Echosounder Effects on Beaked Whales in the Tongue of the Ocean, Bahamas

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ABSTRACT

Increasing human activity in the ocean has lead to an increase in anthropogenic noise in the ocean. Beaked whales are deep-diving odontocetes known to feed in the tongue of the ocean, Bahamas. Recent studies show that anthropogenic noise in the sea can have significant effects on marine mammals. Of particular concern are beaked whales, which have been shown to mass strand in response to naval sonar. The detrimental link between naval sonar and marine mammals has been established in several court cases, but little is known about the effects echosounders, used in scientific research, have on marine mammals.

This master's project investigates the effects echosounders may have on beaked whales in the tongue of the ocean, Bahamas, as well as the policy and management implications surrounding this issue. In 2008 an echosounder was deployed in the study area and the corresponding beaked whale click data was obtained from the Naval Undersea Warfare Center. The data were analyzed to determine whether a change or cessation in click activity occurred pre-, during or post echosounder deployment.

The results indicated that no change was observed in click duration comparing pre-, during or post echosounder deployment. The data sets for during and post echosounder deployments were significantly smaller than pre- and could be a contributing factor to these results. These results are preliminary and further analysis into the behavioral effects of echosounders on beaked whales will be conducted. Alongside this, recent studies have shown that beaked whales respond to acoustic stimuli at much lower levels than are currently regulated for marine mammals, suggesting that there is need for a lower threshold for beaked whales in the United States than is currently being implemented.

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INTRODUCTION

Increasing human activity in the oceans has lead to an increase in anthropogenic noise in the ocean. Noise from activities such as seismic oil and gas exploration, echosounders used for scientific research, and simple electronic devices such as a fish finder can have an impact on all aquatic life. More specifically, recent studies are showing that anthropogenic noise in the sea has a profound effect on marine mammals (e.g. Nowacek et al. 2007; Cox et al. 2006). Sound is transmitted very efficiently through water (Richardson 1995). Unlike in the air, where sound travels at a speed of 340 m/s with a 1 km range, sound travels through water at 1500 m/s and has a range of 10-100 km (Figure A1) (Hoelzel 2002). Due to this efficiency, marine mammals have developed acoustic communication as an effective way to obtain information from their surrounding environment (Richardson 1995). Anthropogenic noise can impact this ribbon of communication in a number of ways such as masking (affecting the ability of marine mammals to recognize sound signals amidst noise), permanent and temporary hearing threshold shifts, and behavioral disturbances (Richardson et al. 1995).

Beaked whales (specifically Blainville's *Mesoplodon densirostris* and Cuvier's *Ziphius cavirostris*) are deep-diving odontocetes known to feed in the tongue of the ocean, Bahamas (Johnson et al. 2004). Scientists know the least about this family of marine mammals, and much of that knowledge is obtained from stranding events (Johnson et al. 2004). Beaked whales use intense ultrasonic clicks to echolocate prey, which is often squid (Wilson et al. 2007). They also utilize clicking and other vocalizations to communicate with other members of their species (Richardson 1995). One severe reaction to stressful sounds in the marine environment is a mass stranding event of multiple species of whale. On several occasions, mass stranding events have occurred following naval sonar exercises (Simmonds and Lopez-Jurado 1991; Frantzis 1998;

Jepson et al. 2003). Intense sonar use may impair the ability of beaked whales to "hear" properly in their environment, but nothing is known about how these animals react to less intense anthropogenic noise.

There is a growing debate in the scientific community regarding the affects of anthropogenic noise on marine mammals. Several court cases have been decided in recent years regarding the use of Naval sonar in areas where marine mammals are known to frequent (See Winter v. NRDC, 2008); however, little is known about the effects an echosounder used in scientific research has on marine mammals. Often, scientists use echosounders to study the marine environment to detect biomass in the ocean, including the prey of beaked whales (Nowacek *pers. comm.*; Hazen et al., in press 2011). Using the prey biomass, scientists can model beaked whale presence and abundance (Hazen et al., in press 2011). However, the use of echosounders could actually alter the behavior of the beaked whales, making the results of the model less accurate. No current studies have examined the effects that echosounders may have on beaked whale behavior.

Because beaked whales are highly elusive and relatively little is known about them, it is of great scientific and management importance to fully understand the effects these tools have on beaked whales. If the equipment used affects the whale's behavior, not only will scientists encounter difficulty in accurately understanding the behaviors of these animals, but managers will also find their conservation efforts more difficult. Because the population status is not known, potential management and conservation actions cannot be effective without accurate information. This paper will address current regulations in place regarding marine mammals and noise, both nationally and internationally, and examine what effect these have on scientific research. It will also investigate current international negotiations on determining international jurisdiction in the oceans, specifically how it affects the Bahamas.

BACKGROUND

What is an echosounder?

Echosounders have been used for fisheries research purposes for more than seventy years. Echosounders use active acoustics (sending and receiving signals) and can be used to detect biomass in the ocean (Simrad 2010), including the prey of beaked whales (Nowacek *pers. comm.;* Hazen et al., in press 2011). This instrument is still today the standard tool for stock assessments of our commercially important fish resources (Simrad 2010). Traditionally echosounders transmit a sound beam from the surface towards the bottom. The sound beam bounces off the bottom or prey biomass back towards the boat and is received by the transmitter. This information, together with catch data from trawls, is used to estimate fish abundance and size distribution (Simrad 2010). The Simrad EK60 echosounder was used to gather data on the prey biomass of beaked whales in the Tongue of the Ocean (TOTO, Hazen et al., in press 2011). The most basic Simrad EK60 echosounder system consists of one transducer, one transceiver unit and one processor unit and can operate seven echosounder frequencies simultaneously ranging from 18 kHz to 710 kHz (Simrad 2010).

Beaked Whales

Beaked whales (*Mesoplodon densirostris* and *Ziphius cavirostris*) are deep-diving odontocetes (toothed whales, Figure A2). Scientists know the least about this family of marine mammals (Mann et al. 2000), and much of that knowledge is obtained from mass stranding events (Simmonds and Lopez-Jurado 1991; Frantzis 1998; Jepson et al. 2003). On average, beaked whales dive in excess of 1,200 meters and duration of longer than 60 minutes, spending the majority of time at depth (Baird et al. 2005; Tyack et al. 2006). Recently scientists recorded a beaked whale that dove to a depth of 2,500 meters with a dive time of two hours (Nowacek *pers. comm.*).

Beaked whales feed on deep-sea animals, most often squid, and use intense ultrasonic clicks to echolocate their prey (Mead 1989; Clarke 1996; Santos et al. 2001). *M. densirostris* produces short upsweep clicks from 25 to 55 kHz and an inter-click interval of 0.2 to 0.4 seconds (Johnson et al. 2004; Johnson et al. 2006). Beaked whales start echolocating at around 400 meters on descent and stop clicking around 875 meters upon ascent (Johnson et al. 2004). Click intervals often increase the closer they get to their prey item, accelerating to what is often called a “buzz” (Johnson et al. 2004). Blainville’s beaked whales have also been shown to produce two distinct types of click sounds during different phases of foraging: search clicks and buzz clicks (Johnson et al. 2006). Search clicks are similar to chirp signals in bats and are produced during foraging dives, with an inter-click interval of 0.2-0.4 s and bandwidth from 26 to 51 kHz (Johnson et al. 2006). Buzz clicks, on the other hand, are produced when a whale is closing in on its prey. These occur in short bursts at a bandwidth from 25 to 80 kHz (Johnson et al. 2006). Johnson et al. (2008) suggests that alongside the two distinct click sounds produced, Blainville’s beaked whales alter their clicking rate depending on their target’s range at the beginning of the buzz click. This, then, suggests that Blainville’s beaked whales focus their echolocation efforts on specific selected targets instead of a number of targets (Johnson et al. 2008). Beaked whales also utilize clicking and other vocalizations to communicate with other members of their species (Hoelzel 2002); however, echoes from items in the water ensonified by beaked whale clicks are a frequent occurrence, leading one to believe that these vocalizations are utilized mainly for locating prey (Johnson et al. 2004; Tyack et al. 2006).

Beaked whales separated from the main-toothed whales during their evolutionary history, and they are distinguished by a reduced number of teeth (Mead et al. 2002). Many beaked whale species have a single pair of teeth, usually occurring only in males, which protrude from the lower jaw (Hoelzer 2002). Not much is known of their foraging or actual eating behavior; however, it would appear that they employ suction to capture their prey instead of grasping with their teeth like other odontocetes (Hoelzer 2002).

Beaked whales, like other odontocetes, are conscious breathers, meaning they consciously choose when to breathe or not. Conscious breathing coupled with long, deep periods of foraging, mean that the lungs of beaked whales have to be adapted for changes in pressure. Beaked whales (and other odontocetes) have adapted to and thrive in their aquatic environment. During activities on the water surface, oxygen travels from ambient air to lungs, diffusing from alveoli into capillaries before being transported through the cardiovascular system to the skeletal muscles (Hoelzel 2005). Oxygen is stored within the tissues of each major anatomical component (i.e. lungs, muscles, heart, as well as blood), a feature that plays a role in marine mammal's prolonged submergence (Hoelzel 2005). When diving, these oxygen pathways close—with ambient air no longer available for respiration, marine mammal lungs often collapse with hydrostatic pressure (Hoelzel 2005). Decreased heart rate (bradycardia) results in a reduction of cardiac output and thus a change in the transport of oxygen to skeletal muscles (Hoelzel 2005). Kooyman et al. (1970) tested this theory and found that tracheal collapse occurred in Weddell seals (*Leptonychotes weddelli*) and northern elephant seals (*Mirounga angustirostris*) when exposed to increased hydrostatic pressure. Subsequent tests on bottlenose dolphins (*Tursiops truncatus*) (Hoelzel 2005), pilot whales (*Globicephala melaena*) (Olsen et al. 1969), and sei whales (*Baleanoptera borealis*) (Scholander 1940) also show that the bronchi, trachea and alveoli of cetacean lungs are collapsible and only the boney nares (Ridgeway et al. 1969) remain rigid. Since beaked whales spend most of their time at depth and little is known about their anatomy, it is imperative that further studies be conducted to determine the effects of anthropogenic noise on these marine mammals.

The Tongue of the Ocean

The Tongue of the Ocean (TOTO) is a deep water basin and is one of two main branches that form the Great Bahama Canyon (Figure A3). The Great Bahama Canyon is more than 140 miles (225 km) in length. During the last Ice Age, nearly 12,000 years ago, much of the Bahama Shelf was above sea level. Rainfall during that period formed gullies or small canyons as rainwater flowed off the shelf into the Tongue of the Ocean. As the climate warmed and the ice melted, sea levels rose to present levels covering the eroded gullies (NASA 2010).

The actual tongue itself is 110 nautical miles long and 20 nautical miles wide, varying in depth from 1280 to 2012 meters (Mobley 2004). The basin floor is relatively smooth and soft, with very gradual depth changes (Global Security 2010). TOTO is bounded on the west by Andros Island, to the south and east by large areas of very shallow banks that are non-navigable, and to the north by the Northwest Providence Channel (Global Security 2010). This unique geography results in very low vessel traffic, minimal distant shipping noise, an absence of large ocean swells, and slight currents, while providing operational security and easy access to deep water. These factors make the TOTO an excellent location for a US Naval test facility (Global Security 2010).

The Atlantic Undersea Test and Evaluation Center (AUTEC)

The AUTEC range is located off of Andros Island in the Bahamas, in the Tongue of the Ocean (Figure A4, DiMarzio et al. 2008; Tyack et al. 2011; Hazen et al., in press 2011). The range itself consists of 82 bottom-mounted hydrophones deployed up to depths of 2000 meters (Hazen et al., in press 2011; DiMarzio et al. 2008) and are spaced 4 km apart (Nowacek et al. 2008). Of the hydrophones, 68 have a bandwidth of 50 Hz—50 kHz; while the remaining hydrophones operate within a bandwidth of 8—50kHz (Nowacek et al. 2008). The system is designed to detect and track undersea vehicles equipped with tracking pingers (Nowacek et al. 2008; Tyack et al. 2011) and is an active training range (Moriarty 2009). The United States Navy leases the substrate the hydrophones are on from the Bahamian government. During the 2008-2009 year, the United States leased this area at a cost of $13,050,000 US Dollars (The Government of the Bahamas). The hydrophones are constantly recording and have consequently recorded beaked whale click activity as well as naval activity. Thus, data were readily available from this location to use for the study (Nowacek *pers. comm.*).

INSTITUTIONS

Despite the fact that the Atlantic Undersea Test and Evaluation Center (AUTEC) is under the jurisdiction of the US Navy, the sea floor, water column and any living organisms within the range are not (Nowacek *pers. comm.*). The US Navy leases the substrate from the Bahamian government (The Government of the Bahamas 2010), and as such, any research, recreation, naval testing, etc. is subject to Bahamian laws and regulations.

Bahamian Government

The Marine Mammal Protection Act was enacted in 2005 by the Bahamian government and is regulated by the Minister of the Department of Marine Resources (The Government of the Bahamas 2010). This act, much like the Marine Mammal Protection Act of the United States, states that no person "shall take, harass, hunt, kill or attempt to take, harass, hunt, kill any marine mammal within the Bahamas" without a license or permit granted by the government (The Government of the Bahamas 2010). While the act does not specifically define exactly what harass or take is, it does allow for the exception of such where it is "necessary…to ensure the preservation of such marine mammal," or when a person is authorized to "rescue or attempt to rescue a stranded or beached marine mammal" (The Government of the Bahamas 2010). The act also allows permits to be issued to scientists at the discretion of the minister; however, a license or permit to study or disturb marine mammals in the Bahamas has a stipulation attached. A permit or license will only be issued if the results will likely be accepted for publication to a reputable scientific journal or likely to contribute to the basic knowledge of marine mammal biology (The Government of the Bahamas 2010). Since the behavioral response study conducted was likely to result in publication and will contribute to the basic knowledge of marine mammal biology, a permit was issued for the current study.

The United States Navy

Even though the US Navy is leasing the substrate from the Bahamian Government under contract, they still have to obtain permits from the minister of the Department of Marine Affairs and abide by the Bahamian MMPA (The Government of the Bahamas 2010). Interestingly enough, the United States Navy does not need to complete an environmental impact statement (EIS) since they are in the territorial waters of another country; however, the necessity to conduct an EIS internationally is a gray area and is still debated today (Greenpeace USA v. Stone, 1990; Kormos et al., 13 Geo. Int'l Envtl. L. Rev. 661 (2001)). The Navy, understanding that their actions will most likely have environmental impacts on marine mammals in Bahamian waters, has, however, taken responsibility for their actions. They have hired scientists to continuously conduct research on the effects of their activity on marine mammals in the Bahamas and the funding for Dr. Nowacek's research came from the Office of Naval Research (Nowacek *pers. comm.*).

THE ISSUES

Masking, Temporary Threshold Shift, and Permanent Threshold Shift

Marine mammals have been shown to have adverse reactions to stressful sounds in their environment (Richardson 1995). The four most common reactions to stressful sounds are: masking, temporary threshold shift (TTS) and permanent threshold shift (PTS), and behavioral responses which often result in mass stranding events (Richardson 1995). Masking occurs when a loud sound drowns out a softer sound or when noise is at the same frequency as a sound signal (Richardson 1995). For example, a blue whale call is drown out, or "masked," by low-frequency naval sonar making communication between whales difficult; or a beaked whale echolocation click is masked by mid-frequency naval sonar making foraging difficult. TTS and PTS occur when the softest sound that the animal can hear is louder than it was before exposure to the sound. In other words, they have lost the ability to hear the softest sounds they could hear prior to exposure (Richardson 1995). The shift will be temporary or reversible, and the threshold will return to near normal levels, or not. As sound exposure increases, a level will be reached at which a permanent shift occurs (Richardson 1995). It is unclear why mass stranding events occur following stressful sounds such as naval sonar; however, several hypotheses have been proposed (Cox et al. 2006), which will be discussed further in the following section.

Mass Stranding Events

Beaked whales have been shown to have a higher sensitivity to sound in their environment, including naval sonar. There have been five mass stranding events of beaked whales following naval sonar since 1996, including a mass stranding in the Bahamas in March 2000 (Cox et al. 2006). These mass stranding events have led to the hypothesis that the exposure to anthropogenic sounds experienced by these animals is causing behavioral changes. It has also been hypothesized that due to their diving and foraging behavior beaked whales have chronic accumulation of nitrogen in their tissues. This accumulation makes them particularly vulnerable to diving related pathologies (i.e. the "bends") when their normal diving patterns are disrupted (Cox et al. 2006).

Fernandez et al. (2005) examined ten beaked whales that stranded after naval sonar activity in the Canary Islands during 2002. They were looking for the presence or absence of gas and fat emboli in the whales. Gas and fat emboli were observed in the vital organs of all ten animals, prompting further investigation. Fernandez et al. (2005) also proposed three hypotheses regarding gas and fat emboli formation: bubbles are formed in vivo when exposed to intense sonar sound and are exacerbated by intense nitrogen supersaturation and changes in dive pattern (i.e. decompression sickness); sonar exposure lowers the threshold for the expansion of in vivo bubbles; and a combination of the two results in an increase in bubble growth.

Hooker et al. (2009) then set out to model and predict blood and tissue tension N_2 (P_{N2}) to determine if physiology or dive behavior would lead to differences in risk of decompression sickness in three types of beaked whales. Their model suggests that deep diving whales, such as beaked whales, permanently live with blood and tissue (P_{N2}) levels that are greater than their shallow-diving counterparts (Hooker et al. 2009). Their model also suggests that diving lung volume, extent of dive response and dive profile had the largest influence on P_{N2}. This suggests that beaked whales live their daily lives with tissues that are supersaturated with nitrogen. It also suggests that there are potential differences in beaked whale species with Cuvier's beaked whales having the greatest impact from acoustic signals and thus, are at a greater risk for stranding and decompression sickness. Regardless, beaked whales live their lives with higher nitrogen concentrations, so any change to their diving and foraging behavior could cause decompression sickness.

Furthermore, if anthropogenic sounds such as sonar can cause beaked whales to remain at the surface or at depth for longer periods, then these behavioral responses coupled with their anatomy could pose a problem. Previous research (Hooker and Baird 1999) has suggested that some beaked whales chronically accumulate nitrogen in their system, much like human "saturation divers" (Cox et al. 2006). They dive deep for long periods of time, ascend relatively slowly and perform a series of "bounce" dives between 100-400 m depth (Hooker and Baird 1999; Cox et al. 2006). These repetitive "bounce" dives pose a risk of decompression sickness in beaked whales (Zimmer and Tyack 2007). Zimmer and Tyack (2007) predicted that the depth of alveolar collapse for beaked whales (*Ziphius*) is at around 72 m. This is due to the fact that deep-diving odontocetes need sufficient air to maintain echolocation at depth (Madsen et al. 2002), resulting in relatively small lungs compared to other mammals (Scholander 1940). Therefore, beaked whales and other deep-divers have shallower depths of alveolar collapse (Zimmer and Tyack 2007). Due to the nature of alveolar collapse and dive profiles of beaked whales, Zimmer and Tyack (2007) suggest that a longer series of shallow "bounce" dives where the depth of alveolar collapse is not exceeded poses greater risk for decompression sickness (i.e. the bends). Conversely, if beaked whales remain at depth for longer than normal, hypoxia (deprive of adequate oxygen supply) could set in (Cox et al. 2006). Nitrogen supersaturation of tissues could occur from altered dive paths as well, leading to the formation of gas bubbles in the blood stream (Cox et al. 2006). These gas bubbles have the potential to damage multiple organs and interfere with physiological function (Cox et al. 2006) and as such, the animal has the potential to strand.

It is clear that some physiological effects are occurring in beaked whales after naval sonar exposure in the form of mass stranding events and gas/fat emboli. Beaked whales seem to be hyper-sensitive to acoustic changes in their environment; this is cause to hypothesize that echosounders may be impacting their behavior as well. Because these animals have already shown intense adverse reactions to naval sonar and because echosounders are used extensively in marine research, it is important to understand how these animals do or do not react to this noise. Since we know so little about beaked whales and their role in their environment, it is imperative we understand the effects of anthropogenic noise on beaked whales and how those effects relate to the population.

METHODS

Data Collection

Data was collected onboard the *R/V Revelle* from September 12^{th}-October 2^{nd}, 2008 to examine the distribution of the deep scattering layer (beaked whale prey) (Hazen et al., in press 2011). Fisheries acoustic and hydrographic surveys were conducted using a 38 kHz SIMRAD EK60 echosounder. The survey consisted of 8 clover-leaf patterns (four 5km transects), three E-W cross-basin transects, and two N-S along-basin transects (Hazen et al., in press 2011). (See Figure A5). It is important to note that each clover transect occurred in numerical order, that is to say clover 2 was the earliest clover during the survey and clover 8 was the last.

Additionally, the US Navy's Atlantic Undersea Test and Evaluation Center (AUTEC), comprised of a total of 82 hydrophones, records 24 hours a day, barring any technical difficulties. Acoustic data from 82 of the bottom-mounted hydrophones were recorded simultaneously at a 96 kHz sampling rate (Hazen et al., in press 2011). Moretti et al. (2006) found that a multi-stage FFT based energy detector has successfully been used to detect clicks from echolocating odontocetes, including Blainville's beaked whales. Using an automatic click detector with an inter-click interval criterion of 0.15-1 seconds, Blainville's beaked whale clicks were able to be quantified (Hazen et al., in press 2011; Ward et al. 2008). Due to this, I was able to obtain beaked whale click activity in addition to the echosounder audio. Due to time and data constraints, only preliminary results are included in this paper; however, they are not the sole focus of this paper. Full results can be found in a paper for publication.

Data Analysis

Dave Moretti of the Naval Undersea Warfare Center (NUWC) provided the data. Data came in the form of pre-processed beaked whale acoustic click data and included data from August 22, 2008 to October 3, 2008. I was given an Excel spreadsheet that included: the date, Julian day, click start time, click stop time, click duration, center hydrophone, surrounding hydrophones, location, and whether it was day or night. From this pre-processed acoustic data, I was able to analyze data to determine whether or not the use of the EK60 echosounder had an effect on beaked whale click activity. I was looking to see if there was a difference in click activity before, during and after EK60 deployment. Any evidence of effect would be indicated by changes in click activity found in acoustical data. In order to do so, I first organized my data in numerical order by center hydrophone by date. I did this in order to get an overall idea of how much click activity data I had for each of the hydrophones on the AUTEC range.

I decided that the data sets for some of the hydrophones were too small to perform any statistical analysis (and in some case nonexistent) so I analyzed the data on a clover by clover basis. Recall that the survey from September 12th-October 2nd, 2008, consisted of 8 clover leaf patterns. Five of these clover leaf patterns (2, 4, 5, 6, and 8) were on the range and are included in this analysis (Figure A5).

In order to analyze click activity, I first determined which hydrophones were included in each clover by using a schematic of the layout of the hydrophones on the range as well as the latitude and longitude location of each hydrophone. Because beaked whale echolocation clicks are highly directional (Au 1993), I also included a buffer zone around the clovers, which consisted of the hydrophones surrounding the clover that were not initially included and allowed for any changes in beaked whale orientation. (Table A1 for Clovers and included hydrophones).

I then created Excel spreadsheets for each of the clovers, organizing them by date from August to October. I added the click duration for each click event recorded for each day for each clover, effectively yielding a table ranging from August 22nd-October 3rd, 2008 that included total number of click minutes for each day. From there I calculated the average number of click minutes for each day per clover in order to get a general idea of how click lengths were changing throughout the survey. It is important to note that during the period of September 5th-September 10th, 2008, the data was lost and was not included in any of this analysis.

After obtaining average click minutes per day for each clover, I was then able to analyze the data using the statistical program JMP Pro 9. I created JMP files for each of the five clovers, further separating the data out to include not only date, hydrophone number, total click minutes per day, average click min per day per clover, but also to include pre-EK60, EK60 and post-EK60. Pre-EK60 was any click activity data that was recorded prior to EK60 deployment for that clover; EK60 was any click activity data that was recorded during EK60 deployment for that clover; and post-EK60 was any click activity data that was recorded after EK60 deployment. EK60 deployment was different for each hydrophone and, as such, the dates and number of data points for each clover is different. Pre-EK60 included data prior to deployment, which includes data from the beginning of the dataset (8-22-08). Post-EK60 data included any data after EK60 deployment and, in most cases, is a small dataset.

Using JMP Pro 9, I analyzed pre-EK60, EK60 and post-EK60 data for each clover using a basic ANOVA test for each clover, followed by a Tukey Test to determine variance, if any. Roughly half of the clovers had relatively normal distributions, so I was able to use only the ANOVA. However, the remaining clovers were not normally distributed, so a non-parametric test had to be used. I used a Wilcox's signed-ranks test to test whether or not each group (pre-, during and post-EK60) changed. Any deviation from a mean of 0 would indicate a change in click activity.

Results

The results from the ANOVA and Tukey Test indicate that no change was observed in click duration comparing pre-, during and post-EK60 data; however, my data sets for during and post-EK60 were significantly smaller than pre-EK60 which could contribute to this factor (Table A2). The only statistically significant difference was in Clover 2. The Tukey test indicated that the significant difference was in pre-EK60 and post-EK60 data. In fact, the result of the Tukey test indicated that average click activity increased post-EK60. One potential reason for an increase could be due to the location of the clover and the date of EK60 deployment. The clover is in the northwestern-most corner of the range and was the earliest clover to be surveyed. Beaked whales in TOTO could have moved into this area post-EK60, when the EK60 was being deployed elsewhere in the range. The non-parametric test run on my data did not actually measure what I was intending it to, and further analysis will need to be performed to determine whether or not there is a change in click activity.

Discussion

From my preliminary results, there appears to be no statistically significant effect of echosounders on beaked whales in TOTO. A non-significant finding is still important because it preliminarily indicates that echosounders have no effect on beaked whale click activity, and, thus, their foraging. Clearly, more statistical tests have to be run on the data to determine whether there is actually an effect. I am also planning on looking at the relationship between the acoustic records, EK60 deployment and prey biomass from Hazen et al. (2011, in press). Hazen et al. found that the majority of the prey biomass occurred in the Southwest corner of the range, roughly in the location of clover 4. One hypothesis I have is that the beaked whales are affected by echosounder deployment, but their desire to forage where the prey is outweighs any potential annoyance of the EK60. Tyack et al. (2011) also found that beaked whales' group click rate increased following exposure to active sonar operations. In that study, the whales took three days to recover from exposure before increasing their foraging (and subsequently, click rate). With further analysis, this study could also indicate a similar effect for echosounders.

POLICY ANALYSIS

Marine Mammal Protection Act (1972)

The Marine Mammal Protection Act (MMPA) was enacted in 1972 and is overseen and implemented by the National Marine Fisheries Service (NMFS) (16 USCS § 1361). It prohibits the "take" of any marine mammal within the United States and defines take as: "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal" (16 USCS § 1362(13); 16 USCS § 1362 (14)). Harass is defined by the MMPA as:

> (A) any act of pursuit, torment, or annoyance which—
>
> i. has the potential to injure a marine mammal or marine mammal stock in the wild; or
>
> ii. has the potential to disturb a marine mammal or marine mammal stock in the world by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.
>
> (B) In the case of a military readiness activity or a scientific research activity conducted by or on behalf of the Federal Government consistent with section 16 U.S.C. §1374(c)(3), the term "harassment" means—
>
> i. Any act that injures or has the significant potential to injure a marine mammal or marine mammal stock in the wild; or
>
> ii. Any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns, including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering, to a point where such behavioral patterns are abandoned or significantly altered.
>
> (C) The term "Level A harassment" means harassment described in subparagraph (A)(i) or, in the case of a military readiness activity or scientific research activity described in subparagraph (B), harassment described in subparagraph (B)(i).
>
> (D) The term "Level B harassment" means harassment described in subparagraph (A)(ii) or, in the case of a military readiness activity or scientific research activity described in subparagraph (B), harassment described in subparagraph (B)(ii).
>
> 16 USCS § 1362

Level A and Level B harassment are defined by NMFS as causing a permanent threshold shift, serious injury, or death (level A) and temporary threshold shift or behavioral disruption (level B) (Southall et al. 2007; NOAA 2011). The threshold for level A harassment is 180 dB_{rms} for cetaceans, while level B has a threshold of 160 dB_{rms} (impulse noise such as pile driving) and 120 dB_{rms} (non-pulse noise such as drilling), respectively (NOAA 2011). While it is not entirely clear whether the thresholds are the same for naval sonar, NMFS nonetheless has implemented a "do not exceed" criteria of 180 dB: re 1 μPa for sequences of pulsed sounds and a 160 dB: re 1 μPa for pulsed sounds (Southall et al. 2007).

The MMPA, however, carves out exceptions for scientific research so long as it is permitted by NMFS and the result of which research will likely be accepted for publication in a scientific journal, is likely to contribute to the understanding of the marine mammal biology or ecology, or is likely to help identify, evaluate or resolve conservation issues (16 USCS § 1362(22)(a-c)). It is unlawful without such written permission to "take" a marine mammal. Since there is growing concern about the effects of anthropogenic noise in the ocean on marine mammals, understanding the effects of sounds emitted from military activity and scientific research are of utmost importance. Especially given the fact that beaked whales have been shown to strand after naval sonar events, understanding their interaction with their environment and with scientific echosounders could help with management and conservation.

In fact, regarding level A and level B harassment levels, Tyack et al. (2011) found that beaked whales in TOTO exposed to simulated and actual navy sonar exhibited behavioral harassment responses at levels well below those used by regulators in the United States as criteria for behavioral disruption (level B harassment). Tyack et al. (2011) found that beaked whales, when exposed to simulated naval sonar, actual sonar and simulated killer whale calls, showed marked changes in foraging and ascent behaviors at sound levels near 140 dB. They also showed avoidance behavior during naval sonar, moving tens of kilometers away from the exercises and out of deep-water habitat, the result of which could increase their risk of stranding (Tyack et al. 2011). While further research needs to be conducted, this result suggests that beaked whales are sensitive to acoustic exposure, at least in terms of behavioral response, and, thus, the need for a lower threshold for beaked whales in the US than is currently being implemented (Tyack et al. 2011).

An International Approach

Starting with the US Navy's Ship Shock Program in 1993, ocean noise pollution has been a growing concern and highly controversial subject (McCarthy 2004). Ship shock testing was employed to determine the strength of the hull and ship conditions during simulated war conditions by detonating explosives at various distances (McCarthy 2004). A year later the National Marine Fisheries Service (NMFS) authorized the "taking" of marine mammals during these ship shock tests (McCarthy 2004). This caused an uproar, and within two months the Natural Resource Defense Council (NRDC) filed suit claiming that the "Navy and NMFS failed to consider possible alternative sites for the trials and that an Environmental Impact Statement was required" (McCarthy 2004). The court found for the NRDC, stating that the failure of NMFS to at least consider alternative sites was a violation of the Marine Mammal Protection Act (MMPA), and issued an injunction (Natural Resource Defense Council, Inc. v. United States Department of the Navy, 857 F. Supp. 734 (C.D. Cal. 1994)). And so the domestic debate over noise pollution began and still continues to this day.

While the United States has protection for marine mammals in the form of the MMPA and is currently interested in the effects anthropogenic sound has on them, the same cannot be said globally. It is true that the Bahamas have enacted a very similar version of their own MMPA; however, it does not take anthropogenic sound into account. In fact, I had a hard time finding anything regarding the Bahamian government's efforts regarding sound in the ocean. Despite an apparent lack of cooperation or data, there have been international events regarding sound and marine mammals that have brought international attention to this issue.

In 1996 a number of beaked whales stranded alive on a stretch of beach along the Kyparissiakos Gulf in Greece (Frantzis 1998) and, despite efforts, several animals died (McCarthy 2004). At the time of the mass stranding event, the US Navy and the North Atlantic Treaty Organization (NATO) were conducting underwater experiments using high-powered, low frequency sonar (McCarthy 2004). Dr. A. Frantzis, a biologist at the University of Athens, linked the deaths and stranding to the use of sonar and pointed out that deep-diving whales seem to be affected by low-frequency sounds (Frantzis 1998). This mass stranding in Greece led to a meeting of international experts in 1998 to not only discuss the possible explanations for the stranding, but also to develop policy regarding sonar and marine life (McCarthy 2004). Although the experts could not prove a link between sonar and the whales' deaths, it brought to light the importance of research needed to determine the effects of underwater sound on marine mammals and underscored the regulatory challenges posed by a transboundary issue (McCarthy 2004). No consensus was issued; instead member states opted for self-regulation over a new national or international legislation (McCarthy 2004).

Unfortunately the mass stranding in Greece was the first of many involving sonar and marine mammals. More recently, in 2000 there was a mass stranding of marine mammals in the

Bahamas (Cox et al. 2006). Seventeen mammals stranded in the Bahamas, fourteen of which were beaked whales (Cox et al. 2006), while the US Navy was conducting acoustic antisubmarine activities in the area (McCarthy 2004). Eight of the beaked whales were returned to the water alive; however their fate is not known (Cox et al. 2006). Necropsies of the animals showed hemorrhaging in the temporal region and cochlear duct, injuries consistent with acoustic or impulse damage; however, the post mortem time varied, possibly compromising the results (Cox et al. 2006). Despite the possible compromise of data, the increase in strandings in conjunction with sonar activities (Madeira, May 2000; Canary Islands, September 2002; Gulf of California, 2002) is alarming and cause for concern (Cox et al. 2006). As such, international regulation is necessary to best handle this transboundary issue.

McCarthy (2004) offers up an interesting route of handling international "noise pollution." Using the Trail Smelter case and international regulations of transboundary pollutants, she points out the fact that noise in the ocean is analogous to the smoke of the Trail Smelter case, and claims that it can be considered as a transboundary pollutant (McCarthy 2004). She makes the comparison by using the 1982 United Nations Convention on the Law of the Sea (UNCLOS) definition of marine pollution. Marine pollution, as defined by UNCLOS, is:

> the introduction by man, directly or indirectly, of substances of energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.
> (UNCLOS 1982).

McCarthy (2004) states that because acoustic emissions involve the "introduction of energy into the marine environment and may involve deleterious effects to marine mammals, noise can clearly be considered pollution under the 1982 UN Convention on the Law of the Sea."

As a transboundary pollutant, McCarthy (2004) states that noise in the ocean mandate an international approach to address potential sources and effects. This, she states, can occur on the high seas or within states. Regardless of where they occur, international agreement is necessary to protect ocean resources, in this case marine mammals. While this seems plausible, international agreement is exceedingly difficult. International litigation over other transboundary pollutants such as radiation further justifies the need for an international approach (McCarthy 2004). McCarthy (2004) proposed creating an international framework within UNCLOS, modeled after the Convention on Long-Range Transboundary Air Pollution, since the definition of pollutant in UNCLOS includes energy. Perhaps a convention specifically dealing with noise pollution under the umbrella of UNCLOS will facilitate the necessary international regulation to address the effects of anthropogenic noise on marine mammals.

POTENTIAL IMPACTS AND IMPLICATIONS FOR SCIENCE

There are three possible constituents that I believe could be affected by the results of this study. These constituents are: the U.S. Navy, scientific researchers and the Bahamian Government. If scientific echosounders have a prominent effect on beaked whale click activities, this clearly has implications for future scientific research since echosounders are used widely for fish stock assessments and prey biomass of marine mammals. If scientists are using echosounders to study marine mammals and those echosounders have an effect on the marine mammals, scientists could potentially be obtaining compromised data. This has broader implications for management and conservation of marine mammals. It could also affect future funding for scientists studying marine mammals and could potentially change the way fish biology and marine mammal studies are conducted.

If echosounders have an impact, this also adds another facet to the current debate on noise pollution in the marine environment. This new layer could give environmental advocacy groups the fuel needed to lobby for stricter legislation and regulation of noise pollution. It also could have huge implications on the potential impact of naval sonar. Should an effect be found, it could lead to possible changes in the lease agreement between the United States and the Bahamas. It could also lead to changes or cessation in underwater warfare training not only in the Bahamas, but also in areas with similar ecosystems for the United States.

Conversely, this could also have broader implications for the Bahamian government. While many tourists do not go to the Bahamas to see beaked whales, a portion of the Bahamian government depends on the United States Navy remaining in TOTO ($13,050,000 US Dollars in 2008-2009) (The Government of the Bahamas 2010). Should an effect be found and the United

States Navy decides to cease training, the lease could expire. As such, the Bahamian government would not receive the $13 million dollars annually, and a plethora of other activities could lose funding due to this.

RECOMMENDATIONS AND CONCLUSIONS

Increasing human activity in the oceans has lead to an increase in anthropogenic noise in the ocean. Several studies have indicated that anthropogenic noise in the sea has a profound effect on marine mammals (e.g. Nowacek et al. 2007; Cox et al. 2006). More specifically, beaked whales seem to be hyper-sensitive to acoustic changes in their environment. It has been hypothesized that these mammals, which normally spend the majority of their time at depth foraging, are spending more time at the surface due to anthropogenic noise (sonar) in the ocean (Cox et al. 2006). Due to their cryptic nature, beaked whales are difficult to study and, as such, little is known about them (Mann et al. 2000). What we do know comes from stranding events (Simmonds and Lopez-Jurado 1991; Frantzis 1998; Jepson et al. 2003). Since beaked whales spend most of their time at depth and little is known about their anatomy, it is imperative that further studies be conducted to determine the effects of anthropogenic noise on these marine mammals and international laws or regulations be created to deal with noise.

McCarthy (2004) proposed an interesting ideology when dealing with anthropogenic noise, or "noise pollution," as she calls it. She suggested that anthropogenic noise, sonar more specifically, is a transboundary pollutant and should be dealt with as such. Under the 1982 UNCLOS definition of pollution, I can see her argument. Provisions under UNCLOS that deal with pollution include energy as a pollutant. Anthropogenic noise (energy) should be regulated as such under an international convention. While I agree that "noise pollution" is a global issue, I am skeptical that it can actually be dealt with as such. Knowing how difficult international law and regulation can be and seeing several other failed attempts at regulating global pollution, it would indeed be difficult to regulate internationally. With that said, however, I do think that the best option for regulating global anthropogenic noise is under an international convention or agency. Perhaps, as McCarthy suggests, the best venue for international regulation is under UNCLOS as a transboundary pollutant. Creating an agency under the umbrella of UNCLOS comprised of the world's experts on marine mammals and noise would be ideal. Regardless, sound in the ocean has to be regulated.

Furthermore, Tyack et al. (2011) found that beaked whales respond to simulated and actual sonar at levels much lower than is currently in place by the US to regulate sound, indicating that a lower threshold for disturbance for beaked whales is necessary. NMFS could easily implement a lower threshold for beaked whales regarding sound, much like they do for harbor porpoises, especially in areas where beaked whales and naval sonar overlap (such as TOTO). Further analysis needs to be done on my data; however, preliminary results show that echosounders do not have an effect on beaked whale click activity. Depending on how the results of these further analyses turn out, there could be further implications for conservation and management. Because these animals have already shown intense adverse reactions to naval sonar and little is known about them, coupled with the fact that echosounders are used extensively in marine research, it is important to understand how these animal react (or don't react) to this noise. It is also important to note that no other studies have examined the effects that echosounders may have on beaked whale behavior. Understanding the habitats of these whales and how they utilize them will improve future analyses of broad scale models of beaked whale foraging habitat as well as assessments of risk from exposure to anthropogenic sound.

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APPENDIX

Table 6.1 Comparison of the range, speed and locatability of different sensory modalities in air and under water. This table summarizes different physical attributes of acoustic, light, chemical and electrical cues in these two environments, along with features that are relevant for antidetection or location strategies.

Sensory modality	Mode of sensing	Mode of production	Range		Speed (m/s)		Locatability	Antidetection and location strategies
			Air	Water	Air	Water		
Acoustic	Hearing	Vocalization	1 km?	10–100 km	340	1500	Moderate	Faint hard-to-localize signal
Light	Vision	Luminescence	1–10 km	1–100 m	3×10^8	2.25×10^8	Good	Disruptive coloration; counter-illumination
Chemical	Olfaction	Pheromone	1 km?	10–100 m	Slow (wind)	Slow (current)	Moderate	Highly specific chemical signal and sense
Electrical	Electrical sense	Electric organ discharge	NA	Few metres	NA	Fast	Moderate	Jamming?

NA, not applicable.

Figure A1. Properties of Sound in Air and Water, among other mediums (Hoelzel 2002).

Figure A2. Blainville's Beaked Whale (*Mesoplodon densirostris*) (Photo courtesy: http://www.oceantaiwan.com/eyereach/whale/whale-10.htm)

Figure A3. Image of the Tongue of the Ocean and Andros Island (Photo Courtesy: NASA http://eol.jsc.nasa.gov/sseop/EFS/lores.pl?PHOTO=NM23-739-93)

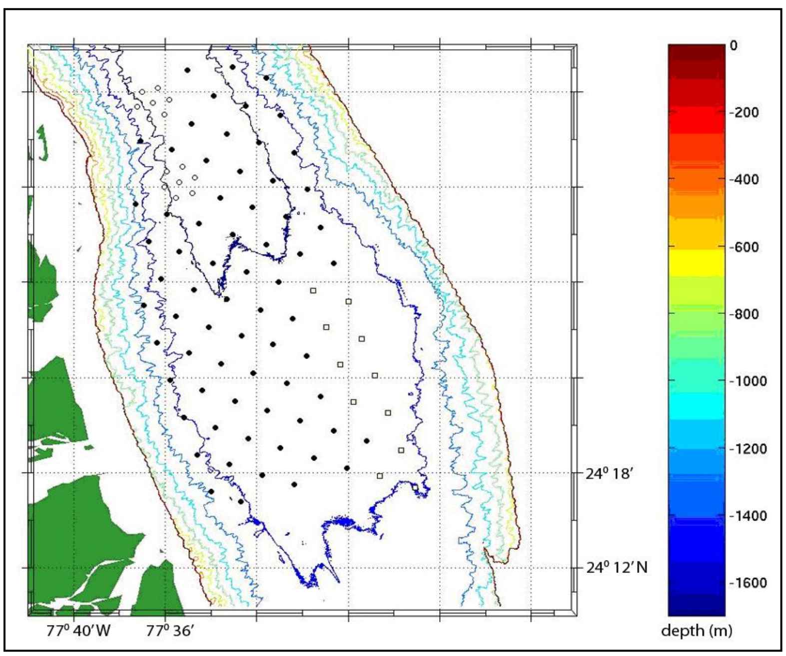

Figure A4. Map of bottom-mounted hydrophone array, AUTEC (Photo courtesy: Nowacek et al. 2008).

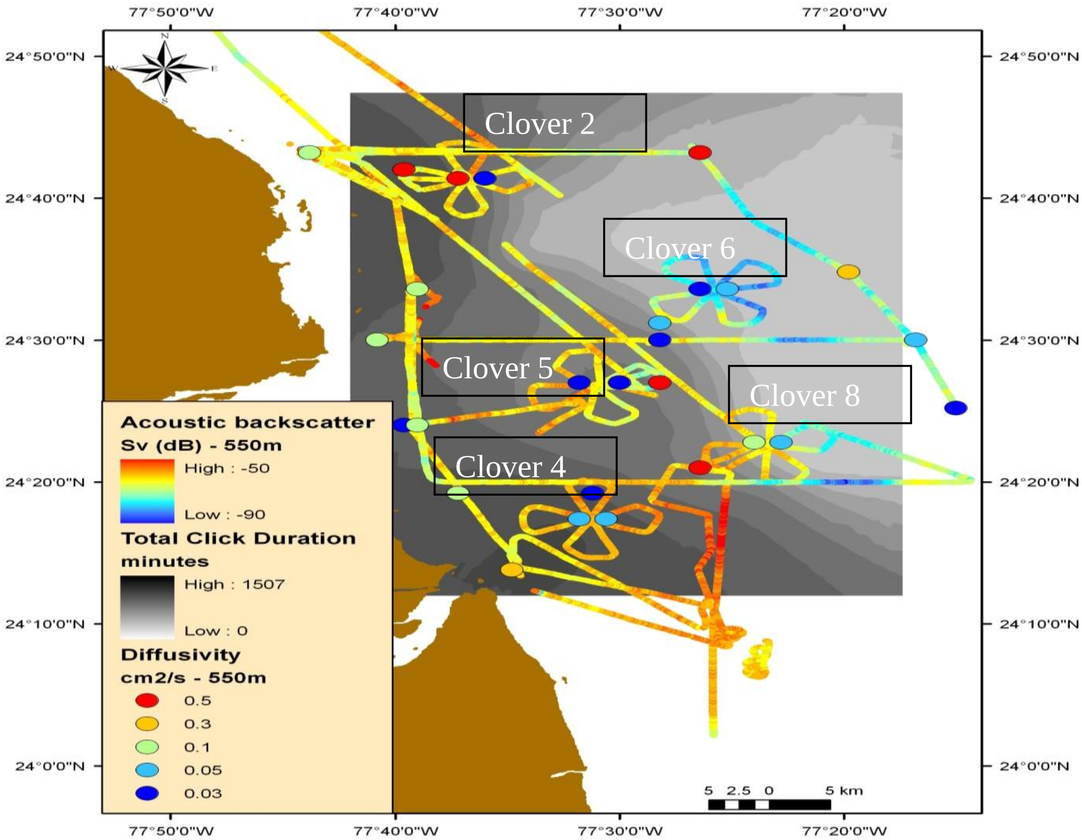

Figure A5. Clover leaf patterns (Hazen et al., in press 2011).

Clover	**Clover Hydrophones**	**Buffer Hydrophones**
2	1,2,3,4,5,6,7	17,21,25,26
4	90,92,93	82,83,88,89,91
5	52,59	45,46,61,53,58,60,66,67
6	34,40,41	30,33,39,46,47,48
8	70	62,63,69,71,77,78

Table A1. Hydrophones included in Clovers for analysis

Clover	ANOVA (p-value)	Pre-EK60/EK60	EK60/Post-EK60	Pre-EK60/Post-EK60
2	0.0086*	0.6546	0.8091	0.0061*
4	0.2877	0.6582	0.9841	0.3125
5	0.2633	0.2441	0.3983	0.834
6	0.2927	0.9758	0.9156	0.2617
8	0.4703	0.6497	0.4378	0.6975

Table A2. ANOVA and Tukey Test Results, stars indicate statistical significance

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