MARINE MAMMAL MONITORING OF WESTERNGECO'S OPEN-WATER SEISMIC PROGRAM IN THE ALASKAN BEAUFORT SEA, 2001

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National Marine Fisheries Service
Anchorage, AK, and Silver Spring, MD

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ACRONYMS AND ABBREVIATIONS

The following list shows the meaning of acronyms and abbreviations used in this report.

AEWC	Alaska Eskimo Whaling Commission
ASAR	Autonomous Seafloor Acoustic Recorder
ASL	Above Sea Level
BCX	Bottom Cable Extended (a type of OBC equipment)
BP	British Petroleum
CPA	Closest Point of Approach
dB re 1 μPa	decibels in relation to a reference pressure of 1 micropascal
DGPS	Differential Global Positioning System
DWM	Department of Wildlife Management (as in NSB-DWM)
ft	foot or feet (1 foot = 0.305 m)
FWS	Fish & Wildlife Service, U.S. Dept of the Interior
GPS	Global Positioning System
HESS	High Energy Seismic Survey
IHA	Incidental Harassment Authorization
m	meter (1 m = 1.09 yards or 3.28 feet)
km	kilometer (1 km = 3281 ft, 0.62 st.mi., or 0.54 n.mi.)
K-S	Kolmogorov-Smirnov Test
MMO	Marine Mammal Observer
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service, U.S. Dept of the Interior
MRX	Mini Remote Extended (a type of OBC equipment)
NMFS	National Marine Fisheries Service, U.S. Dept of Commerce
n.mi.	nautical mile (1 n.mi. = 1.15 statute miles or 1.853 km)
NSB	North Slope Borough
NVD	Night Vision Device
OBC	Ocean Bottom Cable
OBRL	Ocean Bottom Receiver Localization
psi	pounds per square inch
RAM	Range-dependent Acoustic Model
rms	root mean square (a type of average)
SEL	Sound Exposure Level
SNR	Signal-to-Noise Ratio
SPL	Sound Pressure Level
st.mi.	statute or land mile (1 st.mi. = 1.61 km or 0.87 n.mi.)
TTS	Temporary Threshold Shift

EXECUTIVE SUMMARY

Introduction

WesternGeco LLC (WesternGeco or WG hereafter) conducted an open-water seismic program in shallow waters of the central Alaskan Beaufort Sea from 2 to 26 August 2001. This project was a continuation of programs conducted by Western Geophysical during July to October 1998, July – August 1999, and July – August 2000.

Nearshore waters of the central Alaskan Beaufort Sea are occupied by ringed and bearded seals throughout the open-water period. A few spotted seals also occur there. Bowhead and beluga whales migrate west through the region in late summer and autumn. Gray whales rarely occur there, although some were present in 1998.

There are few published data on reactions of toothed whales or pinnipeds to open-water seismic surveys. However, monitoring studies in 1996-2000 showed that seals (mainly ringed seals) often tolerate strong sound pulses from a nearby seismic vessel. Those studies showed localized avoidance by some seals within a few hundred meters of the airguns. Effects on seal behavior were not consistent or conspicuous.

Inupiat whalers are concerned that seismic programs may displace some bowhead whales farther offshore, making them less accessible to hunters. They also report that whales exposed to seismic noise are more "skittish" and difficult to hunt. Inupiat whalers believe that, during autumn migration, bowhead whales exposed to seismic operations while migrating west through the Alaskan Beaufort Sea can be displaced northward by as much as 30 miles from their normal migration corridor.

Recent (1996-98) monitoring studies have indicated that, during autumn, most migrating bowheads avoid an area with a radius of about 20-30 km (11-16 n.mi. or 12-19 st.mi.) around a seismic vessel operating in nearshore waters. This is a larger avoidance radius than was evident from scientific studies conducted in the 1980s. However, it is less than the 30 miles suggested by the hunters based on their experience with the types of seismic operations that occurred in the Beaufort Sea before 1996. Studies in the 1980s indicated that subtle behavioral reactions extend beyond the avoidance radius.

Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the Marine Mammal Protection Act (MMPA). Under the MMPA, Incidental Harassment Authorizations (IHAs) can be issued by the National Marine Fisheries Service (NMFS) if the "taking will have a negligible impact on the species or stock(s) of marine mammals and will not have an unmitigable adverse impact on the availability of the species or stock(s) for subsistence uses". IHAs can authorize unintentional disturbance but not serious injury or mortality.

It is not known whether seismic exploration sounds are strong enough to cause temporary or permanent hearing impairment in any marine mammals that occur close to the seismic source. To minimize this possibility, NMFS requires that seismic programs conducted under IHAs include provision to monitor for marine mammals and to shut down the airguns when mammals are detected within designated safety radii. Shutdown procedures in 2001 were consistent with those during related 1996-2000 projects in the Beaufort Sea. The airguns were to be shut down if seals and whales were seen within the expected or measured 190 dB and 180 dB re 1 μPa (rms) radii, respectively.

An IHA Application and draft monitoring and mitigation plan for 2001 were submitted by WesternGeco to NMFS during April 2001. The proposed monitoring program was reviewed by NMFS, representatives of the subsistence hunters, and other stakeholders at a meeting in Seattle on 5 – 6 June 2001. No modifications of the draft monitoring plan were required. That plan was then used as the basis for the monitoring work in July-August.

In addition, an updated 2001 version of a "Conflict Avoidance Agreement" was negotiated among WesternGeco, BP Exploration (Alaska), the Alaska Eskimo Whaling Commission (AEWC), and the Whaling Captains' Associations of the villages of Nuiqsut, Kaktovik and Barrow. One of its provisions was that seismic operations would be limited to areas west of the hunting area around Cross Island during the 2001 whale hunting season.

On 21 May and 23 July 2001, North Slope Borough and Alaska State permits, respectively, were issued to WesternGeco to conduct the planned geophysical operations in state waters. An IHA was issued by NMFS to WesternGeco on 1 August 2001, shortly after which seismic surveys began.

Having completed survey work on the prospect, WesternGeco decided to terminate the 2001 seismic program on 26 August. Monitoring work planned for September – October was, therefore, not required.

The monitoring program was planned to include two main components: vessel-based observers, and (commencing 1 September) acoustical monitoring and aerial surveys.

Vessel-based observers watched for marine mammals whenever the airgun array sources were operating or about to operate, and at some other times. They documented the occurrence of marine mammals (exclusively seals in 2001) near the vessels towing the airgun array sources. They called for immediate shutdown of the sources when marine mammals were seen within or about to enter the designated safety zones around these sources.

Two airgun arrays were operated alternately during August 2001: a 12-airgun array with total volume 1210 in^3 (as had also been used in 1999 and 2000), and an 8-airgun array with total volume 320 in^3. Acoustic measurements to document levels, characteristics, and propagation of underwater sounds emitted by the 1210 in^3 source had already been acquired in 1999, and there was no need to repeat those measurements in 2001. NMFS and the stakeholder group agreed that measurements of sounds from the smaller airgun array would not be required given that WesternGeco proposed to use the same safety radii during operations with the smaller airgun array as had been developed for the 1210 in^3 array. If the seismic project had continued during September-October 2001, seafloor recording devices would have been deployed to document bowhead whale calling patterns and to measure long-distance propagation of airgun pulses. Because the seismic program terminated on 26 August in 2001, seafloor recorders were not deployed this year.

Aerial surveys were planned to occur daily (weather permitting) if seismic work was done during the bowhead migration season in September-October 2001. The surveys would have documented whale distribution around the area of seismic work at times with and without active airgun operations. In the absence of seismic surveys during September-October, no aerial surveys were done in 2001, and no air-dropped sonobuoys were deployed.

The report summarized here is a comprehensive report on the 2001 monitoring work, as required by the IHA issued to WesternGeco. This report describes the 2001 seismic program, the associated marine mammal monitoring program, the basic monitoring results from 2001, and (for seals) monitoring results from 1996-2001 combined. If required, a revised version of this report will be submitted after the next peer/stakeholder meeting (expected in autumn 2002), taking account of any comments received before or at that meeting.

OBC Seismic Program Described, 2001

WesternGeco's open-water seismic program in the Alaskan Beaufort Sea during 2001 consisted of an Ocean Bottom Cable (OBC) seismic survey in nearshore waters approximately 48 km (25.9 n.mi.) west of Prudhoe Bay, in the Simpson Lagoon area. This work was conducted from 2 to 26 August 2001. Testing of the 320 in^3 airgun array began on 2 August and production operations commenced on 7 August. The last airgun operations were on 26 August and WesternGeco terminated the project on that date, prior to the start of the subsistence hunt for bowhead whales passing Cross Island.

The 2001 WesternGeco seismic project employed the OBC method, as did the 1996-2000 open-water seismic programs in the Beaufort Sea. Using the OBC method, the area to be surveyed was divided into patches. Within each patch, receiving cables were placed on the bottom parallel to one another. Seismic data for each patch were acquired while the source vessels *Peregrine* or *Arctic Star* towed an airgun array along a series of source lines oriented perpendicular to the receiving cables. While seismic data were acquired on one patch, one of WesternGeco's two flexifloat cable deployment vessels was anchored to serve as a data-recording vessel. The other cable vessels typically were laying cables in the patch to be surveyed next and/or retrieving cables from the patch where surveys had just been completed.

During the 2001 program, seismic data were acquired from five patches, most of which were in shallow waters near or inshore of the barrier islands bordering Simpson Lagoon. A standard patch included four receiver lines, which varied in length depending on water depth and location of the barrier islands. The receiver lines were spaced 500 m (1640 ft) apart. There were approximately 69 source lines per patch (spaced 200 m apart). Like the receiver lines, each source line also varied in length depending on water depth and location of the barrier islands. In all cases, patches had non-standard shapes due to presence of shallow water or barrier islands. In 2001, the total distance traveled by the *Peregrine* and *Arctic Star* while shooting seismic, including turns during line changes and testing, was approximately 787 km (425 n.mi. or 489 st.mi.) and 352 km (190 n.mi. or 219 st.mi.), respectively. Water depths within the survey area ranged from 0.6 to 13.7 m (2 to 45 ft).

In 2001, WesternGeco operated two different airgun arrays. On the *Peregrine*, a 640 in^3 airgun array composed of 16 identical 40-in^3 airguns was deployed from the port and starboard midships positions, and operated at an airgun depth of 1 m (3.3 ft). Four clusters of four 40-in^3 airguns were swung out from two positions on the port and two positions on the starboard side of this vessel. Only half of these airguns were fired during production seismic operations, so the active array volume was actually 320 in^3. The larger seismic source used in 2001 was the same one as was used in 1999-2000. It consisted of an array of 12 sleeve-type airguns totaling 1210 in^3, which was towed by the *Arctic Star*. In this larger array, individual airgun volumes ranged from 40 in^3 to 150 in^3, including two 2×150 in^3 airgun clusters at the front of the array. These 12 airguns were suspended 2.3 m (7.5 ft) below the surface during operations in 2001. The 1999-2001 array deployed from *Arctic Star* was smaller than the 16-gun 1500-in^3 array that was deployed from that vessel in 1998. In 2001 the two arrays were never operated simultaneously.

One to three marine mammal monitoring personnel were aboard the OBC source vessels throughout the period of operations. On the *Peregrine*, they were assisted by members of the bridge crew. The marine mammal monitors watched for marine mammals at all times (day and night) while airguns operated, and helped implement provisions of the IHA issued by NMFS. The observers also conducted watches during periods when the source vessels were underway but the airguns were not firing. There was 24-h daylight in early August, but increasing amounts of darkness from mid-August until the end of operations on 26 August. Image intensifiers were used to assist with night observations. Relatively few seals but no whales were seen from the source vessel in 2001. When seals were seen within the "safety radii" specified in WesternGeco's IHA for 2001, the airguns were immediately shut down. (See "Seals… 2001", below.)

Seals Seen During OBC Seismic Programs, 2001 and 1996-2001 Combined

A total of 38 seals were sighted from the source vessels *Arctic Star* and *Peregrine* during 336.2 hours of vessel-based observations during WesternGeco's 2001 OBC seismic program in the Beaufort Sea. At least one airgun was operating during 74.7% of these hours of observation (251.0 h). The "large array" (normally 12 airguns totaling 1210 in^3) operated for 71.3 hours and the "small array" (normally 8 guns totaling 320 in^3) operated for 154 hours. Of the 30 seals identified to species, 27 were ringed seals and three were spotted seals; no bearded seals were identified. Most seals (27 of 38) were sighted during seismic operations.

As in 1996-2000, the operation of the airgun array had minor and variable effects on the behavior of some seals within a few hundred meters of the array and possibly (to a limited extent) the distribution of seals around the source vessel. Nonetheless, seals were observed throughout the season in the general area where seismic operations were occurring.

Seal sighting rates in 2001 were very slightly lower during airgun operations than during no-airgun periods (0.11 vs. 0.13 seals/h). However, based on combined 1996-2001 data, seal sighting rates were significantly lower during airgun operations than during no-gun periods (0.24 vs. 0.37 seals/h). Also, in most years, the seals tended to be observed at greater distances from the source vessel during operation of the airgun array than during non-seismic periods; this difference was significant based on combined 1996-2001 data. In 2001, seals tended to be observed at greater distances from the source vessel during operation of the airgun array than during non-seismic periods, but this difference was not statistically significant. A higher proportion of the seals seen in 2001 were beyond the 190 dB (re 1 μPa_{rms}) radius than within it; this was true both with and without airgun operations. This result probably reflects the relatively small 190 dB radii applicable in 2001. It is possible that seals tend to avoid a small radius around a vessel regardless of whether or not seismic operations were underway.

Seals were categorized as "swimming", "looking", or "diving". The 2001 and combined 1996-2001 behavioral data indicated that some seals were more likely to "swim away" from the source vessel during periods of airgun operations than during non-seismic periods. Similar proportions of seals were observed "swimming" during periods with and without airgun operations in 2001 and 1996-2001. No consistent relationship was observed between exposure to airgun noise and proportions of seals that "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs.

Not all seals occurring within the approximate 190 dB (re 1 μPa_{rms}) radius around the operating airgun array were detectable by vessel-based observers. For the 320 in^3 array, the conservatively-estimated 190 dB re 1 μPa_{rms} radii were 15 m for airgun operations in <10 m water depth, and 50 m for >10 m water depth. For the 1210 in^3 array, the 190 dB radii were 50 m in <10 m water depth and 150 m >10 m water depth. Sighting rate generally diminished with increasing radial and especially lateral distance. In 2001 and 1996-2001 combined, sighting rate diminished beyond a radial distance of 150 m (492 ft) and beyond a lateral distance of 50 m (164 ft).

More seals were sighted when two observers were on watch than when a single observer was on duty both in 2001 and in all years combined. No seals were seen during the short periods of darkness in mid-late August of 2001. Only two seals were seen at night during LGL's 1996-2001 seismic monitoring projects in the Alaskan Beaufort Sea.

Our "direct" estimate of the number of seal "takes by harassment" was 16 in 2001. Only eight of these represent seals within the safety radius as designated in the IHA; the others were seals that showed possible disturbance reactions at greater distances. This estimate does not consider seals that may have been present but unseen during daylight surveys. An "indirect" estimate of the number of seal "takes by harassment" in 2001, based on the observed density of seals in the area, indicated a potential of 23 takes. These estimates are both subject to various assumptions and biases discussed in the text, and count all seals estimated to occur within designated safety radii that were larger than the actual 190 dB radii. Also, it is very likely that some individual seals were exposed to strong sounds on more than one occasion, so the total number of seals "taken by harassment" would be less than the estimated number of "takes". Based on the observed density of seals in the operating area in 2001, six seals were estimated as "taken" based on the safety radii. About 12 ringed seals may have been exposed to seismic pulses with received sound levels as high as 160 dB re 1 μPa (rms) at some time during the course of the 2001 seismic operations.

The 2001 airgun operations were suspended 10 times when seals were sighted within or about to enter the designated safety radii. In these cases, the number of strong sound pulses received by seals was lower than would have been the case without shutdowns. In most cases, there was no more than one pulse (and usually none) between the time a seal was sighted in or near the safety zone and the time when the airguns were shut down. The maximum received level presumably was also reduced as a result of the shutdowns in the majority of the "shutdown" cases.

There was no evidence that seals were displaced far enough from the seismic operation to affect accessibility to hunters, although there may have been some local displacement within a few hundred meters of the seismic vessel when the airguns were in use during 2001. There was apparently no overlap between seal hunting and WesternGeco's 2001 seismic program, and there was no indication that the seismic program interfered with seal hunting.

Whales, 2001

No whales were seen by marine mammal observers aboard WesternGeco's seismic source vessels during the 2 – 26 August monitoring period in 2001. The 2001 seismic program ended on 26 August, five days before the site-specific aerial surveys and continuous acoustic monitoring for bowhead calls were scheduled to begin, so no data of those types were collected. There is no indication that any whales were "taken by harassment" during the 2001 seismic program. Small numbers of belugas and very small numbers of gray whales might have been present in nearshore waters near Prudhoe Bay during August, and a few early-migrating bowheads might have reached the area by the time seismic surveys ended. However, if any unseen whales were disturbed, the numbers were undoubtedly low.

1. INTRODUCTION[1]

WesternGeco conducted an open-water seismic program in shallow waters of the central Alaskan Beaufort Sea from 2 to 26 August 2001. This project used some of the same techniques and technology as during similar programs conducted by Western Geophysical in the same general region during July to October 1998, July – August 1999, and July – August 2000. WesternGeco's 2001 seismic program employed, at times, the same array of 12 airguns totaling 1210 in^3 in volume as was used in 1999 and 2000; a 16-gun, 1500 in^3 array was the primary source in 1998. However, for most of the seismic production in 2001, WesternGeco used a much smaller airgun array with a total volume of 640 in^3. This smaller array was deployed from the shallow-draft vessel *Peregrine*. After initial tests near West Dock, this array was operated at half volume (320 in^3) for all subsequent data acquisition on the prospect.

Marine seismic projects emit strong sounds into the water (Greene and Richardson 1988). Given the known auditory and behavioral sensitivity of many marine mammals to underwater sounds (Richardson et al. 1995), marine seismic projects have the potential to affect marine mammals. Seals and whales in the Beaufort Sea are hunted by subsistence hunters. Thus, there is also the potential for acoustic disturbance of marine mammals to have indirect effects on the accessibility of marine mammals to hunters. Ringed and bearded seals occupy the nearshore waters of the central Alaskan Beaufort Sea throughout the open water period. A few spotted seals also occur in the area. Bowhead and beluga whales migrate westward through the region in late summer and autumn, although the main migration corridor of belugas is far offshore from the area of seismic exploration. Gray whales rarely occur in the area.

In April 2001, WesternGeco requested that the National Marine Fisheries Service (NMFS) issue an Incidental Harassment Authorization (IHA) to allow disturbance of seals and whales during the seismic program planned for the summer and autumn of 2001. At the same time, WesternGeco submitted a draft marine mammal and acoustical monitoring program for 2001. On 14 June 2001, NMFS published a notice in the *Federal Register* indicating its intent to issue the IHA (NMFS 2001a). The monitoring plan was discussed at a peer/stakeholder review meeting in Seattle on 5 - 6 June 2001, after which no changes were required (LGL and Greeneridge 2001). That plan was used as the basis for the monitoring work in August. An IHA was issued by NMFS to WesternGeco on 1 August 2001 (NMFS 2001b; see Appendix A).

As in 2000, ice breakup in the Prudhoe Bay area was relatively late and incomplete in 2001 as compared with some other recent years (e.g., 1997, 1998). Ice delayed the start of seismic operations until 2 August, and even then the seismic operations on the outer margins of the nearshore prospect were constrained for much of the season by the presence of heavy drifting pack ice. Considerable ice persisted just offshore of the barrier islands throughout August. This delayed access to some survey areas outside the barrier islands. Following completion of all seismic acquisition, seismic survey operations (and concurrent marine mammal monitoring) were suspended on 26 August. This was prior to the agreed completion date stated in WesternGeco's agreement with the Alaska Eskimo Whaling Commission and the whaling captains' associations of Nuiqsut, Kaktovik and Barrow.

The 2001 IHA and Monitoring Plan called for submission of a preliminary report on the results of the OBC monitoring work within 90 days after completion of fieldwork. A preliminary "90-day report"

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was submitted on 30 November 2001 (Richardson [ed.] 2001b). It described the 2001 seismic operations, and the observations of seals during those operations. Since seismic operations ceased prior to 1 September, acoustical monitoring work was not required during this year's operations (see IHA in Appendix A).

The IHA also requires that a technical report on the 2001 marine mammal monitoring work be submitted to NMFS by 30 April 2002.[2] This volume constitutes the required technical report. It includes a major expansion of Chapter 3 on "Seals", minor updates to other sections, and Appendix B on estimated sound levels from the 320 in^3 array. The "Seals" chapter now includes not only the 2001 results (as in the 90-day report) but also an analysis of the combined 1996-2001 data on seals seen near seismic operations in the Alaskan Beaufort Sea. Analyses of the 1996-2001 data are based on revised "190 dB radii" provided by C.R. Greene Jr. (in prep.)—see Chapter 3 for details. If required, a revised version of this report will be submitted after the peer/stakeholder review meeting expected to occur in the autumn of 2002. That revised version would take account of comments received before or at the meeting.

As predicted based on the proposed location of the seismic operations in shallow water, mainly inshore of barrier islands, observers aboard the seismic survey vessels during August 2001 saw relatively few seals and no whales. Although a few bowheads have been found in the Prudhoe Bay area as early as late August in some years, including 2001 (Greene et al. 2002), the main bowhead migration does not begin until early September. Because there were no seismic operations after 31 August in 2001, the 2001 monitoring project did not include site-specific aerial surveys or the use of seafloor acoustic recorders to monitor seismic pulses or whale calls. In accordance with the final Monitoring Plan (LGL and Greeneridge 2001), those components of the work would have commenced on 1 September if seismic operations had continued into September. In the absence of any whale sightings during the 2001 monitoring work up to 31 August, and in the absence of any seismic operations thereafter, the only references to whales in this report are the background information and statements of objectives in later sections of this INTRODUCTION chapter. Seismic operations ceased on or before 1 September in 1999 and 2000 as well, so seismic monitoring work did not continue during the main bowhead migration season in 1999-2001. The most recent results concerning effects of the present type of marine seismic operation on bowhead, beluga and gray whales are given in the final report on Western Geophysical's 1998 seismic monitoring program (Greene et al. 1999; Miller et al. 1999).

1.1 Previous Evidence on Reactions to Seismic Pulses

1.1.1 Seals

Very little information about reactions of pinnipeds to open-water seismic operations was available up to 1995. However, observations of pinnipeds exposed to other types of strong impulsive sounds

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[2] The IHA specifies that a draft technical report is to be submitted to NMFS by 1 March 2002, and a final technical report by 30 April 2002. NMFS subsequently agreed that the draft technical report would be due on 30 April 2002 (as in other recent years), with a final report being due within 45 days after the final Minutes of the open-water peer/stakeholder meeting are released by NMFS (S. Roberts, NMFS Office of Protected Resources, pers. comm., 3 Aug. 2001).

suggested that they might be quite tolerant of those sounds (Richardson et al. 1995:291). Arnold (1996) mentioned that pinnipeds (mainly California sea lions) showed highly variable reactions to a seismic program off California, but gave no details.

In 1996 through 2000, BP Exploration (Alaska) Inc. (in 1996-97) and Western Geophysical (in 1998-2000) conducted open-water seismic programs in nearshore waters of the central Alaskan Beaufort Sea. These projects were conducted under IHAs issued by NMFS, and included marine mammal and acoustical monitoring programs (Richardson [ed.] 1997a, 1998, 1999, 2000, 2001a). This monitoring work in 1996-2000 provided considerable new information regarding the behavior of seals exposed to seismic pulses (Harris et al. 1997, 1998, 2001; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001). Radial distances of seals from the source vessel were significantly greater when an airgun array was firing than during no-seismic periods. This indicated either some avoidance of the operating airguns or a change in behavior making the closer seals less conspicuous when airguns were operating (or both). However, there was little direct evidence of behavioral reactions. Also, avoidance reactions were apparently limited to a radius of no more than a few hundred meters, and many of the seals well inside that distance showed no evidence of either avoidance or behavioral reactions.

Preliminary results of a radio telemetry study by Thompson et al. (1998) suggest that more pronounced (but short-term) behavioral changes can occur in harbor seals and gray seals exposed to airgun pulses. They stated that normal foraging dives were interrupted and that avoidance reactions usually occurred. The seals returned to their previous foraging areas after airgun operations ceased. These preliminary results suggest that seal reactions to airgun pulses may be more pronounced than can be documented by visual observations at the surface.

1.1.2 Bowhead Whales

Bowhead whales were shown, during studies in the early-mid 1980s, to exhibit avoidance reactions to seismic vessels operating within several kilometers (Richardson et al. 1986; Ljungblad et al. 1988; Richardson and Malme 1993). Studies prior to 1996 provided inconclusive results concerning avoidance at greater distances. However, there were indications that some bowheads may show avoidance at distances as great as 24 km — that is, 13 nautical miles (n.mi.) or 15 statute or land miles (st.mi.) (Koski and Johnson 1987). Subtle behavioral reactions were suspected to extend even farther (Richardson et al. 1986; Richardson and Malme 1993). It is not known whether these behavioral reactions represent a biologically significant impact. Reactions of gray and humpback whales to seismic exploration (Malme et al. 1984, 1988; McCauley et al. 1998, 2000) are similar to those documented during earlier studies of bowheads. Fin whales off the U.K. coast also seem to show localized avoidance of seismic vessels (Stone 1997, 1998, 2000).

Inupiat whalers are especially concerned that seismic programs may displace some bowhead whales farther offshore, making the whales less accessible to hunters (Jolles [ed.] 1995; Rexford 1996). Based on their accumulated observations and experience, the Inupiat whalers also report that whales exposed to seismic and other industrial noises are more "skittish" and difficult to hunt (MMS 1997). Inupiat whalers believe that, during autumn migration, bowhead whales migrating west through the Alaskan Beaufort Sea can be displaced northward by as much as 30 miles from their normal migration corridor (Kanayurak et al., *in* MMS 1997). This belief is based on experience with the types of open-water seismic operations that occurred in the Beaufort Sea before 1996. As compared with the recent (1996-2001) seismic projects in the Beaufort Sea, the pre-1996 projects often involved larger arrays of airguns working in larger areas, including areas farther from shore.

The results of the BP and Western Geophysical monitoring work in 1996-98 revealed a tendency for the general migration corridor of bowhead whales traveling west across the central Beaufort Sea to be farther offshore at times with seismic operations, although the distances of bowheads from shore during airgun operations overlapped with those in the absence of airgun operations (Miller et al. 1999). On a more localized scale, there was near total avoidance of the area within 20 km or 11 n.mi. (12 st.mi.) of the seismic operation at times influenced by airgun operations. In 1998, the sighting rate 20-30 km (11-16 n.mi. or 12-19 st.mi.) from the seismic operation was also significantly reduced during periods with airgun operations. Bowhead sightings within 20 km of the seismic operations were scarce up to about 12 hours after seismic work ended, but the sighting rate within 20 km returned to normal within 12-24 h after the end of airgun operations (Miller et al. 1999). Acoustic monitoring showed that the detection rate for bowhead calls was significantly reduced close to the seismic vessel when the airguns were operating, at least in 1996. This meant either that some bowheads avoided that area, or that they called less frequently when exposed to airgun pulses, or (most likely) a combination of both effects (Greene et al. 1999).

These results indicate that, for migrating bowheads passing a nearshore seismic operation, avoidance effects in 1996-98 extended to distances greater than had been documented in previous scientific studies. In 1998, there was at least partial avoidance of the area out to 30 km (16 n.mi. or 19 st.mi.). However, offshore displacement did not extend to the 30-mile distance suggested by the hunters based on their experience with different types of seismic programs in earlier years. The 1996-98 results suggested that the offshore displacement may have begun roughly 35 km (19 n.mi. or 22 st.mi.) to the east, and may have persisted >30 km (16 n.mi. or 19 st.mi.) to the west. In 1998, offshore displacement may have persisted for at least 40-50 km west (22-27 n.mi. or 25-31 st.mi.). However, Miller et al. (1999) concluded that additional data would be necessary to characterize the east-west extent of the deflection in a quantitative manner.

Despite the avoidance reactions by bowheads to the 1996-98 seismic surveys, those surveys did not have a significant effect on the availability of westward-migrating bowheads to subsistence hunting. Seismic surveys during the hunting season were done in areas west ("downstream") of the hunting area, in accordance with agreements between the hunters and BP (1996-97) or Western Geophysical (1998).

A dominant consideration during the design of the 1999, 2000, and 2001 projects was the need to better characterize how far to the east and west the displacement effect extended. To that end, the plans for site-specific aerial surveys during the autumns of 1999, 2000, and 2001 called for the survey effort to extend slightly farther east and west than in 1998, with less intensive survey effort in the region close to the seismic operations (LGL and Greeneridge 1999, 2000, 2001). This revision in procedures was agreed upon at the 1999, 2000, and 2001 peer/stakeholder review meetings. It takes into account the results of previous research and also the experience and concerns of the Inupiat whalers, both of which are useful in formulating and refining hypotheses and study designs. Because seismic surveys and associated monitoring work terminated on 1 September in 1999, 31 August in 2000, and 26 August 2001, the plans for extended survey coverage have not been implemented.

1.1.3 Toothed Whales

There are few published data on reactions of belugas or other toothed whales to open-water seismic exploration. However, given what is known about the hearing abilities of belugas, they undoubtedly can hear airgun sounds (Richardson et al. 1995; Richardson and Würsig 1997). Because the autumn migration corridor of belugas through the Alaskan Beaufort Sea is far offshore, very few migrating pods approach nearshore seismic operations. Thus, negative effects are not expected, and monitoring projects have not documented any effects (Miller et al. 1997, 1998, 1999). Goold (1996) concluded that common dolphins avoided the area within 1 km (0.54 n.mi.) of an airgun array. Observers on seismic vessels near the U.K. saw dolphins at lower rates and greater distances when the airguns were operating (Stone 1997, 1998, 2000). Also, avoidance was more common when the airguns were operating. Pilot whales and sperm whales near the U.K. seemed less sensitive than dolphins to seismic operations (Stone 1997, 1998, 2000), although elsewhere there are anecdotal reports of sperm whales becoming quiet and/or moving away when exposed to airgun pulses (Bowles et al. 1994; Mate et al. 1994).

Quan and Calambokidis (1999) reported that many common dolphins approached a seismic source vessel to bow ride during airgun operations in the Southern California Bight. Other odontocetes and baleen whales (e.g., blue whales) were also sighted from the source vessel during operations.

1.1.4 Hearing Impairment

Whether seismic exploration sounds are strong enough to cause temporary or permanent hearing impairment in any marine mammals that occur very close to the seismic source is unknown (Richardson et al. 1995, p. 366). In part to avoid any such possibility, NMFS concluded in 1995 that baleen whales (and sperm whales) should not be exposed to seismic pulses with received levels above 180 dB re 1 μPa, and that pinnipeds and small odontocetes should not be exposed to levels above 190 dB re 1 μPa (NMFS 1995). A technical workshop on seismic/marine mammal issues held during June 1997 concluded that data are insufficient to allow firm conclusions about thresholds of hearing impairment for marine mammals exposed to seismic pulses. However, the workshop concluded that there was reason for concern when marine mammals of any type are exposed to pulse pressures exceeding 180 dB re 1 μPa, measured on a root mean square (rms) basis over the pulse duration (HESS 1999). NMFS has recently concluded that neither baleen whales nor toothed whales should be exposed to levels above 180 dB re 1 μPa rms, and that pinnipeds should not be exposed to levels above 190 dB re 1 μPa (NMFS 2000).

Monitoring studies such as this one provide valuable data on disturbance responses of seals and whales, and on the behavior of seals seen within the zone where there is concern about the possibility of effects on hearing. Direct studies of the effects of strong sounds on hearing thresholds of captive marine mammals are also widely recognized as being needed (NRC 1994, 2000; Richardson et al. 1995; Richardson 1997b; Popper 1999). Several studies of this type are underway and results are beginning to appear (e.g., Ridgway et al. 1997; Au et al. 1999; Kastak et al. 1999; Finneran et al. 2000a; Schlundt et al. 2000). Those studies confirm that strong sounds can cause temporary reduction in hearing acuity (Temporary Threshold Shift, TTS) in dolphins and pinnipeds. Recent TTS studies have confirmed that in dolphins and pinnipeds, as in terrestrial mammals, the received level necessary to elicit TTS is inversely related to the duration of exposure (Finneran et al. 2000a; Schusterman et al. 2000). The TTS thresholds of seals exposed to a series of intermittent seismic pulses have not been measured, but are expected to be higher than the TTS thresholds measured (by Kastak et al. 1999) in pinnipeds exposed to 20-22 min of steady noise. Results from a study testing the effects of a single watergun pulse on hearing sensitivity in belugas and dolphins may be available soon (Finneran et al. 2000b).

1.2 Incidental Harassment Authorization

Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the Marine Mammal Protection Act (MMPA). Such disturbance falls within the MMPA definition of Level B harassment, which entails "disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering". "Taking" of marine mammals without special authorization is prohibited. However, under the 1994 amendments to the MMPA and regulations finalized in 1996, "citizens of the United States can apply for an authorization to take incidentally, but not intentionally, small numbers of marine mammals by harassment" (NMFS 1996). Incidental Harassment Authorizations (IHAs) can be issued if "taking will have a negligible impact on the species or stock(s) of marine mammals and will not have an unmitigable adverse impact on the availability of the species or stock(s) for subsistence uses". IHAs can authorize unintentional harassment that does not involve serious injuries or deaths of marine mammals.

The monitoring program designed for the 2001 season was designed, in part, to provide the data needed to estimate the numbers of seals and whales "taken by harassment", and the nature of this "taking". Those data would provide the basis for assessing whether the "taking" had no more than a negligible effect on these animals. The data would also help in assessing whether there was an unmitigable adverse impact on subsistence. A further purpose for the monitoring was to provide the real-time observations of seals and whales that were needed to implement mitigation measures (shutdown of the airguns).

To minimize the possibility that marine mammals close to the seismic sources might be exposed to levels of sound high enough to cause hearing damage or other injuries, IHAs issued to seismic operators call for shutdown of the seismic source when mammals are seen within designated "safety radii". The 2001 IHA Application stipulated safety radii for seals and whales near seismic operations with WesternGeco's 640 in^3 and 1210 in^3 arrays operating at 1, 2.3 and 5 m airgun depths in water >10 m and <10 m deep (see Table 1 in Appendix A). For seals, the safety radii ranged from

- 100 m (328 ft) for the 640 in^3 array operating at 1 m (3.3 ft) gun depth when deployed in water <10 m deep, to
- 260 m (853 ft) for the 1210 in^3 array operating at 5 m (16.4 ft) gun depth when deployed in water >10 m deep (see Table 2.3 in Chapter 2, SEALS).

For whales, the safety radii ranged from

- 150 m (492 ft) for the 640 in^3 array operating at 1 m (3.3 ft) gun depth when deployed in water <10 m deep, to
- 900 m (2953 ft) for the 1210 in^3 array operating at 5 m (16.4 ft) gun depth when deployed in water >10 m deep (see Table 2.3 in Chapter 2, SEALS).

The smaller radii during operations with airguns 1 and 2.3 m deep reflect the fact that an airgun array has a lower effective source level when the guns are close to the air-water interface. The larger safety radii for operations in water >10 m deep are a result of the less rapid attenuation of the airgun pulses in deeper water. A copy of the IHA issued to WesternGeco by NMFS for the 2001 seismic work is included in this report as Appendix A.

1.3 Objectives

Three different but related sets of tasks and objectives have been specified for this monitoring project. (1) The monitoring plan identified a set of field tasks that needed to be performed. (2) The monitoring plan also identified a list of specific objectives. (3) The IHA issued by NMFS for 2001 identified various reporting requirements. These three lists of task and objectives overlap strongly, but each list includes specific requirements not fully covered by any of the other lists. Hence, all three are included below.

In previous years, the list of objectives – item (2) – was split into two lists of questions to be addressed (e.g., LGL and Greeneridge 1999, 2000). Of those two former lists, the longer one was developed by industry and the monitoring contractors. The other was developed by the peer/stakeholder group in 1996. At the request of reviewers in 2000, the monitoring plan for 2000 combined these two lists into a single overall list of objectives, and this approach has been continued for 2001.

1.3.1 Field Tasks Identified in 2001 Monitoring Plan

The tasks to be addressed by the 2001 marine mammal monitoring program, quoted from the monitoring plan (LGL and Greeneridge 2001, p. 11-12), were as follows. Tasks in *italics* are those that were planned only if seismic operations continued during the whale migration season in September-October. Because seismic operations terminated prior to 1 September again in 2001 (as in 1999 and 2000), the italicized tasks were not required and were not conducted in 2001.

Vessel-Based Observers

- Provide qualified marine mammal observers (biologists and Inupiat observers) for the two seismic source vessels throughout the OBC seismic exploration period in 2001. These observers will monitor the occurrence and behavior of marine mammals near each seismic source during daytime and nighttime periods when it is and is not operating. This will fulfil the vessel-based monitoring and mitigation conditions of the IHA and other permits, along with the anticipated requirement for involvement of Inupiat observers. Enhanced vessel lighting (on the *Arctic Star*) and night vision equipment (image intensifier) will be used at night. [See Chapters 2 and 3]

Aerial Surveys

- *If OBC seismic work occurs after 31 Aug., conduct aerial surveys to monitor the distribution, movements and general activities of bowheads and other marine mammals in and near the seismic exploration area. These surveys are to provide the data needed to estimate "take by harassment", to characterize the anticipated displacement of the bowhead migration corridor during seismic operations, and to evaluate any potential effects on subsistence hunting. Aerial survey work will occur from 1 Sept. (or the date when seismic operations resume if they are shut down on 1 Sept.) until 1 day after airgun operations end.* [Not applicable]

- *If OBC seismic work occurs after 31 Aug., exchange 2001 aerial survey data with MMS. As compared with the proposed WesternGeco/LGL aerial surveys, the MMS surveys will cover a longer period and a larger area but will provide fewer data from any one location. MMS surveys will begin on or about 31 Aug. 2001 and continue until the end of the bowhead migration season. Use of MMS data will (a) increase the sample size in the area of seismic operations and (b) help place the results from the WesternGeco/LGL surveys into a broader regional and seasonal context.* [Not applicable]

Acoustical Data

- No acoustical measurements using boat-based hydrophones to measure the characteristics and propagation of the resulting waterborne sound pulses were required for the 2001 program. [See the IHA in Appendix A]

- *If OBC seismic work occurs after 31 Aug., use autonomous seafloor acoustic recorders (ASARs) to document bowhead whale calling rates continuously during September (ice permitting) at a location near the seismic operations area, at a "reference" site farther offshore, and at another reference location about 40 km to the east. Calling rates at these locations will be documented and compared at times with and without seismic work.* [Not applicable]

- *If OBC seismic work occurs after 31 Aug., document characteristics of seismic pulses at locations within the bowhead migration corridor offshore and east of the area of seismic operations. Corresponding ambient noise levels will also be determined, allowing seismic-to-ambient ratios [to be determined]. This work will be done using seafloor recorders and air-dropped sonobuoys.* [Not applicable]

Analyses and Reporting

- Evaluate the effects of the 2001 OBC seismic program on the distribution and movements *of bowhead whales (if seismic operations occur in Sept./Oct.) and* on other species of cetaceans and seals, based on all sources of data described above. Also, use the combined 1996-2001 data to assess the effects of this type of nearshore seismic program on these species. [For seals, 2001 results and combined 1996-2001 results are in Chapter 3; not applicable for bowhead whales.]

- Prepare the "90 day report" on the monitoring and estimated "take by harassment", and a subsequent comprehensive report on all aspects of the 2001 work. [This is the comprehensive report.]

1.3.2 Objectives Identified in 2001 Monitoring Plan

The Monitoring Plan (LGL and Greeneridge 2001, p. 12-13) identified the following objectives to be addressed based on data collected during WesternGeco's 2001 monitoring program and (when relevant) during other projects back to 1979. As noted in the Monitoring Plan, the objectives pertaining to bowhead whales (in *italics*) were to be addressed only if the 2001 seismic program continued in Sept./Oct., which was not the case.

Bowhead Whales **[Not applicable]**

1. *Determine the migration corridor, headings, activities, migration timing, and abundance indices of bowhead whales passing the seismic exploration area during autumn 2001, and during the 1996-98 plus 2001 seismic programs generally.*
2. *Determine whether the migration corridor, headings, and activities of bowheads differ at times with and without seismic exploration during 2001, and during 1996-98 plus 2001 combined.*
   - *Determine whether the migration corridor through the area of seismic exploration is farther offshore when airguns are active, and (if so) by how much.*
   - *Determine whether headings and activities of bowheads approaching, passing, and west of the area of seismic exploration differ at times with and without airgun operations.*
3. *Determine how far to the east and west of the active seismic operation the offshore deflection of the bowhead migration corridor extends based on combined 1996-98 plus 2001 data, and obtain more precise estimates of the extent of offshore deflection when bowheads were passing the active seismic operation in those years.*

4. *Determine whether there are differences in the pattern of bowhead call detection rates near, offshore of, and east of the seismic exploration area at times with and without active seismic operations based on 2001 data and 1996-98 plus 2001 data. If so, use the combined acoustic and aerial survey data to evaluate whether the noise-related differences in call detection rate are attributable to differences in calling behavior, whale distribution, or a combination of the two.*

Other Species of Marine Mammals

5. Determine the distributions, behaviors, seasonal timing, and abundance indices of beluga and gray whales (if any), and of ringed, bearded and spotted seals, in and near the seismic exploration area during late summer and autumn based on data from 2001 and from 1996-2001 combined. [For seals, see Chapter 3; no whale sightings in 2001.]

6. Determine whether the local distribution, behavior and abundance of seals differ at times with and without seismic exploration during 2001 and 1996-2001 combined. If so, determine the nature of the differences, the geographic extent of the effects, and the received sound levels associated with the effects. [See Chapter 3.]

Physical Acoustics Measurements

7. *If a "new" airgun array (640 in^3 or similar) is used in 2001, determine the characteristics and levels of its waterborne sounds in relation to distance when operating with representative water and airgun depths. Relevant pulse characteristics for each source are effective source level for horizontal propagation, received levels (peak, rms, energy) and pulse durations vs. range, spectral properties, and signal-to-ambient ratios.* [Not required by the IHA; however, Appendix B, by C.R. Greene Jr. of Greeneridge Sciences, predicts the distances within which received levels of pulses from the 320 in^3 array used in 2001 are expected to diminish to various values.]

8. *If seismic operations continue in Sept./Oct. 2001, determine the characteristics of airgun array pulses as received in the bowhead migration corridor at varying distances offshore and to the east of the area of seismic exploration in 2001 and in 1996-98 plus 2001 combined. Pulse characteristics to be determined are received levels (peak, rms, energy) and pulse durations vs. range offshore and to the east, spectral properties, and signal-to-ambient ratios. Determine how the levels of sound pulses (on a peak pressure, rms pressure, and energy basis) are affected by the characteristics of the airgun array, airgun depth, water depth, aspect, and distance, based on all relevant measurements in 1996-2001.* [Not applicable]

Impacts on Marine Mammals and Subsistence

9. Estimate how many marine mammals of each species are "taken by harassment" or exposed to specified levels of pulsed sounds during WesternGeco's 2001 seismic program. Estimates are required based on each of the criteria applied in previous years of seismic monitoring, plus any new criteria stipulated in the IHA for 2001. Criteria will include the numbers of seals exposed to a received level of 190 dB re 1 μPa_{rms}, the numbers of cetaceans exposed to 180 dB, the numbers of both seals and cetaceans exposed to 160 dB, and the numbers of bowheads that would have passed within 20 km of the operating seismic vessel if they had not avoided. [See Chapter 3 for seals; no whales were sighted during the 2001 monitoring work.]

10. Determine the nature of the takes to be reported under (9), and under what circumstances they occurred (e.g., distance, [received] sound levels, signal-to-ambient ratios). [See Chapter 3.]

11. *If the 2001 seismic program continues into September, determine whether the migration corridor of bowheads was altered during periods of seismic exploration in 2001. Based on combined 1996-98 and 2001 data, determine how far the displacement effect extended to the east, offshore, and to the west, and determine the received sound levels at those distances offshore and alongshore to the east.* [Not applicable]

12. Assess whether the 2001 seismic program had unmitigated adverse effects on the accessibility of *bowheads or* other marine mammals to subsistence hunters. [See Chapter 3 for seals; not applicable for bowheads.]

The MMPA definition of "take by harassment" is subject to interpretation, and NMFS definitions and requirements for estimating "take" are evolving. Consequently, more than one answer is required in response to objective (9), with the estimated number of "takes" varying according to the definition used.

1.3.3 Reporting Requirements Specified in the IHA

The Incidental Harassment Authorization issued by NMFS on 1 August 2001 included the following requirements for the "90 Day Report" (quoted verbatim; see Appendix A for complete IHA):

1. Dates and specific locations of the seismic operations; [See Chapter 2]

2. Specifications of the survey including, but not limited to, a description of the acoustic sources used, and transmission times (day, time of day, duration, interruption in transmission for other marine mammal incidents etc.). [See Chapter 2; additional details on the sounds from the 1210 in^3 airgun array were provided in Greene et al. (2000).]

3. Results of the visual vessel-based monitoring program, including: (a) Information on the numbers (by species) of marine mammals observed during the survey; (b) the estimated number of marine mammals (by species) that may have been harassed by either the seismic sources or vessel activity through a noted behavioral change or because an animal was within its designated safety zone described under conditions 5 (b) and (c) of this Authorization; (c) marine mammal behavior patterns observed within the safety zone whenever the acoustic sources are not operating (speed, direction, submergence time, respiration, etc.); and (d) any behavioral responses or modifications of these behavioral indicators due either to the operation of the seismic source or vessel activity. [See Chapter 3 for seals; no whales were sighted.]

The IHA for 2001 specifies that "A draft technical report on the reporting items listed above must be submitted to [NMFS] by March 1, 2002... A final technical report...will be provided...no later than April 30, 2002. Both 90-day and draft reports will be subject to review and comment by [NMFS]. Any recommendations made by [NMFS] must be addressed in the final technical report prior to acceptance by [NMFS]." As noted earlier, in footnote (2), on 3 August 2001 the due-date for the draft technical report was modified to 30 April 2002. The present document constitutes that report. Any comments received on this report before or during an anticipated peer/stakeholder meeting in autumn 2002 will be taken into account in a revised technical report, if required.

1.4 Report Organization

This report includes three chapters, generally paralleling the structure of our previous reports on the 1996-2000 seismic monitoring projects for BP and Western Geophysical. In this report, a chapter on whales is excluded because seismic operations ceased on 26 August 2001, prior to the start of the bowhead migration season, and no whales had been sighted up to that date. The three chapters include

1. background and introduction [this chapter];
2. description of WesternGeco's 2001 open-water seismic program [Chapter 2];
3. results of monitoring for seals, and estimated numbers of seals "taken by harassment", in 2001 and in 1996-2001 combined [Chapter 3].

In addition, Appendix A provides the text of the NMFS IHA issued to WesternGeco for this project and Appendix B describes how estimates of 190, 180 and 160 dB distances were derived for the 320 in^3 array used in 2001.

The primary purpose of this report is to describe the 2001 seismic program, the associated monitoring program, and the monitoring results from 2001. However, Chapter 3 also includes integrated analyses of seal data from 1996-2001, as called for by the approved monitoring plan for 2001 (LGL and Greeneridge 2001). The 1996-2000 data used in those analyses were collected during monitoring of seismic operations conducted for BP in 1996-97 and Western Geophysical in 1998-2000. Those 1996-2000 results are described in detail in Richardson [ed.] (1997a, 1998, 1999, 2000, 2001a).

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- LGL Ltd./LGL Alaska (Dr. J. Lawson, Dr. W.J. Richardson, W. Wilson)
- Minerals Management Service (S. Treacy, F. Wendling),
- National Marine Fisheries Service (R. Angliss [chair], K. Hollingshead, Dr. S. Moore, B. Smith),
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1.6 Literature Cited

Arnold, B.W. 1996. Visual monitoring of marine mammal activity during the Exxon 3-D seismic survey/Santa Ynez Unit, offshore California/9 November to 12 December 1995. Rep. From Impact Sciences Inc., San Diego, CA, for Exxon Co. U.S.A., Thousand Oaks, CA. 25 p.

Au, W.W.L., P.E. Nachtigall and J.L. Pawloski. 1999. Temporary threshold shift in hearing induced by an octave band of continuous noise in the bottlenose dolphin. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2251.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. **J. Acoust. Soc. Am.** 96(4):2469-2484.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin and S.H. Ridgway. 2000a. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. **J. Acoust. Soc. Am.** 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder and S.H. Ridgway. 2000b. Masked temporary threshold shift (MTTS) in odontocetes after exposure to single underwater impulses from a seismic watergun. **J. Acoust. Soc. Am.** 108(5, Pt. 2):2515.

Goold, J.C. 1996. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. **J. Mar. Biol. Assoc. U.K.** 76:811-820.

Greene, C.R., Jr., and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. **J. Acoust. Soc. Am.** 83(6):2246-2254.

Greene, C.R., Jr., N.S. Altman and W.J. Richardson. 1999. Bowhead whale calls [1998]. p. 6-1 to 6-23 *In*: W.J. Richardson (ed., 1999, *q.v.*).

Greene, C.R., Jr., and W.C. Burgess, with R. Norman and R.W. Blaylock. 2000. Physical acoustics measurements, 1999. p. 3-1 to 3-45 *In*: W.J. Richardson (ed., 2000, *q.v.*).

Greene, C.R., Jr., M.W. McLennan, T.L. McDonald and W.J. Richardson. 2002. Acoustic monitoring of bowhead whale migration, autumn 2001. Chapter 8 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and whale calls during construction of BP's Northstar oil development, Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

Harris, R.E., G.W. Miller, R.E. Elliott and W.J. Richardson. 1997. Seals [1996]. p. 4-1 to 4-42 *In*: W.J.Richardson (ed., 1997a, *q.v.*).

Harris, R.E., A.N. Balla-Holden, S.A. MacLean and W.J. Richardson. 1998. Seals [1997]. p. 4-1 to 4-54 *In*: W.J. Richardson (ed., 1998, *q.v.*).

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17(4):795-812.

HESS. 1999. High energy seismic survey review process and interim operational guidelines for marine surveys offshore Southern California. Rep. from High Energy Seismic Survey Team for Calif. State Lands Comm. and U.S. Minerals Manage. Serv. [Camarillo, CA]. 39 p. + Appendices.

Jolles, C.Z. (ed.). 1995. Speaking of whaling: a transcript of the Alaska Eskimo Whaling Commission panel presentation on native whaling. p. 315-337 *In*: A.P. McCartney (ed.), Hunting the largest animals/Native whaling in the western Arctic and subarctic. Studies in Whaling 3. Can. Circumpolar Inst., Univ. Alberta, Edmonton, Alb. 345 p.

Kanayurak, F., B. Rexford, V. Edwardsen, H. Brower Jr., M. Nageak, B. Itta, O. Leavitt, J. Kaleak, J.A. Killbear, J. Lampe, E. Rexford, C. Brower, T. Napageak, A. Ahkivianna, G. Taalak, E. Nukapigak and R. Oyagak Jr. 1997. Conclusion of Whaling Captains present at "*Arctic seismic synthesis and mitigating measures workshop*", Barrow, AK, 6 March 1997. *In:* MMS (1997, *q.v.*).

Kastak, D., R.J. Schusterman, B.L. Southall and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. **J. Acoust. Soc. Am.** 106(2):1142-1148.

Koski, W.R. and S.R. Johnson. 1987. Behavioral studies and aerial photogrammetry. (Chap. 4) *In*: LGL and Greeneridge, Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, autumn 1986. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western E & P Inc., Anchorage, AK. 371 p.

Lawson, J.W. and V.D. Moulton. 1999. Seals [1998]. p. 4-1 to 4-69 *In*: W.J. Richardson (ed., 1999, *q.v.*).

LGL and Greeneridge. 1999. Marine mammal and acoustic monitoring plan for Western Geophysical's 1999 open-water seismic program, Alaskan Beaufort Sea, Final (Aug. 1999) ed. LGL Rep. TA2313-1. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD, and Anchorage, AK. 49 p.

LGL and Greeneridge. 2000. Marine mammal and acoustic monitoring plan for Western Geophysical's 2000 open-water seismic program, Alaskan Beaufort Sea, Final (July 2000) ed. LGL Rep. TA2424-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD, and Anchorage, AK. 55 p.

LGL and Greeneridge. 2001. Marine mammal and acoustic monitoring plan for WesternGeco's 2001 open-water seismic program, Alaskan Beaufort Sea, April 2001 ed. LGL Rep. TA2564-1. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD, and Anchorage, AK. 52 p.

Ljungblad, D.K., B. Würsig, S.L. Swartz and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. **Arctic** 41(3):183-194.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. Var. pag. NTIS PB86-218377.

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In*: W.M. Sackinger, M.O. Jeffries, J.L. Imm and S.D. Treacy (eds.), Port and ocean engineering under arctic conditions, vol. II. Geophysical Inst., Univ. Alaska, Fairbanks, AK. 111 p.

Mate, B.R., K.M. Stafford and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. **J. Acoust. Soc. Am.** 96(5, Pt. 2):3268-3269.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. **APPEA (Austral. Petrol. Prod. & Explor. Assoc.) J.** 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch and K. McCabe. 2000. Marine seismic surveys – a study of environmental implications. **APPEA (Austral. Petrol. Prod. & Explor. Assoc.) J.** 40:692-708.

Miller, G.W., R.E. Elliott, W.R. Koski and W.J. Richardson. 1997. Whales [1996]. p. 5-1 to 5-115 *In*: W.J. Richardson (ed., 1997a, *q.v.*).

Miller, G.W., R.E. Elliott and W.J. Richardson. 1998. Whales [1997]. p. 5-1 to 5-124 *In*: W.J. Richardson (ed., 1998, *q.v.*).

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton and W.J. Richardson. 1999. Whales [1998]. p. 5-1 to 5-109 *In*: W.J. Richardson (ed., 1999, *q.v.*).

Moulton, V.D. and J.W. Lawson. 2000. Seals, 1999. p. 4-1 to 4-58 *In*: W.J. Richardson (ed., 2000, *q.v.*),

Moulton, V.D. and J.W. Lawson. 2001. Seals, 2000. p. 4-1 to 4-50 *In*: W.J. Richardson (ed., 2001, *q.v.*),

MMS. 1997. Arctic seismic synthesis and mitigating measures workshop/Proceedings. OCS Study MMS 97-0014. U.S. Minerals Manage. Serv., Anchorage, AK. Var. pag.

NMFS. 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. **Fed. Regist.** 60(200, 17 Oct.):53753-53760.

NMFS. 1996. Small takes of marine mammals; harassment takings incidental to specified activities in arctic waters; regulation consolidation. **Fed. Regist.** 61(70, 10 Apr.):15884-15891.

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California/Notice of receipt of application. **Fed. Regist.** 65(60, 28 Mar.):16374-16379.

NMFS. 2001a. Small takes of marine mammals incidental to specified activities; offshore seismic activities in the Beaufort Sea/Notice of receipt of application and proposed authorization for a small take exemption; request for comments. **Fed. Regist.** 66(115):32321-32328.

NMFS. 2001b. Small takes of marine mammals incidental to specified activities; seismic activities in the Beaufrot Sea/Notice of issuance of an incidental harrassment authorization. **Fed. Regist.** 66(150):42515-42523.

NRC. 1994. Low-frequency sound and marine mammals/Current knowledge and research needs. U.S. Nat. Res. Counc., Ocean Studies Board, Committee on low-frequency sound and marine mammals (D.M. Green, H.A. DeFerrari, D. McFadden, J.S. Pearse, A.N. Popper, W.J. Richardson, S.H. Ridgway and P.L. Tyack). Nat. Acad. Press, Washington, DC. 75 p.

NRC. 2000. Marine mammals and low-frequency sound/Progress since 1994. U.S. Nat. Res. Counc., Ocean Studies Board, Committee to Review Results of ATOC's Marine Mammal Research Program (A.N. Popper, H.A. DeFerrari, W.F. Dolphin, P.L. Edds-Walton, G.M. Greve, D. McFadden, P.B. Rhines, S.H. Ridgway, R.M. Seyfarth, S.L. Smith and P.L. Tyack). Nat. Acad. Press, Washington, DC. 146 p.

Popper, A.N. (compiler). 1999. Effects of anthropogenic sounds on the hearing of marine animals. p. 19-57 *In*: R.C. Gisiner (ed.), Proceedings/Workshop on the effects of anthropogenic noise in the marine environment, Bethesda, MD, Feb. 1998. Office of Naval Research, Arlington, VA. 141 p.

Quan, J., and J. Calambokidis. 1999. Marine mammal observations and mitigation associated with USGS seismic surveys in the Southern California Bight in 1999. Open-file Rep. 560. Rep. by Cascadia Research, Olympia, WA, for U.S. Geological Survey, Menlo Park, CA, Olympia, WA. 15 p.

Rexford, B. 1996. The Alaska Eskimo Whaling Commission and history of subsistence whaling off Point Barrow "Nuvuk" [and General Discussion]. p. 77-85 *In*: Proc. 1995 Arctic Synth. Meeting, Anchorage, AK, Oct. 1995. OCS Study MMS 95-0065. U.S. Minerals Manage. Serv., Anchorage.

Richardson, W.J. (ed.). 1997a. Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. vii + 245 p.

Richardson, W.J. 1997b. Marine mammals and man-made noise: current issues. p. 39-50 *In*: Underwater bio-sonar and bioacoustics symposium, Loughborough Univ., Dec. 1997. Proc. Inst. Acoust. 19(9). St. Albans, Herts., U.K. 293 p.

Richardson, W.J. (ed.). 1998. Marine mammal and acoustical monitoring of BP Exploration (Alaska)'s open-water seismic program in the Alaskan Beaufort Sea, 1997. LGL Rep. TA2150-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xx + 318 p.

Richardson, W.J. (ed.). 1999. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xx + 390 p.

Richardson, W.J. (ed.). 2000. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1999. LGL Rep. 2313-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xiii + 155 p.

Richardson, W.J. (ed.) 2001a. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2424-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 133 p.

Richardson, W.J. (ed.) 2001b. Marine mammal and acoustical monitoring of WesternGeco's open-water seismic program in the Alaskan Beaufort Sea, 2001: 90-day report. LGL Rep. TA2564-3. Rep. from LGL Ltd., King City, Ont., for WesternGeco LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 86 p.

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 *In*: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The bowhead whale. Spec. Publ. 2. Soc. Mar. Mamm., Lawrence, KS. 787 p.

Richardson, W.J. and B. Würsig. 1997. Influences of man-made noise and other human actions on cetacean behaviour. **Mar. Freshwat. Behav. Physiol.** 29(1-4):183-209.

Richardson, W.J., B. Würsig and C.R. Greene Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. **J. Acoust. Soc. Am.** 79(4):1117-1128.

Richardson, W.J., C.R. Greene Jr., C.I. Malme, D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Ridgway, S.H., D.A. Carder, R.R. Smith, T. Kamolnick, C.E. Schlundt and W.R. Elsberry. 1997. Behavioral responses and temporary shift in masked hearing threshold of bottlenose dolphins, *Tursiops truncatus*, to 1-second tones of 141 to 201 dB re 1 μPa. Tech. Rep. 1751. NRaD, RDT&E Div., Naval Command, Control & Ocean Surveillance Center, San Diego, CA. 27 p.

Schlundt, C.E., J.J. Finneran, D.A. Carder and S.H. Ridgway. 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. **J. Acoust. Soc. Am.** 107(6):3496-3508.

Schusterman, R., D. Kastak, B. Southall and C. Kastak. 2000. Underwater temporary threshold shifts in pinnipeds: tradeoffs between noise intensity and duration. **J. Acoust. Soc. Am.** 108(5, Pt. 2):2515-2516.

Stone, C.J. 1997. Cetacean observations during seismic surveys in 1996. JNCC Rep. 228. Joint Nature Conserv. Commit., Aberdeen, Scotland. 39 p. + Appendices.

Stone, C.J. 1998. Cetacean observations during seismic surveys in 1997. JNCC Rep. 278. Joint Nature Conserv. Commit., Aberdeen, Scotland. 55 p. + Appendices.

Stone, C.J. 2000. Cetacean observations during seismic surveys in 1998. JNCC Report 301. Joint Nature Conserv. Commit., Aberdeen, Scotland. 62 p. + Appendices.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell and A. Bj• rge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. Abstr. World Mar. Mamm. Sci. Conf., Monaco, Jan. 1998:134. 160 p.

2. SEISMIC PROGRAM DESCRIBED, 2001[1]

2.1 Introduction

WesternGeco's open-water seismic program in 2001 consisted of an Ocean Bottom Cable (OBC) seismic survey in nearshore waters of the central Alaskan Beaufort Sea. This work was conducted by WesternGeco from 2 to 26 August 2000. The primary seismic source was an array of 16 identical sleeve-type airguns, each of 40 in^3 volume and totaling 640 in^3, deployed from the *Peregrine* (see §2.2.4). Following initial tests at 640 in^3, this array was operated thereafter at half volume (8 airguns for a total of 320 in^3). In addition, a second, larger array of 12 sleeve-type airguns of various individual volumes totaling 1210 in^3 was towed by the *Arctic Star* (see §2.2.4), and alternated operation with the smaller array. The *Arctic Star*'s 2001 array was identical to that used in Western's 2000 seismic program (Lawson 2001). It was smaller in total volume than the 16-gun array of 1500 in^3 that Western Geophysical operated from the *Star* in 1998 (Lawson 1999), and similar to the "Full Array" configuration used by BP Exploration (Alaska) Inc. for its open-water seismic program in the Beaufort Sea during 1996. In the 1996 project the total airgun volume was up to 1320 in^3 (Greene et al. 1997). Testing of the 640 in^3 airgun array began on 2 August in 2001; production operations commenced on 6 August and continued until WesternGeco ended airgun operations on 26 August. Seismic exploration work was conducted in the Simpson Lagoon area of the central Alaskan Beaufort Sea within 48 km (25.9 n.mi) of Prudhoe Bay (see §2.2.6). Water depths within the survey area ranged from 0.6 to 12.8 m (2 to 42 ft).

The 2001 WesternGeco seismic project was similar to recent open-water seismic programs conducted in the Beaufort Sea in that the OBC method was employed (Rayson 1997; Kidd 1999; Lawson 1999, 2000, 2001; Madtson and Sanders 1999). The area to be surveyed was divided into patches. Within each patch, multiple receiving cables were placed on the bottom parallel to one another. Seismic data for each patch were acquired while towing one of the airgun arrays along a series of source lines oriented perpendicular to the receiving cables. The *Peregrine* and *Arctic Star* acquired the seismic data using a Syntron Syntrak 480 system (see §2.2.2). During the 2001 program, seismic data were acquired from five patches. The *Peregrine*'s 320 in^3 array was used to acquire most of the seismic data in 2001 as the *Arctic Star* was not able to operate in the shallower waters of the patches located inshore of the barrier islands.

Marine mammal monitoring personnel were aboard the source vessels throughout the period of operations. They helped implement provisions of an Incidental Harassment Authorization (IHA) that was issued on 1 August 2001 by the National Marine Fisheries Service (NMFS) for Western's 2001 seismic program (Appendix A). There was 24-h daylight in early August, but increasing amounts of darkness starting in mid-August. Marine mammal observations occurred both during daytime and at night.

The observers conducted watches at all times when airguns were firing and also during the relatively few periods when either of the source vessels was underway but the airguns were not firing. Relatively few seals, and no whales, were seen from the source vessels during the 2001 monitoring program. The IHA required that WesternGeco "Immediately shut-down the seismic sources whenever any ringed, bearded, or spotted seal enters, or is about to enter the area delineated by the 190 dB (re 1 μPa_{rms}) safety zone..." When seals were seen within the "safety radii" specified in WesternGeco's IHA Application,

[1] By **John W. Lawson**, LGL Ltd., environmental research associates.

the airguns were immediately shut down. The designated safety radii for seals (and whales) depended on operating depth and water depth (see §2.3.2 and Appendix A).

The following subsection provides additional details about the equipment used for the 2001 seismic program and its mode of operation, insofar as these are relevant to marine mammal monitoring and mitigation. The subsequent subsection summarizes marine mammal monitoring and mitigation procedures. Underwater sounds from the larger (1210 in^3) airgun array used in 2001 were described by Greene et al. (2000), based on measurements obtained in 1999 with that array. Results of marine mammal monitoring in 2001, and estimates of numbers of seals "taken by harassment", are given in Chapter 3 on SEALS.

2.2 Equipment and Operations

During the 2001 OBC seismic program, Western Geophysical utilized five vessels: *Peregrine*, *Arctic Star*, *Western Endeavor*, *Western Frontier*, and *Mr. Jim*. Except for the *Mr. Jim*, these were the same vessels that were used for Western's 2000 OBC program (Lawson 2001). These vessels were largely self-contained, with the crew of each (except the *Mr. Jim*) living aboard that vessel. Vessel waste water was treated on board and handled in accordance with federal regulations. The descriptions and functions of each vessel are given in the following subsections.

2.2.1 Source Vessels

R/V Peregrine.—This small (94 ft length by 24 ft beam), jet- and prop-driven, aluminum landing craft had a 30 in draft, and was the primary source vessel for WesternGeco in 2001. It was modified following the 1998 season by adding a new bridge deck, adding 12 ft to the vessel's length at the stern, and changing the propulsion system. It was further modified following the 1999 season by enlarging the bridge decking and lengthening the stern by several feet.

In 2001 an "airgun compressor, deployment and controller module" was installed on the *Peregrine*'s foredeck (Fig. 2.1) (see §2.2.4).

The *Peregrine* was powered by three Cummins diesels, of 300 hp each, driving two Kodiak model 403 water jets, and a single four-bladed propeller mounted within a 30 in recess at the stern. (In 1998 *Peregrine* had been driven by three water jets.) During seismic production this vessel operated at speeds of approximately 4 to 5 knots. Vessel noise from the *Peregrine* itself was measured previously in 1996 and 1999 (Greene et al. 1997, 2000).

The *Peregrine* also served as a platform from which vessel-based marine mammal observers (MMOs) watched for marine mammals. The elevated bridge spanned the width of the vessel near the stern and afforded good visibility for the observers within almost a 360 degree arc (Fig. 2.2).

R/V Arctic Star.—The largest vessel in the fleet was the same source vessel used in the 1998-2000 OBC seismic programs (Fig. 2.3). R/V *Arctic Star* has a length of 110 ft, a beam of 30 ft and a draft of 6 ft. This vessel was used to tow an airgun array (see §2.2.4) back and forth over the seismic patches or portions of patches located in waters outside the barrier islands. The *Arctic Star* was powered by two 6V71 GM diesels of 500 hp (370 kW) each. Each engine drove a four-bladed stainless steel propeller at 1800 rpm, producing a towing speed of 5 to 6 knots. For docking and anchoring operations, the *Arctic Star* was equipped with a small bow thruster located in a transverse tunnel. Four diesel compressors on the stern deck provided compressed air for the airgun array.

FIGURE 2.1. The primary source vessel R/V *Peregrine* as it appeared in 2001 after an "airgun compressor, deployment and controller module", painted blue, was installed on the foredeck (photograph by J. Lawson, LGL).

FIGURE 2.2. Bridge crew of the R/V *Peregrine* (Captain Jeff Johnson, left, and First Mate Bill Vogel, right) assisting MMO Lawson (center) during airgun operations inshore of the barrier islands (photograph by P. Hann, LGL). The large windows of the *Peregrine*'s elevated bridge provided excellent visibility.

FIGURE 2.3. WesternGeco's larger source vessel, the R/V *Arctic Star.* This steel-hulled vessel was used to operate the 1210 in^3 airgun array (1999 photograph by W. Burgess, Greeneridge Sciences).

Like the *Peregrine*, the *Arctic Star* also served as a platform from which mammal observers watched for marine mammals. The bridge spanned the width of the vessel near the bow and afforded good visibility for the observers within a 320 degree arc. Visibility in a 40 degree arc immediately astern of the *Arctic Star* was restricted due to intervening superstructures (Fig. 2.3).

To facilitate night vision by the bridge crew and observers, the bridge interior was darkened almost completely when operating after nightfall. As a further measure to improve observers' ability to sight marine mammals during periods of darkness, WesternGeco installed six broad-beam, 1000-Watt floodlights in 1999: two aimed forward, two aimed at 45 degrees to the direction of travel, and two aimed perpendicular to the direction of travel (Fig. 2.4). There was a workstation in the port forward side of the bridge, with a swiveling, elevated seat on which observers could sit while recording data and rest when not crossing the ship's bridge (Fig. 2.5).

Levels and characteristics of the general vessel noise from *Arctic Star* and other project vessels are described in Greene et al. (2000).

2.2.2 OBC Cable Vessels

R/V Western Endeavor and Western Frontier.—Of the vessels employed to deploy and retrieve OBC cables, two were composite "Flexifloats" of less than 300 tons, with dimensions of 135 ft by 50 ft and with drafts of 3 to 5 ft (Fig. 2.6). These vessels were each powered by three shrouded thrusters driven by two diesel engines of 400 hp and one of 250 hp. These thrusters could be raised to decrease the draft of the Flexifloat, and were often elevated out of the water when the vessel was anchored.

The OBC cables were deployed from the stern of each Flexifloat and retrieved from the bow at speeds up to four knots. About 40 km (25 mi) of OBC cable was used for day-to-day operations at one location (see §2.2.5 below). The cable-laying vessel steamed in a straight line as indicated by differential GPS (DGPS) positioning, and the OBC cable was laid out over the stern. After the OBC cable had collected sufficient data, the cable vessel retraced its route along the cable and lifted it back aboard. When not laying cable, one of the Flexifloats acted as the recorder vessel to receive and archive the seismic data recorded by the hydrophones and geophones in the OBC cables. The OBC cables were powered by the recording Flexifloat. The *Endeavor* and *Frontier* used diesel generators to power the cables for testing and operation. The utility vessel *Mr. Jim* (described below) also acted as a cable vessel when needed.

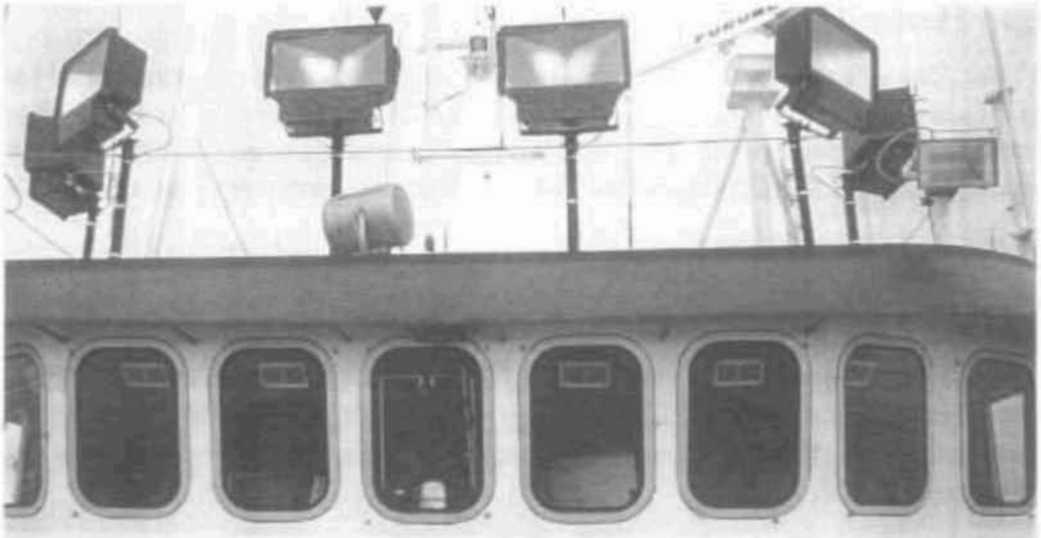

FIGURE 2.4. Six broad-beam, 1000-Watt floodlights above the bridge of the R/V *Arctic Star* (1999 photograph by J. Lawson, LGL).

FIGURE 2.5. A view of the bridge of the R/V *Arctic Star* showing the viewing windows and the elevated marine mammal observer's station on the port side (1999 photograph by J. Lawson, LGL).

FIGURE 2.6. One of WesternGeco's cable vessels, the R/V *Western Frontier*, seen from the R/V *Arctic Star* (2000 photograph by J. Lawson, LGL). One of its three thrusters can be seen in an elevated configuration at the stern of the vessel.

2.2.3 Support Vessels

M/V Mr. Jim.—This small (53 ft length by 16 ft beam), jet-driven, aluminum vessel had a 50 in draft (Fig. 2.7). It was used to conduct crew supply and transfer, and assisted with cable deployment and interconnection. *Mr. Jim* was powered by two 6CTA 8.3 Cummins diesels, of 300 hp each, driving two North American Marine TJ II-300 Tractor Jets. The vessel had a cruising speed (unladen) of 18 knots.

2.2.4 Airgun Array Characteristics

320 in^3 Array.—During its 2001 OBC seismic operations in the Beaufort Sea, WesternGeco employed half of a 640 in^3 airgun array composed of 16 identical airguns deployed over the port and starboard sides of the *Peregrine*. Four clusters (Fig. 2.8) of four 40 in^3 airguns (total of 16) were swung out from two positions on the port and two positions on the starboard side of this vessel (Fig. 2.9). Since only half of these airguns (8×40 in^3) were fired during production seismic operations, the active array volume was actually 320 in^3.

The compressors for the array (aboard the *Peregrine*) were connected to the source with four lines called umbilicals. Umbilicals contained firing lines, sensor lines, and spare lines. The array was deployed and retrieved from the vessel using hydraulic winches (Fig. 2.9).

The 320 in^3 array was charged with compressed air at 1900 ± 100 psi, and was activated by an electronic controller at a rate of approximately one discharge every 8 to 10 s. The firing rate was determined largely by the compressed air availability (i.e., time) on the source vessel, rather than distance. All eight guns were fired simultaneously, except during ramping up or testing. The *Peregrine* typically traveled at about 5 knots (9.0 km/h) (see §2.2.5 for patch configurations).

FIGURE 2.7. The multiple-purpose utility vessel M/V *Mr. Jim* (left, photograph by WesternGeco), and *Mr. Jim* docked behind *Arctic Star* (right) to illustrate its relative size (photograph by J. Lawson, LGL).

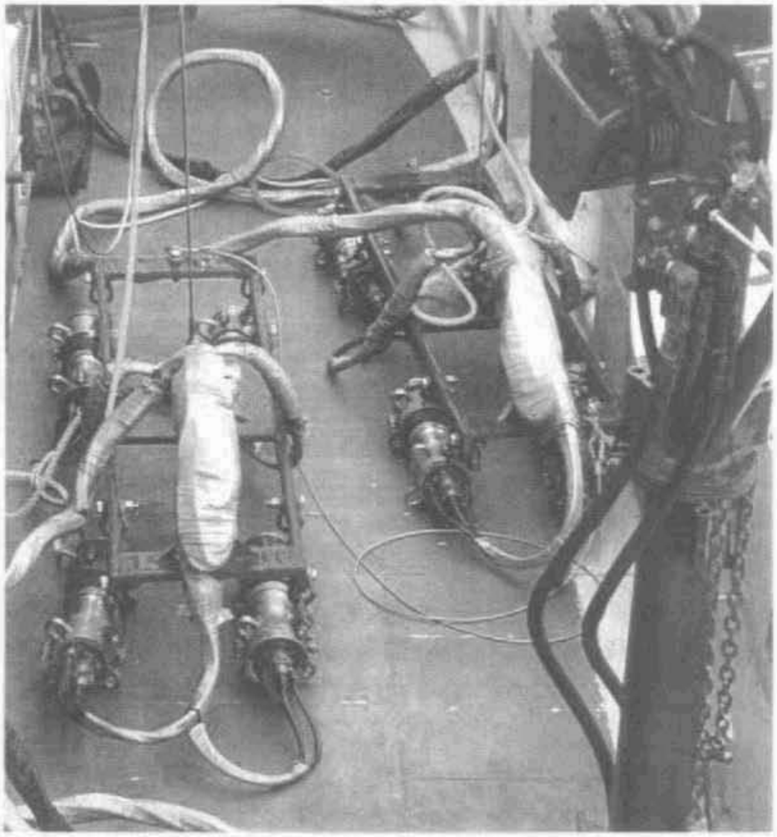

FIGURE 2.8. View of two 4-airgun clusters that formed half of the 320 in^3 airgun array deployed from the *Peregrine* in 2001 (photograph by J. Lawson, LGL). The gray tape covers and protects the high-pressure umbilical cables, which provided air pressure and firing control for each 40 in^3 airgun.

FIGURE 2.9. Starboard pair of 4-airgun clusters that formed half of the 320 in^3 airgun array deployed from the *Peregrine* in 2001 (photograph by J. Lawson, LGL). The square steel frames, suspended from the two davits kept the airguns positioned at the correct water depth and spaced precisely.

When airgun operations commenced after a period without airgun operations, the number of guns firing was increased gradually ("ramp-up"; see §2.3.2, Mitigation Measures).

Airguns, or airgun clusters, were suspended in the water from steel frames (Fig. 2.9). Horizontal spacing of the airguns was ensured by cable harnesses attached to these steel frames, which extended out from either side of the *Peregrine* during seismic operations (Fig. 2.9). As in the 1210 in^3 array (see below), the airguns were oriented horizontally.

The 320 in^3 airgun array was operated at a shallow airgun depth of 1 m (3 ft) on all of the seismic patches on which the *Peregrine* operated in 2001.

***1210 in³ Array*.**—WesternGeco also employed a 1210 in^3 airgun array whose acoustic characteristics were described by Greene et al. (2000), with some updated information in Chapter 3 of Richardson [ed.] (2001).

The compressors for this larger array were connected to the source with four lines called umbilicals. Umbilicals contained firing lines, sensor lines, and spare lines. The array was deployed and retrieved from the stern of the vessel using hydraulic winches (Fig. 2.10).

The airgun array was charged with compressed air at 1900 ± 100 psi, and was activated by an electronic control at a rate of approximately one discharge every 12 to 24 s. Pulses were timed to occur every 50 m along the shot lines, so the firing rate was determined largely by the speed of the source vessel. All of the guns in the array were fired simultaneously, except during ramping up or testing. In 2000, the *Arctic Star* typically traveled at about 5 knots (9.0 km/h), covering a source line in just over 30 min (see §2.2.5 for patch configurations).

When airgun operations commenced after a period without airgun operations, the number of guns firing was increased gradually ("ramp-up"; see §2.3.2, Mitigation Measures).

The airgun array was composed of 12 sleeve-type airguns with a total volume of 1210 in^3. The volumes of the individual guns varied from 40 in^3 at the port-side rear corner of the array to pairs of 150 in^3 guns mounted at the port and starboard forward corners (Fig. 2.11A). Airguns, or airgun clusters, were suspended in the water from air-filled floats (Fig. 2.10, 2.11B). Horizontal spacing of the airguns was ensured by cable harnesses attached to two towing booms, which extended out from either side of the *Arctic Star* during seismic operations (Fig. 2.11A, 2.12). The airguns were oriented horizontally.

The depth at which the airgun array can be operated varies depending on the water depths of the seismic patch. On all patches in 2001, the *Arctic Star* towed its array at 2.3 m (7.5 ft)[2] below the water's surface (measured to the middle of the gun pair in the larger inboard pairs, Fig. 2.11B).

The dominant frequencies of the sound pulses emitted by the array ranged from a few hertz up to about 188 Hz. The characteristics of the sounds emitted by the airgun array are described in detail in Greene et al. (2000).

In terms of total airgun volume, the *Arctic Star*'s airgun array deployed in 1999-2001 was smaller than the arrays used most commonly in 1996 and 1998. However, it was larger than the array used in 1997, and also larger than the small array deployed from the primary source vessel (*Peregrine*) in 2001, and the secondary source vessel (*Saber Tooth*) in 1998 (Table 2.1).

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[2] The 1500 in^3 array used in 1998 and the 1210 in^3 array used in 1999-2001 were towed at either 2.3 or 5 m gun depth, although for 1998 the shallower gun depth was reported as 2 m (Lawson 1999, 2000).

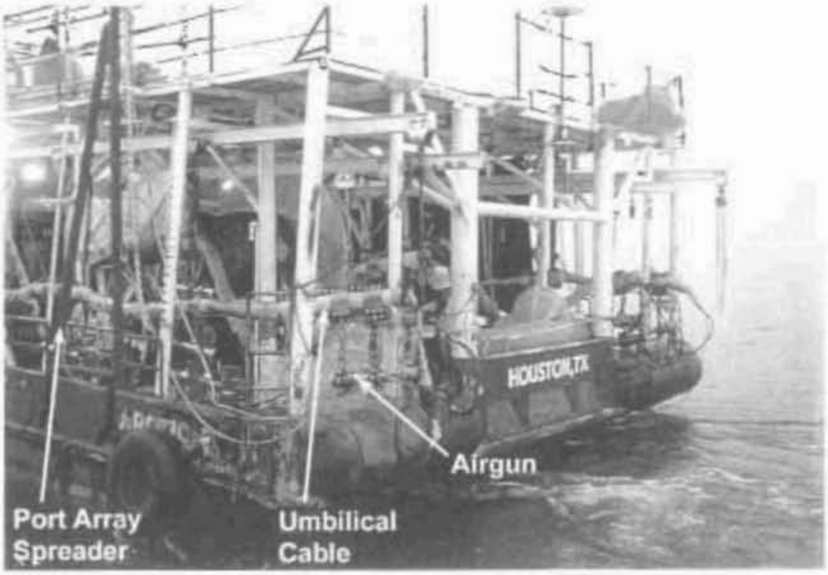

Figure 2.10. The 1210 in^3 airgun array stowed aboard the R/V *Arctic Star* (photograph by J. Lawson, LGL). The airgun umbilicals can be seen hung from chain supports, as well as the array floats and the airguns themselves.

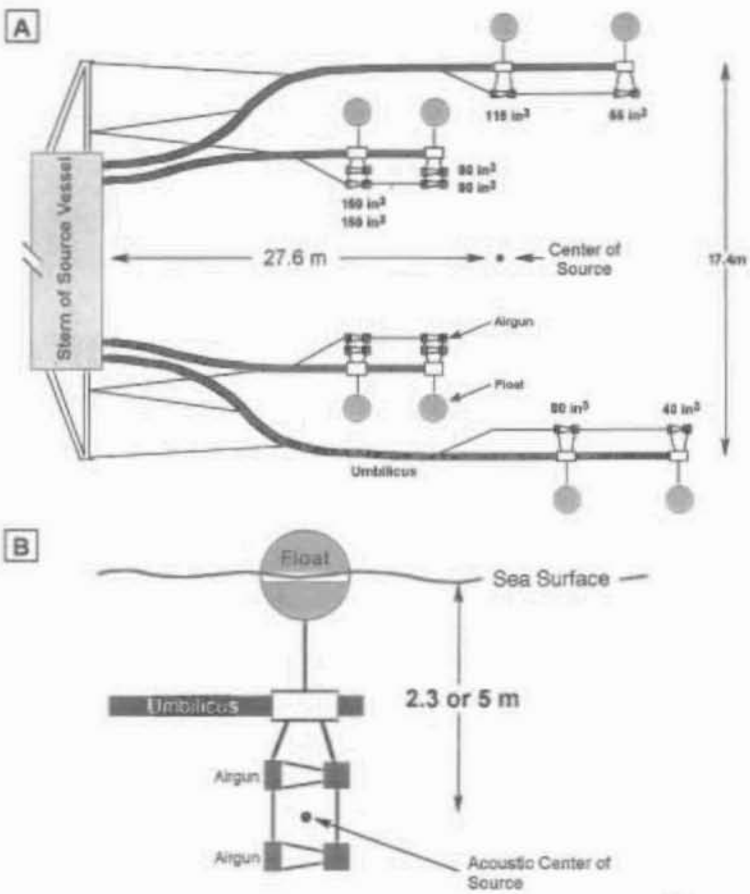

FIGURE 2.11. Schematic diagrams of ***(A)*** the asymmetrical 12-gun, 1210 in^3 airgun array towed by the R/V *Arctic Star* in 1999-2001, and ***(B)*** a pair of 150 in^3 guns in the anterior portion of the array showing how the gun depth was measured.

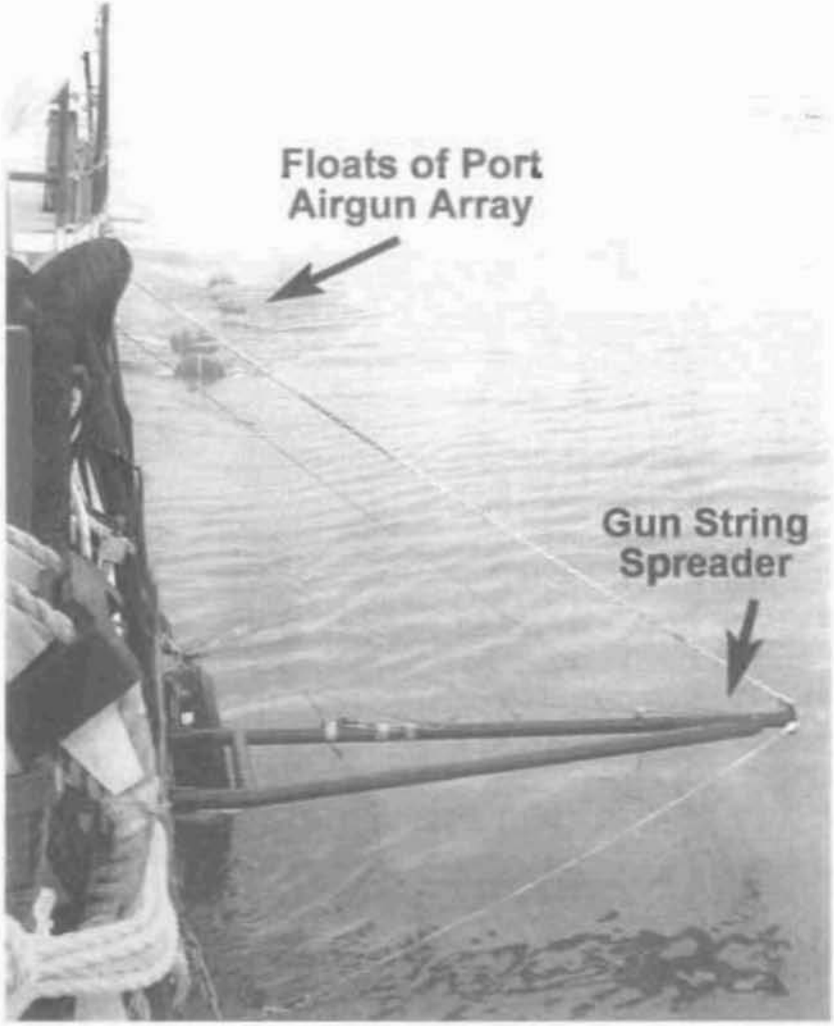

FIGURE 2.12. Horizontal spacing of the airguns was ensured by cable harnesses attached to two towing booms ("gun string spreaders"), which extended out from either side of the R/V *Arctic Star* during seismic operations. The floats of the port side of the airgun array can be seen in the water astern of the vessel (photograph by J. Lawson, LGL).

2.2.5 Ocean Bottom Cable System and Source Lines

The airgun arrays were the only sound sources used by WesternGeco to investigate geological structures under the seafloor. To receive this sound after it had reflected back from subsurface structures, WesternGeco deployed receiving cables in a specified configuration (a "patch") on the ocean floor. A standard patch consisted of four parallel receiver lines containing the sensors (Fig. 2.13). Each of these receiver lines had a series of cable sections, with six hydrophone/geophone groups per section. Cable sections were connected to an electronic module, which collected analog signals from the sensors, converted these analog signals to a digital format, and then transmitted the digital data along the cable toward the recording/telemetry vessel (R/V *Western Frontier*). Each receiver line was made up of approximately 66 cable sections and 66 modules.

TABLE 2.1. Operational summary and airgun array characteristics for open-water seismic operations in the Beaufort Sea in 1996 to 2001.

Year	Dates of Operation	Source Vessel Name(s)	Airgun Volume(s) (In^3)	Number of Airguns	Range of Airgun Depths (m)	Hours of Shooting - Large Array [a]	Hours of Shooting - Small Array [a]	Hours of Shooting - Single Airgun	Km of Airgun Operation[b]
1996	24 July to 19 Sept	*Point Barrow* (tug)	1320	11	4	355	-	-	2946
			120	1	-	-	-	98	834
1997	26 July to 25 Sept	*Sag River, Point Thompson* (tugs)	720 (810 briefly)	6	2.5	-	221	-	1544
			90	1	3	-	-	13.5	29.3
1998	24 July to 11 Oct	*Arctic Star*	1500	16 [c]	2.3 to 5	561.6	-	-	3380
		Saber Tooth	560	8 [c]	2	-	78	-	1180
1999	23 July to 1 Sept	*Arctic Star*	1210	12	2.3 to 5	227.6	-	-	2175
2000	29 July to 28 Aug	*Arctic Star*	1210	12	2.3	368.3	20.6	-	2465
	29 July to 28 Aug	*Arctic Star*	40 [d]	1	2.3		78.8 [d]	-	
2001	2 to 26 August	*Peregrine*	320 [e]	16	1.0	-	161.6	-	787
	7 to 18 August	*Arctic Star*	1210	12	2.3	78.7	-	-	352.4

[a] Does not include airgun operations during ramp-up and testing when operating array volumes varied.

[b] Does not include airgun firing during line changes.

[c] The single airgun used only at the start of ramp-up on the *Arctic Star* equaled 80 in^3 and the 16-airgun array totaled 1500 in^3; one airgun on the *Saber Tooth* equaled 70 in^3 (used only at the start of ramp-up).

[d] To allow resumption of seismic work during periods of poor visibility while remaining in compliance with an MMS permit applicable at the start of the 2000 season, one or more airguns (predominantly a single 40 in^3 airgun) were often operated during periods when the airguns would otherwise have been silent. In this way, Western Geophysical would not have been prevented from resuming operations with the full 1210 in^3 array should visibility have fallen below 3 miles. This procedure was discontinued after receipt of an IHA, whose provisions superseded those of the MMS permit.

[e] On the *Peregrine*, a single airgun, used only at the start of ramp-up, equaled 40 in^3; and the 16-airgun array totaled 640 in^3. However, after initial testing of the 16-gun 640 in^3 array, only half of the array volume was used during seismic production (8 airguns totaling 320 in^3).

The receiver lines varied in length depending on water depth and the presence of barrier islands, and normally each line was separated from the next line by 500 m (Fig. 2.13). Individual receiver lines were connected to adjacent lines with jumper sections (not shown in the Figure). The jumper sections allowed information to be transmitted from one line to the next, thus connecting all receiver lines into a group of lines that transmitted information back to the recording vessel. The patch was connected to the recording vessel by a jumper cable that could be as short as several hundred meters, or as long as several kilometers. Cables were usually deployed or retrieved by the *Western Frontier* or *Western Endeavor*, although the *Mr. Jim* performed this duty when the receiver lines were laid in very shallow waters.

The source vessels operated along a series of source lines oriented perpendicular to the OBC receiving cables. As an airgun array was towed over the bottom cable on the sea floor, the acoustic signals that were generated from each sound pulse of the source were sensed by the hydrophones and geophones in the OBCs and sent along the line to the recording vessel. The data from the patch were recorded, along with navigation data, on magnetic tape. Adjacent source lines were spaced 200 m apart; as for the receiver lines, the length of each source line varied depending on water depth and the presence of barrier islands. Most patches had non-standard shapes due to presence of shallow water or barrier islands (Fig. 2.14).

WesternGeco's IHA Application estimated that their geophysical investigations in 2001 would cover as many as 18 patches, or as much as 18% of the area covered by their 2000 IHA Application (LGL 2000, 2001). In practice, startup was again delayed by late ice breakup in the Prudhoe Bay region in 2001, and operations were suspended on 26 August. WesternGeco completed operations on five patches or about 4% of the area covered by the IHA. The total distance traveled by the *Peregrine* and *Arctic Star* while shooting seismic during 2001, including turns during line changes and testing, was approximately 787 km (424.9 n.mi. or 488.7 st.mi.) and 352.4 km (190.3 n.mi. or 218.8 st.mi.), respectively.

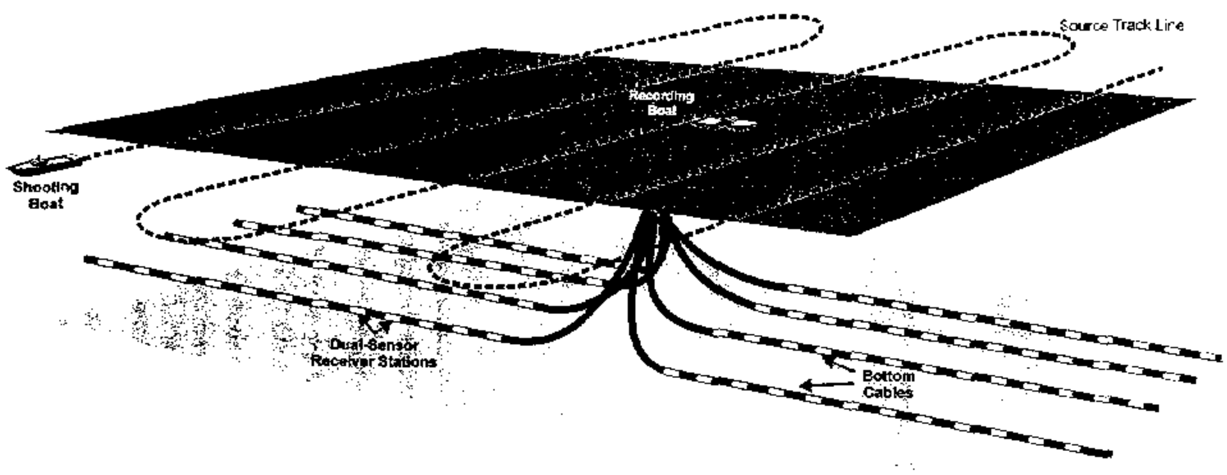

FIGURE 2.13. Three-dimensional representation of the four OBC receiver lines in a typical seismic patch operated by WesternGeco in the Beaufort Sea. As in 1999-2000, the airgun sources were towed back and forth across the receiver cables along shot lines oriented perpendicular to the receiver lines.

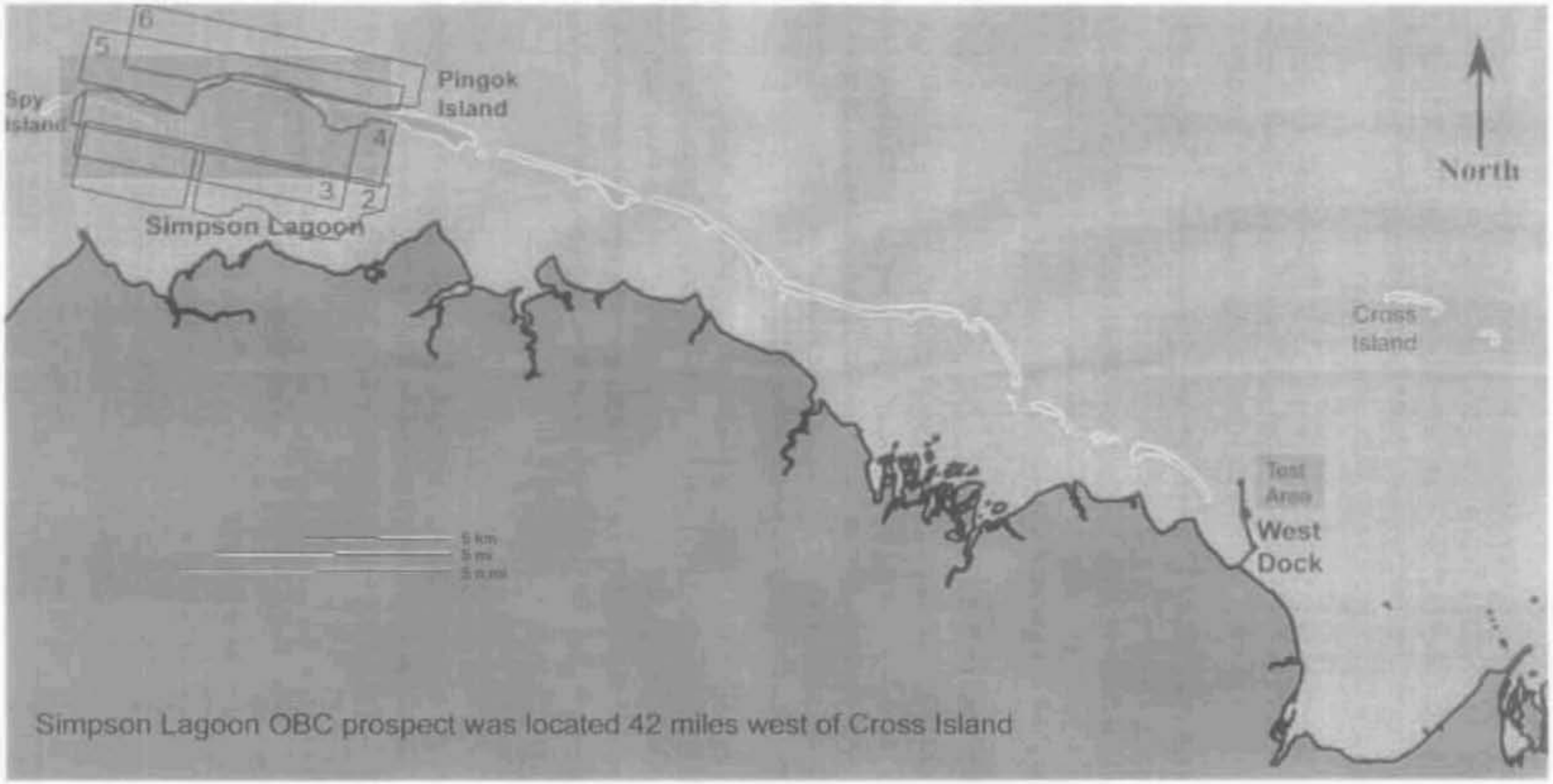

FIGURE 2.14. Map indicating the locations of the five OBC seismic patches (labeled 2-6) in the Alaskan Beaufort Sea surveyed by WesternGeco during the 2001 open-water season. Source lines associated with each patch extended outside the "receive" patch locations shown here (see Fig. 2.13). A small area near West Dock was used for array and OBC cable testing for several days at the start of operations.

2.2.6 Navigation, Vessel Movements, and Operating Areas

Locations of all primary vessels were determined within an accuracy of a few meters by Differential GPS receivers. Locations were sent by telemetry to all vessels in the WesternGeco fleet. A real-time map display of vessel locations and other relevant data was used to help manage the operations. Throughout the season, positions, speeds and activities of all WesternGeco vessels were logged digitally every 2 min. In addition, positions of the operating source vessel and airgun array were logged for every airgun shot, along with water depth and other information about each seismic shot.

Ancillary vessel movements were usually limited to cable deployment and retrieval operations. Once the OBC patch was in place, usually the only vessel moving in the area was the source vessel. Additional vessel movements were sometimes necessary in order to repair faulty OBC cables.

WesternGeco's vessels operated on five OBC seismic patches from 2 August until airgun operations were halted on 26 August (Table 2.2, Fig. 2.14 and 2.15). In 2001, most of the patches with airgun operations were located between the mainland and the barrier islands (primarily south of, and near, Spy Island and Reindeer Island) in Simpson Lagoon. Less than half of each patch extended outside the barrier islands and these deeper portions were scouted and shot by the *Arctic Star* (Fig. 2.15)

2.2.7 Interruptions by Weather and Ice

As in 1999-2000, during WesternGeco's OBC operations in the summer of 2001 there were operational complications due to sea ice intrusion. From startup in early August until the end of seismic operations on 26 August, open water was generally limited to an area along the coast. The pack ice edge or floe accumulations persisted immediately offshore near the barrier islands. Broken ice floes were evident for much of the 2001 seismic program during operations near Spy Island.

There were several periods when airgun operations on one, or both, vessels were suspended for periods of 1 to 3 days as a result of heavy seas and other operational problems (total of 5 days). During these periods, the high winds and rough seas caused considerable complications in deploying and retrieving cables, and sometimes made it necessary for the Flexifloat vessels to take shelter. OBC cable laying and/or cable retrieval continued during some of the times when airgun operations were suspended because of weather.

TABLE 2.2. Five OBC patches surveyed during WesternGeco's 2001 Beaufort Sea open-water seismic program. For each patch, the Table shows an identification (ID) number, operating dates, shooting vessel(s), airgun depth (meters), and the maximum water depths (meters)[a]. See Figure 2.14 for patch locations.

Patch ID	Shooting Date(s)	Shooting Vessel(s)	Maximum Depth (m)
2	24-26 August	*Peregrine*	2.7
3	21-24 August	*Peregrine*	3.2
4	17-21 August	*Peregrine, Arctic Star*	3.3
5	13-18 August	*Arctic Star*	7.3
6	7-12 August	*Peregrine, Arctic Star*	12.8

[a] Depth values were derived using data from both the OBC source patches and from areas adjacent to the patches that may have been exposed to sound levels of 190 dB re 1 μPa (rms) from the operating airgun array(s).

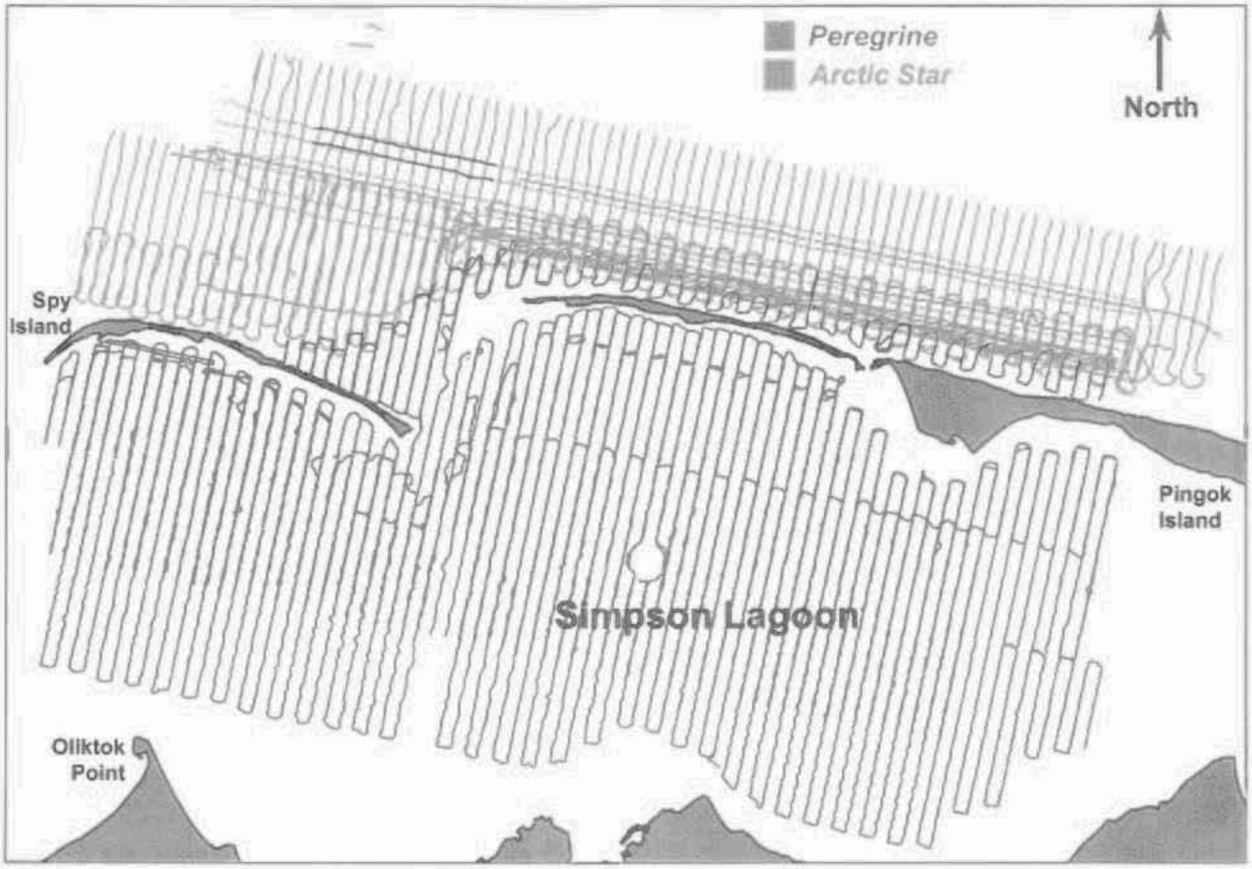

FIGURE 2.15. Seismic lines shot by the *Peregrine* (8-gun 320 in^3 array, green lines) and *Arctic Star* (12-gun 1210 in^3 array, red lines) during WesternGeco's 2001 seismic operations in Simpson Lagoon.

2.3 Marine Mammal Monitoring and Mitigation

2.3.1 Vessel-Based Monitoring

The Incidental Harassment Authorization issued by NMFS for WesternGeco's 2001 seismic program is included as Appendix A. The IHA required that trained biologists be present on both source vessels. Their duties included watching for and identifying marine mammals; recording their numbers, distances and reactions to the seismic operations; initiating mitigation measures when appropriate; and reporting the results. There was no IHA requirement for suspension of seismic operations during times with poor visibility or at night, and seismic work often continued during such periods. (However, because seismic work ended on 26 August, there were few hours of night operation in 2001.) Details of the vessel-based monitoring effort are given in Chapter 3 on SEALS. This section includes only a brief introduction to the monitoring procedures, followed by a description of the mitigation measures that were implemented when marine mammals were seen close to the source vessel.

As specified in the IHA (Appendix A), at least one biologist observer plus one Inupiat observer/communicator were assigned to the *Peregrine* at all times during the 2001 operations. Two biologist observers plus one Inupiat observer/communicator (Fig. 2.16) were assigned to the *Arctic Star* at all times as well. Usually, all observers on the *Peregrine* or *Arctic Star* (including the Inupiat) had considerable

FIGURE 2.16. Inupiat observer/communicator Sally Brower entering marine mammal sighting data while off-watch aboard the R/V *Arctic Star* (photograph by J. Lawson, LGL).

prior experience with marine mammal observations and vessel-based seismic monitoring. A statement documenting the qualifications of each biologist observer was provided to NMFS prior to deployment, either as part of the monitoring plan (LGL and Greeneridge 2001) or through delivery of a résumé to the NMFS Western Alaska office. Each observer was issued a marine mammal observer handbook. This handbook was first prepared prior to the start of the 1999 seismic season and was updated for the 2001 operations. This handbook provided observers and vessel crew with background and reference material for the marine mammal monitoring program, in addition to instructions on observation, ramp-up and shut-down protocols, and data recording, entry, and verification.

Whenever seismic operations were underway, or when they were expected to begin within 30 min, at least one observer aboard the active source vessel (either *Peregrine* or *Arctic Star*) watched continuously for marine mammals. On both vessels two observers[3] were on duty during ramp-up at the start of airgun operations (as required by the IHA), and at some other times while the airguns were operating. To compare marine mammal sighting rates during periods with and without airgun operations, observers were often on duty at times when the source vessel was underway but not operating its airgun array. Overall, two observers were on duty for ~99% of the observation time on the *Peregrine*; for most of this time the second observer was a crew member who assisted the biologist or Inupiat observer. On *Arctic Star*, two observers were on duty for 34.6% of the time and one observer was on duty 65.4% of the time. Crew members on the bridge were briefed on the observer methodology prior to the start of operations and assisted with marine mammal observations. In particular, as required in the IHA, the bridge crew on the *Peregrine* assisted the observers during virtually all observation periods, and at times when the observer was off the bridge (Fig. 2.17). The observer(s) scanned around the vessel using unaided eyes or 7 × 50 Fujinon binoculars that were equipped with reticles to measure depression angle relative to the horizon (an indicator of distance – see §3.2.1 in Chapter 3, SEALS).

[3] On the *Peregrine*, the second observer on duty during ramp-up was either a second marine mammal observer aboard the vessel, or a member of the *Peregrine*'s on-duty bridge crew.

FIGURE 2.17. Marine mammal observer Peggy Hann is assisted by Captain Jeff Johnson (right) aboard the R/V *Peregrine* (photograph by J. Lawson, LGL).

During early August there was no total darkness. Thereafter periods of darkness during the night became longer. At night, the observers used both the 7 × 50 binoculars and Bushnell/ITT F5000 binocular night vision devices (NVD). These were "third generation" image intensifiers. In practice, monitoring personnel observed at all times, night or day, when airguns were operating or were expected to start operating within the next 30 min. Notwithstanding the use of NVDs, the observers' abilities to detect marine mammals were much reduced at night. There were relatively few hours of operation during periods of darkness in 2001, and no marine mammals were detected during these nighttime observations in 2001. During the corresponding monitoring work for previous open-water seismic programs, one seal was detected at night during each of 1996 and 1998, and none during 1997, 1999, and 2000 (Harris et al. 1997, 1998, 2001; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001). There were broad-beam floodlights on the bow structure of the *Peregrine* (Fig 2.1), in addition to bridge-mounted running lights. The broad-beam floodlights added to the *Arctic Star* before the 1999 season provided improved visibility at night near the vessel. However, in 2001 there were too few hours of operation during periods of true darkness and too few seals in the area (based on the low daytime sighting rate) to assess the efficacy of these lights in improving marine mammal observers' visual perception. Operations ended earlier in the season in 1999-2001 (26 Aug. in 2001, 28 Aug. in 2000, 1 Sept in 1999) than in 1996-98 (16 Sept. - 11 Oct.; Table 2.2), providing much less opportunity for night observation in 2001 than in some other years.

Observers on watch recorded operational information (such as shooting or non-shooting, array volume, vessel position and speed) and meteorological conditions (visibility, sea state, ice presence) at regular intervals, usually at the end of each source line or every 30 min. Details are given in Chapter 3, SEALS. These written records were supplemented with accounts of marine mammals sighted. When a marine mammal was sighted by the marine mammal observer(s) on the bridge of the source vessel, the observer recorded its distance from the source, direction of travel, behavior, and apparent reaction to the vessel's activities.

To minimize errors during data recording and computer entry, field records were keypunched into a custom Microsoft Excel database aboard the source vessel within one to three days after the period of observation. The database facilitated accurate data entry by providing lookup lists and error dialogues indicating out-of-range values. Both written and computer records were also checked manually by the crew leader during the field program. After the field season LGL used a custom BASIC computer program developed in prior years to further check for entry and coding errors in the digital database prior to analysis. Procedures were largely consistent with those used in the Western Geophysical seismic monitoring projects in 1998 to 2000, and in seismic monitoring projects for BP in 1996 and 1997 (Harris et al. 1997, 1998, 2001), to facilitate comparisons and combined analyses. However, several marine mammal behavior codes and a behavior "pace" category had been added to the data collection protocol during the 1998 season in order to better characterize the behavior of seals sighted near the source vessel.

2.3.2 Mitigation Measures

Ramp-up.—The IHA called for the seismic operator to ramp-up the seismic sources when beginning operations any time after the guns had been powered down. Ramp-ups were to begin "... with an air volume discharge not to exceed 80 in^3 for the 1,210 in^3 airgun array and 40 in^3 for the 640 in^3 airgun array." Ramp-ups were done by commencing firing with a single 40 or 80 in^3 airgun, and then adding additional guns in sequence at a "rate of increase in source level ... no greater than 6 dB per minute". The ramp-up process is sometimes described as a "soft start" (e.g., Stone 1998, 2000).

The ramp-up procedure applied during 1999-2001 differed slightly from that in 1996-98 due to the different configuration of the 1210 in^3 volume array employed in 1999-2001, and the 320 in^3 array employed in 2001. Like the 1996-98 processes, ramp-ups involved a step-wise increase in the number and total volume of airguns firing until the full volume was achieved. For the 2001 array of 1210 in^3 volume, ramp-up began with an 80 in^3 airgun. For both the 1210 in^3 and 320 in^3 arrays, the ramp-up lasted at least 4 min, resulted in no more than a doubling of the active array volume each minute, and thus produced a progressive increase in source level. There were occasional variances from these nominal ramp-up sequences (i.e., the ramp-ups took longer during some testing operations), but at all times the ramp-ups were gradual rather than a sudden onset of full-array firing.

The airguns fired intermittently during normal operations—typically about once every 12 to 24 s. The exact time interval depended on vessel speed. Thus, it was necessary to define how long a gap between shots could occur without it being necessary to ramp-up before again firing the full array. As in 1996-2000, a ramp-up was specified if there had been an interval of 1 min or longer when no gun had fired (or an interval of at least 2 min if vessel speed was $\leq$3 knots).

Line Changes.—In 2001, the source vessel generally continued firing its full array during line changes to avoid the need to go through a ramp-up sequence at the start of the next line. Occasionally, the interval between array firings was increased to almost 1 min during line changes, and then decreased to the nominal 12 to 24 s once the next shot line was reached.

Shutdown Criteria.— The IHA required that the permittee "Immediately shut-down the seismic sources whenever any ringed, bearded, or spotted seal [or cetacean] enters, or is about to enter", its respective safety zone. Safety radii applicable at different times depended on the depth of the airguns below the surface, and type of marine mammal (Table 2.3). The safety zones were based on an assumption that seismic pulses at received levels below 190 dB re 1 μPa for seals or below 180 dB re 1 μPa for cetaceans are unlikely to affect hearing abilities, but that higher received levels might have some such effects. These 190 and 180 dB re 1 μPa levels are measured on a root mean square (rms) basis over the duration of the seismic pulse (Greene et al. 1997, 1998).

WesternGeco's IHA Application for 2001 (LGL 2001) proposed conservative (i.e., generally over-estimated) shutdown criteria based on precedents from prior years and measurements of sounds from the 1210 in^3 array in 1999 (Greene et al. 2000).

TABLE 2.3. Safety radii used by WesternGeco in 2001 for 320 in^3 and 1210 in^3 sleeve-type airgun arrays operating at different airgun depths. These values are from Table 1 of the 2001 NMFS IHA (Appendix A), which were based on previous LGL and Greeneridge recommendations. Actual 190 and 180 dB distances were generally less than the nominal designated distances.

Source (in^3)	Operating Depth of Airgun Array (m / ft)	Water Depth (m / ft)	Safety Radii (m / ft) 190 dB (Seals)	Safety Radii (m / ft) 180 db (Whales)
1210	2.3 / 7.5	<10 / <32.8	100 / 328	150 / 492
1210	2.3 / 7.5	>10 / >32.8	160 / 525	550 / 1804
1210	5.0 / 16.4	<10 / <32.8	160 / 525	350 / 1148
1210	5.0 / 16.4	>10 / >32.8	260 / 853	900 / 2953
320	1.0 / 3.3	<10 / <32.8	100 / 328	150 / 492
320	1.0 / 3.3	>10 / >32.8	160 / 525	550 / 1804

The IHA issued by NMFS in 2001 (Appendix A) specified particular shutdown distances, and called for shutdowns when seals and whales entered, or were about to enter, the designated safety zones (Table 2.3). When more than one airgun (but less than the full array) was operated, the safety radius applicable for the full array was used – a precautionary approach.

The intention of the shutdown criteria was to minimize any possibility of hearing damage to marine mammals (e.g., Richardson et al. 1995). It is recognized that, at least among bowhead whales, avoidance and other disturbance reactions can occur at received sound levels considerably lower than the shutdown criteria (see Chapter 1, INTRODUCTION). Also, some seals have been observed to show disturbance reactions at distances exceeding the shutdown radii. Disturbance to small numbers of seals, bowhead, beluga and gray whales was authorized under the provisions of the IHA issued to WesternGeco for this project (Appendix A).

Shutdown Implementation.—Whenever the marine mammal monitor(s) or other personnel in the wheelhouse sighted a marine mammal within the safety radius, the gunners were notified immediately by ship intercom and the airguns were shut off. The airguns were shut off within several seconds after a seal was sighted inside the safety radius. Given the normal shot interval of about 12 to 24 s, there typically was either no shot or no more than one shot between the time the seal was seen and the time when the shutdown took effect. Although observers were located on the bridge ahead of the center of the airgun array on the *Arctic Star* (Fig. 2.1, 2.11), the shutdown criterion was based on distance from the observer(s) rather than from the array—a conservative approach. This added 45 m (150 ft) to the anterior aspect of the effective safety radii on the *Arctic Star*. The bridge was close to, and overlooked, the center of the array on the *Peregrine* (Fig. 2.1).

Procedures after shutdown varied. Sometimes the source vessel turned away from the marine mammal and initiated a circle of about 300 to 400 m in diameter. About half way around the circle, a ramp-up of the airguns was begun. This timing was selected so that, with a normal ramp-up schedule and no further marine mammal sightings, the full array would be shooting by the time the vessel returned to the point on the source line where the shutdown had occurred. At that point, the vessel resumed the original course along the source-line.

On other occasions, the vessel continued along the source line after shutting down the airguns, and resumed firing when the marine mammal was out of the safety radius. This necessitated not firing the airguns at several of the pre-planned shot-points, which were at 50 m intervals. These "missed" points were sometimes shot at a later time.

When another seal sighting occurred within the safety radius during a shutdown, the shutdown continued until no seals were known to be within the safety zone.

Fewer seals were seen within the safety radii during airgun operations in 2001 (10 shutdowns) than during 1996 or 1998 when, respectively, 112 and 57 shutdowns occurred (Harris et al. 2001; Lawson and Moulton 1999). The 2001 shutdowns were similar in number to those in 1997 (12; Harris et al. 1998), 1999 (10; Moulton and Lawson 2000), and 2000 (14; Moulton and Lawson 2001). The shorter operating season in 2001 was partly responsible for the low number of shutdowns in 2001, as was the shallow water depth and inshore location of the operational area. The 2001 results for seals are described in Chapter 3.

In 2001, observers aboard the source vessels saw no whales during periods either while the airguns were operating or at other times. Therefore, as in 1999 and 2000, no shutdowns for whales were required in 2001. There had been no shutdowns for whales during Western's 1998 and 1999, or BP's 1996, seismic operations, and one shutdown for a bowhead whale in 1997 (Miller et al. 1997, 1998, 1999).

2.3.3 Field Reports

Throughout the seismic program, the vessel-based marine mammal monitoring team prepared weekly reports summarizing the numbers of seals and whales sighted during periods with and without seismic shooting, the distances of these animals from the airguns, and the apparent reactions (if any) to the vessel and/or airguns. These reports were sent via electronic mail to the NMFS Western Alaska Field Office, Anchorage, with follow-up telephone contact as necessary to discuss any questions or concerns.

2.4 Acknowledgements

This study was conducted for WesternGeco LLC and funded by BP Exploration (Alaska) Inc. We thank Peter Van Borssum and John Davis of WesternGeco for their support and assistance during the planning phase. The Captains and crews of the *Peregrine* and *Arctic Star* were again very supportive and cooperative during these monitoring activities. Doug Wyer kindly answered questions regarding operational procedures, and supported the LGL marine mammal monitoring effort at sea. Curt Schneider (WesternGeco, Anchorage) answered our questions regarding seismic operations, navigation, and data formats. We thank Allan Ross and Gwen Perrin at BP Exploration (Alaska) for funding the project and subsequent analyses.

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Additional general acknowledgements relevant to the project as a whole are included at the end of Chapter 1.

2.5 Literature Cited

Greene, C.R., Jr, with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements [1996]. p. 3-1 to 3-63 *In:* W.J. Richardson (ed., 1997, *q.v.*).

Greene, C.R., Jr., R. Norman and J.S. Hanna, with R.W. Blaylock. 1998. Physical acoustics measurements [1997]. p. 3-1 to 3-66 *In:* W.J. Richardson (ed., 1998, *q.v.*).

Greene, C.R., Jr., and W.C. Burgess, with R. Norman and R.W. Blaylock. 2000. Physical acoustics measurements, 1999. p. 3-1 to 3-45 *In:* W.J. Richardson (ed., 2000, *q.v.*).

Harris, R.E., G.W. Miller, R.E. Elliott and W.J. Richardson. 1997. Seals [1996]. p. 4-1 to 4-42 *In:* W.J. Richardson (ed., 1997, *q.v.*).

Harris, R.E., A.N. Balla-Holden, S.A. MacLean and W.J. Richardson. 1998. Seals [1997]. p. 4-1 to 4-54 *In:* W.J. Richardson (ed., 1998, *q.v.*).

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17(4):795-812.

Kidd, G.D. 1999. Fundamentals of 3-D seismic volume visualization. **Sea Technol.** 40(9, Sept.):19-23.

Lawson, J.W. 1999. Seismic program described [1998]. p. 2-1 to 2-25 *In*: W.J. Richardson (ed., 1999, *q.v.*).

Lawson, J.W. 2000. Seismic program described, 1999. p. 2-1 to 2-21 *In*: W.J. Richardson (ed., 2000, *q.v.*).

Lawson, J.W. 2001. Seismic program described, 2000. p. 2-1 to 2-25 *In*: W.J. Richardson (ed., 2001, *q.v.*).

Lawson, J.W. and V.D. Moulton. 1999. Seals [1998]. p. 4-1 to 4-69 *In*: W.J. Richardson (ed., 1999, *q.v.*).

LGL. 2000. Request by Western Geophysical for an Incidental Harassment Authorization to allow the incidental take of whales and seals during an open-water seismic program in the Alaskan Beaufort Sea, summer-autumn 2000. Submitted February 2000 by Western Geophysical, Anchorage, AK, to Nat. Mar. Fish. Serv., Silver Spring, MD, and Anchorage, AK; prepared by LGL Ltd., King City, Ont. 75 p.

LGL. 2001. Request by WesternGeco for an Incidental Harassment Authorization to allow the incidental take of whales and seals during an open-water seismic program in the Alaskan Beaufort Sea, summer-autumn 2001. Submitted April 2001 by WesternGeco, Anchorage, AK, to Nat. Mar. Fish. Serv., Silver Spring, MD, and Anchorage, AK; prepared by LGL Ltd., King City, Ont. 77 p.

LGL and Greeneridge. 2001. Marine mammal and acoustic monitoring plan for WesternGeco's 2001 open-water seismic program, Alaskan Beaufort Sea. LGL Rep. TA2564-1. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Anchorage, AK. 57 p.

Madtson, E.A. and J.I. Sanders. 1999. OBC: multicomponent seafloor seismic exploration. **Sea Technol.** 40(9, Sept.):25-33.

Miller, G.W., R.E. Elliott, W.R. Koski and W.J. Richardson. 1997. Whales [1996]. p. 5-1 to 5-115 *In:* W.J. Richardson (ed., 1997, *q.v.*).

Miller, G.W., R.E. Elliott and W.J. Richardson. 1998. Whales [1997]. p. 5-1 to 5-124 *In:* W.J. Richardson (ed., 1998, *q.v.*).

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton and W.J. Richardson. 1999. Whales [1998]. p. 5-1 to 5-109 *In:* W.J. Richardson (ed., 1999, *q.v.*).

Moulton, V.D. and J.W. Lawson. 2000. Seals, 1999. p. 4-1 to 4-58 *In*: W.J. Richardson (ed., 2000, *q.v.*).

Moulton, V.D. and J.W. Lawson. 2001. Seals, 2000. p. 4-1 to 4-50 *In*: W.J. Richardson (ed., 2001, *q.v.*).

Rayson, M. 1997. Ocean bottom seismic surveying. **HYDRO Intern.**, August, pp. 49-51.

Richardson, W.J. (ed.). 1997. Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. vii + 245 p.

Richardson, W.J. (ed.). 1998. Marine mammal and acoustical monitoring of BP Exploration (Alaska)'s open-water seismic program in the Alaskan Beaufort Sea, 1997. LGL Rep. TA2150-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xx + 318 p.

Richardson, W.J. (ed.). 1999. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xx + 390 p.

Richardson, W.J. (ed.). 2000. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1999. LGL Rep. 2313-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. xiii + 155 p.

Richardson, W.J. (ed.) 2001. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 2000. [Draft, April 2001.] LGL Rep. TA2424-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 133 p.

Richardson, W.J., C.R. Greene Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Stone, C.J. 1998. Cetacean observations during seismic surveys in 1997. JNCC Rep. 278. Joint Nature Conserv. Commit., Aberdeen, Scotland. 55 p. + Appendices.

Stone, C.J. 2000. Cetacean observations during seismic surveys in 1998. JNCC Rep. 301. Joint Nature Conserv., Aberdeen, Scotland. 62 + appendices.

3. SEALS, 2001[1]

3.1 Introduction

3.1.1 Status of Seals in the Area

Three species of seals occur in the area where WesternGeco's open-water seismic surveys were conducted during July and August of 2001. Ringed seals, *Phoca hispida*, are year-round residents in the Beaufort Sea and are the most consistently encountered of the seals in the project area. Bearded seals, *Erignathus barbatus*, are also distributed widely in the region, but in lower numbers. Spotted seals, *Phoca largha*, are uncommon in the Prudhoe Bay area, as this is the northeasternmost edge of their range.

Ringed Seal.—The population of ringed seals in the Bering-Chukchi-Beaufort area has been estimated to contain 1.0 to 1.5 million seals, but this estimate is not considered reliable (Kelly 1988; Angliss et al. 2001). There are an estimated 80,000 seals in the Beaufort Sea during summer and 40,000 during winter (Frost and Lowry 1981). The Alaska stock of ringed seals is not classified as a "strategic stock" (as defined in the Marine Mammal Protection Act). The world-wide population of ringed seals is estimated at 2.3 to 7 million (Stirling and Calvert 1979; Angliss et al. 2001).

During winter, ringed seals occupy the landfast ice and offshore pack ice of the Bering, Chukchi, and Beaufort seas (and elsewhere in the Arctic). In winter and spring, the highest densities of ringed seals are found on stable shore-fast ice. However, in some areas with limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice exceed those on fast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). Using their claws, ringed seals maintain breathing holes in the ice and lairs in accumulated snow (Smith and Stirling 1975). Ringed seals give birth in these lairs beginning in late March and nurse their pups for five to eight weeks. The highest densities of breeding ringed seals occur in areas of landfast ice. Mating occurs in late April and May.

During summer, ringed seals are found dispersed throughout open-water areas, although in some regions they move into coastal areas. In the eastern Beaufort Sea and Amundsen Gulf, ringed seals concentrate in similar offshore areas from one year to the next and are often found in large groups (Harwood and Stirling 1992). It appears that these concentrations are found in areas of greater food abundance that may be related to oceanographic features. Similar summer concentrations have not been reported in the central and western Beaufort Sea. Ringed seals encountered there during open-water seismic activities were broadly dispersed as individuals or small groups (Harris et al. 1997, 1998, 2001; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001). Their local distribution and density during late summer and autumn are poorly documented, so numbers within the operational area at these seasons are not known specifically. Ringed seals are significant predators of small fish and zooplankton. The ringed seal is the principal prey of polar bears (Stirling 1974; Kingsley 1990), and is important to other predators such as the arctic fox (Smith 1976).

In addition to local movements in response to seasonal changes in ice conditions, there may be large-scale movements of ringed seals into and out of the Beaufort Sea. Smith and Stirling (1978) described a westward migration of subadult seals in the eastern Beaufort Sea prior to autumn freeze-up, and a small number of long-distance movements of marked individuals have been documented. Recent informa-

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