Biological Conservation 108 (2002) 113–118

BIOLOGICAL CONSERVATION

www.elsevier.com/locate/biocon

The effect of acoustic harassment devices on harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy, Canada

Dave W. Johnston[a] [b],*

[a]*Nicholas School of the Environment and Earth Sciences, Duke University Marine Laboratory, 135 Duke Marine Lab Road, Beaufort, NC 28516, USA*
[b]*International Marine Mammal Association Inc., 1474 Gordon Street, Guelph, ON, Canada N1L 1C8*

Received 25 September 2000; received in revised form 11 October 2001; accepted 17 December 2001

Abstract

Many salmon aquaculture sites in the Bay of Fundy employ acoustic harassment devices (AHDs) to deter seals from approaching fish pens. These devices may also exclude harbour porpoises (*Phocoena phocoena*) from important habitat. To determine the effects of AHDs on harbour porpoises an AHD was deployed experimentally in the Bay of Fundy, Canada. Relative porpoise abundance (visual scans) and porpoise movements (tracked by theodolite) were recorded for separate, daily, 2-h periods in the vicinity of either an active ($n=9$) or inactive ($n=7$) AHD. Fewer porpoises were sighted during active periods (0.22 ± 0.44, mean$\pm$SD) than inactive periods (2.91 ± 1.29; $P<0.05$). The mean closest observed approach of porpoises to the AHD during active periods (991 ± 302 m) was significantly greater than during inactive periods (364 ± 261 m; $P<0.01$). Porpoise density was therefore reduced in the vicinity of active an AHD. These results should be considered before AHDs are deployed in porpoise habitat. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Harbour porpoise; Phocoena; Acoustic harassment device; AHD; Bay of Fundy, Canada; Noise pollution; Aquaculture; Salmon farm; Seal

1. Introduction

The number of salmon aquaculture sites in the Bay of Fundy has increased dramatically in the last 10 years (Johnston and Woodley, 1998) and many of these sites now employ high amplitude sonic devices, commonly referred to as acoustic harassment devices (AHDs) or seal scrammers, in attempts to deter seals from approaching fish pens (Johnston and Woodley, 1998).

Acoustic harassment devices generally produce sounds with full spectrum source levels of between 152 and 194 dB re 1 μPa measured at 1 m (Haller and Lemon, 1995; Taylor et al., 1997). Most models produce sound with fundamental frequencies between 5 and 35 kHz (Taylor et al., 1997), coinciding with the greatest hearing sensitivity of phocid seals (Richardson et al., 1995). As their name indicates, AHDs are designed to emit sound that will induce fear and pain in marine mammals, and are often deployed with the intent of permanently excluding them from portions of their habitat (Johnston and Woodley, 1998).

The most commonly used AHDs in the Bay of Fundy produce sound with a full spectrum sound pressure level of greater than 180 dB re 1 μPa at 1 m and a fundamental frequency of 10 kHz (Johnston and Woodley, 1998; Taylor et al., 1997; Haller and Lemon, 1995). These devices were designed primarily to target harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) but other species with similar hearing thresholds may be affected by the sounds they produce. For example, many salmon farms in the Bay of Fundy are located in areas frequented by harbour porpoises (*Phocoena phocoena*) (Watts and Gaskin, 1985; Westgate and Read, 1998) and there is growing concern that AHDs may exclude these small cetaceans from important portions of their habitat (Johnston and Woodley, 1998). Harbour porpoises are currently listed by the Committee on the Status of Endangered Wildlife in Canada as a threatened species in the Bay of Fundy (Gaskin, 1992).

Harbour porpoises have a "w" shaped audiogram, with two ranges of best hearing frequencies (Bibikov, 1992; Popov et al., 1986). The lower range spans 8–32 kHz (Anderson, 1970), indicating that they are sensitive to the sounds produced by AHDs. Indeed, harbour porpoises, and other odontocete cetaceans, may actually

* Tel.: +1-252-504-7529; fax: +1252-504-7648.
E-mail address: davej@duke.edu (D. Johnston).

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PII: S0006-3207(02)00099-X

be more sensitive to AHD sounds than are phocid seals (Richardson et al., 1995).

On the west coast of Canada, Olesiuk et al. (1996) found that harbour porpoise density was 90% lower than expected within 3.5 km of an active AHD array, and only 1% of the expected number of porpoises were spotted within 600 m of the array. They could not, however, accurately estimate how close individual porpoises approached the sound source.

The objectives of the present study were threefold: (1) to examine the effects of AHDs on harbour porpoises in the Bay of Fundy, (2) to determine the closest distance to which porpoises would approach an active AHD and (3) to compare the distribution of porpoise sightings with the theoretical sound field and zone of influence produced by the AHD.

2. Methods and materials

2.1. Study location and sound source

The experiment was conducted between 22 July and 2 September 1998. A commercial AHD[1] with a single transducer (fundamental frequency of 10 kHz and a full spectrum source level of approximately 180 dB re 1 μPa at 1 m) was used. The maximum in situ full spectrum source level of this type of AHD was recently confirmed as 181 dB re 1 μPa at 1 m (D. Potter, NEFSC 166 Water Street Woods Hole, MA 02543–1026; personal communication). The AHD produced a short train of 2.5 ms pulses repeated every 17 s. The AHD was deployed near the northern end of Grand Manan Island in the Bay of Fundy (N 44°48′17″, W 66°46′39″) (Fig. 1) approximately 4 m below the surface of the water from a small boat moored approximately 450 m from a point on the shore (Fig. 2). This is an area free of the confounding effects of other AHDs (Johnston and Woodley, 1998) and frequented by porpoises on a daily basis (Watts and Gaskin, 1985).

2.2. Experimental design

The AHD was deployed for 2-h periods on clear days when the Beaufort sea state was less than or equal to one. Only one experimental period was conducted on any given day. To avoid potential variation associated with tide-phase related changes in porpoise density, all experimental periods were conducted during the same tide phase (approximately 1 h before high tide to 1 h after low tide). Sixteen experimental periods were conducted, comprising nine periods when the AHD was active and seven control periods when the AHD was inactive. Active and inactive periods were chosen randomly on a per week basis shortly before each experimental period was initiated. The AHD was activated 5 min before the experiment started to allow for the device to ramp up to full power and to reduce any startle effects.

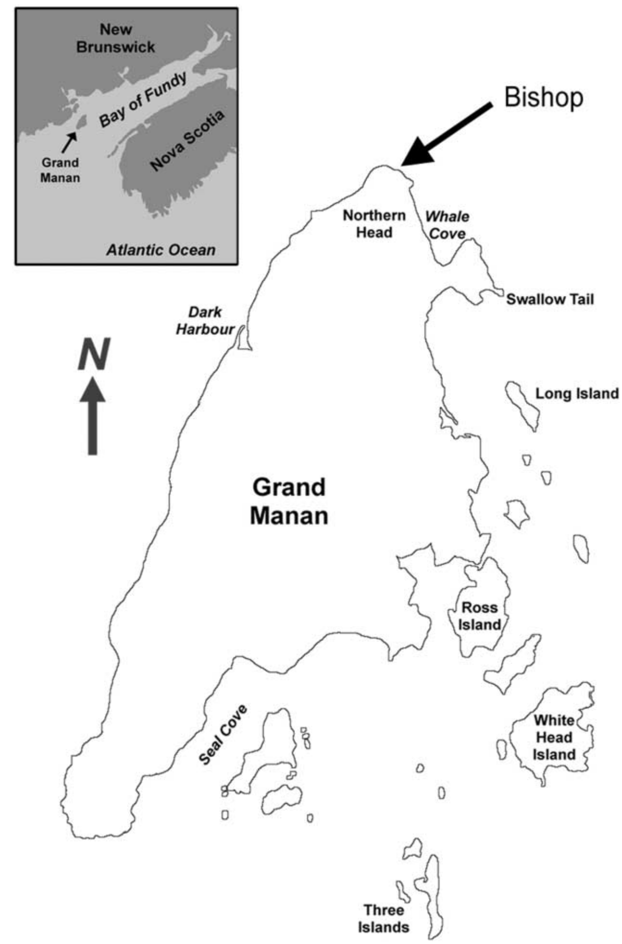

Fig. 1. Map of Grand Manan and the location of the study area. Inset details the location of Grand Manan within the Bay of Fundy, Canada.

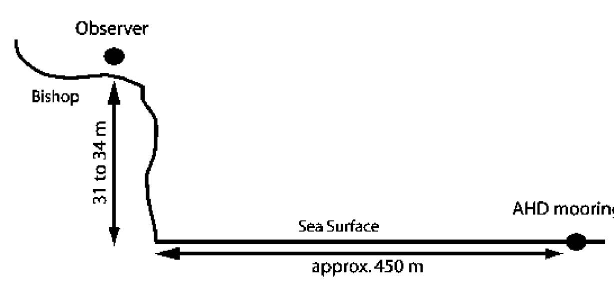

Fig. 2. Location of AHD mooring relative to the observation station on the Bishop, Grand Manan, NB, Canada.

2.3. Visual scans and tracking

During all experimental periods, an observer located on the Bishop (a cliff-top that ranged between 31 and 34

[1] Airmar dB II Plus. Airmar Technologies Corporation, Milford, NH, USA. For a more detailed analysis of this sound source, see Johnston and Woodley (1998), Taylor et al. (1997) and Haller and Lemon (1995).

m above sea level during each study period) recorded the number of porpoises and tracked porpoise movements in the study area by digital theodolite (Koschinski and Culik, 1997). The observer was unaware of the state of the AHD (active or inactive) during all experimental periods. The observer recorded the number of porpoises within a 1500 m radius of the AHD from visual scans with 7×40 binoculars. Visual scans were conducted at the start of the experiment and every 30 min afterwards, resulting in five scans per experimental period. Surfacings of porpoises or porpoise groups (2–5 individuals) were tracked by the observer with a Geodimeter 600 series digital theodolite between visual scans. Individual porpoises and groups were tracked by theodolite until they exited the study area or the observer lost sight of the porpoise(s) and a re-sighting could not be confirmed. Because the location of AHD varied slightly from day to day, it was localized every 30 min during all experimental periods by digital theodolite. Although the sightability of porpoises will decrease as distance from the observer increases, this decrease would remain constant between active and inactive periods.

2.4. Theoretical sound field

Although received levels of sound were not measured directly in the present study, they were approximated using the spreading model detailed in Marsh and Schulkin (1962) and used in Johnston and Woodley (1998). This model estimates transmission losses to both spherical and cylindrical spreading of AHD sound in shallow water.

2.5. Statistical treatment

To test for differences in the abundance of harbour porpoises in the study area between treatment and control periods, the visual scan data were analysed with a Repeated Measures ANOVA (Zar, 1996). Tracking data were parsed to produce, for each surfacing, the distance of the porpoise or group to the AHD. For each track, the closest observed approach (COA) of the porpoise(s) to the AHD was extracted. A Mann–Whitney *U*-Test (Zar, 1996) was used to test for differences in COA between treatment and control periods. All statistical analyses were completed with SPSS version 9.0 (SPSS Inc. Chicago, IL USA).

3. Results

3.1. Visual scans

The results of the visual scans (means±SD) are presented in Fig. 3. The mean number of porpoises sighted

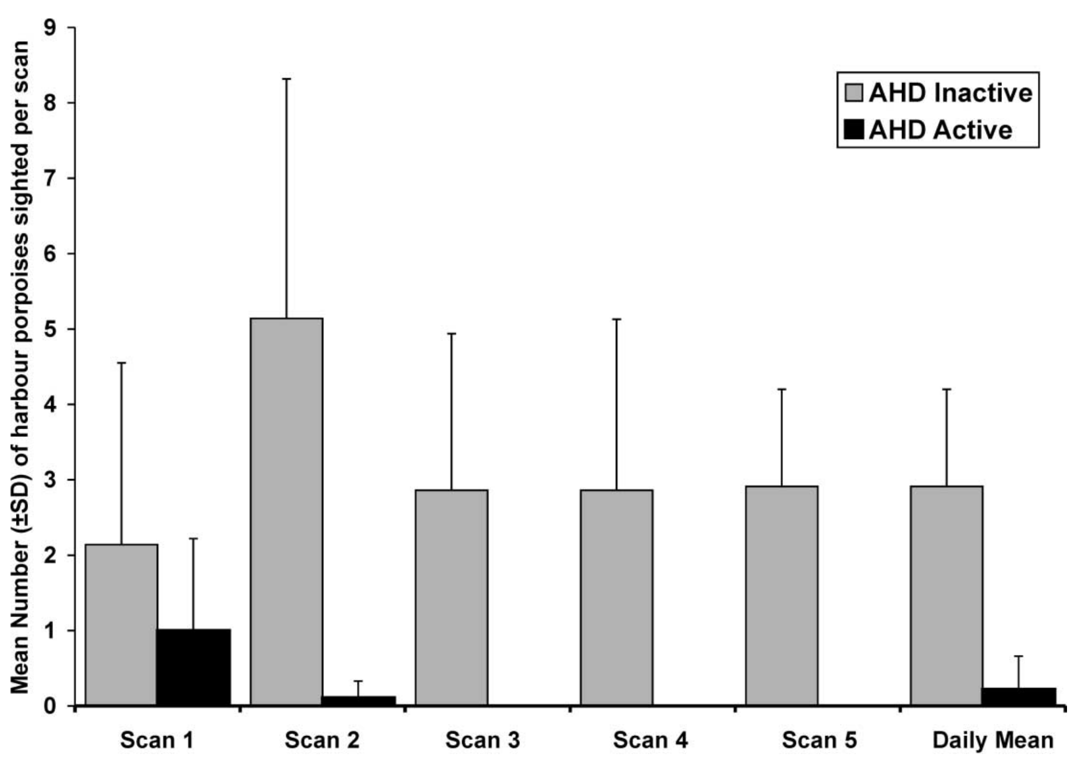

Fig. 3. Mean (±SD) porpoises sighted per scan and mean (±SD) number of porpoises sighted per day during visuals scans around an active ($n=9$) and inactive ($n=7$) acoustic harassment device in the Bay of Fundy, NB, Canada. Asterisks (*) indicate a significant difference ($P<0.05$) between active and inactive periods.

per scan was significantly lower while the AHD was active than during inactive periods ($P<0.05$). The ANOVA model also indicated that there was no significant difference in mean number of porpoise sightings during the first scan periods of the active and control periods ($P=0.23$). The observed power for this specific comparison was relatively low ($\beta=0.21$), however, when compared to the other between-treatment comparisons ($\beta=0.77$–0.99).

3.2. *Closest observed approach and theoretical sound field*

During 16 experimental periods, 69 separate tracks of individuals or groups of porpoises were recorded, 60 during inactive periods and nine during active periods (Table 1). The mean COA of porpoises to the AHD during inactive periods was significantly less than during active periods (Table 1). During active periods, the absolute COA of porpoises to the AHD was 645 m whereas the absolute COA during inactive periods was 6 m.

The distribution of all theodolite sightings of porpoise surfacings relative to the AHD during both inactive and active periods is presented in Fig. 4. Although separate COAs were calculated independently for each track (to account for observed changes in the location of the AHD and height above sea level), sound field and zone of influence radii are depicted as originating from the initial AHD location. The approximate received sound level at the absolute COA of porpoises to the active AHD (645 m) was 128 dB re 1 μPa and the approximate received sound level at the mean COA (991 m) was 125 dB re 1 μPa (Fig. 4).

4. Discussion

The results of the present study indicate that AHDs can have a significant and adverse effect on harbour porpoises in the Bay of Fundy and support the general hypothesis that the use of these devices at salmon farms may be excluding porpoises from important portions of their habitat (Olesiuk et al., 1996; Johnston and Woodley, 1998; Taylor et al., 1997). These results complement the findings of Olesiuk et al. (1996), who found no porpoises within 200 m of active AHDs, and only 1% of the predicted number of within 600 m of the active AHDs. They also found that porpoise density was 90% lower than expected within 3500 m of their AHD array. The COA of porpoises to the active AHD in the present study (645 m) is similar to the range within which porpoise density was 99% lower than expected in Olesiuk et al. (1996).

In the present study the number of porpoises sighted during the first visual scans during both the active and inactive periods was not significantly different. This may simply be an artefact of the low observed statistical power for that specific comparison, or it may reflect the behaviour of porpoises in the study as they reacted to the newly activated AHD. Although the AHD was activated 5 min before starting the experiment periods, this may not have provided enough time for porpoises to exit the 1500 m visual scan radius around the device. For example, if a porpoise was near the sound source at start-up, it would have to travel at over 5 m/s in order to travel 1500 m during the 5 min start-up period. Although porpoises can travel at burst speeds of 5.8 m/s when chased (Gaskin et al., 1974), their sustained maximum swimming speed over 1500 m is likely to be less than this value. This may account for the similar numbers of porpoises sighted during the initial scans of both the active and inactive periods.

Taylor et al. (1997) published theoretical zones of influence on porpoises (based on human and porpoise hearing models) for three types of acoustic alarms. They predicted that the *zone of severe disturbance and discomfort* for porpoises to a similar AHD would occur

Table 1
Sample size, closest observed approach (COA), median COA and mean (±SD) COA of porpoises to an active and inactive acoustic harassment device in the Bay of Fundy, NB, Canada

AHD State	*n*	COA (m)	Median COA (m)	Mean COA (m)
Active	9	645	994	991±302
Inactive	60	6	313	364±261[a]
P value		na		<0.01

[a] Significantly lower, Mann–Whitney *U*-Test.

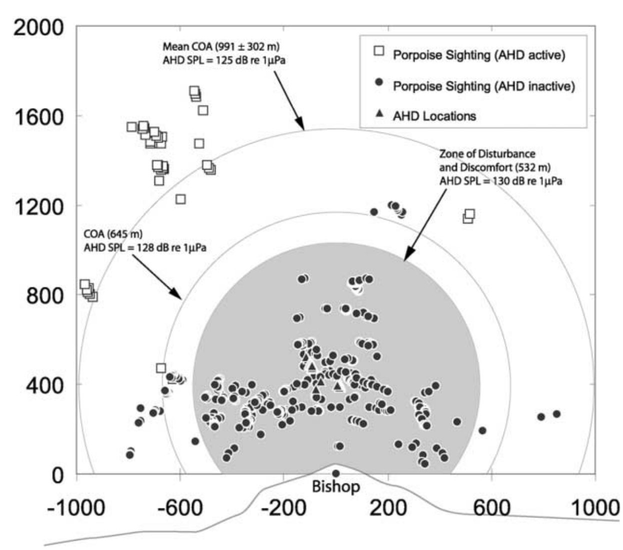

Fig. 4. Closest observed approach (COA), mean COA, theoretical received levels and porpoise sightings by theodolite around an active and inactive acoustic harassment device in the Bay of Fundy, NB, Canada.

where the received sound pressure level was equal to or greater than 130 dB re 1 μPa (hearing threshold + 50 dB). Using the above spreading model, the predicted *zone of severe disturbance and discomfort* for the AHD in the present study would be at approximately 532 m (Fig. 4). The COA of porpoises to the AHD in the present study (645 m) is higher than the predicted *zone of severe disturbance and discomfort* (532 m) as calculated by Taylor et al. (1997).

The present study does not address the potential for porpoises to habituate to AHDs. Cox et al. (2001) found that harbour porpoises habituate to lower amplitude acoustic deterrent devices (ADDs), or "pingers", within 5 days of exposure. However, the response of porpoises to the AHD stimulus in the present study did not wane during 2-h exposures (Fig. 1.), nor was there any evidence of habituation to the AHD array over a 4-week period in the study conducted by Olesiuk et al. (1996). Also, it is likely that the porpoises sighted and tracked in the present study had previously encountered AHDs; the use of AHDs in the inshore areas of the lower Bay of Fundy is now widespread (see Johnston and Woodley, 1998) and past radio tracking studies of porpoises in this region indicate that they moved between locations currently influenced by AHDs in the Bay of Fundy (see Read and Gaskin, 1985; Westgate et al., 1995; Westgate and Read, 1998). Further research is required to test for habituation of porpoises to AHDs deployed on salmon farms.

Harbour porpoises may not be the only non-target marine mammal species affected by the use of AHDs on salmon farms. For example, a recent decline in pacific white-sided dolphin occurrence on the West coast of Canada was recently correlated with the introduction of AHDs on salmon farms in the area (Morton, 2000). Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) are relatively sensitive to the frequencies produced by the AHDs used in that region (Tremmel et al., 1998) and the observed decline in dolphin occurence could indicate avoidance of habitat influenced by AHD sound (Morton, 2000). As well, Morton and Symonds (2002) correlated a significant decrease in the occurrance of killer whales (*Orcinus orca*) in the same area while AHDs were active.

The results of the present study support Johnston and Woodley's (1998) hypothesis that AHDs used on salmon farms in the lower Bay of Fundy may exclude porpoises from important habitat. For example, Johnston and Woodley (1998) found that many aquaculture sites in the Bay of Fundy are located in or near habitat that historically has been important for foraging porpoises (Watts and Gaskin, 1984; Gaskin et al., 1985) including lactating females nursing calves (Smith and Gaskin, 1983). Also, some salmon farms with active AHDs are located near narrow passages which connect larger portions of porpoise habitat that historically supported large numbers of porpoises (Gaskin, 1983; Gaskin et al., 1985). The continued use of AHDs in such areas will likely exclude harbour porpoises from important portions of their habitat and may restrict their movement between adjacent areas.

Acknowledgements

This study was conducted under Research Permits issued by the Canadian Department of Fisheries and Oceans, Canada. This project was funded by the International Marine Mammal Association, the International Fund for Animal Welfare, and by an NSERC grant to David M. Lavigne. Steve Christensen from Airmar Technologies Corp. provided the DB II Plus AHD system for this experiment. Additional logistical support for this project was provided by the Grand Manan Whale and Seabird Research Station. I also thank Tara Cox, Ashley Dayer, Sheryl Fink, Heather Koopman, Tom MacDougall, Rob Ronconi, Andy Read, Jeremy Rusin, Krystal Tolley and Andrew Westgate for help in the field and for comments on earlier drafts of this manuscript. David M. Lavigne also provided comments on earlier drafts of this manuscript.

References

Anderson, S., 1970. Auditory sensitivity of the harbour porpoise Phocoena phocoena. Investigations of Cetacea 2, 255–259.

Bibikov, N.G., 1992. Auditory brainstem responses in the harbour porpoise (*Phocoena phocoena*). In: Thomas, J.A., Kastelein, R.A., Ya Supin, A. (Eds.), Marine Mammal Sensory Systems. Plenum, New York, pp. 197–211.

Cox, T.M., Read, A.J., Solow, A., Tregenza, N., 2001. Responses of Harbour Porpoises (*Phocoena phocoena*) to Pingers (IWC Working Paper SC/51/SM48).

Gaskin, D.E., 1992. Status of the Harbour Porpoise, *Phocoena phocoena*, in Canada. Canadian Field-Naturalist 106, 36–54.

Gaskin, D.E. 1983. The marine mammal community. In: Thomas, M.L.H. (Ed.) Marine and Coastal Systems of the Quoddy Region, New Brunswick, Canada. Spec. Publ. Fish. Aquat. Sci.

Gaskin, D.E., Read, A.J., Watts, P.F., Smith, G.J.D., 1985. Population dispersal, and interactions of harbour porpoises in the Bay of Fundy and Gulf of Maine. Can. Tech. Rep. Fish. Aquat. Sci. 1291, 28.

Gaskin, D.E., Arnold, P.W., Blair, B.A., 1974. *Phocoena phocoena*. Mammalian Species 42, 1–8.

Haller, D.R., Lemon, D.D., 1995. Acoustic source levels of Airmar and PRA seal-scarers. Final Report for Fisheries and Oceans Canada (Contract No. XSA FP941–3-8025/00/A). ASL Environmental Service Ltd, Sidney BC.

Johnston, D.W., Woodley, T.H., 1998. A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. Aquatic Mammals 24 (1), 51–61.

Koschinski, S., Culik, B., 1997. Deterring harbour porpoises (*Phocoena phocoena*) from gillnets: observed reactions to passive reflectors and pingers. Rep. Int. Whal. Commn 47, 659–668.

Marsh, H.W., Schulkin, M., 1962. Shallow water transmission. Journal of the Acoustical Society of America 34, 863–864.

Morton, A., 2000. Occurrence, photo-identification and prey of pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in the Broughton

Archipelago, Canada 1984–1998. Marine Mammal Science 16 (1), 80–93.

Morton, A.B., Symonds, H.K. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. ICES Journal of Marine Science, in press.

Olesiuk, P.F., Nichol, L.M., Sowden, P.J., Ford, J.K.B. Effects of the sound generated by an acoustic deterrent device on the relative abundance and distribution of harbor porpoise (*Phocoena phocoena*) in Retreat Passage, British Columbia. Marine Mammal Science, in press.

Popov, V.V., Ladygina, T.F., Ya Supin, A., 1986. Evoked potentials of the auditory cortex of the porpoise, *Phocoena phocoena*. Journal of Comparative Physiology (A) 158, 705–711.

Read, A.J., Gaskin, D.E., 1985. Radio tracking the movements and activities of harbor porpoises, *Phocoena phocoena*, in the Bay of Fundy. Fishery Bulletin (U.S.) 83, 543–552.

Richardson, W.J., Greene, C.R., Malme, C.I., Thomson, D.H., 1995. Marine Mammals and Noise. Academic Press, San Diego CA.

Smith, G.J.D., Gaskin, D.E., 1983. An environmental index for habitat utilization by female harbour porpoises with calves near Deer Island, Bay of Fundy. Ophelia 22, 1–13.

Taylor, V.J., Johnston, D.W., Verboom, W.C., 1997. Acoustic harassment device (AHD) use in the aquaculture industry and implications for marine mammals. Proc. Inst. Acoust. 19 (9), 267–275.

Tremmel, D.P., Thomas, J.A., Ramirez, K.T., Dye, G.S., Bachman, W.A., Orban, A.N., Grimm, K.K., 1998. Underwater hearing sensitivity of a Pacific white-sided dolphin, *Lagenorhynchus obliquidens*. Aquatic Mammals 24 (2), 63–69.

Watts, P., Gaskin, D.E., 1985. Habitat index analysis of the harbour porpoise (*Phocoena phocoena*) in the southern coastal Bay of Fundy, Canada. Journal of Mammalogy 66, 733–744.

Westgate, A.J., Read, A.J., 1998. Applications of new technology to the conservation of porpoises. MTS Journal 32 (1), 70–81.

Westgate, A.J., Read, A.J., Berggren, P., Koopman, H.N., Gaskin, D.E., 1995. Diving behaviour of harbour porpoises, *Phocoena phocoena*. Canadian Journal of Fisheries and Aquatic Sciences 52, 1064–1073.

Zar, J.H., 1996. Biostatistical Analysis. Prentice Hall, New Jersey.