RESULTS

A. Seasonal Distribution of Up-Calls

A total of 22,522 up-calls were detected by the Automated Recording Units in the SBNMS between January to May 2006, July to December 2006, and January to February 2007 (13 months). The number of days in a month over which data was recorded ranged from 21 to 31, depending on when ARUs were retrieved. The number of up-calls detected on a single ARU ranged from 0 to 3856 (Appendix C, Figure 1). The number of right whale up-calls varied and the Kruskal-Wallis test found a significant difference (x^2 = 740.481, df = 12, 3855, P = $1.27e^{-152}$) in the number of up-calls among the 13 months. The highest mean number of up-calls occurred in April (n = 1204/ARU), followed by May (n = 457/ARU), and March (n = 388/ARU). The lowest mean number (n = 5/ARU) was detected in November and surrounding months (September, October, December). No up-calls were detected in July and August (Appendix C, Figure 2). Recordings were made both in January and February of 2006 and 2007. Clear differences in the mean number of up-calls are apparent with fewer up-calls in 2007 (January: 71/ARU; February: 186/ARU) compared with 2006 (January: 196/ARU; February: 328/ARU).

Up-calls were detected over 58.3% of the recording days over all months, excluding July and August when zero up-calls were heard. The percentage of days on which up-calls were recorded varied from 100% in February, March, and April 2006 to 58.3% in September 2006 (Appendix C, Figure 3).

The distribution and occurrence of vocalizing up-calls varied spatially throughout the sanctuary over the 13 month period. Densities of up-calls at each ARU were calculated (mean number of up-calls) in order to view the spatial patterns of the data (Appendix C, Figure 4). In January through February 2006, more than 800 up-calls were detected predominately in the northeast corner with 200 up-calls along the eastern side. Up-calls continued to remain above 800 in the northeast corner in March 2006, and spread downward to the southwest. The following two months, April and May 2006, experienced high numbers of up-calls as well, this time throughout the entire sanctuary. The number of up-calls surpassed 800 on the western side of the sanctuary, and above 200 and 400 on the east. There were zero up-calls detected on the ARUs in July and August 2006, while ARUs from September through November 2006 detected less than 25 up-calls across the sanctuary. In December 2006 through February 2007, up-calls estimated around 400 in the north and 100 and 50 in the middle and south.

B. Diel Distribution of Up-Calls

Right whale up-calls were not heard with the same relative frequency over the 24 hour day (x^2 = 4581.83, 22 df, P = 0). These results indicate that a significant difference existed between hourly right whale detection rates in SBNMS (Appendix C, Figure 5). The highest number of up-calls occurred at 2200 (n = 2085), followed by 2100 (n = 1760) and the surrounding hours (1700; 1800; 1900; 2000). The lowest number of up-calls occurred at 0500 (n = 477) and surrounding hours (0600; 0700; 0800). No up-calls were detected in July or August. The average sunset and sunrise times were also calculated for each month from data obtained from the U.S. Naval Observatory. An hour was added for Daylight Saving Time from April through October (Buzzards Bay National Estuary Program 2006). The peak up-calling occurred between 1700 and 2200 for all 13 months, and January and February had average sunset times of 1640 and 1715. The average sunset times grew later as the months progressed until October.

Diel activity differed over the months (Appendix C, Figure 6). In January, the highest number of up-calls occurred around midday (1100; 1200).

The highest number of up-calls occurred later in the evening for February (1600- 1800) and March (1600-1900), and even later in April (2000-2200) and May (2000-2200). The lowest number of up-calls occurred in the late evening for January compared with around midday for all other months.

C. Visual versus Acoustic Detections of right whales

The Right Whale Sighting Advisory System visually observed 2 whales in the SBNMS area in each of the following months: January, March, and October 2006, and February 2007. The number of visual observations increased in the 2006 summer months with a total of 232 right whales in April, 63 in May, and 8 in July. There were a total of 33 days with coincident aerial and acoustic survey and a total of 311 right whales sighted.

The 33 RWSAS observed sightings were compiled and plotted in an ARCINFO based Geographic Information System program (Appendix C, Figure 7-8). An 8 nautical mile buffer was encircled around the Automated Recording Units in the sanctuary as a maximum distance capable of detecting up-calls. The numbers of up-calls detected on ARUs throughout the sanctuary were compared to counts from visual sightings on each given day (Appendix C, Figure 9). For the 33 RWSAS sightings, the number of up-calls within 8 nautical miles of the sighting ranged from 0 to 406 up-calls. There were 10,756 instances where up-calls were heard and no sightings were made. Of the 366 days over the 13 months with acoustic array monitoring, there were 103 days (28.14%) when no whales were seen and no whales were heard, there were 333 days (90.98%) when no whales were seen but whales were heard, and there was 6 days (1.64%) when whales were seen but no whales were heard.

The Northeast Fisheries Science Center's North Atlantic Right Whale Sighting Survey conducted aerial surveys 42 days out of the 366 day study period (11.48%) in SBNMS. Figure 10 illustrates NARWSS effort with the survey lines flown throughout the sanctuary and their sightings (Appendix C).

DISCUSSION

A. Seasonal Distribution of Up-Calls

This study has shown that right whales call throughout all months in the Stellwagen Bank National Marine Sanctuary except for July and August. Although it cannot be entirely assumed that a lack of call detections means a lack of whales, but 0 recordings for 62 days (July and August) is a noticeable difference. This demonstrates that right whales are present in this area throughout 9 months of the year. While it is not possible to determine a relationship between the number of calls and the number of right whales present, these results show a peak in up-calls during the months when there is clear evidence that more whales are present in the sanctuary. For example, figure 4 shows a high density of right whales in March throughout the sanctuary (Appendix C). This pattern supports the observation of migrating mother and calf right whales tucking into the arm of Cape Cod and the adjacent SBNMS since the water is calm and food is abundant (Mayo and Marx 1990; Brown et al. 2002). In addition, the months of April and May

2006 show a high number of right whales utilizing the sanctuary as the whales feed on dense copepod patches in the area (Kenney et al. 1995; Beardsley et al. 1996).

There was variability in number of up-calls when the winter months of 2007 and 2006 were compared, with fewer calls in 2007 (Appendix C, Figure 2). This may be due to an actual decrease in numbers of right whales, or the whales may have been less vocal in 2007 than in 2006. From September to November 2006 there were less than 25 up-calls detected from ARUs and the distributions were scattered throughout the sanctuary (Appendix C, Figure 4). This pattern is not surprising, since a majority of the right whale population is arriving in warm waters off the coasts of Georgia and Florida at this time (Winn et al. 1986; Kenney 2001). However it is important to note that there are some right whales periodically calling during these months despite observed migratory patterns. These calls may be produced by a couple whales traveling alone or in small groups that are briefly crossing the SBNMS, in a possible attempt to locate food. Currently though, it is unknown if right whales share food resources, and so the question of why they are calling in a feeding area still remains largely unanswered.

Overall the distribution and occurrence of vocalizing up-calls varied spatially throughout the sanctuary, suggesting right whales utilize the entire area at some point in the year (Appendix C, Figure 4). Furthermore, up-calls were heard over half of the days in each month and in some months every single day, demonstrating the temporary residency of right whales (Appendix

C, Figure 3). As mentioned before, the location of the wintering ground for male and non-pregnant female right whales is widely unknown. However their geographic selection is most likely attributed to the presence of food and mates, and SBNMS could be an option. Recent research has provided evidence of a possible midwinter conception, and if true, the wintering ground would also serve as a mating ground. Identifying and protecting this area may become critical for the protection of the right whale population. The use of widespread listening systems, such as the Automated Recording Units, could be a useful tool when searching for unknown right whale grounds. Wilkinson and Jeffries Ledge (northeast of SBNMS) are current areas being explored by winter surveys for the presence of right whales. This study showed a higher density of up-calls located to the northeast of SBNMS, in proximity to Jeffries Ledge. Other studies have found winter up-call activity off Canada (Melllinger et al. 2007), and data is currently being analyzed from Jeffries Ledge, Iceland, and Greenland.

The observed seasonal patterns could also reflect the movement of vocalizing whales into and out of the sanctuary, or of seasonal changes in the behavior associated with up-calls. The vocalizing rate of the up-call may increase or decrease with feeding behavior, socializing, or migration. More data on the age and sex of the whales making the calls, as well as the function of the call itself are required to further understand these observed seasonal trends.

B. Diel Distribution of Up-Calls

The diel distribution of up-calls illustrates that the time of day when whales are most vocal does not necessarily coincide with the time of day when daylight is available. The peak number of up-calls for all data over the 13 months occurred after or right before the average sunset time from 1700 to 2200, which either means there are more whales present or the whales are more active. Whichever the explanation, it is an important message when devising survey techniques because aerial surveys primarily take place during daylight hours. This information reinforces the potential of acoustic techniques to assist in effectively monitor the right whale population. Tyack and Parks (2005) sampled recordings from Cape Cod Bay, the Great South Channel, and the Bay of Fundy from 2004 and found similar diel calling patterns. In all three areas, the total numbers of calls recorded between dusk and dawn was significantly higher than the number of calls recorded during daylight hours. This pattern suggests a change in behavioral activity of right whales at night, and future research is required to explain the driving forces. When individual months are analyzed further there is an interesting diel pattern from January to March 2006. The month of January contrasted with all other months when the highest number of up-calls occurred in the late evening. The results show a gradual migration of the highest number of up-calls from the afternoon in January, to the early evening in February and March, and to the late evening in April and May. While this pattern could be related to the progression of the time of sunset from earlier in winter to later in spring, it is only observed in these months. Other possible explanations for this pattern require more knowledge on right whale social activity and feeding behavior.

The primary prey of the North Atlantic right whales is the 2- to 3-mm-long calanoid copepod *Calanus finmarchicus*, which is located within the Cape Cod Bay feeding area (Mayo and Marx 1990). Scientists' current understanding of how right whales locate and communicate prey patches on such large spatial scales is relatively unknown. One possibility though, is the right whales cooperate with each other to find food, since the population is so small and the whales are often highly aggregated in their feeding grounds. Right whales may use acoustic vocalizations to announce a prey patch to other whales (Lowry 1993; Winn et al. 1995), which could explain the diel activity of their vocalizations. Another possibility may relate to the migration of *Calanus finmarchicus* into the upper water layers at night, a pattern observed in a 2003 right whale feeding ecology study. The findings suggest the energetic costs of foraging at the surface are lower than at deeper layers (Baumgartner et al. 2003). As a result of the energetic benefit, the whales may feed on these patches in larger groups and hence produce more vocal activity. While up-calls were previously recorded in the Cape Cod Bay area at times when individuals are thought to be feeding (Parks and Clark 2007), another study suggests that when right whales are skim feeding they may be silent (Jaquet pers. comm.). Mentioned earlier, the up-call is thought to function primarily as a contact call, so the shift in peak activity may relate to communication needs of individuals and groups rather than patterns of foraging activity.

C. Visual versus Acoustic Detections of Right Whales

The acoustic results show that right whales utilize Stellwagen Bank National Marine Sanctuary to a greater extent than previously thought during the winter months. It is unclear whether this pattern resulted from an increase in survey effort or an actual change in right whale occurrence within the SBNMS. However given the paucity of data available for the winter months the former is likely to be true.

While the automated call detector is efficient (80 to 85% accurate), a tradeoff between proportion of right whale up-calls detected and the number of false detections still exists. The cost of detecting the absolute number of up-calls is the time it takes to sort through all the data, while on the other hand a less detailed search can result in a number of up-calls that were overlooked. In addition to this trade-off, the Automated Recording Units cannot estimate the absolute numbers of right whales, and presence is the only assumption that can be made. Currently it is not know whether right whale up-calls are individually distinctive enough in terms of call duration and frequency to accurately estimate numbers of calling whales based on call features alone. In order to determine this each call must be localized and attributed to a given individual. Localizing individual calling whales is an extensive analysis that requires comparing the time of arrival differences recorded by neighboring ARUs. The ARU locations of the past two years were set slightly too far apart which did not provide enough overlap. These reasons, coupled with the noisy environment of the sanctuary, made it impossible to calculate the location of an individual whale through the process of triangulation. The ARU array will be placed closer together in the next three years of the project, which will allow individual whales to be followed throughout the sanctuary.

Other biological and anthropogenic noises are also recorded on the ARUs, and at times it is difficult to verify a right whale up-call. The whale calls can be masked by ambient noise, especially from anthropogenic sources. Humpbacks are also known to have acoustic characteristics similar to right whales. Distinguishing vocalizations of right whales from those of humpback whales is a problem in acoustic surveys since both species produce sounds in the 50 to 500 hertz frequency band (Appendix D, Figure 1). To distinguish between right and humpback vocalizations, the following set of criteria were used: 1) humpbacks often call in repetitive patterns and during their breeding season call in song, whereas right whales produce independent calls (Payne and McVay 1971); 2) humpbacks usually produce calls with stronger frequencies than right whales; and 3) humpbacks call repeatedly, whereas right whales have longer periods between calls. As a result of human choice, right whale up-calls could have been overlooked and/or misreported.

To combat these issues, it is crucial to compare data from acoustic and visual monitoring to validate these results and estimate biases. It is possible to relate call rates to whale density in SBNMS where acoustic and visual data have been collected concurrently. Visual monitoring however is also biased in that it under represents the number of whales since they are not all equally available for viewing at the surface. Aerial surveys have short comings in that they are very expensive, and there are safety concerns associated with aerial surveys that fly at low altitudes. Therefore comparisons between these two platforms are difficult since it requires the comparison of two biases techniques. There are effort differences between these two platforms as well, with Automated Recording Units recording continuously and aerial surveys flying only when weather and light conditions permit. For example, the North Atlantic Right Whale Sighting Survey completed only 11.48% of aerial surveys within SBNMS over the 13 month study period. It is evident that the NARWSS sightings as well as additional sightings from the Right Whale Sighting Advisory System did not account for all the acoustic behavior present throughout the sanctuary. Furthermore, the ARUs detected whales in SBNMS earlier than aerial surveys across all 13 months. This suggests that passive acoustics is an effective tool for monitoring right whale activity and distribution when other techniques are severely limited by weather and daylight conditions. In addition, it provides information on the acoustic and social behavior of right whales that previously was limited to visual observations made at the surface.

Despite limitations, the existing data set serves as a source for conservation policy. The data contains the relative density of calls, and one recorded up-call means at least one right whale is present in the sanctuary. It is important to remember that "presence" triggers an immediate management action; therefore while relating numbers to whales would be informative and valuable, it is not critical. The information on calling patterns is enough to direct and improve management decisions in relation to the right whales.

D. Conclusions

In order to effectively apply acoustic techniques to right whale conservation, information on the presence and distribution of right whales must be available in real time so that ships can make timely and strategic decisions about their routes and speeds. Automatic recording units which report in real time are a recent innovation, and should significantly assist ships in reducing collisions and entanglements with the right whales. The real time system detects up-calls in the ARU's immediate vicinity and communicates the information to shore via cell phone or satellite link (Appendix D, Figure 2). The data is validated every day and available on a website in the forms of recent up-call detections, maps of detection regions, audio clips, ARUs status, and reports (NRWBUOYS 2008). In the future researchers hope to directly relay whale positions to ship captains and fishermen by internet so they can plan their routes accordingly, and thus reduce the risk of collisions and entanglements. Currently there are ten real time buoys deployed along the right whale migration route where they cross paths with the densest Boston shipping traffic, and an additional three inside Cape Cod Bay.

These analytical efforts demonstrate that passive acoustics can be an effective tool to highlight concentrations of right whales within the Stellwagen Bank National Marine Sanctuary. Passive acoustic monitoring provides insights into how whales communicate and how they migrate, while seeking to reduce the numbers of animals killed in their increasingly urbanized environment. This study has shown that right whales are present in the sanctuary throughout 9 months of the year. The high presence of vocalizing right whales within the sanctuary can offer one possible explanation to where males and non-pregnant females go during winter months, an idea that will require further analysis. Right whales are large mammals with a broad home range, which makes it difficult to conduct traditional research on individual behavior and sound production. All existing marine mammal evidence indicates that cetaceans are well adapted for producing and perceiving sound in their fluid environment. Therefore from the standpoint of observing and understanding right whale behavior and activity, sound is the best tactic. This technique, compared to aerial and shipboard surveys, is arguably the most promising tool for identifying the general location and numbers of whales over a large domain and long time period.

The acoustic behavior of the right whale is poorly understood compared to other cetaceans, but hopefully passive acoustics will increase the description of their sound production and related behavior. This information will be critical for determining the associations between sounds and certain diel and seasonal times when right whales are most vulnerable. Research will continue to understand the sound production of right whales, their related behavior, and adaptations they may undertake with increasing noise pollution. The SBNMS passive acoustic project is the first of its kind, and will serve as a model that could be exported to other ecosystems, in hopes of developing a global monitoring network for marine mammals. Ultimately this data as well as future work will improve information on distribution and occurrence of right whale populations, and contribute to the understanding of how to identify and mitigate ship collisions and gear entanglements with this endangered species.

Publications resulting from this study:

1. Long term seasonal and diurnal patterns of right whale up calls throughout the Stellwagen Bank National Marine Sanctuary. To be submitted to Endangered Species Research in August 2008.

2. Comparative analyses between acoustic and aerial surveys for determining right whale presence. To be submitted to Journal of Applied Ecology in October 2008.

APPENDIX A

Figure 1. Example of an ARCINFO based map that Northeast U.S. Right Whale Sighting Advisory System created on November 9, 2007. Numbers of right whales are encircled in red with a 5 kilometer buffer zone, and cities along the coast and major shipping lanes are labeled (Northeast U.S. RWSAS 2008).

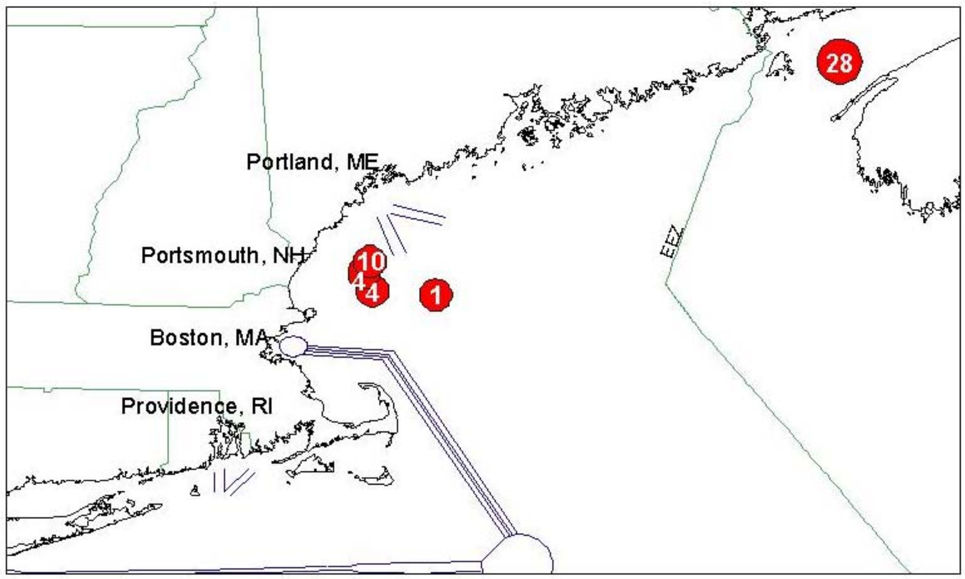


Figure 2. Spectrogram examples of the three main categories of right whale calls: 1) blow sounds, 2) broadband impulsive sounds, and 3) tonal call types, including frequency in kilohertz and time in seconds (Parks 2003; Parks and Clark 2005; Parks et al. 2005).

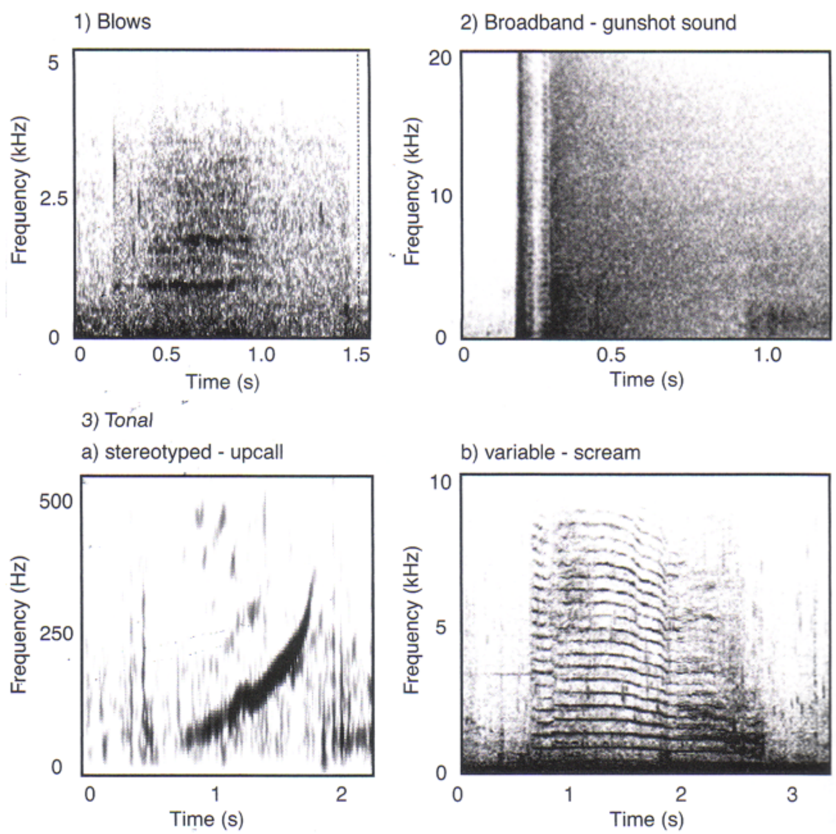


Figure 3. Proportion of call types (■ gunshot, ■ tonal, and ■ up-call) heard in the Cape Cod Bay (CCB), Great South Channel (GSC), and Bay of Fundy (BOF) (Parks and Clark 2004).

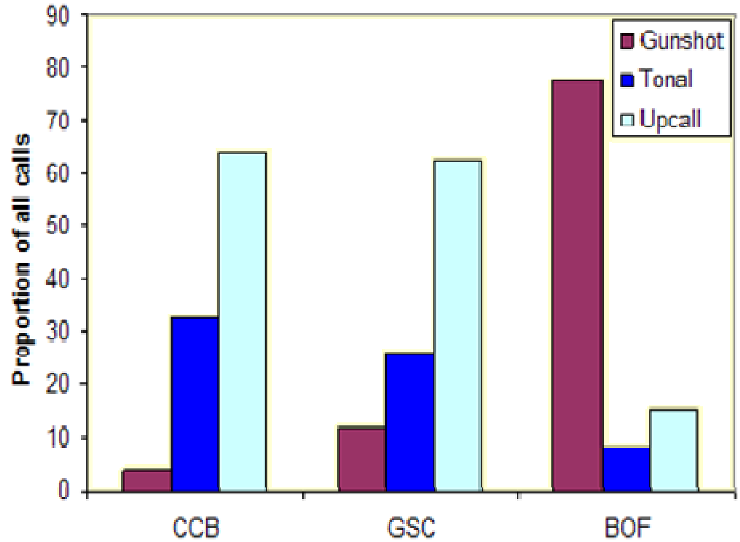


Figure 4. Map depicting the current distribution of North Atlantic right whale along the eastern United States and Canadian coast, including conservation areas, sightings, and migration zones (Kerry Lagueux 2007).

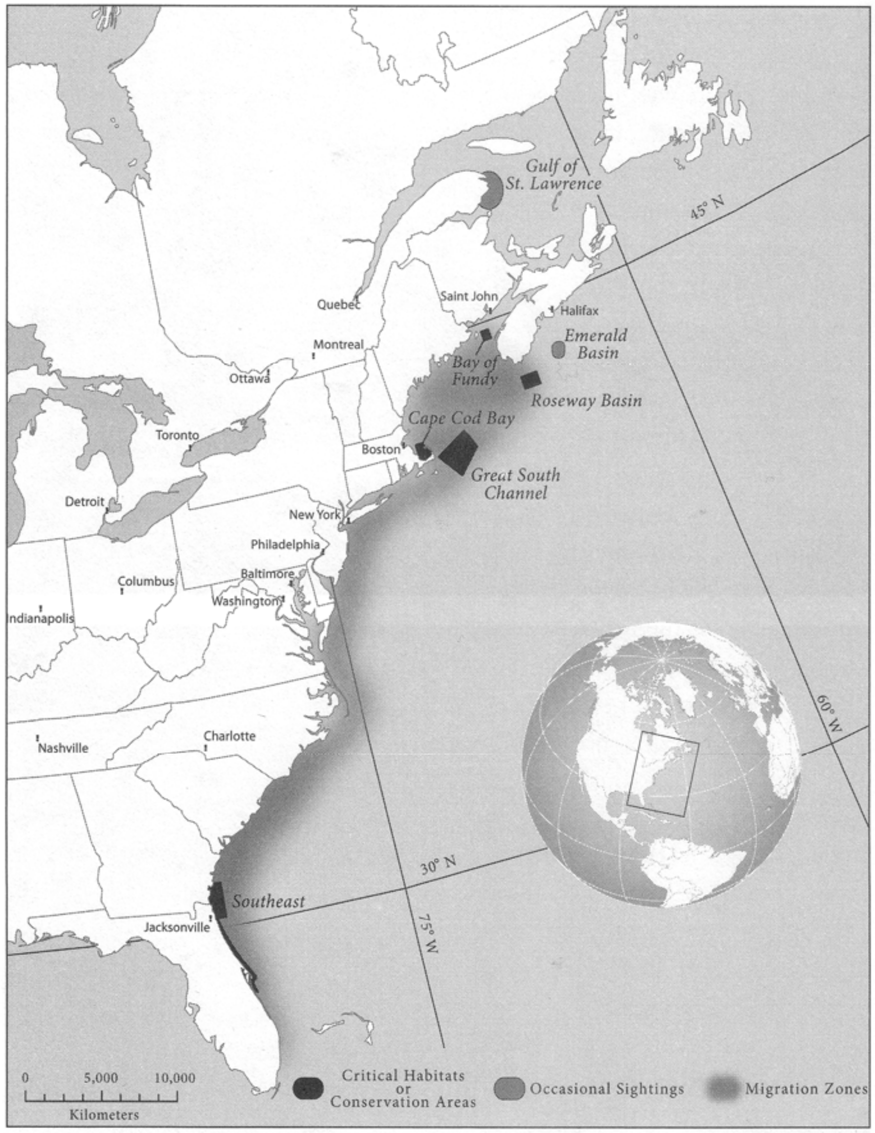


Figure 5. Map depicting the timing of the right whale migration along the eastern United States coast between the feeding and courting grounds and the breeding and calving grounds. Stellwagen Bank National Marine Sanctuary is indicated by the blue rectangle.

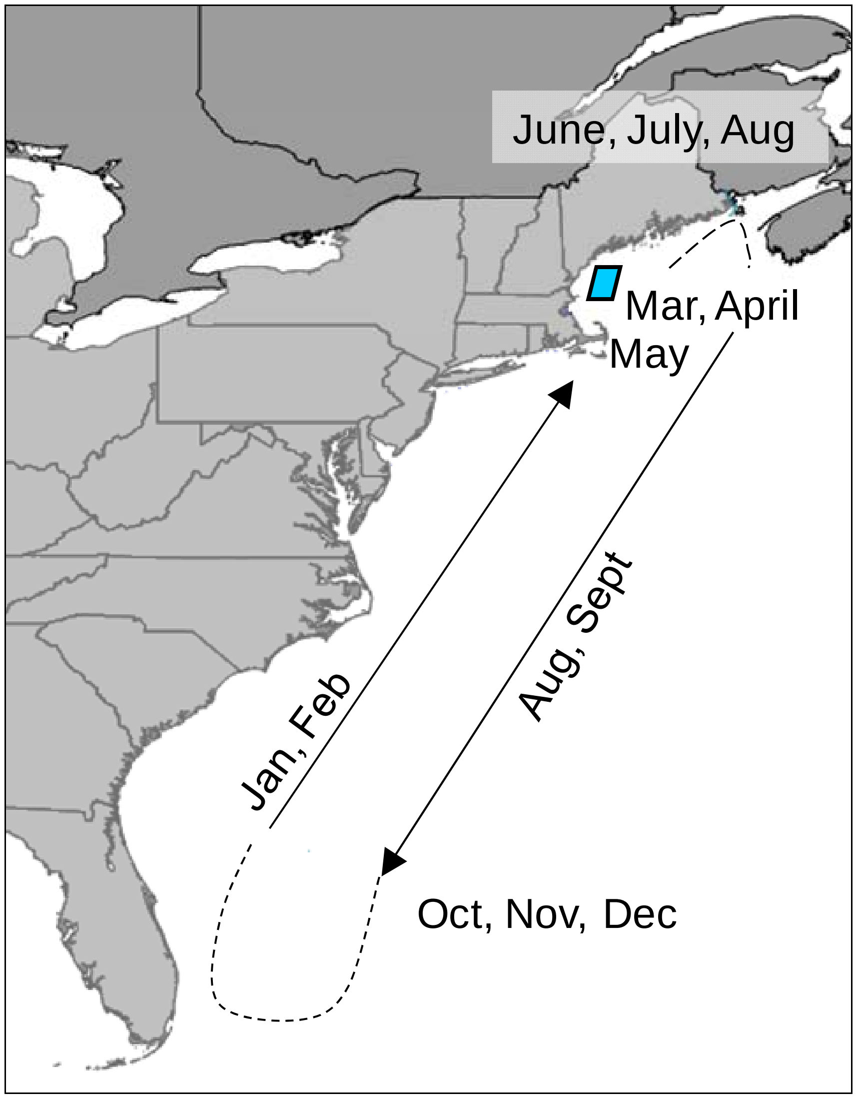


Figure 6. Approximate distribution of ship struck baleen whales indicated by red circles along the eastern seaboard of the United States with high concentrations near the Massachusetts area (Jensen & Silber 2003).

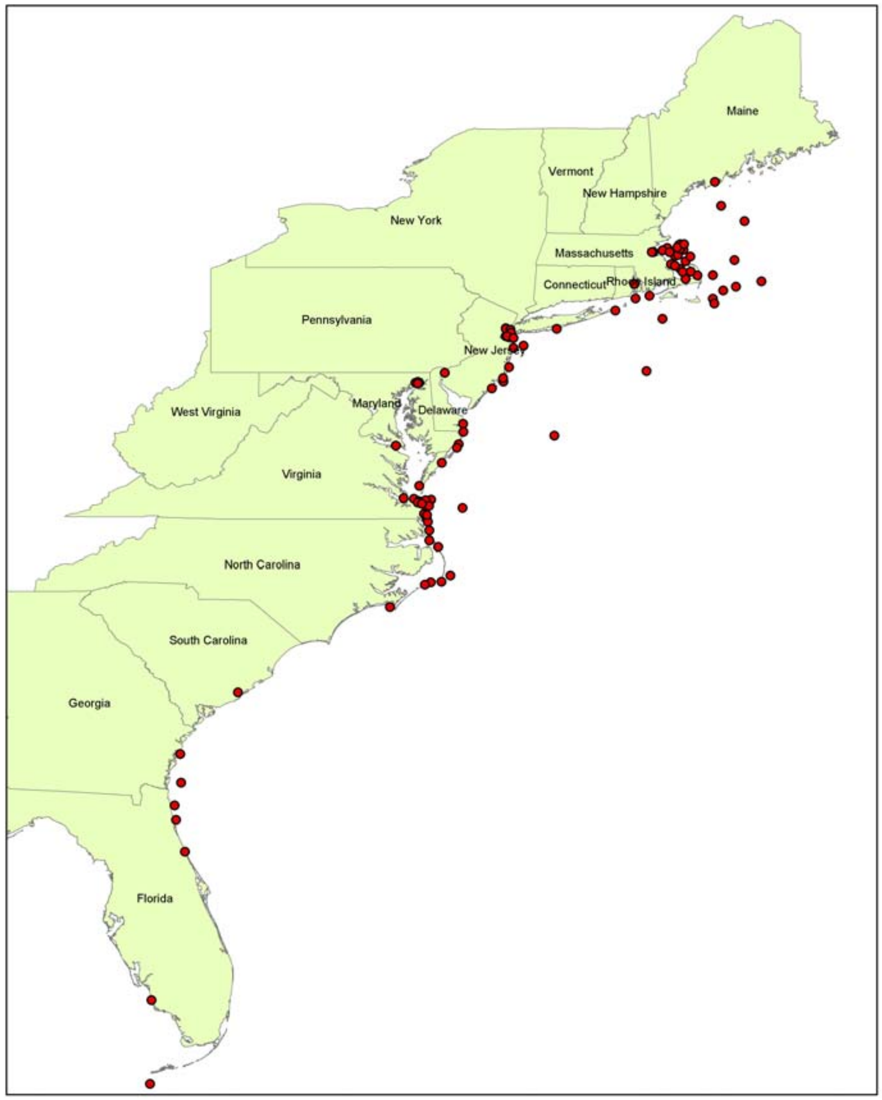


Figure 7. Position of the Stellwagen Bank National Marine Sanctuary along the eastern edge of the mouth of the Massachusetts Bay and underlying topography. Major cities are indicated by red stars (Schmidt et al. 2007).

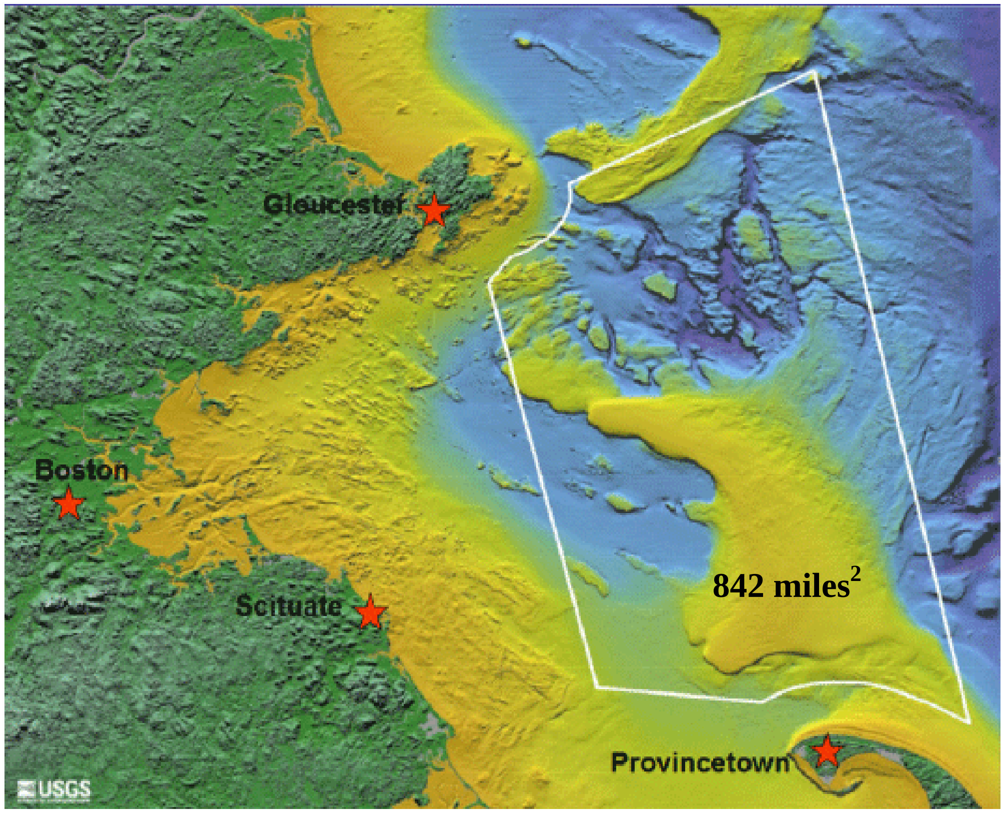


Figure 8. Distribution and density (high density in red to low density in blue) of baleen whale sightings (North Atlantic right whale visual sightings in circles) relative to the previous (straight line) and revised (dotted line) positioning of the Boston shipping lane (Smrcina 2006).

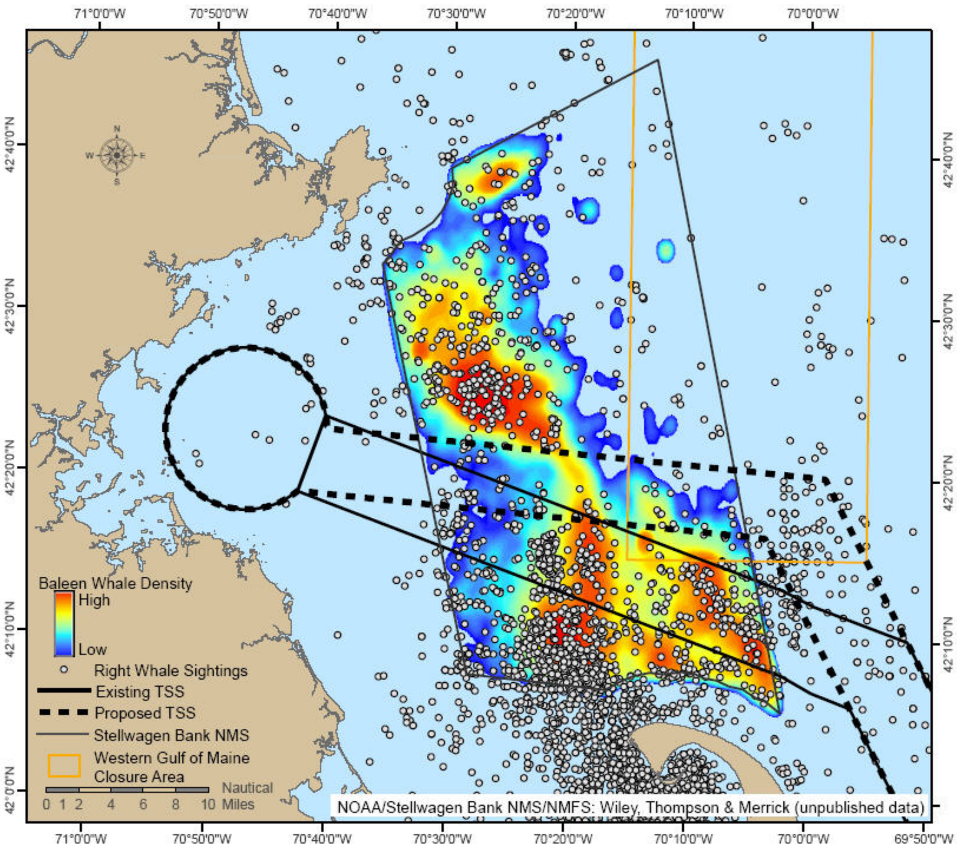
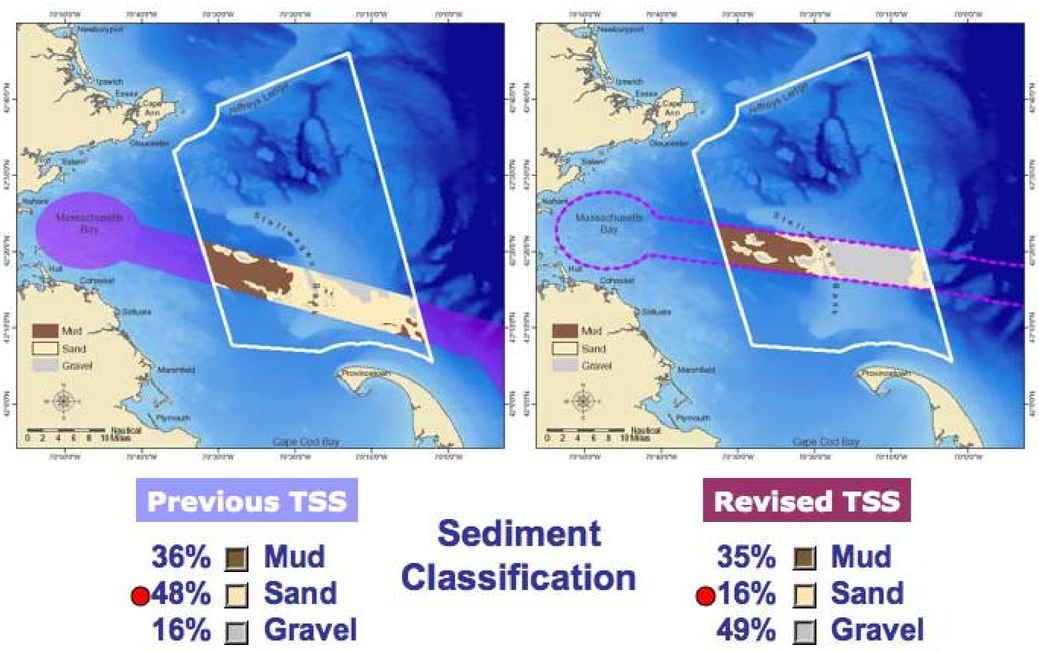


Figure 9. Percentage of habitat types in the Traffic Separation Schemes for the previous and revised Boston shipping lane in the Stellwagen Bank National Marine Sanctuary (Smrcina 2006).



APPENDIX B

Figure 1. Automated Recording Unit equipped with batteries, a microphone, a computer hard drive, and sandbags, being deployed off the side of a National Oceanic and Atmospheric Administrative vessel.

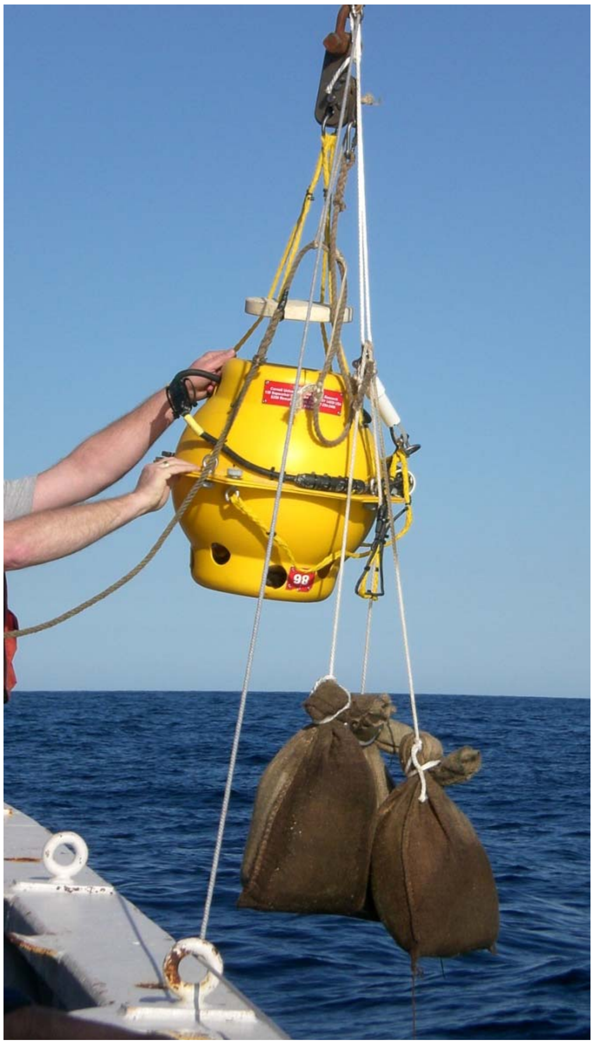


Figure 2. An example of the configuration of 10 Automated Recording Units during the 2006 pilot study in Stellwagen Bank National Marine Sanctuary achieving 85% coverage (Van Parijs pers. comm.).

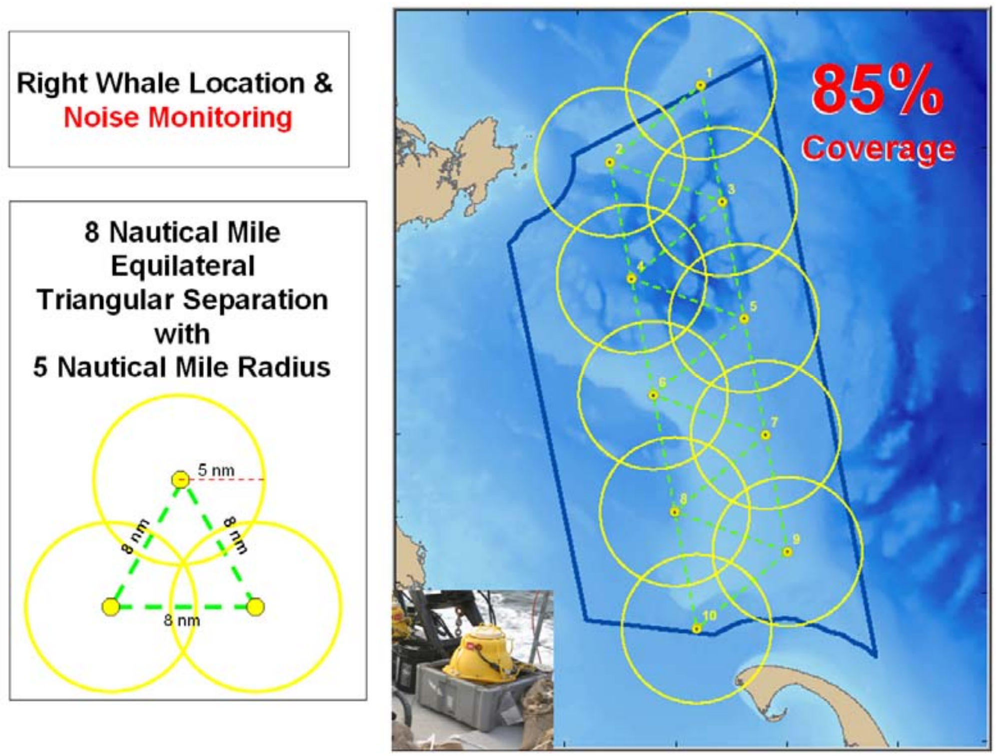
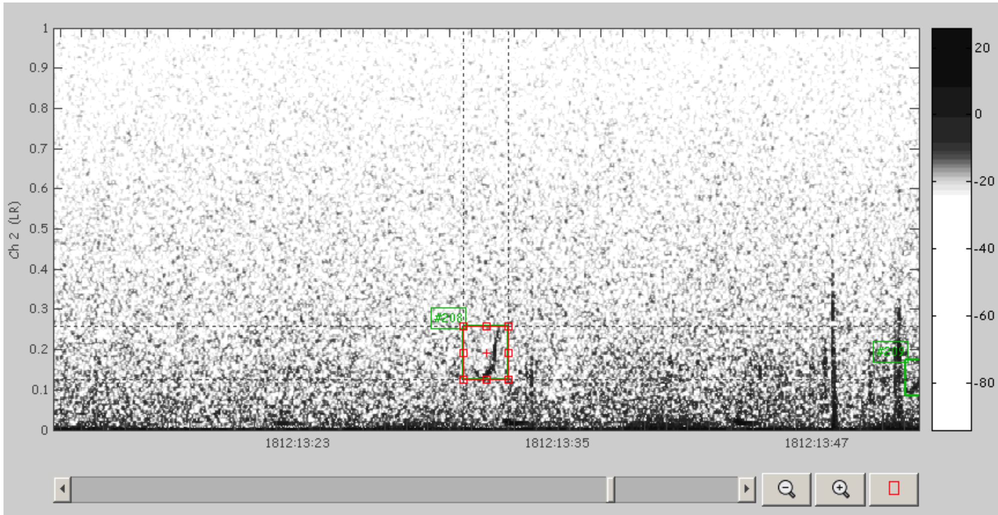


Figure 3. A snapshot of the spectrogram in the Extensible BioAcoustic Tool (XBAT) browser indicating a detected right whale up-call boxed in red. Frequency is represented by the *y* axis in kilohertz and duration by the *x* axis in seconds. The color bar on the right corresponds with the intensity of the sound.



APPENDIX C

Figure 1. Total number of up-calls over the 13 months per Automated Recording Unit (ARU) location with total number of recording days and average up-calls/ARU/month ("–" = no ARU for part of month or entire month).

	Number of up-calls													
Location Number	January'06	February	March	April	May	July	August	September	October	November	December	January'07	February	TOTAL
1	2	90	116	3856	623	0	0, –	11	5	8	26	219	363	5319
2	793	969	860	2114	328, –	0	0	14	26	1	22	7	339	5473
3	286	249	341	2232	1898	0	0	7	14	10	12	1	179	5229
4	136	434	1084	505	472	0	0, –	5	12	4	0	0	0	2652
5	154	185	99	1040	495	0	0	0	6	0	1	128	48	2156
6	3, –	–	125	469	153	0	0	2	32	8	–	–	–	792
7	0	40	88, –	224, –	99	0	0	–	6, –	4	–	–	–	461
8	–	–	–	80, –	13	0	0	–	0, –	–	–	–	–	93
9	–	–	–	312, –	35	0	0	–	0, –	–	–	–	–	347
10	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total number of recording days	26	28	29	30	24	31	31	25	31	28	31	31	21	366
Total of up-calls	1374	1967	2713	10832	4116	0	0	39	101	35	61	355	929	22522
Average up-calls/ARU/month	196.29	327.83	387.57	1203.56	457.33	0	0	6.50	11.22	5.00	12.20	71.00	185.80	

Figure 2. Mean number of up-calls per Automated Recording Unit per month for ■ 2006 and ■ 2007 with migratory patterns indicated above (N = north; SBNMS = Stellwagen Bank National Marine Sanctuary; GSC = Great South Channel; S = south; x = no data).

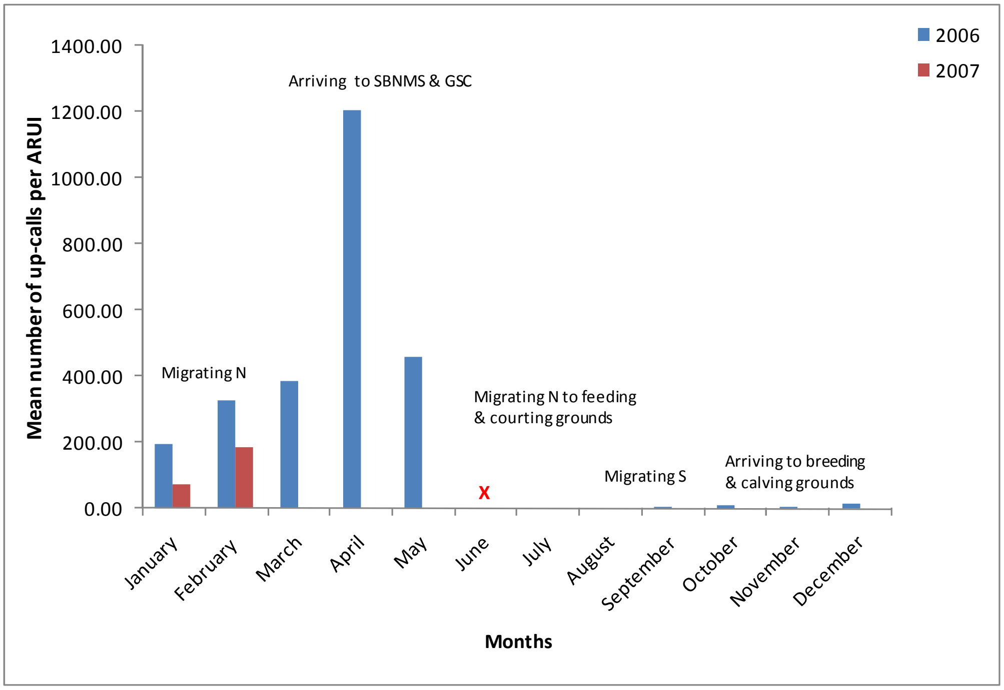


Figure 3. Percent days up-calls heard over 13 months for ■ 2006 and ■ 2007 (x = no data).

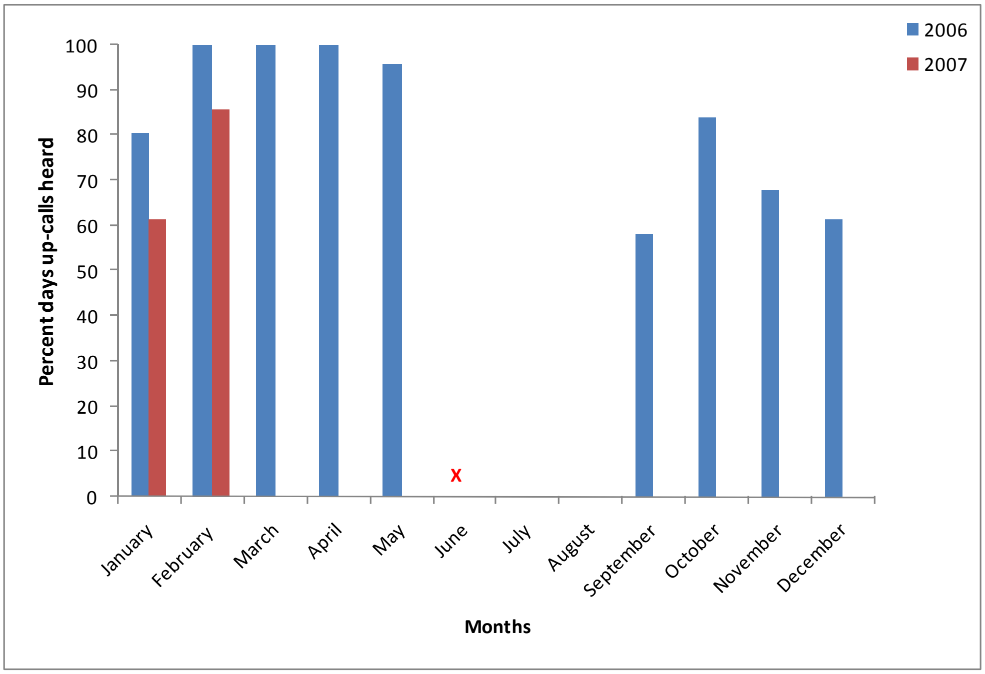


Figure 4. Occurrence and distribution maps of densities of up-calls at each Automated Recording Unit in Stellwagen Bank National Marine Sanctuary for January through February 2006; March 2006; April through May 2006; July through August 2006; September through November 2006; and December 2006 through February 2007.

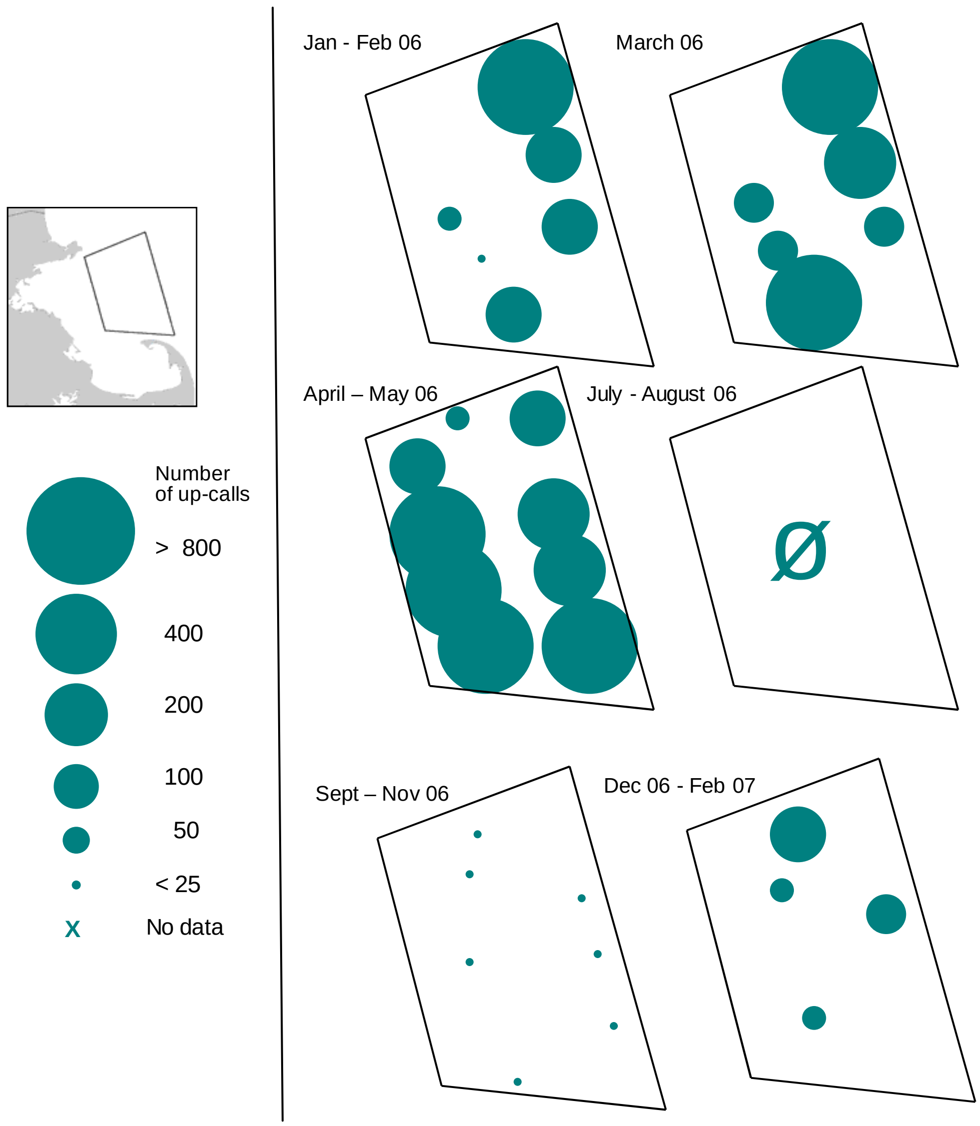


Figure 5. Total number of up-calls per hour over 13 months +/- standard error.

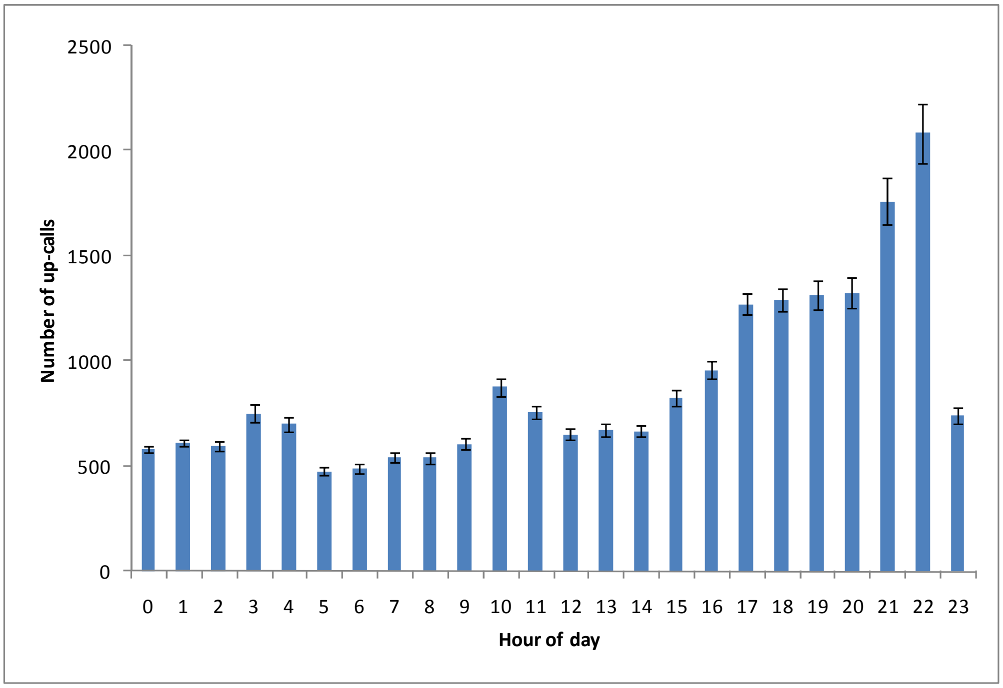
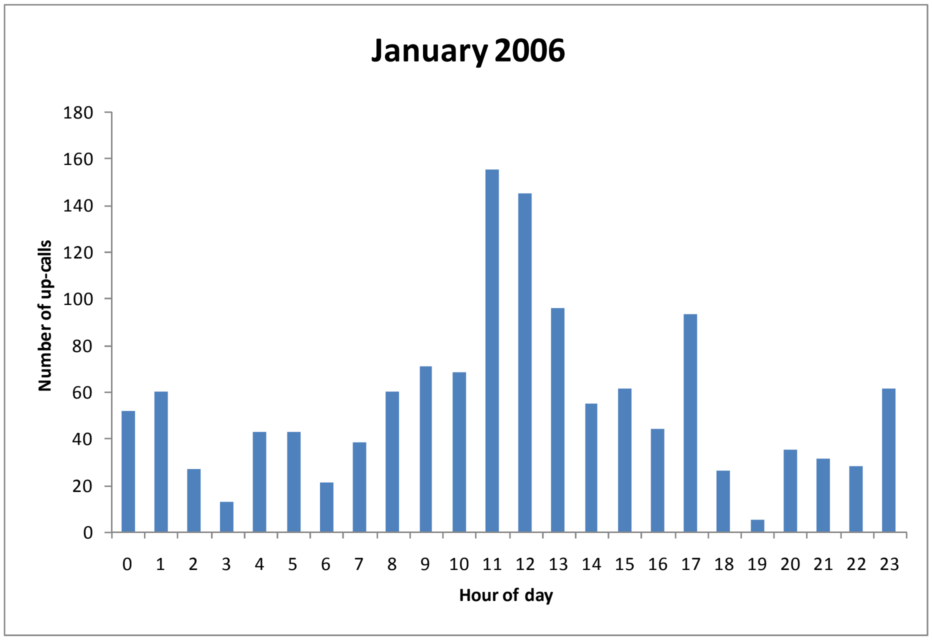
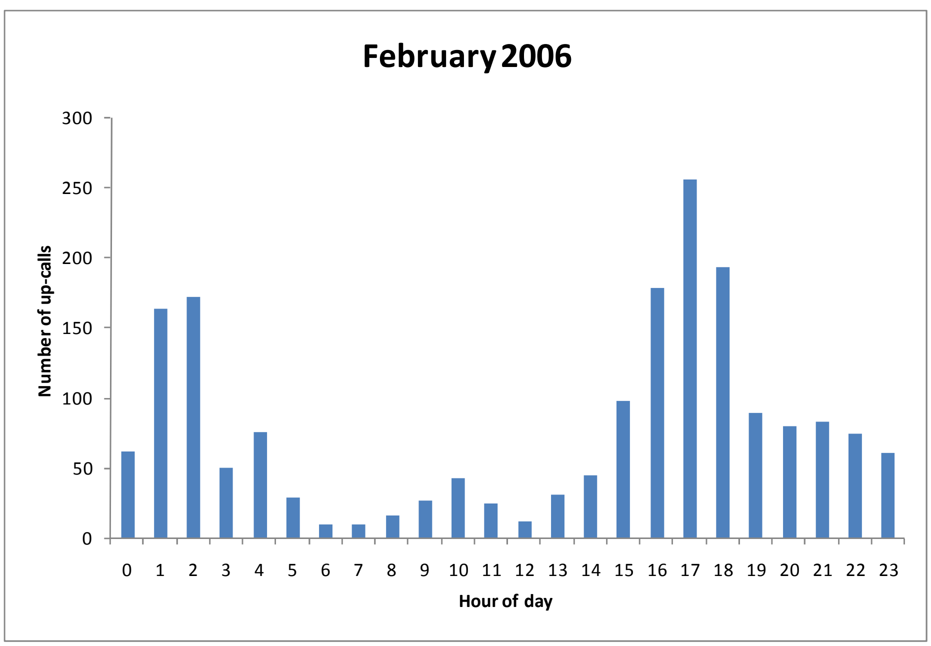


Figure 6. Total number of up-calls per hour for January through May 2006 (a – e) and September through December 2006 (e – h).

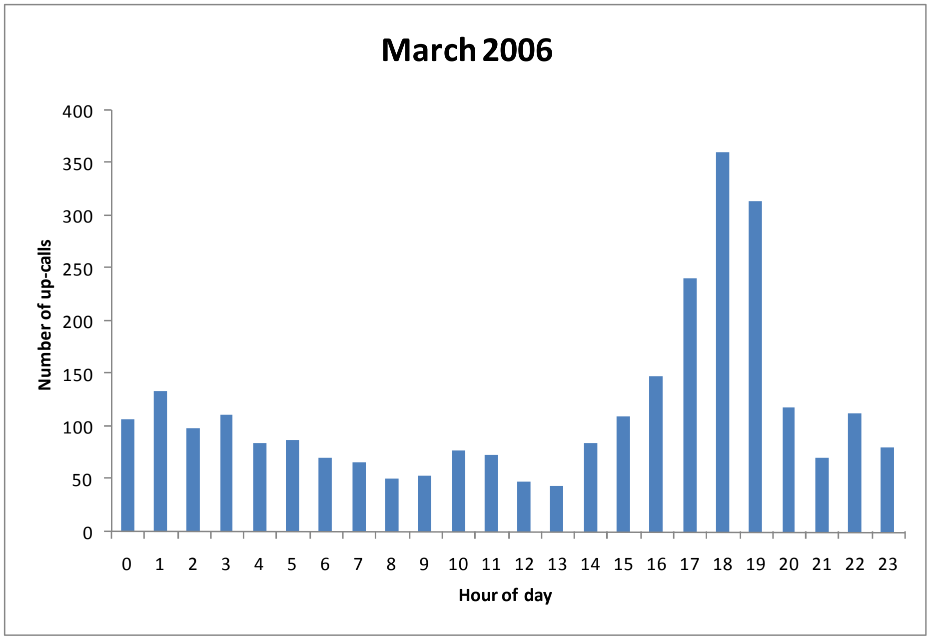
a)



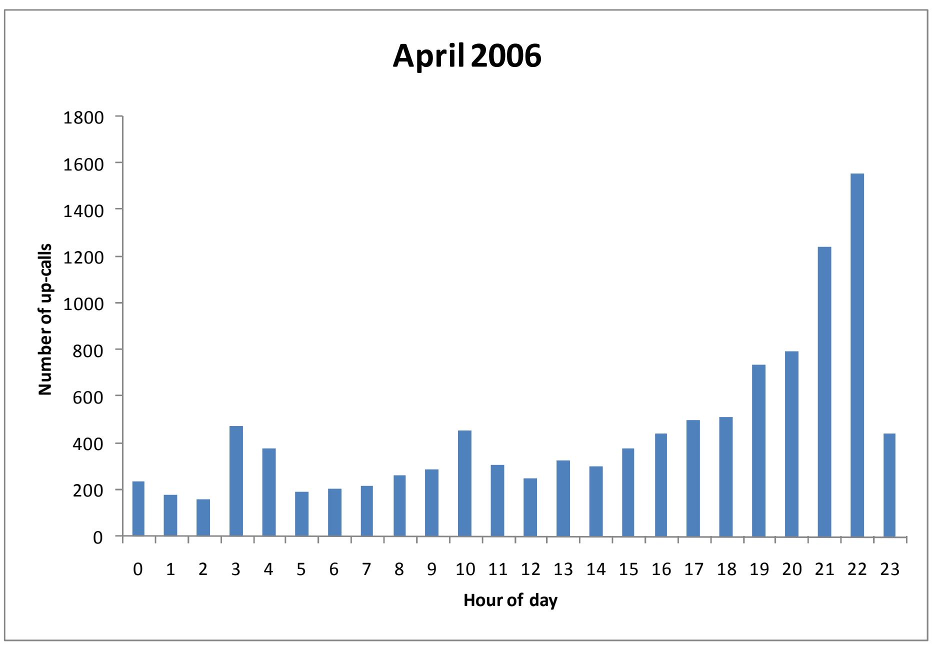
b)



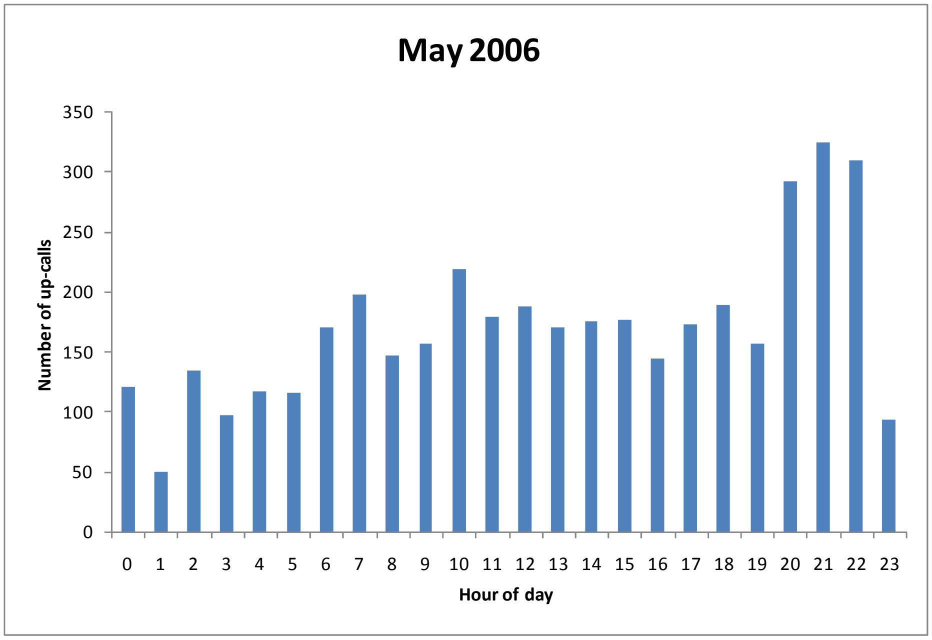
c)


March 2006
Number of up-calls
Hour of day
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

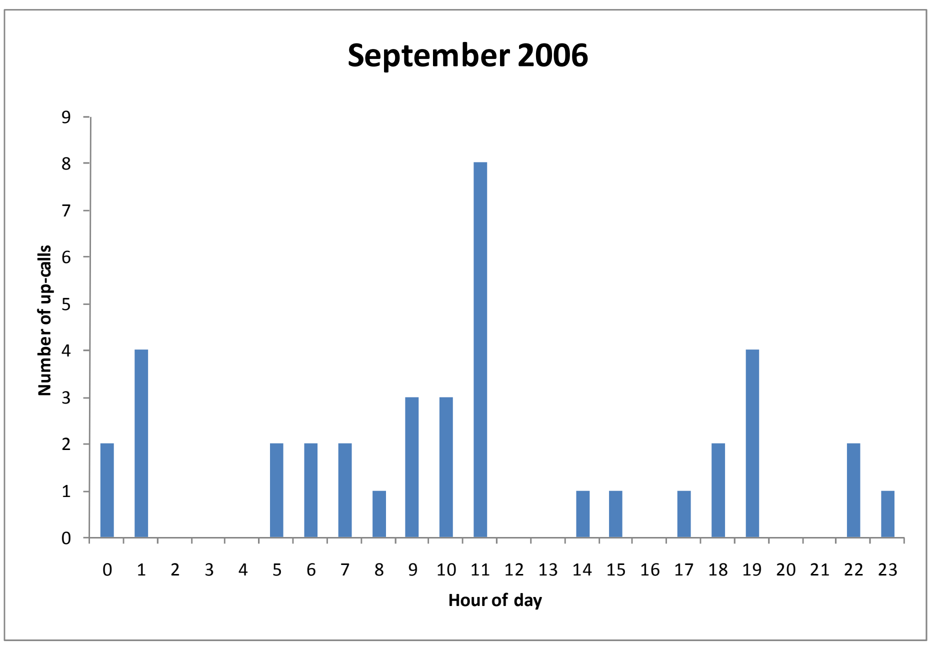
d)


April 2006
Number of up-calls
Hour of day
1800
1600
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

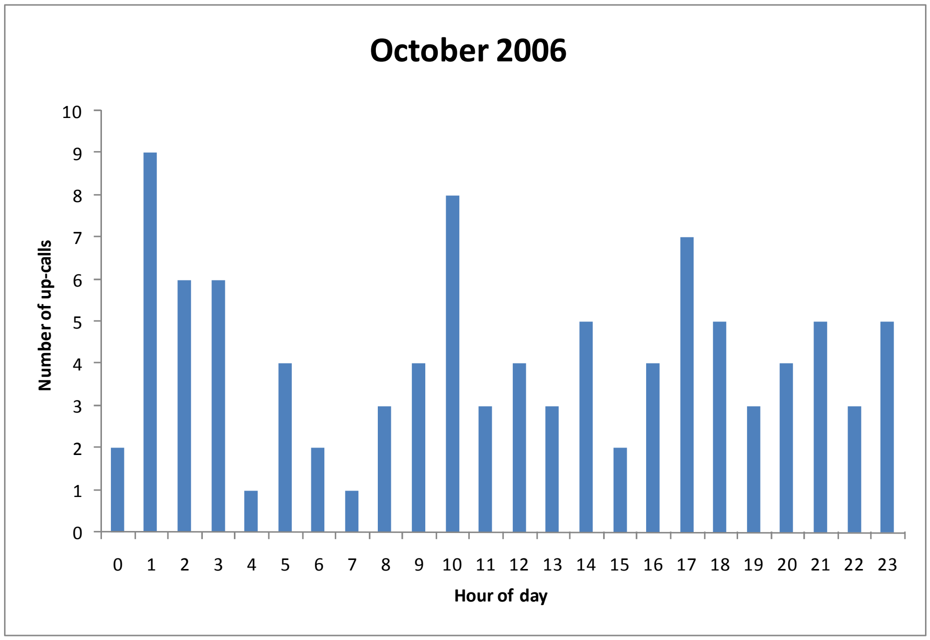
e)


May 2006
350
300
250
200
150
100
50
0
Number of up-calls
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of day

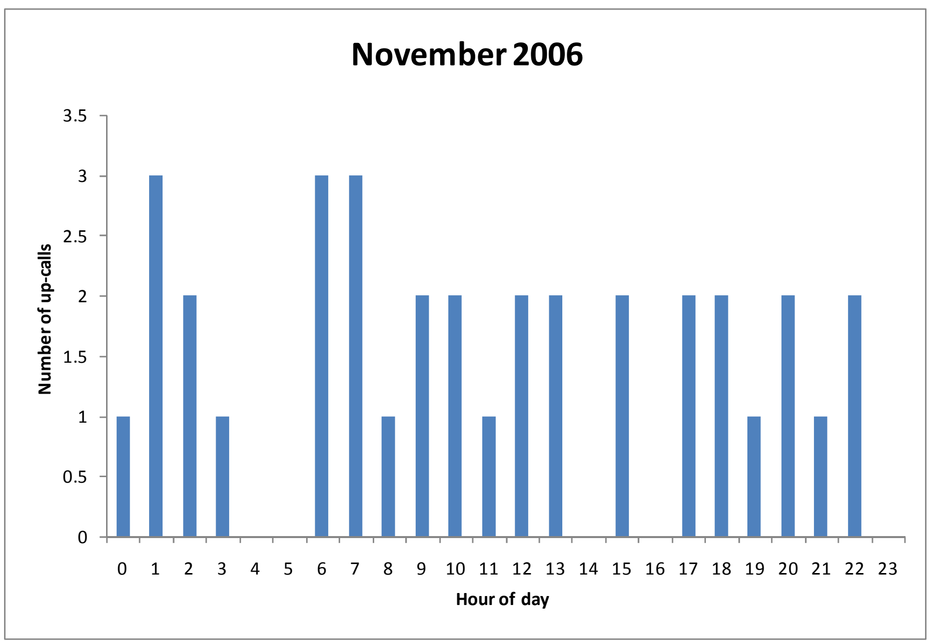
f)


September 2006
9
8
7
6
5
4
3
2
1
0
Number of up-calls
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of day

g)


October 2006
10
9
8
7
6
5
4
3
2
1
0
Number of up-calls
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of day

h)


November 2006
3.5
3
2.5
2
1.5
1
0.5
0
Number of up-calls
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of day

i)

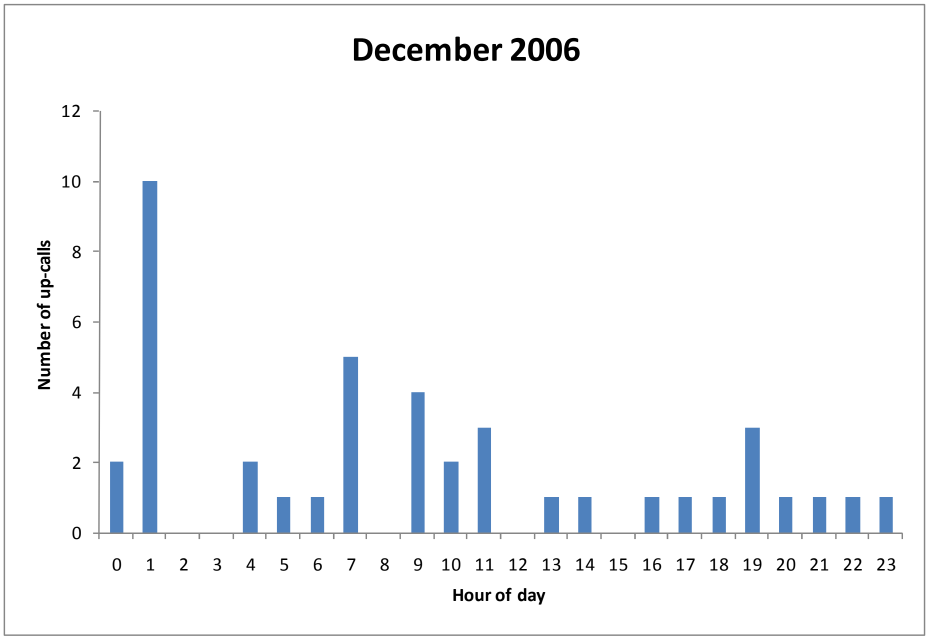

December 2006
Number of up-calls
Hour of day
0 2 4 6 8 10 12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Figure 7. Total Right Whale Sighting Advisory System sightings indicated by colored circles in Stellwagen Bank National Marine Sanctuary over the 13 months, plotted in an ARCINFO based Geographic Information System program (● January, February, March 2006; ● April, May 2006; ● July, August 2006; ● September, October, November 2006; ● December 2006, January, February 2007). The blue triangles represent the Automated Recording Units and the blue channel represents the current Boston shipping lane (Niemeyer 2008).

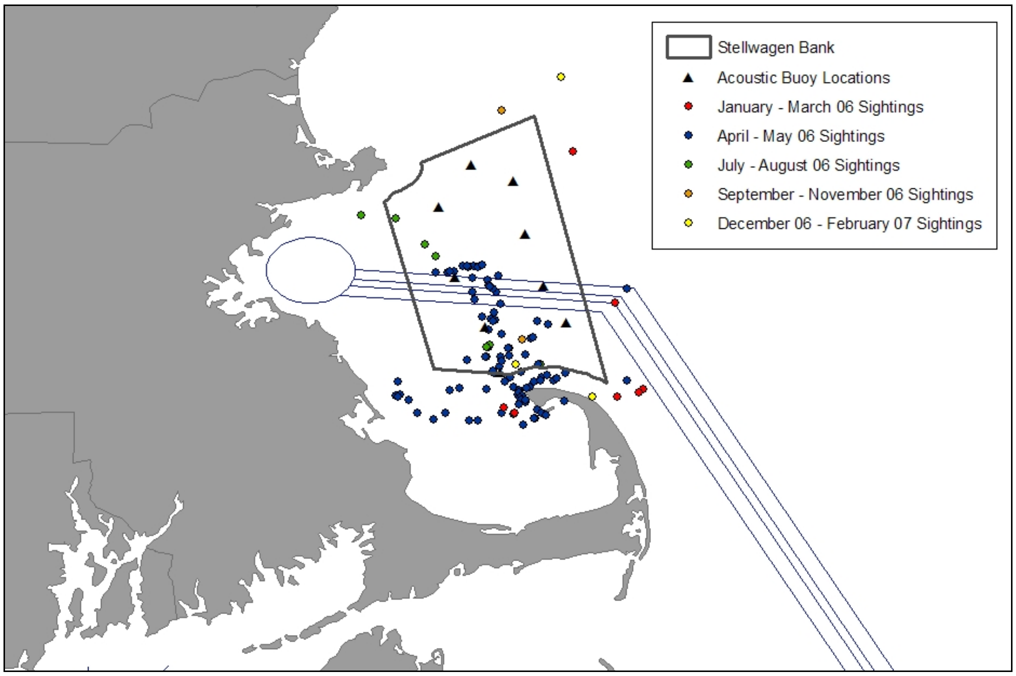
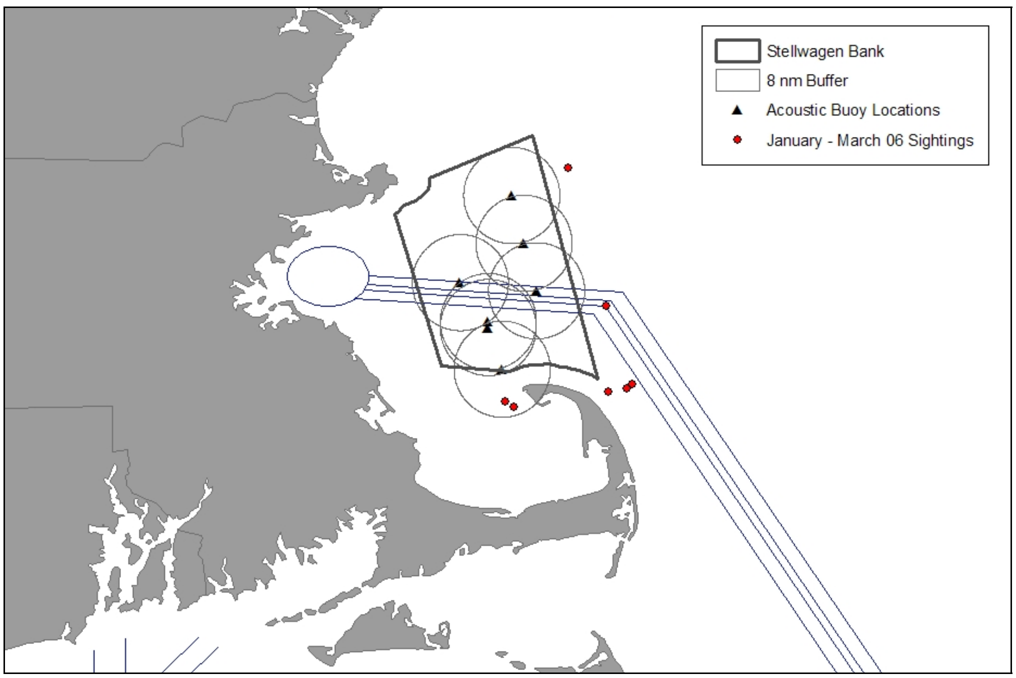
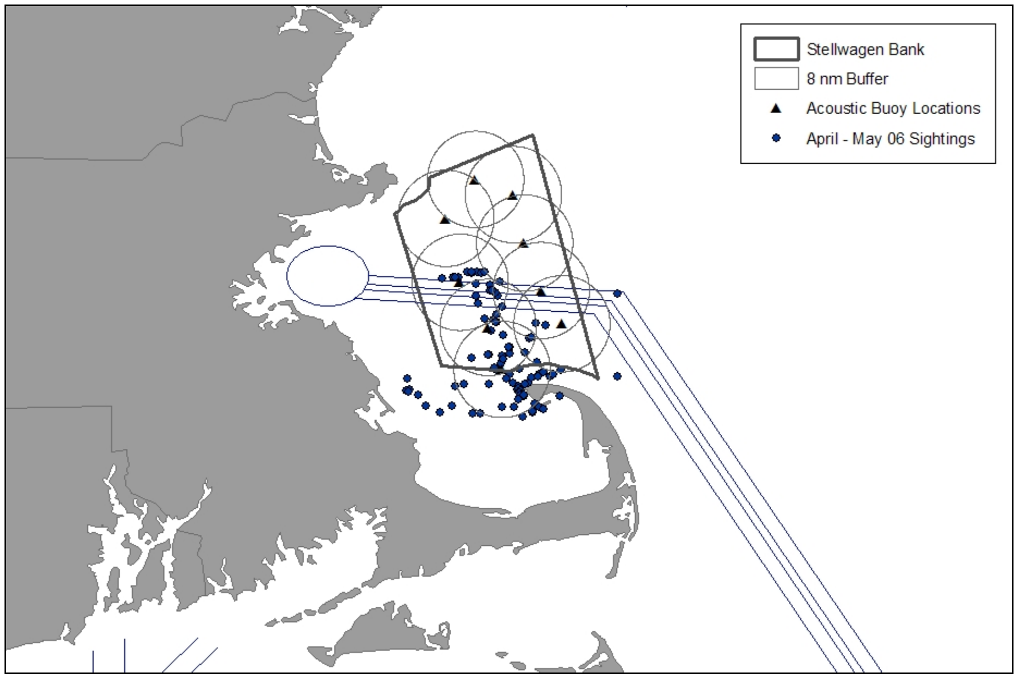


Figure 8. Total Right Whale Sighting Advisory System sightings indicated by colored circles in Stellwagen Bank National Marine Sanctuary for a) ● January, February, March 2006; b) ● April, May 2006; c) ● July, August 2006; d) ● September, October, November 2006; d) ● December 2006, January, February 2007, plotted in an ARCINFO based Geographic Information System program and encircled with an 8 kilometer buffer zone. The blue triangles represent the Automated Recording Units and the blue channel represents the current Boston shipping lane (Niemeyer 2008).

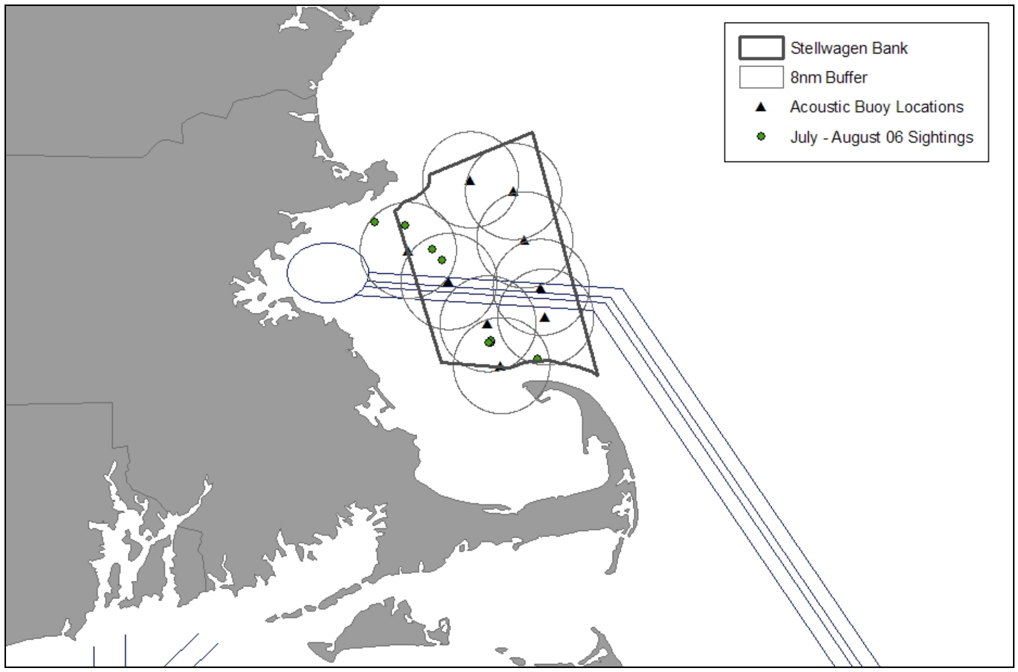
a)



b)

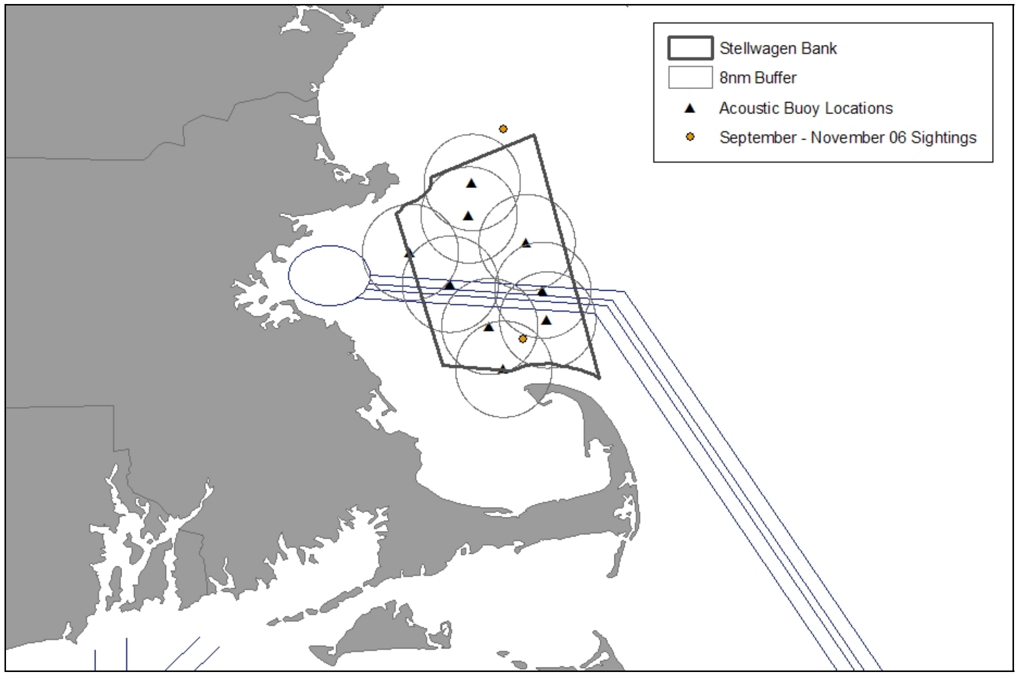

Stellwagen Bank
8 nm Buffer
Acoustic Buoy Locations
April - May 06 Sightings

c)

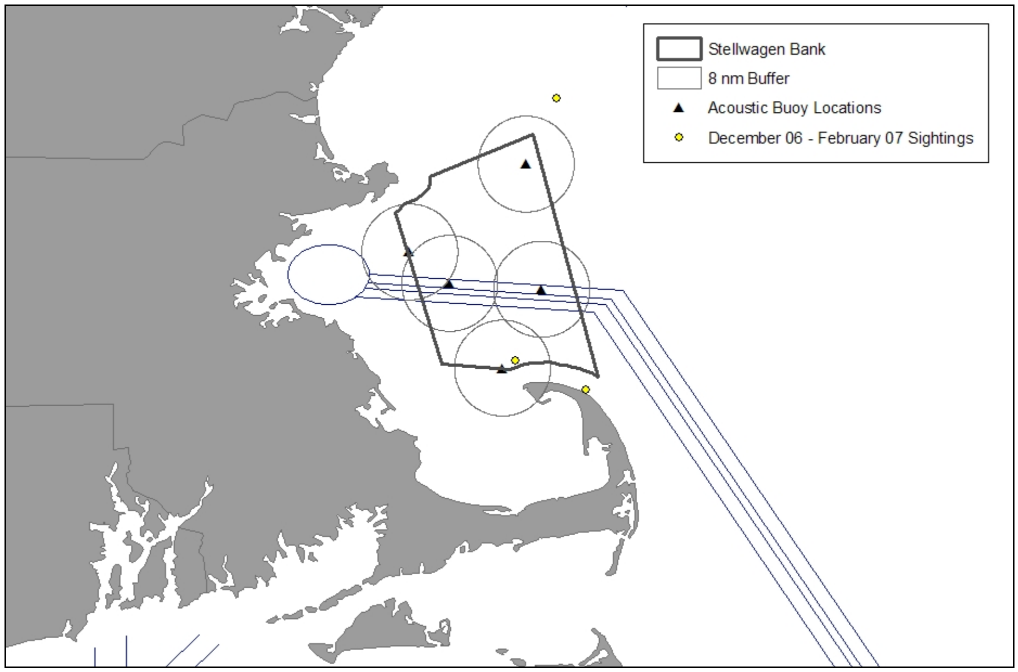


Stellwagen Bank
8nm Buffer
Acoustic Buoy Locations
July - August 06 Sightings

d)


Stellwagen Bank
8nm Buffer
Acoustic Buoy Locations
September - November 06 Sightings

e)



Stellwagen Bank
8 nm Buffer
Acoustic Buoy Locations
December 06 - February 07 Sightings

Figure 9. The date, type, location, and number of right whale visual sightings within the 13 months and the related number of up-calls. The type of sighting boxed in red indicates an aerial survey by the North Atlantic Right Whale Sighting Survey.

Date of sighting	Type of sighting	Species Identification	Location	Number of right whales	Number of up-calls from ARU closest to sighting	Total number of up-calls on sighting day
3-Apr-06	Aerial	Definite	42°083' N, 70°227'W	2	39	239
5-Apr-06	Aerial	Definite	42°100' N, 69°983'W	4	1	10
10-Apr-06	Aerial	Definite	42°080' N, 70°405'W	3	190	267
11-Apr-06	Aerial	Definite	42°330' N, 69°983'W	1	5	152
	Aerial	Definite	42°118' N, 70°138'W	1	5	
12-Apr-06	Aerial	Definite	42°017' N, 70°300'W	1	20	68
	Aerial	Definite	42°140' N, 70°205'W	2	20	
	Aerial	Definite	42°015' N, 70°268'W	6	20	
14-Apr-06	Aerial	Definite	42°078' N, 70°338'W	2	187	644
	Aerial	Definite	42°083' N, 70°270'W	1	187	
	Aerial	Definite	42°080' N, 70°237'W	17	187	
	Aerial	Definite	42°047' N, 70°240'W	3	187	
15-Apr-06	Whale Watch	Definite	42°026' N, 70°210'W	2	335	514
	Whale Watch	Definite	42°096' N, 70°218'W	8	335	
	Whale Watch	Definite	42°107' N, 70°198'W	3	335	
	Whale Watch	Definite	42°002' N, 70°215'W	1	335	

Date of sighting	Type of sighting	Species Identification	Location	Number of right whales	Number of up-calls from ARU closest to sighting	Total number of up-calls on sighting day
	Whale Watch	Definite	42°160' N, 70°338'W	3	335	
	Whale Watch	Definite	42°165' N, 70°238'W	1	335	
	Shipboard	Definite	42°064' N, 70°257'W	10	335	
	Shipboard	Definite	42°099' N, 70°167'W	10	335	
19-Apr-06	Whale Watch	Definite	41°988' N, 70°244'W	5	242	303
20-Apr-06	Whale Watch	Definite	42°003' N, 70°216'W	1	186	416
21-Apr-06	Whale Watch	Definite	42°045' N, 70°239'W	3	136	311
22-Apr-06	Opportunistic	Definite	42°162' N, 70°279'W	2	213	504
	Opportunistic	Definite	42°181' N, 70°279'W	2	186	
	Opportunistic	Definite	42°180' N, 70°283'W	3	186	
	Opportunistic	Definite	42°251' N, 70°316'W	1	125	
	Opportunistic	Definite	42°255' N, 70°326'W	4	125	
	Opportunistic	Definite	42°388' N, 70°370'W	5	129	
	Opportunistic	Definite	42°389' N, 70°397'W	1	129	
	Opportunistic	Definite	42°385' N, 70°359'W	1	129	
	Opportunistic	Definite	42°249' N, 70°320'W	12	125	
	Opportunistic	Definite	42°074' N, 70°255'W	4	186	
	Whale Watch	Definite	42°068' N, 70°254'W	4	186	
	Whale Watch	Definite	42°135' N, 70°304'W	2	186	

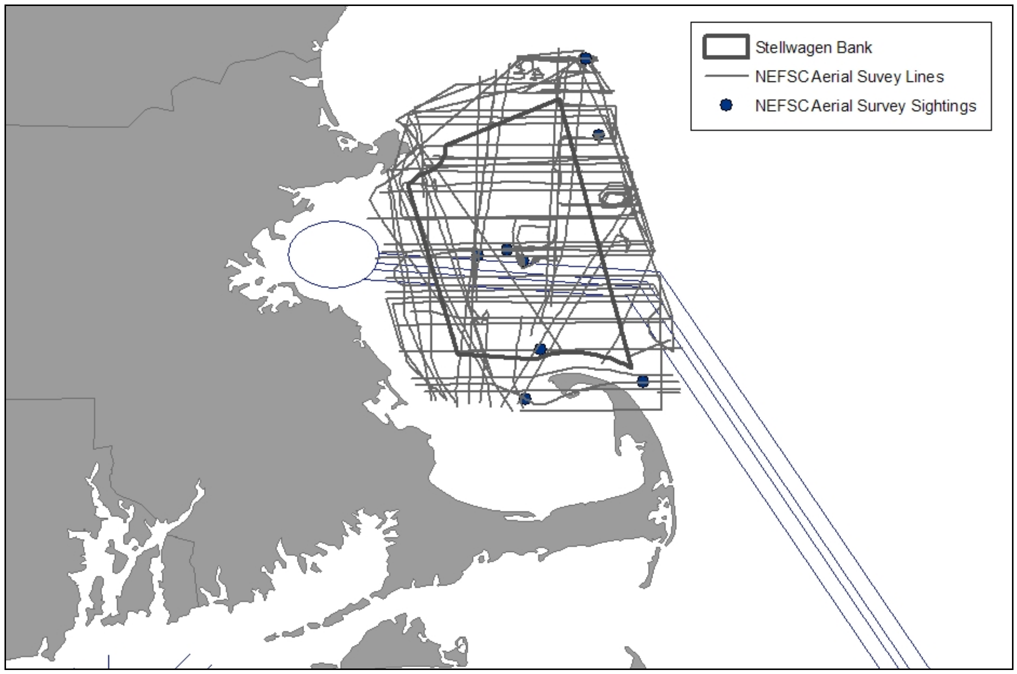
Date of sighting	Type of sighting	Species Identification	Location	Number of right whales	Number of up-calls from ARU closest to sighting	Total number of up-calls on sighting day
	Whale Watch	Definite	42°100' N, 70°200'W	1	16	
23-Apr-06	Whale Watch	Definite	42°373' N, 70°436'W	2	336	561
	Whale Watch	Definite	42°353' N, 70°334'W	1	336	
	Whale Watch	Definite	42°017' N, 70°197'W	1	43	
	Whale Watch	Definite	42°011' N, 70°186'W	2	43	
25-Apr-06	Whale Watch	Definite	42°061' N, 70°248'W	1	88	574
26-Apr-06	Whale Watch	Definite	42°107' N, 70°278'W	2	172	866
	Aerial	Definite	42°105' N, 70°160'W	4	172	
	Aerial	Definite	42°095' N, 70°290'W	5	172	
	Aerial	Definite	42°363' N, 70°307'W	12	406	
	Aerial	Definite	42°390' N, 70°348'W	1	406	
	Aerial	Definite	42°375' N, 70°420'W	2	406	
27-Apr-06	Aerial	Definite	42°112' N, 70°185'W	14	10	576
	Whale Watch	Definite	42°056' N, 70°253'W	10	69	
	Whale Watch	Definite	42°158' N, 70°301'W	5	69	
	Shipboard	Definite	42°050' N, 70°250'W	3	69	
	Shipboard	Definite	42°160' N, 70°339'W	3	69	
	Shipboard	Definite	42°149' N, 70°298'W	3	69	
	Shipboard	Definite	42°215' N, 70°299'W	1	314	

Date of sighting	Type of sighting	Species Identification	Location	Number of right whales	Number of up-calls from ARU closest to sighting	Total number of up-calls on sighting day
28-Apr-06	Whale Watch	Definite	42°357' N, 70°373'W	15	54	313
29-Apr-06	Whale Watch	Definite	42°049' N, 70°239'W	1	166	572
	Whale Watch	Definite	42°386' N, 70°385'W	1	194	
	Whale Watch	Definite	42°374' N, 70°429'W	2	194	
	Whale Watch	Definite	42°372' N, 70°465'W	1	194	
	Coast Guard	Definite	42°388' N, 70°386'W	1	194	
	Whale Watch	Definite	41°998' N, 70°360'W	1	1	
	Whale Watch	Definite	41°997' N, 70°382'W	1	1	
30-Apr-06	Whale Watch	Definite	41°151' N, 70°386'W	4	261	597
	Whale Watch	Definite	41°151' N, 70°386'W	1	261	
5-May-06	Aerial	Definite	42°073' N, 70°430'W	1	7	102
	Aerial	Definite	42°018' N, 70°440'W	1	7	
	Whale Watch	Definite	42°248' N, 70°208'W	2	16	
	Whale Watch	Definite	42°259' N, 70°349'W	1	no data	
	Whale Watch	Definite	42°272' N, 70°317'W	1	no data	
	Whale Watch	Definite	42°294' N, 70°301'W	1	no data	
6-May-06	Whale Watch	Definite	42°046' N, 70°141'W	1	21	82
	Aerial	Definite	42°050' N, 70°533'W	7	18	
	Aerial	Definite	42°117' N, 70°317'W	1	18	

Date of sighting	Type of sighting	Species Identification	Location	Number of right whales	Number of up-calls from ARU closest to sighting	Total number of up-calls on sighting day
	Whale Watch	Definite	42°303' N, 70°367'W	1	40	
	Whale Watch	Definite	42°323' N, 70°372'W	1	40	
	Whale Watch	Definite	42°095' N, 70°562'W	1	18	
	Whale Watch	Definite	42°063' N, 70°557'W	2	18	
7-May-06	Whale Watch	Definite	42°338' N, 70°333'W	20	43	172
	Whale Watch	Definite	42°038' N, 70°254'W	1	10	
	Whale Watch	Definite	42°323' N, 70°312'W	2	43	
	Whale Watch	Definite	42°061' N, 70°556'W	3	10	
	Whale Watch	Definite	42°121' N, 70°251'W	1	10	
	Whale Watch	Definite	42°206' N, 70°224'W	1	18	
8-May-06	Shipboard	Definite	42°240' N, 70°181'W	2	58	125
	Shipboard	Definite	42°207' N, 70°220'W	1	58	
	Whale Watch	Definite	42°058' N, 70°560'W	2	10	
	Whale Watch	Definite	42°227' N, 70°332'W	1	no data	
	Whale Watch	Definite	42°332' N, 70°320'W	2	36	
	Whale Watch	Definite	42°337' N, 70°328'W	1	36	
	Whale Watch	Definite	42°124' N, 70°321'W	3	10	
	Shipboard	Definite	42°018' N, 70°512'W	1	10	
	Shipboard	Definite	42°000' N, 70°472'W	1	10	

Date of sighting	Type of sighting	Species Identification	Location	Number of right whales	Number of up-calls from ARU closest to sighting	Total number of up-calls on sighting day
3-Jul-06	Whale Watch	Probable	42°508' N, 70°568'W	1	0	0
6-Jul-06	Opportunistic	Probable	42°413' N, 70°465'W	1	0	0
8-Jul-06	Coast Guard	Unknown	42°517' N, 70°654'W	1	0	0
10-Jul-06	Whale Watch	Definite	42°184' N, 70°332'W	1	0	0
	Whale Watch	Definite	42°190' N, 70°330'W	1	0	
	Whale Watch	Definite	42°184' N, 70°337'W	1	0	
17-Jul-06	Whale Watch	Definite	42°443' N, 70°493'W	1	0	0
26-Jul-06	Opportunistic	Unknown	42°140' N, 70°200'W	1	0	0
29-Jan-06	Aerial	Definite	42°677' N, 70°118'W	2	40	43
2-Mar-06	Aerial	Definite	42°017' N, 70°267'W	1	144	156
24-Mar-06	Aerial	Definite	42°03' N, 70°293'W	1	26	39
30-Oct-06	Commercial	Unknown	42°203'N, 70°246'W	2	2	2
21-Feb-07	Aerial	Definite	41°987'N, 70°202'W	2	7	56
Totals				**311**	**11766**	**8264**

Figure 10. The number of the North Atlantic Right Whale Sighting Survey track lines flown through Stellwagen Bank National Marine Sanctuary over the 13 months with their aerial survey sightings indicated by blue circles. The blue channel represents the current Boston shipping lane (Niemeyer 2008).



APPENDIX D

Figure 1. Examples of typical right whale up-calls, fish sounds, and a pair of humpback song calls in a spectrogram. Frequency is represented by the *y* axis in hertz and duration by the *x* axis in seconds (Clark et al. 2007).

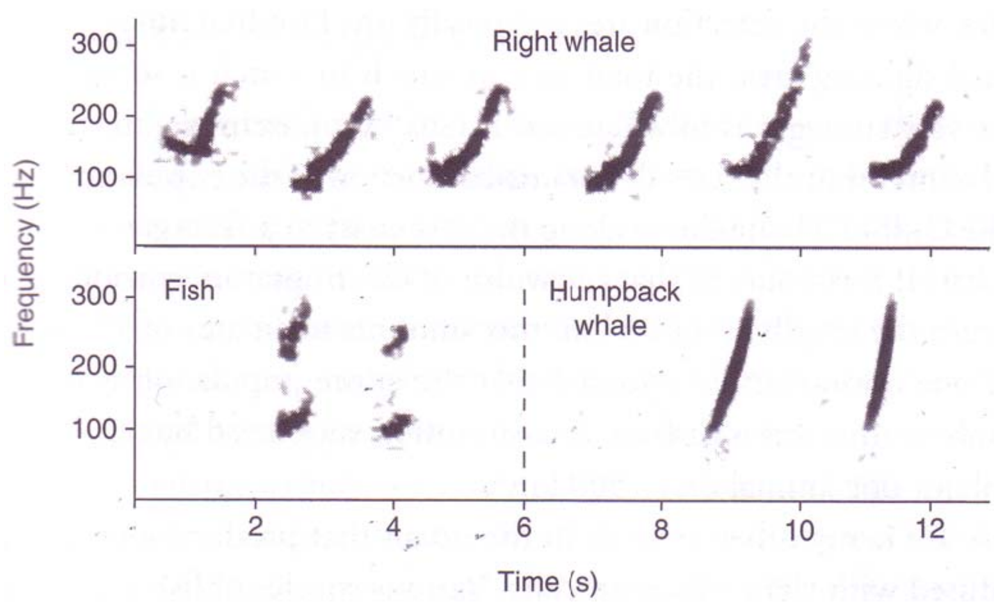


Figure 2. A real time auto detection buoy deployed in Cape Cod Bay. (NRWBUOYS 2008).

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