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A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada

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Abstract

The number of salmon acquaculture sites in the Bay of Fundy has increased over the past ten years. An unknown proportion of these sites are using acoustic harassment devices (AHDs) to deter seals from approaching salmon cages. A preliminary survey of AHD use at salmon aquaculture sites in the Quoddy Region and Grand Manan Island, NB, was conducted between 17 August and 7 September 1996. In the Quoddy Region, 46% of aquaculture sites were using some form of AHD during daylight hours. In the Grand Manan area, 22% of aquaculture sites surveyed during the day were using AHDs. An evening survey of four sites in the Quoddy Region revealed that one AHD was activated only during evening hours, indicating our daytime survey data underestimates total AHD use. Three different forms of AHDs (10 kHz peak signal, 15 kHz peak signal, and a multi-frequency signal) were identified. The level of noise pollution associated with these devices may negatively impact marine mammal populations, including the threatened harbour porpoise (*Phocoena phocoena*), which use these regions on a seasonal or annual basis.

Introduction

In recent years many commercial fishing operations have turned to acoustical methods to mitigate operational interactions with marine mammals. For example, Kraus *et al.* (1997) used acoustical alarms (commonly referred to as 'pingers') on sink gillnets deployed on the East Coast of North America in an attempt to reduce the level of harbour porpoise (*Phocoena phocoena*) bycatch. The success of this experiment led to the commercial production of alarms (e.g. Dukane 1997) and increased use in US gillnet fisheries. Similarly, tests of acoustic alarms have been done on set-net fisheries on the West coast (Gearin *et al.*, 1996) to help reduce porpoise bycatch. These devices characteristically have low acoustical power and are designed to temporarily alert marine mammals to the presence of fishing gear or other potential dangers. Biologists now refer to these types of acoustical alarms as acoustic deterrent devices (ADDs).

Acoustical alarms have also been used in attempts to deter seals from approaching nets, aquaculture sites and areas where there are perceived interactions between marine mammals and fishing/aquaculture interests (see Mate and Harvey, 1986). These types of acoustic alarms differ from those used to limit cetacean bycatch in two important ways. Often, they are used continually on permanently deployed equipment and they have greater acoustical power to reduce habituation by the target species to the sound source. These devices, designed to frighten or induce pain in marine mammals and permanently displace them from portions of habitat, are now commonly referred to as acoustic harassment devices (AHDs).

The number of salmon aquaculture sites on the East coast of Canada has increased in recent years (Aquafacts, 1996) and there has been a concomitant increase in the use of acoustic harassment devices to deter seals from approaching such sites. Strong *et al.* (1995) indicated that the majority of salmon aquaculture sites in the Quoddy Region and around Grand Manan Island were using AHDs for at least part of the year (primarily December to April), but the exact number of sites using them, and the duration of their use was unknown. Although the use of AHDs at aquaculture sites is common on both coasts of Canada and the US (Olesiuk *et al.*, 1996), little is known of their effects on non-target species (Richardson *et al.*, 1995; Olesiuk *et al.*, 1996). The hearing of some odontocetes is believed to be more sensitive to such noise sources than that of pinnipeds (Richardson *et al.*, 1995) and the effects of AHDs on species such as the harbour porpoise (*Phocoena phocoena*) may be greater. Indeed, Olesiuk *et al.* (1996) suggests that porpoises in the waters of British Columbia are excluded from within 400 m of one type of AHD, and their abundance is significantly reduced within 3.5 km of the device.

Many of the aquaculture sites in the Quoddy Region and Grand Manan area are located in or near areas that are frequently used by harbour porpoises during the summer months (Gaskin, 1992*a*). Harbour porpoises are currently listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Gaskin, 1992*a*) primarily because of high levels of incidental mortality in gillnets (Gaskin, 1992; Trippel *et al.*, 1996). Considering that we know very little about AHDs and their effects on non-target species such as the harbour porpoise, more information is required on the magnitude and duration of AHD use in the Quoddy Region. This paper provides baseline information on the extent of AHD use during the late summer, the time of peak porpoise abundance in this area of the Bay of Fundy (Gaskin, 1992*a*).

Methods

A daytime survey (0900 to 1700 hr. Atlantic Daylight Time) of AHD sounds at salmon aquaculture sites located in the Canadian waters of the Quoddy Region (N45°11′00″, W67°03′00″, N44°52′00″ and W66°45′50″; see Fig. 1) and Grand Manan Island (N45°00′50″, W66°27′18″, N44°46′35″ and W66°41′25″; see Fig. 2.) New Brunswick, Canada was conducted between 24 August and 5 September, 1996. The general locations of all registered aquaculture sites were obtained from inventory maps published by the New Brunswick Department of Fisheries and Aquaculture (DFA, 1996*a*, 1996*b*) and all registered Canadian aquaculture sites were sampled for AHD sounds. With the exception of one site (Dark Harbour, Grand Manan) which was assessed from shore, all aquaculture sites were sampled from a small Boston Whaler (5 m) with an outboard engine. All sound measurements were taken within 150 m of the sites, positions (Latitude and Longitude) were obtained using GPS navigational aid with differential correction (Garmin GPS 38 and GBR-1 Beacon Receiver, Garmin International, Lenexa, KS). For each site, the presence/absence of solar panels and wind generators (primarily used to recharge AHD system batteries; S. Christenson, Airmar Corp., pers. comm.) were also recorded.

A night-time (1930 to 2100 hr. Atlantic Daylight Time) shore-based survey of 4 of the cage sites (included in the above survey) around Deer Island was also conducted, on 6 September, 1996, following the above procedures.

In-water AHD sounds were detected using a hydrophone comprised of a Benthos AQ-4 hydrophone cartridge and a custom preamplifier suspended in vegetable oil within a 30.5 cm length of a sealed 2.54 cm PVC pipe. Direct measurements of relative overall sound levels received were obtained using a modified Radio Shack Sound Pressure Level Meter attached to the hydrophone. The sound pressure level meter was zeroed at total ambient sound levels measured at a site distant from all AHD sounds, providing the largest comparative range of relative measurements with the meter (0 dB to 70 dB). The presence/absence of an active AHD at each site was determined by comparing the peak received AHD signal levels at the survey site with those measured at a similar distance from a reference site using an AHD. Where cage sites were close together (<150 m), measurements were made on opposite sides of adjoining sites and, if necessary, multiple measurements around sites were made to determine the origin of the AHD signal. Observers also listened for AHD sounds at all locations.

Acoustic harassment device sounds from various aquaculture sites were recorded to a Sony TCD-D8 digital audio tape (DAT) at a sampling frequency of 44.1 kHz for spectral and frequency analysis. Sounds were transferred from the DAT to a Pentium IBM ThinkPad 760L equipped with an ESS ES1688 AudioDrive sound board. Frequency and spectral analyses were conducted using CoolEdit (Version 95, Syntrillium Software Corp. Phoenix, AZ). Frequency analysis was verified by recording and analyzing sounds of known frequencies from a compact disk (Stereophile Test CD2, 1992, Sante Fe, NM).

Results

Quoddy Region

The results of the salmon cage survey of the Quoddy Region are presented in Table 1. Of the 69 sites surveyed in this area, 32 (46%) were using some form of AHD during daylight hours. All four cages surveyed during the evening were using AHDs, although one of these sites (Lords Cove) was not using them during the daylight survey.

Two different types of AHDs were identified. One type (termed 'ringer') produced a short train (2.5 seconds) of 2.0 ms pulses centered around 10 kHz (Fig. 7) that was repeated continually every 3.5 seconds (Fig. 8). When compared to an Airmar dB II Plus AHD system recording, frequency peaks were found to be similar (Fig. 7). The second type (termed 'squeaker') produced sixteen short (0.4 s) trains of 3 ms pulses of approximately 15 kHz (Fig. 8) every 75 seconds (Fig. 8). One cage site employed both forms of AHD simultaneously (Table 1). Measurements of AHD sounds in Western Passage indicated that two aquaculture

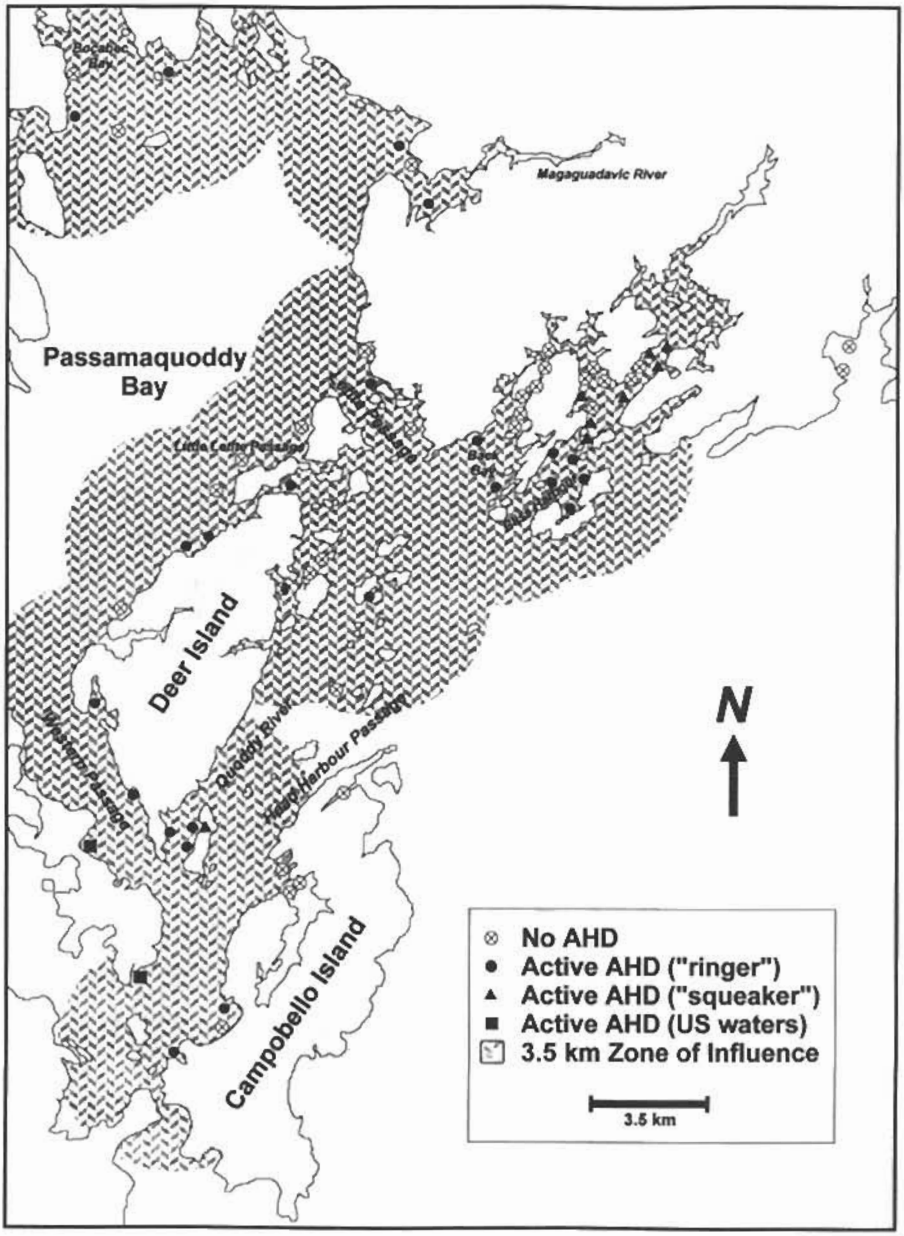

Figure 1. Locations of surveyed aquaculture sites, active acoustic harassment devices (AHDs) and 3.5 km minimum zones of influence (MZIs) within the Quoddy Region, NB, Canada.

sites in US waters were also using 'ringer' type AHDs. They were not included in further analysis.

Grand Manan Island

The results of the salmon cage survey of Grand Manan Island are also presented in Table 1. Of the nine cage sites surveyed, 2 (22%) were using some form of AHD during daylight hours.

Two forms of AHD were in use by cage sites in this area. One type produced a single signal centered around 10 kHz (Fig. 3), and was similar to the reference recording of the Airmar dB II

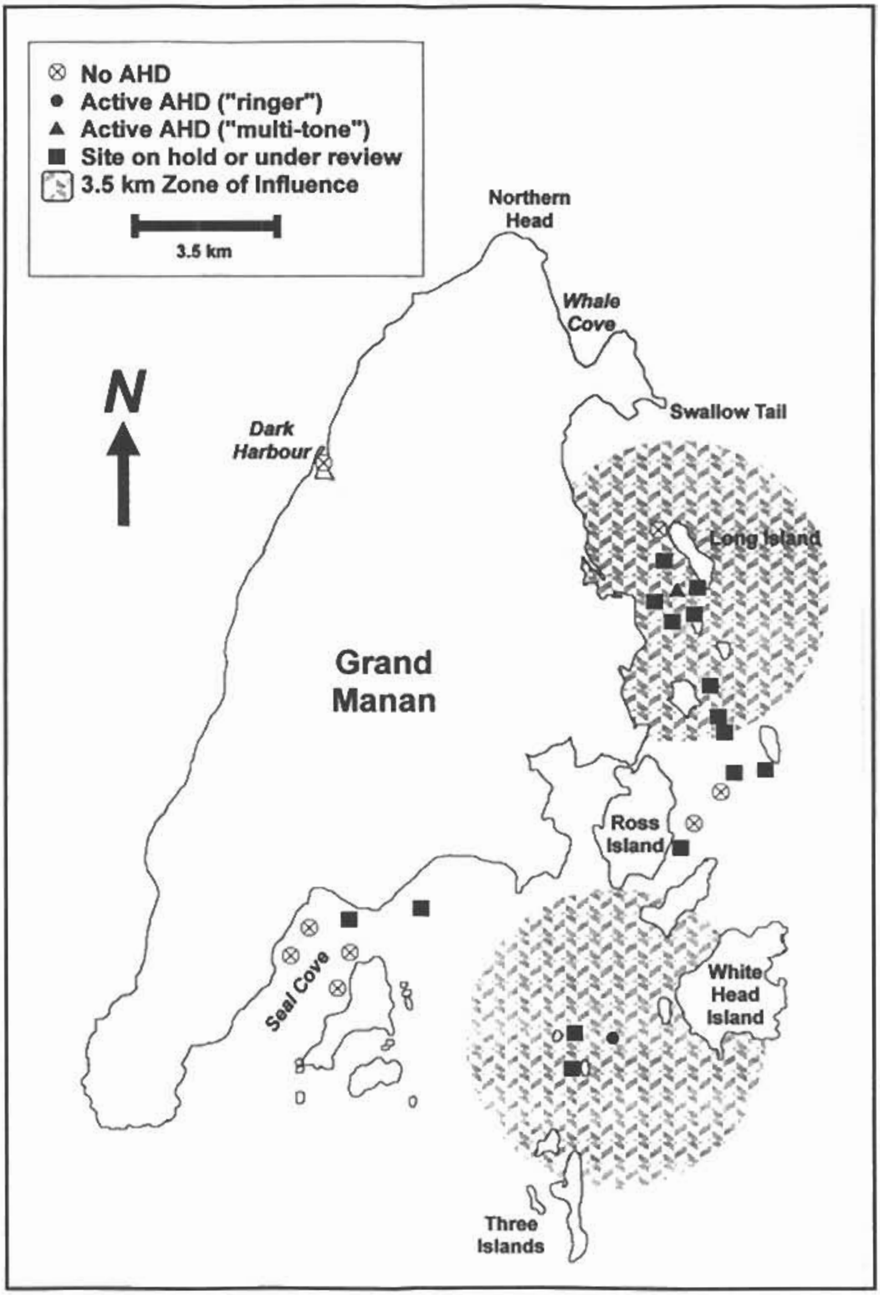

Figure 2. Locations of surveyed aquaculture sites, active acoustic harassment devices (AHDs) and 3.5 km minimum zones of influence (MZIs) within the Grand Manan Region, NB, Canada.

Plus system (termed 'ringer'). The other type (termed 'multi-tone') produced a multi-frequency burst (Fig. 7) approximately 22 seconds long with tones produced in 'random' fashion (Fig. 8). Frequency components of the 'multi-tone' AHD ranged from 2 kHz up to 22 kHz (the limits of our recording equipment). The bursts appeared to occur randomly over two 20 minute recordings. No 'squeaker' type AHDs were found in this area.

Table 1. Totals, percentages and types of AHDs in use during the day in the Quoddy and Grand Manan regions, NB, Canada

Location	Number of sites	Total with AHD	Total with solar/wind	Total with solar/wind using AHD	Total with 'ringer'	Total with 'squeaker' or 'multi-tone'	Total with both
Quoddy Region	69	32	48	32	24	7	1
Grand Manan	9	2	3	2	1	1	0

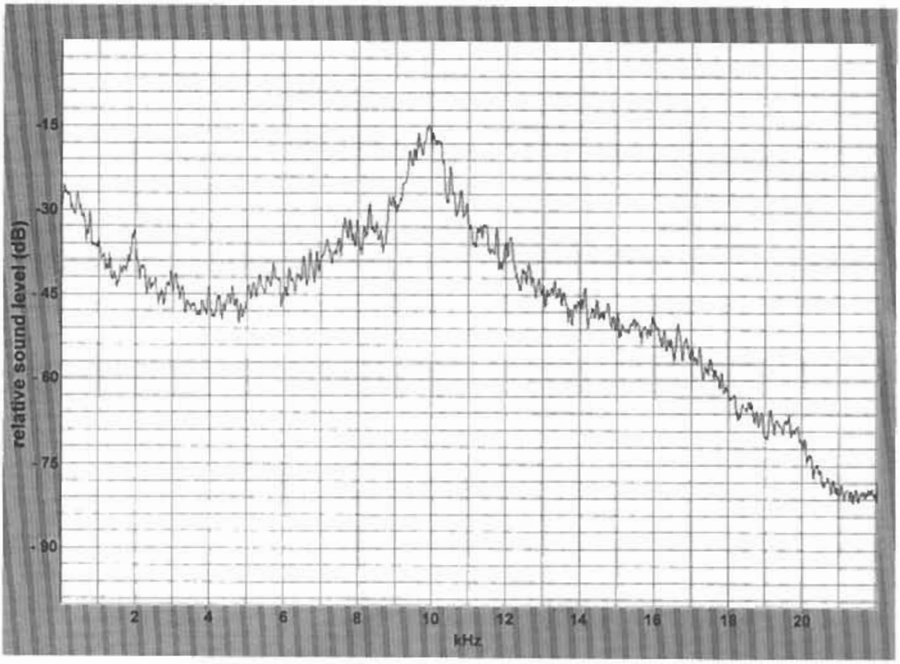

Figure 3. Frequency Analysis of 'ringer' AHD recorded in the Quoddy Region, NB, Canada.

Potentially affected area

The salmon aquaculture sites found to be using AHDs in the Quoddy Region and Grand Manan area during our survey are presented in figures 1 and 2 respectively. Previously, Olesiuk *et al.* (1996) found that porpoise abundance is reduced within at least 3.5 km of a 'ringer' type AHD, and this minimum zone of influence or MZI (a circle with radius of 3.5 km drawn around active AHDs) was used to illustrate areas within the Quoddy and Grand Manan regions that might be similarly affected. In the Quoddy Region, Letite and Little Letite passages are completely encompassed by the 3.5 km zone of influence, as is Western Passage. Other areas potentially influenced include portions of the Quoddy River, Head Harbour Passage, Bocabec Bay, and all of Back Bay, Bliss Harbour and Lime Kiln Bay (Fig. 1).

The location of salmon cage sites with active AHDs in the Grand Manan region, and their potential zones of influence, are presented in Fig. 2. This map shows the locations of sites without active AHDs and also shows the locations of future aquaculture sites that are currently under environmental review by the New Brunswick Department of Fisheries and Aquaculture (DFA, 1996*b*). The two areas potentially affected by active AHDs are the waters surrounding Long Island, and the area south of White Head Island and north of the Three Islands (Fig. 2).

Discussion

Almost half of the salmon aquaculture sites in Bay of Fundy, NB, are using acoustic harassment devices during the late summer, contrary to the

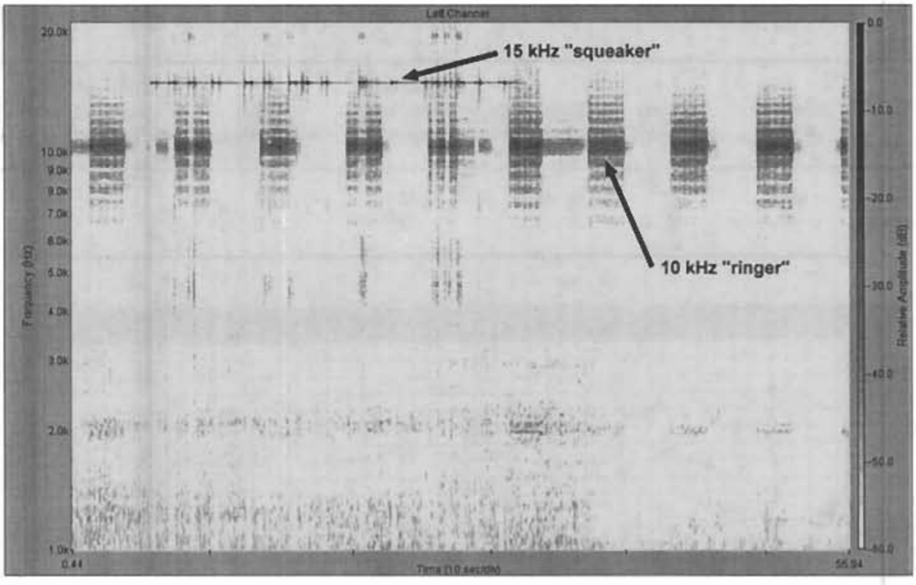

Figure 4. Spectrogram of 'ringer' and 'squeaker' AHDs recorded in the Quoddy Region, NB Canada.

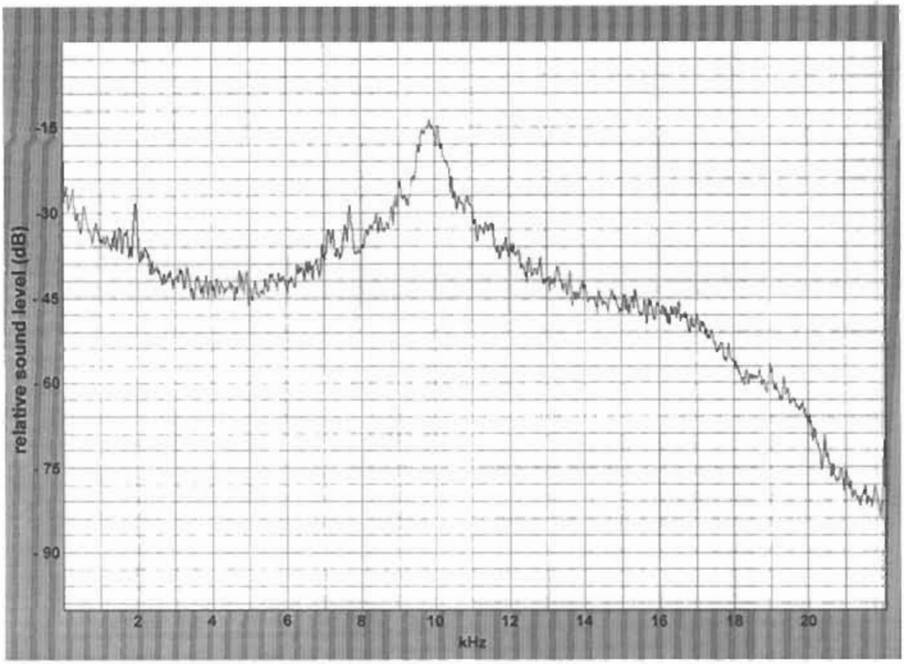

Figure 5. Frequency Analysis of Airmar dB II Plus AHD recorded in the Quoddy Region, NB, Canada.

Canadian Department of Fisheries and Oceans preliminary recommendations (Strong *et al.*, 1995). The night survey of cage sites around Deer Island revealed that one salmon aquaculture operation, not using an AHD during the daylight hours, was activating it at the end of the day—a common

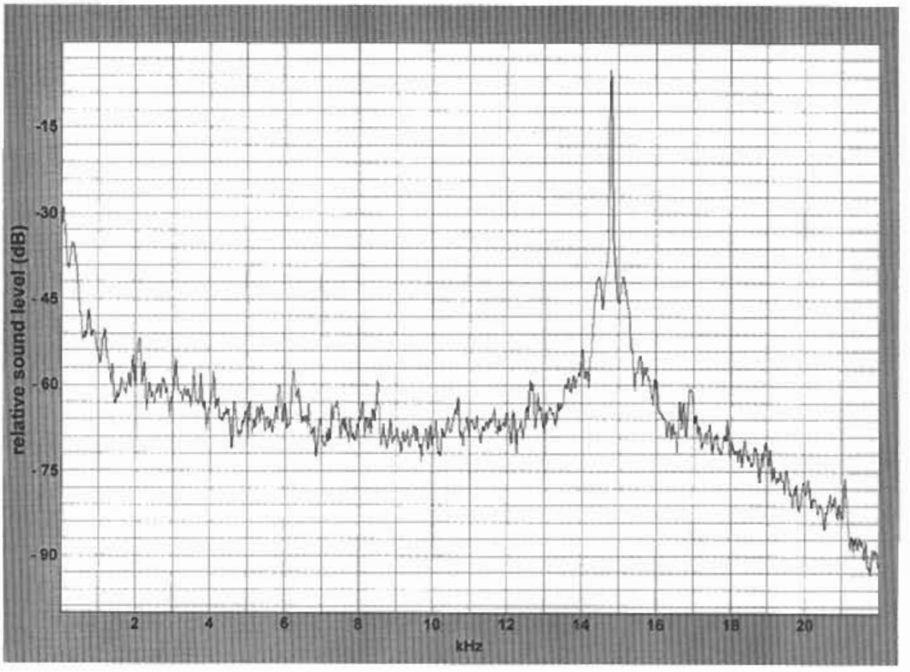

Figure 6. Frequency analysis of 'squeaker' AHD recorded in the Quoddy Region, NB, Canada.

practice at salmon aquaculture stations on the West coast of Canada (Olesiuk *et al.*, 1996). The exact number of cage sites employing a similar strategy in our study areas is currently unknown as full night surveys of either region were not conducted due to the hazards posed by weather and night navigation. Regardless, the numbers presented here for salmon cage sites with active AHDs must be viewed as a minimum, especially considering the large percentage of sites in both regions equipped with solar panels or wind generators (Table 1) used primarily to charge AHD system batteries (S. Christenson, Airmar Technology Corp., pers. comm.). These sites most likely employ some form of acoustic harassment device during the year. Also, AHD use in the Bay of Fundy is not limited to the single 10 kHz model as suggested by Strong *et al.* (1995). At least three different forms of AHDs are being used, each with a different frequency range and duty cycle.

AHDs

Not surprisingly, all three models of AHDs found in our study areas have frequency components that overlap with the range of best frequencies (the range frequencies the subject is most sensitive to) for phocid seals (Richardson *et al.*, 1995). Frequency components of all three AHDs also overlap with the range of best frequencies described for harbour porpoises. Porpoises appear to have two ranges of best frequencies, one which spans 120 to 130 kHz (Bibikov, 1992; Popov *et al.*, 1986), and another lower range that spans 8 to 32 kHz (Anderson, 1970). The 10 kHz 'ringer' signal, 15 kHz 'squeaker' signal, and several components of the 'multi-tone' signal overlap this lower range of best frequencies and are therefore within the hearing range of harbour porpoises. The striking similarity between the frequency components of the 'ringer' recordings and Airmar dB II Plus reference recording suggests that the 'ringer' AHD in use in these regions is an Airmar AHD. Discussions with Airmar Technology Corp. have confirmed that its products are in use in these areas (S. Christenson, Airmar Corp., pers. comm.). The full spectrum source level for this type of Airmar unit is approximately 194 dB re 1 μPa (Haller & Lemon, 1993). Full identification of the 'squeaker' and 'multi-tone' AHDs has not been completed although the recorded frequency components and random duty cycle of the 'multi-tone' unit are very similar to the specifications of the Mk3 Seal Scrammer unit produced by Ferranti-Thomson (FTSS, 1995). Literature for this product rates the source level (24V system) at 200 dB re 1 μPa @ 25 kHz (FTSS, 1995). Unfortunately, this dominant frequency is too high to record with our DAT equipment and its presence in our recordings could not be confirmed.

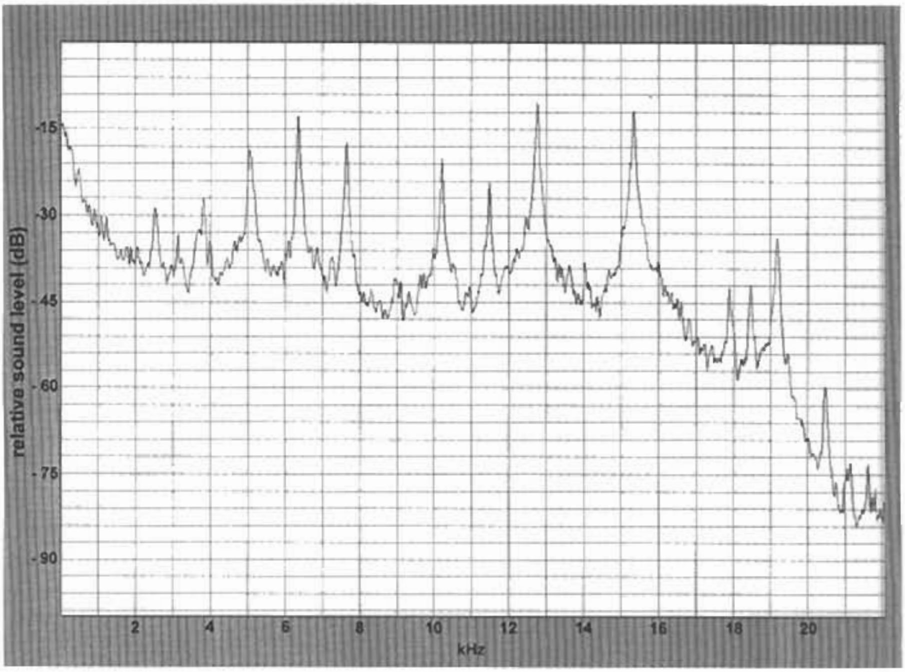

Figure 7. Frequency analysis of 'multi-tone' AHD recorded in the Grand Manan Region, NB, Canada.

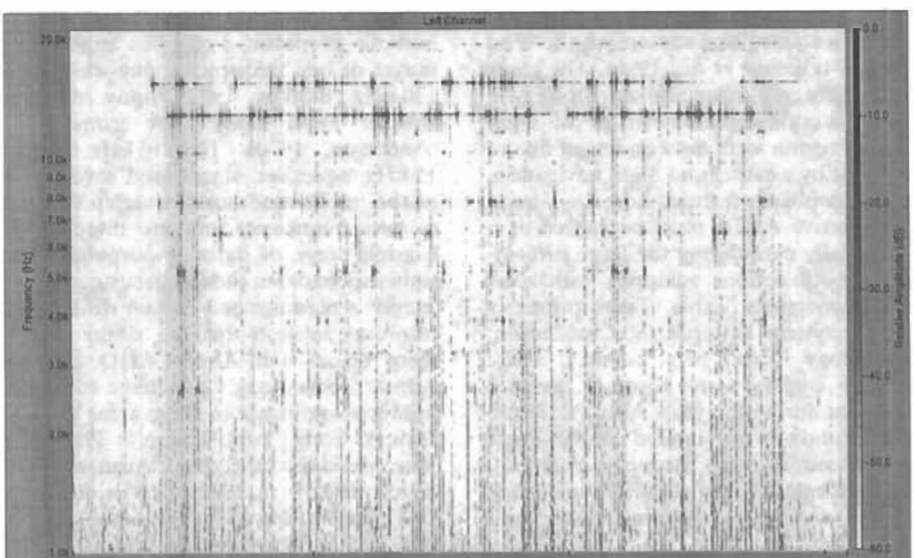

Figure 8. Spectrogram of 'multi-tone' AHD recorded in the Grand Manan Region, NB, Canada.

Zones of influence

Olesiuk *et al.* (1996) indicated that harbour porpoise abundance can be reduced by 90.3% within a range of 2.5 to 3.5 km from a 'ringer' type AHD and that harbour porpoises were excluded entirely from within 400 m of the sound source. Harbour porpoises also spent less time in the vicinity when the AHD was active (Olesiuk *et al.*, 1996). They also indicated that the 3.5 km limit of AHD effects was not based on observed changes in porpoise behaviour or abundance but on their inability to monitor porpoises at a greater distance (Olesiuk *et al.*, 1996). The 3.5 km limit should be viewed, therefore, as the minimum zone of influence of the AHD in that study. Strong *et al.* (1995) reported the value of 2.5 km as the range within which porpoise abundance could be similarly effected by AHDs in the Quoddy Region, NB. This value is based arbitrarily on the lower limit of the range given by Olesiuk *et al.* (1996) (2.5 km; see above; M. Strong, Department of Fisheries and Oceans, pers. comm.).

Both Olesiuk *et al.* (1996)'s and Strong *et al.* (1995)'s estimates of received sound levels at distance are based on a simple spherical spreading model that does not allow for bottom and absorption effects. Such effects are expected for moderately high frequency sources such as AHDs operating in shallow coastal waters (Richardson *et al.*, 1995). As the average water depth for areas within 5 km of aquaculture sites in our study area is less than 50 m, the following model (Marsh & Schulkin, 1962), which estimates losses to both spherical and cylindrical spreading in shallow water (although not for peculiarities in bottom topography), was used to estimate received sound levels. (Only the 10 kHz sound from an Airmar dB II Plus unit is considered here as it is the most prevalent form of AHD in use and the identification of both 'squeaker' and 'multi-tone' AHDs is still incomplete.)

$$L_r = L_s - 20 \log R_t - 15 \log R/R_t - aR$$

where

L_r = the received level in dB re 1 µPa
L_s = the source level at one meter with the same units
= 194 dB for Airmar unit
R_t = the transition range (m) where spherical spreading changes to cylindrical spreading (generally defined as depth of water in the area).
= 50 m
R = the range from sound source in meters.
a = absorption of 10 kHz sound by water (dB/m).
= $0.036(10\ \text{kHz})^{1.5}$ (from Richardson *et al.*, 1995: 73)
= 0.00114 dB/m.

Therefore the received sound level at 3.5 km would be:

$$L_{3.5} = 194 - (20 \log 50) - 15 \log (3500/50) - 0.000114\ (3500) = 128\ \text{dB}$$

For comparison, the received sound level at 2.5 km would be:

$$L_{2.5} = 194 - (20 \log 50) - 15 \log 2500/50 - 0.00114\ (2500) = 132\ \text{dB}$$

Assuming that the absolute hearing threshold for porpoises at 10 kHz is 50 dB re 1 µPa (Anderson, 1970), the signal to noise ratio of a harbour porpoise is 28 dB (Johnson, 1968), and the spectrum levels of ambient noise near 10 kHz are 60 dB (values cited as ambient noise levels for coastal situations in Olesiuk *et al.*, 1996), AHDs would be audible to porpoises when overall AHD received levels were greater than 88 dB. On this basis, we feel justified in using the more conservative 3.5 km minimum zone of influence. We also acknowledge, however, that the acoustic environment is complex, and the actual range at which AHDs will be audible or perceived as threatening by porpoises in these regions will vary, depending on local physical environments and ambient noise levels.

The Quoddy Region is known to be an important habitat for harbour porpoises during the summer months (see below) and some porpoises can be found there year round (Gaskin, 1992*a*). Gaskin (1983) indicated that in the 1970s and early 1980s, porpoises were generally abundant during August and September in the entrance to Head Harbour and Letite Passage, and in the entrances to Western Passage as well (see Fig. 1). Smith & Gaskin (1983) supported these findings and noted that the inshore areas around Deer Island were particularly frequented by mothers with calves, suggesting these areas may be important habitat for nursing or pregnant porpoises and also for young of the year porpoises. Radio tracking studies also revealed that porpoises frequented the Quoddy Region (Read & Gaskin, 1985; Westgate *et al.*, 1995) and that their movements were correlated with the direction of tidal flow (Read & Gaskin, 1985). Porpoises have also been sighted in the Passamaquoddy Bay proper (Read & Gaskin, 1985), although in lower densities than those found in the entrances to Head Harbour and Letite Passage, and in the entrances to Western Passage (Prescott *et al.*, 1981; Smith & Gaskin, 1983). The aforementioned passages characteristically produce oceanographic conditions (large upwellings and tidal rips) that concentrate Atlantic herring (*Clupea harengus*) (Jovellanos & Gaskin, 1983; Gaskin *et al.*, 1985), the main prey species of harbour porpoises in this area (Reccia & Read, 1989; Palka *et al.*, 1996). Porpoise distributions within the Quoddy Region are correlated strongly with these 'herring concentrating' oceanographic conditions (Watts & Gaskin, 1984; Gaskin *et al.*, 1985), indicating that these areas are likely important foraging habitat for harbour porpoises (Gaskin *et al.*, 1985).

It is clear that many of the areas described above may be contaminated by the level of AHD use in the Quoddy Region (Fig. 1) and, subsequently, harbour porpoises may be excluded from important foraging and nursery habitat. Indeed, anecdotal evidence indicates that porpoise abundance in the Quoddy Region may have decreased in recent years (Gaskin, 1992*a*) but the level of effort dedicated to quantifying porpoise abundance has also decreased (Gaskin, 1992*a*) making it difficult to draw any firm conclusions.

Gaskin (1983) noted that harbour porpoises are also found in large numbers off upper Grand Manan, between Northern Head and Swallowtail (Gaskin, 1983). These areas also tend to produce strong tidal rips and upwellings and they are likely to be important foraging habitat for harbour porpoises. Radio tracking studies (Read & Gaskin, 1985), depth of dive studies (Westgate *et al*., 1995) and data on the entrapment of porpoises in nearby herring weirs (Neimanis *et al*., 1996) confirm that porpoises continue to use this habitat on at least a seasonal basis. Currently, this area is not likely to be severely contaminated by noise pollution from salmon aquaculture sites as the majority of salmon farming occurs in the sheltered waters further down island (see Fig. 2). Porpoises have also been spotted south of Seal Cove and south of White Head Island (Gaskin, 1983) and these areas may be negatively affected by active AHDs (Fig. 2). The relative importance of this habitat to harbour porpoises is unknown.

Currently, the Grand Manan aquaculture industry is not nearly as developed as that in the Quoddy Region. However, the large number of aquaculture sites currently under environmental review by the New Brunswick Department of Fisheries and Aquaculture (Fig. 2; DFA, 1996*b*) indicates that the industry may be growing and noise pollution from salmon cages may become a concern if more aquaculture operations begin to employ AHDs.

Both the Quoddy Region and Grand Manan area are also visited by white-sided dolphins (*Lagenorhynchus acutus*) (Gaskin, 1992*b*), fin whales (*Baleanoptera physalus*), minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae*) and critically endangered northern white whales (*Eubalaena glacialis*) (Gaskin, 1983). Although there are no hearing sensitivity data available for Atlantic white-sided dolphins, Pacific white sided dolphins (*Lagenorhynchus obliquidens*) have a hearing threshold of approximately 77 dB re 1 μPa at 10 kHz and are most sensitive to 32 kHz sounds (a threshold of 66 dB re 1 μPa) (Tremmel, 1996). These data suggest that Atlantic white-sided dolphins may also be sensitive to the range of AHD sounds discussed here. The effects of AHDs on both Pacific and Atlantic white-sided dolphins, and other odontocete cetaceans, remain untested. Baleen whales sometimes react to various sounds at frequencies as high as those produced by AHDs (Watkins, 1986; Richardson *et al*., 1995: 237), but the effects of AHDs on baleen whales have also not been studied.

The results of the present study suggest that harbour porpoises in the Quoddy Region, and to a lesser extent the Grand Manan area, may be negatively affected by AHD use at salmon farms. Clearly, more research is required to investigate the behaviour and distribution of harbour porpoises, and other cetaceans, in the vicinity of salmon farms with active AHDs.

Acknowledgements

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