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Assessing the effects of industrial activity on large cetaceans in Trinity Bay, Newfoundland (1992–1995)

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Abstract

The effects of industrial activity on large cetaceans in Bull Arm, Trinity Bay, Newfoundland from 1992 through 1995 were assessed. The response of individually-identified animals indicated short, and possible long-term disturbance due to the activities. Humpback whales (*Megaptera novaeangliae*) appeared tolerant of transient blasting and frequent vessel traffic, but were more affected by continuous activity from dredging, coupled with vessel traffic. A significant decreased return rate to feeding grounds indicated a possible long-term effect of exposure to blasting. Individually-identified minke whales (*Balaenoptera acutorostrata*) were resighted in the industrialized area, and appeared tolerant of vessel traffic, but number of sightings were inadequate to indicate how resight interval was affected. Tracking individually-identified animals appeared to provide a more sensitive means of assessing the impacts of industrial activity than did abundance and distribution of populations.

Introduction

The United States National Research Council's report on the effects of noise on marine mammals expressed an urgent need for further research on effects of low-frequency sounds (Green *et al*., 1994). Currently there is inadequate information for scientists and managers to develop regulations on the use of sounds in the ocean (Geraci & St. Aubin, 1980; Green *et al*., 1994; Lien *et al*., 1995). Studies that can adequately assess the potential long-term effects of anthropogenic low-frequency sound on cetaceans are needed (Richardson, 1995*a*).

Most studies have investigated short-term behavioural responses (Richardson, 1995*b*) using changes in measures such as abundance, distribution, respiration, and orientation (e.g. Malme *et al*., 1983, 1988; Richardson *et al*., 1986; Richardson *et al*., 1987*a*; Cosens & Dueck, 1988; Ljungblad *et al*., 1988; Bauer *et al*., 1993; Tyack, 1993; Mate *et al*., 1994; Richardson *et al*., 1995). Although short-term behavioural responses to anthropogenic noise are sometimes detected in such studies, these do not necessarily indicate long-term impacts (Richardson *et al*., 1985*a*; Richardson *et al*., 1987*a*; Reeves, 1992; Richardson & Würsig, 1995). Alternatively, the lack of demonstrated short-term behavioural change does not necessarily indicate that there are no effects (Richardson & Würsig, 1995; Todd *et al*., 1996); rather such results may indicate tolerance of, or habituation to, anthropogenic noise by marine mammals (Richardson, 1995*b*; Richardson & Würsig, 1997). Alternatively, these results may indicate that the measurements themselves may not have been sensitive enough to detect effects.

Many reviews of impacts of anthropogenic activity on marine mammals have identified the need for control studies (Turl, 1982; Reeves *et al*., 1984; Green *et al*., 1994; Richardson & Würsig, 1995; Richardson *et al*., 1995). However, interpretation of results from studies with controls can be difficult. For example, one study found that abundance of bowhead whales changed in both industrial and non-industrial areas, so causation could not be attributed solely to the industrial activity (Richardson *et al*., 1987*a*). In another, when humpback whale movements varied both during the control and experimental conditions, no conclusion was possible about responses to the noise source (Malme *et al*., 1985). Effects of anthropogenic noise may not always be apparent even with control designs because of natural variation in dependent measures.

Indicators and experimental designs with sufficient sensitivity are needed to assess impacts on individuals and populations of marine mammals. Long-term tracking of individually-identified animals may help determine the true impacts of anthropogenic noise (Richardson *et al.*, 1985*b*; Reeves, 1992; Green *et al.*, 1994; Richardson & Würsig, 1995; Richardson & Würsig, 1997). According to Richardson & Würsig (1995), information is needed on identified animals displaced from disturbed areas, as well as identified animals from control areas. Comparing resighting, resight interval, and return rates of individually-identified whales over longer time periods may assist in determining impacts of disturbance (e.g. Davis *et al.*, 1986; Weinrich *et al.*, 1991; von Ziegesar *et al.*, 1994).

Some studies have used individually-identified animals to assess the effects of anthropogenic activity (e.g. Baker *et al.*, 1983, 1988; Davis *et al.*, 1986; Richardson *et al.*, 1987*b*; Koski *et al.*, 1988; Wartzok *et al.*, 1989; Todd *et al.*, 1996). However, to date, there have been few long-term studies using individually-identified animals both from control and experimental impact areas in assessing the impact of anthropogenic changes.

In 1992, a monitoring program began in Trinity Bay, Newfoundland to assess impacts, if any, of industrial activity produced by the construction of an offshore-oil-support platform in Great Mosquito Cove, Bull Arm on large cetaceans in the area (Fig. 1) (Lien *et al.*, 1995; Todd *et al.*, 1996). Early results from this study indicated orientation failures based on an increased entrapment rate (Todd *et al.*, 1996) and anatomical evidence of ear damage (Ketten, 1995), and suggested that some humpback whales were seriously impacted by blasting and drilling activity. However, changes in the distribution, resighting, resight interval, and overall behaviour of individual humpback whales feeding in the area were not detected (Todd *et al.*, 1996).

This paper reports on the continued monitoring of Trinity Bay, Newfoundland during heavy periods of industrial activity through 1995. Control/impact areas were used, and observable behaviours were measured to test for the effects of noise. In addition, photo-identification of individual animals enabled long-term impacts of industrial activity to be assessed.

Methods

Data collection

1992 From 1991–1992, blasting and drilling constituted the predominant underwater activity in Great Mosquito Cove, Bull Arm, Trinity Bay, Newfoundland (47°48.65′N, 53°53.30′W) (Fig. 1), with periodic clamshell dredging and vessel traffic (Todd *et al.*, 1996) (Table 1). During 1992, blast charges were typically between 1000 and 2000 kg with a maximum of 5500 kg (Todd *et al.*, 1996). Todd *et al.* (1996) reported received sound levels at 1 nm from the blast site of between 148–153 dB (re 1 μPa).

For 9 days, between 6–25 June 1992, two boats monitored the occurrence of individually-identified humpback whales using methods described in Todd *et al.* (1996). During 1992, humpback whales were also individually-identified during surveys throughout Newfoundland and Labrador, but primarily along the eastern coastline of Newfoundland, from June–September, as part of the Years of the North Atlantic Humpback Whale (YoNAH) survey of humpback whales (Palsbøll *et al.*, 1997; Smith *et al.*, 1999).

1993 In 1993, vessel traffic was the only industrial activity in Bull Arm (Table 1). YoNAH surveys (Palsbøll *et al.*, 1997; Smith *et al.*, 1999) were again conducted throughout Newfoundland and Labrador, but primarily along the eastern coastline of Newfoundland, including northern Trinity Bay. From June–August two boats conducted photo-identification surveys of humpback whales, but no special monitoring surveys occurred in the Bull Arm, Trinity Bay area.

1994 & 1995 In 1994, clamshell dredging, blasting (POURVEX® EXTRA®/DETALINE® Delay System), drilling and vessel activity occurred in Great Mosquito Cove (47°48.500′N, 53°53.500′W) (Table 1; Fig. 1). Monitoring occurred in southern Trinity Bay for 35 days within the main observation period from 5 July–10 September. Coastal surveys following YoNAH sampling protocols (Smith *et al.*, 1999) were conducted in 1994 primarily along the eastern coastline of Newfoundland from 16 June–17 September, but survey effort was not as high as previous years. In 1995, vessel traffic was the only industrial activity in Bull Arm (47°49.390′N, 53°52.218′W) (Table 1; Fig. 1). Preliminary surveys in 1995 indicated that whales were abundant earlier than in 1994. Monitoring during 1995 occurred in southern Trinity Bay for 36 days from 17 June–8 August. No coastal surveys were conducted in 1995.

The longitudinal line of 53°42′W, at the Bellevue Peninsula, divided southern Trinity Bay (<48°N) into a control area, and an experimental area, including Bull Arm (Fig. 1). This division was based on the attenuation of sound from Bull Arm due to distance, and the presence of a land boundary. Acoustic recordings indicated that industrial activity sounds were prevalent in the experimental area, and far less so in the control area (Borggaard,

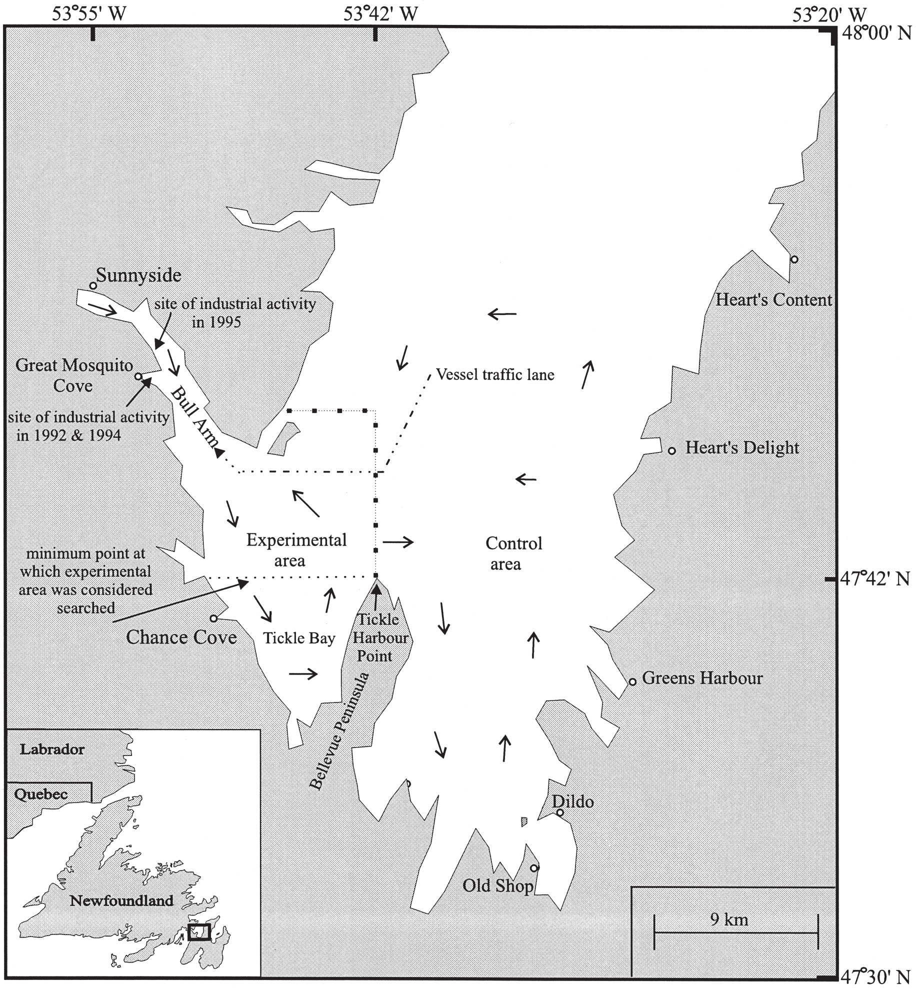

Figure 1. Southern Trinity Bay, Newfoundland study area including experimental and control areas, vessel traffic lane, and general survey route (→).

1996). The experimental area was monitored by surveys that reached a minimum point of 47°42′N.

Surveys were conducted daily, weather permitting, with 2 or 3 observers aboard a 6 m boat traveling at a steady speed. Due to the small nature of the study site, the transect route followed the coastline, allowing for complete monitoring of the survey area in a day. Times and Global Positioning System (GPS) positions were recorded for the start and finish of each trip; changes in the vessel's speed, direction, or activity; changes in weather condition (e.g. visibility and Beaufort scale); and each whale sighting. Observers went off effort when sightings were made to record the species, maximum/minimum number of individuals, and 20 min of behaviour. Humpback and minke whales were then photographed for individual identification (Katona *et al.*, 1979; Dorsey, 1983) before continuing the survey. Each sighting was considered new unless it was positively determined to be a resighting for that day either in the field or later by photographic matching. Survey completion, whale observations, and success in photographing depended on weather, time, and sightings (e.g. whale's behaviour).

While humpback whales were the initial focus of the 1992–1995 study, increasing effort was spent on minke whales in 1994 and 1995. Photographic effort for minke whales was greater in 1995 than 1994.

Data analysis

Daily searching effort varied; therefore whale counts were standardized. The relative abundance

Table 1. Industrial activities in Bull Arm, Trinity Bay, 1991–1995. Averages are reported from June–September for all years unless otherwise noted. The 1991 and 1992 values are based on available charge sizes (from Todd *et al.*, 1996)

	Dredging		Blasting		Vessel activity			
Year	Total m^3/yr	Average m^3/mo	Total no./yr (average size)	Average no./mo (average size)	Total no. arrivals/yr	Average no. arrivals/mo	Average no. arrivals and departures/mo	Average no./day on site
1991	106 480	16 464[a]	115 (884 kg)	24.3[b] (832 kg)	Similar to 1992	—	—	—
1992	124 370	2239	55 (1055 kg)	5.5 (1254 kg)	7	0.7[b]	1.3[a]	0.07[a]
1993	none	—	none	—	15	1.8	3.0	2.1
1994	502 886	128 449[a]	90 (701 kg)	32.5[b] (690 kg)	71	8.3	14.3	7.7
1995	none	—	none	—	84	5.0	9.8	15.4

—not applicable.
[a]July–September.
[b]August–September.

(RA) of each species sighted each day was calculated as the minimum number of whales seen per searching effort (whales/hr). GPS positions were used to calculate distances (D=km) between sightings and the industrial activity in Bull Arm; the initial daily sighting for each individual animal was used. Distances from the industrial site were calculated as straight lines regardless of land boundary (similar to Todd *et al.*, 1996).

Effects of wind (Beaufort scale) and visibility on the sightability of each species in 1994 and 1995 were tested separately. The number of sightings per searching hr in each Beaufort and visibility condition (0–20, 21–40, 41–60 km) per day were considered. Beaufort 0, 1, 2, and 3 were used; sightings and effort were combined for Beaufort equal to or greater than 3 as these occurrences were rare. Analyses controlled for day of the year. Days used ranged from the first day a species was sighted until the last for the entire study period, and only if the entire experimental area was searched.

General Linear Models (GLM) were used to analyze distance and relative abundance. Interaction terms were included in models except for those in which day of the year acted as a statistical control for season. G-tests were used for comparisons of the number of humpback whales identified between years. For the purpose of parametric statistical analysis, data that produced residuals which appeared associated with the statistical model were transformed, thereby removing any association. Transformations (see Sokal & Rohlf, 1995) are noted as L for natural logarithm, SQ for the square, and INV for the inverse value. Data for tests with non-normal residuals were randomized 1000 times (see Crowley, 1992) to obtain probability values based on the distribution of the statistic given the data (P_r), rather than a theoretical distribution of the statistic (P_F). The significance level (α) was set at <0.05. The average distance ($\overline{D}$) and relative abundance ($\overline{RA}$) are reported ± the standard error (SE).

Capelin are the key forage species that determine inshore abundance of cetaceans in Newfoundland waters (Whitehead & Carscadden, 1985; Piatt *et al.*, 1989). In 1994 and 1995, daily observations from Chance Cove indicated capelin were present most of July and into early August (Nakashima, DFO, St. John's, NF, unpubl. data). Capelin relative abundance, or daily surface area (m^2) of capelin schools, was higher in southern Trinity Bay in 1994 than in any year since 1991 (Nakashima, 1996). In addition, the experimental area (1 507 000 m^2) had a higher relative abundance of capelin than the control area (334 000 m^2) in 1994. Indications of capelin, based on daily observations in Chance Cove (Fig. 1), occurred on 5 July 1994, and 4 July 1995; and the peak in capelin relative abundance from aerial surveys occurred on 15 July in both years (Nakashima, 1996). Based on these findings no seasonal adjustments were made when the two years were compared.

Changes in the RA and D of whales in the experimental area were tested using days during the main observation period, and during various industrial activities where appropriate. Comparisons of RA between the experimental and control areas were done for days when effort occurred in both, and controlled for day of the year. To enable comparisons in the experimental and control areas

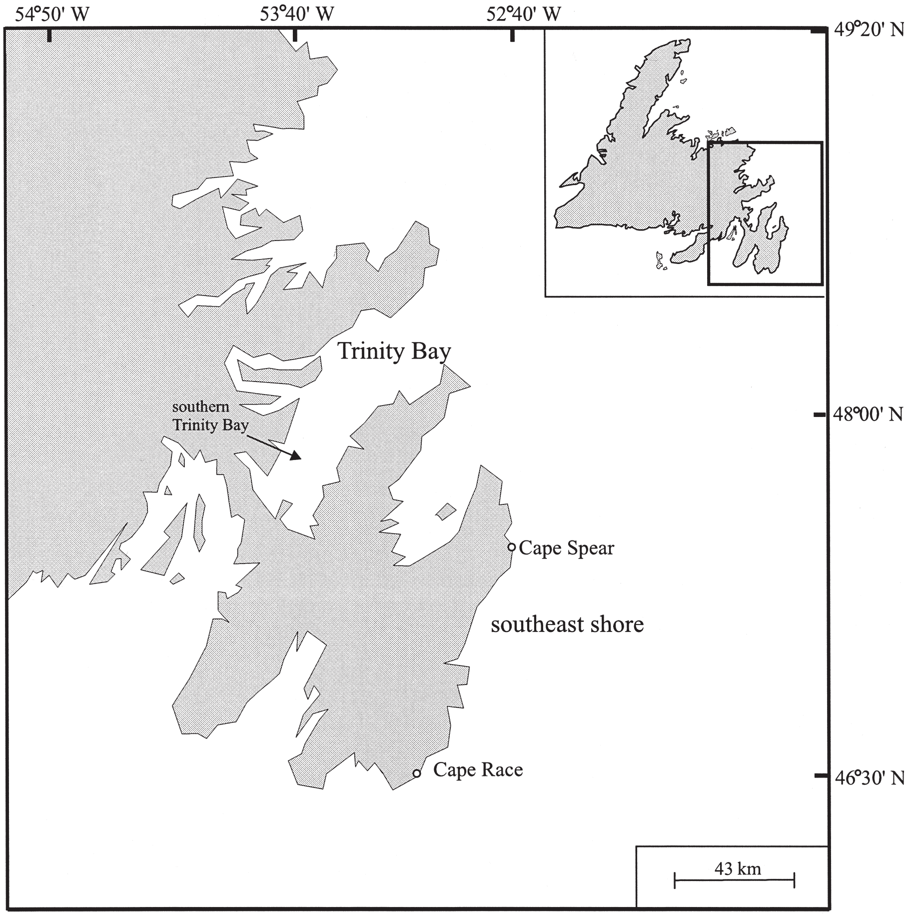

Figure 2. Trinity Bay and the southeast shore study areas used for between year comparisons.

to 1992, relative abundance was calculated as the number of humpback whales sighted during the total time the monitoring boat was on the water.

Calculations involving individually-identified humpback whales followed methodology from Todd *et al.* (1996) to enable comparisons; some results from 1992 (data from Todd *et al.*, 1996) were recalculated to standardize the limits of the study area. To test whether any differences in resighting and resight interval were due to different time periods, the 1995 study period was divided into two periods. The period from 17 June–4 July 1995 was compared to the 1992 study (6 June–25 June); the period from 5 July– 8 August 1995 was compared to the 1994 study (5 July–29 July).

The YoNAH photographic archive (College of the Atlantic, Bar Harbor, ME, USA) was used to compare the numbers of individually-identified whales sighted inside southern Trinity Bay (n=67) and outside in 1992 (n=225), then resighted in eastern Canada (n=629) and Newfoundland (n=359) in 1993. Individually-identified humpback whales in southern Trinity Bay in 1992 were also compared with those from eastern Newfoundland in 1994 (n=162). In addition, comparisons were made between the number of YoNAH humpback whales sighted along the southeast shore (n=64) (Cape Spear to Cape Race) in 1992, then resighted in eastern Newfoundland in 1993 and 1994 (Fig. 2).

There is no established catalogue of photo-identified minke whales in Newfoundland waters. Two matchers conducted blind matches of all good-quality minke whale photographs within and between 1994 and 1995; a third matcher provided additional confirmation for all potential resightings. If resightings could not be confirmed by all the matchers, they were not used. Matches were not based on dorsal shape alone unless the shape was unique or notches were present. Minke whale photographs showing the left side of the body were

Table 2. Total survey time during the main observation period and number of humpback whales (*Megaptera novaeangliae*) photo-identified in southern Trinity Bay, Newfoundland in 1992 (data from Todd *et al.,* 1996), 1994, and 1995

Year	Month	Total survey time (hr)	No. humpbacks identified
1992 (9–25 Jun)[a]	Jun	77.2	65
1994 (5 Jul–10 Sept)	Jul	110.6	23
	Aug	167.4	0
	Sept	17.6	0
1995 (17 Jun–8 Aug)	Jun	63.7	16
	Jul	95.2	17
	Aug	23.8	1

[a]survey time is not available for 6 June. Two whales identified only on this day were excluded from the table.

used when reporting the number of whales photographed. Photographs of animals in which only the right side of the body was obtained were used for resightings and counts only if they had unique dorsal fin shapes.

Results

Abundance and distribution of humpback whales for 1992 is presented in Todd *et al.* (1996); data from 1993–1995 are summarized here.

Environmental conditions

Most observation time was spent in calm sea conditions and good visibility due to the small size of the survey boat. In 1994 and 1995, sea conditions and visibility did not significantly affect sightings of humpback or minke whales.

Effort

The time spent searching in each distance category in the experimental area (0–10 and 11–20 km) was similar in 1994 (63.0 and 53.4 hr) and 1995 (27.7 and 24.8 hr). There was a difference in the amount of searching time between years; however, the number of whales were standardized by searching effort.

Survey effort varied between years, but the higher effort years did not necessarily result in a larger number of sightings (Table 2). Nonetheless, these effort differences could affect the probability of within-year resights (Clapham *et al*., 1993). Also, differences in ports used between 1992 and 1994/1995 could affect distance resight variables. To account for these potential biases, between year comparisons of abundance and resighting variables (within year only) are compared qualitatively.

Abundance and distribution

1994—Dredging During dredging in 1994 (Table 3), distance of humpback whales from the industrial site increased during the main observation period (Fig. 3) ($F_{1,15}=19.26$, $P_r=0.002$), but L-RA relative abundance did not change ($F_{1,11}=0.02$, $P_r=0.91$). The L-RA relative abundance was significantly lower in the experimental ($\overline{RA}=0.50\pm0.19$) compared to the control area ($\overline{RA}=5.40\pm1.49$) when common days were compared (exp/con: $F_{1,15}=19.44$, $P_r=0.002$; date: $F_{1,15}=5.96$, $P_r=0.03$).

1995—Vessel Activity Only In 1995 (Table 3), SQ-D distance of humpback whales from the industrial site increased during the main observation period (Fig. 4) ($F_{1,37}=10.49$, $P_r=0.003$), but SQ-RA relative abundance did not change ($F_{1,19}=0.02$, $P_r=0.92$). The INV-RA relative abundance was not significantly different in the experimental area ($\overline{RA}=0.84\pm0.17$) compared to the control area ($\overline{RA}=1.76\pm0.50$) when common days were compared due to the high variability of sightings (exp/con: $F_{1,13}=0.09$, $P_r=0.84$; date: $F_{1,13}=1.33$, $P_r=0.29$). When the survey period was fixed to test for between year differences in the experimental area, the same trends were found. However, before the fixed survey period there was no change in distance ($F_{1,13}=0.07$, $P_r=0.81$).

Abundance comparisons across years

There were differences in the relative abundance of humpback whales in the experimental and control areas in southern Trinity Bay across years (Table 4). In 1992, more humpback whales per hr occurred in

Table 3. Results of analyses testing the effect of various explanatory variables on distance and relative abundance of humpback whales (*Megaptera novaeangliae*) observed in 1994 and 1995

Comparisons	Distance	Relative abundance
1994		
Dates during dredging[a]	$F_{1,15}=19.26$, $\mathbf{P_r=0.002}$	$F_{1,11}=0.02$, $P_r=0.91^b$
Experimental vs. control area (controlling for date)	—	**exp/con**: $F_{1,15}=19.44$, $\mathbf{P_r=0.002}$ **date**: $F_{1,15}=5.96$, $\mathbf{P_r=0.03^b}$
1995		
Dates of main observation period	$F_{1,37}=10.49$, $\mathbf{P_r=0{\cdot}003^c}$	$F_{1,19}=0.02$, $P_r=0.92^c$
Experimental vs. control area (controlling for date)	—	exp/con: $F_{1,13}=0.09$, $P_r=0.84$ date: $F_{1,13}=1.33$, $P_r=0.29^d$
Dates of 1994 study	$F_{1,22}=7.10$, $\mathbf{P_r=0.02^b}$	$F_{1,10}=1.24$, $P_1=0.29^c$
Dates before 1994 study	$F_{1,13}=0.07$, $P_r=0.81$	$F_{1,7}=1.41$, $P_r=0.27$

[a]same as main observation period.
[b]L, [c]SQ, and [d]INV transformed response variables.

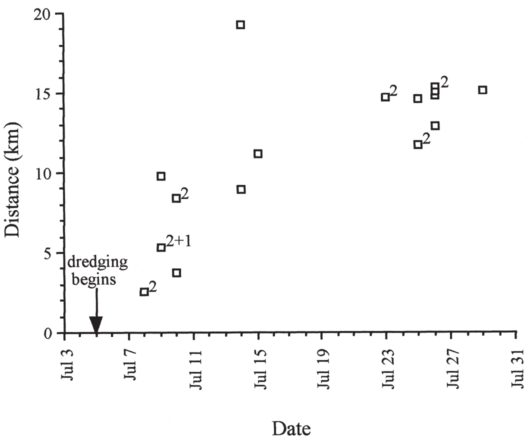

Figure 3. Distance (km) from the industrial site of all humpback whales (*Megaptera novaeangliae*) observed in the experimental area during dredging activity in 1994. The average distance ($\bar{D} \pm SE$) during dredging was 11.10 ± 1.16. Numbers indicate group size of whales at the same location.

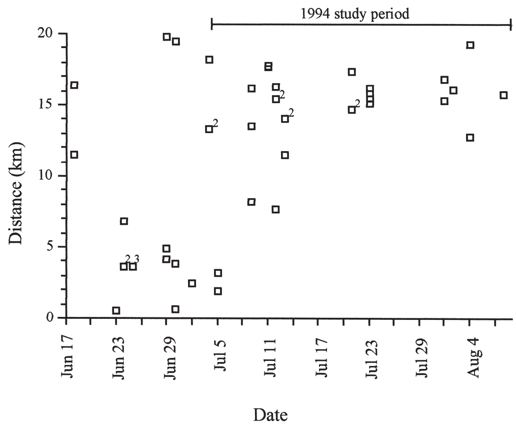

Figure 4. Distance (km) from the industrial site of all humpback whales (*Megaptera novaeangliae*) observed in the experimental area during vessel activity in 1995. The average distance in 1995 ($\bar{D} \pm SE$) was 8.61 ± 1.83 before the 1994 study period, and 13.90 ± 0.90 during this time period. Numbers indicate the group size of whales at the same location.

the experimental area, as compared to the control area, during blasting, dredging, and vessel traffic. The opposite trend occurred in 1994 and 1995 when no blasting occurred. In addition, more humpback whales per hr were observed in 1992 compared to 1994 and 1995.

Photo-identification

Resightings across 1992 and 1994 Few humpback whales were resighted between years within the study area. Two humpback whales from 1992 were resighted in 1994, three from 1992 were resighted in 1995, and four from 1994 were resighted in 1995. Newfoundland humpback whales are not known to have preferred ranges, and resight interval is typically reported as less than three days (Whitehead *et al.*, 1980).

The proportion of individually-identified humpback whales sighted in Trinity Bay in 1992 (Table 5), and resighted in eastern Canada in 1993 (0.13), did not differ from the resighting proportion of animals from the rest of Newfoundland (0.24) ($G_1=3.4$, $P_F=0.06$). However, a significantly smaller proportion of animals sighted in Trinity Bay in 1992 were resighted in Newfoundland in 1993 (0.07), compared to the resighting proportion of animals from the rest of Newfoundland (0.21) ($G_1=7.8$, $P_F=0.005$).

Table 4. Average relative abundance (no. whales/hr ± SE) of humpback whales (*Megaptera novaeangliae*), in the experimental and control areas, during 1992 (data from Todd *et al.,* 1996), 1994, and 1995. Only days on which monitoring occurred in both areas were used

	1992 (n=4 days)	1994 (n=9 days)	1995 (n=8 days)
Experimental area	4.05 ± 0.44	0.40 ± 0.16	0.54 ± 0.11
Control area	1.65 ± 0.35	1.22 ± 0.25	0.97 ± 0.30

Table 5. Number of humpback whales (*Megaptera novaeangliae*) from Trinity Bay and eastern Newfoundland from 1992, resighted in eastern Canada and Newfoundland in 1993. As well as, the number of humpback whales from Trinity Bay and along the southeast shore from 1992, resighted in eastern Newfoundland in 1993 and 1994

	Total no. identified 1992	No. resighted in Canada 1993	No. resighted in Newfoundland 1993	No. resighted in Newfoundland 1994
Newfoundland	225	53	48 } *	—
Trinity Bay	67	9	5 } *	5
southeast shore	64	—	18	7

*significant return proportions.
—number of resights were not available.

Further, a significantly smaller proportion of humpback whales sighted in Trinity Bay in 1992, were resighted in Newfoundland in 1993 (0.07), compared to the resighting proportion of animals from the southeast shore (0.28) ($G_1=10.11$, $P_F=0.002$). The proportion of humpback whales sighted in Trinity Bay in 1992, and resighted in Newfoundland in 1994 (0.07), did not differ significantly from the resighting proportion of animals from the southeast shore (0.11) ($G_1=0.48$, $P_F=0.49$); however, the 1994 photographic sample was considerably smaller than previous years (n=162).

Resightings and resight intervals among years
For animals that were identified within the study area on subsequent days, there was movement away from the industrial site when dredging was the predominant activity (1994—76% of 17 cases), but not blasting (1992—47% of 53 cases) (Todd *et al.*, 1996) or vessel activity (1995- 50% of 80 cases). Individually-identified humpback whales were resighted more often closer to the blasting activity in 1992 and vessel activity in 1995; during dredging activity in 1994 they were resighted more often further away (Fig. 5). Differences in resighting and resight interval were found between years; the longest intervals occurred in 1995 (Table 6). Four humpback whales were repeatedly resighted near the industrial site in 1995. When the 1995 survey period was divided (based on prey presence) to test for seasonal differences, trends similar to the entire 1995 survey period were observed. The earlier time period produced results fairly comparable to 1992, and the later period produced results still higher than 1994.

Minke whales

Abundance and distribution
1994—Dredging and Blasting In 1994 (Table 7), distance of minke whales from the industrial site increased during the main observation period ($F_{1,42}=9.92$, $P_r=0.005$), and relative abundance decreased ($F_{1,33}=9.44$, $P_r=0.005$). Similar trends were observed during dredging, but before blasting. There was no change in distance from the site during blasting ($F_{1,11}=0.30$, $P_r=0.63$), nor change in L-RA relative abundance ($F_{1,13}=0.03$, $P_r=0.88$). Similar trends were found before and during blasting. One minke whale was followed through a blast, but no change in distance from the site, or surface and diving behaviour could be detected.

There was no significant difference in L-RA relative abundance in the experimental ($\overline{RA}=0.53\pm0.16$) or control area ($\overline{RA}=1.10\pm0.29$) when common days were compared (exp/con: $F_{1,29}=3.09$, $P_r=0.10$; date: $F_{1,29}=8.29$, $P_r=0.006$). As the data set contained days in which sightings occurred in one area and not the other, the sighting variability was too large to detect potential changes.

1995—Vessel Activity Only
In 1995 (Table 7), distance of minke whales from the industrial site increased during the main

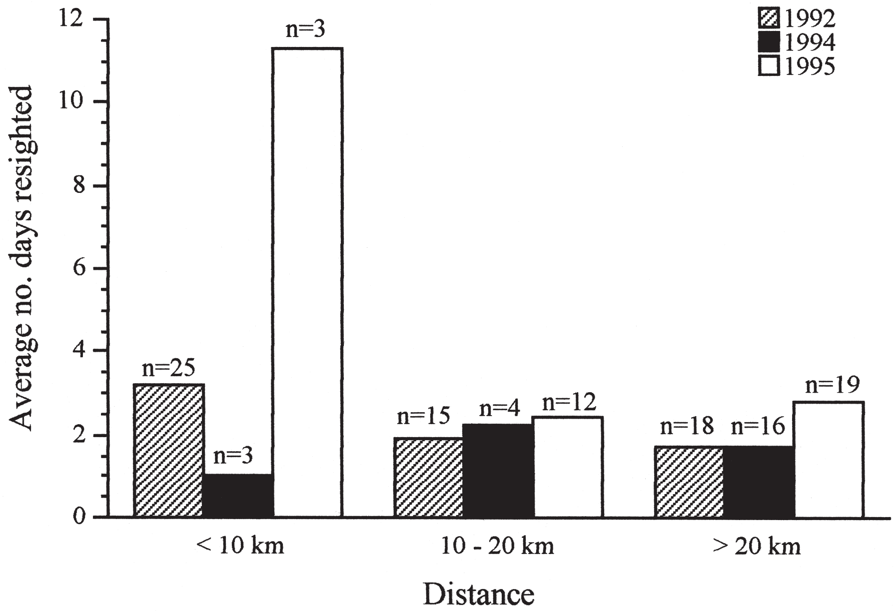

Figure 5. Distance (km) from the industrial activity of individually-identified humpback whale (*Megaptera novaeangliae*) (n=no. of whales) resightings in 1992 (data from Todd *et al.,* 1996), 1994, and 1995. Distance is based on the average of multiple resightings of the same individual (Todd *et al.,* 1996).

Table 6. Resighting and resight interval of individually-identified humpback whales (*Megaptera novaeangliae*) in southern Trinity Bay, Newfoundland in 1992 (data from Todd *et al.,* 1996), 1994, and 1995

Year	No. humpbacks identified	Average resighting (days)	Average resight interval of humpbacks seen >1 day (days)	Average resight interval of all humpbacks (days)	Maximum resight interval (days)
1992 (6–25 Jun)	67	2.3	7.8	4.6	19
1994 (5–29 Jul)	23	1.7	7.5	3.3	17
1995 (17 Jun–8 Aug)	34	3.4	16.7	9.8	44
17 Jun–4 Jul	18	2.8	8.4	4.2	16
5 Jul–8 Aug	23	2.9	12.1	7.4	34

observation period ($F_{1,49}$=22.51, P_r=0.002), but relative abundance did not change ($F_{1,19}$=3.72, P_r=0.07). The relative abundance observed in the experimental area ($\overline{RA}$=0.98 ± 0.26) was comparable to the control area ($\overline{RA}$=0.79 ± 0.25) when common days were compared (exp/con: $F_{1,21}$=0.33, P_r=0.56; date: $F_{1,21}$=5.25, P_r=0.04). When the survey period was fixed to test for between year differences in the experimental area, the only difference with 1994 was that relative abundance did not change ($F_{1,10}$=0.04, P_r=0.83). No change in distance ($F_{1,10}$<0.005, P_r=0.96) or relative abundance ($F_{1,7}$=0.02, P_r=0.88) occurred before the fixed survey period.

Photo-identification In 1994 only 10 minke whales were identified and no individuals were re-identified within the year. In 1995, with higher photographic effort, there were 26 animals identified, some on more than one day. One animal was resighted on four days, 8 animals resighted on two days, and 17 animals sighted on a single day. Resight intervals ranged from 1–45 days ($\overline{X}$=10.1). Animals were generally resighted in the same general area where

Table 7. Results of analyses testing the effect of various explanatory variables on distance and relative abundance of minke whales (*Balaenoptera acutorostrata*) observed in 1994 and 1995

Comparisons	Distance	Relative abundance
1994		
Dates of main observation period	$F_{1,42}=9.92$, $\boldsymbol{P_r=0.005}$	$F_{1,33}=9.44$, $\boldsymbol{P_r=0.005}$
Dates during dredging	$F_{1,29}=9.60$, $\boldsymbol{P_r=0.01}$	$F_{1,18}=7.93$, $\boldsymbol{P_r=0.02}$
Dates during blasting	$F_{1,11}=0.30$, $P_r=0.63$	$F_{1,13}=0.03$, $P_r=0.88^a$
Before and during blasting	$F_{1,42}=3.40$, $P_r=0.08$	$F_{1,33}=3.03$, $P_r=0.09$
Experimental vs. control area	—	exp/con: $F_{1,29}=3.09$, $P_r=0.10$
(controlling for date)		**date**: $F_{1,29}=8.29$, $\boldsymbol{P_r=0.006^a}$
1995		
Date of main observation period	$F_{1,49}=22.51$, $\boldsymbol{P_r=0.002}$	$F_{1,19}=3.72$, $P_r=0.07$
Experimental vs. control area	—	exp/con: $F_{1,21}=0.33$, $P_r=0.56$
(controlling for date)		**date**: $F_{1,21}=5.25$, $\boldsymbol{P_r=0.04}$
Dates of 1994 study	$F_{1,37}=6.13$, $\boldsymbol{P_r=0.02}$	$F_{1,10}=0.04$, $P_r=.088$
Dates before 1994 study	$F_{1,10}=0.005$, $P_r=0.96$	$F_{1,7}<0.02$, $P_r=0.88$

[a] L transformed response variable.

they were first observed, and no overall directional movement was apparent. There were 3 resightings of identified individuals between 1994 and 1995.

Discussion

Marine mammals were monitored in southern Trinity Bay during 1992 (Todd *et al.*, 1996), 1994, and 1995 concurrently with various industrial activities in Bull Arm. Each year the predominant industrial activity was different: blasting in 1992, dredging in 1994, and vessel activity in 1995. This monitoring program compared the occurrence of marine mammals in an experimental area close to the industrial activity, and a control area that was further away and less affected by industrial activity.

Abundance and distribution measures did not indicate that marine mammals were responding to the industrial activity; these measures varied irregularly. Distance of humpback whales from the industrial site increased in 1994 and 1995, but did not change during the beginning of the 1995 study. There was no change in relative abundance. Distance of minke whales from the site increased in 1994, but there was a concurrent decrease in relative abundance. During the same time period in 1995, there was a similar increase in distance of minke whales; however, during the earlier time period of the study there was no change in distance. These changes observed in abundance and distribution measures could not be attributed solely to industrial activity as there could have been potential changes in prey distribution or seasonal differences.

Comparisons of abundance between the experimental and control areas were also not able to detect potential impacts with certainty. Although minke whales were found comparably in areas with and without industrial activity during 1994 and 1995, the high variability in 1994 made it difficult to detect potential changes. Although the 1994 results suggest humpback whales responded to the industrial activity based on a significantly lower relative abundance in the experimental area compared to the control area, it cannot be concluded that no effects occurred in 1995. Consequently, it is difficult to attribute the decrease in number of humpback whales per hr since 1992, and their shift to areas further from the industrial site, to a reduced use of the area. With such variability in abundance, confounded by seasonal and yearly changes, assessment of impacts by comparisons between the two areas are difficult to interpret.

Abundance measures may not be an adequate indicator of impact from industrial noise in this study. The variability in abundance could be due to natural fluctuations, occurrence of whales outside the transect route, or industrial activity. Pre-impact data may have helped to detect effects on abundance, but even with baseline data the results could be difficult to interpret. Abundance can be influenced by anthropogenic activity, as well as other variables such as prey abundance; it is difficult to attribute causation if changes are observed because these factors may be confounded (Reeves *et al.*, 1984; Richardson *et al.*, 1987*a*; Reeves, 1992).

Tracking individual animals appeared to be a more sensitive indicator of reaction to industrial activity. Both sightings and resightings of individual minke whales showed that some remained in an area with high vessel activity. In addition, resightings between 1994 and 1995 showed that individual minke whales returned to the area in spite of industrial activity.

Impacts of industrial activities in southern Trinity Bay on individually-identified humpback whales appeared to be different. In 1994, humpback whales were less likely to be resighted near dredging, and there was a tendency for individual whales to move away from the site. No such trends were detected during blasting in 1992 or vessel activity in 1995. In addition, the lower resightings and resight intervals in 1994 were suggestive of dredging impact, especially since the relative abundance of capelin in the area was reported higher during that year than other years (Nakashima, 1996). Although the exact component of the anthropogenic activity responsible for changes observed is often difficult to isolate (Richardson & Würsig, 1995), different results between years suggest effects on the whales fluctuated with the type of industrial activity (see Richardson, 1995*b*; Richardson & Würsig, 1997).

Photographic resights between 1992–1995 suggest long-term behavioural effects of industrial noise on humpback whales. Todd *et al.* (1996) reports that exposure to blasting at the site in 1992 is related to fishing gear collisions which may reflect orientation disturbances. Further, ear damage was found from some whales that died in fishing gear in lower Trinity Bay in 1992 (Ketten, 1995). Comparison of the return rates of individuals identified in southern Trinity Bay during 1992 with those identified elsewhere in Newfoundland in that year shows that significantly fewer of the individuals initially photographed in Trinity Bay were subsequently resighted in Newfoundland waters in 1993. In contrast, significantly more individuals identified along the southeast shore of Newfoundland in 1992 were resighted in 1993 than were those identified from Trinity Bay in 1992. These findings are consistent with other studies which have suggested some whale species abandon an area with industrial activity (e.g. Gard, 1974; Richardson *et al*., 1987*a*). The present study, however, provides evidence that these changes in distribution may persist at least across several years. Another explanation of the lower resightings of animals exposed to blasting could be higher mortality.

It should be noted that resightings and resight intervals can be influenced by a number of factors. For example, re-identification can be influenced by heterogeneity between individuals and the area surveyed (Hammond, 1990). Mate *et al.* (1992) found that radio-tagged right whales traveled large distances between sightings and suggested resight intervals may not necessarily indicate length of stay. In addition, fluctuations in effort and prey abundance can affect photographic resight variables (Clapham *et al*., 1993). However, compared to other measures, these indicators appear more sensitive to detect effects of industrial activity.

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References

Baker, C. S., Herman, L. M., Bays, B. G. & Bauer, G. B. (1983) The impact of vessel traffic on the behavior of humpback whales in southeast Alaska: 1982 season. Report to U.S. National Marine Fisheries Service, Seattle, WA. 30 pp.+figs., tables. (Available from National Marine Mammal Laboratory, Seattle, WA.)

Baker, C. S., Perry, A. & Vequist, G. (1988) Conservation update/Humpback whales of Glacier Bay, Alaska. *Whalewatcher* **22**(3), 13–17.

Bauer, G. B., Mobley, J. R. & Herman, L. M. (1993) Responses of wintering humpback whales to vessel traffic. *J. Acoust. Soc. Am.* **94**(3), 1848 (Abstract).

Borggaard, D. (1996) Assessing the effects of industrial activity on cetaceans in Trinity Bay, Newfoundland. M.Sc. thesis. Memorial University of Newfoundland, St. John's, Newfoundland, Canada. 167 pp.

Clapham, P. J., Baraff, L. S., Carlson, C. A., Christian, M. A., Mattila, D. K., Mayo, C. A., Murphy, M. A. & Pittman, S. (1993) Seasonal occurrence and annual return of humpback whales, *Megaptera novaeangliae*, in the southern Gulf of Maine. *Can. J. Zool.* **71,** 440–443.

Cosens, S. E. & Dueck, L. P. (1988) Responses of migrating narwhal and beluga to icebreaker traffic at the Admiralty Inlet ice-edge, N. W. T. in 1986. In: W. M. Sackinger, M. O. Jeffries, J. L. Imm & S. D. Treacy (eds) *Port and ocean engineering under arctic conditions*, Vol. II. pp. 39–54. Geophysical Institute, University of Alaska, Fairbanks, AK.

Crowley, P. H. (1992) Resampling methods for computation-intensive data analysis in ecology and evolution. *Annu. Rev. Ecol. Syst.* **23**, 405–447.

Davis, R. A., Koski, W. R. & Miller, G. W. (1986) Experimental use of aerial photogrammetry to assess the long term responses of bowhead whales to offshore industrial activities in the Canadian Beaufort Sea, 1984. Report to Indian and Northern Affairs Canada, Ottawa, Ont. 157 pp.

Dorsey, E. M. (1983) Exclusive adjoining ranges in individually identified minke whales (*Balaenoptera acutorostrata*) in Washington state. *Can. J. Zool.* **61**, 174–181.

Gard, R. (1974) Aerial census of gray whales in Baja California lagoons, 1970 and 1973, with notes on behavior, mortality and conservation. *Calif. Fish & Game* **60**, 132–143.

Geraci, J. R. & St. Aubin, D. J. (1980) Offshore petroleum resource development and marine mammals: A review and research recommendations. *Mar. Fish. Rev.* **42**(11), 1–12.

Green, D. M., Deferrari, H. A., McFadden, D., Pearse, J. S., Popper, A. N., Richardson, W. J., Ridgway, S. H. & Tyack, P. L. (1994) Low-frequency sound and marine mammals: current knowledge and research needs. National Research Council, Washington, D.C. 75 pp.

Hammond, P. S. (1990) Heterogeneity in the Gulf of Maine? Estimating humpback whale population size when capture probabilities are not equal. *Rep. Int. Whal. Comm.,* special issue **12**, 135–140.

Katona, S., Baxter, B., Brazier, O., Kraus, S., Perkins, J. & Whitehead, H. (1979) Identification of humpback whales by fluke photographs. In: H. E. Winn & B. L. Olla (eds) *Behavior of marine animals* pp. 33–44. Plenum Press: New York, NY.

Ketten, D. R. (1995) Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In: R. A. Kastelein, J. A. Thomas & P. E. Nachtigall (eds) *Sensory systems of aquatic mammals* pp. 391–407. De Spil Publishers: Woerden, the Netherlands.

Koski, W. R., Miller, G. W. & Davis, R. A. (1988) The potential effects of tanker traffic on the bowhead whale in the Beaufort Sea. Report to Department of Indian Affairs and Northern Development, Hull, Que. 150 pp.

Lien, J., Taylor, D. G. & Borggaard, D. (1995) Management of underwater explosions in areas of high whale abundance. In: *MARIENV '95: Proceedings of the International Conference on Technologies for Marine Environment Preservation*. pp. 627–632. Organized by The Society of Naval Architects of Japan, 24–29 September 1995, Tokyo, Japan.

Ljungblad, D. K., Würsig, B., Swartz, S. L. & Keene, J. M. (1988) Observations of the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. *Arctic* **41**, 183–194.

Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P. & Bird, J. E. (1983) Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Report to U.S. Minerals Management Service, Anchorage, AK. Var. pag. (Available from NTIS, Springfield, VA; PB86–174174.)

Malme, C. I., Miles, P. R., Tyack, P., Clark, C. W. & Bird, J. E. (1985) Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. Report to U.S. Minerals Management Service, Anchorage, AK. Var. pag. (Available from NTIS, Springfield, VA; PB86–218385.)

Malme, C. I., Würsig, B., Bird, J. E. & Tyack, P. (1988) Observations of feeding gray whale responses to controlled industrial noise exposure. In: W. M. Sackinger, M. O. Jeffries, J. L. Imm & S. D. Treacy (eds) *Port and ocean engineering under arctic conditions*, Vol. II. pp. 55–73. Geophysical Institute, University of Alaska, Fairbanks, AK.

Mate, B. R., Nieukirk, S., Mesecar, R. & Martin, T. (1992) Application of remote sensing methods for tracking large cetaceans: North Atlantic right whales (*Eubalaena glacialis*). Report to U.S. Department of the Interior, Minerals Management Service, Alaska and Atlantic OCS Regional Offices. OCS Study MMS91–0069. 167 pp.

Mate, B. R., Stafford, K. M. & Ljungblad, D. K. (1994) A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. *J. Acoust. Soc. Am.* **96**(5), 3268–3269 (Abstract).

Nakashima, B. S. (1996) Results of the 1995 CASI aerial survey of capelin (*Mallotus villosus*) schools. In Anon. Capelin in SA2+Div. 3KL. pp. 50–60. Dep. Fish. Oceans Atl. Fish. Res. Doc. 96/90.

Palsbøll, P. J., Allen, J., Bérubé, M., Clapham, P. J., Feddersen, T. P., Hammond, P. S., Hudson, R. R., Jórgensen, H., Katona, S., Larsen, A. H., Larsen, F., Lien, J., Mattila, D. K., Sigurjónsson, J., Sears, R., Smith, T., Sponer, R., Stevick, P. & Øien, N. (1997) Genetic tagging of humpback whales. *Nature* **388**, 767–769.

Piatt, J. F., Methven, D. A., Burger, A. E., McLagan, R. L., Mercer, V. & Creelman, E. (1989) Baleen whales and their prey in a coastal environment. *Can. J. Zool.* **67**, 1523–1530.

Reeves, R. R. (1992) Whale responses to anthropogenic sounds: A literature review. Department of Conservation, Wellington, New Zealand. Sci. and Res. Ser., no. 47. 47 pp.

Reeves, R. R., Ljungblad, D. K. & Clarke, J. T. (1984) Bowhead whales and acoustic seismic surveys in the Beaufort Sea. *Pol. Rec.* **22**, 271–280.

Richardson, W. J. (1995*a*) Conclusions and data needs. In: W. J. Richardson, C. R. Greene, Jr., C. I. Malme & D. H. Thomson, with S. E. Moore & B. Würsig (eds) *Marine mammals and noise* pp. 425–452. Academic Press: San Diego, CA.

Richardson, W. J. (1995*b*) Documented disturbance reactions. In: W. J. Richardson, C. R. Greene, Jr., C. I. Malme & D. H. Thomson, with S. E. Moore & B. Würsig (eds) *Marine mammals and noise* pp. 241–324. Academic Press: San Diego, CA.

Richardson, W. J. & Würsig, B. (1995) Significance of responses and noise impacts. In: W. J. Richardson, C. R. Greene, Jr., C. I. Malme & D. H. Thomson, with S. E. Moore & B. Würsig (eds) *Marine mammals and noise* pp. 387–424. Academic Press: San Diego, CA.

Richardson, W. J. & Würsig, B. (1997) Influences of man-made noise and other human actions on cetacean behaviour. *Mar. Fresh. Behav. Physiol.* **29**, 183–209.

Richardson, W. J., Fraker, M. A., Würsig, B. & Wells, R. S. (1985*a*) Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort Sea: Reactions to industrial activities. *Biol. Conserv.* **32**, 195–230.

Richardson, W. J., Wells, R. S. & Würsig, B. (1985*b*) Disturbance responses of bowheads, 1980–1984. In: W. J. Richardson (ed) *Behavior, disturbance responses and distribution of bowhead whales* Balaena mysticetus *in the eastern Beaufort Sea, 1980–84* pp. 89–196. Report to U.S. Minerals Management Service, Reston, VA. (Available from NTIS, Springfield, VA; PB87–124376.)

Richardson, W. J., Würsig, B. & Greene, C. R., Jr. (1986) Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. *J. Acoust. Soc. Am.* **79**, 1117–1128.

Richardson, W. J., Davis, R. A., Evans, C. R., Ljungblad, D. K. & Norton, P. (1987*a*) Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980–84. *Arctic* **40**, 93–104.

Richardson, W. J., Würsig, B. & Miller, G. W. (1987*b*) Bowhead distribution, numbers and activities. In: W. J. Richardson (ed) *Importance of the eastern Alaskan Beaufort Sea to feeding bowhead whales, 1985–86* pp. 257–368. Report to U.S. Minerals Management Service, Reston, VA. (Available from NTIS, Springfield, VA; PB88–150271.)

Richardson, W. J., Finley, K. J., Miller, G. W., Davis, R. A. & Koski, W. R. (1995) Feeding, social and migration behavior of bowhead whales, *Balaena mysticetus*, in Baffin Bay vs. the Beaufort Sea-Regions with diferent amounts of human activity. *Mar. Mamm. Sci.* **11**, 1–45.

Smith, T. D., Allen, J., Clapham, P. J., Hammond, P. S., Katona, S., Larsen, F., Lien, J., Mattila, D., Palsbøll, P. J., Sigurjónsson, J., Stevick, P. T. & Øien, N. (1999) An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Megaptera novaeangliae*). *Mar. Mamm. Sci.* **15**, 1–32.

Sokal, R. R. & Rohlf, F. J. (1995) *Biometry. The principles and practice of statistics in biological research.* W. H. Freeman and Company: New York, NY.

Todd, S., Stevick, P., Lien, J., Marques, F. & Ketten, D. (1996) Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). *Can. J. Zool.* **74**, 1661–1672.

Turl, C. W. (1982) Possible effects of noise from offshore oil and gas drilling activities on marine mammals: A survey of the literature. Report to Bureau of Land Management, New York, NY. Report NOSC TR 776. 24 pp. (Available from U.S. Naval Ocean Systems Center, San Diego, CA.)

Tyack, P. L. (1993) Reactions of bottlenose dolphins, *Tursiops truncatus*, and migrating gray whales, *Eschrichtius robustus*, to experimental playback of low-frequency man-made noise. *J. Acoust. Soc. Am.* **94**(2), 1830 (Abstract).

von Ziegesar, O., Miller, E. & Dahlheim, M. E. (1994) Impacts on humpback whales in Prince William Sound. In: T. R. Loughlin (ed) *Marine mammals and the Exxon Valdez* pp. 173–191. Academic Press: New York, NY.

Wartzok, D., Watkins, W. A., Würsig, B. & Malme, C. I. (1989) Movements and behaviors of bowhead whales in response to repeated exposures to noises associated with industrial activities in the Beaufort Sea. Report to Amoco Production Company, Denver, CO. 228 pp.

Weinrich, M. T., Lambertson, R. H., Baker, C. S., Schilling, M. R. & Belt, C. R. (1991) Behavioural responses of humpback whales (*Megaptera novaeangliae*) in the southern Gulf of Maine to biopsy sampling. *Rep. Int. Whal. Comm.*, special issue **13**, 91–97.

Whitehead, H. & Carscadden, J. E. (1985) Predicting inshore whale abundance-whales and capelin off the Newfoundland coast. *Can. J. Fish. Aquat. Sci.* **42**: 976–981.

Whitehead, H., Harcourt, P., Ingham, K. & Clark, H. (1980) The migration of humpback whales past the Bay de Verde Peninsula, Newfoundland, during June and July, 1978. *Can. J. Zool.* **58**, 687–692.