Acoustic behavior of North Atlantic right whales in a potential winter mating ground: Implications for management of human activity

by

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Table of Contents

Acknowledgements ..... **III**

List of Tables ..... **VI**

List of Figures ..... **VII**

Abstract ..... **X**

Introduction **1**
- Range and Movement 2
- Study Area 4
- Social Behavior and Acoustics 5
- Southern Right Whales 5
- North Atlantic Wight Whales 7

Right Whales and Policy: Management and Reduction of Anthropogenic Derived Mortality **13**
- Introduction 13
- Mitigation to Fishing-Derived Activity 16
- Mitigation to Shipping-Derived Activity 22

Methods **24**
- Study Area 24
- MARU Design and Deployment 24
- Data Processing and Analysis 28
- Statistical Analysis 31
- Call Parameters 31
- Aerial Surveys 32
- Social Sounds 32

Results **34**
- False Positive and Negative Rates 34
- Call Seasonality 34
- Diel Patterns 55
- Call Parameters 66
- Aerial Surveys 69
- Social Sounds 72
  - Grunts 72
  - Moans 72
  - Long Calls 73
  - Worm Calls 73
  - High Calls 74
  - Pre-gunshot Calls 74

Discussion **86**
- False Positive and Negative Rates 87
- Call Seasonality 88
- Diel Patterns 89
- Other Species Detected in the Area 89
- Call Parameters 93
- Social Sounds 93
- Comparison to Adjacent Habitats 95

Aerial Surveys 97

Additional Recommendations 98

Continued Long-Term Monitoring 98
Aerial Surveys 99
Mitigations with the Fishing Industry 99
Further Seasonal Protection from Shipping 101

Conclusions 105

Literature Cited 107

Appendix A 114

Appendix B 118

Appendix C 120

List of Tables

Table 1. Deployment schedule and locations of MARUs.....27
Table 2. Monthly totals for detected upcalls and gunshots. 39
Table 3. ANOVA results for call rates between months for upcalls 51
Table 4. P-values for *post-hoc* analysis of month/upcall rate comparison.....52
Table 5. ANOVA results for call rates between months for gunshots.....53
Table 6. P-values for *post-hoc* analysis of month/gunshot rate comparison 54
Table 7. Two-way ANOVA for month/hour/upcall rate comparison. 56
Table 8. ANOVA results for effect of hour on upcall rate 57
Table 9. P-values for *post-hoc* analysis of hour/upcall comparison.....58
Table 10. Two-way ANOVA for month/hour/gunshot comparison 59
Table 11. ANOVA results for effect of hour on gunshots 60
Table 12. P-values for *post-hoc* analysis for hour/gunshot rate comparison.....61
Table 13. ANOVA results for call parameters by month 67
Table 14. Call parameters for upcalls and gunshots.....68
Table 15. Call parameters for different categories of social sounds 75

List of Figures

Figure 1. Spectrogram of a North Atlantic right whale upcall 37
Figure 2. Spectrogram of a North Atlantic right whale gunshot call 38
Figure 3. Frequency of occurrence of false negative ratios 40
Figure 4. Frequency of occurrence of false positive ratios 41
Figure 5. Total number of upcalls per month 42
Figure 6. Total number of gunshots per month 43
Figure 7. Total numbers of upcalls verses gunshots per montb 44
Figure 8. Total number of upcalls per day 45
Figure 9. Total number of gunshots per day 46
Figure 10. Total numbers of upcalls and gunshots by day 47
Figure 11. Average numbers of upcalls per month 48
Figure 12. Average number of gunshots per month 49
Figure 13. Average numbers of upcalls and gunshots per month 50
Figure 14. Hourly upcall rate averaged by month 62
Figure 15. Average hourly upcall rate for the entire recording period 63
Figure 16. Hourly gunshot rate averaged by month 64
Figure 17. Average hourly gunshot rate for the entire recording period 65
Figure 18. Scatter plot of aerial survey against number of calls 70
Figure 19. Map of aerial survey data 71
Figure 20. A grunt followed by two upcalls 76
Figure 21. Moans along with a series of upcalls 77
Figure 22. Moans along with other known right whale calls 78
Figure 23. Variability in upcalls and moans 79
Figure 24. Variable moan sounds 80
Figure 25. “Worm” calls 81
Figure 26. Long call 82
Figure 27. A long call lasting nearly 8 seconds 83
Figure 28. High frequency sounds 84
Figure 29. Pre-gunshot call 85
Figure 30. Spectrogram of sei and fin whale vocalizations 91
Figure 31. Spectrogram of detected humpback whale song 92

Figure 32. Northeast SMAs.....103
Figure 33. Overlay of aerial survey data with vessel density map.....104

Abstract

The North Atlantic right whale (*Eubalaena glacialis*) is critically endangered, with a current population of approximately 473 individuals. Although this population has been protected internationally from whaling since 1935, it continues to decline because of negative human interactions. Protecting these animals from ship-strike and fishing gear entanglement requires additional legislation that is dependent on careful and continuous monitoring. One monitoring technique that leads to a better understanding of behavior and habitat preferences of the species is passive acoustic monitoring. This study utilized marine autonomous recording units in the Outer Fall region of the Gulf of Maine, an area recently identified as a wintering and possible mating ground for right whales. Recordings were made for 11 months from October 2009 to October 2010. We analyzed the recordings for two known right whale call types—the upcall, and the gunshot call (associated with mating/social behavior)—for seasonal and diel patterns. A variety of social sounds potentially produced by right whales were also identified and described. There was a strong seasonality in the frequency of call detections, with the majority of calls found in November, December and January. There was also a strong peak in diel calling patterns, with the majority of the calls occurring between 1400 and 2300. Determining how right whales use this area is essential to establishing protective legislation, especially when mitigating fishing activity or determining if Outer Fall/Central Gulf of Maine should be considered a Dynamic or Seasonal Management Area for ship traffic management.

Introduction

The North Atlantic right whale (*Eubalaena glacialis*) is critically endangered with a population presently estimated to be around 473 individuals (Pettis 2010). Some population models suggest that at current rates of mortality, they could become extinct within the next 100-400 years (Caswell *et al.* 1999, Fujiwara and Caswell 2001). Although protected internationally from whaling since 1935, many hypothesize that the population continues to decline, or is at least slow to recover, because of negative anthropomorphic interactions (Kraus 1990). Between 1986 and 2005 there were 50 documented right whale deaths (Nicols *et al.* 2008, Kraus *et al.* 2005, Moore *et al.* 2005), at least 19 of which were caused by ship strikes. Of the 61 confirmed cases of entanglement in fishing gear (Kraus *et al.* 2005), a minimum of six resulted in death (Nichols *et al.* 2008, Kraus *et al.* 2005). Research has shown that preventing the deaths of just two reproductive females per year would bring the population growth rate back to replacement level (Fujiwara and Caswell 2001, Moscrop *et al.* 2004). However, protecting these animals from negative human interaction requires additional legislation—legislation that is dependent on careful and continuous monitoring (see following chapter).

One monitoring technique that may lead to a better understanding of behavior and habitat preferences of the species is passive acoustic monitoring (PAM). Russell and Knowlton (2001) call for more passive acoustic research as a method to track and therefore reduce ship strikes in North Atlantic right whales. However, in order to

effectively employ PAM, we need a more complete understanding of the acoustic behavior of North Atlantic right whales.

My research entails using marine acoustic recording units (MARU or "pop up buoys"), a passive acoustic monitoring tool developed by Cornell University (Tremblay *et al.* 2009). A series of buoys were deployed which resulted in a year-round study of the Outer Fall/Jordan Basin region of the Gulf of Maine. These units, which can collect long-term acoustic data, even during periods of rough weather and at night, allow researchers to listen for North Atlantic right whales and look for patterns in seasonality, call rate, and call type (Mussoline et al. In review.). The study area has recently been identified as a possible wintering and breeding ground for right whales by NOAA Northeast Fisheries Science Center aerial surveys (Dawicki 2008). Because sightings in this area are often referred to in association with Jordan Basin, the nearest bathymetric feature of significance: however, it should be noted that the epicenter for these sightings should be more correctly referred to as being on Outer Fall. Discovery of a large concentration of animals during winter is unprecedented; thus, further studies of the Gulf of Maine are timely and important to understanding how North Atlantic right whales use this habitat. Uncovering evidence that this area is utilized as a wintering/mating ground would be critical to management plans.

Range and Movement

Most studies on the North Atlantic right whale have focused on areas clearly identified as summer feeding or wintering grounds; these include Cape Cod and Massachusetts Bay (March-May), the Great South Channel (April-June), Bay of Fundy

and around Nova Scotia (July-October), and for some of the population, the coasts of Florida and Georgia (November-May) (Moses and Finn 1997). The first four of these habitats are designated critically important as feeding grounds. The coast of Florida and Georgia is the only known calving ground. Females migrate 1,800 miles from the northern feeding grounds for the calving and initial rearing of their young (Kraus 1990). Of the known reproductively active females, 74% were sighted in the Southeast calving grounds between 1980 and 1992 (Brown *et al.* 2001). Where the remaining portion of the population (i.e. nonpregnant or juvenile females and males) overwinter is still largely unknown (Kraus *et al*. 1986; Kraus and Rolland, 2007), though it is likely that it is in these areas that mating occurs. Gaskin (1991) hypothesized a portion of the population does not migrate in winter and instead resides in cold offshore waters where secondary plankton production would still be high. Jeffrey's Ledge, a glacial deposit off the coast of northern Massachusetts, New Hampshire, and Maine, has been suggested as a possible area of importance in summer and fall (Weinrich *et al.* 2000). Mother-calf pairs are seen in this area in summer in disproportionately high numbers compared to other age/sex classes, leading to the hypothesis that this is a nursery ground while other whales head for more northern waters where food concentrations are higher. In the fall and early winter, fewer mother-calf pairs are observed around Jeffrey's Ledge, presumably because many of the calves have been weaned by that point (Weinrich *et al.* 2000); however, there are still sightings of solitary animals in the area. Thus, it is thought that whales may utilize Jeffrey's Ledge after exhausting food sources in the Bay of Fundy (Weinrich *et al.* 2000).

It is unknown if the nonpregnant portion of the population feeds or fasts during winter. Whales are possibly spending time on Jeffrey's Ledge to feed before a winter

fasting period. While copepod production in the area in fall is at its lowest, there may be other food sources such as hatchling herring (Weinrich *et al*. 2000). Thus, sightings of right whales in high numbers in the Jeffrey's Ledge region in early winter may indicate that other seasonally important areas exist in the Gulf of Maine.

Study Area

Moscrop *et al.* (2004) called for an extension of passive acoustic monitoring from areas of known importance to lesser-studied areas where North Atlantic right whales may gather or pass through. I focused on the Outer Fall/central region of the Gulf of Maine, an area recently identified as a possible wintering and breeding ground for right whales (Dawicki 2008). Outer Fall lies on the NE edge of Jeffrey's Ledge. A brief historical review of sightings in this region demonstrates its potential as a wintering ground. On December 3, 2008, NOAA Northeast Fisheries Science Center aerial surveys reported sightings of 44 right whales. Ten days later, 41 whales were located west of Jordan Basin (Dawicki 2008). Sightings within the 2009/2010 winter season have also been common (Cole, pers. comm.[1]). The discovery of a concentration of animals of this magnitude in a population so reduced (approximately 9% of the population) warrants further investigation.

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Social Behavior and Acoustics

In order to maximize the effectiveness of a PAM-derived study, it is important to review the current knowledge regarding the acoustic repertoire—and known associated behaviors—of the proposed species. Acoustics have been recognized since the 1960s as an important tool for understanding cetaceans. The earliest studies of right whale acoustics were part of a general characterization of mysticete calls (Schevill and Watkins, 1962). Calls were characterized as "low frequency moans" (Reeves *et al.* 1978). These early studies did not look specifically into whether the sounds had a communicative function; however, the possibility was deemed reasonable (Reeves *et al.* 1978). Watkins and Schevill (1972) discuss some of the first studies to localize the position of a whale using a multiple hydrophone array. Payne and Payne (1971) concluded that right whales do not "sing" as observed in other species, since no long, continuous patterned sequences of sounds were observed.

Southern Right Whales (Eubalaena australis)

Beginning in the 1980s, detailed studies were conducted into how right whales use their calls to communicate. The majority of these studies, which began with the Southern right whale (*E. australis*), were later used as a comparison for studies on their northern counterparts since the call types between these species are similar. Calls from Southern right whales that were simple and predictable in nature were associated with long-distance communication, whereas calls that were highly variable and complex took place while groups of whales were engaged in socially active surface behaviors (Clark 1983). Clark (1983) found that detailed, rich signal repertoires may be indicative of a

complex social system—that certain sounds occurred during particular behavioral activities and could be communicative in nature.

Clark (1983) classified the activities of a group (one or more whales) into five categories: resting; swimming; mild activity or enough activity to create some “white water” but interrupted by periods of rest or swimming; full activity when there is enough activity for constant white water; and sexual activity when an active group contained both males and females and a penis was clearly observed. Sounds were classified into three classes: calls, slaps, and blows. Slaps included sounds made from flippers, breaching, lobtailing, and underwater slaps. Blows were classified as normal, tonal, or growl blow sounds. Calls themselves were grouped into six types: upcalls, down calls, constant calls, high calls, hybrid calls, and pulsive calls.

Activity, group size, and sexual composition affected the rates of sound production. Typically, groups composed entirely of animals of one sex were smaller and less active than groups of mixed sex (excluding mother-calf pairs). Although some silent groups were observed, these groups were usually solitary animals resting or pairs of whales swimming. Over one-half of the total resting groups were silent, while the majority of the vocal resting groups were only observed making blow sounds. Swimming groups produced more upcalls than other groups. Usually upcalls were produced as an animal approached another animal that often responded with an upcall. On two occasions, a calf was separated from its mother and the pair produced upcalls until reunited. Upcalls were also produced as a solitary animal approached an active group. Clark (1983) did not note whether members of the active group responded with an upcall. Down calls were made by animals that appeared agitated, and were often made along with upcalls. Larger

active groups made high calls, hybrid calls, and pulsive calls. Sexually active groups in particular made almost exclusively high, hybrid, and pulsive calls but were never silent.

Clark (1983) suggested that blow sounds might serve a communicative function since they were often loud, tonal, or pulsive if an animal seemed disturbed. Slap sounds were made by active whales and were thought to be a sign of arousal or perhaps a warning. The upcall was the most common call and was produced by all age classes.

To summarize, upcalls were proposed as "contact" calls that functioned as a long distance signal or locator. Down calls were less frequent but were often made in similar contexts to the upcalls. A down call could be a contact call that was also a sign of excitement due to the mild activity of the whales while producing the sound. High and hybrid calls were associated with excitement since whales often produced them during active groups.

More studies are still needed to determine the overall purposes of these calls. Constant calls were made too infrequently to judge a potential context. Pulsive calls may have been produced as a sign of aggression. Clark (1983) concluded that sounds produced by the southern right whale are related to the social context and activity of the whale and speculated that upcalls may possibly be a sort of "signature" to identify individual whales.

North Atlantic Right Whales (Eubalaena glacialis)

Acoustic studies on Southern right whales provided an important foundation for our current knowledge of Northern right whale vocalizations. Much like their southern counterparts, they do not sing like other cetacean species. Matthews *et al.* (2001) found

the rate of vocalization in North Atlantic right whales—as defined as the number of sounds per unit of time divided by the number of animals in a group—depended on group size, location, and time of day. Lone feeding whales were usually quiet, and small aggregations had higher vocalization rates than solitary animals. Overall, vocalization rate increased with group size, especially in the case of "moan" calls and "gunshot" sounds (Matthews *et al*. 2001). Vocalizations are more frequent at night (Matthews *et al.* 2001). "Moan" calls as described by Matthews *et al.* (2001) are in the range of 50-500 Hz, are between 0.4-1.5 s, have a frequency modulation over 100Hz, and a time-bandwidth product of ≥50, making them easy to detect and localize.

Many of the most comprehensive studies on North Atlantic right whale acoustics have been carried out during surface active groups—a term adopted to encompass the mild, full, and sexual activity categories described by Clark (1983). A "surface active group" (SAG), defined as two or more animals interacting at the surface in frequent physical contact (Kraus and Hatch 2001), is a general term that may encompass different social groupings involving different behavioral interactions (Parks and Tyack 2005). Because SAGs are so heavily featured in the acoustic literature and because they are commonly associated with sexual activity, I briefly review such studies here—particularly since any incident of SAG-associated calls may be representative of sexual activity.

SAGs may be comprised of all males, all females, mixed sex, or mixed age classes, including calves. Many SAGs are clearly sexual in nature, while others may be "practice" to size up competition for mating or to expose young calves to behaviors that will be important later in life (Kraus and Hatch 2001; Parks and Tyack 2005). SAGs

have been observed in all areas where North Atlantic right whales have been studied, although they occur very rarely in the Southeastern U.S. (Kraus and Hatch 2001). The main theory for the occurrence of SAGs is that female whales use these interactions to incite competition among males, ensuring that the fittest male is given the highest probability to mate. In most observed SAGs, male right whales appear to compete for access to the focal female that is at the center of all activity. In most cases, the focal female is an adult although some of the females observed in SAGs have never been seen with a calf, indicating that they may be immature or infertile (Kraus and Hatch 2001).

While 43% of observed SAGs involve an adult female and male where copulation is observed (Parks *et al.* 2007), the timing of most observed SAGs (spring, summer and fall) does not correlate with current data on the gestation periods, births, and birth intervals of North Atlantic right whales (Kraus and Hatch 2001; Parks and Tyack 2005). There is a lack of survey effort in late fall and early winter, so an artificial decline is observed when reviewing seasonal changes in SAGs (Parks *et al.* 2007). Calves are born in December-February, after a 12-to-13-month gestation period; therefore, copulation should take place in the same months a year earlier—assuming no delayed implantation (Kraus and Hatch 2001). However, the whereabouts of the nonpregnant portion of the population has been unknown until very recently when large aggregations have been noted in Outer Fall, an offshore Gulf of Maine habitat (Dawicki 2008). It is not known if SAGs take place within this habitat. Kraus and Hatch (2001) note the importance of determining whether SAGs take place within wintering habitats and if they are consistent with SAGs noted in other seasons. The rate of SAG in Southern right whales increases during what is believed to be the mating period (Best *et al.* 2003), so it is hypothesized

that SAGs should continue into December in the northern population (Parks *et al.* 2007). Given the proposed importance of SAGs in courtship and sexual activity, it is important to identify any acoustic behaviors uniquely associated with these events.

Extensive acoustic characterization has been performed for SAGs since they are an easily detected and identified behavior (Parks and Tyack 2005). Parks and Tyack (2005) used several methods to characterize the vocal behaviors during SAGs in the Bay of Fundy to see if call types were a function of group composition. These methods included: a single hydrophone, a hydrophone array to confirm that observed bearings of animals matched calculated bearings of produced sounds, and video recordings to determine if the focal animal was breathing as certain sounds were produced. This study used a simplified classification system based on the Clark (1983) system. “Scream” calls encompassed the “high,” “hybrid,” and “pulsive” categories. “Gunshots” corresponded to the “underwater slap” sounds. “Upcall,” “downcall,” and “blow” remained the same. An additional category was added to this analysis to account for a call observed only when calves were present, the “warble” call—a scream-like call that is stuttered and higher in pitch (Parks and Tyack 2005). Source levels for tonal calls were 137 to 163 dB rms *re* 1 μPa –m, and 174 to 192 dB rms *re* 1 μPa –m for broadband gunshot sounds (Parks and Tyack 2005).

Parks *et al.* (2005) offer a detailed description of the “gunshot” sound—a brief, intense broadband signal from 20 Hz to 20 kHz (the upper limit due to recording equipment). It has been recorded as an initial signal with an echo and prolonged reverberation. The reverberation can be explained by reflection off the bottom, since sound speed and water depth were calculated. Gunshots were often produced in pulses.

Parks *et al.* (2005) point out that the gunshot sound is similar to flipper slapping because of the broadband-frequency content and duration; however, they are louder and have higher frequencies. The gunshot sounds were not associated with any movement of a flipper or fluke, but they were often preceded by a lifting of the head out of the water and occurred before a dive. Gunshots were produced by both solitary males and ones engaged in a SAG. Parks *et al.* (2005) state that is unlikely that gunshots are needed to "stun" prey since their prey are slow moving and form large aggregations. Females seem to advertise themselves acoustically when receptive to mating behavior, making it unlikely that it is a form of echolocation to locate females. It is most likely that gunshots are used as both an advertisement to the female whale and as a threat towards other males.

In Parks and Tyack's (2005) study, it was not possible to identify the individual producing the gunshot sounds, only that they were coming from the SAG. Gunshots were produced when females were both present and absent, making it likely that gunshots are only produced by male animals. This does not rule out the possibility of the female as the source of gunshots.

Thus, the literature clearly show two main call types—the upcall and gunshot call—that appear to be associated with SAGs; both are easily recognized. The upcall identifies the presence of right whales, while the gunshot call is associated with mating behavior. Determining the occurrence rate of these calls in Outer Fall should indicate how these animals are using this habitat. A seasonal variation in upcalls will determine the residency time of whales in the habitat. A seasonal variation of gunshots will indicate if mating or social behavior is present within this habitat during a time when female whales may be impregnated based on estimated gestation times. It is also possible that

other calls exist within the North Atlantic right whale vocal repertoire that may be important for communication during this time of year. Determining the diel patterns of this area will be useful in terms of mitigating shipping and fishing industry conflicts should this area prove to be seasonally important. Based on these premises, I propose the following hypotheses which I will test in this study:

1. Right whale vocalizations, including upcalls and gunshot calls will be detected in the Outer Fall region.
2. Call rate for both upcalls and gunshots will vary by season in the Outer Fall region.
3. Call rate will be highest in winter months.
4. Call rate for both upcalls and gunshots will vary over a diel scale.
5. Call rate will be highest in the evening and at night.
6. Call rate will increase with the number of whales present in the area as shown by aerial survey.
7. Other calls may indicate the presence of North Atlantic right whales in the area.

Right Whales and Policy: Management and Reduction of Anthropogenic-Derived Mortality

Introduction

Right whales were one of the first large whale species to be afforded protection from whaling both in the United States and internationally. The League of Nations (the precursor to the United Nations) granted right whales international protection from whaling through the 1931 Convention for the Regulation of Whaling, which took effect in 1935 (Waring *et al*. 2001). Right whales were also protected by further conventions drafted by the International Whaling Commission in 1949. The Marine Mammal Protection Act (MMPA) was enacted in the United States in 1972 and the Endangered Species Act (ESA) followed in 1973.

The National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries), which is part of the U.S. Department of Commerce, is the main federal agency in charge of regulating and promoting stewardship of marine resources and habitats (NOAA 2011). Within NOAA Fisheries, the Office of Protected Resources (OPR) is specifically responsible for interpreting and upholding the MMPA and the ESA.

The North Atlantic right whale is currently listed by NOAA Fisheries as a strategic stock. A strategic stock is a marine mammal stock that is listed on the ESA, and will be for the foreseeable future, whose direct human-caused mortality rate exceeds the calculated potential biological removal level (PBR). The PBR is calculated using the minimum population estimate of the stock, one-half the maximum theoretical or

estimated net productivity rate of the stock at a small population size, and a recovery factor between 0.1 and 1.0 (for all species listed in the ESA this latter figure is automatically defined as 0.1). The MMPA specifies that these figures must be compiled annually in a Stock Assessment Report (SAR) for all marine mammal species in US waters. The SARs for populations listed as strategic stocks are re-evaluated every year. The latest calculation of PBR for the North Atlantic right whale, as reported in the 2009 SAR was zero (Waring *et al.* 2009). This means that no right whales may be killed as a result of human activity.

One of NOAA Fisheries' responsibilities as stated by the ESA Section 4(f) is to draft a recovery plan for any listed species under its jurisdiction. The Northern Right Whale Recovery Team was put in place in 1987; NOAA Fisheries drafted the first recovery plan that took effect in 1991. A revised recovery plan was published in 2005, outlining a strategy that includes the need for scientific research and habitat conservation. It states that the most significant need in protecting this species from extinction is to reduce or eliminate deaths and injuries from anthropogenic activities, most importantly shipping and commercial fishing operations. Strict criteria stating when the right whale may be delisted or at least reclassified to "threatened" status are listed, including an average population growth rate of 2% over a 35-year period. The plan admits that the chance of delisting is unlikely based on the current slow population growth and high mortality rates for this specie. The plan also advocates using "pop up" buoys to monitor right whale occurrence and distribution as well as the feasibility and efficiency in detecting submerged whales, as well as assess the level of acoustic pollution which can change call behavior (Parks *et al.* 2009).

The 1994 amendment to the MMPA required that regional Take Reduction Teams (TRT) be formed to help reduce serious injury and mortality to particular species and stocks of marine mammals. TRTs are also included as a protective measure in the Recovery Plan for the North Atlantic right whale. TRTs are designed to serve NOAA Fisheries as nonconsensus advisory groups. These teams are made up of industry, conservation, and academic professionals who review scientific reports related to incidental take issues, recommend bycatch reduction strategies, or the kind of research needed to address the issue in question. Based on recommendations from the appropriate TRT, NOAA Fisheries then decides the final rulemaking on take-reduction issues. These teams are also responsible for drafting take reduction plans—similar to species recovery plans—although these plans are usually more focused, and apply only to marine mammal takes as defined by the MMPA. Take Reduction Plans (TRP) outline specific rules that fishing, shipping, and other industries—industries whose operations could directly or indirectly impact marine mammals or their habitat—must follow in order to be in compliance. The Atlantic Large Whale Take Reduction Plan (ALWTRP) focuses primarily on commercial trap/pot and gillnet fisheries interactions and seeks to protect not only right whales but also humpback (*Megaptera novaeangliae*) and fin (*Balaenoptera physalus*) whales in the shelf waters of the U.S. Western Atlantic. The PBR calculations for each species are the driving forces behind this plan. The long-term goal of the plan, as written in 1999, was a mortality rate of zero within 5 years of implementation (64 FR 7556, February 16, 1999). It was recognized in the plan that this goal would be difficult to achieve, and the plan stated that closures to fisheries beyond

what was initially outlined might be needed. Since 1999, the annual human-induced mortality rate for right whales has been above PBR; the 5-year goal was never reached.

So, despite these conservation efforts, the species still has a long climb before its status on the Endangered Species List is lowered, or until the species is no longer considered a strategic stock by the MMPA. Despite the many attempts to achieve compromise between right whales and fishing and shipping, right whale deaths from anthropogenic interactions still occur.

Mitigation to Fishing-Derived Mortality

Two strategies of the ALWTRP that had mixed reviews from both conservationists and fishermen alike were the Dynamic and Seasonal Area Management (DAM, SAM) programs (67 FR 1133, January 9, 2002, 67 FR 65722, October 28, 2002, 68 FR 51195, August 26. 2003). Based on the known migration times of right whales and likelihood of aggregations of right whales occurring in particular habitats, the SAM program established areas that would receive seasonal protection from fishing. The initial SAM area was a polygon that extended from Cape Cod to Cape Ann, and out to the end of the U.S. Exclusive Economic Zone (67 FR 1133, January 9, 2002). This was then split into two zones that would be in effect at different times. SAM West was in effect from March 1 to April 30 and extended from Cape Cod to 69° 24'. SAM East was from 69° 24' to the EEZ and was in effect from May 1 to July 1. Fishermen who fished north of these area were not affected.

DAMs could be enacted any time an unexpected aggregation of right whales occurred in an area not protected by a SAM, or during times when the SAM was not in

effect. A DAM could be triggered by any reliable report of 3 or more right whales within a radius of 75 nm. A DAM could require fishing gear to be removed from the area within two days of the ruling being published in the Federal Register. In some DAMs, NMFS could rule fishing activity as acceptable if it used gear deemed or certified as reducing the risk of whale entanglement (such as sinking ground line, weak links) during the period the DAM was in effect. However, in other cases a DAM would not require or allow gear modifications; rather the DAM simply halted all fishing activity. Factors influencing how the DAM was managed included weather, the location of the DAM with respect to other fishery closures, the amount of gear already in the area, and current right whale entanglement and mortality data. Fishermen had 3–5 days advanced notice before the ruling was published in the Federal Register, giving them a little extra time to comply with the ruling.

Unlike SAMs, DAMs were particularly frustrating for lobstermen. SAMs were specified for set areas during set times for which lobstermen fishing in the area could prepare ahead of time. But DAMs were irregular and could happen at any time with very little warning. Compliance with a DAM often meant extra time on the water as well as added expense. If the gear that needed to be removed has recently been set, DAM closures may also have caused a loss of income since the fishermen did not have enough time to fish the area. Many lobstermen were not able to invest in whale-safe gear, or did not see an advantage to having separate gear for use during periods when DAMs were in effect. Many fishermen have stated that sinking groundline behaves differently than floating line when being hauled into their vessels and can be dangerous.

In October 2007, a final rule was issued that replaced the SAM and DAM programs (72 FR 57104, October 5, 2007). Instead of seasonally closing an area, or requiring that only a particular type of gear be used on extremely short notice, all fishermen on the U.S. east coast were required to make gear modifications. The new "whale-safe" gear included sinking ground line as well as weak links on all vertical lines. This new ruling was controversial for many reasons. Lobstermen argued such a broad-based change on such a broad level did not make sense, since there is so much variability in habitat as well as the number of whale sightings within the Gulf of Maine. While many right whales congregate in areas such as Cape Cod Bay, fishermen claimed few whales were ever sighted within Maine state waters, where 80% of all Maine lobstermen fish (Maine Lobstermen's Association 2011). Instead of adopting broad-based measures for the entire east coast, many fishermen proposed that these measures would be more effective if based on regional differences in habitat type and whale distribution. Thus, such a ruling would only effect areas where the likelihood of entanglement was greatest. Some data exist that in part support this claim (Todd, pers. comm.[2]). Thus, many lobstermen feel that the gear modifications should not apply to state waters. As a result of petitions, the ruling was amended to allow for a ~3 nm close-to-shore exemption zone where floating gear could still be used—however this line did not correspond to the demarcation between state and federal waters.

Another problem lobstermen cited with the new gear regulations is that sinking ground line causes too much gear to be lost when fishing in rocky-bottomed habitats. The lines connecting multi-trawl traps become "hung-down" under rocks, which can cause an entire string of traps to be lost. Sinking ground line, according to the fishermen who use

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it, is also far more susceptible to chafing against the rocks, causing gear to be lost or replaced much sooner than when using floating line. Considering the difficulties experienced during my study (see pp. 24-26)—with the anchoring systems for MARUs malfunctioning quite possibly due to the chafing of nylon tethers or sandbags against the rocks—it is hard to argue these points. The northern Gulf of Maine is not an easy place to deploy gear so that it can be retrieved, primarily because of the reefy, rocky bottom type and strong tidal scouring. Further, gear modifications were extremely costly for lobstermen who had to replace their entire supply of line when the switch from floating to sinking line came into effect.

While these gear modifications probably reduced the likelihood that lines between traps could entangle whales, risk of entanglement in vertical line remained an issue. While the new rule also called for weak links at all buoys that would break if a whale became entangled—potentially allowing the line to slip off the whale without it getting tangled on the buoy—this did not guarantee that a line could not wrap around the whale in some way once the line was detached. However, traditional methods to reduce vertical lines in the water (such as grappling for gear) that work in sandy-bottomed habitats characteristic of Florida or North Carolina would not work in rocky-bottomed habitats. NOAA is currently soliciting proposals for vertical-line reduction from each individual state to avoid broad-based modifications that might not work well on a regional level (Summers, pers. comm.[3]).

The issue of incidental right whales takes by pot/trap fisheries is further complicated in that many fishermen themselves feel a sense of ownership over waters

[3] Erin Summers, Maine Department of Marine Resources, PO Box 8, West Boothbay Harbor, ME 04575

traditionally fished through generations of their families. Generally, Maine lobstermen are fiercely proud of their culture. Unless lobstermen are involved in conservation efforts, they will likely resist policy change that may lessen the threat of entanglement to right whales on the basis that it might negatively impact their income. Two groups—the Maine Lobstermen's Association and the Downeast Lobstermen's Association—are extremely politically active, and have significant lobbying power with the state and federal governments. Rather than continuing to create a culture of distrust that will force lobstermen and the agencies representing them to fight policy changes, lobstermen should be actively solicited for advice on potential solutions. For example, a recent entanglement workshop that brought fishermen and scientists together was lauded by both parties as a progressive move in implementing bipartisan solutions.

Disentanglement protocols are a second area where the fishing industry can be brought in for potential gains on both sides. For many years, the exclusive license for the disentanglement of marine mammals was held by one organization, the Provincetown Center for Coastal Studies. While the caliber of work performed by this organization to further the science of whale disentanglement is exceptional, the political atmosphere created by having only one organization authorized to handle entanglements was likely detrimental to the whales since it placed too much responsibility on one group to perform all disentanglement tasks. Whale disentanglement is extremely dangerous work and it is important to regulate how entanglements are handled to ensure no humans are injured, that the efforts actually result in whales being freed of all gear, and that the best data possible are collected from each incident. However, it is possible that with training, lobstermen could be an asset to disentanglement efforts. Not only do they have the

practical skills involved with boat and line handling, but many lobstermen probably know the gear in question better than a disentanglement team and could help determine how fishing line will behave in certain situations. However, in most cases lobstermen have not been engaged in disentanglement efforts, and some have expressed feeling belittled if told they cannot assist in freeing a whale from fishing gear. Fishermen that feel disrespected by the government and whale scientists are less likely to comply with rulings set in place to conserve right whales. In addition, lobstermen are also less likely to assist or even report an entangled whale if they feel that the only reaction from the federal government would be to shut down their fishing area. Despite the concerns of fishermen, many scientists and conservationists believe that as long as there is any fishing gear in the water, the future of the right whale is in question.

This culture of distrust within Maine has been cultivated over many years and still continues to some extent despite efforts to change it—certainly, distrust between fishermen and government overseers is a common theme in many federal and state fisheries. Disentanglements are now handled by a disentanglement network; this includes organizations along the entire east coast and extending into Canada that are overseen by NOAA Fisheries or the Canadian Division of Fisheries and Oceans. This network could begin to train local U.S. fishermen in their response efforts, although liability issues still prevent such an action (Johnson 2005). Industry professionals, scientists, and conservationists are increasing efforts to collaborate and meet to discuss issues during meetings such as the Atlantic Large Whale Take Reduction Team meetings, or the Maine Fishermen's Forum. Because of outreach efforts such as these the relationship between industry professionals, the government, and whale scientists and conservationists is

slowly improving (although the current political climate in Maine has eroded some of that progress). Some lobstermen have been willing to take part in gear modification studies that test new technologies in reducing entanglements. Efforts to listen to the viewpoints of fishermen and engage them in conservation efforts should be taken at every opportunity, for it is only through compromise and collaboration by all involved parties that those efforts will be successful (Johnson 2005).

Mitigation to Shipping-Derived Mortality

There are currently only three areas, known as Seasonal Management Areas (SMAs), within known right whale habitat that have mandatory seasonal speed restrictions for all vessels. The first is in the waters off the Southeastern U.S. between November 15 and April 15 in order to protect calving and nursing grounds. The second is in mid-Atlantic waters between November 1 and April 30 in several locations including a range from Brunswick, SC to Wilmington, NC, the port of Morehead City, NC, the entrances to the Chesapeake and Delaware Bays, New York Harbor, and Block Island Sound. The third is in waters off New England: this area is divided into three smaller regions that are protected during different times of the year corresponding to the times of highest right whale use. Cape Cod Bay is protected from January 1 to May 15. The waters off Race Point are protected from March 1 through April 30. Great South Channel is protected from April 1 to July 13 (see Figure 32).

SMAs attempt to reduce the threat of collisions between right whales and shipping traffic by requiring all vessels greater than 19.8 m to travel at 10 kts or less within the SMA boundaries. This ruling was put into place in 2008 after a federally

mandated public comment period (73 FR. 60173 October 10 2008). Along with this ruling, it was deemed that right whales may need protection outside of designated SMAs or within these area during times when the SMAs are not in effect. Similar to the case originally explored within the fishing industry for times when right whales unpredictably occur in high numbers, dynamic management areas (DMAs) can be put into effect. DMAs require that vessels either attempt to avoid the area or restrict their speed while in the area to 10 kts or less. DMAs are temporary, only lasting up to 15 days with an optional extension of 15 days if whales are re-sighted. DMAs can only be put into effect if three or more right whales are sighted within a particular radius by a reliable source. The biggest weakness of these rulings is that they are voluntary—the rule states that a vessel is "expected but not required" to follow the speed restriction. With Automated Identification System (AIS) tracking technology required on large vessels, it is likely that most vessels comply with DMA rulings (though there is no guarantee); however, NOAA stated that if compliance with DMAs was not high enough then DMAs could be made mandatory rather than voluntary.

Methods

Study Area

By analyzing aerial survey data of Outer Fall from 2003-2007 provided by NOAA Northeast Fisheries Science Center, we located the buoy in an area with the most numerous and recent sightings of right whales in winter—approximately 43° 18' 23"N and 68° 37' 40"W (Khan 2009). The water depth at the chosen site was 168 m.

MARU Design and Deployments

Although passive acoustic monitoring using bottom mounted systems is an increasingly popular method of study, it is challenging when working with bottom mounted gear in the Gulf of Maine due to the rocky bottom habitat, harsh weather, and strong tidal conditions. Designs that typically work for other areas are not suitable in this region because of the amount of chafing that can occur in lines and other pieces of equipment. We found that designs meant for shallow water systems, which are more exposed to wave conditions, worked well for deep water Gulf of Maine applications, and the changes we made to our bottom mounted system throughout the three deployments of the study (Table 1) will be discussed here. Photos documenting the changes can be found in Appendix A.

Since 2006 College of the Atlantic (COA) has deployed Marine Autonomous Recording Units (MARU, or "pop up buoys"), developed by the Cornell University Bioacoustics Research Program (Cornell BRP), around the Mount Desert Rock and Inner Schoodic Ridge regions in summer months. We extended our collaboration with the Cornell BRP and Maine Department of Marine Resources to deploy MARUs in the Outer

Fall region year-round. These units consist of a vacuum-sealed 43.18 cm glass sphere containing a microprocessor, hard drive, batteries, and other electrical equipment. The sphere is encased in a durable and easily visible yellow case. The unit is anchored to the bottom and can be released by sending an acoustic signal which triggers a release system, leaving the anchoring system on the sea floor. These units utilize an externally mounted hydrophone (High Tech, Inc. 94-SSQ) with sensitivity up to -165 dB re 1 V / μPa and a preamplifier system providing a frequency response of 10 Hz to 32 kHz. The pop up buoy system has a flat frequency response (±1 dB) from 20 to 800 Hz. These units initially record onto a 120 GB hard drive in binary format at a sample rate of 2 kHz. A unit set up this way can record for approximately 120 days. With these specifications, the recording system will capture signals up to 1 kHz.

Our first deployment consisted of a single MARU anchored with three 18 kg sandbags and 3 m tethers, which is the standard for pop up buoy deployments in other areas. We deployed the first unit off the R/V *Stellwagen* on July 13, 2009. On October 2, 2009 we attempted to retrieve the unit on the M/V *Indigo*. After the initial retrieval failed, we followed a circular search pattern with regular communication to the buoy out to 10 nm away from the original site. The buoy could not be relocated. It is possible the unit failed or was brought up by a bottom trawl fishing vessel.[4] However, there was also an extreme weather event during the deployment period. Hurricane Bill, a Category 3 hurricane, went through the offshore Gulf of Maine on August 23, 2009 and generated significant wave intensities. It is possible that the storm also created currents that dislodged the buoy from its anchoring system.

[4] All deployed units have a plaque advertising a bounty if found by a third party such as a fisherman. This method often works but clearly did not in this case.

We decided to modify the mooring system for the second deployment. The sandbags, which have a high probability of ripping or chafing against rocks, were replaced with a 90 kg steel I-beam. The added weight provided extra protection from strong currents. We configured the second unit as a "double bubble," which is a single MARU attached to an extra unit which just holds batteries. This extended the life of the buoys from 3 months to 6-8 months and allows the buoy to remain deployed and functional over the entire winter when retrieval would be difficult. We deployed the unit October 30, 2009 off the M/V *Bay King III*, and retrieved it successfully using the M/V *Indigo* on May 28, 2010. Deployment of a new unit at the time of retrieval was not possible. We did not deploy a new unit until the end of June, leaving a month-long gap in the data set.

For the third deployment, we created a concrete anchor weighing 81 kg and fitted it with steel rebar to attach anchor lines. We also modified the anchoring tethers, deemed to be too susceptible to chafing, replacing them with a single 3 m length of Uniline, a bonded polyester core wrapped in neoprene and covered with braided polyester with a urethane coating made by Yale Cordage. We deployed the third unit on June 29, 2010 using the M/V *Lady Anne* owned by Sea Ventures Charters out of Port Clyde, ME. We retrieved the unit successfully on October 13, 2010, also aboard the M/V *Lady Anne*. Based on our success and failures in deploying MARU systems in this region, I recommend using the configuration used in this deployment for future studies.

Table 1. Deployment schedule and locations of MARUs, vessels used for deployments and retrievals, and amount of data each buoy recorded.

Deployment	Vessels	Area	Location	Deployment Dates	Amount of Data
1	R/V *Stellwagen* M/V *Indigo*	Outer Fall	43° 18N 068°37W	July 30 2009 (not retrieved)	n/a
2	M/V *Bay King III* M/V *Indigo*	Outer Fall	43° 18.190N 068°37.338W	October 30 2009 May 28 2010	67.7 GB
3	M/V *Lady Anne*	Outer Fall	43° 18.234N 068° 37.336W	June 29 2010 October 13 2010	34.1 GB

Data Processing and Analysis

We shipped both units to Cornell BRP for processing. At Cornell, all recordings were processed from binary into AIFF files in either 15- or 30- minute intervals and stored on a hard drive and returned to COA. Data are stored at COA on a Drobo robotic hard drive array capable of supporting 16 TB of data. We analyzed the data primarily through eXtensible BioAcoustic Tool (XBAT), a MATLAB (Mathworks 2006) supported open source analysis software for sound analysis and management of large-scale acoustic data sets developed by Cornell BRP (Figueroa 2008). Obviously no data were available from the first deployment.

Analysis of the second deployment was by month. October 2009 only contained two days of data so both days were analyzed. However, due to the size of the dataset, data for all other months were sub-sampled analyzing every third day of data. In total, we analyzed 108 days of data. For the purposes of analysis, we chose to search for two call types since they are the most well-described in the literature—the upcall and the gunshot call (Figures 1 and 2). In addition, upcalls are most commonly associated with right whale presence, and gunshot calls are most strongly associated with mating activity.

First, we ran an automatic detector for right whale upcalls, ISRAT (Urazghildiiev and Clark 2006), on all days. This detector functions as a generalized likelihood ratio test by examining a sound file second by second to determine how similar each is to a right whale upcall template. We ran ISRAT with a .35 minimum detection correlation threshold (the minimum percentage of similarity of the detected calls to the template) since this is the threshold used in other areas, and has been shown to reduce false

detections while still returning a high rate of true detections (Risch, pers. comm.[5]). The data for each day were also manually analyzed for gunshot calls, a process known as "hand-browsing." I manually analyzed 70.5 days of data myself. For the remaining 37.5 days of data, I trained a team of nine undergraduate volunteers to perform the analysis. Each volunteer met with me individually to learn XBAT and the different call types. Each received a copy of a protocol detailing how I determined call type with example spectrograms. I was usually present during analysis in case the analyst had questions or the computer malfunctioned. When an analyst completed a day of data, I then reviewed each log to ensure consistency.

Since the data were both processed by the algorithm and hand-browsed, we could correct the logs created by ISRAT for false positives (detections made by ISRAT that were not made by a right whale) and logged false negatives (right whale calls not detected by ISRAT). False positives came from anthropogenic noise sources such as boats, natural events such as weather, the calls of other marine mammals, and the noise of the MARU hard drive as it spun to back up data. I calculated the ratio of false positives by dividing the number of incorrect detections made by ISRAT by the original number of detections before being manually corrected, and multiplying by 100 to get a percentage. I did the same for false negatives by dividing the number of upcalls detected by manually browsing the data by the total number of upcalls detected for that day, and multiplying by 100. I then binned these ratios by frequency of occurrence and plotted a histogram to examine the rate of false positive and negatives throughout the analysis.

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166 Water Street Woods Hole, MA 02543-1026

As data were processed, we found other calls that were possibly made by right whales and logged them as social sounds. This included moans, grunts, and other frequency modulated calls within range of known right whale calls. A call was logged as questionable if the analyst was unsure if a call was made by a right whale. Many of the questionable calls were in areas where the signal-to-noise ratio was low and calls were difficult to distinguish. Sometimes a call was unfamiliar or undocumented in the literature, or occurred in an area where a high number of calls from other whale species were present (such as humpback whales, described in the next paragraph). These calls were not included in the final analysis.

There are currently no clear criteria for distinguishing right whale upcalls from similar calls made by humpback whales (Mussoline *et al.* In review.). Humpback whale song was detected almost every day from November through December. If an upcall was detected during a sequence of humpback whale song or within 15 minutes of a humpback whale call, as a conservative measure the detection was classified as a false positive and was removed from the final dataset. Upcall-like calls were detected in high numbers in summer months. However, these calls were in shorter, quicker sequences than right whale calls, were usually accompanied by other humpback whale calls within a few minutes, and were not frequently confirmed by ISRAT. These calls were also classified as humpback whale or questionable and not counted. This approach was deliberately conservative due to the ambiguity involved in distinguishing humpback whale upcalls from right whale upcalls.

I calculated the total number of upcalls for each day from both the manual and ISRAT analysis. I then analyzed these for seasonal and diel patterns. I averaged and

plotted the total number of both upcalls and gunshots by month to examine if the average call rates changed throughout the year. In order to examine diel patterns, I calculated the total number of both call types per hour for each day and then averaged by month.

Statistical Analysis

I performed statistical analysis using Data Desk (Velleman 1997). An ANOVA was performed on the seasonal data for both upcalls and gunshots to determine if month had an effect on the total number of calls. The call rate data were log-transformed to assure normal distribution. A two-way ANOVA was performed on the diel data to determine if month or hour had an effect on total number of calls individually, or if there was an interaction between month and hour of call. Calls by hour were also log-transformed.

Call Parameters

In order to determine call parameters for gunshots and upcalls, the 15 highest-quality calls were chosen from each month having a substantial numbers of each call type. A call was rated as high quality when harmonics were present with minimum ambient noise. January and October 2010 did not have enough high quality calls to contribute 15 calls to the final dataset, and so all calls from those months were used. The logs created in XBAT for these calls were transferred to Raven (another sound analysis program developed by Cornell BRP, http://www.birds.cornell.edu/raven) to measure more specific call parameters than could be measured in XBAT. Call parameters analyzed were high frequency, low frequency, center frequency, delta frequency, and

delta time. An ANOVA was run to see if call parameters differed among months, or if all calls could be binned together when determining call parameters. Averages for each call parameter were determined for each month and for the entire data set. The median and range of each parameter were also calculated.

Aerial Surveys

Aerial survey data taken on all tracks above 42° during the deployment of first successful MARU were received from NOAA Northeast Fisheries Science Center. Aerial survey teams recorded actual positions (AP) of right whales during transect surveys by breaking track and circling over each whale when possible (Khan, pers. comm. [6]). The data used for this analysis were "final estimate" data—which is a summary of all right whales seen during all break tracks, whether or not NOAA was able to collect the AP data. Aerial surveys where right whales were sighted occurred 17 days during the recording period of this study. Of those days, there were 7 days where the surveys were flown within the acoustic range of the MARU. The number of whales sighted during these surveys was plotted against the number of calls for that day. A contingency table was created, and a *chi*-square analysis was run on this data. A GIS map was also created showing sighting data compared the location and probable acoustic range of the MARU.

Social Sounds

Social sounds (sounds likely to be right whale based on the proximity to other right whale calls) were logged in a general category as data was analyzed. These calls

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were later re-categorized into several groups- grunts, moans, "worm" calls, long calls, high calls, and pre-gunshot calls. These categories were based on visual assessment and calls within them are still quite variable due to the sheer volume of calls observed. Spectrograms are presented in this paper. General call parameters were calculated using the same methods as upcalls and gunshots, however it should be noted that calls within these categories can be grouped into subcategories based on their variability. Calls were sub-sampled from the total dataset using every third day of data within the months that had multiple days with social sounds. If a month had less than three days containing social sounds, all days were analyzed.

Results

False Positive and Negative Rates

The average false positive rate for ISRAT detections was 72.38% (SD=32.57). The average false negative rate was 29.67% (SD=31.69). The average false positive rate between the two MARU units was not statistically significant (T = 1.406 df = 51 p = 0.16). Histograms of false positive and negative ratios are shown in Figures 3 and 4.

Call Seasonality

In total, I analyzed 108 days of data between October 2009 and October 2010 (Appendix B). Upcalls were the most numerous call type with the observed (n=28,497). Gunshot calls were not observed as frequently as upcalls but were still numerous (n=16,790). There were no days where gunshot calls were present without the presence of upcalls; however, there were 20 days where upcalls were present without gunshots. Both call types were seasonally distributed (Figures 5-7), with the most calls taking place in fall months and infrequently in summer months. Upcalls were most frequent in November 2009 (n=8,719), and gunshots were most frequent in December 2009 (n=5,680). Table 2 details the rate of each call type by month.

October 2009 was not complete due to the deployment of the MARU taking place on October 30. However, these two days of data show that whales were present and calling very frequently (Figures 8-10). The total number of upcalls for October 2009 was less than that of other fall months (n=553); however, the total number of gunshots was quite high comparatively (n=2,929). October 2009 was removed from the dataset for statistical analysis so that only months with a larger spread of data were used.

When the call rate was averaged for each month (Figures 11-13), upcalls were still highest in fall months, with the highest average call rate occurring in November, and remaining high until February. There was then a decrease in calling through May. Because of the deployment schedule, June only had one day available for analysis and was also removed from the data set for statistical analysis. Although upcalls were detected in July, the average was still small compared to other months. Average call rate continued to increase through September. October 2010 was not complete since the MARU was retrieved that month, though the average call rate was still relatively high for only four days of data.

Average call rate for gunshots was high from October 2009 through December. Gunshots were detected in January, but the average call rate was comparatively much smaller than in other winter months. No gunshots were observed March through May, and production rate was still very low in July. Average call rate then increased steadily beginning in August through the end of the dataset.

The average gunshot call rate between October 2009 and October 2010 is very different, most likely due to a difference in the number of days analyzed, and such a high number of gunshots recorded within those two days of October 2009.

An ANOVA showed month had a significant effect on upcall call rate ($F(_{9,57}$ 10.123, $p \leq 0.001$) (Table 3). *Post-hoc* analyses using the Bonferroni post-hoc criterion indicated that in general months with fewer calls (February, March, July) were significantly different from months with many calls (November, December, January) (table 4). An ANOVA showed that month also had a significant effect on call rate for gunshots ($F(_{7,38}) = 5.7452$, $p \leq 0.0001$) (Table 5). *Post-hoc* analyses using the Bonferroni

post-hoc criterion indicated that July was significantly different than September, November, and December, and that January and December were also significantly different (Table 6). Months where the mean was zero were not calculated in the pair-wise comparisons.

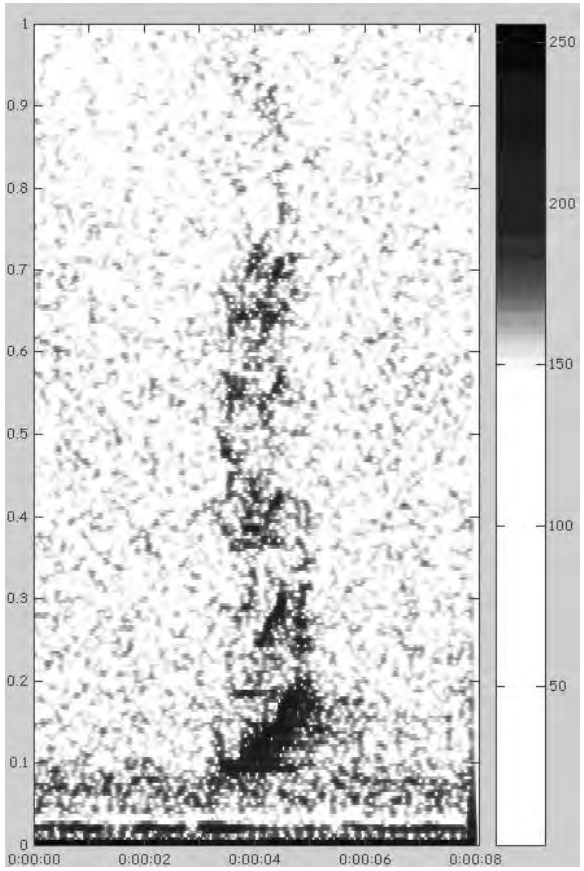

Figure 1. Spectrogram of a North Atlantic right whale upcall. Time is in h:min:sec on the x-axis, frequency is in kHz on the y-axis. Amplitude is in grey-scale. This was generated in XBAT using a Hann window, 512-point FFT, 25% overlap, and a window length of 8.065 s.

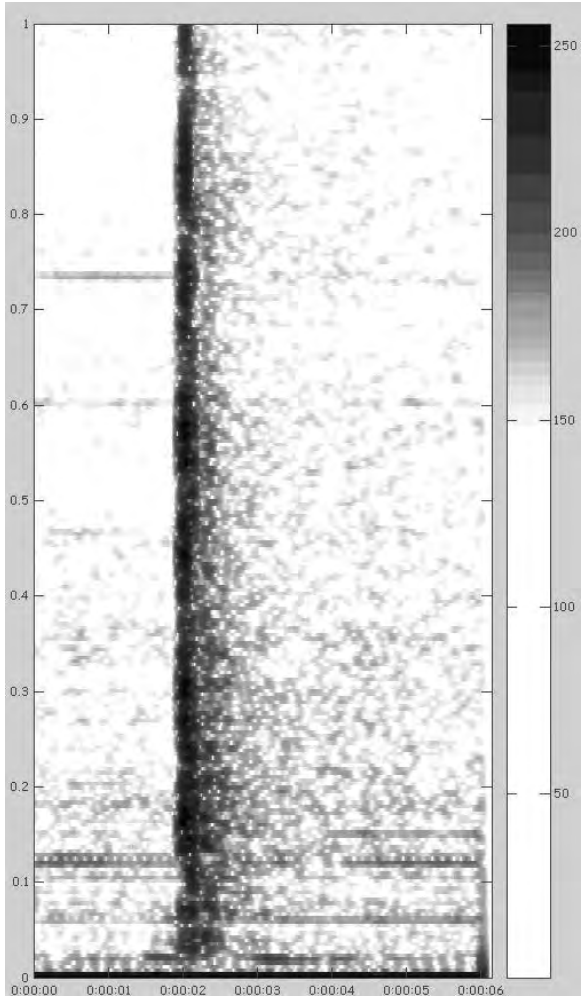

Figure 2. Spectrogram of a North Atlantic right whale gunshot call. Time is in h:min:sec on the x-axis, frequency is in kHz on the y-axis. Amplitude is in grey-scale. This was generated in XBAT using a Hann window, 512-point FFT, 25% overlap, and a window length of 6.1505 s.

Table 2. Monthly totals for detected upcalls and gunshots, average upcalls and gunshots, and the associated standard deviations.

Month	Total Upcalls	Total Gunshots	Average Upcalls	Average Gunshots	St. Dev. Upcalls	St. Dev Gunshots
October	553	2929	276.5	1464.5	102.53	803.98
November	8719	5297	871.9	529.7	615.87	390.94
December	6324	5680	574.91	516.36	298.48	439.98
January	6027	432	602.7	43.2	438.55	33.43
February	209	6	23.22	0.66	37.8	2
March	59	0	5.36	0	8.33	0
April	47	0	4.7	0	11.78	0
May	0	0	0	0.11	0	0.33
July	164	13	14.91	1.18	32.69	2.18
August	403	504	40.3	50.6	112.11	159.31
September	4800	1092	480	109.2	843.07	143.4
October	1192	837	298	209.25	377.87	242.30

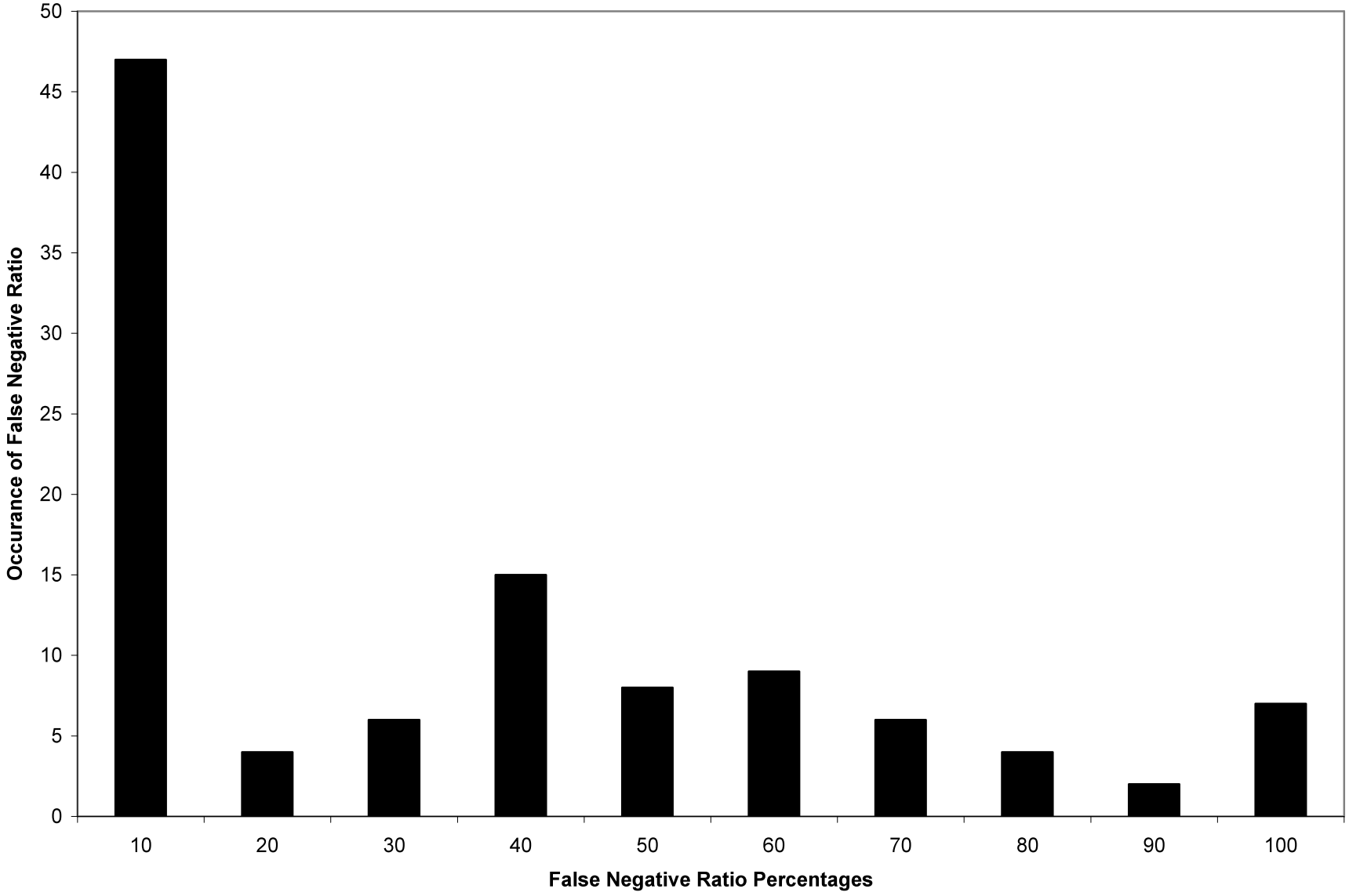

Figure 3. Frequency of occurrence of false negative ratios.

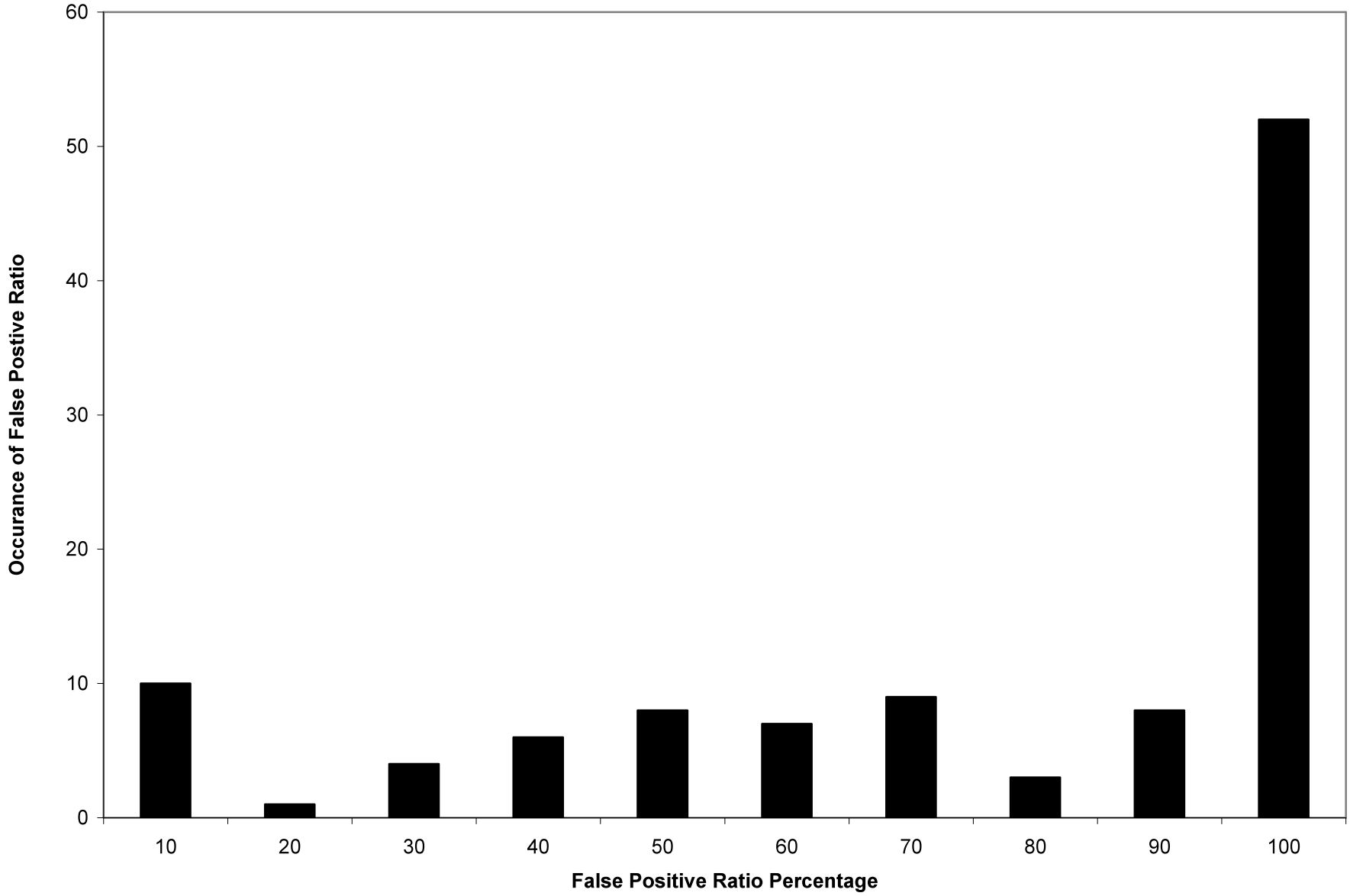

Figure 4. Frequency of occurrence of false positive ratios.

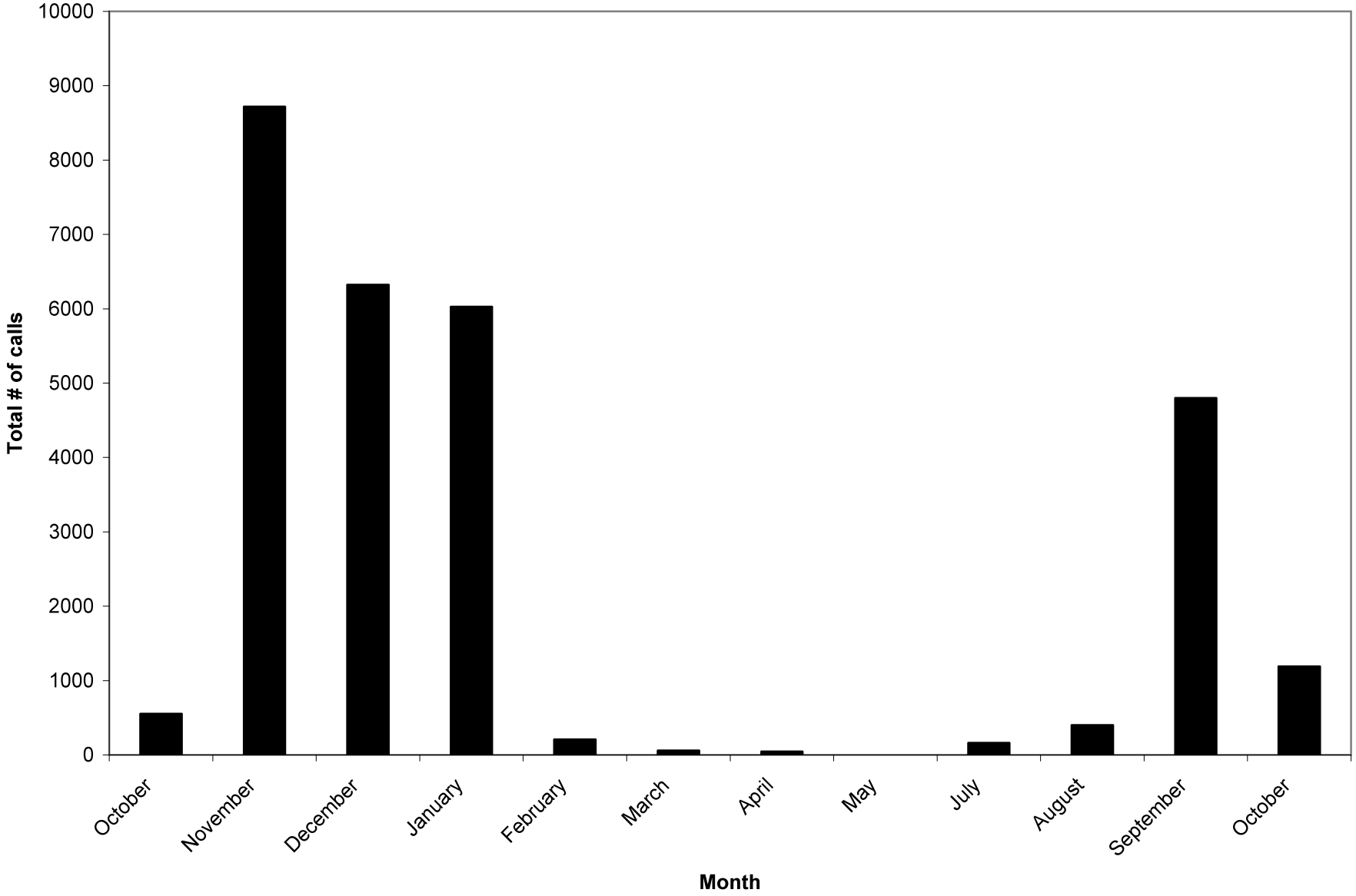

Figure 5. Total number of upcalls per month.

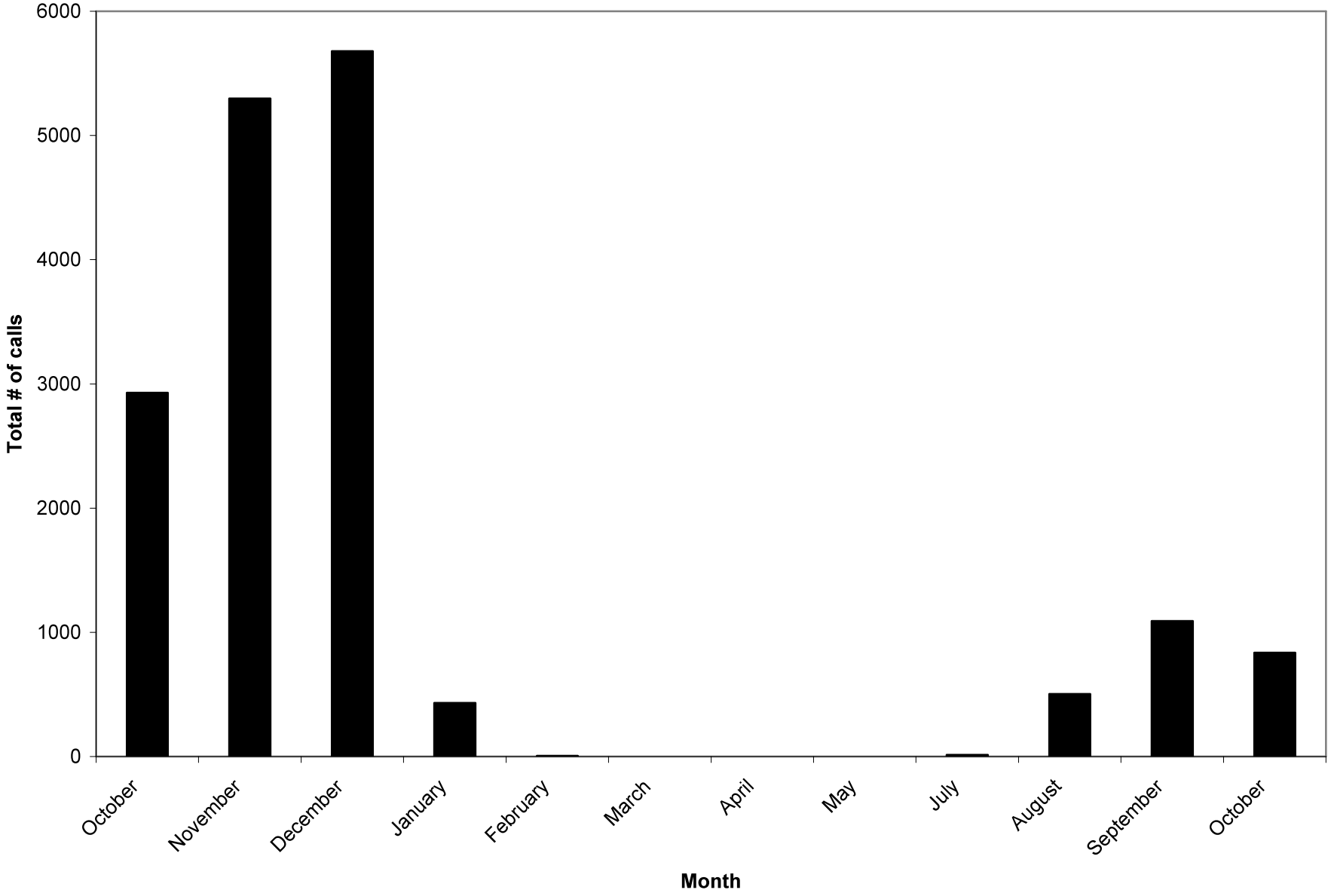

Figure 6. Total number of gunshots per month.

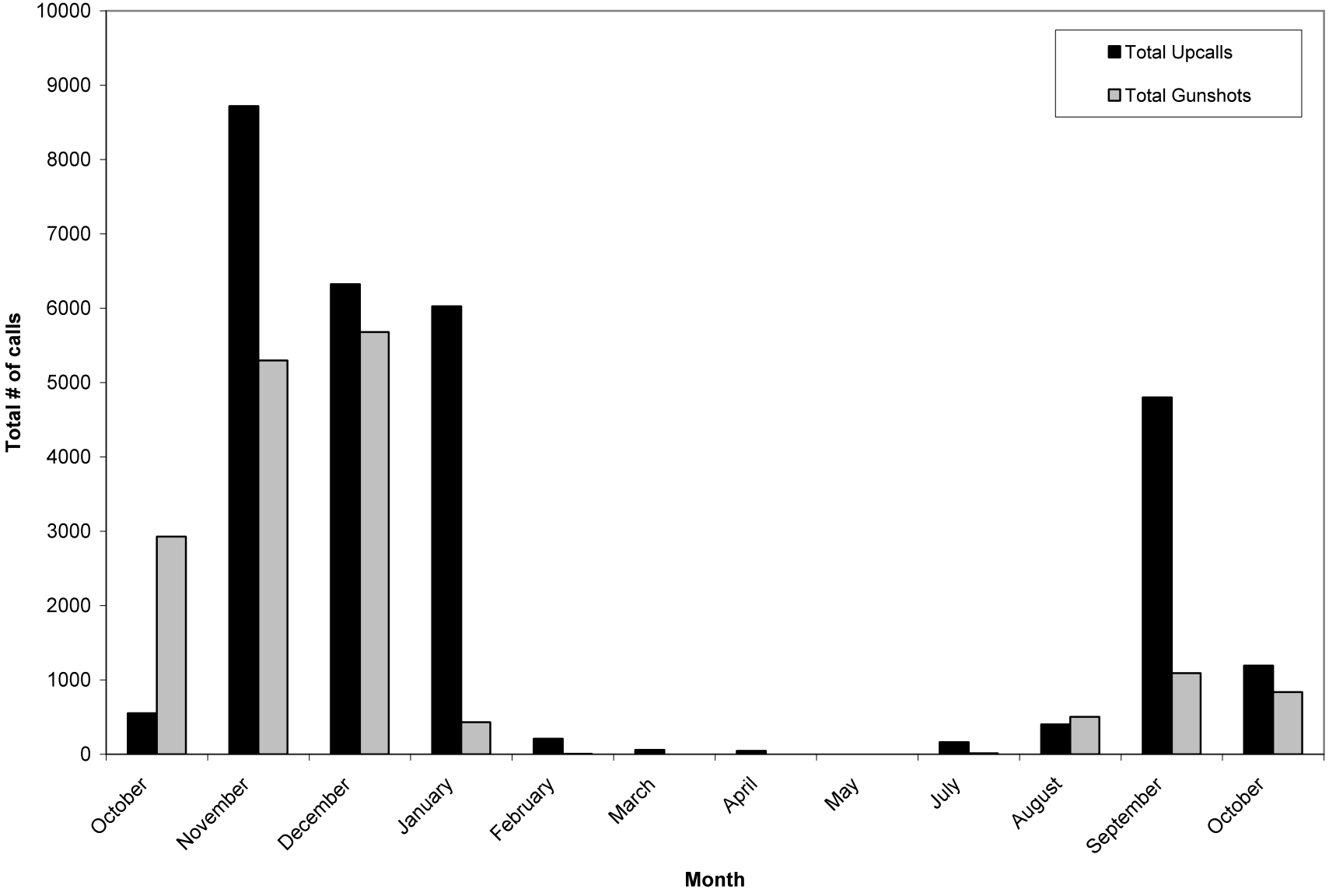

Figure 7. Total numbers of upcalls verses gunshots per month.

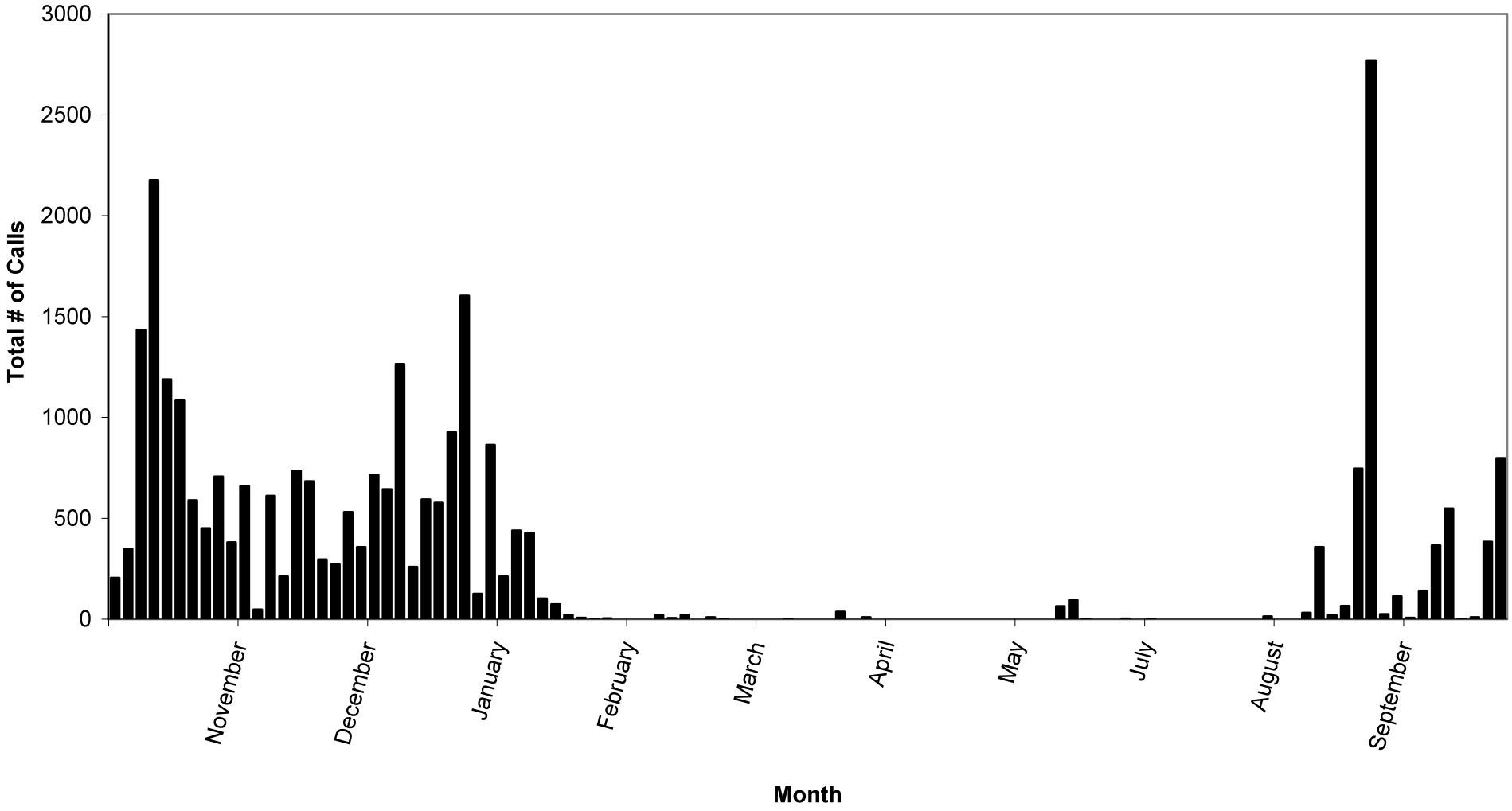

Figure 8. Total number of upcalls per day from October 30, 2009 to October 11, 2010. Data was sub-sampled every three days starting in November. June is not included.

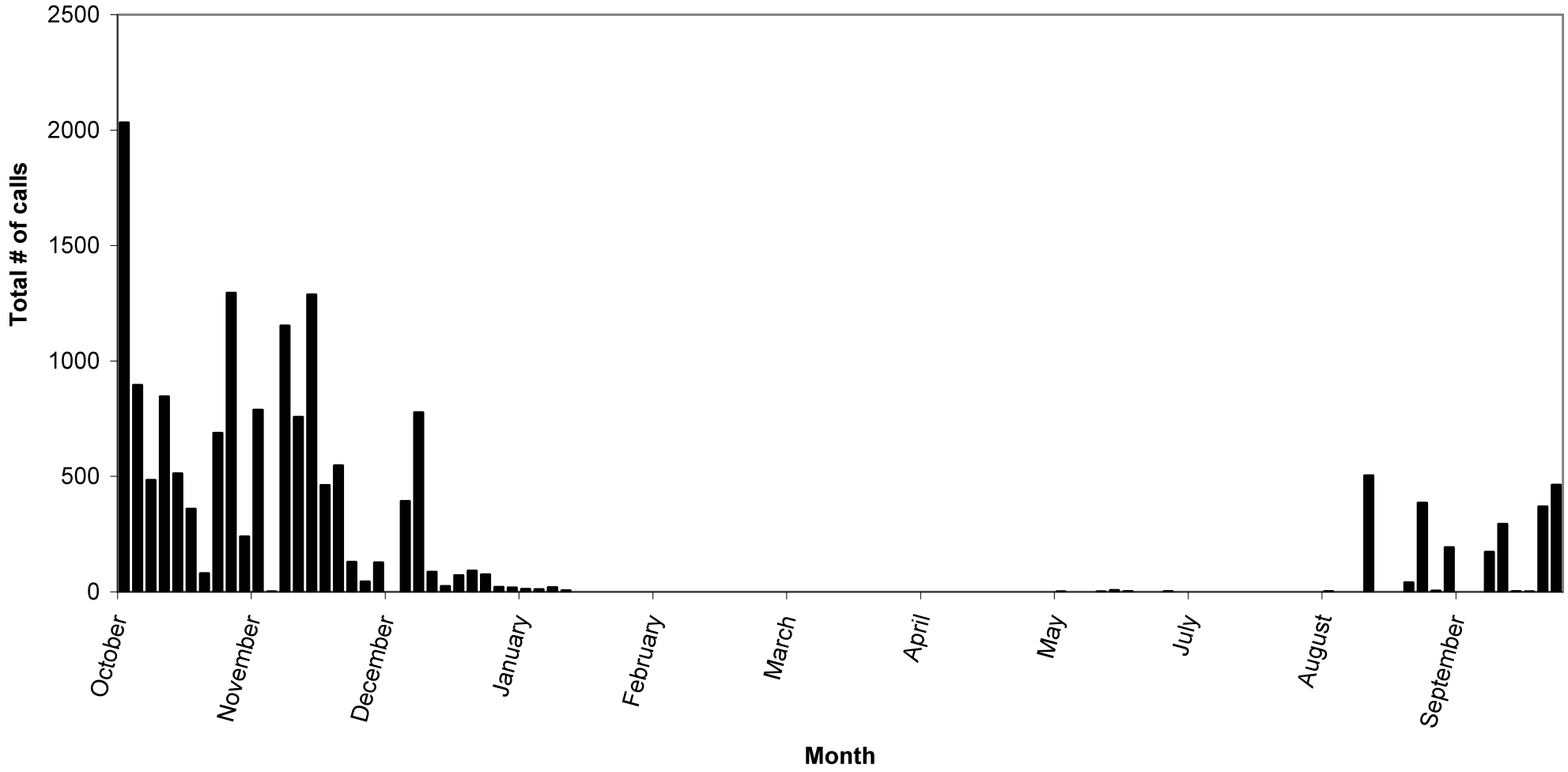

Figure 9. Total number of gunshots per day from October 30, 2009 to October 11, 2010. Data was sub-sampled every three days starting in November. June is not included.

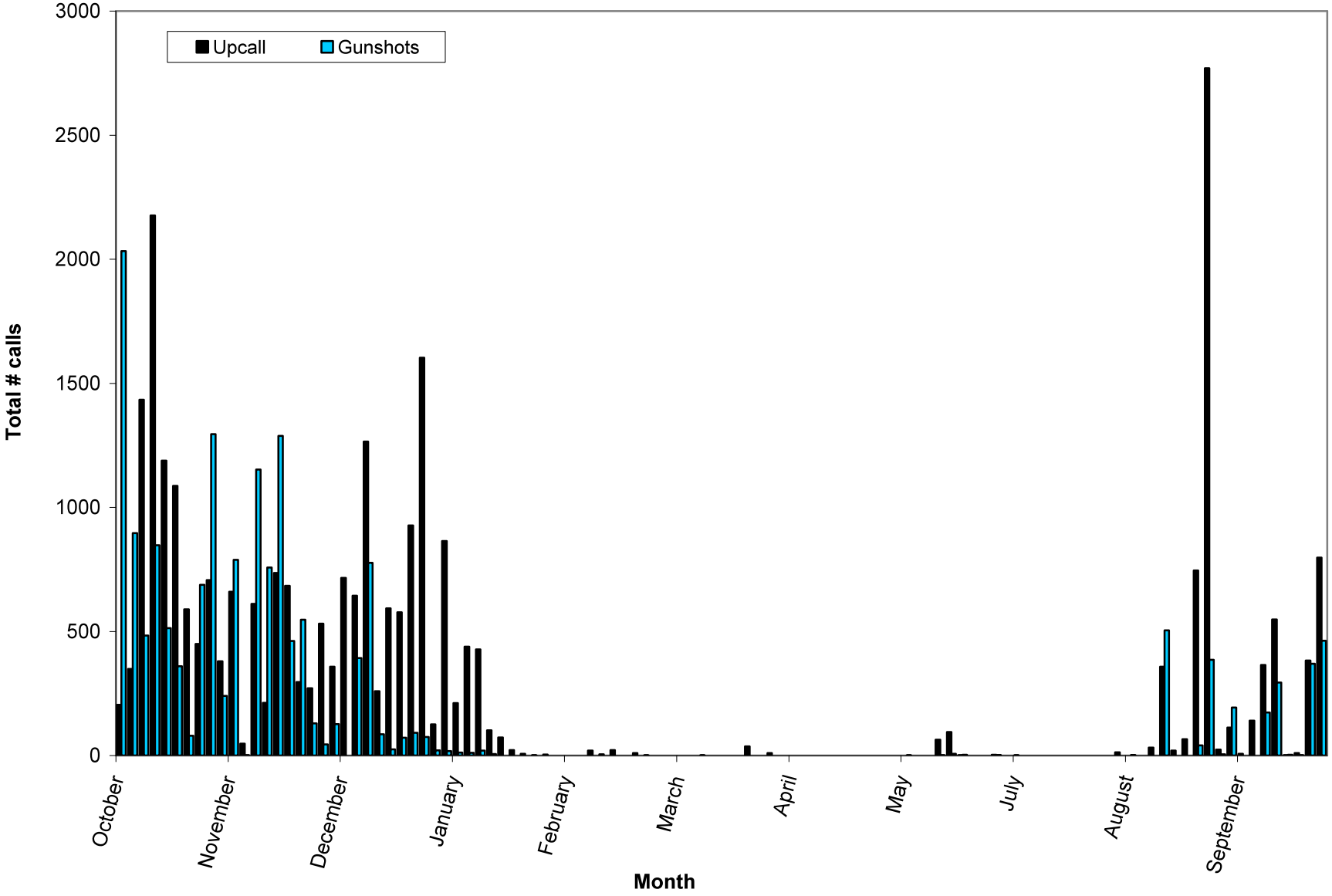

Figure 10. Total numbers of upcalls and gunshots by day from October 30, 2009 to October 11, 2010. June is not included.

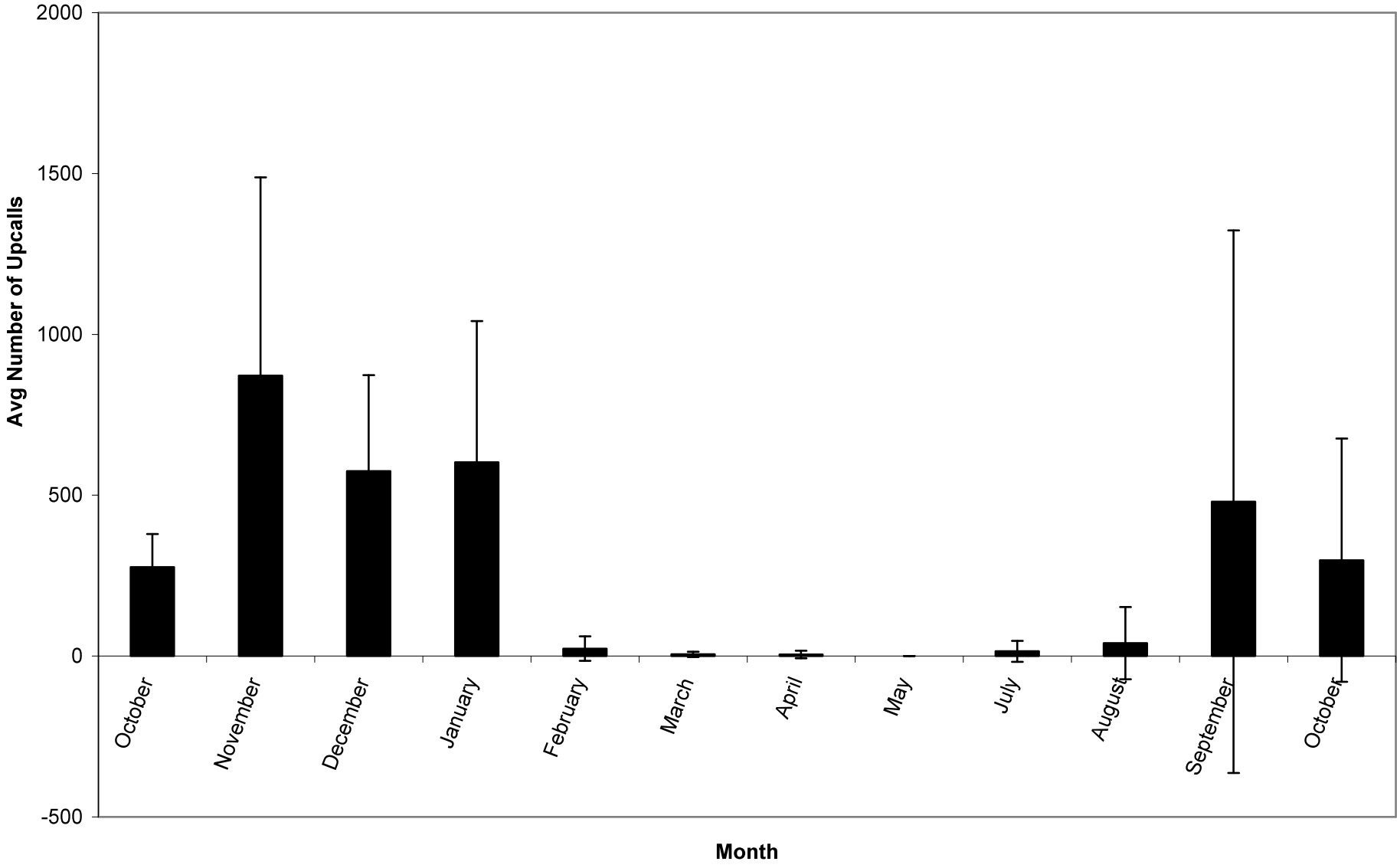

Figure 11. Average number of upcalls per month with standard deviations.

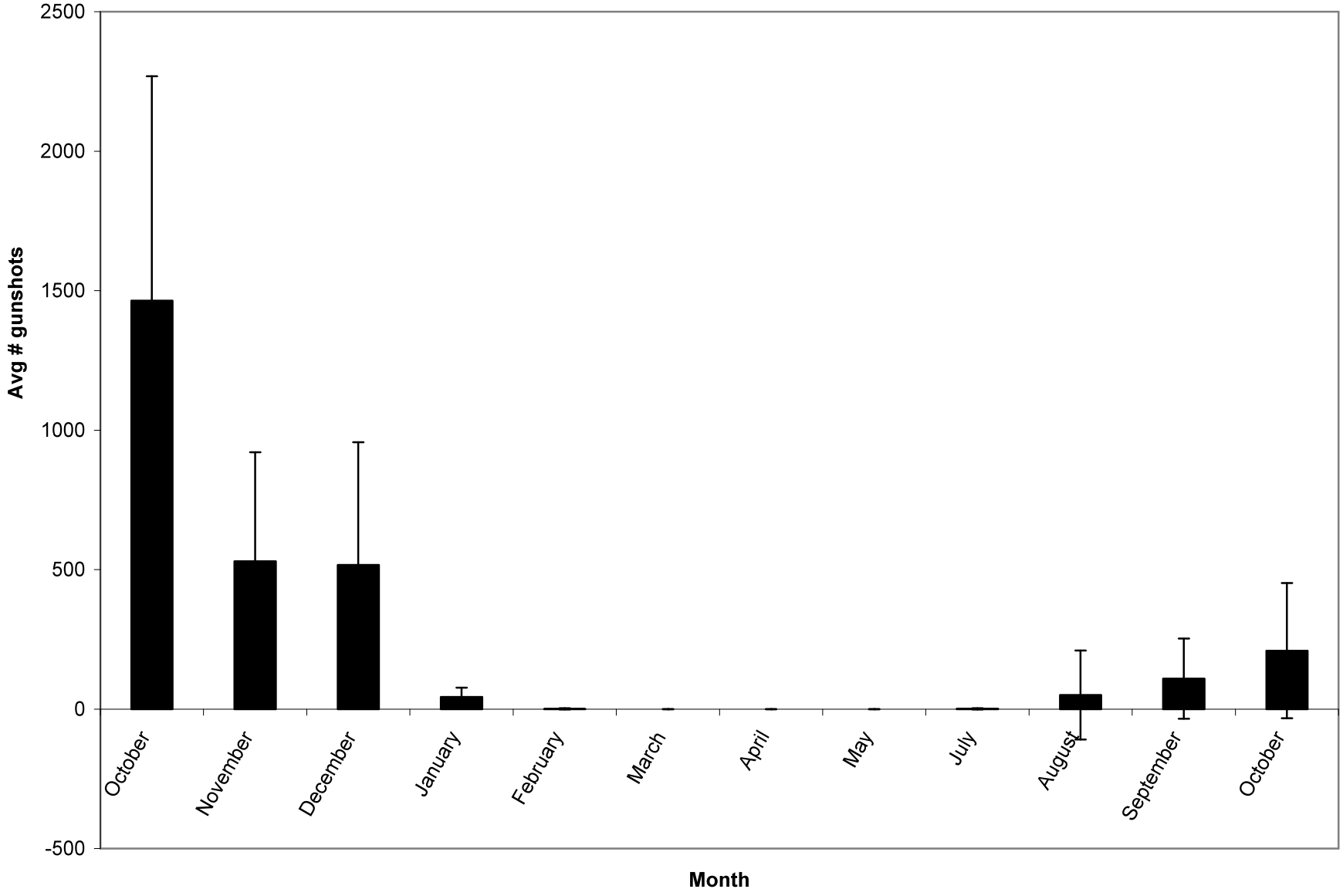

Figure 12. Average number of gunshots per month with standard deviations.

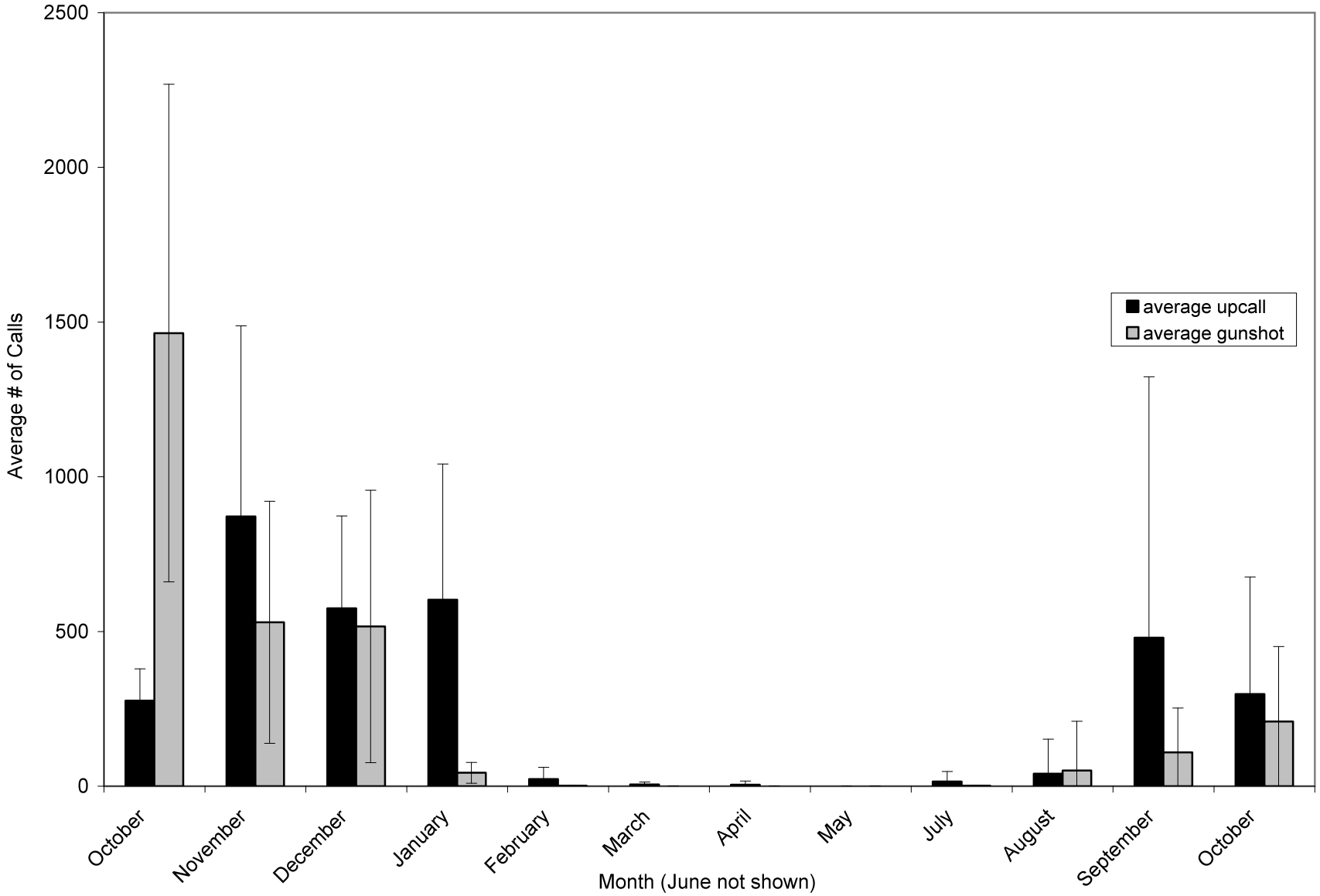

Figure 13. Average numbers of upcalls and gunshots per month with standard deviations.

Table 3. ANOVA results for average call rates between months for upcalls. Call rate was log-transformed to assure normalization of data. *Post-hoc* pairwise comparisons detailed in Table 3.

	SS	d.f.	MS	F	p
Month	39.43	9	4.38	10.12	≤ 0.0001
Error	24.67	57	0.43		
Total	64.09	66			

Table 4. P-values from Bonferroni *post-hoc* analysis of the effect of month on average call rate for upcalls. Bold p-values are significant at < 0.05

	Nov.	Dec.	Jan.	Feb.	March	April	May	July	Aug.	Sept.
December	1									
January	1	1								
February	**0.0003**	**0.0005**	0.001							
March	**0.000004**	**0.000008**	**0.000017**	1						
April	0.18	0.26	0.31	1	1					
May	Na	na	Na	na	na	na				
July	**0.000062**	**0.000116**	**0.000210**	1	1	1	na			
August	0.52	0.69	0.77	0.99	0.80	1	na	0.96		
September	0.67	0.87	0.94	0.18	0.006	0.99	na	**0.39**	1	
Oct. 10	0.16	0.25	0.33	0.99	0.83	1	na	0.98	1	0.99

Table 5.ANOVA results for average call rates between months for gunshots. Call rate was log-transformed to assure normalization of data. *Post-hoc* pairwise comparisons detailed in Table 5.

	SS	d.f.	MS	F	P
Month	20.48	7	2.93	5.74	≤ 0.0001
Error	19.36	38	0.51		
Total	39.85	45			

Table 6. P-values from Bonferroni *post-hoc* analysis of the effect of month on average call rate for gunshots. Bold p-values are significant at < 0.05

	Nov.	Dec.	Jan.	Feb.	March	April	May	July	Aug.	Sept.
December	1									
January	0.19	**0.04**								
February	0.64	0.44	0.99							
March	na	na	na	na						
April	na	na	na	na	na					
May	na	na	na	na	na	na				
July	**0.0008**	**0.00023**	0.31	1	na	na	na			
August	1	1	0.96	0.84	na	na	na	0.16		
September	0.99	0.96	0.99	0.97	na	na	na	**0.04**	0.99	
Oct. 10	0.53	0.23	1	1	na	na	na	0.76	0.97	0.99

Diel Patterns

A two-way ANOVA was run to see if month and time of day affected upcall rate for upcalls (Table 7). The test showed that there was no interaction between month and hour on average call rate ($F_{(164,646)} = 1.0453$ $p = .3505$), and so the analysis was simplified to 2 single ANOVAs. A one way ANOVA showed that the mean call rate was significantly different between hours ($F_{(23,819)} = 2.0460$ $p=0.0027$) (Table 8). *Post-hoc* analyses using the Bonferroni post-hoc criterion indicated that hour 9 was significantly different from hours 15, 16, and 17 (Table 9).

Similar tests were run for gunshot calls (Table 10). Again, there was no interaction between month and hour on average call rate ($F_{(99,396)} = 0.94833$ $p = 0.6179$). Hourly call rate was significantly different between hours of the day ($F_{(23,852)} = 1.9672$ $p = 0.0044$) (Table 11). *Post-hoc* analyses using the Bonferroni *post-hoc* criterion indicated that hours later in the day were significantly different from hours mid-day (Table 12).

Average number of upcalls per hour were plotted by month on a circular radar graph with an axis for every hour (Figure 14), as well as collapsed throughout the entire year (Figure 15). The same was done for gunshots (Figures 16 and 17). These radar graphs are a clear way to visualize the diel patterns in call rate throughout the day, and a higher call rate beginning around 1400 for upcalls and 1700 for gunshots through 2300 for both call types is clearly shown. Upcalls also had a high call rate in the early morning with a break in calling around 1100.

Table 7. Two-way ANOVA showing the effects of month and hour on average call rate per hour of the day for upcalls.

	SS	d.f.	MS	F	p
Hour	15.68	23	0.68	1.84	≤ 0.0098
Month	15.76	9	1.75	4.73	≤ 0.0001
Hour*Month	63.43	164	0.39	1.04	0.35
Error	239.04	646	0.37		
Total	382.7	842			

Table 8. One-way ANOVA showing the effect of hour on call rate for upcalls.

	SS	d.f.	MS	F	p
Hour	20.79	23	0.90	2.04	0.0027
Error	361.98	819	0.44		
Total	382.77	842			

Table 9. P-values from Bonferroni *post-hoc* analysis of the effect of hour on average call rate for upcalls. Bold p-values are significant at < 0.05

Hour

Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1																						
2	1	1																					
3	1	1	1																				
4	1	1	1	1																			
5	1	1	1	1	1																		
6	1	1	1	1	1	1																	
7	1	1	1	1	1	1	1																
8	1	1	1	1	1	1	1	1															
9	0.31	0.17	0.99	0.99	0.90	0.22	0.29	0.99	1														
10	1	1	1	1	1	1	1	1	1	1													
11	0.99	0.99	1	1	1	0.99	0.99		1	1	1												
12	1	1	1	1	1	1	1	1	1	0.99	1	1											
13	1	1	1	1	1	1	1	1	1	0.12	1	0.99	1										
14	1	1	1	1	1	1	1	1	1	0.77	1	1	1	1									
15	1	1	0.99	0.94	1	1	1	0.99	0.78	**0.0009**	0.99	0.11	0.98	1	1								
16	1	1	0.99	0.98	1	1	1	0.99	0.90	**0.001**	0.99	0.17	0.99	1	1	1							
17	1	1	1	1	1	1	1	1	0.99	**0.013**	1	0.64	1	1	1	1	1						
18	1	1	1	1	1	1	1	1	1	0.53	1	1	1	1	1	0.99	1	1					
19	1	1	1	1	1	1	1	1	1	0.24	1	0.99	1	1	1	1	1	1	1				
20	1	1	1	1	1	1	1	1	1	0.86	1	1	1	1	1	0.99	0.99	1	1	1			
21	1	1	1	1	1	1	1	1	1	0.07	1	0.96	1	1	1	1	1	1	1	1	1		
22	1	1	1	1	1	1	1	1	1	0.53	1	1	1	1	1	1	1	1	1	1	1	1	
23	1	1	1	1	1	1	1	1	1	0.72	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 10. Two-way ANOVA showing the effects of month and hour on average call rate per hour of the day for gunshots.

	SS	d.f.	MS	F	p
Hour	13.25	23	0.57	1.60	0.0396
Month	21.31	7	3.04	8.47	≤ 0.0001
Hour*Month	33.75	99	0.34	0.94	0.617
Error	142.35	396	0.35		
Total	255.61	525			

Table 11. One-way ANOVA showing the effect of hour on call rate for gunshots.

	SS	d.f.	s^2	F	p
Hour	47.95	23	2.08	5.04	≤ 0.0001
Error	207.67	502	0.41		
Total	255.61	525			

Table 12. P-values from Bonferroni post-hoc analysis of the effect of hour on average call rate for gunshots. Bold p-values are significant at < 0.05

Hour

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
2	1	1																					
3	1	1	1																				
4	0.99	1	1	1																			
5	0.31	0.53	0.81	0.97	1																		
6	0.99	0.99	1	1	1	1																	
7	**0.02**	**0.04**	0.12	0.32	1	1	1																
8	0.54	0.79	0.96	0.99	1	1	1	1															
9	0.90	0.98	0.99	1	1	1	1	1	1														
10	0.51	0.76	0.94	0.99	1	1	1	1	1	1													
11	0.99	0.99	1	1	1	1	1		1	1	1												
12	1	1	1	1	1	1	1	0.99	1	1	1	1											
13	1	1	1	1	1	1	1	0.99	1	1	1	1	1										
14	0.99	1	1	1	1	1	1	1	1	1	1	1	1	1									
15	0.99	1	1	1	1	1	1	0.99	1	1	1	1	1	1	1								
16	1	1	1	1	1	0.43	0.99	**0.03**	0.70	0.97	0.67	0.99	1	1	1	1							
17	1	0.99	0.99	0.99	**0.05**	**0.0002**	**0.03**	**0.000009**	**0.0007**	**0.006**	**0.0007**	**0.043**	0.22	0.09	0.06	**0.05**	0.99						
18	1	1	1	1	0.19	**0.0014**	0.11	**0.00004**	**0.003**	**0.02**	**0.003**	0.146	0.57	0.31	0.21	0.21	1	1					
19	1	1	1	1	0.16	**0.001**	0.09	**0.000038**	**0.003**	**0.021**	**0.003**	0.12	0.51	0.26	0.18	0.17	1	1	1				
20	1	1	1	1	0.97	0.068	0.84	0.003	0.15	0.48	0.14	0.89	0.99	0.99	0.98	0.98	1	1	1	1			
21	1	1	1	1	1	0.96	1	0.269	0.998	1	0.99	1	1	1	1	1	1	0.98	0.99	0.99	1		
22	1	1	1	1	1	1	1	0.97	1	1	1	1	1	1	1	1	1	0.16	0.50	0.44	0.99	1	
23	1	1	1	1	1	0.84	1	0.14	0.97	0.99	0.96	1	1	1	1	1	1	0.99	1	1	1	1	1

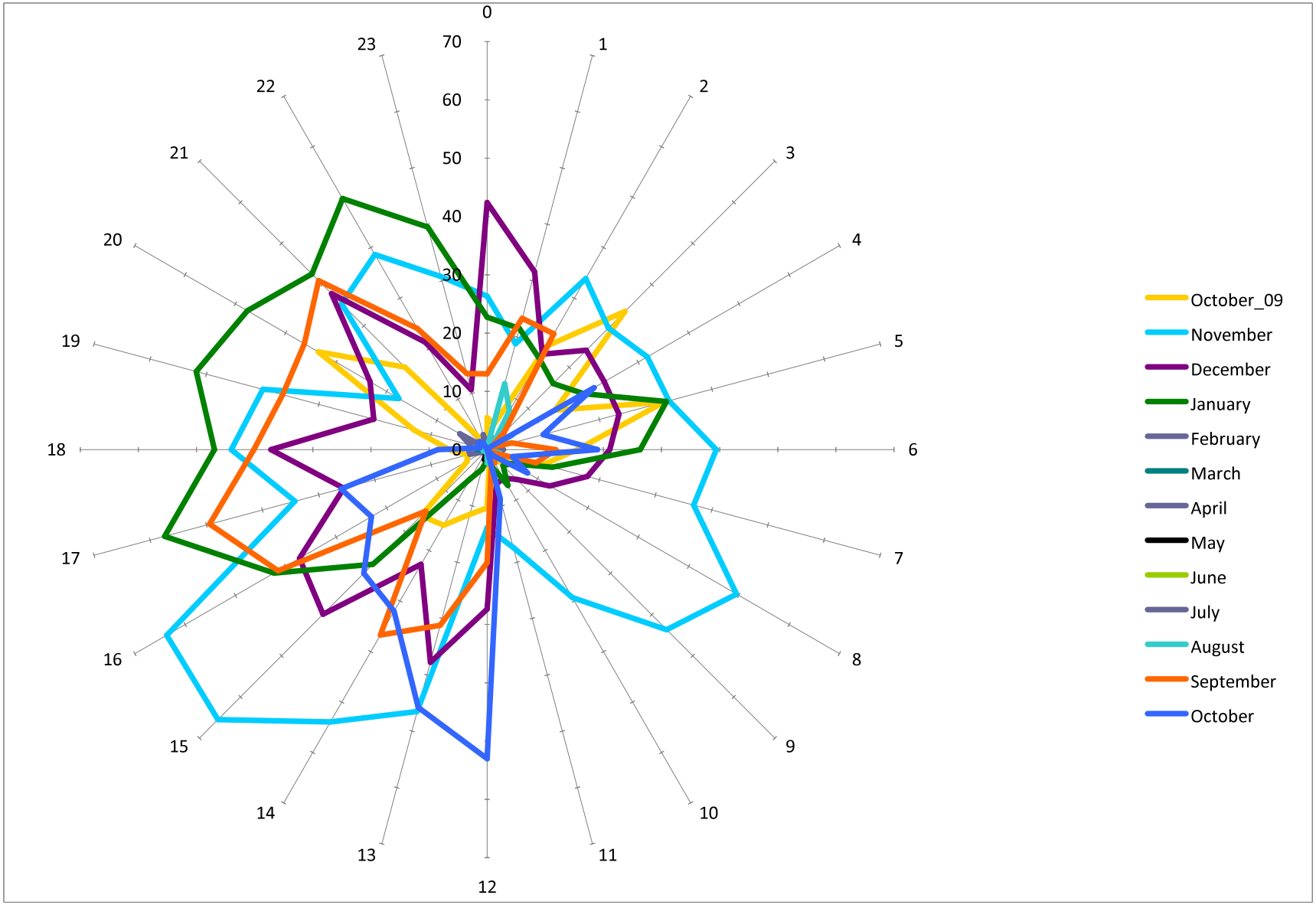

Figure 14. Hourly upcall rate averaged by month. The axes represent a 24 hour clock.

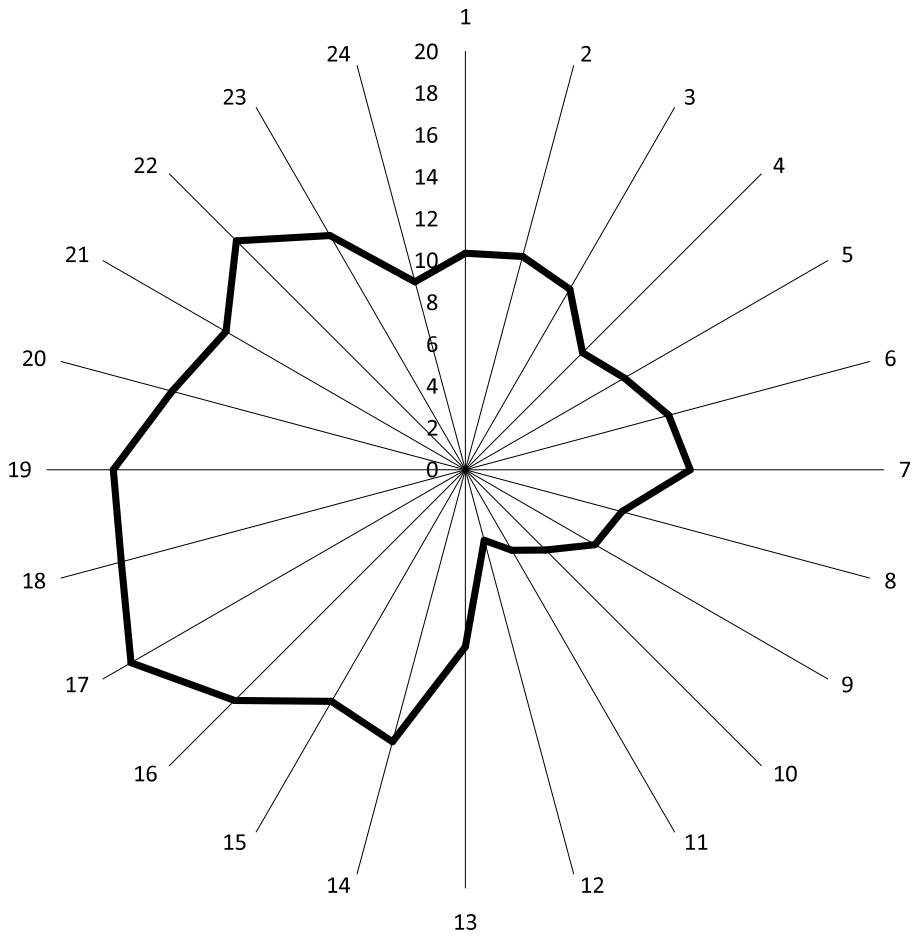

Figure 15. Average hourly upcall rate for the entire recording period. The axes represent a 24 hour clock.

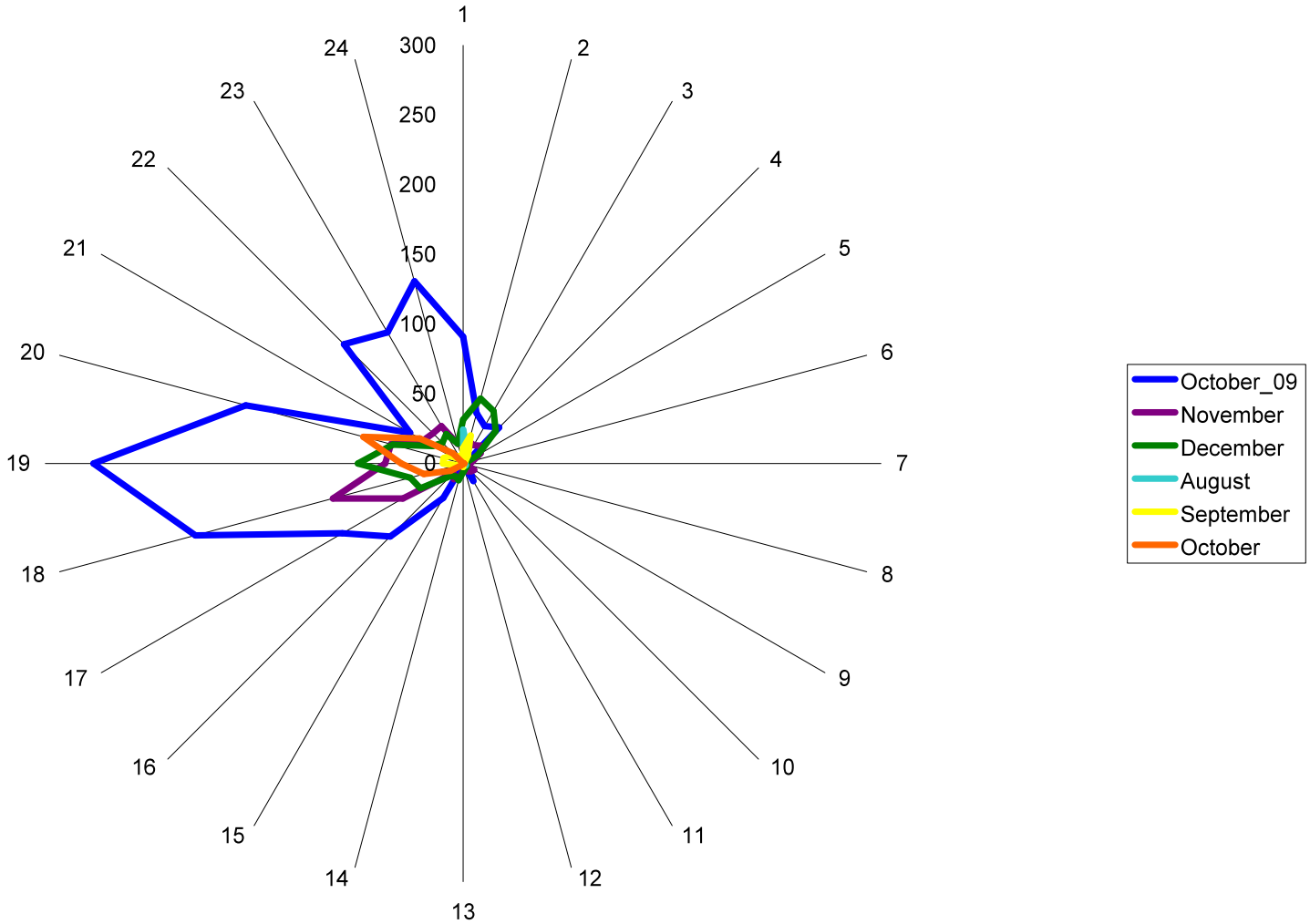

Figure 16. Hourly gunshot rate averaged for months where gunshots occurred. The axes represent a 24 hour clock.

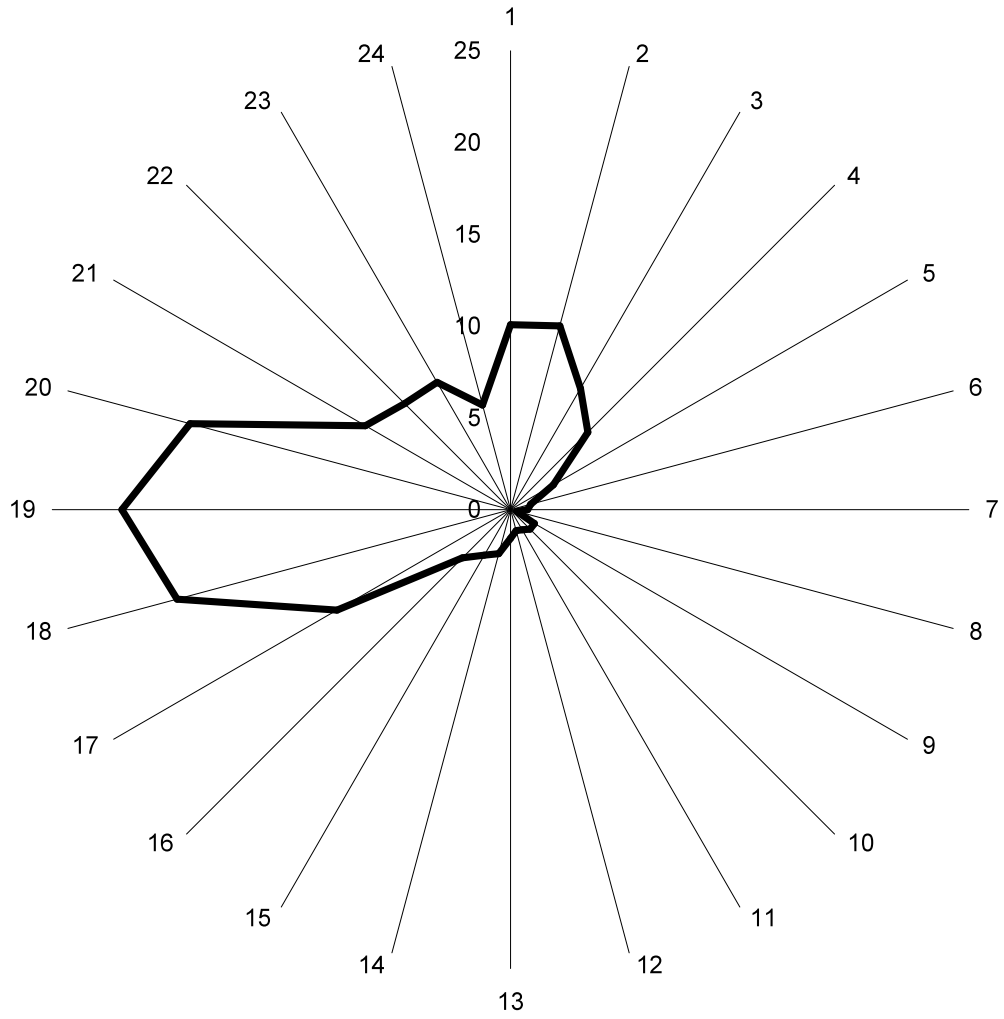

Figure 17. Average hourly gunshot rate for the entire recording period. The axes represent a 24 hour clock.

Call Parameters

The means of all call parameters measured (low frequency, high frequency, center frequency, delta frequency, delta time) for upcalls were significantly different between months with the exception of center frequency (summarized in Table 13). *Post-hoc* analyses using the Bonferroni *post-hoc* criterion indicated that August was significantly different from November and December for Delta Frequency, and was also different from September, November, and December for High Frequency and Low Frequency. September, October, November, and December differed from one another for Low Frequency and Delta Time. When the month of August was removed from the analysis, high frequency was no longer significantly different. However, most of these results, while statistically significant, may not be biologically significant given the low inter-mean differences. For example, the mean differences ranged from .005 to .82 for Delta Time. This shows that the difference in call duration between months would only be a few tenths of a second in most cases, which from a biological standpoint is probably not caused by any substantial change of behavior from the whales. For this reason I binned all calls from the year together to calculate the mean, standard deviation, median, and range for each call parameter (Table 14).

Table 13. ANOVA results for mean call parameters by month. Bold p-values are significant at < 0.05.

	With August			Without August		
Parameter	F	df	p	F	df	p
Delta Time	6.84	6, 73	**≤0.0001**	6.96	5, 59	**≤0.0001**
Low Frequency	5.59	6, 73	**≤0.0001**	3.37	5, 59	**0.0095**
High Frequency	5.01	6, 73	**0.0002**	1.64	5, 59	0.0626
Center Frequency	2.10	6, 73	0.0633	2.19	5, 59	0.0671
Delta Frequency	4.32	6, 73	**0.0009**	2.71	5, 59	**0.0283**

Table 14. Call parameters for upcalls and gunshots. Approximately 15 of the highest quality calls per month were chosen for analysis.

Call Type	*n*		Low Freq (Hz)	High Freq (Hz)	Center Freq (Hz)	Delta Time (s)	Delta Freq (Hz)
Upcall	80	Mean	80.92	243.43	133.30	1.62	162.50
		SD	18.10	58.76	22.3	0.44	58.48
		Median	82.4	232.6	128.9	1.5705	153.85
		Range	29.6-117.9	146.9-412.9	93.8-195.3	0.96-3.549	50-320.4
Gunshot	94	Mean	13.42	996.15	159.32	1.46	982.73
		SD	10.27	6.26	116.62	0.35	12.96
		Median	13.85	998.2	140.6	1.45	984.25
		Range	0-49.5	957.9-1000	7.8-460.9	0.874-2.451	940-1000

Aerial Surveys

Aerial survey data taken from October 2009 to May 2009 was provided by the NOAA Northeast Fisheries Science Center had conducted 7 surveys within the "Jordan Basin" area during the recording period of MARU deployment 2. There was only one survey where no right whales were sighted in the area. Call rate does not increase linearly with the number of whales sighted in the area (Figure 18). In fact, a similar number of calls were recorded on a day when only 1 whale was sighted and on a day when 37 whales were sighted. A chi square showed that you are more likely to hear whales on days where whales were sighted and not when whales are not sighted, $\chi^2=(1\ n = 7)=7$, $p < 0.01$.

All right whales sighted during the aerial surveys that were flown while MARU deployment 2 was recording were mapped along with the MARU location and a 10nm buffer to better visualize which sightings would have fallen into the estimated recording range. (Figure 19)

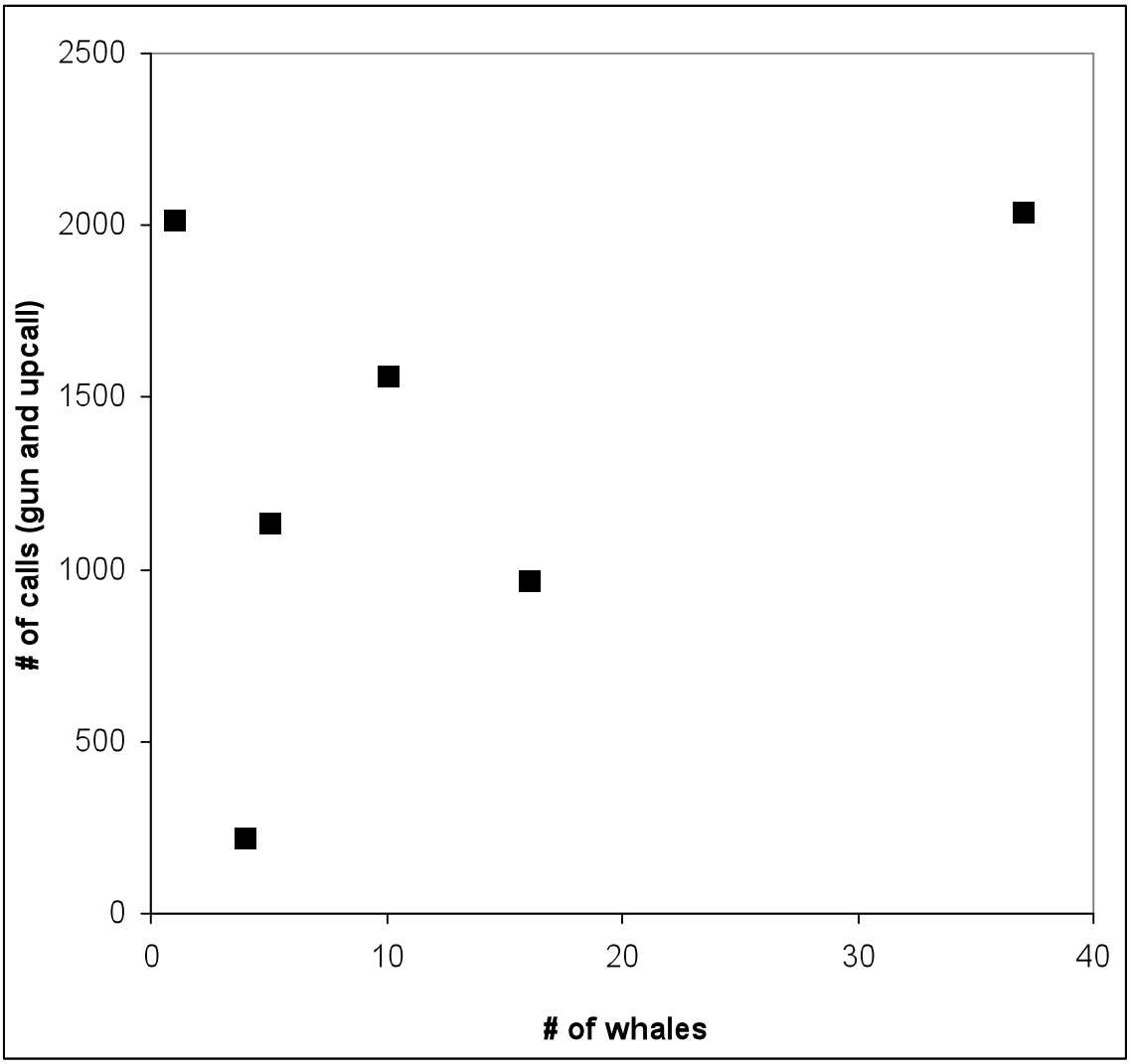

Figure 18. Scatter plot of number of whales sighted during surveys against number of calls detected on that day.

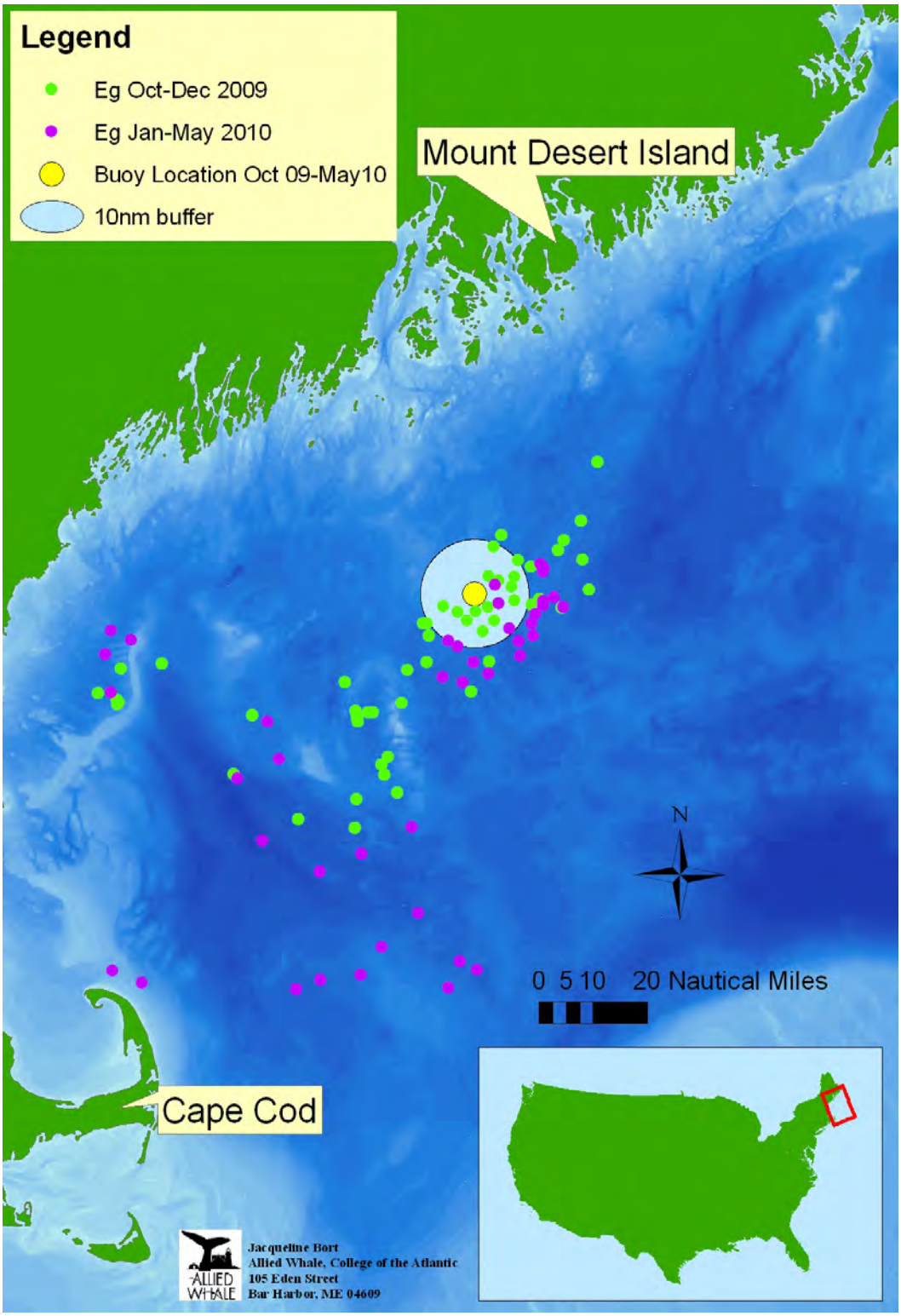

Figure 19. Aerial Survey Data N of 42° provided by NOAA NEFSC for October 2009 to May 2010. MARU from deployment #2 is plotted, along with a 10nm buffer zone around the unit.

Social Sounds

These calls were highly variable and numerous within the dataset. I categorized calls in a very general way based on the visual characteristics of the spectrograms. Since these categories were made visually, a more extensive analysis is needed in order to determine subcategories within the categories I determined for this analysis. The variability in these calls suggest that the vocal repertoire of the North Atlantic right whale is not quite as stereotyped as the current literature suggests. Average call parameters are recorded in Table 15.

Grunts

Often upcalls were found in long successions spaced around 4-6 s apart (Figure 20). Within these series, an upcall would sometimes be replaced with another type of call. I categorized one of these replacement calls as a "grunt". Grunts were typically very short, stunted calls ranging from 0.69 seconds to 3.715 s, with an average duration of 1.78 s. Typically these calls were in a low frequency range, averaging between 100-165 Hz. Often when a grunt was produced it would be followed by several more grunts, and then revert back to upcalls. Sometimes once grunts were gradually replaced by "moans", described in the next section.

Moans

Moans (Figure 21) produced by right whales have been described previously in the literature. The frequency range of the moans seen in this dataset is consistent with the findings of Matthews *et al.* (2001), though were still quite variable at times (Figure 23). However, the moans in my dataset differed in duration. The average duration was 3 s.

Moan calls were difficult to distinguish in some cases and may overlap into other categories described here, namely long call and worm calls. In general, moan calls were not as frequency modulated as these other categories and were shorter in duration (Figure 22).

There were many cases where a series of upcalls would be replaced by moans. In some cases, moans would then be followed by much more frequency modulated calls which were often "U" shaped. This was not as frequent so the call parameters of these calls were not measured in this study; however, a spectrogram of these moan-like frequency modulated calls is shown in Figure 24.

Long Calls

Long calls (Figures 26 and 27) are similar to moans, however the duration was usually a lot longer, averaging around 7 s. The longest duration within this call type was 15.16 s. In general these calls were a lot less frequency modulated, though some wavered slightly. I classified calls that were extremely frequency modulated in a separate category.

Worm Calls

These are frequency modulated moans or long calls, affectionately named "worm" calls during analysis due to their visual similarities to an annelid (Figure 25). These were classified separately not only due to their variability in frequency, but were usually slightly longer in duration than other moans at 4.65 seconds, but were shorter in duration from long calls.

High Calls

Higher frequency calls were often observed primarily in November during times when there were frequent upcall and gunshot calls (Figure 28). These were highly variable and almost resembled "singing" in some places. These ranged from 0.597 s to 13.009 s in duration depending on the call. This is a category that needs to be further sub-categorized as this category encompasses many call types that were simply in a higher frequency range than the calls typically made by right whales.

Pre-gunshot Calls

While other higher frequency calls were also observed within this dataset, a downsweep typically in the 350-500 Hz range was often associated with gunshot calls (Figure 29). They were often not seen along with other high frequency calls. Typically these calls were fairly short in duration, averaging 1.65 s.

Table 15. Call parameters for different categories of social sounds.

Call Type	*n*		Low Freq (Hz)	High Freq (Hz)	Center Freq (Hz)	Delta Time (s)	Delta Freq (Hz)
Grunt	335	Mean	104.04	165.63	131.94	1.78	61.59
		SD	19.67	22.52	17.75	0.49	20.006
		Median	104.6	165.1	132.8	1.78	59
		Range	52.6-181.7	111.9-368.1	78.1-195.3	0.69-3.715	25.3-251.5
Moan	745	Mean	105.23	164.68	132.12	3.007	59.45
		SD	19.18	28.15	18.26	1.01	25.20
		Median	105.9	160.6	132.8	2.81	55.7
		Range	45.8-370.6	104.7-518.8	78.1-390.6	1.152-9.619	24.2-420.1
Long call	137	Mean	98.82	181.19	138.79	7.03	82.36
		SD	22.70	45.55	26.56	2.08	45.40
		Median	95	171	132.8	6.901	75.7
		Range	51.4-189.2	130.3-545.2	85.9-226.6	2.26-15.16	37.9-461.37
Worm	179	Mean	119.94	208.79	158.21	4.65	88.84
		SD	28.62	65.62	30.77	1.57	63.56
		Median	116.9	200.4	156.2	4.416	79.8
		Range	50.7-213.1	135-938.2	93.8-234.4	1.83-9.35	32.6-869
Pregun	157	Mean	401.62	516.11	447.90	1.65	114.48
		SD	64.82	76.09	63.60	0.59	56.002
		Median	407.2	509.8	445.3	1.54	103.8
		Range	208.6-605	275.1-845.8	234.4-625	0.88-5.59	41.1-463.1
High	412	Mean	344.98	436.82	387.34	1.64	91.83
		SD	63.81	62.83	61.51	0.76	47.55
		Median	347.85	433.5	382.8	1.54	78.6
		Range	28.4-557.3	132.4-631.9	54.7-585.9	0.59-13.009	27.9-518.4

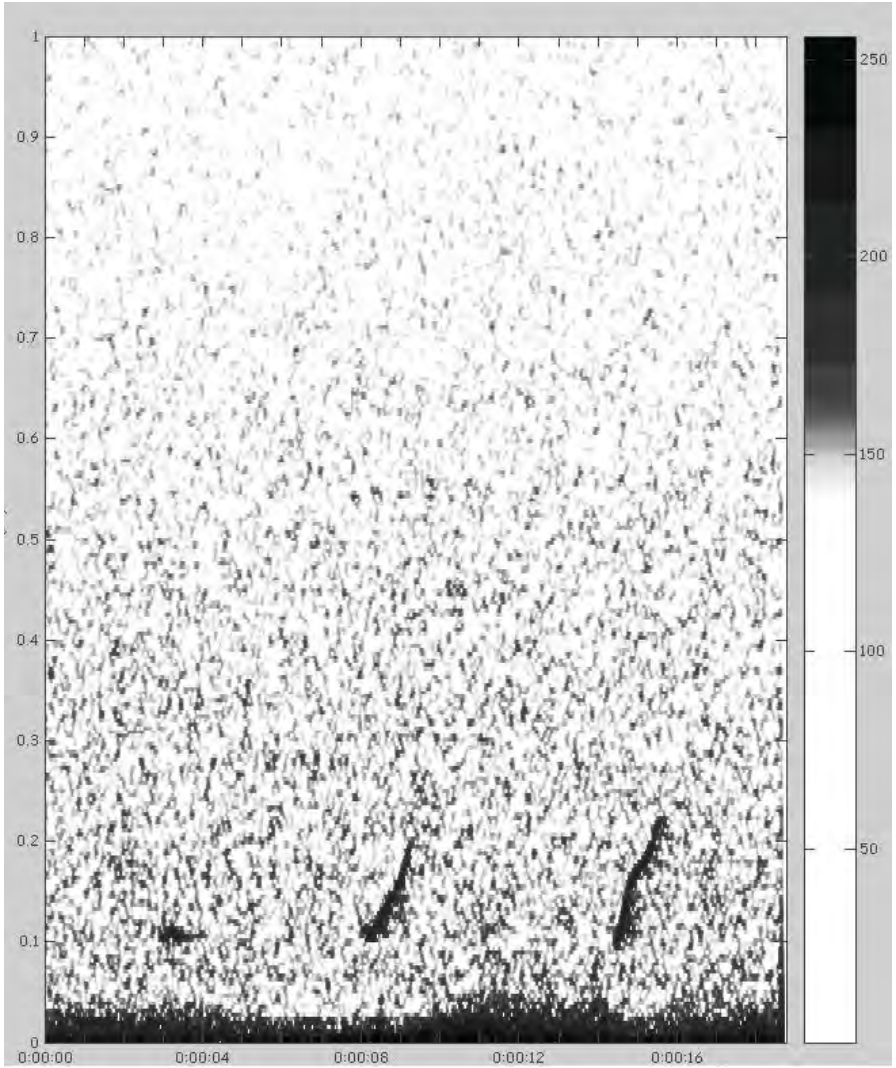

Figure 20. A grunt followed by two upcalls.

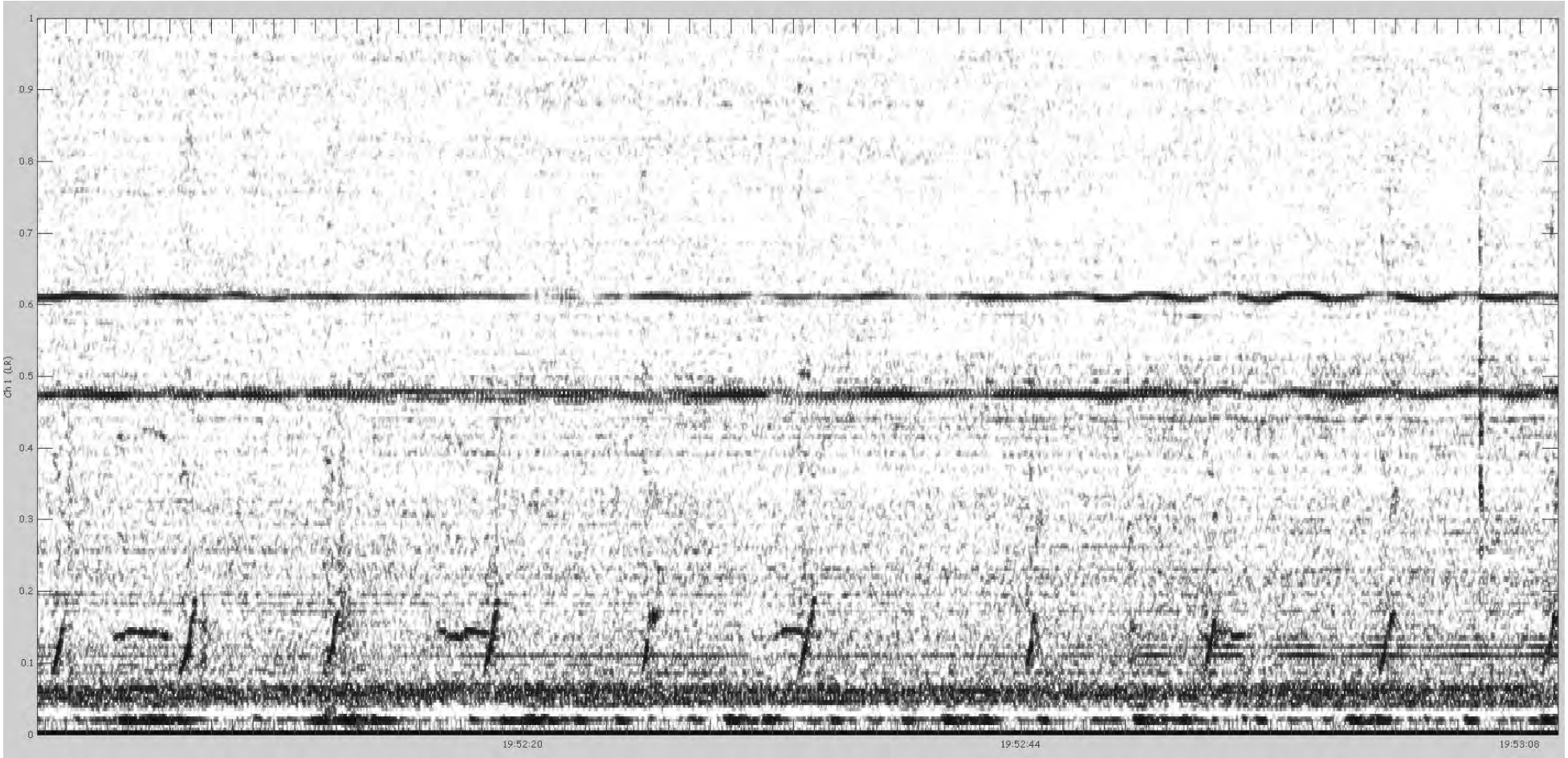

Figure 21. Moans along with a series of upcalls.

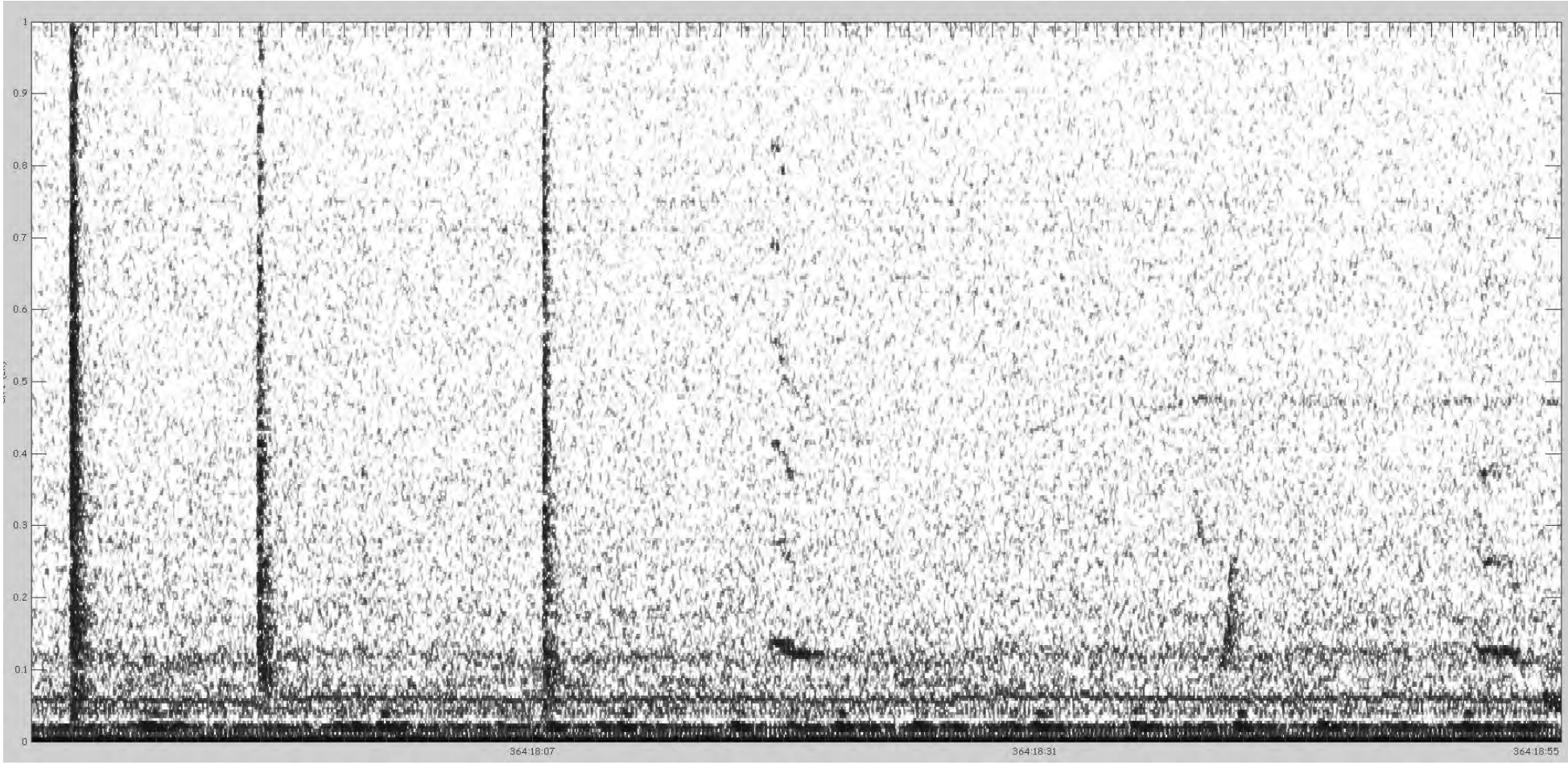

Figure 22. Moans along with other known right whale calls.

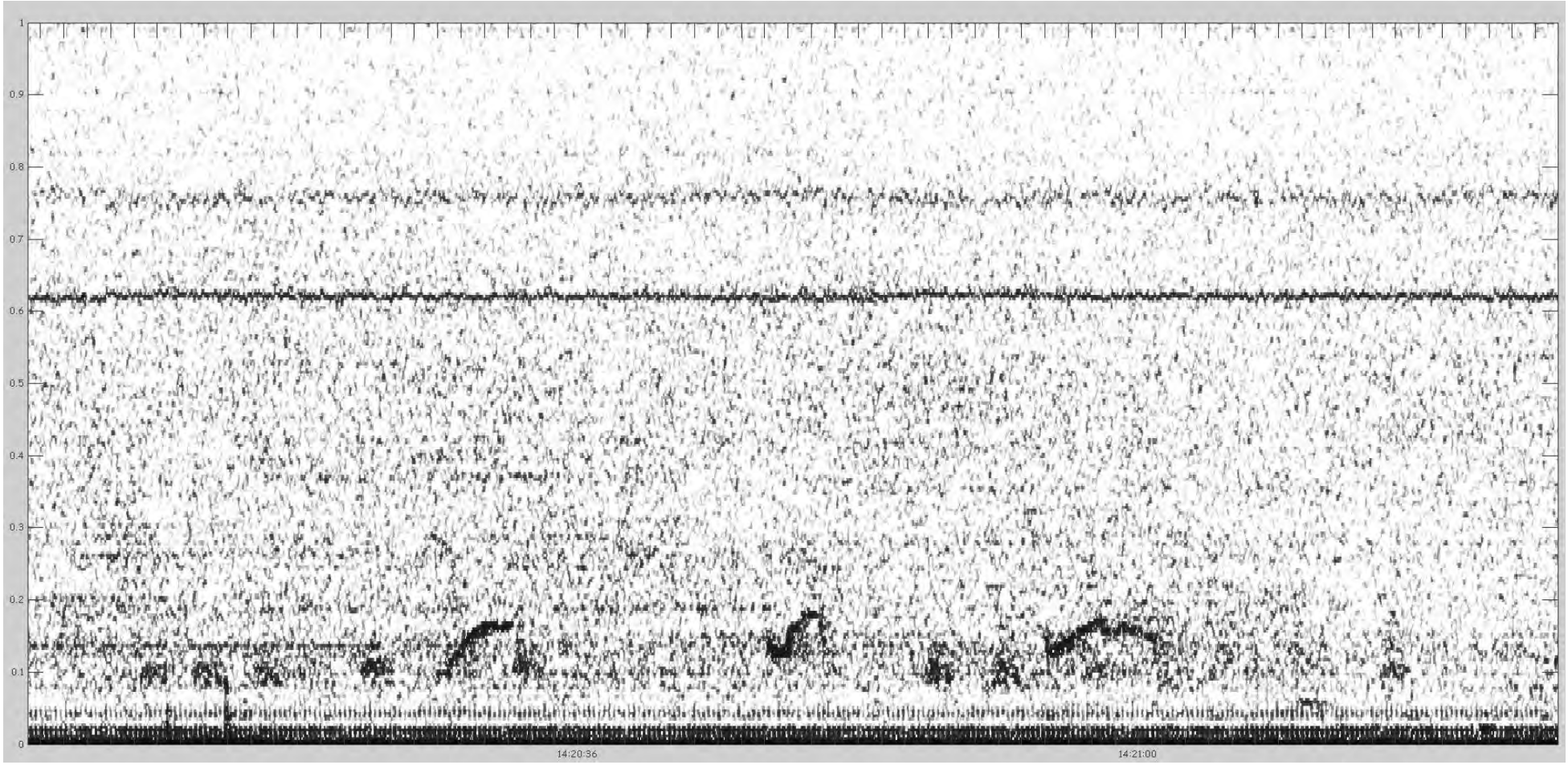

Figure 23. Variability in upcalls and moans.

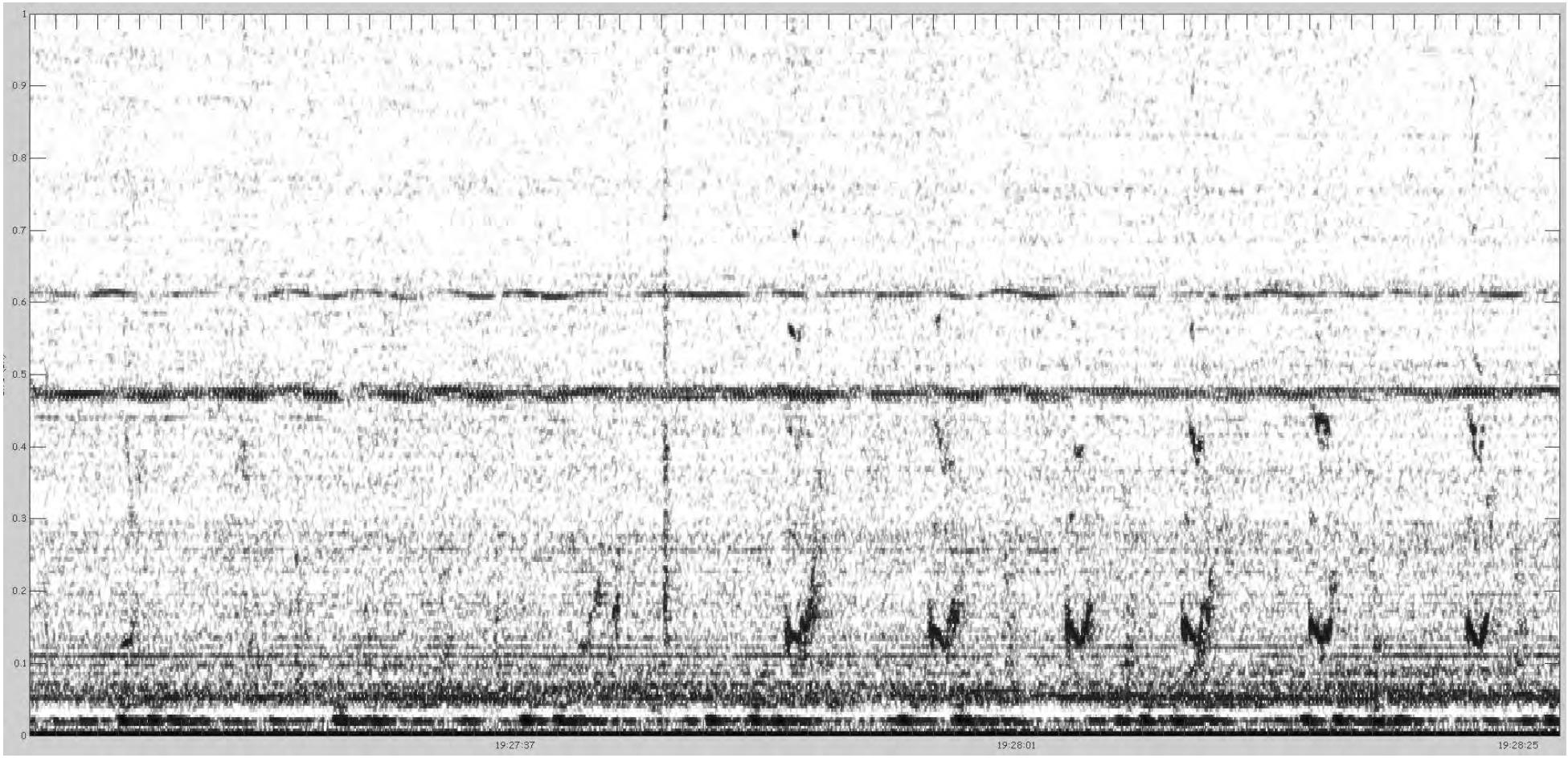

Figure 24. Variable moan sounds. There were many cases where a long series of upcalls would change to a more frequency-modulated call.

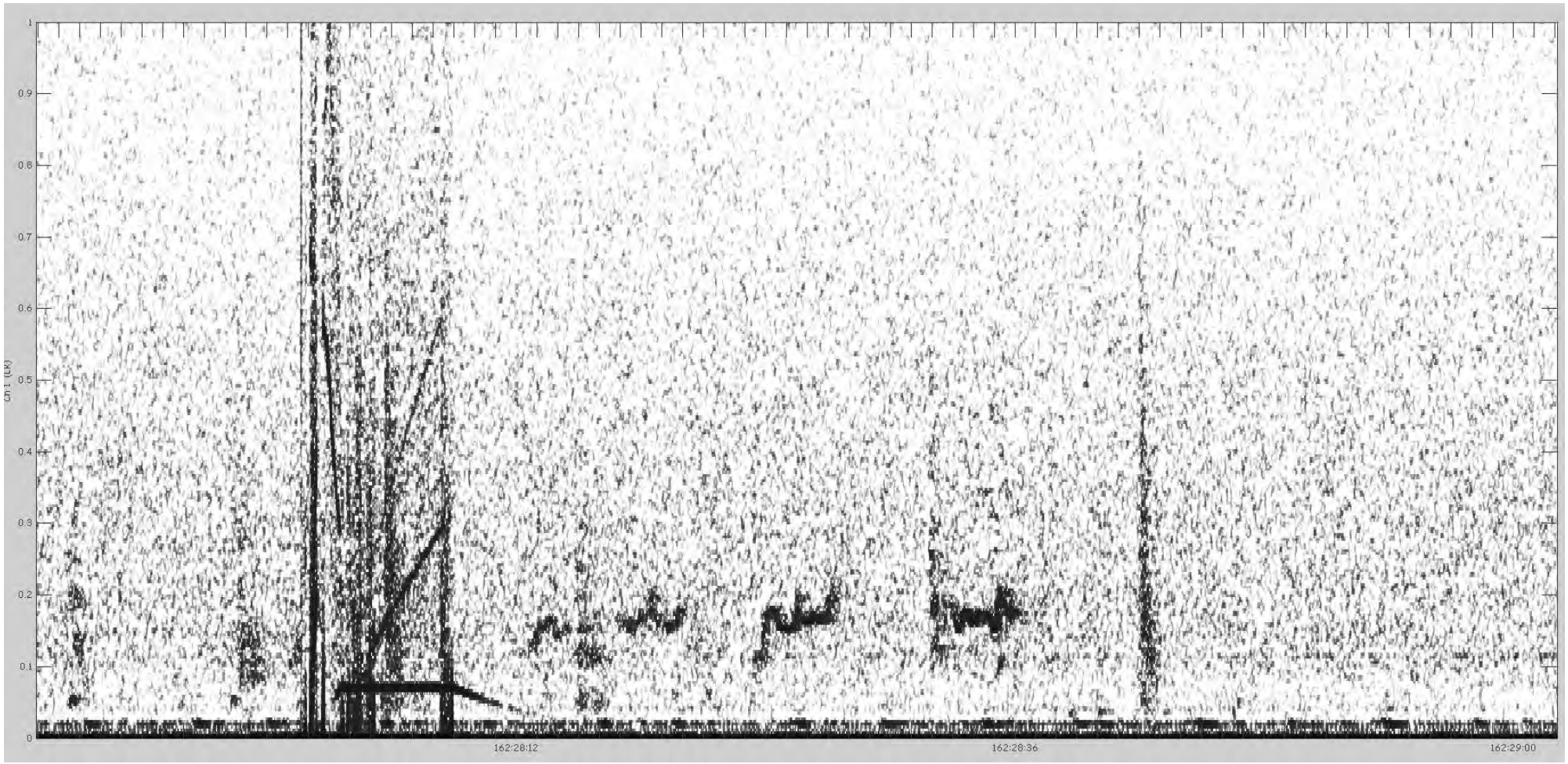

Figure 25. "Worm calls". These are frequency modulated moans usually lasting around 4 seconds.

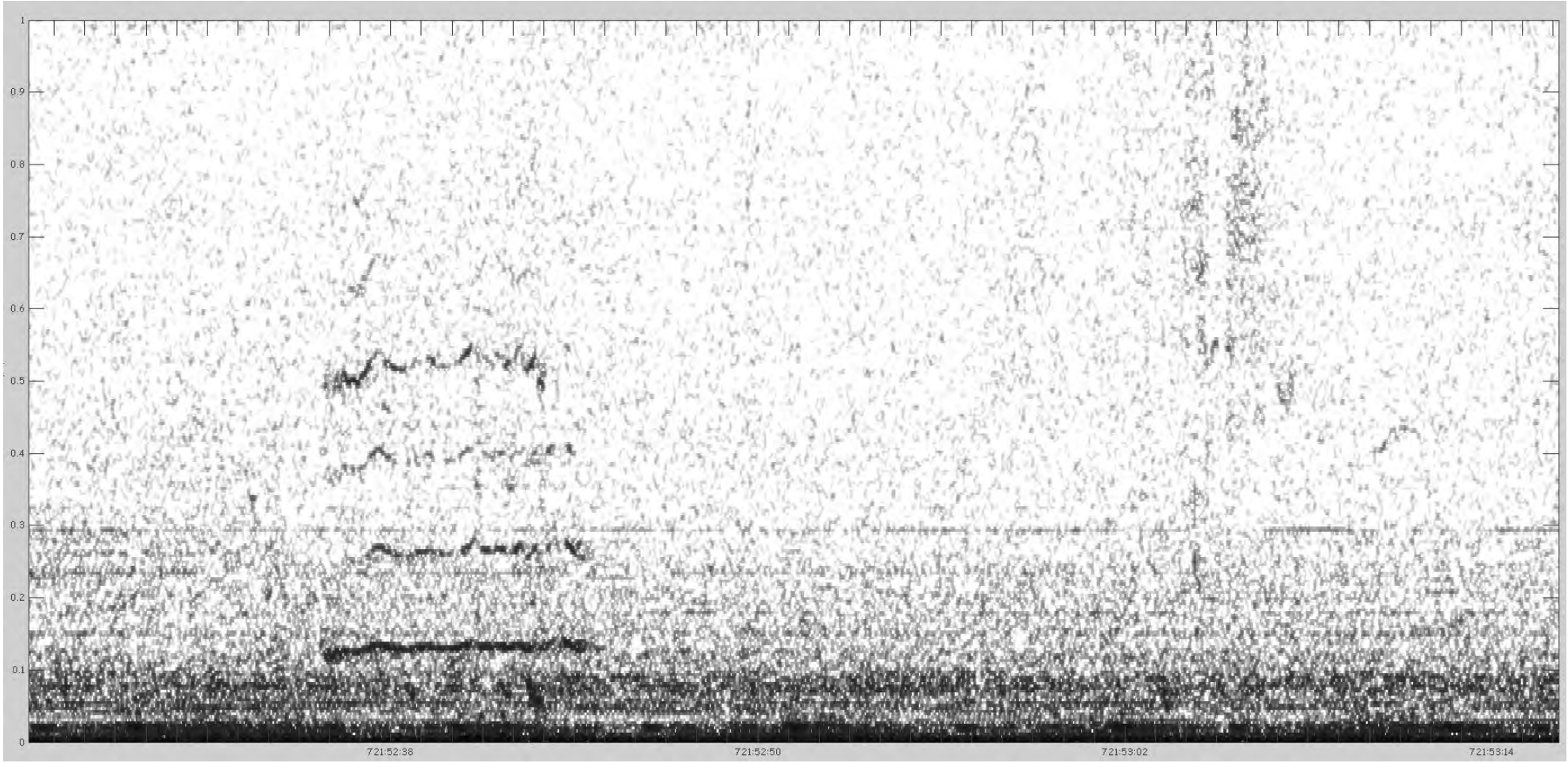

Figure 26. Long call. Usually less frequency modulated when compared to "worm" calls and lasted approximately 8 seconds.

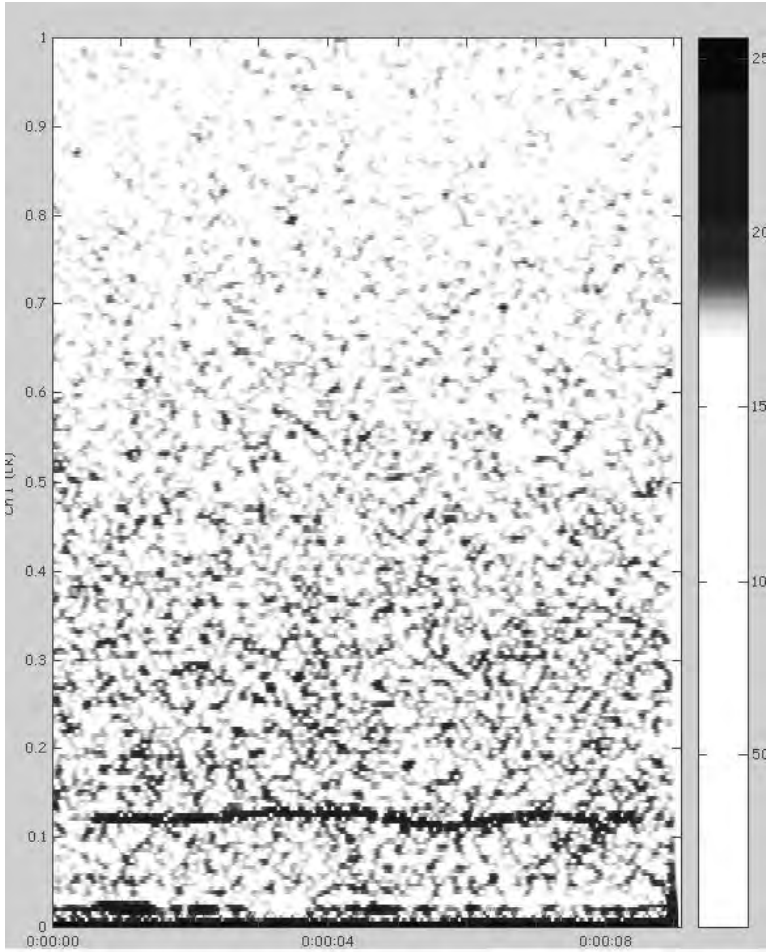

Figure 27. A long call lasting nearly 8 seconds.

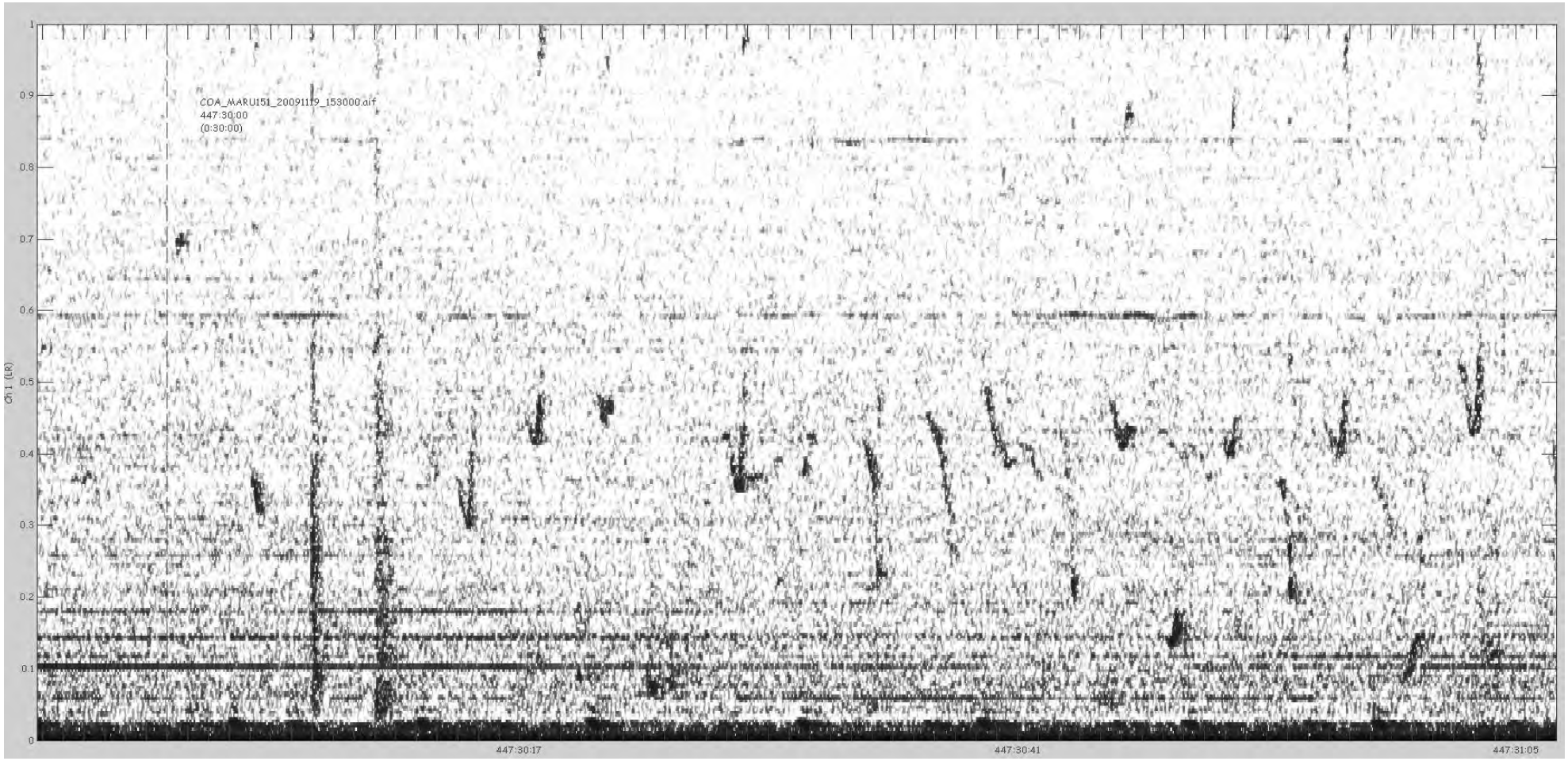

Figure 28. High frequency sounds often associated with other known right whale calls. These calls were inconsistent with humpback whale song observed in the area. The humpback whale song observed in this habitat was uniform and usually contained the same series of calls.

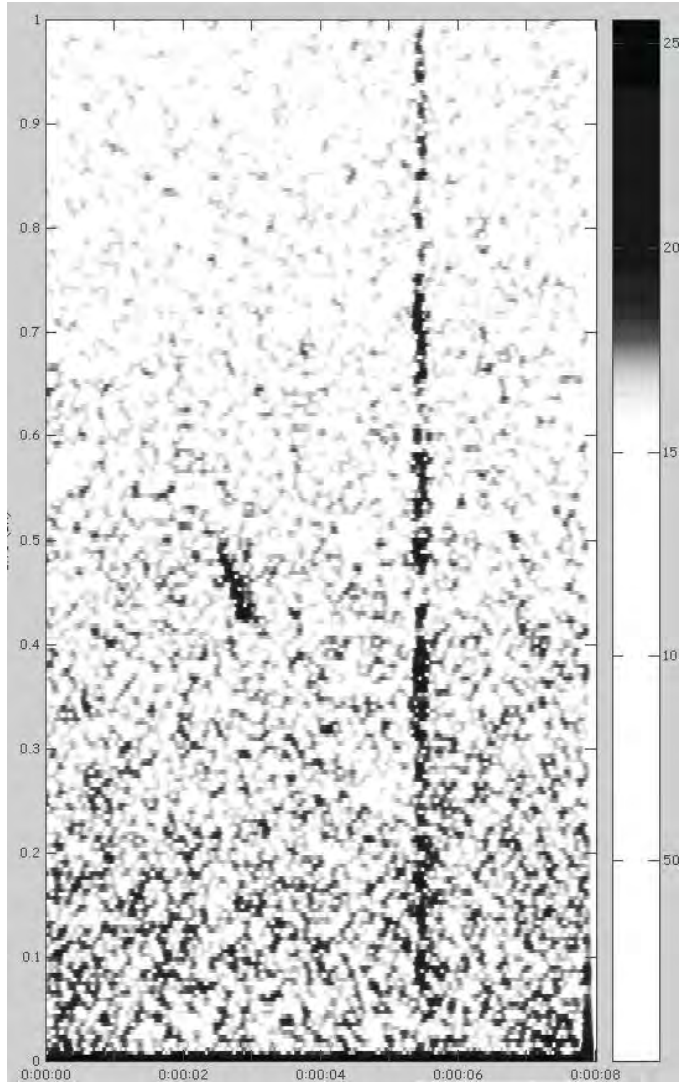

Figure 29. Pre-gunshot call. There were many occurrences of these high frequency calls around 350-500 Hz before or around gunshot calls.

Discussion

The North Atlantic right whale, with a population numbering less than 500 individuals, is monitored closely in U.S. waters in an attempt to reduce negative anthropogenic interactions (NMFS 2005). The winter location of the nonpregnant portion of the North Atlantic right whale was, until very recently, unknown (Kraus *et al*. 1986; Kraus and Rolland 2007). It is now proposed that a particular region of the Gulf of Maine known as Outer Fall may be a wintering ground as well as a potential mating ground (Dawicki 2008). Determining whether this is a mating ground requires visual surveys that are difficult to conduct because of harsh weather conditions during times when right whales are thought to be present. One solution is to use acoustic census techniques. These techniques may be particularly apt since many calls produced by right whales have been correlated to certain behaviors (Clark 1983; Parks and Tyack 2005), and thus it is possible to infer from acoustic data what a whale may be doing when certain types of calls are detected. For example, gunshot calls are strongly associated with mating behavior, and the detection of these types of vocalizations may strengthen evidence that supports this area as a mating ground.

This study utilized passive acoustic monitoring techniques to support the proposal of Outer Fall as a seasonally important habitat for this critically endangered species. Marine autonomous recording units that were anchored to the sea floor recorded right whale calls—including gunshots, upcalls, and other social sounds—during 11 months of the 12-month study. The calls were seasonally distributed, with the majority of calling taking place during the fall and winter months. There was also diel variation in call rates, with the most calls occurring from 1400 hrs to 2300 hrs. The call parameters for this

study were within range of the call parameters measured in similar studies using similar recording methods. Aerial surveys were not run often enough in the area to accurately measure if the frequency of sightings correlates with the call rates of either of the measured call types. Social sounds are highly variable and require further analysis.

False Negative and False Positive Rates

The false negative rates for ISRAT in other studies (7-19%) were much lower (Urazghildiiev *et al.* 2009, Mussoline *et al.* In review.) than the rates determined within this study (mean = 29%, SD = 31.69). Both of these studies tested the detector using about a month's worth of data, whereas I calculated the rate for my entire dataset (*n* = 108 days). Perhaps most notable was the unusual range in false negative rates over the span of this study, ranging from 0 to 100. The study period included days where calls ranged from a few hundred to over 2,000. In some months there was also a high rate of boat traffic throughout the area; this added to the variability of the detection rate.

Even though false positive rates were also calculated, essentially false positives were reduced to a minimum in the final dataset by the process of hand-browsing. While care was taken to eliminate error in the data, it is possible that some of the sounds attributed to right whales in this data were actually made by humpback whales; however, this error is probably minimal based on the conservative approach taken when known humpback whale calls were detected. The temporal coincidence and similarity in measured parameters between humpback and right whale upcalls lead to the intriguing possibility of call mimicry, although this hypothesis needs far more data to substantiate such interspecific interactions.

Call Seasonality

Right whale call rates were highest in fall and winter months. Although the dataset was sub-sampled every three days, right whale calls were present in every day analyzed between October 30, 2009 and February 8, 2010, and again from August 27, 2010 to October 11, 2010. We estimate that the recording range of a MARU is approximately 8-10 nm based on various other reports (Clark and Clapham 2004; Clark *et al.* 2010). Since whales were detected in every day analyzed within a nearly 4-month dataset, it is likely that a considerable number of whales are congregating specifically in this area. Furthermore, visual data (Khan 2010, 2011) suggest substantial numbers of sightings beyond the acoustic range of the MARU. Considered together, this region clearly has importance to this species. Upcalls were highest in November, remaining high in December and January, and decreasing into April. Whales were not detected in May, but were detected in July, and the number of calls increased into October. This suggests that this habitat is seasonally important to the species.

Gunshot calls are most closely associated with social and/or mating behavior. Gunshot calls were detected most frequently in November and December, but dropped off in February. Gunshots were not detected at all in March or April, although right whale upcalls are still present. The rate of gunshots during winter months in Outer Fall supports the theory that mating behavior may be taking place in this region at that time. Right whales are thought to have a one-year gestation period, and calves are typically born around December and January in southern waters. If the current estimated gestation period is correct, than mating behavior observed in winter months should be leading to

impregnation. It also supports the gunshot as a seasonally important call for the detection of right whales.

Diel Patterns

The hour of call activity may facilitate an understanding of how a whale might behave throughout the day; this could be important when developing policy for the area. These data show that right whales tend to be more acoustically active late in the day. There is a clear association between vocal activity and physical activity (Clark 1983). A ship in transit may be more likely to notice whales in the area during times when whales are probably going to be active, especially at the surface. Whales that are not calling are most likely engaged in behavior that could make them more susceptible to ship strike. For example, a logging or resting whale is likely to be lying motionless at or near the surface, and its reaction time may be slowed. Similarly, a feeding whale is most likely at or near the surface. To protect the whales, shipping traffic should either be routed around this area entirely, or be required to have extra observers on watch at times of high use by right whales.

Other Species Detected in the Area

While this study did not focus on any species besides the North Atlantic right whale, other species were acoustically detected on a regular basis while hand-browsing the data. The presence of these other species suggests that this area may be important for more species than just the North Atlantic right whale. Other species detected include fin, sei (*B. borealis*) (Baumgartner *et al.* 2008) (Figure 30), and humpback whales.

Humpback whale vocalizations included singing (Payne and McVay 1971) from November through December (Figure 31). Although no concrete analysis of these other calls is provided here, studies utilizing this dataset are being planned to further investigate the calls of other species. These studies include a comparison of humpback whale song on northern winter migration stops such as Outer Fall to southern stop offs such as Bermuda, as well as a comparison of sei whale vocalization rates to that of right whales. If sei and right whales are congregating in the same areas, it is possible they are relying on this habitat for food resources since both species feed on copepods.

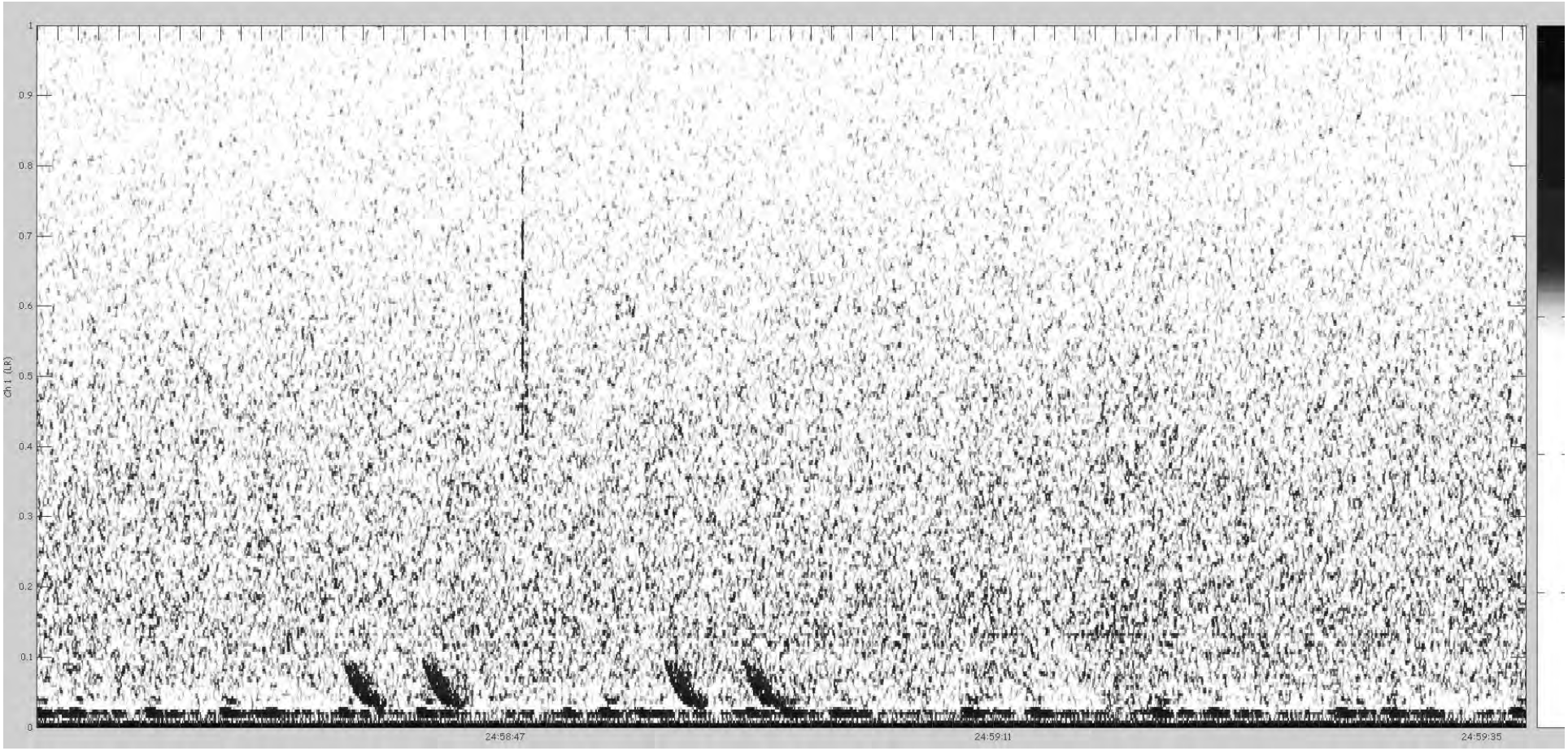

Figure 30. Spectrogram of sei and fin whale vocalizations. Time is in h:min:sec on the x-axis, frequency is in kHz on the y-axis. Amplitude is in grey-scale. This was generated in XBAT using a Hann window, 512-point FFT, 25% overlap, and a window length of 73.19 s.

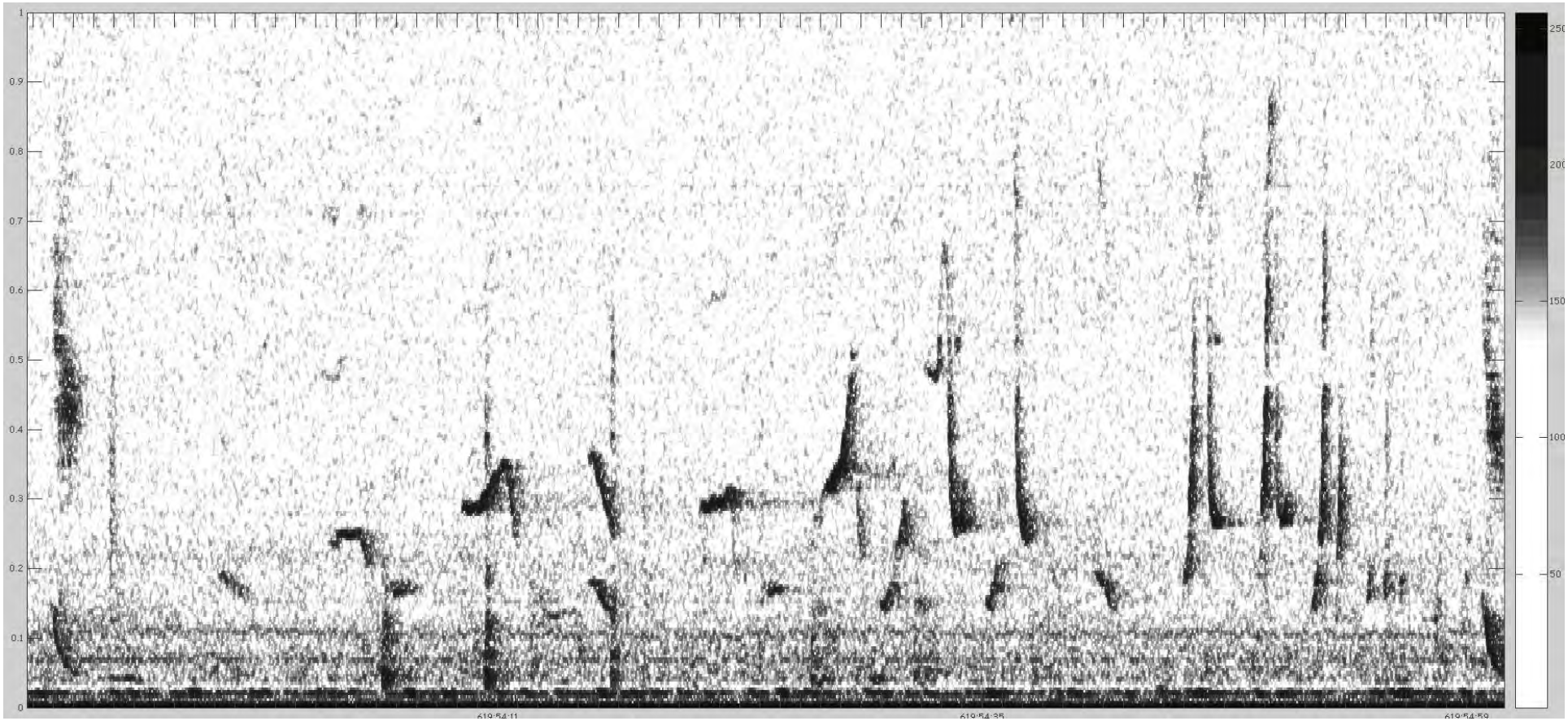

Figure 31. Spectrogram of detected humpback whale song. Time is in h:min:sec on the x-axis, frequency is in kHz on the y-axis. Amplitude is in grey-scale. This was generated in XBAT using a Hann window, 512-point FFT, 25% overlap, and a window length of 73.19s.

Call Parameters

Call parameters averaged throughout the study period are comparable to call parameters recorded with similar equipment in other areas. Parks *et al*. (2009) reported ranges for 3 upcall parameters: delta time (duration), minimum frequency, and maximum frequency. These were recorded on MARU units deployed in three known right whale habitats. While Parks *et al.* (2009) suggested that call parameters change depending on the peak frequency of the ambient noise in a particular area, the means for the upcall parameters measured in my study fall within these ranges. It is likely that upcalls also change depending on ambient noise levels in my study area; however, this is not reflected in my study since only high quality calls with little ambient noise were selected for measurement. Ambient noise was measured visually based on spectrogram qualities but not on any mathematical equation; thus, it is possible that the ambient noise level varied slightly between these calls.

Social Sounds

While I can attribute a social sound to a right whale with some degree of confidence, it is possible that some of these sounds were actually produced by humpback whales. The lack of visual data and the inability to localize calls prevents me from explicitly designating these calls as those of right whales. However these sounds were usually closely associated with other known right whale calls and frequently observed when no other confirmed humpback whale sounds were produced. The majority of humpback whale calls occurred during November and December, and they were often contained within sequences of singing behavior. The high frequency calls I attributed to

right whale were inconsistent with the humpback whale song observed within this dataset, and were often detected along with known right whale calls. These high frequency sounds, including the pre-gunshot call, may be similar to scream calls; however, the call parameters and spectrograms differ from what is currently published in the literature (Parks and Tyack 2005). This could be attributed to the recording method, since previous studies have placed hydrophones directly next to surface active whales, whereas the MARU units were located at an unknown range to any one calling animal. Higher frequency aspects of calls would have experienced an especially high degree of transmission loss before reaching the MARU unit unless the whale was very close to the unit while calling.

These calls may not have been previously described in detail, especially if they have a reproductive function and are only associated with reproductive behavior. Many SAGs are not reproductive in function and can occur in habitats not normally used for breeding (Parks *et al*. 2007). Should the central Gulf of Maine area prove to be the main mating ground for this species, it is possible that there is a repertoire of calls only associated with this area. Further analysis is required to determine if these calls differ from calls observed in other areas.

These social sounds are intriguing and should be analyzed further to more accurately categorize calls based on the variability in frequency modulation within these categories. However, until visual observations can be directly correlated with acoustic data for these calls, these calls may not be directly attributed to right whales.

Comparison to Adjacent Habitats

The findings of this study are particularly interesting when compared to studies done in other regions known to be important to right whales. A 13-month study of two locations on the Scotian Shelf was conducted in 2004-2005 (Mellinger *et al.* 2007); this study had the highest call rate during the months of August through October, with sporadic calls in December. Mellinger *et al.* (2007) described the detection of calls so late in the year as "surprising," since right whales were thought to leave this area in fall. These data show that some whales either stay in this area longer, or possibly transit from Gulf of Maine habitats into the Scotian Shelf habitats periodically during winter months.

A similar long-term study was conducted using MARUs on Jeffery's Ledge and Stellwagen Bank National Marine Sanctuary (hereon referred to as Stellwagen Bank) (Mussoline *et al.* In review.). Upcalls were examined over a 7-month period in 2004/2005 at Jeffery's Ledge at 2-4 locations spread 9-13 nm apart, and a over 13-month period in 2006/2007 at Stellwagen Bank at 6-9 locations spread 8 nm apart. Upcalls at Jeffery's Ledge were highest in November, and remained high through March, decreasing during March through May. Upcalls were highest in Stellwagen Bank in January, February, and March with a peak in April. Upcalls then decreased in May with none detected in July and August, and fewer upcalls were observed from September-December. The findings for the Outer Fall region are similar to those at Jeffery's Ledge in terms of seasonality, but differ in terms of total calls detected. More upcalls were detected at Outer Fall in November 2009 (n = 8,719) using a single MARU than on Jeffery's Ledge (n = 2,447) using multiple buoys (and therefore a more extensive range). The findings for the Outer Fall region match up well with the findings from Stellwagen Bank when viewed as

adjacent habitats with separate uses throughout the year. Call rates between these habitats seem to mirror known right whale migration patterns.

These findings suggest that whales spend time feeding at Stellwagen Bank with peak use in April, then move to the Bay of Fundy for late summer and fall. While some adults head south for calving grounds in Florida and Georgia (Krauss 1990, Brown *et al*. 2001), a significant number of nonpregnant whales move from Bay of Fundy to Outer Fall beginning in September and remain in the Outer Fall area throughout the winter, sometimes spreading out into adjacent habitats such as Jeffery's Ledge. Jeffrey's Ledge is approximately 60 nm away from the Outer Fall region but within a day's journey at the speed right whales are known to travel (Watkins and Schevill 1979, Mate *et al.* 1997). Whales were also seen in high numbers on Cashes Ledge in winter of 2010 (Cole, pers. comm.[7]), so the winter habitat may encompass all surrounding habitats but center in the Outer Fall region. Further aerial surveys may confirm this. However, it should be noted that our current knowledge of winter habitat use by right whales in the Gulf of Maine comes from a variety of studies conducted between two and four years apart, so shifts in right whale distribution may have other causes, including changes in oceanographic conditions, prey abundance, and prey distribution.

June is not represented in either of the Gulf of Maine studies. This is due to logistical complications during the Outer Fall study, and the high rate of bottom trawl fishing in Stellwagen Bank and Jeffery's Ledge (Mussoline *et al*. In review.). It would be useful to collect data for this period to gain a complete understanding of year-round right

[7] Tim Cole, NOAA National Marine Fisheries Service Northeast Fisheries Science Center
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whale habitat use. It would also be interesting to compare my findings to the Scotian Shelf study, since the earliest calls detected in that habitat were in June. However, the only means of compensating for an inability to deploy acoustic gear due to fishing activity is through visual surveys, which may not be cost-effective if few whales are seen in the Gulf of Maine during those times.

Aerial Surveys

Although aerial surveys are flown on a regular basis over areas of the Gulf of Maine known to be important habitats for right whales, the acoustic range for my study encompassed too small an area to infer many results when compared to aerial survey data. There were too few days where surveys passed over the acoustic range of my buoy (n = 7). Results from chi-square analysis on this data suggest that a whale will always be detected acoustically if detected visually, and similarly that when no vocalizations are detected there will also be no whales detected visually. Realistically, this is most likely not the case and is a result of the small sample size in this comparison. A study by Clark *et al*. (2010) showed that whales could be detected acoustically much more frequently than they were sighted visually during aerial surveys. Whales were spotted by aerial surveys on 26 of 42 days in the analysis; however, whales were detected acoustically on all 42 days. Clark *et al.* (2010) offers a much more reliable estimate of the reliability of visual and acoustic survey techniques since it sampled different years and took into account sea conditions and other factors affecting visual sightings.

Additional Recommendations

Continued Long-Term Monitoring

While the data in this study are consistent with findings from aerial surveys, as well as acoustic data from other regions, the data still only represent one year of study. It is important to continue to monitor this habitat to verify that the seasonal use described in this study does not fluctuate. It would be useful in subsequent studies to deploy several buoys in the area over a greater distance to determine spatial distribution within the habitat. Having buoys within an array in order to localize particular calls would also aid in comparing acoustic and aerial survey data. A study set up in this way may be able to directly attribute the observed social activity found in visual surveys with acoustic data; such a study will further our understanding of how these calls are used as well as support the idea that Outer Fall and the greater central Gulf of Maine is a winter mating ground.

During the 2010 winter season, three boat-based surveys led by the New England Aquarium were run in the Outer Fall region. Future boat-based surveys could also be set up so that they travel within acoustic range of a deployed MARU array to aid in characterizing calls and attributing calls to specific behaviors. One of the goals of the vessel surveys was to collect fecal samples to test for hormone levels, another indicator of potential sexual behavior. These surveys should continue until these samples are obtained. Focal follows of animals within range of MARUs could determine if there are significant behavioral differences between whales in this and other habitats. A hydrophone array could be deployed off the vessel for comparison and confirmation that the MARU is detecting the same whale that the visual surveys are observing.

My data also detected a high level of shipping noise that often made detections of whale calls difficult. Measuring of the amount of shipping traffic through the area, time spent in the area, and the impacts of acoustic pollution by this traffic can be inferred from the Outer Fall data and should be examined in a future study.

Aerial Surveys

This study notes that vocalization rates, and therefore presumably right whale presence on Outer Fall, increases beginning in August. However, aerial surveys are not typically flown in this region until October (Khan 2010, 2011). One recommendation for NOAA that can be supported by this study is to conduct aerial surveys beginning in late August to better match the acoustic detection of these animals in the Outer Fall region. Although call rates varied during these months, call rates on some days were high enough to suspect that more than one whale was in the area. If three or more whales are sighted within ~5 nm zone, an area with a radius of 15 nm away from where the whales were sighted can be deemed a DMA.

Mitigations with the Fishing Industry

Long-term monitoring of habitats important to endangered marine mammals is required by the MMPA and the ESA in order to determine potential impacts of human activity within the habitat. This study shows that the offshore areas of the Gulf of Maine should be considered important seasonal habitat for right whales—specifically in fall and winter months. But this is precisely the time that offshore pot/trap fisheries move offshore. There are several areas within this habitat that are already closed to

groundfishing either seasonally or year-round (50 CFR 648.81). Further closures to the area to pot/trap fisheries could be put in place; however, according to the data collected in this study, the wintering ground of North Atlantic right whales could extend to the entire central area of the Gulf of Maine. Mitigating closures on such a wide scale would be extremely contentious given the other changes that have been made to this fishery within recent years. A better solution may be to limit the number of vertical lines allowed in the area—either by limiting the total number of traps allowed in the area or requiring that more traps be set together. As a compromise, the inshore exemption zone to the broadband gear modifications could be extended to encompass all state waters in Maine, where few right whales are sighted. Further studies on whale-safe lobster gear that is also safe for fishermen to work with are also necessary—one study that seems promising is a Time Tension Line Cutter for vertical lines (Baldwin and Pickett 2009, NOAA Contract NA08NMF4270419), which has already undergone a pilot study.

My study did not concurrently document the specific fishing effort in this area by either the private or commercial lobster industry. It is possible that few fishermen utilize the area in question, and that protections given to this area would have a minimal effect on the industry. The current impact by the lobster fishing industry on the area may already be relatively small and policy changes might not be needed. Data on fishing effort in this area should be integrated with data from this study in order to determine the impact of pot/trap fisheries on the Outer Fall region.

I believe that government and science participation in events such as the Maine Fishermen's Forum are important to strengthen the relationship between all parties involved in right whale conservation. It would be beneficial to all parties if more

scientists and conservationists were invited to attend or speak at such events, and perhaps be given a session to outline the fundamentals of right whale biology, life history, and mortality data. From my experience at such events, as well as interviews locally with fishermen, it seems that fishermen are interested in conservation as long as it is based on good science. However, since fishermen are often not fully aware of all the research on which policy decisions are based, it is important that all parties are communicating and working with the same knowledge in order to make effective changes to right whale policy.

Further Seasonal Protection from Shipping

The protection afforded to right whales by DMAs is not adequate for an area such as Outer Fall where whales are sighted consistently during winter months. The area often receives DMA protection, and consistently requires the protection to be extended beyond the initial 15 days. I believe that changing the central Gulf of Maine to an SMA during winter months is more appropriate considering the high densities of whales in this area. This would mean that speed restrictions would be mandatory in the Outer Fall region. Speed restrictions set in place by an Outer Fall SMA would not overlap with the largest current SMA within the region (Figure 32) in location or duration. Although the protection afforded by SMAs is still fairly weak, it would be impossible to restrict all shipping traffic through the Gulf of Maine over several months. Amending the ruling to include mandates for increased observers during times when right whales are known to be present may help to compensate for this weakness.

According to Mahaffey (2006), three major shipping routes pass through the Outer Fall area. The data used by Mahaffey (2006) to plot vessels transiting the Gulf of Maine were originally collected by the Army Corps of Engineers Navigation Data Center. Mahaffey (2006) determined seasonal shipping densities in the Gulf of Maine using GIS techniques and a cell resolution of 5x5 nm When the aerial survey data used in my study are overlaid with this map, it is clear that Outer Fall requires mitigation during times of high use by right whales and ships (Figure 33). Further studies to determine how many vessels pass through this area during times of high right whale use are still needed to assess the probability of a ship strike.

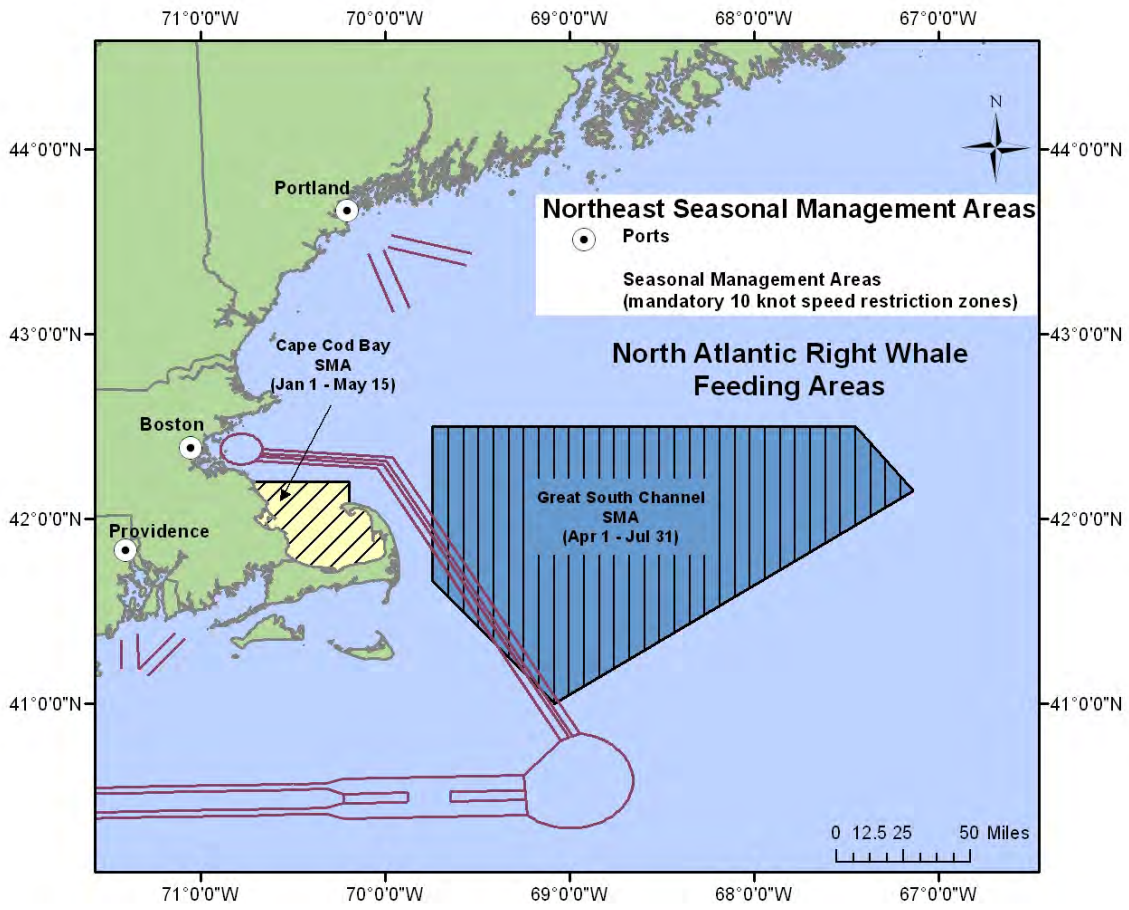

Figure 32. Northeast SMAs. Image taken from NOAA Fisheries Office of Protected Resources Ship Strike Reduction Page.

http://www.nmfs.noaa.gov/pr/shipstrike/

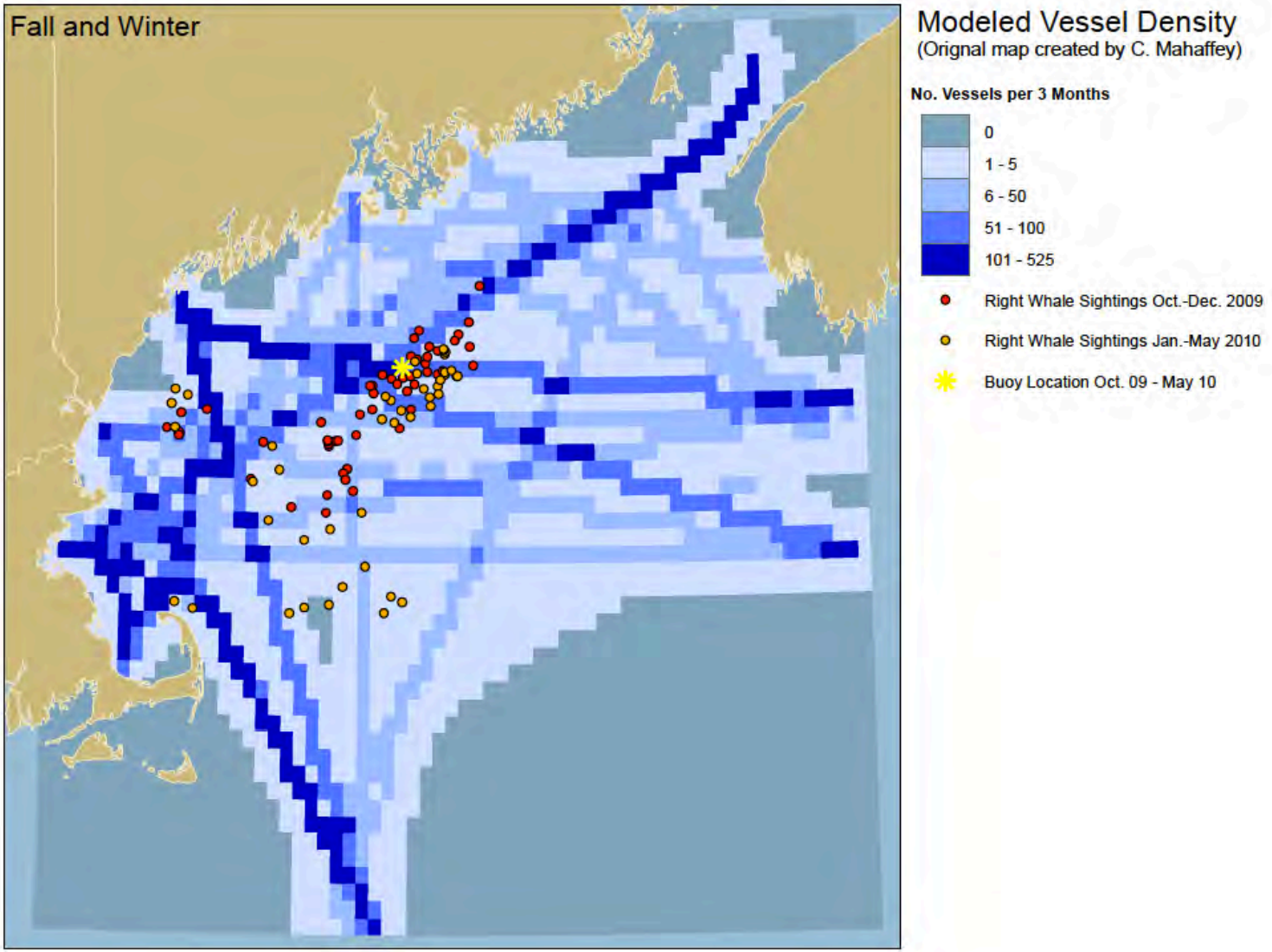

Figure 33. Overlay of 2009 right whale aerial survey data and deployment two buoy location with a modeled vessel density map created by Mahaffey (2006). Three clear lanes of high vessel traffic intersect near the area of highest right whale concentrations.

Conclusions

This study utilized marine autonomous recording units to detect the presence of North Atlantic right whales in a newly discovered wintering ground that may also serve as a mating ground. Acoustic data were analyzed to determine seasonal and diel patterns for two known right whale calls—the upcall and the gunshot call. Gunshot calls particularly are thought to be associated with mating behavior. These data as well as call parameters were compared to similar acoustic data from other habitats and aerial survey data.

Based on the high numbers of calls detected, with the highest call rates observed in November-January, this study confirms that right whales are utilizing this habitat in some way during winter months. These data fit well with studies conducted in surrounding habitats; combined, these studies are beginning to paint a clear picture of the times when right whales use offshore habitat in the Gulf of Maine. While this study can not definitively describe the Outer Fall region of the Gulf of Maine as a mating ground, the data support the idea that reproductive behavior is likely occurring based on the high numbers of gunshot calls detected in the area. The parameters for the calls detected within this habitat are consistent with right whale calls found in other areas.

Determining whether this habitat is actually used by the North Atlantic right whale as a mating ground will require further studies including aerial and boat-based transect surveys, further acoustic monitoring, and characterization of calls. Social sounds in particular need further classification since some may be directly associated with reproductive surface active behavior. Social sounds described in this study must be

correlated with visual sightings to confirm that they are produced by right whales and not another species of cetacean.

If further studies concretely determine this area as a mating ground, this would qualify Outer Fall and the greater central Gulf of Maine for further protections from possible anthropogenic disturbance. This will greatly affect shipping and fishing industries that work within the area. Offshore lobstering takes place in winter months in the Gulf of Maine. This study did not examine the fishing effort that takes place within the Outer Fall region and the greater central Gulf of Maine during winter months; under any scenario, these data would be difficult to obtain and would require the trust of the lobster industry. Nonetheless, such data are critical—if only to determine how many fishermen would be affected if further protection of this region is deemed warranted. Shipping may also be affected if the area is given seasonal protection instead of dynamic protection based on individual sighting records, although impacts to shipping lanes could be minimized if vessels took avoidance action early in their voyage, thus only requiring slight angular changes to heading.

Ensuring that the North Atlantic right whale is given every protection possible is crucial to the survival of the species. It is my hope, however, that future protections afforded to right whales also keep in mind the difficult situation that fishermen and other mariners face when dealing with these measures, and that a compromise can be reached.

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Appendix A.

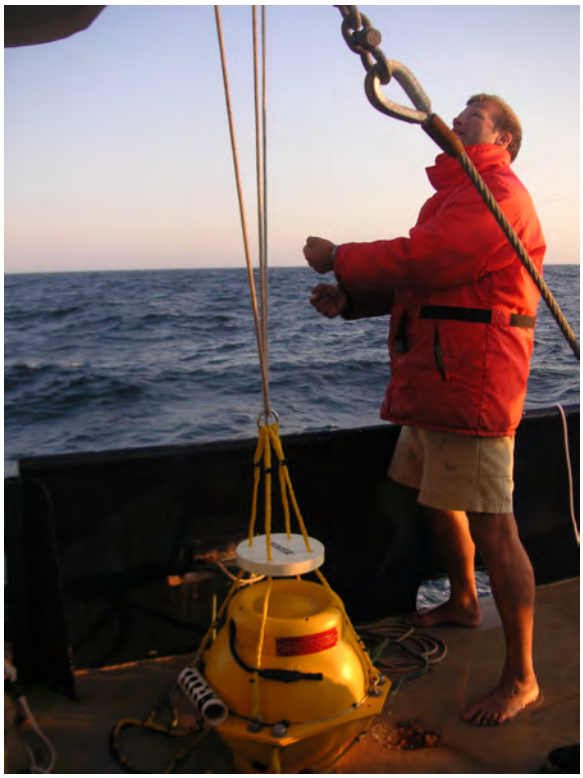

Figure A1. Single MARU or "pop up buoy." The hydrophone is mounted on the side of the unit. This unit was used in deployment 1 and was lost at sea following Hurricane Bill.

Figure A2. The sandbags used in typical MARU deployments. It was later discovered that these were not able to withstand the harsh conditions in the Gulf of Maine, and a shallow water deployment configuration was used in future deployments.

Figure A3. Double-bubble MARU. The hydrophone is mounted on the top of the unit, and the lower bubble contains extra battery packs for extended recording life.

Figure A4. Double-bubble configuration used in deployment 2. The 200 lb. I-beam was fitted with eyebolts on either side for attaching the tethers.

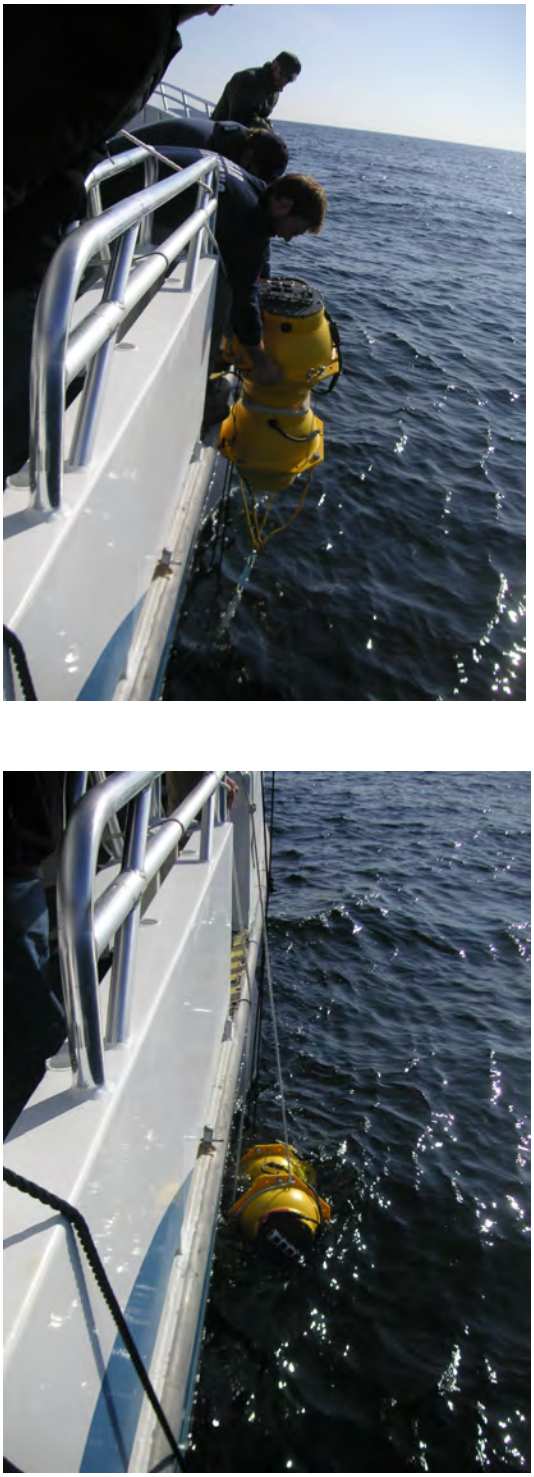

Figure A5. MARU units are lowered over the side of the vessel with a bridle and floated at the surface until the anchor can be lowered. When the anchor is deployed, one end of the bridle is released and the buoy sinks to the bottom. The tethers attached to the buoy are approximately 10 ft.

Figure A6. Concrete anchors with rebar hooks used for deployment 3. Uniline was slipped onto the rebar hooks before they were set in the concrete. Rebar is coated with epoxy to reduce the chance of acoustic disturbance during deployment. The dimensions of the anchor were 24" l X 24" w X6" d.

Appendix B.

List of all days analyzed, including technician and total number of upcalls and gunshot calls. BB= Barbara Beblowski, JB= Jackie Bort, AB=Alex Brett, MK=Michelle Klein, JM= Jessica McCordic, LN=Lindsey Nielsen, PO=Phinn Onens, AP= Alison Pierik, NR= Nadya Ramirez, RSL=Rachel Sullivan-Lord, YT=Yuka Takemon

Date	Technician	Total Upcall	Total Gunshots
October 30 2009	JB	204	2033
October 31 2009	JB	349	896
November 1 2009	JB	1434	484
November 4 2009	JB	2176	847
November 7 2009	JB	1188	513
November 10 2009	JB	1087	360
November 13 2009	JB	589	80
November 16 2009	JB	450	688
November 19 2009	JB	707	1295
November 22 2009	JB	380	240
November 25 2009	JB	660	789
November 28 2009	JB	48	1
December 1 2009	JB	611	1153
December 4 2009	JB	212	758
December 7 2009	JB	736	1288
December 10 2009	JB	684	462
December 13 2009	JB	296	547
December 16 2009	JB	271	130
December 19 2009	JB	531	45
December 22 2009	JB	358	127
December 25 2009	JB	716	0
December 28 2009	JB	644	393
December 31 2009	JB	1265	777
January 3 2010	JB	259	86
January 6 2010	JB	593	25
January 9 2010	JB	577	72
January 12 2010	JB	927	92
January 15 2010	JB	1603	75
January 18 2010	JB	126	21
January 21 2010	JB	864	18
January 24 2010	JB	211	12
January 27 2010	JB	439	11
January 30 2010	JB	428	20
February 2 2010	JB	102	6
February 5 2010	JB	73	0
February 8 2010	JB	22	0
February 11 2010	JB	7	0
February 14 2010	JB	1	0
February 17 2010	JB	4	0
February 20 2010	JB	0	0
February 23 2010	JB	0	0
February 26 2010	JB	0	0
March 1 2010	JB	20	0
March 4 2010	JB	5	0
March 7 2010	JB	22	0
March 10 2010	JB	0	0
March 13 2010	JB	10	0
March 16 2010	JB	1	0
March 19 2010	JB	0	0
March 22 2010	JB	0	0
March 25 2010	JB	0	0
March 28 2010	JB	0	0
March 31 2010	JB	1	0
April 3 2010	JB	0	0
April 6 2010	RSL	0	0

April 9 2010	JB	0	0
April 12 2010	YT	37	0
April 15 2010	JB	0	0
April 18 2010	JB	10	0
April 21 2010	JB	0	0
April 24 2010	LN	0	0
April 27 2010	JM	0	0
April 30 2010	MK	0	0
May 3 2010	AP	0	0
May 6 2010	JM	0	0
May 9 2010	AB	0	0
May 12 2010	JM	0	0
May 15 2010	PO	0	0
May 18 2010	LN	0	0
May 21 2010	YT	0	0
May 24 2010	RSL	0	0
May 27 2010	BB	0	0
June 30 2010	LN	0	0
July 1 2010	YT	64	1
July 4 2010	JM	95	7
July 7 2010	JM	1	3
July 10 2010	NR/LN	0	0
July 13 2010	LN	0	0
July 16 2010	YT	3	2
July 19 2010	JM	0	0
July 22 2010	AB	1	0
July 25 2010	MK	0	0
July 28 2010	AP	0	0
July 31 2010	RSL	0	0
August 3 2010	JM	0	0
August 6 2010	JM	0	0
August 9 2010	AB	0	0
August 12 2010	MK	0	0
August 15 2010	PO	0	0
August 18 2010	YT	13	0
August 21 2010	JM	0	0
August 24 2010	LN	0	0
August 27 2010	AB	32	0
August 30 2010	AB/JB	358	504
September 2 2010	LN	20	0
September 5 2010	RSL	66	0
September 8 2010	JB	746	41
Sepetember 11 2010	MK/JB	2770	386
September 14 2010	JB	24	5
September 17 2010	JB	113	193
September 20 2010	JB	7	0
September 23 2010	JB	141	0
September 26 2010	JB	365	173
September 29 2010	JB	548	294
October 2 2010	JB	1	3
October 5 2010	JB	10	1
October 8 2010	JB	383	370
October 11 2010	JB	798	463
	TOTALS	28497	16790

Appendix C. Acoustic Computer Specifications as recommended by Cornell BRP

Dell Precision T5500 64bit Dual Processor

Dell Precision T5500 Workstation, Genuine Windows® 7 Professional to XP Pro,SP2,64bit,Media,English
Catalog Number: 25 E1763_64_2

Module	**Description**
Dell Precision T5500	Dell Precision T5500 Workstation
Operating System	Genuine Windows® 7 Professional to XP Pro,SP2,64bit,Media,English
Processor	Dual (2) Dual Core Intel® Xeon® Processors E5502 1.86GHz,4M L3, 4.8GT/s
Memory	6GB, 1066MHz, DDR3 SDRAM, ECC (6 DIMMS)
Keyboard	Dell QuietKey Keyboard
Monitor	No Monitor
Graphics	256MB ATI FireMV® 2260, 2MON, 2 DP w/ 1 DP to DVI Adapter
Boot Hard Drive	250GB SATA 3.0Gb/s with NCQ and 8MB DataBurst Cache™
Hard Drive Configuration	C6 All SATA drives, RAID 0, 2 drive total configuration
Floppy Drive and Media Card Reader Options	No Floppy Drive and No Media Card Reader
Mouse	New Dell USB Optical Mouse with scroll, All Black Design
Chassis Configuration and 1394	Mini-Tower Chassis Configuration
Speakers	No Speaker option
Power Supplies	Precision T5500 Power Supply
2nd Hard Drive	250GB SATA 3.0Gb/s with NCQ and 8MB DataBurst Cache™
Hard Drive Internal Controller Option	Integrated Intel chipset SATA 3.0Gb/s controller
Resource DVD	Resource DVD - contains Diagnostics and Drivers
Multi Select Monitors	(2) Dell Professional P2210H 21.5in HAS Wide Monitor, VGA/ DVI/ DP