THE INFLUENCE OF HIGH-AMPLITUDE ACOUSTIC DETERRENTS ON THE DISTRIBUTION, ABUNDANCE, AND BEHAVIOUR OF BALEEN WHALES

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by

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ABSTRACT

The influence of high-amplitude acoustic deterrents (HAADs) on mysticetes, including humpback whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), and minke whales (*B. acutorostrata*), was investigated at Cape Saint Francis, Newfoundland, Canada during the summers of 1995 and 1996. The influence of HAADs on baleen whale distribution, abundance, and behaviour was evaluated by shore-based monitoring of a study site. A HAADs system was moored inshore at a water depth of 10m and the average sound pressure level of these pulses was 194 dB re 1μPa at 1 m with energy concentrated around 10 kHz and a single harmonic at 20 kHz. The acoustic device was randomly operated on a 24 hour basis (either 'on' or 'off'). Observers stationed on a 60m cliff documented species, number of individuals, behaviour and presence/absence of vessels in the area with each whale sighting throughout the day. Whale movements were tracked with a theodolite and observers were unaware of the operating condition of HAADs. The distance between whale sightings and HAADs was quantified to determine whale distribution, sighting rate was calculated as a measure of abundance, and the proportion of behaviours were compared between operating condition of HAADS. Results indicated that operation of HAADs was significantly related to the distribution and abundance of baleen whales and may relate to transient and residential species differently. Despite considerable variation in the number of whale sightings between years, overall distance and sighting trends suggest that humpback and fin whales demonstrated an avoidance of operating HAADs while minke whales exhibited no influence and/or an "attraction" to operating HAADs. This result suggests that transient whale species are displaced from areas with operating HAADs, while resident species remain in areas with operating HAADs. To mitigate any possible influences on baleen whales from HAADs, deterrent usage could be seasonally adjusted to avoid biologically important habitats and high concentrations of whales.

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INTRODUCTION

1.1 Anthropogenic Sound in the Marine Environment

The anthropogenic sound evident in today's oceans has led to concern about underwater noise pollution and its possible detrimental effects on cetaceans. Sound is thought to be the fundamental sensory and communication mode in cetaceans (Thomson 1991; Ketten 1992). Man-made noise, often audible with little attenuation kilometers from the sound source, may interfere with cetaceans' ability to detect environmental cues, hamper communication, or cause stress and physical damage to auditory structures (Richardson 1991a). Evidence suggests that anthropogenic noise may result in short-term avoidance responses and temporary local displacement of some cetacean species (Reeves 1992). During the presence of seismic surveys in the Gulf of Mexico, sperm whale (*Physter catodon*) abundance decreased significantly (Mate et al. 1994). Belugas (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) altered their distribution in the vicinity of vessel activity (Finley et al. 1990). In other cases, however, cetaceans appear unaffected by man-made noise (Richardson and Wursig 1995). For example, bowhead whales (*Balaena mysticetus*) were sighted in an area of industrial activity over a period of several years (Richardson et al. 1987). As effects of anthropogenic noise on cetaceans are variable and poorly known, acquiring and understanding information in this area is necessary for fair and effective impact assessment of man-made noise.

In an effort to understand the effects of anthropogenic noise, cetaceans have been monitored in the presence of a diverse spectrum of stimuli. During dredging activity in Newfoundland, humpback whales were less likely to be re-sighted in the vicinity of industrial activity and exhibited movement away from industrial areas (Borggaard 1996). In the Antarctic, minke whales displayed aversive reactions to overflights from helicopters. Responses included lobtailing, breaching, high-speed locomotion at the surface, aggregating, diving, and rapid course changes (Reeves 1992). Bowhead whales observed off Alaska altered their direction and traveling speed within one km of playbacks of drilling platform noise. They also exhibited subtle changes in surfacing and respiration cycles as far as two to four km from the sound source (Richardson 1991b). However, feeding humpback whales in Fredrick Sound, Alaska did not appear to avoid air gun sounds (172 dB) or playbacks of industrial noise (116 dB). In 7 of 19 cases, whales exposed to anthropogenic noise were sighted closer than control subjects, indicating an approach to the stimulus (Malme et al. 1985). In addition, gray whales monitored in breeding lagoons off Baja were attracted to quiet, idling, slow-moving vessels (Richardson 1995b). It is evident from these reports that extensive variability exists among the responses of cetaceans to anthropogenic noise. These data have been interpreted by some as representing conflicting evidence regarding cetacean sensitivity to man-made noise. Given a lack of consensus, defining reaction parameters and implementing appropriate mitigation measures is often difficult.

1.2 Auditory Abilities of Baleen Whales

As water is an excellent medium to transmit sound, acoustic signals are of fundamental importance to cetacean species. Cetaceans are thought to use passive listening and echolocation as a means to aid communicate and obtain environmental information (Richardson 1991a). Audition has been studied in some small odontocetes and the sensitivity and frequency range is relatively well understood (Au 2000). However, the hearing processes and capabilities of baleen whales are poorly understood and information is limited. Sound reception mechanisms in mysticetes are unknown (Ketten 2000) and no data presently exist on the sensitivity, frequency range, or intensity discrimination of baleen whales (Richardson 1995a; Ketten 1992; Au 2000).

On the basis of anatomical and paleontological evidence, it is suggested that mysticete auditory systems are quite sensitive and well adapted for hearing low frequencies (Richardson 1995a). Essential components of the cetacean ear include an outer ear which captures sound, a middle ear to filter and amplify, and the inner ear (cochlea) which transforms sound into neural impulses (Ketten 1995). It is proposed that cetacean hearing is most 3discriminating near the range of their own vocalizations (Green et al. 1994). Underwater sounds emitted by baleen whales are primarily at frequencies below one kHz (Thompson and Richardson 1995). Mysticete vocalizations can range from below 20 Hz in the blue (*Balaenoptera musculus*) and fin whale (*B. physalus*) to a kHz call in the humpback whale (*Megaptera novaeangliae*) (Thomson and Richardson 1995; Ketten 1992; Clark 1990a; Ketten 1991).

Despite considerable knowledge of cetacean anatomy, mechanisms involved in baleen whale vocalization are unknown (Clark 1990b). Mysticetes possess a larynx, which functions as a resonating chamber for sound, but lack vocal cords. Aroyan et al. (2000) proposed a model for sound production in mysticetes involving contractions of the laryngeal sac. Most baleen whale vocalizations are categorized as moans (fundamental frequency < 200 Hz), simple or complex calls (predominantly < 1kHz), or songs (varied composition and spectra, Clark 1990a). While mysticetes are not known to echolocate (Ketten 1992), the cranial sinuses of baleen whales are thought to be involved in infrasonic signals (Ketten 1991).

The evolutionary adaptiveness of the low to infrasonic frequencies used by baleen whales is unclear. Low frequencies have the potential for long distance communication while infrasonics may be used in off-shore navigation and during migration to detect major topographic features (Herman and Tavolga 1980; Ketten 1992). In addition, low-frequency vocalizations might function as a type of echolocation for large targets, such as other cetaceans and dense shoals of prey organisms (Herman and Tavolga 1980). Alternatively, baleen whales may simply be mechanically constrained to low frequencies. As larger whales evolved, the increasing size of the larynx may have dictated lower frequencies while the scaling of the inner ear resulted in increasing sensitivity to progressively lower frequencies (Ketten 1992). Any or all of these theories are plausible, however, more information detailing how baleen whales use sound is necessary to interpret ecological implications.

A primary auditory task of any organism is to detect sound signals in the presence of ambient noise. The critical ratio, or the intensity by which a signal must exceed background noise to be audible, is unknown for mysticetes but thought to be comparable with other marine mammals. Ratios range from 20dB at 1kHz in dolphin species to 40dB at 100 kHz in pinnipeds (Richardson 1991c). Typically ratios increase with higher frequencies, but they may be lower when signal and ambient noise originate from different directions (Richardson 1995a).

The lack of specific data detailing the auditory abilities of baleen whales is a fundamental limitation when evaluating the potential impact of man-made noise. Empirical measures of auditory parameters are difficult to gather but are necessary to obtain for large whale species. These gaps in data are of special concern, as many anthropogenic sounds are concentrated at low frequencies where mysticete hearing is thought to be most discriminating (Richardson 1991a).

1.3 Auditory Damage Resulting from Sound

In terrestrial mammals, exposure to acute sound can immediately impair hearing while chronic exposure to noise can lead to gradual hearing deterioration (Richardson

1995a). In most studies, hearing damage is attributed to high frequency sound and a degeneration of cochlear sensory cells. Auditory damage from noise correlates with peak levels, duration, frequency spectrum, ambient noise, and repetition (Geraci and St. Aubin 1979). Models predicting auditory damage from noise in cetaceans are based on terrestrial mammalian criteria (Bowles 1994; Richardson et al. 1995). While cetaceans possess the basic format of a mammalian ear, specializations include extensive adaptations for rapid pressure changes and large concussive forces (Ketten 1995). Therefore, analogies between the auditory systems of terrestrial mammals and cetaceans may be limited (Richardson and Wursig 1995).

Acoustic trauma in whales from man-made sound can be divided into lethal and sublethal impacts (Ketten 1995). The construction of a submerged oil platform in Trinity Bay, Newfoundland provided an opportunity to document the impact of man-made noise on large cetaceans. Whales were photo-identified, behaviourally monitored during and between underwater explosions, and re-sighted for two subsequent years (Lien et al. 1993). Autopsies of baleen whales found dead in the vicinity of underwater explosions indicated severely damaged ear morphology including: round window rupture, ossicular chain disruption, and tissue trauma (Ketten 1993; Richardson 1995b; Ketten 1995). Individuals surviving the blasts may have also sustained damage.

Hearing loss from exposure to sound is classified as a sublethal impact, even though death may ultimately result by way of impaired foraging and/or predator detection

(Ketten 1995). While cetacean distribution and abundance appeared unaffected during periods of underwater explosions in Trinity Bay, the incidence of whale collisions with fixed fishing gear around Newfoundland increased 17 percent (Todd et al. 1996). The inability of baleen whales to detect or avoid nets in the water after exposure to underwater explosions may indicate some degree of auditory damage. In addition, re-sightings of some 80 individually identified whales exposed to the blasts during subsequent years were significantly lower than for unexposed individuals. These data suggest a possible disruption of normal movement patterns and higher mortality among whales exposed to man-made noise (Lien et al. 1993; Lien 1996).

Most mammals experience a temporary reduction in hearing acuity due to threshold elevation after exposure to high amplitude sound (Richardson et al. 1995). The shift in auditory threshold is generally proportional to the level and duration of the sound source (Green et al. 1994). Recovery of the normal auditory threshold, following an exposure, may require minutes, hours, or days depending on the degree of shift (Richardson et al. 1995). The lack of data detailing cetaceans' responses to sound makes it difficult to assess the impact of a temporary threshold shift. A threshold shift may impair the ability to communicate, locate prey, avoid predators, or navigate (Richardson et al. 1995). The consequences of such reduced access to acoustical information from con-specifics and the environment are unknown (Richardson 1991a).

1.4 Behavioural Responses to Noise Pollution

Anthropogenic noise may impact both the immediate behaviour of whales and their activities over extended periods of time. Acute man-made sound may produce short-term startle reactions among baleen whales, which may include trumpeting through the blow hole, rapid course changes, aggregating, or local displacement (Richardson 1991b). Studies typically document these changes for only minutes or hours after a disturbance, without evaluating the possible lingering nature and effects of a disturbance (Richardson and Wursig 1995). Knowledge concerning the ramifications of long-term displacement, stress, and energetic consequences induced by exposure to chronic anthropogenic sound is limited (Richardson and Wursig 1995). However, it is thought that under some conditions, whales may alter their migratory routes, preferred foraging areas, or breeding/calving grounds in response to human encroachment (Green et al. 1994). Given the paucity of data addressing the rates or role of natural cetacean behaviours, it is difficult to assess induced behavioural changes and their consequences (Richardson and Wursig 1995).

Habituation, or the waning of responsiveness to a chronic stimulus is commonly observed in terrestrial mammals (Richardson and Wursig 1995). Reactions of cetaceans to low-levels of anthropogenic noise appear to decrease in intensity after lengthy exposure, although habituation has not been experimentally quantified in whales (Richardson and Wursig 1995). Habituation may allow baleen whales to adapt to the presence of chronic man-made noise and remain in acoustically hazardous regions (Green et al. 1994). However, it is erroneous to conclude that cetaceans appearing to tolerate anthropogenic activities are unaffected by the disturbance. Many species, because of habitat and prey requirements, have no choice but to occupy acoustically congested areas (Green et al. 1994).

1.5 Acoustic Devices in the Marine Environment

Acoustic devices have been developed to enhance the acoustic properties of fishing gear in an effort to reduce mysticete by-catch (Lien et al. 1990). Whales are incidentally caught in fishing gear throughout most of the world's oceans (Volgenau et al. 1995). In Newfoundland waters, humpback whales commonly collide with fixed inshore fishing gear. Initially, it was thought that these collisions occur when whales fail to detect the presence of nets in the water, as the frequency of entrapment is inversely proportional to the amount of noise emitted by the nets (Lien et al. 1992). Studies indicate that the addition of sound devices to fixed inshore fishing gear significantly reduced the number of collisions and suggested that whales may use man-made noise as sound cues detailing their environment (Lien et al. 1992). Additional research suggests that perhaps whale collisions were not due to the whale's inability to detect nets but may occur when whales are inattentive while foraging or engaged in other behaviors (Todd et al. 1992).

Further studies investigated odontocete and mysticete responses in the presence of acoustical alarms designed to reduce entrapment in fishing gear. Acoustic pingers emitting a ten kHz tone of unknown amplitude were tested on Hector's dolphin (*Cephalorhynchus hectori*) in New Zealand waters. Results indicated that dolphin sightings were distributed significantly further from the sound source when pingers were operating then when pingers were non-operational (Stone et al. 1997). A study investigating the effects of low frequency alarms on baleen whales in Newfoundland waters found that humpback whales approached more closely to working acoustical devices than minke whales (Todd et al. 1992). It was likely that sounds emitted by the alarms were novel to humpback whales, as they were transient in the area. On the other hand, minke whales were thought to be residents and their decreased responsiveness to alarms may have indicated a degree of habituation (Todd et al. 1992). Additional research is necessary to understand cetacean responses to such novel sounds.

The aquaculture industry deploys acoustic deterrent devices near fish pens to reduce predation and net destruction by seals (Mate and Harvey 1987; Olesiuk et al. 1996). These deterrents were developed in the late 1970s and early 1980s; they produced signals between 12 and 17 kHz at about 180dB re 1 μPa at 1 m and were intended to startle seals (Iwama et al. 1997). Results typically illustrated that deterrents initially decreased damage by seals, but success diminished as animals either habituated or suffered hearing loss (Mate 1993). Recently, high-amplitude acoustic deterrents

(HAADs) have been designed with increased amplitudes (200 dB), thought painful to seals, and the ability to broadcast over great distances ($\leq$ 40 km) (Olesiuk et al. 1996). The potential impact of these deterrents on non- target marine mammals, those species that do not attack penned fish or negatively affect aquaculture sites, is of significant concern (Iwama et al. 1997).

Data from research conducted off the coast of British Columbia suggests that HAADs may affect the distribution and abundance of cetaceans. Long-term acoustic and observational monitoring of cetaceans in the Broughton Archipelago noted a decline in sightings of baleen whales and orcas (*Orcinus orca*) that coincided with the introduction of HAADs to the area (Iwama et al. 1997). The effects of acoustic deterrents were tested on odontocete abundance near inshore aquaculture sites. Findings suggest a significant reduction of harbour porpoise (*Phocoena phocoena*) numbers when deterrents were operating, followed by a rapid re-population of the area when acoustic deterrents were not in use (Olesiuk et al. 1996). Additional research in the Broughton Archipeligo tracked orca sightings before, during, and after HAAD activity at local aquaculture sites. Orca sightings during years of HAAD activity were significantly lower than during either pre-exposure or post-exposure periods (Morton and Symonds 2002).

As HAADs usage by aquaculture sites is increasing throughout the world (Strong et al. 1995; Olesiuk et al. 1996), the potential impact these devices have on non-target marine mammals is a growing issue. The Department of Fisheries and Oceans modeled the impact of HAADs on non-target populations of marine mammals in the Bay of Fundy. Based on established sound levels for HAADs (Olesiuk et al. 1996) and the premise that all existing aquaculture sites use deterrents, results suggest that HAADs may seriously limit harbour porpoise usage of several regions in the Bay of Fundy (Strong et al. 1995; Johnston and Woodley 1998). As evidence accumulates that HAADs may impact cetaceans, there still remain questions. It is poorly understood how HAADs may impact larger whales, as the effects of these deterrents have not been directly tested on any mysticete species. A need for information regarding the effects of HAADs on baleen whales is relevant as HAADs operate at frequencies likely audible to baleen whales (Richardson 1995a). The effects of HAADs on baleen whales is also of interest as coastal waters, where aquaculture sites and HAADs usage are common, are seasonally important habitat for baleen whales (Piatt et al. 1989; Katona and Beard 1990; Whitehead et al. 1980; Methven and Piatt 1991).

1.6 Research Objectives

In an attempt to evaluate whether the behaviour of mysticete species is responsive to high-amplitude acoustic deterrents, the responses of humpback, fin, and minke whales to HAADs were investigated off the coast of Newfoundland, Canada. The study was shore-based, the site selected for the study was Cape Saint Francis because of historical sightings of baleen whales in the area (Whitehead et al. 1980; Whitehead et al. 1982) and a lack of other acoustic deterrents in the area. The study took place during summer months, July and August, when baleen whales are typically sighted in dense concentrations (Whitehead et al. 1980) in inshore areas (Whitehead and Carscadden 1985) during their seasonal migration to summer feeding areas. The previously discussed uncertainty surrounding whale responses to anthropogenic noise precluded a directional prediction to be made about the influence of HAADs. Differences in the responses of transient and resident species to HAADs was also of interest, but limited information detailing transient versus resident responses to acoustic devices again prohibited a directional prediction. Therefore, it was hypothesized that mysticete distribution, abundance, and behaviour in the study site would change in response to the operation of HAADs.

METHODS

2.1 Study Site

The influence of HAADs on baleen whales was evaluated by shore-based monitoring of a HAADs installation at Cape Saint Francis, Newfoundland (47^{0}50" N. latitude; 52^{0}45" W. longitude). Cape Saint Francis is located on the eastern coast of Newfoundland, at the southern tip of the mouth of Conception Bay, and is largely surrounded by water. While there are five, small islands just southeast of the Cape, the nearest peninsulas are located about 10 km to the south and 20 km to the north. Shortly before observations began, HAADs were placed on a traditional cod trap berth at Cape Saint Francis and observations were made from a nearby 60 m coastal cliff which afforded approximately a 210^0 view of the study site. HAADs were installed and operational only during the summer months when data were collected for this study; no other acoustic devices were present in the area before or during the duration of this study. The study site was defined as everything within visual range of the observers.

2.2 Equipment

High-amplitude acoustic deterrents from Airmar Technologies Corporation, Milford, New Hampshire were used during this experiment. Four speakers connected to a common battery produced a series of 1.8 ms pulses at 40 ms intervals grouped into 2.3 s trains with 2.1 ms gaps. The average sound pressure level of these pulses was 194 dB re

$1 \mu Pa$ at 1 m with energy concentrated around 10 kHz and a single harmonic at 20 kHz. HAADs were moored to the ocean floor at a site approximately one km from shore (47^0 48" N. latitude; 52^0 46" W. longitude during both years), held at a depth of ten m by floats, and marked at the surface by high-fliers. The deterrents were operated on a random schedule of days 'off' and days 'on' throughout the study. A team of dedicated research personnel aboard a maintenance vessel checked the HAADs installation for operating performance each morning of the study, or as frequently as weather permitted. HAADs operating condition was adjusted and batteries changed on the same schedule. When HAADs were 'off' all four speakers were silent and when HAADs were 'on' all four speakers were emitting sound. Efforts were made to keep observers unaware of the operating condition of HAADs; on some occasions when the maintenance vessel was sighted, observers may have guessed the experimental condition.

Sound profiles of the HAADs were recorded at varying distances and positions from the deterrents. Acoustical data were collected with a Sony DAT TCD-D10 pro II system with a flat ($\pm$ 1 dB) response from 20 Hz - 22 kHz (Sony Corporation, Tokyo, Japan) and hydrophones with a flat ($\pm$ 3 dB) response from 20 Hz - 19kHz (constructed by Technical Services, Memorial University of Newfoundland, St. John's, Canada). In attempt to detect HAADs amplitude differences within the study site and/or within the water column, recordings of HAADs were made at several locations within the study site and at depths of 15 and 30 m.

At each recording site, oceanographic conditions were sampled with a SEALOG-TD temperature/depth probe (VEMCO Ltd., Halifax County, Nova Scotia, Canada). The probe measured temperature to the nearest $0.10^0C \pm 0.3^0C$ and depth to the nearest 1m ± 5 m. The probe recorded measurements every 30 seconds and was lowered slowly to obtain a temperature-depth profile throughout water column.

2.3 Field Observations

Because baleen whales have historically been sighted in dense concentrations off eastern Newfoundland during summer months as they are traveling northward to summer feeding areas, this study took place during July and August. The arrival of baleen whales into the waters off Cape Saint Francis triggered the beginning of the study each year; similarly, observations each year ceased when whales finished moving through the area and were no longer sighted in waters off the Cape. Observation dates extended from 15 July to 4 August 1995 and from 11 July to 15 August 1996. Observations occurred between 0600 – 1800 hours, beginning when observers arrived at the study site and continued until a pre-determined quitting time (visibility permitting), during both years of the study (Tables 1 and 2). During observation sessions, observers visually scanned the study area continually and tracked all whales moving through the study site from the first sighting until the individual or group was no longer visible. A continual scanning method was chosen in lieu of any type of scheduled scanning effort in order to best document sightings that can be brief (lastly only a few seconds) and infrequent (once every few hours or days). Effective sighting distance ranged from 3 km to more than 20 km and was largely weather dependent. While there are islands present off Cape Saint Francis, the geography of the Cape did not limit sighting distance.

Cetacean sightings were made using binoculars and a spotting scope while the positions of whale sightings were tracked with a theodolite. The theodolite provided positions as horizontal and vertical angles from a known reference point. It was not possible to identify individual whales, but movement of an individual and/or group was inferred from the timing and position of successive sightings. The time of day, number of individuals, position, surface behaviour, and presence/absence of vessels in the study site were documented with each sighting. Cetaceans were continually monitored within the study site and environmental conditions were documented every few hours or after rapid change in conditions. These conditions included measures of visibility (1 = visibility unlimited, 2 = visibility < 23.5 km, 3 = visibility < 9.8 km, 4 = visibility < 3 km) and sea state (1 = flat calm, 2 = ripples, 3 = small waves, 4 = large waves (white caps)). Measures of visibility were developed using known, stationary reference points (typically islands) off Cape Saint Francis that could quickly and easily be used to assess weather conditions. Initially, the Beufort Scale was used to measure sea state, however, that proved to be too fine a scale for observers to reliably use from atop a 60 m cliff. Therefore, a courser scale, better suited to the observation conditions specific to this study, was developed to measure sea state. If measures of visibility or sea state exceeded category four, observations were halted until conditions improved.

2.4 Fishery Data

Data detailing the presence of capelin (*Mallotus villosus*) were obtained from the Department of Fisheries and Oceans, St. John's, Newfoundland. The Sentinel Fishery Programme of Fisheries and Oceans maintained a cod trap at Cape Saint Francis (47^0 48" N. latitude; $52^0$46" W. longitude in 1995 and 47^0 38" N. latitude; $52^0$38" W. longitude in 1996) throughout this study. Gear was checked on a regular basis; numbers and weights of fish species caught, the presence of capelin, and observations of seabirds and marine mammals were recorded. Department of Fisheries and Oceans Canadian Stock Assessment Research Documents and Atlantic Fisheries Stock Status Reports provided information on capelin distribution, abundance, and year-class strength for Conception Bay and the east coast of the Avalon Peninsula.

2.5 Data Analysis

The relationship between HAADs and the distribution, abundance, and behaviour of baleen whales was investigated. Sightings of transient whale species (humpback and fin whales) were examined separately from resident species (minke whales) to prevent a loss of information due to ecological differences between species. Analyses were either conducted on all whale sightings (all data for both years) or on known, independent group sightings (known groups for both years). The distance between HAADs and whale sightings was quantified to determine whale distribution and sighting rate was calculated as a measure of abundance.

For the purpose of this study, a sighting was defined as each time a whale and/or whales were observed at the water surface. Therefore, both a single whale traveling alone and/or multiple whales traveling together was considered one sighting. Additionally, all whale sightings were considered independent. For example, if either a single whale or multiple whales traveling together surfaced five times in succession, then five, independent sightings would have been recorded. In actuality, these sightings were likely not independent, but because observers could not reliably identify individuals, defining all sightings as independent was thought to be the best way to handle these data.

Distances between whale sightings and HAADs were calculated in several steps. Positions of whale sightings were obtained with a theodolite as vertical and horizontal angles in reference to a zeroing site. The distance between theodolite and whale sightings was calculated as range = 61.6 m (cliff height)* (tan(180°-vertical angle). The distance between whales and HAADs was determined as distance = square root [((Y coord - 23 (Y coord of HAADs))^{2}) + (X coord - 544 (X coord of HAADs))^{2})] as in Todd et al. (1992). Although these data could have been used to calculate whale swimming rate, that analysis was not attempted as part of this study.

Sighting rates were either calculated per day or per time of day category. A daily sighting rate was calculated by dividing the total number of sightings per day with number of hours observed per day. The four time of day categories were 0600 - 0900 hours, 0900 - 1200 hours, 1200 - 1500 hours, and 1500 - 1800 hours. Time of day sighting rates were calculated by dividing the total number of sightings per time of day category by the number of hours of observed during that time of day category.

Whale sightings temporally or spatially removed from other sightings were defined as known, independent groups and were used in behavioural analyses. After careful review of the data, only whale sightings that were separated by a temporal or spatial margin, adequate to ensure that data were collected from the same whale(s) and that interactions with other whales were minimized, were considered known groups. Using known group data, surface behaviour, approach distance (the distance at which a group is closest to HAADs subtracted from the distance at which the group was initially sighted), and duration spent within the study site were examined. A variety of behaviours were observed during this study (refer to sections 3.5 and 3.6 for a complete list), but not all behaviours were observed during both operating conditions (HAADs 'on' versus HAADs 'off'). Because of the difficulty associated with analyzing behavioural data, only those behaviours know to be associated with important activities and observed during both operating conditions of HAADs were included in the behavioural analysis. These included respirations and fluking for humpback and fin whales and respirations and surfacing for minke whales. Because these behaviours were typically brief in duration (i.e., lasting only a few seconds), analyzing a change in the proportion of these behaviours was thought to be a more sensitive indicator than analyzing a change in the rates of behaviours. Therefore, surface behaviours were analyzed using proportions and proportions were calculated for each behaviour by dividing the frequency of that behaviour by the frequency of all behaviours.

Sound profiles of HAADs were recorded at various locations throughout the study site during both years of the experiment. Relative amplitude of HAADs and distance from sound source were analyzed to determine local sound propagation. Acoustic data were analyzed with Computerized Speech Lab (Kay Elemetrics Corporation, Pine Brook, New Jersey, United States) with a sampling rate of 40 kHz. Positions of the HAADs and recording stations were obtained from a Global Positioning System (GPS NAV 5000DX^{TM}, Magellan System Corporation, San Dimas, California, United States) and were converted to universal transverse mercator (utm) units with the Geographic Calculator (Blue Marble Geographic, Gardiner, Maine, United States). The utm positions were used to calculate distance from the sound source to the recording stations; distance = square root [(alarm position east - recording position east)^2 + (alarm position north - recording position north)^2]. Acoustic data from 1996 were confounded by noise from the research vessel during recording and were not included in any analyses.

Oceanographic data were analyzed to obtain temperature and depth information at HAADs recording stations throughout the study site. SEALOG-TD data were edited to only include downward casts and a complete vertical temperature profile. However, technical difficulties with the probe prevented exact coordinates (latitude/longitude) to be assigned to each cast. Data within years were evaluated to obtain temperature/depth profiles throughout the study site and data between years were compared to assess changing ocean conditions.

2.6 Statistical Analysis

A Generalized Linear Model (GLM) with distance (m) and sighting rate (whales/hour) as response variables was used to analyze variance. Residuals were checked for association with the GLM, if a pattern was evident in the residuals, a transformation was applied to the data. If residuals were not linked to the model, data with non-normal residuals were not randomized when degrees of freedom were large (>100) and p-values far from 0.05 ($0.01 < p > 0.1$). Given that it was unclear how deterrents might influence whale behaviour, a change (two-tailed) in behaviour was tested instead of a predicted change (one-tailed) in behaviour. Statistical significance was determined with alpha set at 0.05 (Sokal and Rohlf 1995). Analyses were calculated using Minitab (Minitab Statistical Software, State College, Pennsylvania, United States) and randomizations were done according to the Schneider and Hendry Quantitative Methods Laboratory Manual (1996).

A GLM was used to analyze the distance between HAADs and whale sightings. The response variable distance was determined for whale sightings during 'on' and 'off' conditions to quantify the distribution of whales. The influence of HAADs was determined by the statistical significance of the relationship between operating condition of HAADs and the behaviour of whales when compared to other explanatory variables, such as time of day, visibility conditions, vessel presence/absence in the study site, and sea state. Initially, the GLM used to analyze the response variable distance resulted in residuals that were associated with the model, this was evident by visible "horn" pattern when the residuals were plotted versus the fitted values (Schneider and Hendry 1996). Therefore, a series of transformations were attempted on the response variable distance. When the response variable distance was transformed by the natural log, there was no evident association between the residuals and the model. Therefore, the natural log of distance was used in all analyses.

Sighting rate was used as a measure of whale abundance. A GLM tested the relationship between operating condition (either 'off' or 'on') of HAADs and time of day on sighting rate.

The behaviour of known, independent groups was analyzed to determine if there was a change between HAADs operating conditions. Surface behaviours (proportion of each behaviour to all other behaviours), time spent within the study site, and approach distance towards HAADs were analyzed by two-tailed T-tests to determine if they changed in response to the operating condition of HAADs.

All distribution, abundance, and behaviour data collected during the study were included in the analyses with two exceptions. No distance data collected on 23 July 1995 were included in any analysis because the theodolite was not zeroed properly, therefore, all whale positions recorded on that day were incorrect. A review of the minke whale distribution data indicated that the majority of sightings were within three km of the HAADs and less than 25 were at distances greater than three km from the HAADs. Because minke whales were more difficult to reliably identify from a distance than humpback or fin whales, the minke whale distribution data were edited to include only minke whales sightings less than three km from HAADs.

Temperature and depth information, collected at recording stations throughout the study area, were analyzed to determine if there was a change between years. Two-tailed T-tests were used to compare temperature/depth data between 1995 and 1996 to assess changing ocean conditions. Because temperature data were collected at or near the end of the field season each year, by which time the majority of baleen whales had already moved out of the waters off Cape Saint Francis, data collected during this study may overestimate temperatures during peak whale concentrations.

Sound profiles of the HAADs were analyzed to determine if there were differences with sound propagation within the study site. Two-tailed T-tests were used to compare relative amplitudes of HAADs recorded at depth of 15 and 30 m throughout the study site during 1995.

RESULTS

The relationship between HAADs and the distribution, abundance, and behaviour of baleen whales was investigated. Results from each of these data categories will be presented for humpback and fin whales first, followed by the results for minke whales. Significant results will be indicated by the use of the words "increased," "decreased," and/or "changed" while results that are not significant will be indicated by the use of the phrases "did not change"and "no change." Because whale distribution, abundance, and behaviour are greatly influenced by environmental and prey conditions, results from temperature and fishery analyses will also be presented followed by the acoustic analysis of HAADs.

3.1 Distance Between HAADs and Humpback and Fin Whale Sightings

Whale distribution, quantified by the distance between HAADs and whale sightings, was analyzed to determine if distribution changed in response to operating condition of HAADs, time of day, visibility, vessel presence or absence, and sea state. Because the natural log of distance was used in all analyses, all distances reported throughout this section will actually be the natural log of distance.

Operating Condition of HAADs

Distance between HAADs and humpback and fin whale sightings increased ($F_{1,3572}$ $= 87.68$; $p < 0.01$) when HAADs were 'on' (8.78 m $\pm$ 8.75 m) as compared to when

HAADs were 'off' (8.17 m ± 8.12 m) during both years of the study (Table 3 and Figure 1). In 1995, distance between HAADs and humpback and fin whale sightings increased ($F_{1,3099} = 130.56$; $p < 0.01$) when HAADs were 'on' (8.93 m ± 8.81 m) as compared to when HAADs were 'off' (8.07 m ± 8.15 m) (Figure 2). In 1996, between HAADs and humpback and fin whale sightings again increased ($F_{1,472} = 35.96$; $p < 0.01$) when HAADs were 'on' (7.86 m ± 7.34 m) as compared to when HAADs were 'off' (7.70 m ± 7.63 m) (Figure 3).

Time of Day

Distance between HAADs and humpback and fin whale sightings changed ($F_{3,3572} = 33.39$; $p < 0.01$) with time of day during both years of the study. Distance increased from 0600 to 0900 hours (8.31 m ± 7.97 m) to 0900 to 1200 hours (8.34 m ± 8.53 m), decreased during 1200 to 1500 hours (8.21 m ± 8.15 m), and increased during 1500 to 1800 hours (8.49 m ± 8.43 m) (Figure 4). In 1995, distance between HAADs and humpback and fin whales sightings changed ($F_{3,3099} = 42.77$; $p < 0.01$) with time of day. Distance increased from 0600 to 0900 hours (8.32 m ± 7.96 m) to 0900 to 1200 hours (8.34 m ± 8.54 m), decreased during 1200 to 1500 hours (8.31 m ± 8.20 m), and increased during 1500 to 1800 hours (8.60 m ± 8.49 m) (Figure 5). In 1996, distance between HAADs and humpback and fin whale sightings changed ($F_{3,472} = 7.16$; $p < 0.01$) with time of day. Distance increased from 0600 to 0900 hours (6.36 m ± 0 m) to 0900 to

1200 hours (8.34 m ± 7.71 m), decreased during 1200 to 1500 hours (7.59 m ± 7.52 m), and increased during 1500 to 1800 hours (7.84 m ± 7.45 m) (Figure 6).

Visibility

Distance between HAADs and humpback and fin whale sightings decreased ($F_{2,3572} = 38.26$; $p < 0.01$) with diminishing visibility during both years of the study. Distance between HAADs and whale sightings during visibility category one was 8.39 m (± 8.43 m), during category two it was 8.09 m (± 8.07 m), and during category three it was 6.18 m (± 1.39 m) (Figure 7). In 1995, distance between HAADs and humpback and fin whale sightings decreased ($F_{2,3099} = 42.77$; $p < 0.01$) with diminishing visibility. Distance between HAADs and whale sightings during visibility category one was 8.42 m (± 8.45 m) and during category two it was 8.28 m (± 8.22 m) (Figure 8). In 1996, distance between HAADs and humpback and fin whale sightings decreased ($F_{2,472} = 7.16$; $p < 0.01$) with diminishing visibility. Distance between HAADs and whale sightings during visibility category one was 7.86 m (± 7.73 m), during category two it was 7.69 m (± 7.40 m), and during category three it was 6.18 m (± 1.39 m) (Figure 9). There were no distance data for visibility category four during either year of the study or for visibility category three during 1995.

Vessel Presence or Absence

Distance between HAADs and humpback and fin whale sightings increased ($F_{1,3572} = 106.72$; $p < 0.01$) when vessels were absent from the study site (8.48 m ± 8.38 m) as compared to when vessels were present in the study site (8.20 m ± 8.36 m) during both years of the study (Figure 10). In 1995, distance between HAADs and humpback and fin whale sightings increased ($F_{1,3099} = 218.52$; $p < 0.01$) when vessels were absent from the study site (8.58 m ± 8.42 m) as compared to when vessels were present in the study site (8.25 m ± 8.40 m) (Figure 11). In 1996, the distance between HAADs and humpback and fin whale sightings when vessels were absent from the study site was 7.74 m (± 7.47 m) and was 7.77 m (± 7.64 m) when vessels were present in the study site (Figure 12). Because of association between the explanatory variable vessel presence/absence and the GLM (i.e., collinearity), the explanatory variable vessel presence/absence could not be included in the 1996 analysis.

Sea State

Distance between HAADs and humpback and fin whale sightings decreased ($F_{3,3572} = 35.89$; $p < 0.01$) with increasing sea state during both years of the study. Distance between HAADs and whale sightings during flat calm was 8.82 m (± 8.78 m), during ripples 8.16 m (± 8.12 m), during small waves 8.42 m (± 8.24 m), and during large waves (white caps) was 7.81 m (± 7.97 m) (Figure 13). In 1995, distance between HAADs and humpback and fin whales sightings decreased ($F_{3,3099}= 27.45$; $p < 0.01$) with increasing sea state. Distance between HAADs and whale sightings during flat calm was 9.09 m (± 8.89 m), during ripples 8.25 m (± 8.16 m), during small waves 8.42 m (± 8.24 m), and during large waves (white caps) was 7.82 m (± 7.97 m) (Figure 14). In 1996, distance between HAADs and humpback and fin whales sightings again decreased ($F_{3,472}$ = 84.71; $p < 0.01$) with increasing sea state. Distance between HAADs and whale sightings during flat calm was 8.07 m (± 7.73 m), during ripples 7.31 m (± 6.66 m), and during large waves (white caps) was 6.95 m (± 5.37 m) (Figure 15).

3.2 Distance Between HAADs and Minke Whale Sightings

The distance between HAADs and minke whale sightings was analyzed to determine if the distribution changed in response to operating condition of HAADs, time of day, visibility, vessel presence or absence, and sea state. Because the natural log of distance was used in all analyses, all distances reported throughout this section will actually be the natural log of distance.

Operating Condition of HAADs

Distance between HAADs and minke whale sightings did not change ($F_{1,248}$ = 0.00; p = 0.95) when HAADs were 'on' (6.72 m ± 6.39 m) as compared to when HAADs were 'off' (6.47 m ± 6.16 m) during both years of the study (Table 4 and Figure 16). In 1995, distance between HAADs and minke whale sightings did not change ($F_{1,160}$ = 0.00; p = 0.99) when HAADs were 'on' (6.41 m ± 5.95 m) as compared to when HAADs were 'off' (6.53 m ± 6.23 m) (Figure 17). In 1996, distance between HAADs and minke whale sightings did not change ($F_{1,87}$ = 2.35; p = 0.13) when HAADs were 'on' (7.02 m ± 6.54 m) as compared to when HAADs were 'off' (6.30 m ± 5.92 m) (Figure 18).

Time of Day

Distance between HAADs and minke whales sightings did not change ($F_{3,248}$ = 0.21; p = 0.89) with time of day when data from both years of the study were pooled. Distance between HAADs and whale sightings during 0600 to 0900 hours was 6.12 m (± 4.69 m), 0900 to 1200 hours was 6.15 m (± 5.44 m), 1200 to 1500 hours was 6.70 m (± 6.39 m), and 1500 to 1800 hours was 6.61 m (± 6.18 m) (Figure 19). In 1995, distance between HAADs and minke whales sightings did not change ($F_{3,160}$ = 0.81; p = 0.49) with time of day. Distance between HAADs and whale sightings during 0600 to 0900 hours was 5.94 m (± 0 m), 0900 to 1200 hours was 6.22 m (± 5.37 m), 1200 to 1500 hours was 6.61 m (± 6.32 m), and 1500 to 1800 hours was 6.42 m (± 5.66 m) (Figure 20). However, during 1996, distance between HAADs and whale sightings increased ($F_{3,87}$= 8.78; p < 0.01) with time of day. Distance between HAADs and minke whale sightings during 0600 to 0900 hours was 6.35 m (± 4.25 m), 0900 to 1200 hours was 5.15 m (± 4.81 m), 1200 to 1500 hours was 6.82 m (± 6.47 m), and 1500 to 1800 hours was 6.80 m (± 6.44 m) (Figure 21).

Visibility

Distance between HAADs and minke whale sightings changed ($F_{3,248}$ = 2.79; p = 0.04) with visibility when data from both years of the study were pooled. Distance between HAADs and minke whale sightings during visibility category one was 6.37 m (± 5.93 m), during category two was 6.79 m (± 6.48 m), during category three 6.86 m (± 6.46 m), and during category four 6.56 m (± 6.15 m) (Figure 22). In 1995, distance between HAADs and whale sightings did not change ($F_{1,160} = 0.10$; $p = 0.76$) with visibility. Distance between HAADs and whale sightings during visibility category one was 6.39 m (± 6.00 m) and during category two was 6.62 m (± 6.27 m) (Figure 23). In 1996, distance between HAADs and minke whales sightings changed ($F_{3,87} = 5.63$; $p < 0.01$) with visibility. In 1996, the average distance between HAADs and minke whale sightings during visibility category one was 6.32 m (± 5.67 m), during category two was 7.02 m (± 6.63 m), during category three 6.86 m (± 6.46 m), and during category four 6.56 m (± 6.15 m) (Figure 24).

Vessel Presence or Absence

Distance between HAADs and minke whale sightings did not change ($F_{1,248} = 0.90$; $p = 0.44$) when vessels were absent from the study site (6.61 m ± 6.33 m) as compared to when vessels were present in the study site (6.58 m ± 6.25 m) when data from both years of the study were pooled (Figure 25). In 1995, distance between HAADs and minke whale sightings did not change ($F_{1,160} = 1.55$; $p = 0.22$) when vessels were absent from the study site (6.38 m ± 5.83 m) as compared to when vessels were present in the study site (6.58 m ± 6.30 m) (Figure 26). In 1996, the distance between HAADs and minke whale sightings when vessels were absent from the study site was 6.88 m (± 6.60

m) and was 6.58 m (± 6.13 m) when vessels were present in the study site (Figure 27). Because of association between the explanatory variable vessel presence/absence and the GLM (i.e., collinearity), the explanatory variable vessel presence/absence could not be included in the 1996 analysis.

Sea State

Distance between HAADs and minke whale sightings decreased ($F_{3,248}$= 3.04; p = 0.03) with increasing sea state when data from both years of the study were pooled. Distance between HAADs and whale sightings during flat calm was 6.84 m (± 6.49 m), during ripples 6.66 m (± 6.41 m), during small waves 6.36 m (± 5.78 m), and during large waves (white caps) was 5.97 m (± 5.11 m) (Figure 28). In 1995, distance between HAADs and minke whale sightings did not differ ($F_{3,160}$ = 2.07; p = 0.11) with sea state. Distance between HAADs and whale sightings during flat calm was 6.52 m (± 6.04 m), during ripples 6.85 m (± 6.46 m), during small waves 6.35 m (± 5.72 m), and during large waves (white caps) was 6.12 m (± 4.73 m) (Figure 29). In 1996, distance between HAADs and whale sightings decreased ($F_{2,87}$= 10.57; $p < 0.01$) with increasing sea state. Distance between HAADs and whale sightings during flat calm was 6.88 m (± 6.47 m), during ripples 6.08 m (± 5.87 m), and during large waves (white caps) was 4.96 m (± 4.08 m) (Figure 30).

3.3 Sighting Rate of Humpback and Fin Whales

Whale abundance, quantified as sighting rate or the number of whales sighted per hour, was analyzed to determine if abundance changed in response to operating condition of HAADs and time of day. Sighting rates were calculated per day or per time of day category by dividing the number of sightings by the number of hours observed. Operating condition of HAADs and time of day were the only explanatory variables collected on a per day or per time of day basis. All other explanatory variables, such as visibility, sea state, and vessel presence or absence, were recorded with each sighting and tended to change throughout the day and/or time of day category, therefore, they could not be included in the analysis.

Operating Condition of HAADs

The sighting rate of humpback and fin whales did not change ($F_{1,25}= 1.24$; p = 0.28) when HAADs were 'on' (17.9 sightings per hour ± 11.3 sightings per hour) as compared to when HAADs were 'off' (33.4 sightings per hour ± 40.6 sightings per hour) when data from both years of the study were pooled (Table 5 and Figure 31). In 1995, the sighting rate of humpback and fin whales decreased ($F_{1,13}= 5.86$; p = 0.03) when HAADs were 'on' (21.9 sightings per hour ± 11.1 sightings per hour) as compared to when HAADs were 'off' (61.4 sightings per hour ± 41.2 sightings per hour) (Figure 32). In 1996, the sighting rate of humpback and fin whale did not change ($F_{1,11} = 0.84$; p = 0.38) when HAADs were 'on' (9.9 sightings per hour ± 8.0 sightings per hour) as compared to when HAADs were 'off' (6.1 sightings per hour ± 5.8 sightings per hour) (Figure 33).

Time of Day

The sighting rate of humpback and fin whales sightings did not change ($F_{2,53}$ = 1.18; p = 0.31) with time of day when data from both years of the study were pooled. The sighting rate during 0600 to 0900 hours was 3.27 sightings per hour (± 16.07 sightings per hour), during 0900 to 1200 hours it was 20.65 sightings per hour (± 32.63 sightings per hour), during 1200 to 1500 hours it was 20.74 sightings per hour (± 31.75 sightings per hour), and during 1500 to 1800 hours it was 25.35 sightings per hour (± 45.57 sightings per hour) (Figure 34). In 1995, the sighting rate of humpback and fin whales sightings did not change ($F_{2,30}$ = 1.79; p = 0.19) with time of day. The sighting rate during 0600 to 0900 hours was 6.07 sightings per hour (± 21.87 sightings per hour), during 0900 to 1200 hours it was 36.77 sightings per hour (± 37.70 sightings per hour), during 1200 to 1500 hours it was 31.62 sightings per hour (± 39.87 sightings per hour), and during 1500 to 1800 hours it was 42.46 sightings per hour (± 56.39 sightings per hour) (Figure 35). In 1996, the sighting rate of humpback and fin whales sightings did not change ($F_{2,22}$ = 0.32; p = 0.73) with time of day. The sighting rate during 0900 to 1200 hours was 1.85 sightings per hour (± 4.91 sightings per hour), during 1200 to 1500 hours it was 8.05 sightings per hour (± 9.3 sightings per hour), and during 1500 to 1800 hours it was 5.39 sightings per hour (± 12.45 sightings per hour) (Figure 36).

3.4 Sighting Rate of Minke Whales

The sighting rate of minke whales was analyzed to determine if abundance changed in response to operating condition of HAADs and time of day. As with the humpback and fin whale analysis, operating condition of HAADs and time of day were the only explanatory variables collected on a per day or per time of day basis. All other explanatory variables, such as visibility, sea state, and vessel presence or absence, were recorded with each sighting and could not be included in the analysis.

Operating Condition of HAADs

The sighting rate of minke whales did not change ($F_{1,23} = 0.55$; $p = 0.47$) when HAADs were 'on' (3.0 sightings per hour ± 3.5 sightings per hour) as compared to when HAADs were 'off' (2.0 sightings per hour ± 2.7 sightings per hour) when data from both years of the study were pooled (Table 6 and Figure 37). In 1995, the sighting rate of minke whales change did not change ($F_{1,9} = 0.00$; $p = 0.99$) when HAADs were 'on' (3.8 sightings per hour ± 5.2 sightings per hour) as compared to when HAADs were 'off' (3.8 sightings per hour ± 3.6 sightings per hour) (Figure 38). In 1996, the sighting rate of minke whales increased ($F_{1,13} = 4.60$; $p = 0.05$) when HAADs were 'on' (2.1 sightings per hour ± 0.9 sightings per hour) as compared to when HAADs were 'off' (0.9 sightings per hour ± 1.0 sightings per hour) (Figure 39) .

Time of Day

The sighting rate of minke whales sightings did not change ($F_{2,31} = 2.17$; $p = 0.13$) with time of day when data from both years of the study were pooled. The sighting rate during 0600 to 0900 hours was 0.1 sightings per hour (±0.6 sightings per hour), during 0900 to 1200 hours was 1.62 sightings per hour (±3.75 sightings per hour), during 1200 to 1500 hours it was 2.21 sightings per hour (±2.21 sightings per hour), and during 1500 to 1800 hours it was 0.85 sightings per hour (±1.96 sightings per hour) (Figure 40). In 1995, the sighting rate of minke whales sightings did not change ($F_{2,15} = 1.16$; $p = 0.34$) with time of day. The sighting rate during 0600 to 0900 hours was 0.3 sightings per hour (±0.95 sightings per hour), during 0900 to 1200 hours it was 3.34 sightings per hour (± 5.34 sightings per hour), during 1200 to 1500 hours it was 2.59 sightings per hour (±2.68 sightings per hour), and during 1500 to 1800 hours it was 1.54 sightings per hour (±2.81 sightings per hour) (Figure 41). In 1996, the sighting rate of minke whales sightings did not change ($F_{2,15} = 0.25$; $p = 0.78$) with time of day. The sighting rate during 0900 to 1200 hours was 0.39 sightings per hour (±1.11 sightings per hour), during 1200 to 1500 hours it was 1.94 sightings per hour (±1.85 sightings per hour), and during 1500 to 1800 hours it was 0.36 sightings per hour (±0.86 sightings per hour) (Figure 42).

3.5 Behaviour of Humpback and Fin Whales

The behaviour of known, independent groups of humpback and fin whales was analyzed to determine if behaviour changed in response to operating condition of HAADs. The surface behaviours observed in humpback and fin whales included: respiration (blow visible), surface (only dorsal surface visible), fluking, breaching, flippering, spy hopping, lunge feeding, and bubble feeding (Tables 7 and 8).

Because of the difficulty associated with analyzing cetacean behavioural data (discussed in section 4.4), this study's low sample size of known, independent groups of whales, and the fact that most behaviours were not observed during both operating conditions (HAADs 'on' versus HAADs 'off'), options for an analysis of behavioural data were limited. Therefore, the analysis attempted to focus on those behaviours known to be associated with important activities (e.g., foraging, breathing) and behaviours that were observed during both operating conditions. The only behaviours that met this criteria for humpback and fin whales were respiration and fluking. A proportion was calculated for respiration and fluking by dividing the frequency of the behaviour by the frequency of all other behaviours, this proportion was then statistically analyzed.

Two-tailed T-tests were used to analyze the behavioural data of known groups of humpback and fin whales during both 'on' and 'off' conditions of HAADs. Analysis of surface behaviours observed indicated there was no change in the proportion of respirations ($t = -0.08$; $df = 23$; $p = 0.94$) or the proportion of fluking ($t = 1.64$; $df = 18$; p

= 0.12) between operating condition of HAADs. In 1995, there were no change in the proportion of respirations (t = -0.99; df = 11; p = 0.35) or the proportion of fluking (t = 1.77; df = 8; p = 0.12) between operating condition of HAADs. In 1996, there were no changes in the proportion of respirations (t = 0.7; df = 14; p = 0.94) or the proportion of fluking (t = 1.29; df = 9; p = 0.23) between operating condition of HAADs.

The duration that known groups were observed within the study site was also compared between 'off' and 'on' conditions of HAADs (Table 9 and 10). The duration known humpback and fin whale groups spent within the study site did not change (t = -0.74; df = 26; p = 0.47) when HAADs were 'on' (33 minutes ± 44 minutes) compared to when HAADs were 'off' (25 minutes ± 25 minutes) when data from both years were pooled. In 1995, the duration known humpback and fin whale groups spent within the study site did not change (t = -0.85; df = 6; p = 0.43) when HAADs were 'on' (44 minutes ± 60 minutes) compared to when HAADs were 'off' (24 minutes ± 26 minutes). In 1996, the duration known humpback and fin whale groups spent within the study site did not change (t = -0.8; df = 21; p = 0.94) when HAADs were 'on' (27 minutes ± 34 minutes) compared to when HAADs were 'off' (26 minutes ± 24 minutes).

Known group data from humpback and fin whales were also used to compare approach distance between operating conditions of HAADs (Table 9 and 10). Approach distance was calculated by subtracting the closest distance to the HAADs that a known group approached from the initial distance where the group was sighted. Analysis of the approach distance for known groups of humpback and fin whales indicated no change (t = -0.44; df = 38; p = 0.66) when HAADs were 'on' (433 m ± 627 m) as compared to when HAADs were 'off' (356 m ± 585 m). In 1995, approach distance did not change (t = -1.66; df = 6; p = 0.15) when HAADs were 'on' (803 m ± 903 m) as compared to when HAADs were 'off' (221 m ± 333 m). In 1996, approach distance did not change (t = 1.32; df = 18; p = 0.20) when HAADs were 'on' (233 m ± 301 m) as compared to when HAADs were 'off' (519 m ± 773 m).

3.6 Behaviour of Minke Whales

The behaviour of known, independent groups of minke whales was analyzed to determine if behaviour changed in response to operating condition of HAADs. The surface behaviours observed in minke whales included: respiration (blow visible), surfacing (only dorsal surface visible), fluking, lunge feeding, and bubble feeding (Table 11 and 12).

Because of the aforementioned difficulty in analyzing cetacean behavioural data, this analysis attempted to focus on those behaviours known to be associated with important activities and observed during both operating conditions (HAADs 'on' versus HAADs 'off'). The only behaviour that met this criteria for minke whales was respiration. However, because surfacing is often difficult to distinguish from respiration in minke whales and surfacing was the only behaviour observed during both years of the study, it too was included in the analysis. A proportion was calculated for respiration and surfacing by dividing the frequency of the behaviour by the frequency of all other behaviours, this proportion was then statistically analyzed.

Two-tailed T-tests were used to analyze the behavioural data of known, independent groups of minke whales during both 'on' and 'off' conditions of HAADs. Analysis of surface behaviours observed during 1995 indicated there was no change in the proportion of respirations ($t = 1.50$; $df = 1$; $p = 0.37$) or the proportion of surfacing ($t = 0.46$; $df = 7$; $p = 0.66$) between operating condition of HAADs. In 1996, the only surface behaviour observed in minke whales during both operating conditions of HAADs was surfacing, thus, a statistical analysis was precluded.

The duration that known groups were observed within the study site was also compared between 'off' and 'on' conditions of HAADs (Table 13 and 14). Analysis of the duration known minke whale groups spent within the study site indicated no change ($t = -1.72$; $df = 11$; $p = 0.11$) when HAADs were 'on' (23 minutes $\pm$ 28 minutes) as compared to when HAADs were 'off' (8 minutes $\pm$ 11 minutes) when data from both years of the study were pooled. In 1995, the duration known groups of minke whales spent within the study site did not change ($t = -01.10$; $df = 4$; $p = 0.33$) when HAADs were 'on' (28 minutes $\pm$ 38 minutes) as compared to when HAADs were 'off' (9 minutes $\pm$ 12 minutes). In 1996, the duration known groups of minke whales spent within the study site did not change (t = -1.69; df = 5; p = 0.15) when HAADs were 'on' (19 minutes ± 18 minutes) as compared to when HAADs were 'off' (6 minutes ± 5 minutes).

Known group data from minke whales was also used to compare approach distance between operating conditions of HAADs (Table 13 and 14). As described previously, approach distance was calculated by subtracting the closest distance to the HAADs that a known group approached from the initial distance where the group was sighted. Analysis of the approach distance for known groups of minke whales indicated that it did not change (t = -0.89; df = 22; p = 0.38) when HAADs were 'on' (158 m ± 176 m) as compared to when HAADs were 'off' (96 m ± 198 m) when data from both years of the study were pooled. In 1995, the approach distance of known groups of minke whales did not change (t = 1.35; df = 16; p = 0.20) when HAADs were 'on' (30 m ± 44 m) as compared to when HAADs were 'off' (113 m ± 226 m). However, in 1996, the approach distance of know groups of minke whales decreased (t = -2.94; df = 5; p = 0.03) when HAADs were 'on' (265 m ± 174 m) as compared to when HAADs were 'off' (47 m ± 48 m).

3.7 Oceanographic Data

Temperature/depth profiles of the water column in the study site were analyzed for both years of the study. Data were collected once during each year of the study, depending on when both a research vessel and the recording equipment were available, and were evaluated from 14 sites on 10 August 1995 (10.5 °C ± 5.2 °C) and at 18 sites on 28 August 1996 (11.5 °C ± 5.5 °C) (Table 15 and Figure 43). To determine if temperature within the study site differed between years, a GLM was used to analyze temperature data from all depths and both years. Water temperature in the study site did not change ($F_{1,5} = 0.31$; $p = 0.61$) from 1995 (10.5 °C ± 5.2 °C) to 1996 (11.5 °C ± 5.5 °C) . Additionally, two-tailed T-tests were used to analyze temperatures at similar depths between years. Analysis indicated that temperatures at depths from 5 m to 25 m increased ($t = -8.67$; df = 15; $p < 0.01$) from 1995 (10.3 °C ± 0.9 °C) to 1996 (14.2 °C ± 1.0 °C), however, temperatures at other depths analyses did not change between years (Table 16).

3.8 Fishery Data

The Sentinel Fishery had only limited information detailing the presence of capelin near the study site during both years of the study. In 1995, capelin were observed from 25 July to 2 August and females appeared ready to spawn on the 26th and 27th of July. Capelin were present in and around the study site from 26 June to 8 August in 1996 and large numbers of capelin that may indicate spawning were recorded on the 2nd of July (H. Vaters, Sentinel Fishery, St. John's, Newfoundland, unpublished data). During the first week of August 1996, observers for this study noted that capelin were visible at the water's surface and accompanied by a great deal of seabird and whale activity. This anecdotal evidence suggests that capelin were present in the study site and may have spawned in the area again during early August 1996.

Canadian Stock Assessment Research Documents and Atlantic Fisheries Stock Status Reports provided information on prey distribution and abundance for Conception Bay and the east coast of the Avalon Peninsula during both years of the study. Standardized estimates of annual biomass indicated that capelin were more abundant in the waters of eastern Newfoundland during 1996 than during 1995 (Nakashima and Winters 1997). In 1995, estimates of cohort abundance suggest that capelin year-class strength was dominated by two year-old capelin, followed by one year-old capelin, followed by three year-old capelin (Anderson and Dalley 1996; Winters 1996). The most abundant capelin year-class during 1996 appeared to be one and three year-old capelin followed by two year-old individuals (Anderson and Dalley 1997).

3.9 Acoustic Levels of HAADs

Recordings of HAADs were made on 10 August 1995 at depths of 15 and 30 m at 19 stations throughout the study site. Four speakers connected to a common battery produced a series of 1.8 ms pulses at 40 ms intervals grouped into 2.3 s trains with 2.1 ms gaps. The pulse-average peaks at 194 dB re 1mPa at 1 m and was concentrated around 10 kHz with a single harmonic at 20 kHz. Relative amplitudes ranged from 78.3 dB re 1mPa at a depth of 15 m at the HAADs' installation to 42.8 dB re 1mPa at a distance of 2.4 km

(Figure 44). A GLM indicated that relative amplitude of HAADs did not change ($F_{1,27}$ = 2.49; p = 0.13) at depths of 15 m (66.8 dB re 1mPa ± 10.1 dB re 1mPa) or 30 m (60.3 dB re 1mPa ± 11.5 dB re 1mPa) and relative amplitude of HAADs did not change ($F_{1,14}$ = 1.42; p = 0.26) with distance from the source.

DISCUSSION

4.1 Distribution of Baleen Whales

Results suggest that the distribution of baleen whales off Cape Saint Francis, Newfoundland was related to operating condition of HAADs, time of day, visibility, vessel presence or absence, and sea state.

During both 1995 and 1996, humpback and fin whales were observed further from operating HAADs than non-operating HAADs. This decreased proximity to operating HAADs suggests an avoidance response. In contrast, the operating condition of HAADs did not have an influence on the distribution of minke whales. This lack of a relationship between the operating condition of HAADs and the distance between minke whales and HAADs suggests that either minke whales are not influenced by HAADs or that their retreat from operating HAADs was too subtle to be detected during this study.

It is possible that the apparent changes in baleen whale distribution with time of day, visibility, and sea state may have reflected a difference in sightability rather than a difference in whale distribution. Sightability of whales at Cape Saint Francis was often dependent on time of day. Sightability was frequently compromised by fog during morning hours, but increased throughout the day. Similarly, visibility conditions would affect sightability. Whales were sighted more closely to HAADs when visibility was declining (increasing measures of visibility), probably reflecting the observer's ability to see whales. Additionally, whales were sighted more closely to HAADs when sea state was increasing (increasing measures of sea state). Again, this result may have been linked to sightability, as whales grew increasingly difficult to see as the sea state increased. Another possibility, however, is that increasing sea state made HAADs more difficult for whales to detect. If HAADs were more difficult to detect when the sea state was increasing, whales may have approached the HAADs installation more closely. As discussed in section 2.6, minke whales were more difficult to reliably identify from a distance than humpback or fin whales, therefore, minke whale distribution data were edited to include only minke whales sightings less than three km from HAADs. It was not expected that sightability varied much for whales within three km of HAADs, making sightability more of an issue for humpback and fin whales than for minke whales. Because observations were halted when conditions of visibility or sea state declined past category four (visibility ≤ 3 km; sea state = large waves with white caps), it was assumed that all observations occurred under appropriate sighting conditions.

When analyzing the influence of HAADs on the observed distribution of baleen whales, it is important to consider the potential biases of visibility and sea state conditions. Therefore, distribution data were reviewed to assess whether observations during HAADs conditions ('on' versus 'off') were made under similar visibility and sea state conditions. During observations of humpback and fin whales, the visibility condition averaged to 'unlimited' during both operating conditions of HAADs. Of humpback and fin whale observations, 79% occurred when visibility was 'unlimited' and

21% occurred when visibility was 'less than 23.5 km'. During observations of minke whales, visibility categories averaged to 'unlimited' when HAADs were 'off' and to 'less than 23.5 km but greater than 9.8 km' when HAADs were 'on'. Therefore, a change in visibility conditions between operating conditions of HAADs was not thought to have affected baleen whale distribution data.

It is possible that there was an association between time of day and visibility and/or sea states conditions, but that relationship was not analyzed as part of this study.

During observations of humpback and fin whales, sea state categories averaged to 'small waves' when HAADs were 'off' and to 'flat calm' when HAADs were 'on'. Of humpback and fin whale observations, 18% occurred when sea state was 'flat calm', 48% occurred when sea state was 'ripples', 21% occurred when sea state was 'small waves', and 13% occurred when sea state was 'large waves'. Less wave action during periods when HAADs were operating may have increased the sightability of humpback and fin whales further from HAADs and contributed to the observed increased distance between HAADs and whale sightings. For observations of minke whales, the average sea state category was 'ripples' during both operating conditions. Of minke whale observations, 40% occurred when sea state was 'flat calm', 18% occurred when sea state was 'ripples', 38% occurred when sea state was 'small waves', and 4% occurred when sea state was 'large waves'. Therefore, it is not expected that a change of sea state conditions between operating conditions of HAADs affected the observed distribution of minke whales.

The observed increase in humpback and fin whale distribution when vessels were absent from the study site is likely more closely linked to data collection methods than an actual change in whale distribution. Any vessel visible to the observers was documented as being present within the study site; vessel presence was recorded without an accompanying measure of vessel proximity to HAADs or to whales in the area. Observers did not categorize the type of vessel observed, therefore, any comparison of vessel types and their effects on the distribution of whales is not possible. Vessel traffic was fairly frequent offshore of Cape Saint Francis, accounting for a high number of whale sightings when vessels were recorded as being present within the study site. However, vessel traffic was fairly infrequent in the vicinity of Cape Saint Francis. A relationship between vessel presence or absence and whale distribution is unlikely, as it is thought that the majority of vessel sightings would have been too far from the whales observed during this study to influence their distribution.

4.2 Abundance of Baleen Whales

Results suggest that baleen whale abundance changed in the presence of operating HAADs but not with time of day. During 1995, the sighting rate of humpback and fin whales decreased in the presence of operating HAADs. Similar to an increase in the distance between whales and HAADs, this decrease in abundance may indicate an avoidance response. Humpback and fin whales may have not occupied the study site when alarms were operating, moved to distances that were not visible from Cape Saint Francis, or spent less time at the water's surface. During 1996, there was no observed change in sighting rate with operating condition of HAADs. Observed differences in sighting rate between years may be partially due to sample size. More humpback and fin whales were sighted during 1995 (3100 sightings) than during 1996 (473 sightings) despite an increase in sighting effort from 1995 (71 hours) to 1996 (103 hours). Perhaps also contributing to the observed differences in sighting rate between years may be prey conditions (discussed in section 4.5). During 1995, there was no observed relationship between operating condition of HAADs and the sighting rate of minke whales, however, during 1996 the sighting rate of minke whales increased in the presence of operating HAADs. Once again, there were differences in sample size between years (161 sightings in 1995 and 88 sightings in 1996). The observed 'attraction' in minke whales to operating HAADs during 1996 may provide evidence that the study site was a more important habitat for minke whales during the second year of the study than during the first (discussed in section 4.5), or it may be an indication of habituation and/or a threshold shift (discussed in section 4.3).

Abundance, or sighting rate, data do not support the time of day influence evident in the distribution data for humpback and fin whales during both years of the study and minke whales during 1996. Much like distribution data, the sighting rate of baleen whales may be influenced by increasing sightability of whales throughout the day. Lack of a change in sighting rate with time of day may also be because not all time periods are equally represented in the data. Observations are more numerous during time periods two (0900 - 1200 hours) and three (1200 - 1500 hours) than during periods one (0600 - 0900 hours) and four (1500 - 1800 hours). Additionally, if whale distribution did change with time of day, this change would have only been evident in sighting rate data if the whales moved far enough offshore to no longer be visible from Cape Saint Francis.

4.3 Ecological Strategies of Transient and Resident Species

Measures of distribution and abundance differed between baleen whales species observed in the presence of operating HAADs. Results indicate that operating HAADs generally encouraged humpback and fin whales to avoid the study site, while operating HAADs either had no observed influence (as in the distribution data) or appeared to be an attractant (as in the abundance data) for minke whales. These seemingly contradictory reactions of humpback/fin and minke whales may be a result of different ecological strategies used by transient and resident species.

Humpback and fin whales are known for lengthy, seasonal migrations between winter breeding grounds and summer foraging areas (Whitehead et al. 1982; Tillman and Donovan 1986). Re-sightings of photographically identified humpback whales indicate site fidelity between years for regional feeding areas (Katona and Beard 1990). In addition, pelagic stocks of fin whales are also thought to return annually to the same general foraging areas (Tillman and Donovan 1986).

Within the Newfoundland and Labrador feeding aggregation, Whitehead et al. (1980) found that humpback whales generally travel in a northward direction. Residency rates of individuals studied at Bay de Verde (47^{0}05" N. latitude; 52^{0}50" W. longitude), located across Conception Bay from Cape Saint Francis, were typically less than three days. Similar residency trends were also evident during this study, as humpback and fin whales tended to move past Cape Saint Francis while heading north within a period of hours. Rarely did individuals remain in the area for any length of time.

These data support the idea that the study site may not have served as important feeding habitat for humpback and fin whales. An avoidance response to the HAADs could be expected if a species was transient in the area and occupation of the study site was not biologically important. However, it is important to note that humpback and fin whales may not be able to avoid acoustic deterrents if they were placed in areas critical for feeding or reproduction.

Previous research in eastern Canada indicated that minke whales are generally evenly distributed throughout study areas and have a preference for coastal waters (Perkins and Whitehead 1977). While little is known about residency patterns in minke whales (Dorsey et al. 1990), studies with individually identified individuals suggested that they hold home ranges seasonally and perhaps year around (Dorsey 1983). In addition, Borggaard (1996) found that minke whales in Newfoundland were re-sighted within and between years in the same general area where they were initially identified and there was no evidence of directional migration. While individual recognition of minke whales was not possible during this study, a single whale was regularly sighted in the same area during 1996. If minke whales exhibit small-scale site fidelity, they would have little opportunity to avoid HAADs placed within their home range.

During this study, an increased sighting rate was observed in minke whales during 1996 when HAADs were operating. While a relatively small sample size (161 observations in 1995 and 88 observations in 1996) may limit the strength of conclusions about minke whales, this observed increase in sighting rate may be linked to several factors. The increase in sighting rate when HAADs were operating may indicate that minke whales were remaining at the water's surface in an effort to decrease sound propagation in the upper layers of the water column. Another possibility is that minke whales observed in the vicinity of the HAADs may have sustained a threshold shift or hearing loss due to exposure. Any reduction in auditory acuity would have caused minke whales to appear unaffected by HAADs. The likelihood of auditory damage is increased if the same individuals were exposed to HAADs during both years of this study. Therefore, until more is learned about the habits of minke whales the apparent attraction observed in minke whales to operating HAADs should not assume tolerance but may instead indicate a cause for concern.

The question of habituation was not addressed in this study as methodology precluded any formal evaluation. Research investigating habituation is necessary over extended periods of time and with known individuals. Cape Saint Francis was well frequented by humpback and fin whales traveling northward, but the site rarely elicited extended residency time. While conducting sightings from a cliff was ideal to detect and observe cetaceans within a several kilometer area, it prohibited documenting known individuals for any lengthy duration. While minke whales were thought to be seasonal residents (Borggaard 1996; Perkins and Whitehead 1977; Todd et al. 1992), once again shore-based observations prevented individually identifying individuals and limited the time spent with any single whale. The increased proximity and sighting rate to operating HAADs observed in minke whales are possible indicators of habituation. Olesiuk et al. (1996) found no apparent evidence of habituation when testing HAADs on harbour porpoise as harbour porpoise tended to vacate the study site when acoustic deterrents were operating. The question of habituation to HAADs by baleen whales is important to address. Whales who adapt to the presence of man-made noise may remain in acoustically congested areas (Green et al. 1994) and increase the likelihood of sustaining hearing damage (Iwama et al. 1997).

4.4 Behaviour of Baleen Whales

Changes in mammalian behaviour are frequently used to measure impacts when environmental concerns are investigated. Therefore, an attempt to evaluate the behaviour of known, independent groups of humpback, fin, and minke whales was made during 1995 and 1996. Not all behaviours were observed during both operating conditions (HAADs 'on' versus HAADs 'off'), but of those that were, results suggest that the operating condition of HAADs had no influence on respirations and fluking in humpback and fin whales or respirations and surfacing in minke whales. It may be important to note that the behavioural diversity, or the number of different behaviours, observed in baleen whales was generally greatest when HAADs were not operating. However, behavioural diversity was neither quantified nor analyzed during this study. The duration spent within the study site and approach distance to HAADs of known independent groups of humpback and fin whales were not influenced by operating HAADs, while the approach distance of minke whales decreased in the presence of operating HAADs during 1996. The lack of a behavioural response observed in humpback, fin, and, to an extent, minke whales to the operating condition of HAADs seemingly contradicts the observed change in whale distribution and abundance in response to HAADs. This inconsistency may be due to the inability of the study to detect a change in behaviour, rather than a lack of behavioural response to HAADs. The sample size for the behavioural portion of this study was small; the number of known humpback and fin whale groups ranged from 5 to

18 with an average of 12 and the number of known minke whale groups ranged from 5 to 15 with an average of 8. In addition, while observing whales from shore removed the confounding presence of a research vessel in and around the study site, it prevented documenting known individuals for any length of time and made it difficult to track subtle changes in behaviour. Being able to monitor a larger number of whales (either known individuals or groups) for a longer duration may have led to an observed change in behaviour between operating conditions of HAADs.

Using behavioural change to evaluate a response to a stimulus in cetaceans has both methodological and interpretative limitations. Most cetacean behavioural data are collected only when the animal is at the water's surface, providing only a "snapshot" of total activity, and on too limited a scale to monitor change effectively. The behaviour a whale exhibits often depends, in part, on the context in which the sound is received; this context consists of an animal's external environment, ongoing distracting events, and its internal environment. Perception of the sound also influences any behavioral response to noise, this perception may be determined by sensory systems and/or prior experience. Instead of documenting whales' responses to sounds, impact assessment research should evaluate whether reactions reduce biological fitness (Gentry et al. 1998). As evaluating behavioural changes in cetaceans is difficult, the absence of significant findings due to HAADs should not be taken as an indicator of tolerance, but as an area for further research.

4.5 Oceanographic and Prey Conditions

Oceanographic conditions are thought to impact cetaceans by affecting the abundance and distribution of prey species (Smith and Whitehead 1993; Harwood and Borstad 1985). Capelin is a pelagic fish that migrates during summer months to spawn in coastal regions of eastern Newfoundland (Methven and Piatt 1991). During this time, baleen whales gather inshore and feed extensively on dense schools of capelin (Piatt et al. 1989; Katona and Beard 1990; Whitehead et al. 1980; Methven and Piatt 1991). Seasonal spawning of fish is well documented, but environmental factors that initiate reproduction are poorly understood (Therriault et al. 1996). However, previous research suggested that water temperatures may influence seasonal abundance of capelin during the spawning season (Methven and Piatt 1991).

In the Newfoundland and Labrador region, capelin traditionally spawn inshore on gravel beaches and in shallow water during June and July (Shackell et al. 1994). During the early to mid 1990s, a decrease in capelin abundance and delayed spawning season were thought to have been influenced by cold ocean events (Frank et al. 1996). A change in ocean temperature within the study site was not detected during this study, however, a warming of ocean temperatures in the waters around Newfoundland between 1995 and 1996 (Colbourne 1996) may have resulted in between year changes in capelin conditions during this study.

Given that the distribution and abundance of baleen whales is known to change in response to capelin (Whitehead and Carscadden 1985; Whitehead et al. 1980; Sergeant 1963; Piatt et al. 1989; Piatt and Methven 1992), between year differences in whale sightings may be a function of prey availability. As capelin abundance increased in eastern Newfoundland from 1995 to 1996 (Nakashima and Winters 1997), the number of baleen whales sighted off Cape Saint Francis decreased. During conditions of low capelin abundance, whales are likely to be widespread and spend much of their time in search of prey. The majority of whales sighted during 1995 were traveling past Cape Saint Francis and were thought to be in search of capelin schools. In response to the higher capelin abundance during 1996, whales may have been concentrated in a few areas of high prey density and not visible to observers at Cape Saint Francis. The earlier spawning of capelin during 1996 than during 1995 (Nakashima 1997) may also have affected baleen whales. If spawning occurred near Cape Saint Francis during the beginning of July, many whales may have already moved passed the study site and out of the area prior to the start of the 1996 field season.

While inter-annual variations in whale abundance appear to be linked to capelin, relationships are complex and differ across mysticete species (Piatt et al. 1989). The presence of baleen whales is correlated with capelin year-class strength and whales can be found inshore when there are few immature capelin offshore (Whitehead and Carscadden 1985). The dominant year-class during 1995 was two-year old capelin, while during 1996 three-year old and one-year old capelin were most abundant (Anderson and Dalley 1996; Winters 1996; Anderson and Dalley 1997). As humpback and fin whales move offshore in response to a strong three-year old age class and to a lesser extent a strong two-year old age class (Whitehead and Carscadden 1985), year-class may account for the decrease in humpback and fin whales sighted from 1995 to 1996. The response of minke whales to varying year-class strengths differs from that of humpback and fin whales. Minke whales move offshore in response to high abundance of one-year old to two-year old capelin (Whitehead and Carscadden 1985). Again, the change in capelin year-class strength between years may have accounted for the decrease in minke whale sighting between years.

As foraging strategies and prey requirements differ across whale species, variations in capelin density may have also had an impact on sighting data (Piatt et al. 1889; Piatt and Methven 1992). Due to the steep ocean floor and swift tides present at Cape Saint Francis, shoals of capelin were thought to be transitory within the study site (B. Nakashima, Research Scientist, Department of Fisheries and Oceans, St. John's, Newfoundland, personal communication). As capelin moved past Cape Saint Francis, the presence and abundance of baleen whale species should have fluctuated in accordance with each species' foraging threshold. Fin and humpback whales should have only occupied the study site on days with high capelin abundance while minke whales should have been present during days with lower capelin density (Piatt et al. 1989; Piatt and

Methven 1992). Although capelin density data from the Cape Saint Francis study area was not available, it is expected that variations in capelin density, together with species-specific feeding preferences of baleen whales, may have accounted for much of the within year variability in sighting data.

4. 6 Acoustic Levels of HAADs

To evaluate the effects of man-made noise on marine mammals, physical acoustics of anthropogenic sound should be examined. While a detailed acoustic analysis was beyond the scope of this study, important characteristics to explore include intensity, frequency, composition and temporal patterns of human-generated sound (Richardson 1991a).

The HAADs used in this study produced pulses with peaks at 194 dB re 1μPa at 1 m and concentrated around 10 kHz with a single harmonic at 20 kHz. As the auditory systems of baleen whales are quite sensitive and well adapted for hearing low frequencies (Richardson 1995a), the intense, low-frequency sound produced by HAADs was thought audible to baleen whales.

Site-specific propagation of sound also warrants investigation, as amplitude greatly varies with local transmission conditions and is not always distance dependent (Richardson 1991d; Malme and Beranek 1995). Results indicated that the relative amplitudes of the HAADs did not significantly vary with depth or distance. Technical difficulties prevented 1996 data from being included in the analysis. Because propagation data show that the audibility of a sound source will vary in time (Richardson 1995c) and considering the observed between year differences in whale abundance at Cape Saint Francis, a between year comparison of HAADs amplitude may yield interesting results.

HAADs were operated on a random schedule of days 'on' and days 'off' throughout both years of the study. While attempts were made to collect data during a similar number of days 'on' as days 'off', the number of observation days during the 'off' condition of HAADs outnumbered the number of observation days during the 'on' condition. This potential bias was more evident in 1996 than 1995. Similarly, the duration of the study varied between years of the study. Each year, the presence of baleen whales in the waters off Cape Saint Francis triggered both the beginning and the end of the study. In 1995, the study occurred from mid-July to early August and HAADs were primarily 'on' during late July. In 1996, the study occurred from mid-July to mid-August and HAADs were primarily 'on' during mid- July and early August. Differences in sample size between days 'on'/days 'off' and differences in seasonality of HAADs operation between 1995 and 1996 may affect this study's ability to drawn conclusions about the influence of HAADs on baleen whales.

Site-specific ambient noise influences cetaceans' ability to detect anthropogenic sound. Some dominant sources of ambient noise are: wind, waves, surf noise, seismic activity, biological noise, sea ice, thermal noise, and vessel traffic (Greene 1995). The relevant prevalence and frequency of occurrence of these various noise sources are not well understood, particularly in shallow water (Frisk et al. 1998). HAADs were moored to the ocean floor in relatively shallow water (10 m) at a distance of approximately one km from shore. Water depth was not documented at HAADs recording stations in the study site, but variation in depth may have played a role in the relative amplitude of HAADs. It is thought that the effects of anthropogenic noise may vary across sites with different ambient levels and decrease as the background noise of an area increases (Richardson 1991a). No direct measures of ambient levels were obtained for Cape Saint Francis during this study. However, the relative amplitude recorded during the study (78.3 dB re 1μPa at a depth of 15 m at the HAADs' installation to 42.8 dB re 1μPa at a distance of 2.4 km) was considerably less than manufacturer's specifications (194 dB re 1μPa at 1 m). Perhaps the difference in relative and absolute amplitude is an approximate measure of the study site's ambient noise. There can be great variability in ambient noise from day to day, minute to minute, and even second to second (Greene 1995). Had ambient noise levels differed significantly within the study site, they may have also played a role in the whale's responses to the operating condition of HAADs.

The ratio of sound signal to ambient noise is an important factor to consider when evaluating the effects of man-made noise on cetaceans. The critical ratios of marine mammals tend to increase with higher frequencies. While no data exist for mysticetes, it is thought that this trend would also be evident in baleen whales (Richardson 1995a). The primary component of the tone emitted by the HAADs was 10 kHz, therefore, it is thought that acoustic deterrents need only have an intensity approximately 20 dB above background noise to have been audible to mysticetes. Based on previous research, HAADs were thought to be audible to whales several kilometers from the sound source (Olesiuk et al. 1996; Iwama et al. 1997; Morton and Symonds 2002).

SUMMARY

5.1 Significant Findings

Results suggest that the operating condition of HAADs was related to the distribution and abundance of baleen whales and may have influenced transient and resident species differently. As transitory species, humpback and fin whales were less likely to occupy the study site when HAADs were operating, perhaps because the area was not a critical habitat to occupy. Conversely, if the study site overlapped with the range of a resident minke whales, occupying the study site would be of some importance. The apparent attraction to operating HAADs observed in minke whale abundance data may indicate a tendency for resident species in remain in acoustically congested habitats out of necessity, habituation to HAADs, and/or a threshold shift due to exposure. While the only behavioural change detected during this study was the decrease in approach distance to operating HAADs observed in minke whales during 1996, given the previously discussed limitations of using behavioural data, the relationship between HAADs and whale behaviour is still an area of concern.

Documenting the relationship between HAADs and baleen whale distribution and abundance provided information detailing the reactions of cetaceans exposed to anthropogenic noise. Results from this study suggest that the 10 kHz frequency of HAADs was audible to humpback, fin, and minke whales. Therefore, caution should be exercised when employing other sources of man-made noise at a similar frequencies. In addition, it is thought that high-amplitude acoustic deterrents influence cetacean species differently. Transient species may avoid areas with operating HAADs more frequently and to a greater degree than resident species. Because resident species may not avoid areas with operating HAADs, they may be increasingly susceptible to temporary threshold shifts or permanent auditory damage. HAADs operate at 194 dB re 1μPa at 1 m while the current allowable limits for human workplace exposures for broad spectrum signals for an eight hour period is 80 - 90 dB re 20μPa (Popper et al. 1998). Assessment of auditory damage requires examining ear morphology or long-term monitoring of behavioural changes in exposed individuals, however, neither approach could have been implemented during this study. As hearing loss may impair the ability of cetaceans to communicate, locate prey, avoid predators, and navigate (Richardson et al. 1995; Ketten 1995: Iwama et al. 1997), further research with HAADs should be conducted with known individuals over extended periods of time.

5.2 Recommendations

The influence of HAADs on baleen whales has important management implications for the conservation of cetaceans in the world's oceans. In response to the aquaculture industry's increasing use of high-amplitude acoustic deterrents, the Department of Fisheries and Oceans made preliminary recommendations for aquaculture sites in the Bay of Fundy to refrain from employing HAADs seasonally (May through

November) in areas frequented by cetaceans (Strong et al. 1995). As part of an environmental impact assessment conducted on salmon aquaculture in British Columbia, the suggestion was made to phase-out the use of high-amplitude acoustic deterrent devices at all fish aquaculture operations over the next two years (Technical Advisory Team 1997). The Gulf of Maine Aquaculture-Pinniped Interactions Task Force expressed reservation about the impact of acoustic deterrents on non-target marine mammals, but concluded that deterrents are a valuable, effective tool and should be available for use by the aquaculture industry (Iwama et al. 1997). After documenting the effects of HAADs on orcas, Morton and Symonds (2002) concluded that if the use of HAADs continues to increase with the expansion of the net-pen aquaculture industry, significant negative impacts on whale habitat can be expected. This lack of a global consensus regarding the impact of high-amplitude acoustic deterrents may result in only minimal action taken to limit deterrent usage and result in regions where cetaceans are still vulnerable to HAADs.

The type of areas where anthropogenic noise is present is thought to largely influence the relationship between man-made noise and baleen whales. Recognition of species-specific patterns of habitat use may identify species prone to exposure from man-made sound and facilitate protection. Whale distribution is dramatically influenced by areas appropriate for foraging, as many cetaceans are migratory, seasonal feeders and use of habitat is very much prey driven (Piatt et al. 1989). The abundance of cetaceans is also influenced by areas important for reproduction, as high concentrations are found in areas appropriate for breeding and calving (Tillman and Donovan 1986). In addition, small-scale site fidelity may place resident species at great risk if anthropogenic activity is conducted within their home ranges. Therefore, concern should be raised when regions with biologically important cetacean habitat have high levels of anthropogenic noise. Mitigation of man-made noise may be most effective if human activities were adjusted seasonally to avoid areas of prime habitat and high cetacean concentrations (Richardson and Wursig 1995; Lien et al. 1995).

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Table 1. Summary of 1995 observation and sighting data used in data analysis.

HAADs not operating						HAADs operating					
Dates	Hours Observed	Time Observed	HMPBK[1/]	MNK[1/]	FIN[1/]	Dates	Hours Observed	Time Observed	HMPBK[1/]	MNK[1/]	FIN[1/]
15 July	5	12:50 - 17:50	3-280 4-342	0	0	20 July	4.0	12:40 - 16:40	3-5	2-28 3-18	0
18 July	8.17	8:40 - 16:50	1-1 2-146 3-227 4-66	0	0	21 July	8.17	8:50 - 17:00	2-97 3-80 4-27	0	0
19 July	4.95	9:23 - 14:20	2-44 3-41	3-2	0	31 July	6.52	9:20 - 15:51	2-27 3-26 4-45	3-2 4-2	0
24 July	4.07	11:26 - 15:30	2-63 3-280 4-63	3-18	0	1 August	6.25	9:45 - 16:00	2-66 3-33 4-13	2-6 3-5	0
25 July	3.5	13:00 - 16:30	3-63 4-110	4-12	0	2 August	2.7	9:56 - 12:38	2-75	0	0
26 July	6.58	9:25 - 16:00	2-136 3-21 4-68	2-7 3-2 4-5	3-9 4-1	4 August	3.25	9:45 - 13:00	2-97 3-5	2-1 3-3	0
27 July	4.15	9:55 - 14:04	2-20 3-77	2-30 3-14	0						
29 July	4	8:00 - 12:00	1-82 2-353	1-3 2-5	0						
Total	40.42					Total	30.89				

[1/] Number of humpback (HMPBK), minke (MNK), and fin (FIN) whale sightings per time of day category (1 = 0600 - 0900 hrs, 2 = 0900 - 1200 hrs, 3 = 1200 - 1500 hrs, 4 = 1500 - 1800 hrs).

Table 2. Summary 1996 observation and sighting data used in data analysis.

HAADs not operating						HAADs operating					
Dates	Hours Observed	Time Observed	HMPBK $^{1/}$	MNK $^{1/}$	FIN $^{1/}$	Dates	Hours Observed	Time Observed	HMPBK $^{1/}$	MNK $^{1/}$	FIN $^{1/}$
11 July	3.67	11:20 - 15:00	0	3-5	0	18 July	3.5	14:00 - 17:30	0	0	0
12 July	4.0	11:30 - 15:30	2-1 3-25 4-1	2-2 3-12	0	19 July	5.5	11:30 - 17:00	3-90 4-11	3-8	0
13 July	4.0	13:30 - 17:30	0	3-2	3-1	3 August	5.0	10:00 - 15:00	0	3-16	0
15 July	5.0	10:30 - 15:30	0	0	0	4 August	4.5	12:30 - 17:00	3-9 4-2	3-6	0
16 July	6.5	10:30 - 17:00	2-1	3-4	0	6 August	5.0	13:00 - 18:00	3-12	3-11 4-8	3-33
22 July	6.0	11:00 - 17:00	3-63 4-4	0	0	7 August	5.0	9:00 - 14:00	0	0	0
23 July	5.0	9:00 - 14:00	0	3-4	0						
29 July	6.5	10:30 - 17:00	2-1 3-25 4-88	3-1	0						
31 July	7.5	10:30 - 18:00	2-26 3-2 4-26	4-1	0						
8 August	4.5	10:00 - 14:30	2-2 3-34	2-3 3-1	0						

Table Continued on the Next Page

Table 2 (Continued). Summary 1996 observation and sighting data used in data analysis.

HAADs not operating						HAADs operating					
Dates	Hours Observed	Time Observed	HMPBK[1/]	MNK[1/]	FIN[1/]	Dates	Hours Observed	Time Observed	HMPBK[1/]	MNK[1/]	FIN[1/]
9 August	4.5	12:30 - 17:00	3-11	3-2	0						
10 August	4.5	12:30 - 17:00	0	3-2	3-3 4-3						
12 August	6.5	10:30 - 17:00	0	0	0						
15 August	6.0	11:00 - 17:00	0	0	0						
Total	74.17					Total	28.5				

[1/] Number of humpback (HMPBK), minke (MNK), and fin (FIN) whale sightings per time of day category (1 = 0600 - 0900 hrs, 2 = 0900 - 1200 hrs, 3 = 1200 - 1500 hrs, 4 = 1500 - 1800 hrs).

Table 3. Natural log distance between HAADs and humpback and fin whale sightings during 1995 (top) and 1996 (bottom).

Date	Number of Sightings	HAADs Off (mean ± S.D) (m)	Date	Number of Sightings	HAADs On (mean ± S.D) (m)
15 July	622	8.16 ± 8.00	20 July	5	7.28 ± 7.01
18 July	440	8.67 ± 8.01	21 July	204	7.96 ± 8.03
19 July	85	8.93 ± 8.61	31 July	98	9.55 ± 8.44
24 July	406	8.31 ± 8.25	1 August	112	9.60 ± 8.72
25 July	173	8.41 ± 8.02	2 August	75	7.98 ± 7.78
26 July	235	7.66 ± 7.99	4 August	102	8.78 ± 7.25
27 July	97	6.24 ± 5.67			
29 July	435	7.60 ± 7.69			
$\bar{x}$ ± S.D.	312	8.07 ± 8.15	$\bar{x}$ ± S.D.	99	8.93 ± 8.81
12 July	27	8.50 ± 8.39	19 July	101	7.58 ± 6.77
13 July	1	6.36 ± 0	4 August	11	7.46 ± 6.48
16 July	1	8.88 ± 0	6 August	45	8.36 ± 7.44
22 July	67	7.29 ± 6.48			
29 July	114	7.31 ± 6.60			
31 July	54	8.31 ± 7.50			
8 August	36	7.24 ± 6.31			
9 August	11	6.95 ± 5.37			
10 August	6	7.46 ± 6.70			
$\bar{x}$ ± S.D.	35	7.70 ± 7.63	$\bar{x}$ ± S.D.	52	7.86 ± 7.34

Table 4. Natural log distance between HAADs and minke whale sightings during 1995 (top) and 1996 (bottom).

Date	Number of Sightings	HAADs Off (mean ± S.D) (m)	Date	Number of Sightings	HAADs On (mean ± S.D) (m)
19 July	2	6.37 ± 0	20 July	46	6.35 ± 5.65
24 July	18	7.09 ± 6.58	31 July	4	6.56 ± 6.02
25 July	12	6.35 ± 4.89	1 August	11	6.68 ± 6.50
26 July	14	6.61 ± 6.08	4 August	3	5.96 ± 3.40
27 July	44	6.28 ± 5.98			
29 July	8	6.12 ± 4.73			
$\bar{x}$ ± S.D.	16	6.53 ± 6.23	$\bar{x}$ ± S.D.	16	6.41 ± 5.95
11 July	5	4.93 ± 4.71	19 July	8	6.27 ± 5.76
12 July	14	4.96 ± 4.08	3 August	16	6.74 ± 6.34
13 July	2	6.07 ± 5.18	4 August	6	7.04 ± 6.41
16 July	4	6.83 ± 6.18	6 August	19	7.37 ± 6.48
23 July	4	6.30 ± 5.60			
29 July	1	6.35 ± 4.25			
31 July	1	6.41 ± 5.97			
8 August	4	6.37 ± 6.16			
9 August	2	5.81 ± 0			
10 August	2	7.06 ± 0			
$\bar{x}$ ± S.D.	4	6.30 ± 5.92	$\bar{x}$ ± S.D.	12	7.02 ± 6.54

Table 5. Sighting rate for humpback and fin whales during 1995 (top) and 1996 (bottom).

Date	HAADs Off (# per hour)	Effort (hours)	Date	HAADs On (# per hour)	Effort (hours)
15 July	124.4	5.0	20 July	1.25	4.0
18 July	53.9	8.17	21 July	25.0	8.17
19 July	17.2	4.95	31 July	27.8	3.52
24 July	99.8	4.07	1 August	17.9	6.25
25 July	49.4	3.5	2 August	27.8	2.7
26 July	35.7	6.58	4 August	31.4	3.25
27 July	23.4	4.15			
29 July	108.8	4.0			
x̄ ± S.D.	61.4 ± 41.2	5.05	x̄ ± S.D.	21.9 ± 11.1	4.65
12 July	6.8	4.0	19 July	18.4	5.5
13 July	0.3	4.0	4 August	2.4	4.5
16 July	0.2	6.5	6 August	9.0	5.0
22 July	11.2	6.0			
29 July	17.5	6.5			
31 July	7.2	7.5			
8 August	8.0	4.5			
9 August	2.4	4.5			
10 August	1.3	4.5			
x̄ ± S.D.	6.1 ± 5.8	5.33	x̄ ± S.D.	9.9 ± 8.0	5.0

Table 6. Sighting rate for minke whales during 1995 (top) and 1996 (bottom).

Date	HAADs Off (# per hour)	Effort (hours)	Date	HAADs On (# per hour)	Effort (hours)
19 July	0.4	4.95	20 July	11.5	4.0
24 July	4.42	4.07	31 July	0.61	6.52
25 July	3.4	3.5	1 August	1.76	6.25
26 July	2.1	6.58	4 August	1.2	3.25
27 July	10.6	4.15			
29 July	2.0	4.0			
$\bar{x} \pm$ S.D.	3.8 ± 3.6	4.54	$\bar{x} \pm$ S.D.	3.8 ± 5.2	4.26
11 July	1.36	3.67	19 July	1.5	5.5
12 July	3.5	4.0	3 August	3.2	5.0
13 July	0.5	4.0	4 August	1.3	4.5
16 July	0.6	6.5	6 August	2.4	5.0
23 July	0.8	5.0			
29 July	0.2	6.5			
31 July	0.1	7.5			
8 August	0.9	4.5			
9 August	0.4	4.5			
10 August	0.4	4.5			
$\bar{x} \pm$ S.D.	0.9 ± 1.0	5.07	$\bar{x} \pm$ S.D.	2.1 ± 0.9	5.0

Table 7. Mean rate of behaviour for known, independent groups of humpback and fin whales during 1995.

Behaviour	HAADs Off (# per hour) (n = 18)	HAADs On (# per hour) (n = 5)
Respiration	59.2	27.6
Surface	6.0	2.0
Fluke Visible	12.8	0.2
Breaching	0.3	0.0
Lunge Feeding	0.1	0.0
Spy Hopping	0.1	0.0

Table 8. Mean rate of behaviour for known, independent groups of humpback and fin whales during 1996.

Behaviour	HAADs Off (# per hour) (n = 15)	HAADs On (# per hour) (n = 13)
Respiration	21.4	16.9
Surface	0.6	0.7
Breaching	8.4	1.7
Flippering	0.0	0.2

Table 9. Behaviour of known, independent groups of humpback and fin whales within the study site during 1995.

Number of Groups	HAADs Off		HAADs On	
	Duration (hours)	Approach Distance (m)	Duration (hours)	Approach Distance (m)
1	1.22	-	0.17	1,761
2	1.03	899	0.62	1021
3	1.15	1086	0.83	48
4	0.03	-	0.02	-
5	0.1	172	0.12	-
6	0.1	-	2.9	568
7	0.03	-	0.45	2221
8	0.16	162		
9	0.15	-		
10	0.58	472		
11	0.4	455		
12	1.03	-		
13	0.05	12		
14	0.03	130		
15	0.08	-		
16	0.35	79		
17	0.05	-		
18	0.62	514		

Table 10. Behaviour of known, independent groups of humpback and fin whales within the study site during 1996.

Number of Groups	HAADs Off		HAADs On	
	Duration (hours)	Approach Distance (m)	Duration (hours)	Approach Distance (m)
1	0.02	81	0.43	274
2	0.33	-	0.02	9
3	0.03	45	0.23	-
4	0.25	532	0.03	-
5	1.53	-	0.33	391
6	0.53	188	0.27	650
7	0.42	-	0.13	845
8	0.87	189	0.33	57
9	0.1	299	1.07	-
10	0.6	447	0.87	640
11	0.52	829	2.01	24
12	0.13	1122	0.01	-
13	0.01	12	0.07	141
14	0.62	1111		
15	0.5	2926		

Table 11. Mean rate of behaviour for known, independent groups of minke whales during 1995.

Behaviour	HAADs Off (# per hour) (n = 15)	HAADs On (# per hour) (n = 5)
Respiration	5.8	1.7
Surface	25.8	21.8
Lunge Feeding	0.0	1.7
Bubble Feeding	0.4	0.0

Table 12. Mean rate of behaviour for known, independent groups of minke whales during 1996.

Behaviour	HAADs Off (# per hour) (n = 5)	HAADs On (# per hour) (n = 6)
Surface	20.0	15.1

Table 13. Behaviour of known, independent groups of minke whales within the study site during 1995.

Number of Groups	HAADs Off		HAADs On	
	Duration (hours)	Approach Distance (m)	Duration (hours)	Approach Distance (m)
1	0.02	-	0.33	-
2	0.47	-	0.13	96
3	0.17	24	0.27	54
4	0.22	-	0.03	-
5	0.03	-	1.58	-
6	0.12	-		
7	0.02	617		
8	0.05	245		
9	0.75	669		
10	0.2	140		
11	0.02	-		
12	0.12	-		
13	0.02	-		
14	0.02	-		
15	0.02	113		

Table 14. Behaviour of known, independent groups of minke whales within the study site during 1996.

Number of Groups	HAADs Off		HAADs On	
	Duration (hours)	Approach Distance (m)	Duration (hours)	Approach Distance (m)
1	0.02	4	0.12	131
2	0.03	-	0.16	280
3	0.22	95	0.03	186
4	0.15	99	0.5	570
5	0.08	36	0.26	331
6			0.85	92

Table 15. Mean temperatures within the study site during 1995 and 1996.

Depths (m) [1/]	1995 ($\bar{x} \pm$ S.D.) (^{o}C)	Number of Readings	1996 ($\bar{x} \pm$ S.D.) (^{o}C)	Number of Readings
0 - 5	14.1 + 1.5	17	16.8 + 3.1	4
5 - 25	10.3 + 0.9	9	14.2 + 1.0	9
25 - 40	1.8 + 1.3	3	4.3 + 0.8	5
40 - 65	-0.3 + 0.2	3	2.7	1
65 - 85	-1.1	1	-	-
85 - 105	-1.2	1	-	-
105 - 120	-1.3	1	-	-

1/ During 1996, no depths exceeding 65 m were sampled.

Table 16. Ocean temperatures within the study site between 1995 and 1996.

Depth of Temperature Data (m)	Explanatory Variable	Statistic		
0 - 5	Year	$t = -1.69$	$df = 3$	$p = 0.19$
25 - 40	Year	$t = -3.0$	$df = 2$	$p = 0.10$

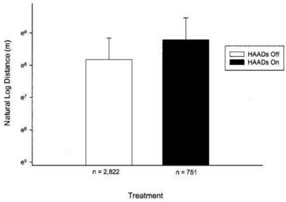

Figure 1. The natural log distance (mean + s.d.) between HAADs and humpback and fin whale sightings by treatment condition.

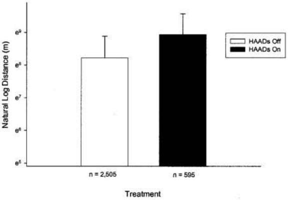

Figure 2. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by treatment condition in 1995.

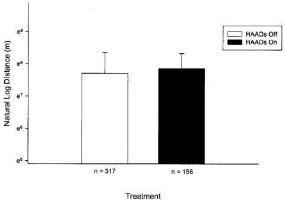

Figure 3. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by treatment condition in 1996.

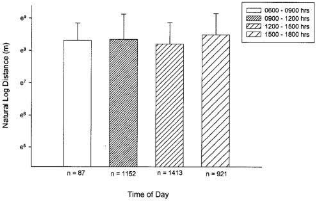

Figure 4. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by time of day.

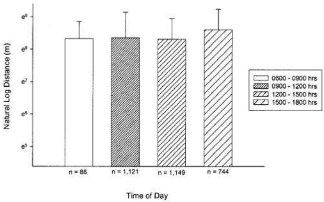

Figure 5. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by time of day in 1995.

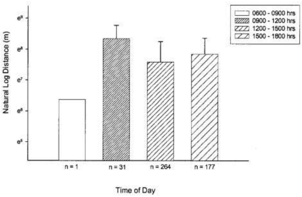

Figure 6. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by time of day in 1996.

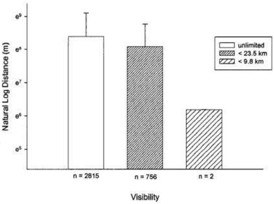

Figure 7. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by visibility condition.

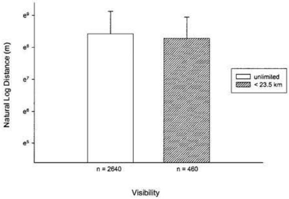

Figure 8. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by visibility condition in 1995.

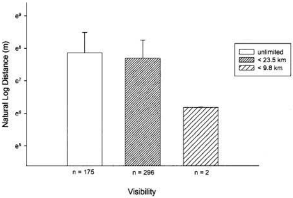

Figure 9. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by visibility condition in 1996.

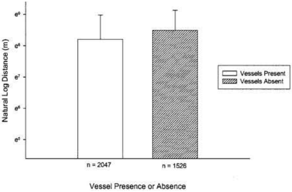

Figure 10. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by vessel presence.

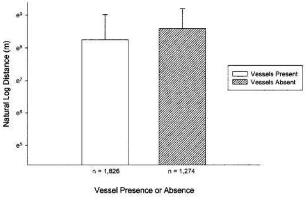

Figure 11. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by vessel presence in 1995.

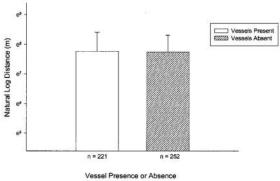

Figure 12. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by vessel presence in 1996.

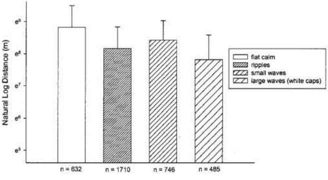

Figure 13. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by sea state condition.

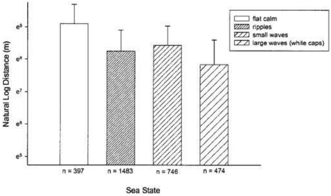

Figure 14. The natural log distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by sea state condition in 1995.

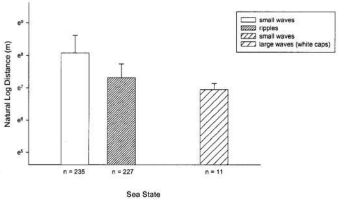

Figure 15. The log natural distance (mean ± s.d.) between HAADs and humpback and fin whale sightings by sea state condition in 1996.

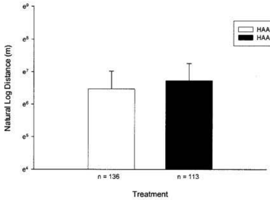

Figure 16. The natural log distance (mean ± s.d.) between HAADs and minke whale sightings by treatment condition.

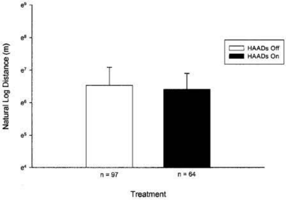

Figure 17. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by treatment condition in 1995.

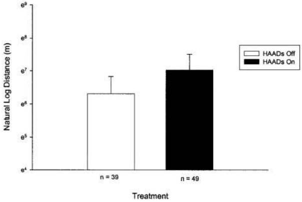

Figure 18. The natural log distance (mean ± s.d.) between HAADs and minke whale sightings by treatment condition in 1996.

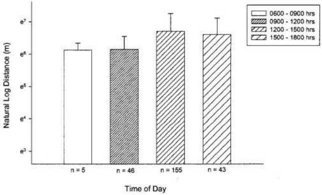

Figure 19. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by time of day.

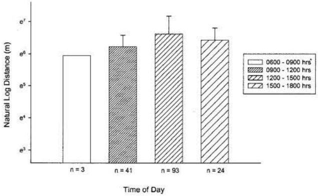

Figure 20. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by time of day in 1995.

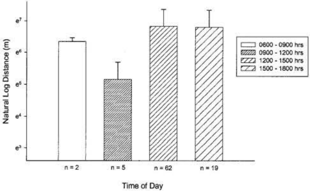

Figure 21. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by time of day in 1996.

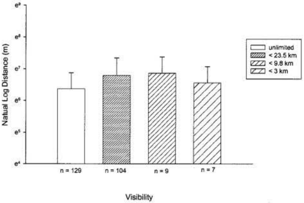

Figure 22. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by visibility condition.

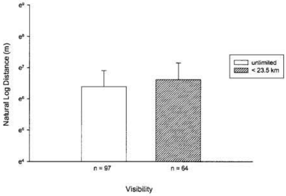

Figure 23. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by visibility condition in 1996.

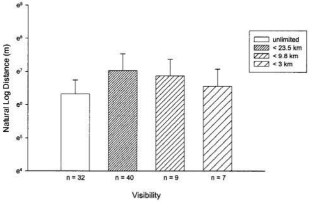

Figure 24. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by visibility condition in 1996.

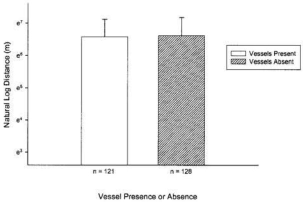

Figure 25. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by vessel presence.

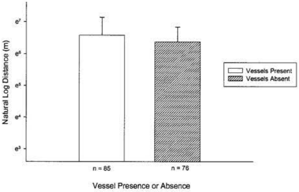

Figure 26. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by vessel presence in 1995.

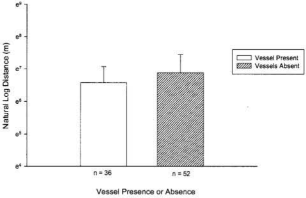

Figure 27. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by vessel presence in 1996.

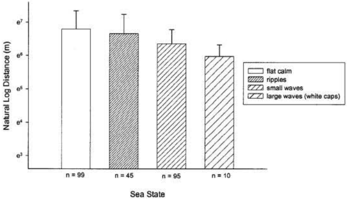

Figure 28. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by sea state condition.

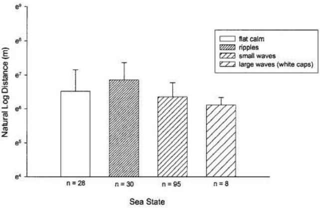

Figure 29. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by sea state condition in 1995.

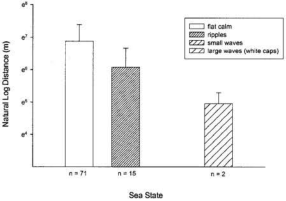

Figure 30. The natural log distance (mean + s.d.) between HAADs and minke whale sightings by sea state condition in 1996.

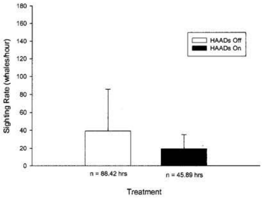

Figure 31. The sighting rate (mean ± s.d.) of humpback and fin whales by treatment condition.

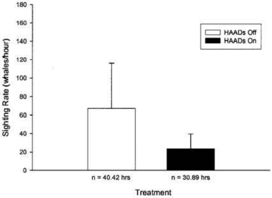

Figure 32. The sighting rate (mean + s.d.) of humpback and fin whales by treatment condition in 1995.

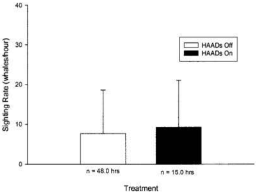

Figure 33. The sighting rate (mean ± s.d.) of humpback and fin whales by treatment condition in 1996.

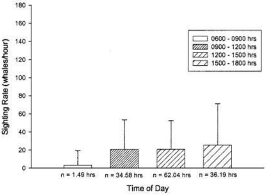

Figure 34. The sighting rate (mean ± s.d.) of humpback and fin whales by time of day.

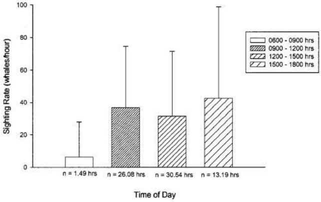

Figure 35. The sighting rate (mean ± s.d.) of humpback and fin whales by time of day in 1995.

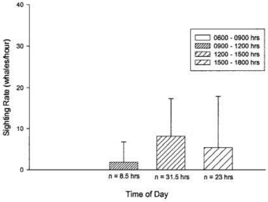

Figure 36. The sighting rate (mean ± s.d.) of humpback and fin whales by time of day in 1996.

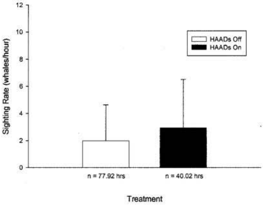

Figure 37. The sighting rate (mean ± S.D.) of minke whales by treatment condition.

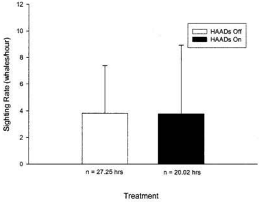

Figure 38. The sighting rate (mean ± S.D.) of minke whales by treatment condition in 1995.

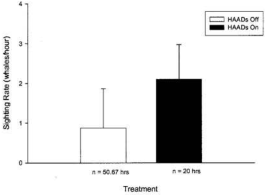

Figure 39. The sighting rate (mean + S.D.) of minke whales by treatment condition in 1996.

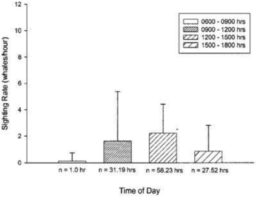

Figure 40. The sighting rate (mean ± S.D.) of minke whales by time of day.

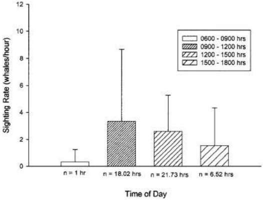

Figure 41. The sighting rate (mean ± S.D.)
of minke whales by time of day in 1995.

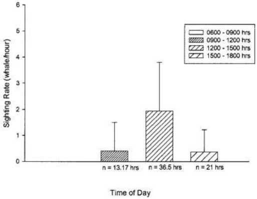

Figure 42. The sighting rate (mean + S.D.)
of minke whales by time of day in 1996.

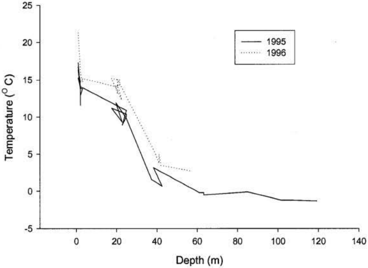

Figure 43. Temperature/depth profile of the study site during 1995 and 1996.

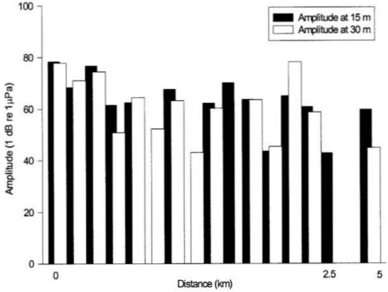

Figure 44. The relative amplitude of HAADs at depths of 15 m and 30 m with increasing distance from sound source.