

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

Prepared by



for

WesternGeco, LLC

351 East International Airport Rd., Anchorage, AK 99518

BP Exploration (Alaska) Inc.

900 East Benson Blvd., Anchorage, AK 99519-6612

and

National Marine Fisheries Service

Anchorage, AK, and Silver Spring, MD

LGL Report TA2564-4

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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 μ Pa (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 in³ (as had also been used in 1999 and 2000), and an 8-airgun array with total volume 320 in³. Acoustic measurements to document levels, characteristics, and propagation of underwater sounds emitted by the 1210 in³ 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 in³ 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 in³ 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 in³ airgun array composed of 16 identical 40-in³ 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-in³ 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 in³. 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 in³, which was towed by the *Arctic Star*. In this larger array, individual airgun volumes ranged from 40 in³ to 150 in³, including two 2 × 150 in³ 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-in³ 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 in³) operated for 71.3 hours and the “small array” (normally 8 guns totaling 320 in³) 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 $\mu\text{Pa}_{\text{rms}}$) 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 $\mu\text{Pa}_{\text{rms}}$) radius around the operating airgun array were detectable by vessel-based observers. For the 320 in³ array, the conservatively-estimated 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$ radii were 15 m for airgun operations in <10 m water depth, and 50 m for >10 m water depth. For the 1210 in³ 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 μ Pa (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. INTRODUCTION¹

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 in³ in volume as was used in 1999 and 2000; a 16-gun, 1500 in³ 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 in³. 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 in³) 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"

¹ By W. John Richardson and John W. Lawson, LGL Ltd., environmental research associates.

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 in³ 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

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 (Jollies [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 μ Pa, and that pinnipeds and small odontocetes should not be exposed to levels above 190 dB re 1 μ Pa (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 μ Pa, 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 μ Pa rms, and that pinnipeds should not be exposed to levels above 190 dB re 1 μ Pa (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 in³ and 1210 in³ 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 in³ 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 in³ 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 in³ 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 in³ 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, off-shore 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 in³ 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 in³ 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 $\mu\text{Pa}_{\text{rms}}$, 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 in³ 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 bow-head 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 in³ 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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- BP Exploration (Alaska) Inc. (A. Ross, C. Bailey, Dr. R. Jakubczak, D. Trudgen),
- Greeneridge Sciences (Dr. C. Greene, Dr. S. Blackwell),
- 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),
- North Slope Borough (Dr. T. Albert),
- WesternGeco (D. Nyland, P. Van Borssum).

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Additional "Acknowledgements" concerning the sections on characteristics of the seismic program, and seals appear near the ends of, respectively, Chapters 2 and 3.

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2. SEISMIC PROGRAM DESCRIBED, 2001¹

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 in³ volume and totaling 640 in³, deployed from the *Peregrine* (see §2.2.4). Following initial tests at 640 in³, this array was operated thereafter at half volume (8 airguns for a total of 320 in³). In addition, a second, larger array of 12 sleeve-type airguns of various individual volumes totaling 1210 in³ 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 in³ 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 in³ (Greene et al. 1997). Testing of the 640 in³ 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 in³ 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 μ Pa_{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 in³) 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 in³ 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.

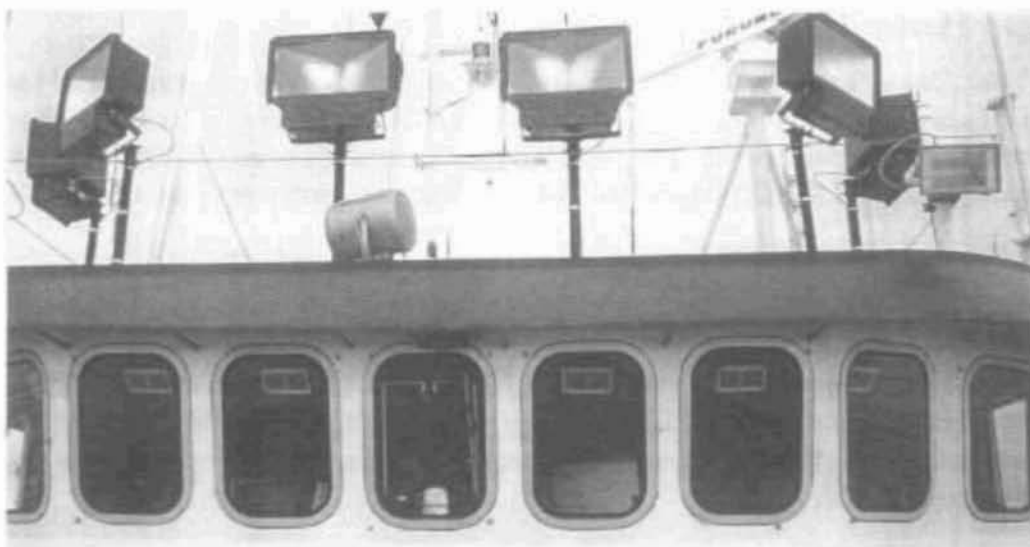


FIGURE 2.4. Six broad-beam, 1000-Watt floodlights above the bridge of the R/V *Arctic Star* (1999 photograph by J. Lawson, LGL).



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 in³ Array.—During its 2001 OBC seismic operations in the Beaufort Sea, WesternGeco employed half of a 640 in³ 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 in³ 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 in³) were fired during production seismic operations, the active array volume was actually 320 in³.

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 in³ 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).

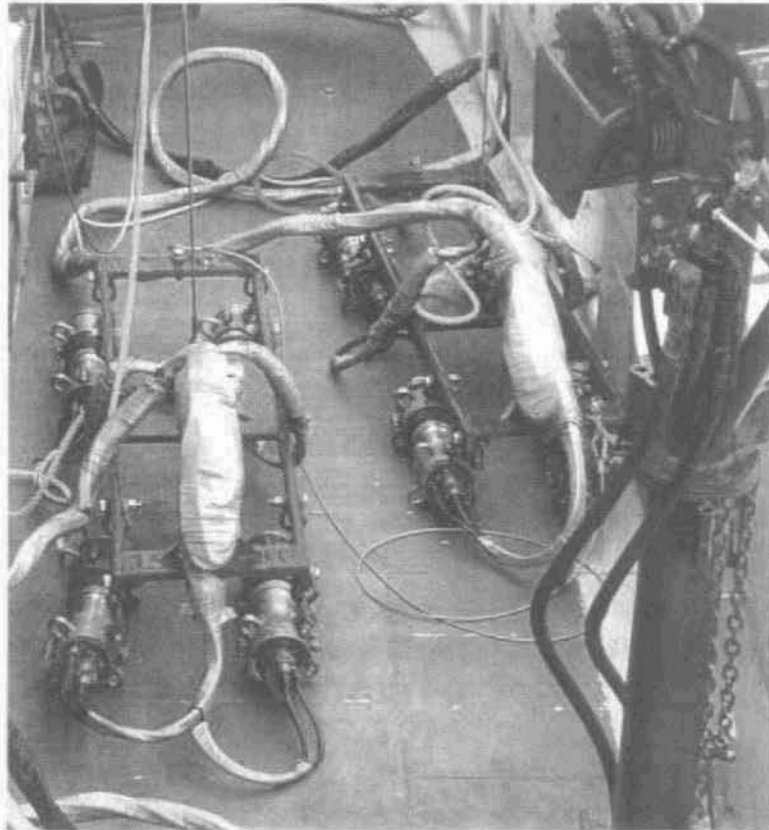


FIGURE 2.8. View of two 4-airgun clusters that formed half of the 320 in³ airgun array deployed from the *Peregrine* in 2001 (photograph by J. Lawson, LGL). The gray tape covers and protects the high-pressure umbilical cables, which provided air pressure and firing control for each 40 in³ airgun.

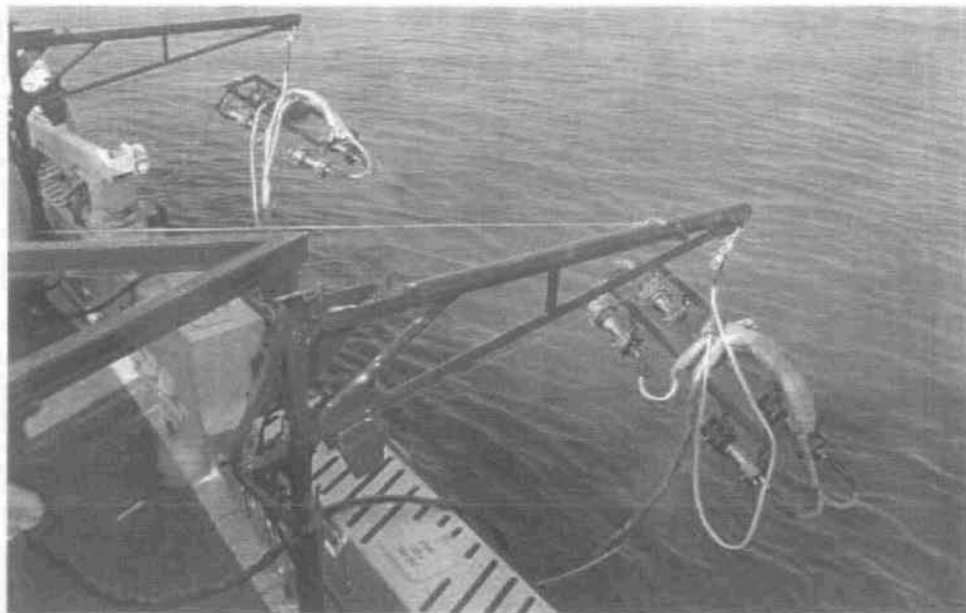


FIGURE 2.9. Starboard pair of 4-airgun clusters that formed half of the 320 in³ airgun array deployed from the *Peregrine* in 2001 (photograph by J. Lawson, LGL). The square steel frames, suspended from the two davits kept the airguns positioned at the correct water depth and spaced precisely.

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 in³ array (see below), the airguns were oriented horizontally.

The 320 in³ 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 in³ 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 in³. The volumes of the individual guns varied from 40 in³ at the port-side rear corner of the array to pairs of 150 in³ 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).

² The 1500 in³ array used in 1998 and the 1210 in³ 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).

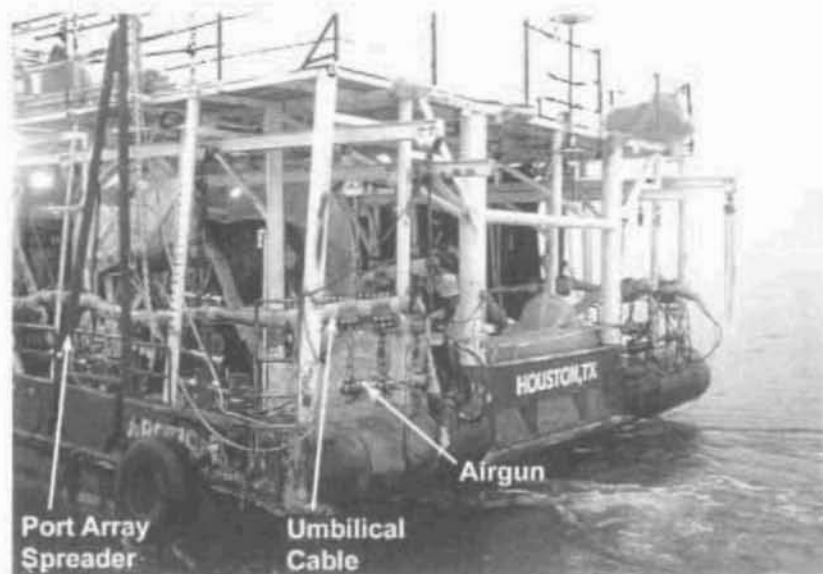


Figure 2.10. The 1210 in³ airgun array stowed aboard the R/V *Arctic Star* (photograph by J. Lawson, LGL). The airgun umbilicals can be seen hung from chain supports, as well as the array floats and the airguns themselves.

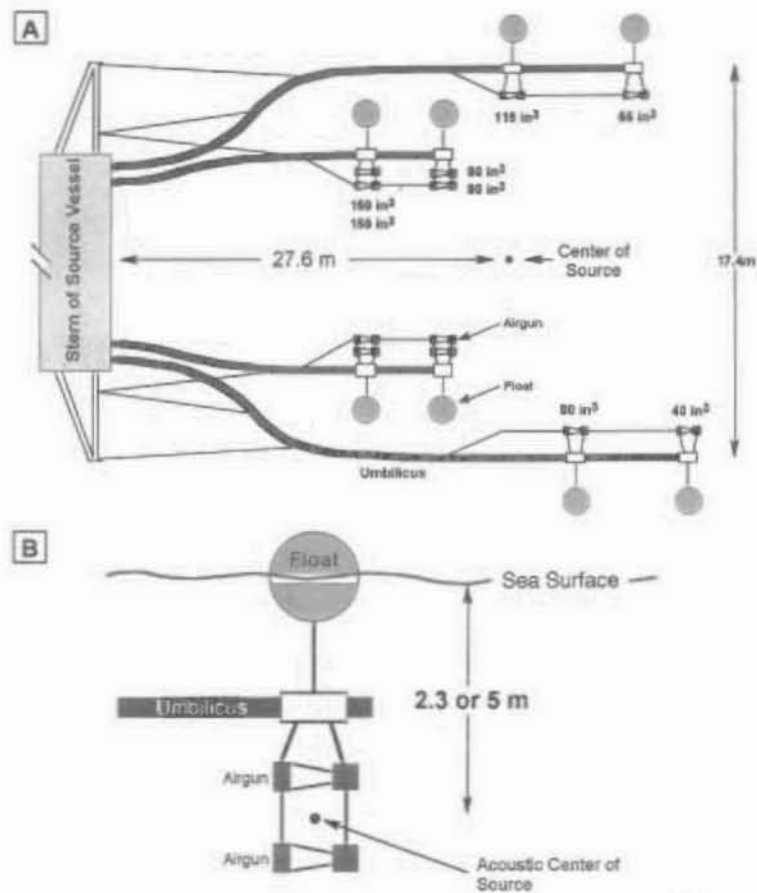


FIGURE 2.11. Schematic diagrams of (A) the asymmetrical 12-gun, 1210 in³ airgun array towed by the R/V *Arctic Star* in 1999-2001, and (B) a pair of 150 in³ guns in the anterior portion of the array showing how the gun depth was measured.

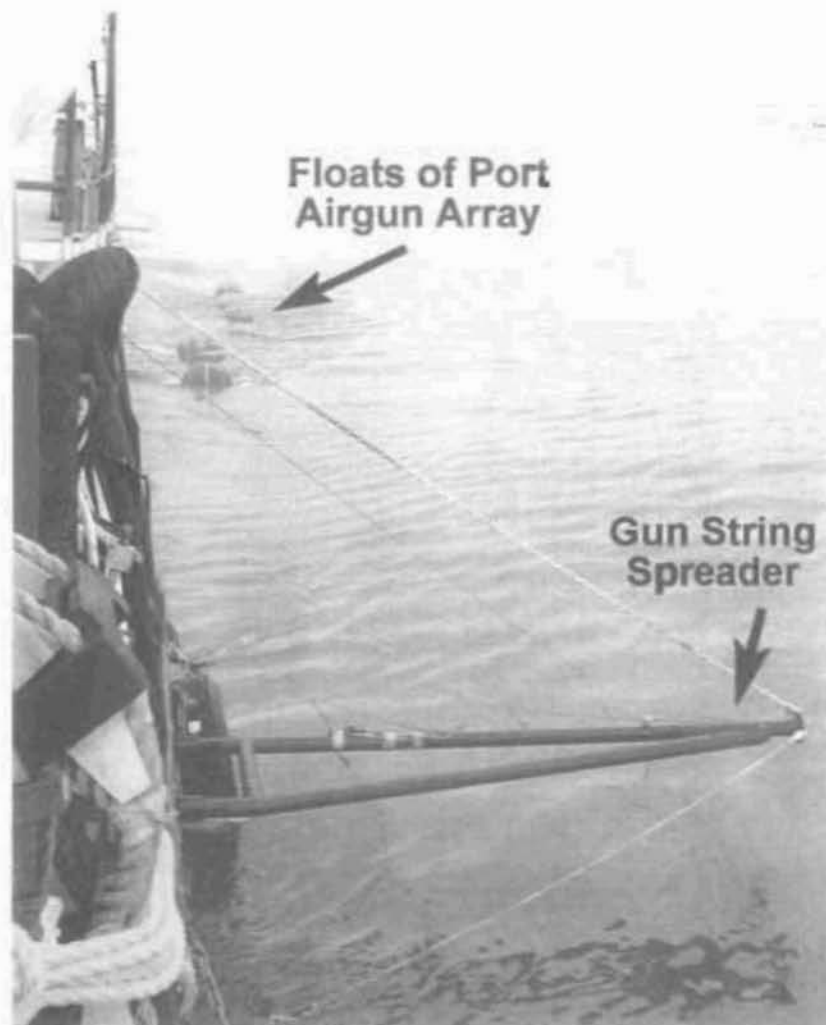


FIGURE 2.12. Horizontal spacing of the airguns was ensured by cable harnesses attached to two towing booms ("gun string spreaders"), which extended out from either side of the R/V *Arctic Star* during seismic operations. The floats of the port side of the airgun array can be seen in the water astern 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 Air-gun Operation ^b
1996	24 July to 19 Sept	<i>Point Barrow</i> (tug)	1320	11	4	355	-	-	2946
			120	1	-	-	-	98	834
1997	26 July to 25 Sept	<i>Sag River, Point Thompson</i> (tugs)	720	6	2.5	-	221	-	1544
			(810 briefly)	90	1	3	-	-	13.5
1998	24 July to 11 Oct	<i>Arctic Star</i>	1500	16 ^c	2.3 to 5	561.6	-	-	3380
		<i>Saber Tooth</i>	560	8 ^c	2	-	78	-	1180
1999	23 July to 1 Sept	<i>Arctic Star</i>	1210	12	2.3 to 5	227.6	-	-	2175
2000	29 July to 28 Aug	<i>Arctic Star</i>	1210	12	2.3	368.3	20.6	-	2465
	29 July to 28 Aug	<i>Arctic Star</i>	40 ^d	1	2.3	-	78.8 ^d	-	-
2001	2 to 26 August	<i>Peregrine</i>	320 ^e	16	1.0	-	161.6	-	787
	7 to 18 August	<i>Arctic Star</i>	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 In³ and the 16-airgun array totaled 1500 In³; one airgun on the *Saber Tooth* equaled 70 In³ (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 In³ 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 In³ 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 In³; and the 16-airgun array totaled 640 In³. However, after initial testing of the 16-gun 640 In³ array, only half of the array volume was used during seismic production (8 airguns totaling 320 In³).

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.

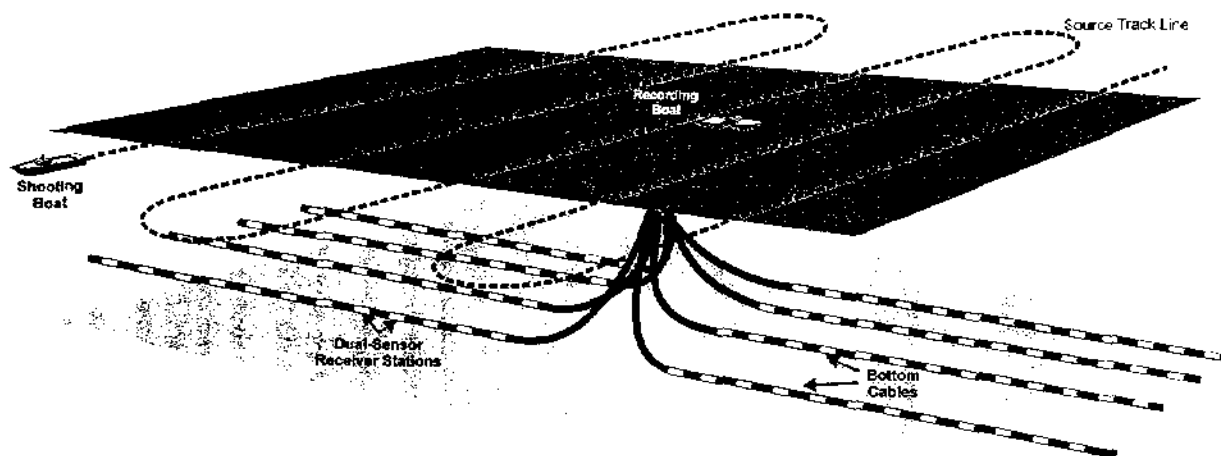


FIGURE 2.13. Three-dimensional representation of the four OBC receiver lines in a typical seismic patch operated by WesternGeco in the Beaufort Sea. As in 1999-2000, the airgun sources were towed back and forth across the receiver cables along shot lines oriented perpendicular to the receiver lines.

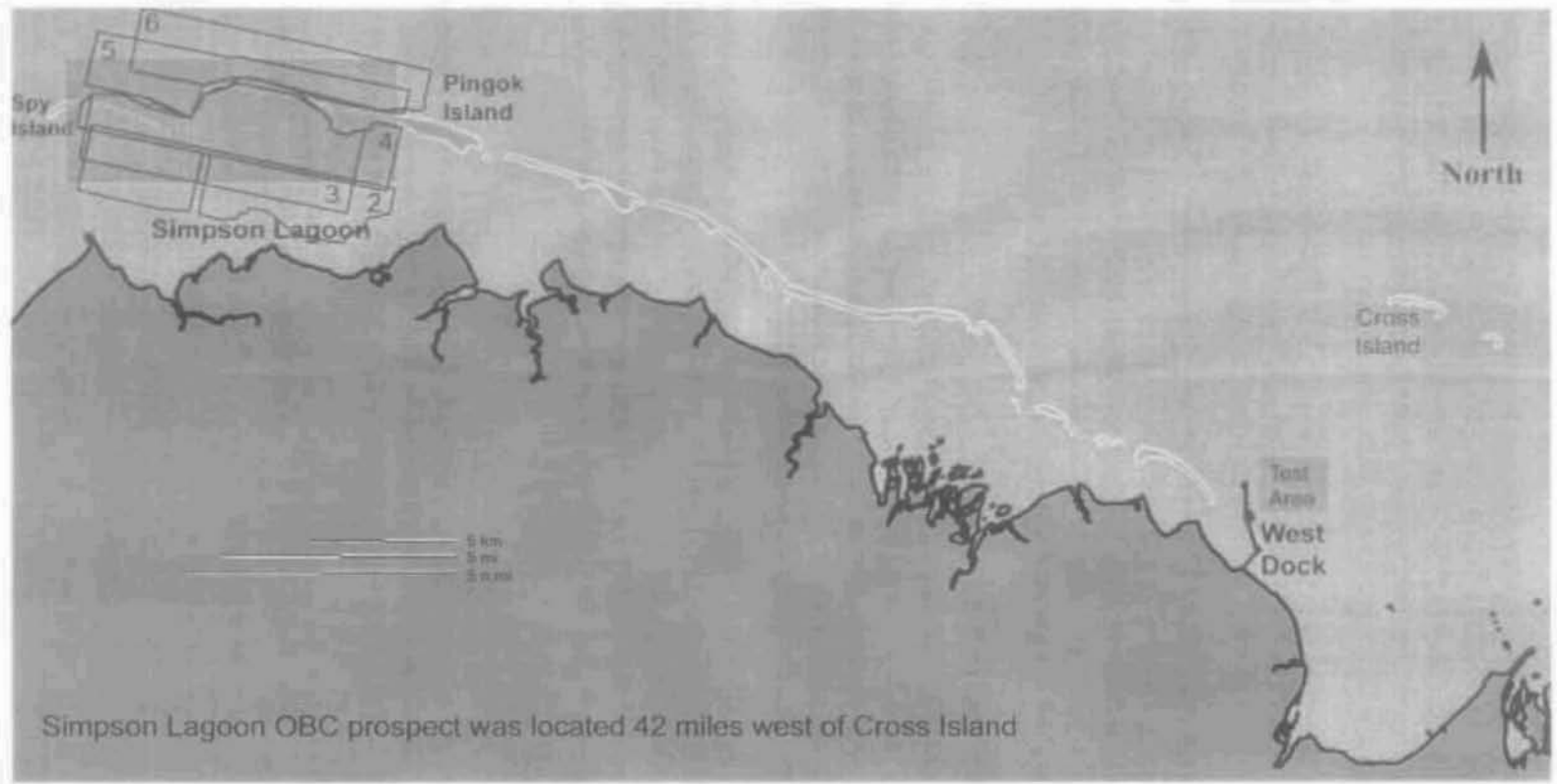


FIGURE 2.14. Map indicating the locations of the five OBC seismic patches (labeled 2-6) in the Alaskan Beaufort Sea surveyed by WesternGeco during the 2001 open-water season. Source lines associated with each patch extended outside the "receive" patch locations shown here (see Fig. 2.13). A small area 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	<i>Peregrine</i>	2.7
3	21-24 August	<i>Peregrine</i>	3.2
4	17-21 August	<i>Peregrine, Arctic Star</i>	3.3
5	13-18 August	<i>Arctic Star</i>	7.3
6	7-12 August	<i>Peregrine, Arctic Star</i>	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 μ Pa (rms) from the operating airgun array(s).

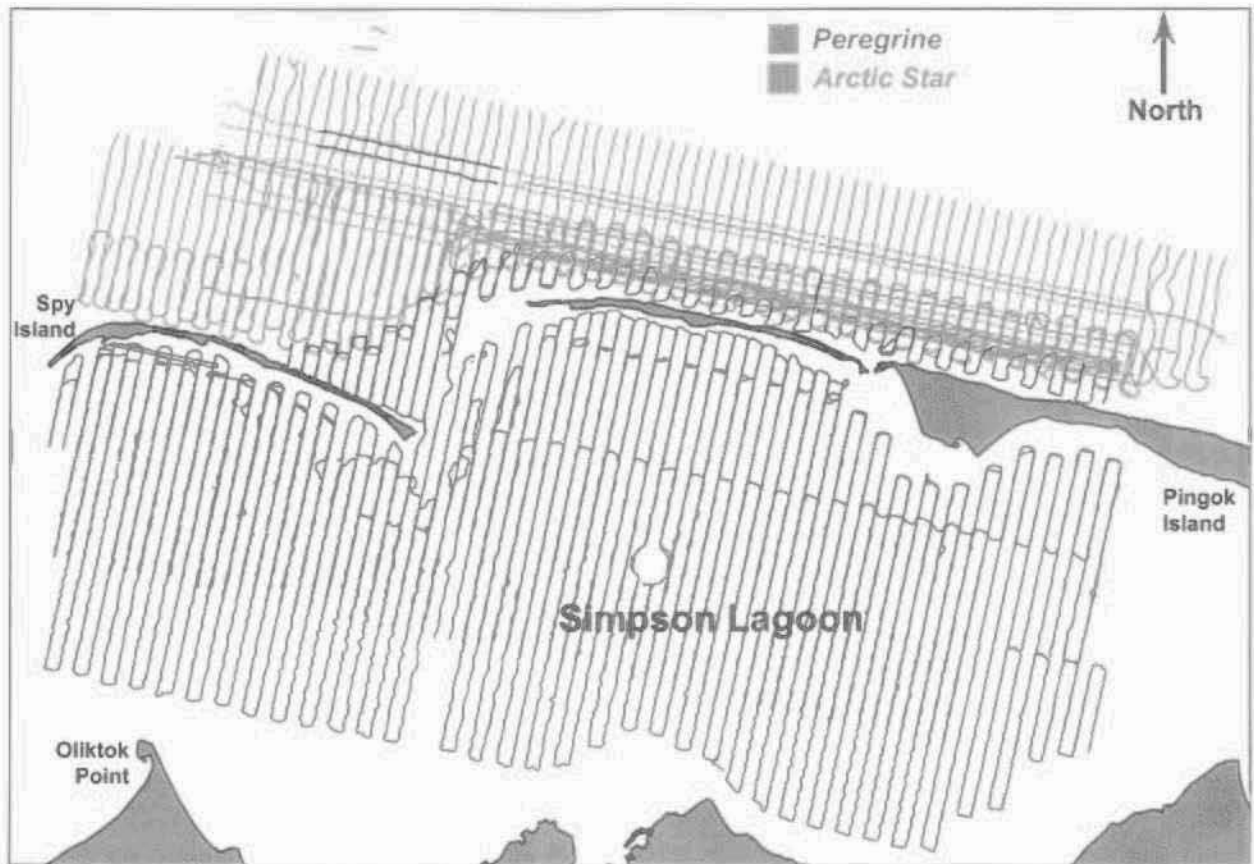


FIGURE 2.15. Seismic lines shot by the *Peregrine* (8-gun 320 in³ array, green lines) and *Arctic Star* (12-gun 1210 in³ array, red lines) during WesternGeco's 2001 seismic operations in Simpson Lagoon.

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 observers³ 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 in³ for the 1,210 in³ airgun array and 40 in³ for the 640 in³ airgun array.” Ramp-ups were done by commencing firing with a single 40 or 80 in³ 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 in³ volume array employed in 1999-2001, and the 320 in³ 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 in³ volume, ramp-up began with an 80 in³ airgun. For both the 1210 in³ and 320 in³ 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 ≤ 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 μ Pa for seals or below 180 dB re 1 μ Pa 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 μ Pa 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 in³ array in 1999 (Greene et al. 2000).

TABLE 2.3. Safety radii used by WesternGeco in 2001 for 320 in³ and 1210 in³ 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		Safety Radii (m / ft)	
	of Airgun Array (m / ft)	Water Depth (m / ft)	190 dB (Seals)	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 air-

guns 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.

Ted Elliott (LGL, King City) provided the patch map and a variety of operational statistics. We thank Bill Burgess (Greeneridge Sciences Inc.) for a photograph used in this chapter.

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

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3. SEALS, 2001¹

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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tion gathered from satellite tags deployed on four subadult ringed seals in Amundsen Gulf supports this suggestion (L. Harwood, DFO, pers. comm.; www.permafrost.com/seals). Shortly after tags were deployed in mid-September 2001, all four ringed seals migrated west; three seals with functioning tags migrated along the north coast of Alaska and traveled >3500 km in a six week period. After reaching Point Barrow, one seal crossed the Chukchi Sea, another moved northwest toward Wrangel Island, and the third seal moved through the Bering Strait to St. Lawrence Island before moving back north. However, the nature and extent of these movements are not well understood (Smith 1987; Kelly 1988).

Bearded Seal.—The Alaska stock of bearded seals, which occupies the Bering, Chukchi, and Beaufort seas off Alaska, may consist of about 300,000 to 450,000 individuals (MMS 1996). However, Angliss et al. (2001) indicate that, “Until additional surveys are conducted, reliable estimates of abundance for the Alaska stock of bearded seals are considered unavailable.” Nevertheless, the Alaska stock of bearded seals is not classified by NMFS as a strategic stock.

The bearded seal is the largest of the northern phocids. It is primarily a bottom feeder and usually prefers areas where the water is less than 200 m (656 ft) deep. However, bearded seals apparently also feed on ice-associated organisms when they are present; a few bearded seals have been found in areas with ice in water depths much greater than 200 m.

Seasonal movements of bearded seals are directly related to the advance and retreat of sea ice and to water depth. As the ice recedes in spring, bearded seals that have overwintered in the Bering Sea migrate northward through the Bering Strait. During the summer most are found near the widely-fragmented margin of multi-year ice covering the continental shelf of the Chukchi Sea and over the continental shelf of the Beaufort Sea. In the Beaufort Sea, bearded seals usually do not use coastal haul-out sites.

Spotted Seal.—An early estimate of the size of the world population of spotted seals was 370,000 to 420,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000 to 250,000 animals (Bigg 1981). The total number of spotted seals in Alaskan waters is not known, but probably is in the tens of thousands (Rugh et al. 1997; Angliss et al. 2001). The Alaska stock of spotted seals is not classified as a strategic stock by NMFS (Angliss et al. 2001).

During spring, when pupping, breeding, and molting occur, spotted seals are found along the southern edge of the sea ice in the Okhotsk and Bering seas (Quakenbush 1988; Rugh et al. 1997). In late April and early May, adult spotted seals are often seen on the ice in female-pup or male-female pairs, or in male-female-pup triads. Subadult seals may be seen in larger groups of up to 200 animals. During the summer, spotted seals are found primarily in the Bering and Chukchi seas, but some range into the Beaufort Sea (Rugh et al. 1997). At this time of year, an unknown proportion of those in the Beaufort Sea haul out on mainland beaches and offshore islands and bars. In summer, they are rarely seen on the pack ice, except when the ice is very near to shore. Spotted seals are commonly seen in bays, lagoons, and estuaries. As the ice cover thickens with the onset of winter, these seals leave the northern portions of their range and move into the Bering Sea.

A few spotted seal haul-outs occur in the central Beaufort Sea in the deltas of the Colville and (at least formerly) the Sagavanirktok rivers. Historically these sites supported as many as 400 to 600 seals, but in recent times <10 seals have been seen at any one site. A few spotted seals haul out at locations as far east as Demarcation Bay on the Alaska/Yukon border (Impact Assessment Inc. 1990). In total, there are probably no more than a few tens of spotted seals along the coast of the central Beaufort Sea during summer and early fall. Numbers identified during previous vessel-based seismic monitoring programs in the central Alaskan Beaufort Sea during 1996 to 2000 have ranged from 0 to 4 per season (Moulton and Lawson 2000, 2001).

3.1.2 Previous Data on Seal Reactions to Seismic Activities

Until recently, few data on the reactions of pinnipeds to open-water seismic exploration have been available (Richardson et al. 1995, p. 291). However, monitoring studies in the Beaufort Sea and elsewhere during the past five years have provided considerable observational information. Pinnipeds undoubtedly can hear seismic pulses, given what is known about their hearing abilities (Richardson et al. 1995, p. 211, 357; Kastak and Schusterman 1998). Pinnipeds (mainly California sea lions, *Zalophus californianus*) observed during a seismic program off southern California in 1995 reportedly showed variable reactions; some individuals avoided, some approached, and some did not react overtly (Arnold 1996). More systematic data were obtained during BP's 1996-97 and Western Geophysical's 1998-2000 seismic projects in the Beaufort Sea (Harris et al. 1997, 1998, 2001; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001). Those studies found no strong difference in the behavior of seals in the presence or absence of seismic but did find that seals usually avoided the area around the vessel during seismic operations (or perhaps changed their behavior so that they were less likely to be detected when near the seismic operations). In the U.K., short-term behavioral changes in harbor seals (*Phoca vitulina*) and gray seals (*Halichoerus grypus*) exposed to airgun pulses have been reported (Thompson et al. 1998). This 2001 WesternGeco project augments what is known about the behavior of seals exposed to pulses of noise from an airgun array (see §3.3, later).

Little is known about the possibility that exposure to strong noise pulses might result in temporary or permanent effects on hearing sensitivity of pinnipeds. Richardson et al. (1995, p. 366) summarized the limited available data on the auditory effects of seismic and other pulsed sounds on pinnipeds. Kastak et al. (1999) describe Temporary Threshold Shift (TTS) in seals exposed to moderate-level steady sounds, but there are no published data on TTS caused by exposure of pinnipeds to impulse sound. In dolphins, as in terrestrial mammals, the level of sound necessary to cause TTS is inversely related to the duration of exposure (Finneran et al. 2000); this is probably true in seals as well (Schusterman et al. 2000). NMFS considers that the maximum level of impulse sounds to which pinnipeds should be exposed is 190 dB re 1 μ Pa on a rms basis, i.e., averaged over the duration of a pulse (NMFS 2000).

3.1.3 Monitoring Objectives

The overall tasks for the 2001 marine mammal and acoustic monitoring program are described in Chapter 1, INTRODUCTION (§1.3.1). The tasks that pertained specifically to seals, as specified in the Monitoring Plan for 2001 (LGL and Greeneridge 2001), were as follows:

- "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."
- "Evaluate the effects of the 2001 seismic program on the distribution and movements of ... 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."

The overall monitoring objectives are described in §1.3.2. The objectives that pertained specifically to seals, as specified in the final Monitoring Plan, were as follows:

- “Determine the distributions, behaviors, seasonal timing, and abundance indices 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.”
- “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.”
- “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...”
- “Determine the nature of the takes..., and under what circumstances (e.g., distance, sound exposure levels, signal-to-ambient ratios) they occurred.”
- “Determine whether the 2001 seismic program had unmitigated adverse effects on the accessibility of ... marine mammals to subsistence hunters.”

Section 6(b)(5)(a) of the IHA (Appendix A) included the following wording to specify the types of information about seals (and other marine mammals) that should be included in this report:

“Vessel-based monitoring will include recording the following information in a standardized format: (a) the species, group size, age/size/sex categories (if determinable), behavior at time of sighting, heading (if consistent), bearing and distance from seismic source vessels, sighting cue, and apparent reaction of all marine mammals seen to the seismic source vessel and/or its acoustic sources...”

This report documents the results of the 2001 vessel-based monitoring program. It also summarizes the combined results concerning seals from the 1996-97 (BP) and 1998-2001 (Western Geophysical/WesternGeco) seismic programs. The multiyear data substantially increase sample sizes and provide an improved basis for assessing the effects of open-water seismic operations on arctic seals.

The final Monitoring Plan listed the following three null hypotheses regarding seismic effects on seals, and called for these hypotheses to be tested based on the combined 1996-2001 results:

- “There is no difference in the occurrence and extent of localized displacement of seals relative to the source vessel during periods with or without airgun operations, or in relation to acoustic characteristics of the airgun array.”
- [There are no differences in] “...numbers of seals in the local area around the seismic vessel during periods with or without airgun operations, or in relation to the seals’ distance from the sound source or its acoustic characteristics.”
- “There is no difference in seals’ behavior during periods with or without airgun operations, or in relation to the seals’ distance from the sound source or its acoustic characteristics.”

Information obtained in 2001 on these topics is summarized in this report. These hypotheses are addressed in detail in this report based on combined 1996-2001 data.

3.1.4 Operational Overview, 2001

In 2001, WesternGeco’s primary source vessel, the *Peregrine*, deployed an array of 16 airguns with a total volume of 640 in³. With the exception of 0.6 h of seismic testing involving the use of the full 640 in³ array, all of the production seismic (154.0 h) was conducted with only half of this array in operation —

320 in³. Hence, the array operated by the *Peregrine* is referred to hereafter as having a volume totaling 320 in³. Alternating with the *Peregrine*, the second source vessel, *Arctic Star*, towed an array of 12 airguns with total volume 1210 in³—the same airgun array as had been used by *Arctic Star* in 1999-2000. Chapter 2 describes the 2001 seismic surveys.

Greene and Burgess (2000) describe airgun pulses emitted by the 1210 in³ airgun array, and review the acoustic characteristics of airgun arrays used in previous years. More recently, Greene (in prep.) has provided revised estimates of the “190 dB radii” for each airgun array used in the 1996-2001 seismic programs. These revised 190 dB radii were (when possible) based upon acoustical measurements of sounds from the specific arrays in question, supplemented by statistical derivations for situations in which direct acoustical measurements were not available. The revised radii account for array depth, water depth, number of airguns, and array volume. These new 190 dB radii are used in the analyses in this chapter (with the exception of §3.4) but were not applied in the field. During each year’s fieldwork, the then-defined safety radii were used in determining when the airguns should be shut down because seals were within or near the then-defined safety radii (see §3.2.2).

Observers aboard the source vessels *Peregrine* and *Arctic Star* watched for seals (and other marine mammals, including whales, polar bears, and walrus) at all times while airgun operations were underway. Observers also watched for seals and other marine mammals during the 30-min periods preceding startup of airgun operations, and at some other times without airgun operations. When seals were seen within, or “about to enter”, defined 190 dB (re 1 $\mu\text{Pa}_{\text{rms}}$) “safety zones” based upon the best available estimates at the time (see Table 3.2, later), the airgun array was immediately shut down, as required by section 5(b) of the IHA (Appendix A). Chapter 2 (§2.3.2) provides more details on procedures. The shutdowns were designed to minimize the possibility that seismic pulses would affect the hearing abilities of seals close to the seismic vessel. Also, the observers documented the numbers, distribution around the source vessel, and behavior of seals seen at times with and without seismic operations. During periods when the airguns were about to start operating, and at some other times as well, two observers were on duty simultaneously. This allowed a further comparison of the effectiveness of one vs. two observers in detecting seals within and near the safety radius.

3.2 Methods

3.2.1 Vessel-Based Monitoring

The vessel-based monitoring procedures for 2001, as described below, were similar to those described in Moulton and Lawson (2000, 2001) and Lawson and Moulton (1999) for monitoring the effects of Western Geophysical’s 1999-2000 OBC seismic programs on seals. The few important differences between the 2001 and the 1998-2000 studies are mentioned.

Daytime Observation Procedures.—Five observers were assigned to the two WesternGeco source vessels at all times during the 2-26 August 2001 period of airgun operations. These observers included three biologists whose qualifications had been submitted in advance to NMFS, plus two Inupiat observer-communicators. Observers were rotated periodically over the duration of the project. At any given time, most or all observers, including the Inupiat, had considerable prior experience with marine mammal observations and vessel-based seismic monitoring. There were generally three observers aboard *Arctic Star* and two aboard *Peregrine*. Space limitations precluded having a third observer on the *Peregrine*. Instead, as required in provision 6(b)(4) of the IHA (Appendix A), the bridge crew had a significant role in assisting the two marine mammal observers (MMOs) aboard that vessel in maintaining 24-h observation coverage.

Observation work aboard the *Peregrine* and *Arctic Star* was scheduled by 24-h period, broken into 4-h watches. Each observer was responsible for two 4-h watches per day that interdigitated with those of the other observer(s). Observers were on watch for no more than 4 h at a time, and whenever possible there were two observers on duty concurrently. Two-observer watches were required by the IHA during startup of airgun operations, but were also conducted at some other times in order to increase the probability of detecting seals, and to compare seal sightability with one vs. two observers. Overall, during 2001 there was one observer on duty for 54.0% of the observation time on the *Peregrine* and for 65.3% of the observation time on *Arctic Star*. Two observers were on duty for 46.0% and 34.7% of the time (including startups and some other periods) on the *Peregrine* and *Arctic Star*, respectively. The percentage of time with two observers on duty on the *Arctic Star* was lower in 2001 than in 1999 (34.6% vs. 41.2%) but higher than in 2000 (20.8%). Three observers were assigned to the *Arctic Star* in 2001, as compared with four observers in 1999 and 2000. In 1999-2000, when four observers were aboard, three observers had the same watch schedule each day while the fourth advanced the start of his or her first watch by 1 h per day.

At all times while airgun operations were underway, or when they were expected to begin within the next 30 min, the on-duty observer(s) watched continuously for marine mammals. Observations were made from the glass-enclosed wheelhouses of the *Peregrine* and the *Arctic Star* – the highest suitable vantage points. Eye level was about 5.2 m (17.1 ft) above the water on the *Peregrine*, and about 5.6 m (18.4 ft) above the water on the *Arctic Star*. The wheelhouse on the *Peregrine* offered an almost unrestricted view completely around the vessel, while the wheel-house of the *Arctic Star* afforded a wide view (see §2.2.1), but with partial obstructions to lateral and rearward vision. Observers moved about the vessels' bridges and frequently viewed to the stern of the vessel by looking through the side windows, or (in the case of the *Arctic Star*) by stepping out onto the outside port or starboard wings of the bridge as required to scan the waters around the vessel.

Observers scanned the water surface around the vessel using 7 × 50 Fujinon FMTRC-SX binoculars as optical instruments during daytime. The binoculars included a reticle to measure depression angle relative to the horizon—an indicator of distance. The compass built into these binoculars was not useful on the metal source vessels, but directional information was readily available in the wheelhouse on color monitors displaying Differential GPS course and speed information.

Although it was not useful in directly measuring distances to seals, observers employed a Bushnell Yardage Pro 400 or 800 laser rangefinder with 4× optics to test and improve their abilities to visually estimate distances to objects in the water. These Class 1 eye-safe devices were very useful in improving distance estimation abilities by checking practice estimates. The devices could measure distances to highly reflective objects such as other vessels as much as 600 m (1970 ft) away.

Nighttime Observation Procedures.—During early August, there were no periods of total darkness, and normal visual observations were possible during all hours when shooting was underway. Thereafter the periods of darkness increased such that, by the end of the 2001 airgun operations on 26 August, there were about 5.5 h of total darkness each night. Frequently, seismic operations continued at night or in periods of poor visibility, and WesternGeco was fully in compliance with the NMFS IHA when doing so. Monitoring personnel were on duty during all nighttime periods while the airgun array was active, and when the guns were expected to start operating within the next 30 min. At night, observers used both the binoculars and night vision devices (NVDs). The NVDs were IIT F5000 Series binocular Night Vision Viewers with Generation 3 technology and up to 6× optics. Lights in the wheelhouses of the source vessels were dimmed to improve the effectiveness of the NVDs (and observers' night vision), although the glare caused by the reflection of the floodlights off the vessel superstructures reduced NVD and visual effectiveness nonetheless.

As a measure to improve observers' ability to sight marine mammals during darkness, six broad-beam, 1000-Watt floodlights (see Fig. 2.4) were installed on *Arctic Star* in 1999 and again used in 2001. The floodlights extended the range out to which there was sufficient light to detect objects with the NVDs. The floodlights illuminated up to 100 m (328 ft) in front of and to the sides of the vessel in clear conditions (often <100 m in fog). The same was generally true for the large crab lights mounted high on the bow of the *Peregrine* (see Fig. 2.1). Vessel lights adequately illuminated the safety zone for seals (radius 100 m) when the 320- or 1210 in³ arrays were deployed at 1 or 2.3 m depth in shallow waters, but did not fully illuminate the larger safety zones applicable to deeper waters or to whales. Notwithstanding the use of the NVDs and the floodlights, the observers' abilities to detect marine mammals were severely reduced at night, and no marine mammals were sighted during the lengthening nights towards the end of August in 2001. (During our seismic monitoring work in 1996-2000, only two seals were seen at night.)

Data Recorded.—While on watch on each source vessel, the marine mammal observers kept systematic written records of the seismic activity and environmental conditions. Additional data were recorded when marine mammals were observed. For all records, the date, time, and observer(s) on duty were recorded. Source vessel position (latitude, longitude) and environmental conditions were recorded manually at the start and end of each source line, or when operational conditions changed. Environmental conditions also were recorded when they changed, and with each marine mammal record. Latitude, longitude, and information about seismic activity were available from the computer monitor in the wheelhouse. Operational activities that were recorded included the patch number being shot, the number of guns in use, the total volume of the air guns in use, and the type of seismic activity—ramping-up, source line shooting, seismic testing, between-line shooting (“line changes”), shutdowns, and other. Environmental conditions that were recorded included ice cover within about 1 km (0.5 n.mi.) of the seismic source vessel (percent cover, primary type), wind force (Beaufort Scale), visibility (km), obstructions to visibility (e.g., snow, fog, darkness), and glare (severity and width on clock face). Standardized codes were used for most of these records, but written descriptive comments were usually added as well.

The positions of the source vessel and all other vessels assisting with the seismic operations were logged automatically every 2 min by the WesternGeco's navigation system. These data files were provided to LGL and used when detailed position information was required.

For each marine mammal sighting, the following information was recorded: species, number of individuals seen, sighting cue, behavior when first sighted, behavior after initial sighting, heading, bearing, distance, behavioral pace, substrate type (in water or on ice), and seismic status. Vessel positions at times of seal sightings were determined from the navigational data (see above). If marine mammals other than seals had been sighted (did not occur in 2001), the position of the source vessel would have also been recorded manually.

The following description of the data recorded for each marine mammal sighting is limited to items relevant for seals. No whales or polar bears were seen from the source vessel in 2001.

The “Sighting Cue” was the feature that initially drew the observer's attention to the seal. These cues included the head or body visible above the water's surface, or a splash resulting from a seal's dive.

Several standardized behavior categories were used. “Behavior 1” was the behavior of the seal when sighted initially, and “Behavior 2” was the behavior observed subsequently. Behavior categories that applied to seals were “sink”, “front dive”, “thrash”, “unspecified dive”, “look”, “swim”, and “other” (with description). “Sink” referred to seals that simply sank, tail first, straight back down underwater from an upright posture. Seals that “front dove” went below the surface head-first. Seals that “thrashed” plunged below the surface head-first in an extremely vigorous way, often accompanied by a splash.

"Unspecified dive" was recorded when it was not known in what manner the seal dove. For analyses, however, the categories "sink", "front dive", "thrash", and "unspecified dive" were grouped into a broader behavioral category called "dive". Seals that "looked" floated at the surface and faced the source vessel. The "swim" category was recorded when the seal was swimming along the surface of the water.

A "Movement Category" was assigned to the behavior type to describe the general direction in which the seal appeared to be moving as it performed the behavior. Seals could be coded as "swimming toward", "swimming away", "swimming parallel", or "fleeing" (a particularly vigorous form of swimming away). Seals that "milled" swam sedately in a limited area with no consistent direction of movement. If it was possible to continue making observations of a seal after the initial sighting, this was done. To aid in subsequent analysis, a brief written description of the seal's behavior and the circumstances of the sighting usually was made, time permitting.

In 2001, as in 1999 and 2000, first and second "Substrate" categories were used to describe the location where the seal was first sighted and the location to which it subsequently moved, if it moved. Substrates could be coded as "water", "ice", or "land". For example, a ringed seal seen first on an ice pan that then went into the water would have "T" entered under the "First Substrate" and "W" in the "Second Substrate". If the seal remained on the ice, there would be two "T" entries. In practice, during 2001 there were no sightings of seals on ice pans.

A subjective assessment was made of the rate ("Pace") at which the seal performed the behavioral act. Seals that appeared to be relatively relaxed or were moving slowly were coded as "sedate". Seals that appeared to be agitated, moved frantically, or dove or moved rapidly away from the source vessel were classed as "vigorous". Seals that behaved at a medium rate (i.e., neither sedately nor vigorously) were classed as "moderate". The "Pace" variable was first used in 1998, and could not be derived retroactively from the data that had been recorded for most 1996 and 1997 seal sightings. The "moderate" pace category was added in 1999 and was not used for the 1998 data.

The seal's direction of movement ("Heading") and initial position relative to the vessel ("Bearing") were recorded by reference to the vessel's heading. Directions relative to the vessel were estimated as hours on a clock face; "1 o'clock", for example, was 30° off the vessel's trackline to starboard.

"Radial Distance" of the seal from the source vessel was estimated visually. In addition, there was usually sufficient time to estimate distance more accurately using the reticle binoculars. The distance and bearing to the seal were measured from the wheelhouse, which was ~55 m (180 ft) ahead of the airguns towed by *Arctic Star*. On the *Peregrine*, the bridge overlooked the center of the array, which was deployed from amidships on both sides of the vessel. During observations, distance estimates made using the binoculars were rounded to the nearest reticle. Due to the nature of the optical system in the reticle binoculars, reticle estimates were more precise for seals sighted closer to the vessel than for those farther away.

All of the above data were entered onto custom paper datasheets, after which the field observers entered data into a computer-based database (Microsoft Excel in 1999-2001) while still in the field. Computer keypunching was done during periods when seismic operations were suspended or at other times when an observer was not on watch. The database prevented entry of out-of-range values and codes. The crew leaders verified data entries manually by comparing listings of the computerized data with the original handwritten datasheets both in the field and upon later analyses. A validation program written in Visual BASIC 5.0 was also applied after the field season as a further check for potential errors in the database.

Shutdown Procedures.—The procedures that were followed when a marine mammal was sighted within the safety radius are given in Chapter 2 (see §2.3.2, "Mitigation Measures"). For seals, the safety

radii around the 320 in³ and 1210 in³ arrays were defined by NMFS in the IHA issued in 2001 to WesternGeco. These radii were based on precautionary estimates of the distances within which received levels of seismic pulses (below the surface) would diminish below 190 dB re 1 μ Pa (rms):

- For the 320 in³ array operating in water depths <10 m, the specified safety radius for seals was 100 m (328 ft) for an airgun depth of 1 m.
- For the 320 in³ array operating in water depths >10 m, the specified safety radius for seals was 160 m (525 ft) for an airgun depth of 1 m.
- For the 1210 in³ array operating in water depths <10 m, the specified safety radii for seals were 100 m (328 ft) for airgun depth approx. 2.3 m, and 160 m (525 ft) for airgun depth 5 m (not used in 2001).
- For the 1210 in³ array operating in water depths >10 m, the specified safety radii for seals were 160 m (525 ft) for airgun depth approx. 2.3 m, and 260 m (853 ft) for airgun depth 5 m (not used in 2001).

On most occasions, the actual received level at the edge of the defined safety zone was less than 190 dB, as these radii were estimated based on a precautionary approach (i.e., usually overestimated). Also, received levels of seismic pulses at and near the surface are less than those at depth (Greene and Richardson 1988). Thus, seals seen in the outer part of the safety zone would not have been exposed to 190 dB unless they dove.

When the airguns were operating, the observer(s) determined, from the distance estimate, whether the seal was within, or about to come within, the safety radius. If so, the observer instituted the shutdown provisions described in §2.3.2. Distance was determined from the observer's position. Because the observer was ~55 m ahead of the airgun array on the *Artic Star* the safety radii were conservative (by a margin of ~55 m) when marine mammals were sighted ahead of this vessel, as they usually were.

In 2001, there were no seismic operations with array depth >2.3 m, and the majority were in water depths <10 m. In all five OBC patches surveyed in 2001, the source lines were predominantly in water <10 m deep (Fig. 2.14). However, source lines extended into water as much as 12.2 m (40 ft) and 13.7 m (45 ft) deep at the northern edges of patches 5 and 6, respectively. Given the overall conservative nature of the safety radii (see above and §3.5) and the predominance of depths <10 m in all patches, the radii listed in the IHA for waters >10 m deep were used only at the northern ends of these particular lines (J. Eddington, pers. comm.). Descriptions of the arrays and safety radii applicable in 1996-2001 for airgun arrays of various sizes operating at different depths are listed in Tables 3.1 and 3.2, based on Harris et al. (1997, 1998), Lawson and Moulton (1999), and Moulton and Lawson (2000, 2001).

Updated Safety Radii Used During Analyses.—During some analyses (see §3.3.3) we classified the distance estimates for seals sighted around the source vessel relative to the position within or beyond the safety radii. As in our reports on the 1998-2000 monitoring work, we used four distance categories: the "Near Half" of the safety radius, "Far Half", "1-2 Times", and ">2 Times". The applicable distances for these four categories in 1996-2001 are listed in Table 3.3. As already mentioned, the safety radii used in analyses are revised estimates of the 190 dB re 1 μ Pa_{rms} distances as provided by Greene (in prep.).

3.2.2 Aerial Surveys

Because there were no seismic operations after 1 September in 2001, WesternGeco's 2001 monitoring project did not include site-specific aerial surveys. In accordance with the Monitoring Plan (LGL and Greeneridge 2001), aerial surveys would have occurred during any periods of seismic operation in September or October 2001 if seismic operations had continued in those months.

TABLE 3.1. Seismic categories and airgun array characteristics for open-water seismic operations in the Beaufort Sea in 1996 to 2001.

Seismic Category	Depth of Guns (m) ^a	Airgun Array Characteristics									
		1996		1997		1998		1999-2000		2001	
		Array Size (in ³)	No. of Airguns	Array Size (in ³)	No. of Airguns	Array Size (in ³)	No. of Airguns	Array Size (in ³)	No. of Airguns	Array Size (in ³)	No. of Airguns
Large Array	<2.5 m	960-1320	8-11	^b	7	1200-1500	14-16	1050-1210	10-12	1210	12
	≥2.5 m	"	"	"	"	"	"	"	"	-	-
Small Array	<2.5 m	240-840	2-7	>180-≤840	2-6	560	8	-	-	320	8
	≥2.5 m	"	"	"	"	"	"	-	-	-	-
Single Gun	Variable	120	1	90	1	80, 70 ^c	1	40-80	1	1	40 ^d , 80 ^d
Ramp-up		120-1320	1-11	90-840	1-6	80-1500, 70-560 ^c	1-8, 1-16 ^c	80-1210	1-12	40-80	1

^a Standard operating depths were 3.5 m in 1996, 3 m in 1997, 2.3 and 5 m in 1998 and 1999, 2.3 m in 2000, and 1 m (*Peregrine*) and 2.3 m (*Arctic Star*) in 2001.

^b The "Small Array" category included arrays totaling 180 to 840 in³. During 1997, the maximum array size was a "Small Array" of 6 airguns totaling 720 in³ (aside from 1 hour of operations with a 810 in³ 6-airgun array and 1 min of operations with a 900 in³ 7-airgun array).

^c In 1998, one airgun on the *Arctic Star* (used only at the start of ramp-up) equaled 80 in³ and the 16-airgun array totaled 1500 in³; one airgun on the *Saber Tooth* equaled 70 in³ (used only at the start of ramp-up) and the 8-airgun array totaled 560 in³.

^d In 2001, one airgun on the *Peregrine* equaled 40 in³ (used only at the start of ramp-up) and the 8-airgun array totaled 320 in³; one airgun on the *Arctic Star* (used only at the start of ramp-up) equaled 80 in³ and the 12-airgun array totaled 1210 in³.

TABLE 3.2. Seismic categories, airgun array operating depth, water depth, and respective safety radii used in the field and in final analyses for open-water seismic operations in the Beaufort Sea in 1996 to 2001. Updated radii for "Final Analyses" are from Greene (in prep.).

Year	Seismic Category	Source (in ³)	Operating Depth (m)	Water Depth (m)	Safety Radii (m) (190 dB)	
					Field	Final Analyses
A. 2001	Large Array	1210	2.3	<10	100	50
	Large Array	1210	2.3	>10	160	150
	Small Array	320	1	<10	100	15
	Small Array	320	1	>10	160	50
B. 2000	Large Array	1210	2.3	<10	90	50
	Large Array	1210	2.3	>10	90	150
	Single Gun ^a	40, 55, 80	2.3	<10	22	40
	Single Gun ^a	40, 55, 80	2.3	>10	22	40
C. 1999	Large Array	1210	2.3	<10	80/90	50
	Large Array	1210	2.3	>10	80/90	150
	Large Array	1210	5	<10	240	80
	Large Array	1210	5	>10	240	230
D. 1998	Large Array	1500	2	<10	200	155
	Large Array	1500	2	>10	200	480
	Large Array	1500	5	<10	350	230
	Large Array	1500	5	>10	350	640
	Small Array	560	2	<10	170/460 ^b	470
	Small Array	560	2	>10	170/460 ^b	1330
E. 1997	Small Array ^c	720	3	<10	130/160 ^d	300
	Small Array	720	3	>10	130/160 ^d	510
	Small Array	720	<2.5	<10	130/160 ^d	250
	Small Array	720	<2.5	>10	130/160 ^d	420
	Single Gun	90	3	<10	60	50
	Single Gun	90	3	>10	60	50
F. 1996	Large Array	1320	3.5	<10	150/250 ^e	370
	Large Array	1320	3.5	>10	150/250 ^e	420
	Small Array	240-840	3.5	<10	150/250 ^e	150
	Small Array	240-840	3.5	>10	150/250 ^e	340
	Single Gun	120	3.5	<10	150	65
	Single Gun	120	3.5	>10	150	65

^a A single 40-80 in³ airgun (primarily a 40 in³) was used during some standby periods in 2000.

^b A safety radius of 170 m was used until 30 Aug 1998; then a 460 m radius was used based on field measurements.

^c During 1997, the maximum array size was a "Small Array" of 6 airguns totaling 720 in³ (aside from 1 hour of operations with a 810 in³ 6-airgun array and 1 min of operations with a 900 in³ 7-airgun array).

^d A safety radius of 130 m was used until 29 Aug 1997; then a 160 m radius was used based on field measurements.

^e A safety radius of 150 m was used until 30 Aug 1996; then a 250 m radius was used based on field measurements.

TABLE 3.3. Updated safety radius categories used for analyses of seal sightings from seismic source vessels in 1996-2001. In all cases, the safety radii have been updated based on recent re-analyses of the acoustical measurements obtained in 1996-2000 by Greeneridge Sciences (Greene in prep.).

	Seismic Category	Operating Depth (m)	Water Depth (m)	Safety Radius (m)	Updated Safety Radius Category (m)			
					Near Half	Far Half	1-2 Times	> 2 Times
A. 2001	Large Array	2.3	<10	50	≤25	26-50	51-100	>100
	Large Array	2.3	>10	150	≤75	76-150	151-300	>300
	Small Array	1	<10	15	≤8	9-15	16-30	>30
	Small Array	1	>10	50	≤25	26-50	51-100	>100
B. 2000	Large Array	2.3	<10	50	≤25	26-50	51-100	>100
	Large Array	2.3	>10	150	≤75	76-150	151-300	>300
	Single Gun	2.3	<10	40	≤20	21-40	41-80	>80
	Single Gun	2.3	>10	40	≤20	21-40	41-80	>80
C. 1999	Large Array	2.3	<10	50	≤25	26-50	51-100	>100
	Large Array	2.3	>10	150	≤75	76-150	151-300	>300
	Large Array	5	<10	80	≤40	41-80	81-160	>160
	Large Array	5	>10	230	≤115	116-230	231-460	>460
D. 1998	Large Array	2	<10	155	≤78	79-155	156-310	>310
	Large Array	2	>10	480	≤240	241-480	481-960	>960
	Large Array	5	<10	230	≤115	116-230	231-460	>460
	Large Array	5	>10	640	≤320	321-640	641-1280	>1280
	Small Array	2	<10	470	≤235	236-470	471-940	>940
	Small Array	2	>10	1330	≤665	666-1330	1331-2660	>2660
E. 1997	Small Array	3	<10	300	≤150	151-300	301-600	>600
	Small Array	3	>10	510	≤255	256-510	511-1020	>1020
	Small Array	<2.5	<10	250	≤125	126-250	251-500	>500
	Small Array	<2.5	>10	420	≤210	211-420	421-840	>840
	Single Gun	3	<10	50	≤25	26-50	51-100	>100
	Single Gun	3	>10	50	≤25	26-50	51-100	>100
F. 1996	Large Array	3.5	<10	370	≤185	186-370	371-740	>740
	Large Array	3.5	>10	420	≤210	211-420	421-840	>840
	Small Array	3.5	<10	150	≤75	76-150	151-300	>300
	Small Array	3.5	>10	340	≤170	171-340	341-680	>680
	Single Gun	3.5	<10	65	≤33	34-65	66-130	>130
	Single Gun	3.5	>10	65	≤33	34-65	66-130	>130

3.3 Monitoring Results

3.3.1 Survey Effort

2001 Operations.—Marine mammal observers were on watch at all times during 2001 when the airguns were operating, and during many periods when the source vessel was underway but not shooting seismic. The numbers of hours of observation per week varied according to the schedule of seismic and other vessel operations. Watches were conducted during daylight and, in mid-late August, during darkness too. The hours of survey effort in 2001, categorized by week, seismic category, and daylight vs. darkness, are summarized in Table 3.4. The hours of survey effort shown in Table 3.4 were used to calculate the numbers of seals observed per hour, as reported later in this chapter.

TABLE 3.4. Weekly survey effort in 2001: the number of hours of observation from the *Peregrine* and *Arctic Star* by marine mammal observers. Effort is categorized by week, seismic category, and daylight vs. darkness periods.

Seismic State	Hours of Observation During Weeks 1-4				Total	%
	Week One 2 Aug - 9 Aug	Week Two 10 - 16 Aug	Week Three 17 - 23 Aug	Week Four 24 - 26 Aug		
Daylight						
No Guns	24.7	20.9	34.3	5.2	85.1	25.5
Small Array	9.5	41.0	67.7	33.0	151.2	45.4
Large Array	19.7	38.7	12.9	-	71.3	21.4
Ramp-up	4.8	2.6	2.7	0.3	10.3	3.1
Testing	12.8	1.3	1.3	-	15.4	4.6
Total	71.6	104.4	118.9	38.4	333.4	
Darkness						
Small Array	-	-	-	2.8	2.8	100.0
Large Array	-	-	-	-	-	
Total	0	0	0	2.8	2.8	
Overall						
No Guns	24.7	20.9	34.3	5.2	85.1	25.3
Small Array	9.5	41.0	67.7	35.8	154.0	45.8
Large Array	19.7	38.7	12.9	-	71.3	21.2
Ramp-up	4.8	2.6	2.7	0.3	10.3	3.1
Testing	12.8	1.3	1.3	-	15.4	4.6
Total	71.6	104.4	118.9	41.2	336.2	

Note: The *Peregrine* deployed a "small array" of 16 airguns totaling 640 in³, but of these only half were operated for a total of 320 in³; these guns fired at 1 m below the surface. The *Arctic Star* towed a "large array" of 12 airguns totaling 1210 in³, firing at 2.3 m below the surface.

Observation hours during 2001 totaled 336.2 h. The great majority of these marine mammal watches were conducted during daylight (333.4 h in daylight vs. 2.8 h in darkness). More observation effort occurred during periods of airgun operations, including full array, ramp-up, and testing, than during non-seismic periods (251.0 h with airgun[s] operating vs. 85.1 h without).

Survey effort varied from week to week, depending primarily on the effect that ice conditions and sea state had on the seismic operator's ability to conduct seismic work. Minimal survey effort occurred during week 4 (41.2 h) because seismic operations were limited to a three-day period. The maximum number of observation hours per week occurred during weeks 2 and 3 (Table 3.4). Seismic production ended on 26 August 2001.

Most production seismic operations by the *Peregrine* in 2001 involved the use of eight airguns with a volume totaling 320 in³. Most production seismic operations by the *Arctic Star* in 2001, as in 1999-2000, involved the use of 12 airguns with volumes totaling 1210 in³. Harris et al. (1997, 1998) categorized array size in 1996-97 as "small array" (≤ 840 in³) and "large array" (> 840 in³, Table 3.1). According to these criteria, during production seismic work in 2001, *Peregrine* operated with a small array and *Arctic Star* with a large array. Combined, the *Peregrine* and *Arctic Star* spent 10.3 h ramping-up and 15.4 h testing airguns (Table 3.4).

Combined 1996-2001 Operations.—For 1996, 1997, 1998, 1999 and 2000, survey effort by week is described in Harris et al. (1997, 1998) Lawson and Moulton (1999), and Moulton and Lawson (2000, 2001), respectively. Table 3.5 summarizes survey effort for 1996-2001, categorized by daylight vs. darkness, and by seismic state. Overall, survey effort in 2001 was less than during most recent years (0.5× that in 1996, 0.8× that in 1997, 0.4× that in 1998, 1.2× that in 1999, and 0.8× that in 2000). Airgun operations ended earlier in the season in 2001 (26 Aug.), 2000 (28 Aug.), and 1999 (1 Sept.) than in 1996-98. A large array (>840 in³) was used for the majority of the production seismic work in 1996 and 1998, and for all of that in 1999 and 2000. Small arrays (≤840 in³) were used for a minority of the work in 1996 and 1998, a majority of the work in 2000, and for essentially all production seismic work in 1997. Single-gun OBRL shooting (Ocean Bottom Receiver Localization) was much more common in 1996 than in 1997; there were no single-gun OBRL operations in 1998-2001. However, in 2000 a single gun or a small array was often used when the vessel was standing-by. The proportion of total observation time that occurred during ramp-up and testing was similar during all six years, although relatively little time was spent testing airguns in 1997 and 1999. The proportion of time spent observing during periods with “no guns operating” was similar in 1996 to 1999, and 2001, but was much lower in 2000.

The timing and total duration of seismic operations varied from year to year because of varying technical or logistical problems plus interannual variation in ice and meteorological conditions. Drifting pack ice was much more prevalent in 1996, 1999, and 2000 than in 1997, 1998, and 2001. This had effects both on the total number of observation hours and on the number of seals observed (see §3.3.1 and 3.3.2). In 2001, some ice occurred near (seaward of) the barrier islands early in the season but it moved offshore after the first week of operations. There was no ice in nearshore areas at most times during the 1997 and 1998 operating seasons. However, storms were more prevalent in 1997. The storms in 1997 were one of the main reasons for the lower number of hours of seismic production (and the earlier termination date) in 1997 than in 1998. More observation hours were conducted in 1998 than in any other year because two source vessels operated (though not simultaneously), and a late freeze-up permitted an extended operating period. There were fewer hours of observations in 1999, 2000, and 2001 because airgun operations ceased by 1 September to accommodate whaling activities based at Cross Island. In 1999, Western Geophysical intended to resume operations after the completion of the whaling season but an extended whaling season, poor weather, and imminent freezeup prevented further seismic operations.

3.3.2 Species Composition

2001 Operations.—Only four seals were seen during watches from the *Peregrine* and 34 seals from the *Arctic Star* when the vessels were working on the OBC seismic program in 2001. No seals were observed during periods of darkness in mid-late August 2001. Of the 30 seals identified to species level, 27 were ringed seals and three were spotted seals (Table 3.6). No bearded seals were identified in 2001. Eight seals were not identified to the species level. All seals sighted were in the water. No polar bears or whales were sighted by observers or crew aboard either source vessel in 2001.

Combined 1996-2001 Operations.—More seals were seen by vessel-based observers during 1996 (419 seals) than during 1998 (252 seals), 1999 (201 seals), 2000 (214), and especially 2001 (38) and 1997 (69 seals) (Table 3.7). Similar proportions of the seals were identified to species level each year from 1996 to 1998, and 2001 (78.3% in 1996, 79.7% in 1997, 79.8% in 1998, 78.9% in 2001; Table 3.7B). A lower proportion of seals (65.7%) were identified to species in 1999 and a higher proportion (84.6%) were identified to species in 2000. The species composition of seals that were identified was similar in all six years. Ringed seals predominated during each year: 92.1% in 1996, 87.3% in 1997, 98.5% in 1998,

TABLE 3.5. Survey effort by year (1996 – 2001) and combined: the number of hours of observation from the source vessel(s) by marine mammal observers. Effort is categorized by year, seismic state, and daylight vs. darkness periods.

Seismic State	Survey Effort													
	1996		1997		1998		1999		2000		2001		1996-2001	
	Total Hours	%	Total Hours	%	Total Hours	%	Total Hours	%	Total Hours	%	Total Hours	%	Total Hours	%
A. Daylight														
No Guns	262.3	34.9	252.2	49.2	539.4	49.8	181.8	45.4	44.9	8.6	85.1	25.5	1365.7	37.9
Single Gun	95.3	12.7	9.0	1.8									104.3	2.9
Small Array	72.0	9.6	216.9	42.4	58.5	5.4			95.6	18.4	151.2	45.4	594.2	16.5
Large Array	269.2	35.8			423.1	39.0	206.4	51.5	349.4	67.3	71.3	21.4	1319.4	36.6
Ramp-up	26.7	3.6	27.2	5.3	39.2	3.6	8.5	2.1	5.8	1.1	10.3	3.1	117.7	3.3
Testing	26.3	3.5	6.8	1.3	23.5	2.2	4.0	1.0	23.8	4.6	15.4	4.6	99.8	2.8
Total	751.8		512.1		1083.7		400.7		519.5		333.3		3601.1	
B. Darkness														
No Guns	37.8	28.3	43.6	44.5	81.1	32.7	15.0	40.2					177.5	32.7
Single Gun	9.9	7.4	0.8	0.8									10.7	2.0
Small Array	14.4	10.8	49.6	50.6	19.5	7.9			4.3	18.5	2.8	100.0	90.6	16.7
Large Array	63.6	47.6			138.5	55.9	21.2	56.8	19.0	81.5			242.3	44.6
Ramp-up	4.8	3.6	3.8	3.9	5.2	2.1	0.7	1.9					14.5	2.7
Testing	3.2	2.4	0.2	0.2	3.5	1.4	0.4	1.1					7.3	1.3
Total	133.7		98.0		247.8		37.3		23.3		2.8		542.9	
C. All Times														
No Guns	300.1	33.9	295.8	48.5	620.5	46.8	196.8	44.9	44.9	8.3	85.1	25.3	1543.2	37.2
Single Gun	105.2	11.9	9.8	1.6									115.0	2.8
Small Array	86.5	9.8	266.5	43.7	78.0	5.9			99.9	18.4	154	45.8	684.9	16.5
Large Array	332.8	37.6			561.6	42.2	227.6	52.0	368.3	67.9	71.3	21.2	1561.6	37.7
Ramp-up	31.5	3.6	31.0	5.1	44.4	3.3	9.2	2.1	5.8	1.1	10.3	3.1	132.2	3.2
Testing	29.4	3.3	7.0	1.1	27.0	2.0	4.4	1.0	23.8	4.4	15.4	4.6	107.0	2.6
Total	885.6		610.1		1331.5		438.0		542.8		336.1		4144.0	

TABLE 3.6. Numbers and species of seals observed from the *Peregrine* and *Arctic Star* in different seismic states during 2001, with percentages relative to the total of all identified seals seen in that seismic category.

Seismic State	Number of Seals							
	Total No.	Identified		Ringed Seal		Spotted Seal		Unidentified No.
		No.	% of Total	No.	% of Identified	No.	% of Identified	
A. All Distances								
No Guns	11	7	63.6	4	57.1	3	42.9	4
Small Array	1	1	100.0	1	100.0			
Large Array	16	13	81.3	13	100.0			3
Ramp-up	5	5	100.0	5	100.0			
Testing	5	4	80.0	4	100.0			1
Total	38	30	78.9	27	90.0	3	10.0	8
B. Within Updated Safety Radius								
No Guns	1	1	100.0	1	100.0			
Small Array								
Large Array	5	5	100.0	5	100.0			
Ramp-up								
Testing	1	1	100.0	1	100.0			
All Seismic	6	6	100.0	6	100.0			

93.2% in 1999, 100% in 2000, and 90.0% in 2001. Bearded seals were the second-most common species each year (7.0% in 1996; 9.1% in 1997; 1.5% in 1998; 3.8% in 1999; none in 2000 and 2001), with the exception of 2001 when spotted seals accounted for 10% of identified seals. Considering all years together, a similar percentage species composition was evident under no guns, single gun, small array, and large array seismic conditions (Table 3.7A).

3.3.3 Daytime Sighting Rates and Distances, With vs. Without Seismic

The data were standardized to numbers of seals observed per hour of daylight survey effort to allow meaningful comparisons of the numbers of seals encountered during different seismic states. When calculating sighting rates, we used only hours of observation during daylight. Detection of seals during darkness was difficult and we did not want to negatively bias the calculated daytime sighting rates by including hours of darkness.

The sighting rate data are presented and analyzed in relation to position within or beyond the most recent estimates of the 190 dB radii ("updated safety radii") applicable to the various arrays and operating conditions (15 m, 50 m, or 100 m for 2001 data; Table 3.3A). Radial distances of seals were categorized as "Near Half" of the that zone, "Far Half", "1-2 Times", and ">2 Times". For example, radial distances from the *Arctic Star* with an array operating at gun depth 2.3 m in waters <10 m deep (190 dB radius 50 m) were categorized as ≤ 25 m (Near Half), 26-50 m (Far Half), 51-100 m (1-2 Times), and >100 m (>2 Times).

Note that the areas under observation in the four distance categories are not equal, and that sightability decreases with increasing distance (see §3.3.6, later). Thus, comparisons of sighting rates across safety radius categories must be done cautiously, emphasizing relative sighting rates and distribution patterns rather than absolute numbers.

TABLE 3.7. Numbers and species of seals observed from the source vessel(s) in different seismic categories during 1996-2001, and overall, with percentages relative to the total of all identified seals seen in that seismic category. Only two seals were seen during periods of darkness over the years.

Seismic State	Year	Total	Number of Seals								
			Identified		Ringed Seal		Bearded Seal		Spotted Seal		Unident.
			No.	% of Total	No.	% of Identified	No.	% of Identified	No.	% of Identified	
A.											
No Guns	1996	173	148	85.5	132	89.2	15	10.1	1		25
	1997 ^a	31	27	87.1	25	92.6	1	3.7	1	3.7	4
	1998	171	135	78.9	135	100.0					36
	1999	171	109	63.7	103	94.5	4	3.7	2	1.8	62
	2000 ^b	32	28	87.5	28	100.0					4
	2001	11	7	63.6	4	57.1			3	42.9	4
	Total	589	454	77.1	427	94.1	20	4.4	7	1.5	131
Single Gun	1996	37	30	81.1	27	90.0	3	10.0			7
	1997										
	2000 ^c	69	63	91.3	63	100.0					6
	Total	106	93	87.7	90	96.8	3	3.2			13
Small Array	1996	14	12	85.7	12	100.0			1	8.3	1
	1997 ^d	36	28	77.8	22	78.6	5	17.9	1	3.6	8
	1998	3	3	100.0	3	100.0					
	2000	7	4	57.1	4	100.0					3
	2001	1	1	100.0	1	100.0					
		Total	61	48	78.7	42	87.5	5	10.4	2	4.2
Large Array	1996	156	115	73.7	109	94.8	5	4.3	1		41
	1997										
	1998	64	52	81.3	51	98.1	1	1.9			12
	1999	26	19	73.1	16	84.2	1	5.3	2	10.6	7
	2000	106	86	81.1	86	100.0					20
	2001	16	13	81.3	13	100.0					3
		Total	368	285	77.4	275	96.5	7	2.5	3	1.1
Ramp-up	1996	22	13	59.1	13	100.0					9
	1997	2									2
	1998	9	9	100.0	9	100.0					
	1999	2	2	100.0	2	100.0					
	2000										
	2001	5	5	100.0	5	100.0					
		Total	40	29	72.5	29	100.0				
Testing	1996	17	9	52.9	9	100.0					8
	1998	5	2	40.0			2	100.0			3
	1999	2	2	100.0	2	100.0					
	2000										
	2001	5	4	80.0	4	100.0					1
	Total	29	17	58.6	15	86.2	2	11.8			12
B. Totals											
	1996	419	328	78.3	302	92.1	23	7.0	3	0.9	91
	1997	69	55	79.7	48	87.3	5	9.1	2	3.6	14
	1998	252	201	79.8	198	98.5	3	1.5			51
	1999	201	132	65.7	123	93.2	5	3.8	4	3.0	69
	2000	214	181	84.6	181	100.0					33
	2001	38	30	78.9	27	90.0			3	10.0	8
	Total	1193	927	77.7	879	94.8	36	3.9	12	1.3	266
Within Safety Radius ^e	1996	161	126	78.3	120	95.2	5	4.0	1	0.8	35
	1997	23	18	78.3	15	83.3	2	11.1	1	5.6	5
	1998 ^c	60	48	80.0	45	93.8	3	6.3			12
	1999	30	23	76.7	20	87.0	1	4.3	2	8.7	7
	2000 ^c	23	22	95.7	22	100.0					1
	2001	6	6	100.0	6	100.0					
		Total	303	243	80.2	228	93.8	11	4.5	4	1.6

^a Seal seen by navigator included here.

^b Includes two seals seen on ice pan.

^c Seal without a distance estimate excluded.

^d Seal seen on ice pan included here.

^e Includes all seals seen within the various safety radii for single gun, small array, large array, ramp-up, and testing at all array depths when the airgun(s) were firing; see Table 3.2 and associated text for summary of all safety radii.

Weekly Sighting Rates During 2001.—There was no significant tendency for the number of seals seen per daylight hour in 2001 either to increase or to decrease progressively from week to week (Page's L Test; $L_{week} = 29.9$, $n = 1, 4$, $P > 0.05$) (Page 1963). Weekly average sighting rates ranged from 0.0 to 0.42 seals/h: Week 1 = 0.42 seals/h, Week 2 = 0.08 seals/h, Week 3 = 0.0 seals/h, Week 4 = 0.0 seals/h. In all but one case, seal sightings were of single animals. During non-seismic operations on the *Arctic Star*, marine mammal observers (MMOs) sighted a single pair of seals of unidentified species.

Numbers Seen With vs. Without Seismic in 2001.—Sighting rates per daylight hour were similar when no guns were operating (0.13 seals/h) and during all seismic operations combined (0.11 seals/h; Fig. 3.1 and Table 3.8). However, sighting rates during seismic operations (large array, ramp-up, and testing) other than those involving the small array were higher than when no guns were firing. The sighting rates during small and large array operations differed greatly (0.01 and 0.22 seals/h, respectively), as only one seal was observed during small-array operations. We were unable to make paired comparisons of weekly sighting rates during non-seismic vs. seismic periods based on a Wilcoxon's matched-pairs signed-ranks as the sample size for 2001 was too small.

The very low sighting rates in 2001 were predicted prior to the start of the season based on the planned area of operations. Inupiat MMOs and hunters told JWL that shallow, muddy waters like those in Simpson Lagoon are not frequented by many seals. This assertion was supported by the very low sighting rate during operations within the lagoon (0.006 seals/h), and by comparing these data to the relatively greater sighting rate for operations by the *Arctic Star* outside the barrier islands (0.11 seals/h).

Overall Sighting Rates by Year.—To control for the interannual differences in survey effort, we compared the seal sighting rates per hour of observation. The overall average sighting rates during daylight were 0.56, 0.13, 0.24, 0.17, 0.41 and 0.11 seals/h during 1996–2001, respectively (Harris et al. 1997, 1998; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001; Table 3.8). These rates exclude sightings from the *Saber Tooth* in 1998 and sightings during the “heavy” ice exclusion period in 1999. Statistical comparisons of annual sighting rates were based on sightings per hour of daylight survey effort, by week, considering times with only one observer on watch for both non-seismic and all seismic periods (includes array, ramp-up, and testing). Sighting rates during non-seismic periods differed significantly among years, with a higher average rate in 2000 than in 1996, 1997, 1998 1999, and 2001 (Kruskal-Wallis Test: $H = 18.337$, $df = 5$, $P = 0.003$). Sighting rates under all seismic conditions did not differ significantly among years ($H = 7.32$, $df = 5$, $P = 0.198$) although the average sighting rates were higher in 1996, 1998, 1999, and 2000 than in 1997 and 2001.

The high frequency of windy weather in 1997 was probably in part responsible for the relatively low sighting rate of seals seen in 1997. The strong winds that were common during 1997 resulted in higher average sea states than in other years, thus making marine mammal detection at sea more difficult (e.g., Northridge et al. 1995). The low sighting rate in 2001 is likely attributable to the shallow water depths (i.e., mostly inside of the barrier islands) where WesternGeco conducted seismic operations; these areas are likely sub-optimal habitat for seals. The higher sighting rate in 1996 is believed to be mainly a result of the apparent association of seals (or at least seal sightings) and ice. It is uncertain how much of an association there is between ringed seals and drifting ice during summer. However, ice dampens the waves and thus increases the sightability of seals in the water by vessel-based observers. In addition, the fact that the vessel is usually moving along at a relatively slow speed (several knots) permits curious seals to follow it more easily, and be counted multiple times. In 1996, drifting ice was common and seals were seen more often in areas with ice (Harris et al. 1997). We also found this to be the case in 1999 when the *Arctic Star* scouted in areas of concentrated ice for several days (Moulton and Lawson 2000).

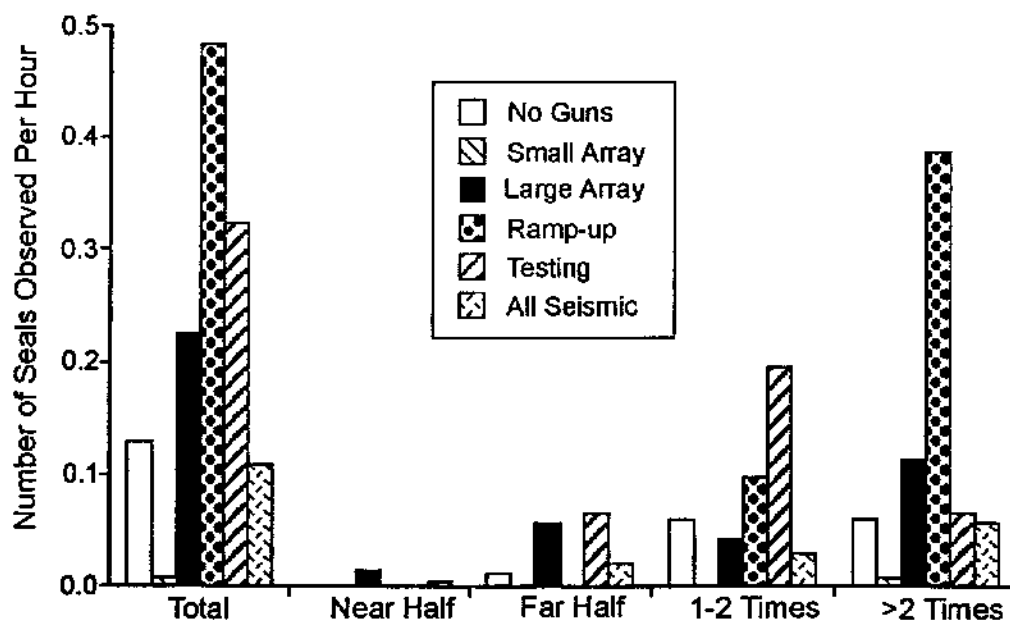


FIGURE 3.1. Numbers of seals seen in 2001 per hour of daylight observation by seismic state and distance from the source vessel relative to the updated safety radius. Safety radii defined as described in Table 3.3.

TABLE 3.8. Numbers of seals seen in 2001 per hour of daylight observation by seismic state and distance from the *Peregrine* or *Arctic Star* relative to the updated safety radii (defined as in Table 3.3).

Seismic State	Hours of Daylight Observation	All Seals Observed		Number of Seals Within Safety Radius Category							
				Near Half		Far Half		1-2 Times		>2 Times	
		No.	No./h	No.	No./h	No.	No./h	No.	No./h	No.	No./h
No Guns	85.1	11	0.13			1	0.01	5	0.06	5	0.06
Small Array	151.2	1	0.01							1	0.01
Large Array	71.3	16	0.22	1	0.01	4	0.06	3	0.04	8	0.11
Ramp-up	10.3	5	0.48				0.00	1	0.10	4	0.39
Testing	15.4	5	0.32			1	0.06	3	0.19	1	0.06
All Seismic	248.3	27	0.11	1	0.004	5	0.02	7	0.03	14	0.06
Total	333.4	38	0.11	1	0.003	6	0.02	12	0.04	19	0.06

Seals were almost undetectable at night despite the use of image intensifiers (all years), thermal imager (1998), or image intensifiers plus floodlights (1999-2001). Only two seals were seen during darkness over the five years—one in 1996 and one in 1998; neither was seen with the aid of NVDs.

Numbers Seen With vs. Without Seismic in 1996-2001.—An analysis of the combined 1996-2001 data shows that the sighting rate was significantly higher during non-seismic periods (0.37 seals/h) than during array seismic operations at all depths (0.24 seals/h; excludes ramp-up, testing, and one-gun operation) ($T_s = 258$, $n = 50$ paired weekly averages of sightings/h, $P < 0.0005$). To control for the

possible effect of number of observers on watch, we also compared the overall 1996-2001 sighting rates during non-seismic and array-seismic periods when only one observer was on watch. Again, the sighting rate was significantly higher during non-seismic periods (0.38 sightings/h; average of weekly values) than during array seismic operations at all depths (0.25 sightings/h; $T_1 = 237$, $n = 43$ paired weekly averages, $0.0005 < P < 0.0025$). The difference in the overall 1996-2001 sighting rates was largely attributable to the 1998 results, which contributed the most data.

Sighting Distances With vs. Without Seismic in 2001.—Most seals were first seen outside the 190 dB distance (updated safety radius), and especially in the zone beyond 2× the safety radius. This was true during both non-seismic and seismic operations (Table 3.8). Considering periods with and without airgun operations together, only 23.7% (9 of 38 seals) of all seals sighted were at distances less than the safety radius. In 2001, the percentage of seals within the safety radius was higher during airgun operations than periods without airguns. During all seismic operations, 22.2% of seals (6 of 27) were seen from the *Peregrine* and *Arctic Star* at estimated distances within the safety radius vs. 9.1% of seals (1 of 11) during non-seismic periods.

The radial distances at which seals were initially sighted during 2001 were, on average, smaller during non-seismic than during all seismic periods. However, this difference was not statistically significant (mean radial distance 186 m vs. 254 m [610 ft vs. 833 ft]; Mann-Whitney $U = 114.5$, $n = 10, 27$, $P = 0.242$). Similarly, seals were first sighted at smaller distances from the source vessel during periods with no guns than with array seismic. Again, however, the difference was not significant (means 186 m vs. 282 m [610 ft vs. 925 ft]; Mann-Whitney $U = 76.0$, $n = 10, 17$, $P = 0.326$).

Sighting Distances, With vs. Without Seismic in 1996-2001.—Results from seismic monitoring work in 1996-2001 showed that seals were rarely sighted at distances greater than about 400 to 500 m (1312 to 1640 ft) (Harris et al. 1997, 1998; Lawson and Moulton 1999; Moulton and Lawson 2000). Hourly sighting rates for 1996 to 2001 were generally higher without seismic than with seismic in the “near half”, and to a lesser extent in the “far half” (Fig. 3.2). This pattern was not as evident in the “1-2 times” zone and in the “>2 time” zone. In some years (1997 and 1998), sighting rates with and without seismic became more similar as distance increased. This suggests that, in these years, airgun operations reduced the number of seals (or at least the number of seal sightings) within the safety radius, but that the effect of airgun operations on sighting rate was reduced or absent beyond the safety radius.

For analysis of the combined 1996-2001 data, we did separate Mann-Whitney U tests comparing radial distances during non-seismic vs. array-seismic periods in each year considering all distances, distances within the safety radius, and distances beyond the safety radius (Table 3.9). We combined the results of these annual tests using the “weighted Z ” method as described by Rosenthal (1978)².

² This approach involves summing the weighted Z (standard normal deviate) values derived from the one-tailed P values associated with Mann-Whitney U tests on the 1996-2001 data. Each Z value was weighted by the number of sightings on which it was based. We added the products of the weights and Z values, and divided the resulting sum by the square root of the sum of the squared weights. The probability associated with the resultant Z is the pooled probability for the overall test based on the independent samples from each year. The signs of the trends in different years are taken into account in the pooled probability. For example, beyond the safety radius, sighting distances in 2000 were significantly greater during non-seismic vs. array seismic periods. This trend was in the opposite direction to that in other years, and reduces, not increases, the overall significance level.

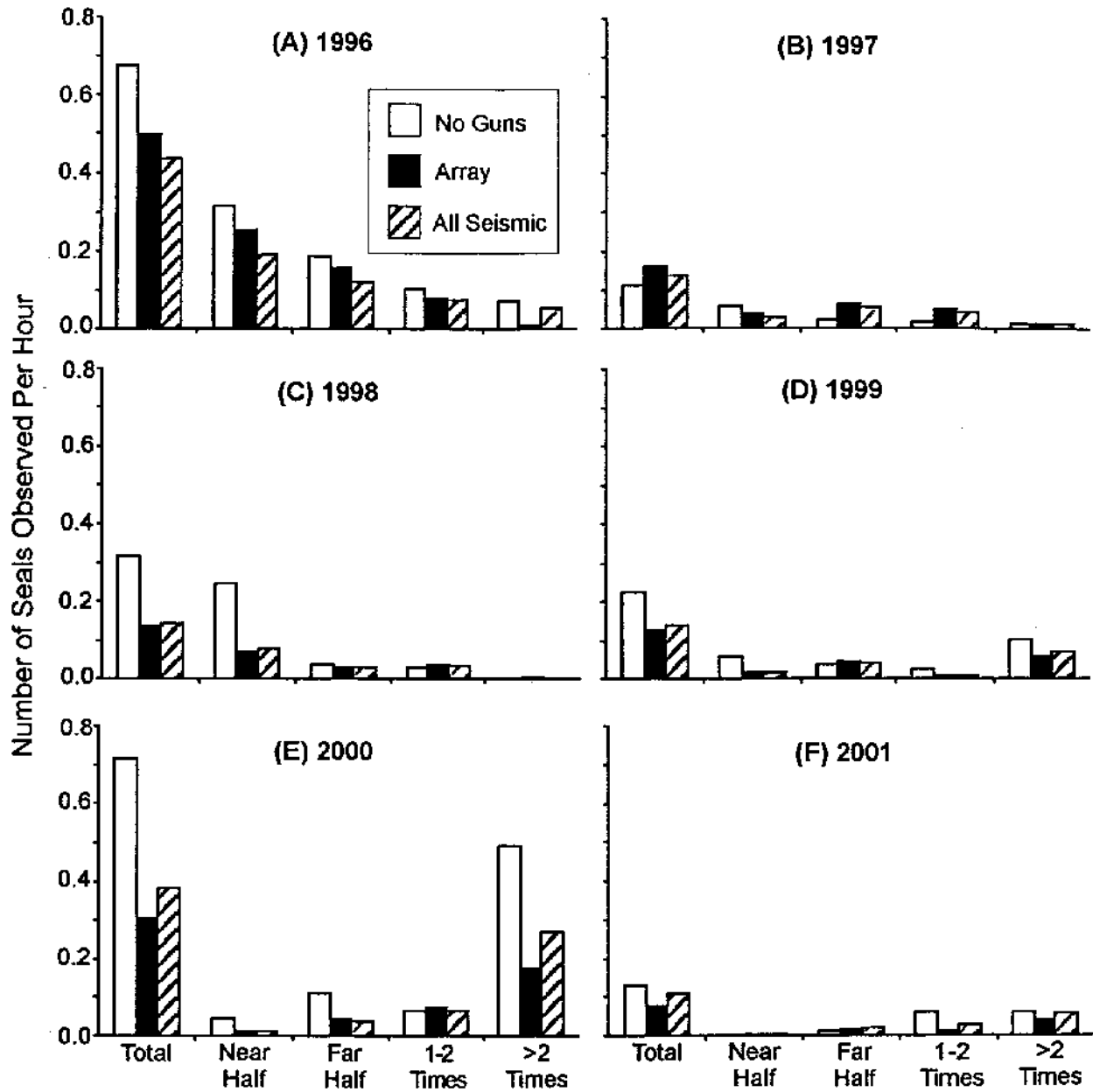


FIGURE 3.2. Numbers of seals seen per hour of daylight observation by seismic state and distance from the source vessel relative to the updated safety radius in 1996 to 2001. Table 3.3 lists the safety radius for each array and operating depth and the sizes of the four distance categories in each year.

TABLE 3.9. Comparison of radial sighting distance at times without vs. with array seismic, 1996-2001, subdivided by updated safety radius category.

Year	Test Type	Within Safety Radius						Beyond Safety Radius						All Distances					
		Non-Seismic		Array Seismic		U	P ^a	Non-seismic		Array Seismic		U	P ^a	Non-seismic		Array Seismic			
		Mean Dist. (m)	n	Mean Dist. (m)	n			Mean Dist. (m)	n	Mean Dist. (m)	n			Mean Dist. (m)	n	Mean Dist. (m)	n	U	P ^a
1996	Mann-Whit. U	125.1	108	167.3	115	4480.5	0.001	203.3	41	482.6	24	151.5	0.001	146.6	149	221.7	139	7182.0	0.001
1997	Mann-Whit. U	117.8	19	189.0	22	130.0	0.019	267.3	7	417.8	11	19.0	0.034	158	26	265.2	33	254.5	0.004
1998	Mann-Whit. U	102.4	148	146.6	47	2870.0	0.036	218	15	289.6	17	84.0	0.048	113	163	184.6	64	3660.5	0.001
1999	Mann-Whit. U	79.2	68	63.3	12	317.5	0.111	235.8	100	273.4	14	587.5	0.165	172.4	168	176.4	26	2476.0	0.413
2000	Mann-Whit. U	86.6	7	92.2	21	65.5	0.335	359.7	22	270.3	91	740.0	0.029	293.8	29	236.9	112	1452.0	0.190
2001	Mann-Whit. U	119.0	1	74.2	5	1.0	0.190	193.2	9	368.6	12	28.0	0.032	186.0	10	282.0	17	76.0	0.326
1996-2001	Pooled Prob. (Weighted) ^b						0.0001						0.0351						<0.0001

^a One-tailed P values.^b Based on Rosenthal (1978).

This method provides an overall test of the hypothesis that the radial distances where seals were first sighted were equal with and without airgun operations during 1996-2001. This approach avoids the indiscriminate pooling of distances regardless of the safety radius and the problems associated with small sample size for some years. Overall, seals were sighted significantly farther away from the source vessel during array-seismic (mean = 223 m or 732 ft) vs. non-seismic periods (mean = 154 m or 505 ft) (Pooled $P < 0.0001$). The radial distances for sightings within the updated safety radius were significantly greater during array seismic activity than during non-seismic periods (Pooled $P = 0.0001$; Table 3.8). Similarly, there was a significant difference for sightings beyond the updated safety radius; sighting distances were greater during array seismic than during non-seismic periods (Pooled $P = 0.035$; Table 3.9). This indicates that some combination of the following effects must have occurred: (1) some seals exposed to seismic pulses kept farther away from the source vessel than seals not exposed to seismic pulses, and/or (2) seals close to the source vessel were less conspicuous when the airguns were operating, and/or (3) seals farther from the source vessel were more conspicuous.

Figure 3.3 illustrates the relationship between seismic state and the radial distances at which seals were sighted, considering all five years combined. During non-seismic periods, the distribution of sighting distances peaked within 150 m (492 ft) of the vessel. With small array or large array operations, or with all seismic operations combined, the sighting distributions were more dispersed, with a higher percentage of the seal sightings occurring farther from the seismic vessels.

3.3.4 Distribution Around Source Vessels, With vs. Without Seismic

Distribution in 2001.—The positions of seal sightings relative to the source vessels under different seismic conditions, and overall, are shown in Figure 3.4. There were 37 distinct sightings, all involving single seals with the exception of one sighting of two individuals.

The recorded distributions in part reflect the data collection methods. Most seal sightings were recorded as being located on imaginary lines radiating from the source vessel at 30-degree (occasionally 15°) intervals (Fig. 3.4). This occurred because the bearing data were collected as “hours of the clock” relative to the vessel’s bow. A seal seen 60° off the bow and to starboard was recorded as being at the 2 o’clock position. Seals on bearings from 45° to 75° to starboard were almost all recorded as being at 2 o’clock. Similarly, many radial distances, particularly the longer ones, were grouped at the distance values corresponding to the reticle markings on the binoculars. However, because these measurements were made the same way for each seismic state, they still permit meaningful comparisons.

Overall, the great majority of initial sightings during 2001 were in front of, and to the sides of, the source vessel (9 through 12 to 3 o’clock; 270° through 0° to 90°; Fig. 3.4). Few of the initial sightings were toward the stern. This pattern primarily reflects the fact that the marine mammal observers spent most of their time trying to detect seals ahead of the vessel, as one of the observers’ primary duties was to initiate an airgun shutdown if a marine mammal about to enter the safety zone was sighted [see IHA in Appendix B, §5(b,c)]. Also, visual obstructions to the sides and rear of the bridge (Figs. 2.1, 2.3) were undoubtedly also a factor.

The locations of sightings relative to the source vessel were similar during non-seismic and seismic periods (Fig. 3.4A vs. B), based on Hotelling’s two-sample test (Batschelet 1981; $T^2 = 1.87$, $n = 10, 27$, $0.25 > P > 0.10$).

In 2001, there was little difference in the proportion of sightings behind the vessel at times with vs. without seismic operations. Without airguns, 100% of sightings were to the front and sides of the source vessel (Fig. 3.4A). When the airgun(s) were firing, 96.3% of 27 sightings were to the front and sides, vs. 3.7% behind (Fig. 3.4B).

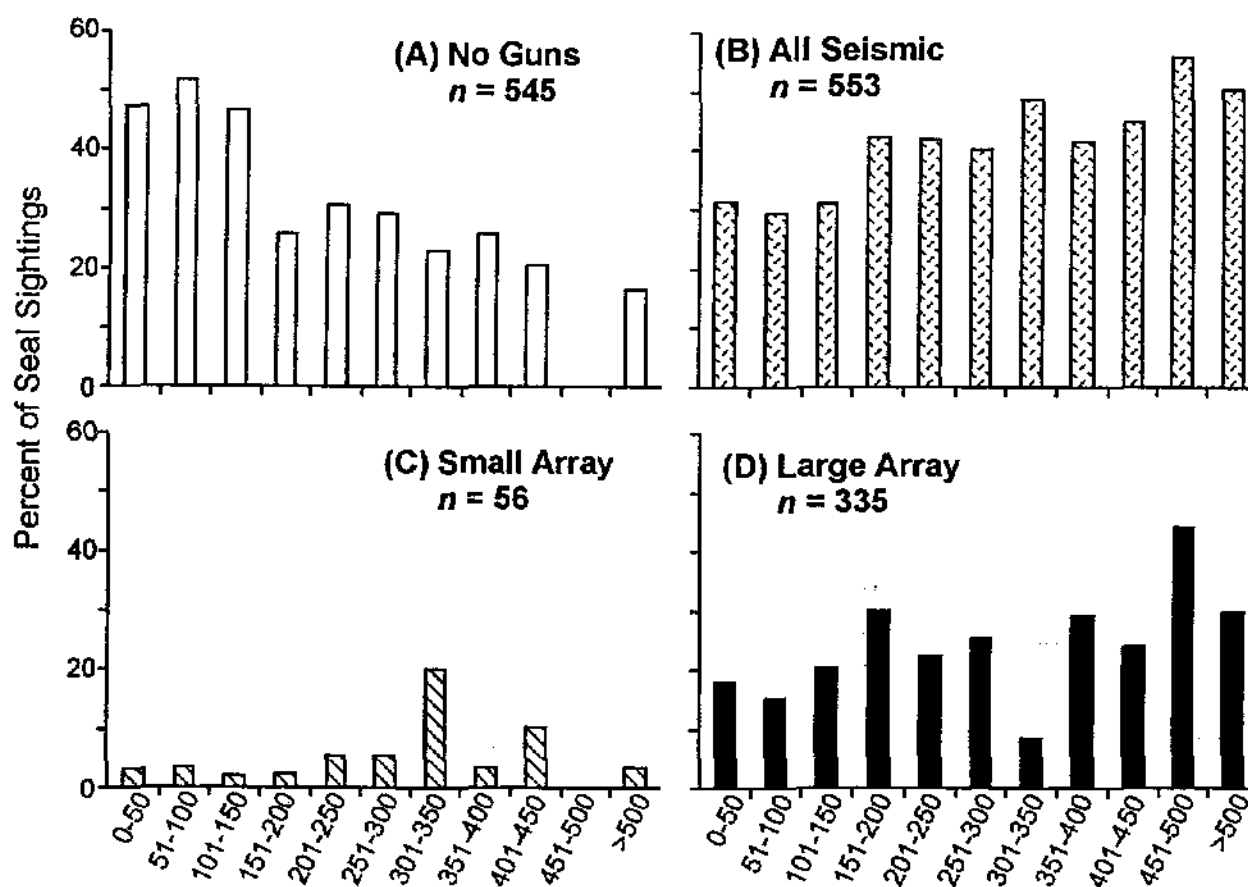


FIGURE 3.3. Percentages of seal sightings in daylight by seismic state and distance from the source vessel, 1996 to 2001 combined. The "All Seismic" category can contain seismic testing, ramp-ups, single-gun OBRL, and unknown seismic operations, and thus can represent up to 100% of the sightings in any one distance category. See Table 3.1 for descriptions of small and large arrays.

When the airgun(s) were firing, 22.2% of the seal sightings recorded in 2001 were directly in front of the vessel (0°); 11.1% were at ± 15 to 30° , 48.1% were at ± 45 to 60° , and 14.8% were to the sides (± 75 to 90°). As noted above, only 3.7% of the sightings were recorded as being in a broad sector behind the source vessel (120° to 240°).

Combined 1996-2001 Operations.—Sighting locations relative to the observation vessels are shown in Figure 3.5A-C for all six years combined. The overall distributions of seal sightings in 1996-2001 were significantly different during non-seismic vs. array seismic conditions (Fig. 3.5B,C; $T^2 = 29.5$, $n = 498, 339$, $P < 0.0005$). During airgun operations, sightings tended to occur farther ahead of the source vessel (by an average of approximately 50 m) than during non-seismic periods. The tendency for sightings to be farther away during array seismic operations than during non-seismic periods is also evident in Figure 3.5B vs. C. As for the 2001 data alone, the overall pattern for the combined 1996-2001 data was for most sightings to occur generally close to the vessels' tracklines.

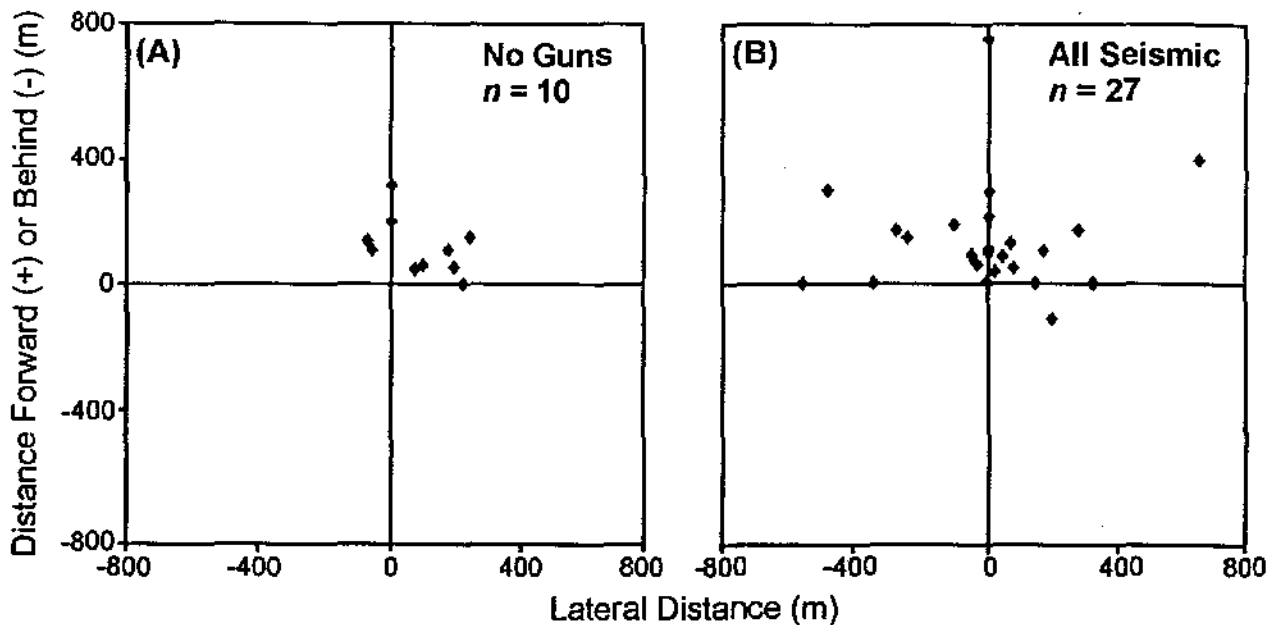


FIGURE 3.4. Relative bearings and distances to seal sightings during the 2001 seismic operations from *Arctic Star* and *Peregrine*. Bearings and distances are measured relative to the observation site on the bridge. One meter equals 3.28 feet.

3.3.5 Behavior Observed from Source Vessels

Seals in the water are generally difficult to observe because of their small size and the short time they spend at the surface. Consequently, behavioral observations were brief and often lacking in detail. Behavioral observations of seals included documentation of “Behavior type”, “Movement type”, and “Pace” (§3.2.1). The 2001 data are summarized below.

Behavior With vs. Without Seismic in 2001.—Figure 3.6A shows the behavior types observed from both seismic vessels in 2001, considering sightings at all distances from the vessels. Figures 3.6B and C show the same data subdivided by radial distance (within vs. beyond the updated safety radius). Data are presented for periods with no seismic operations (white bars) and with all seismic operations, including not only small and large-array but ramp-up and testing (shaded bars).

If seals were negatively influenced by seismic activity, we would expect that they would tend to avoid exposure to the seismic sounds underwater by “looking” or “swimming” (at the surface), rather than “diving”. Received levels of seismic pulses are reduced at and near the surface relative to those at greater depths (Greene and Richardson 1988). It is possible, therefore, that seals staying at the surface (e.g., “looking”) reduce their exposure to the underwater seismic noise. If so, we might expect “looking” and “swimming” to occur more frequently within the safety radius than beyond when the airgun array is firing. Similarly, diving will expose seals to higher levels of underwater seismic noise than would be received if the seals remained at the surface. Therefore, during seismic operations, diving would be expected to occur less frequently within than beyond the safety radius. Also, diving would be expected to occur less frequently during seismic than when no airguns were firing. This argument assumes that seals have learned that they can reduce their exposure to underwater seismic noise by remaining at or near the water surface. However, seals might also dive as a “panic” response, with little concern for noise exposure.

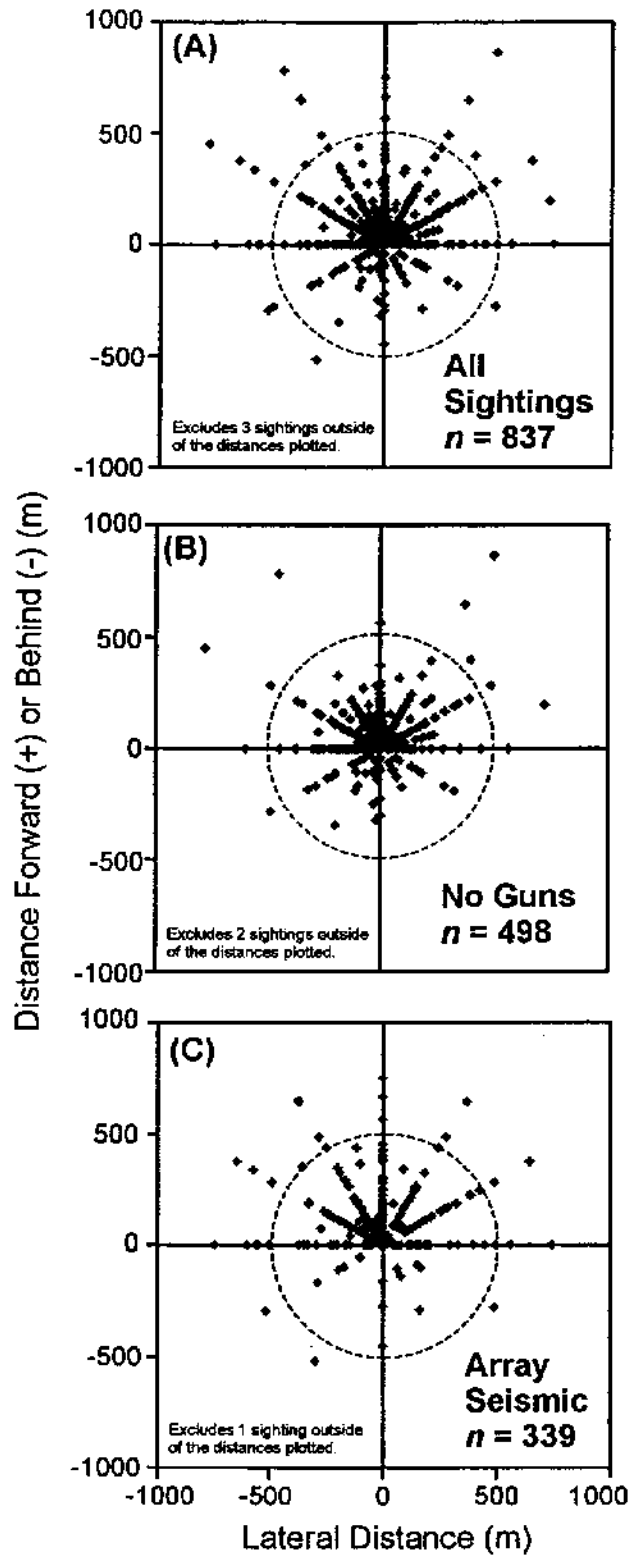


FIGURE 3.5. Relative bearings and distances to seal sightings during the 1996 to 2001 seismic operations combined. The “Combined Sightings” (A) and “Array Seismic” (C) categories do not include OBRL, testing, or ramp-ups. Dashed circle represents 500 m distance from the bridge of the source vessel. One meter equals 3.28 feet.

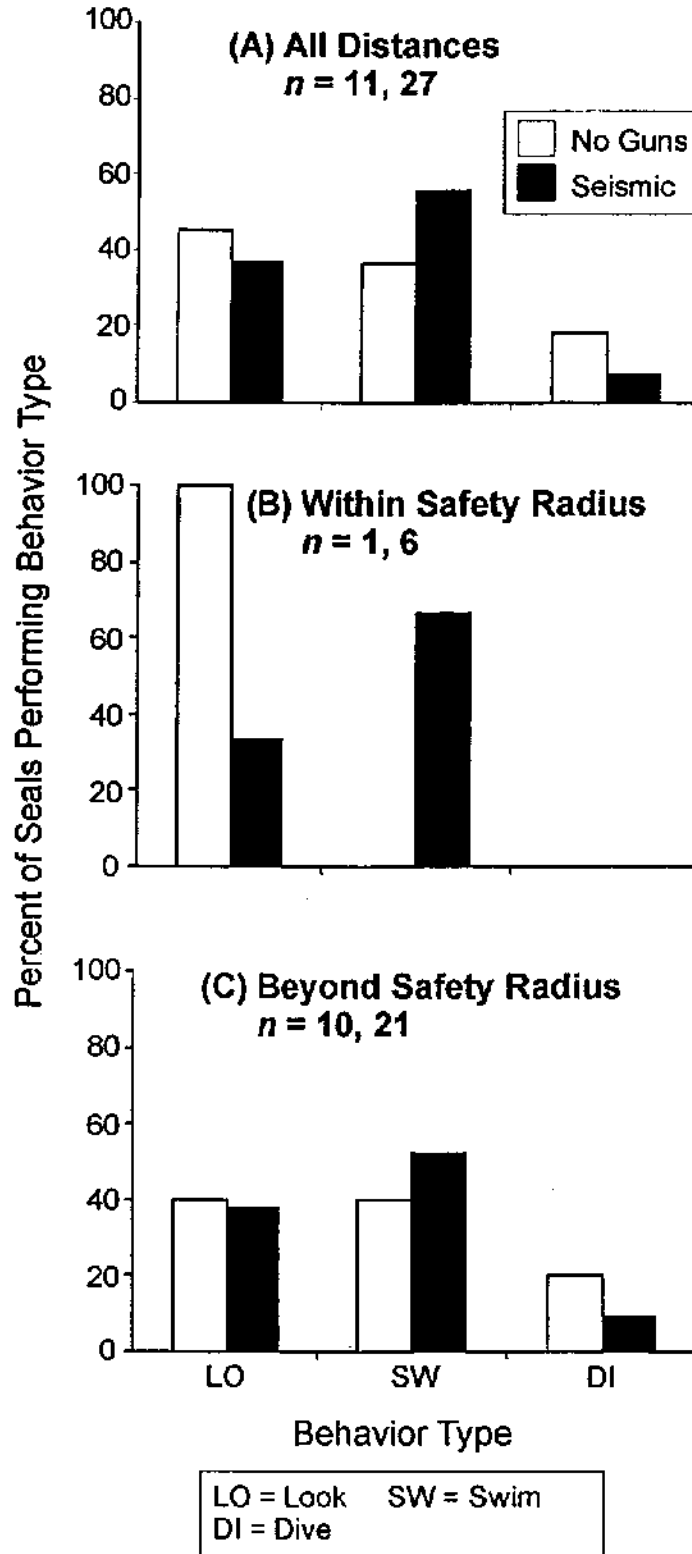


FIGURE 3.6. Percentages of seals showing various behavior types at all distances and within vs. beyond the updated safety radius (190 dB distances, Table 3.2) at times with no airguns vs. all seismic operations, as observed in 2001. The two n values in each panel are the numbers of seals seen with no guns vs. "all seismic" operations, respectively.

During 2001, the most frequent behavior type observed from the source vessel was “swimming”, with “looking” being almost as frequent. Within the (updated) safety radius, sample sizes were too small for meaningful analysis. Most seals beyond the safety radius were first observed “looking” or “swimming”, with little difference between seismic vs. non-seismic periods (Fig. 3.6C). Only two seals sighted beyond the safety radius were observed diving. No seals were initially observed “thrashing”, one of the sub-categories within the “diving” category. Relatively few seals were observed “front diving” or “sinking” below the surface.

In summary, the observed behavior of seals during 2001 does not support the hypothesis that seals tend to reduce exposure to the seismic sounds underwater by “swimming” or “looking” (at the surface), rather than “diving”. The few seals seen within the safety radii were observed “swimming” and “looking”; these behavior types occurred frequently beyond the safety radius as well. There was no clear pattern in the occurrence of behavior types for seismic vs. non-seismic periods; the majority of seals were sighted swimming and looking during both seismic and non-seismic periods.

Movement Type With vs. Without Seismic in 2001.—Figure 3.7 shows the movement types observed from both seismic vessels in 2001, considering sightings at all distances from the vessels (Fig. 3.7A), and within vs. beyond the updated safety radius (Fig. 3.7B, C). White bars show data from periods with no seismic operations; shaded bars show data with all seismic operations, including array, ramp-up, and testing.

We expected that, if seals were negatively influenced by seismic activity, they would tend to “swim away” or “flee” from the vessel, and that this effect would be most pronounced within the safety radius. A higher percentage of seals did “swim away” from the vessel during seismic periods (44.4% of 27) vs. non-seismic periods (18.2% of 11) considering all distances combined (Fig. 3.7A). During seismic periods, the percentage of seals “swimming away” was slightly higher beyond the safety radius vs. within that radius, but the sample size within the safety radius was very low (Fig. 3.7B,C). No seals were observed “fleeing” from the source vessel. Seals were observed “milling” only during non-seismic periods. Similar percentages of seals were observed “swimming parallel” to the vessel during non-seismic vs. seismic periods. Few seals were observed “swimming towards” the seismic vessel whether or not the airguns were operating (Fig. 3.7A).

Combined 1996-2001 Operations.—To further analyze effects of seismic operations on seal behavior, we need a larger sample size than can be obtained in any one year. To this end, we considered the behavioral data collected in 1996-2001 combined.

Similar to the results from 2001 alone, the relative frequencies of various behavior types in 1996-2001 combined were similar during non-seismic vs. seismic periods (Fig. 3.8A-D) “Swimming” was the most frequently observed behavior during “no guns”, “small array”, and “large array” operations—both within and beyond the updated safety radii. “Looking” was notably less common during seismic operations, either within or beyond the safety radius, than it was during no gun operations (Fig. 3.8B-D vs. A). There was little indication that frequency of “looking” depended on distance from the airguns when we combined all seismic activities, including ramp-ups and testing, as well as large array (Fig. 3.8B).

“Diving” was much less frequent than “looking” or “swimming”. Diving was slightly less common (both within and beyond the safety radius) during large array operations than under other conditions (Fig. 3.8D vs. A-C).

In the combined 1996-2001 data, the differences in the observed movements of seals when the airgun array was operating vs. not operating, and when within vs. beyond the updated safety radius, were similar to those in 2001 alone (Fig. 3.9A-D). “Swimming away” was common under all conditions, but was more common during seismic than non-seismic periods (Fig. 3.9B-D vs. A). Also, during airgun operations, “swimming away” was more frequent beyond the safety radius vs. within the safety radius; Fig. 3.9B-D).

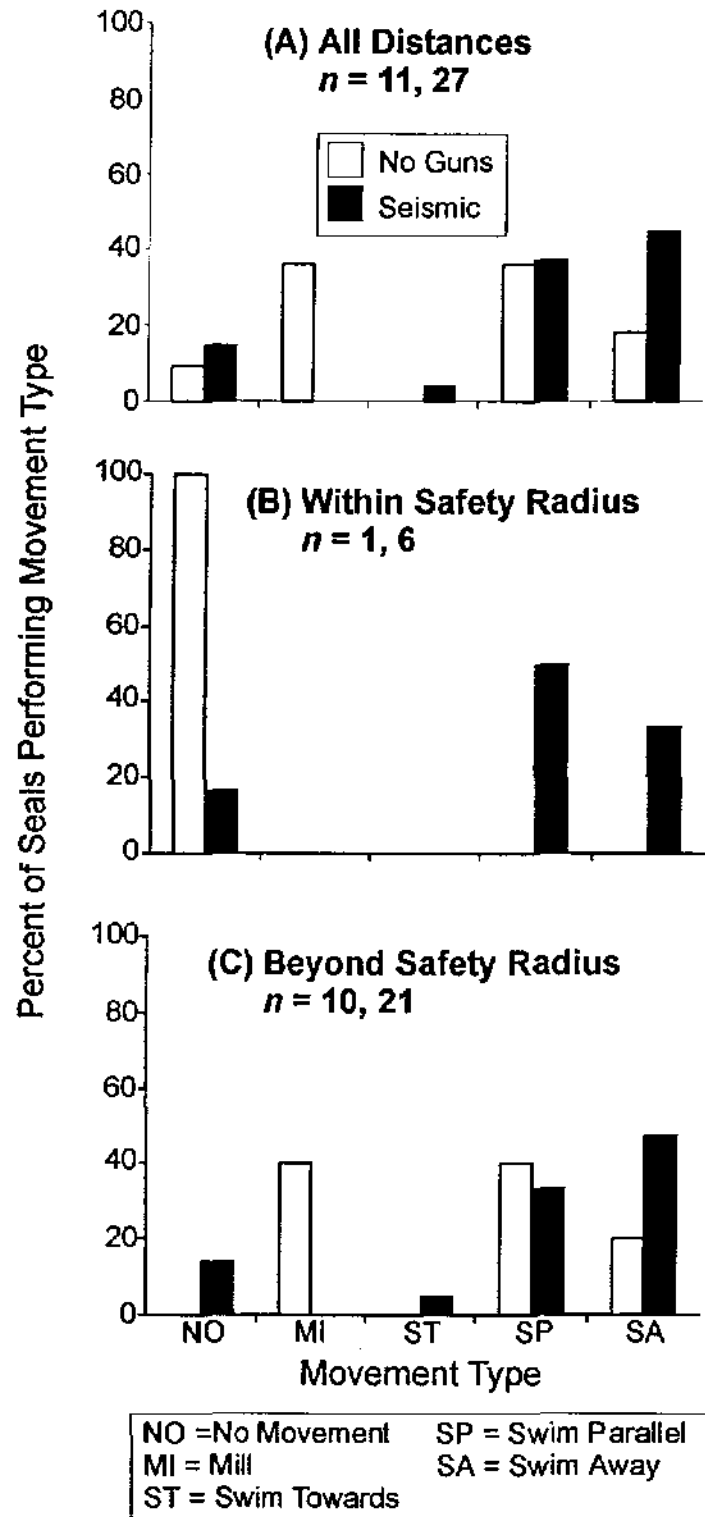


FIGURE 3.7. Percentages of seals showing various movement types at all distances and within vs. beyond the updated safety radius at times with no airguns vs. all seismic operations, as observed in 2001. The two n values in each panel are the numbers of seals seen with no guns vs. "all seismic" operations, respectively.

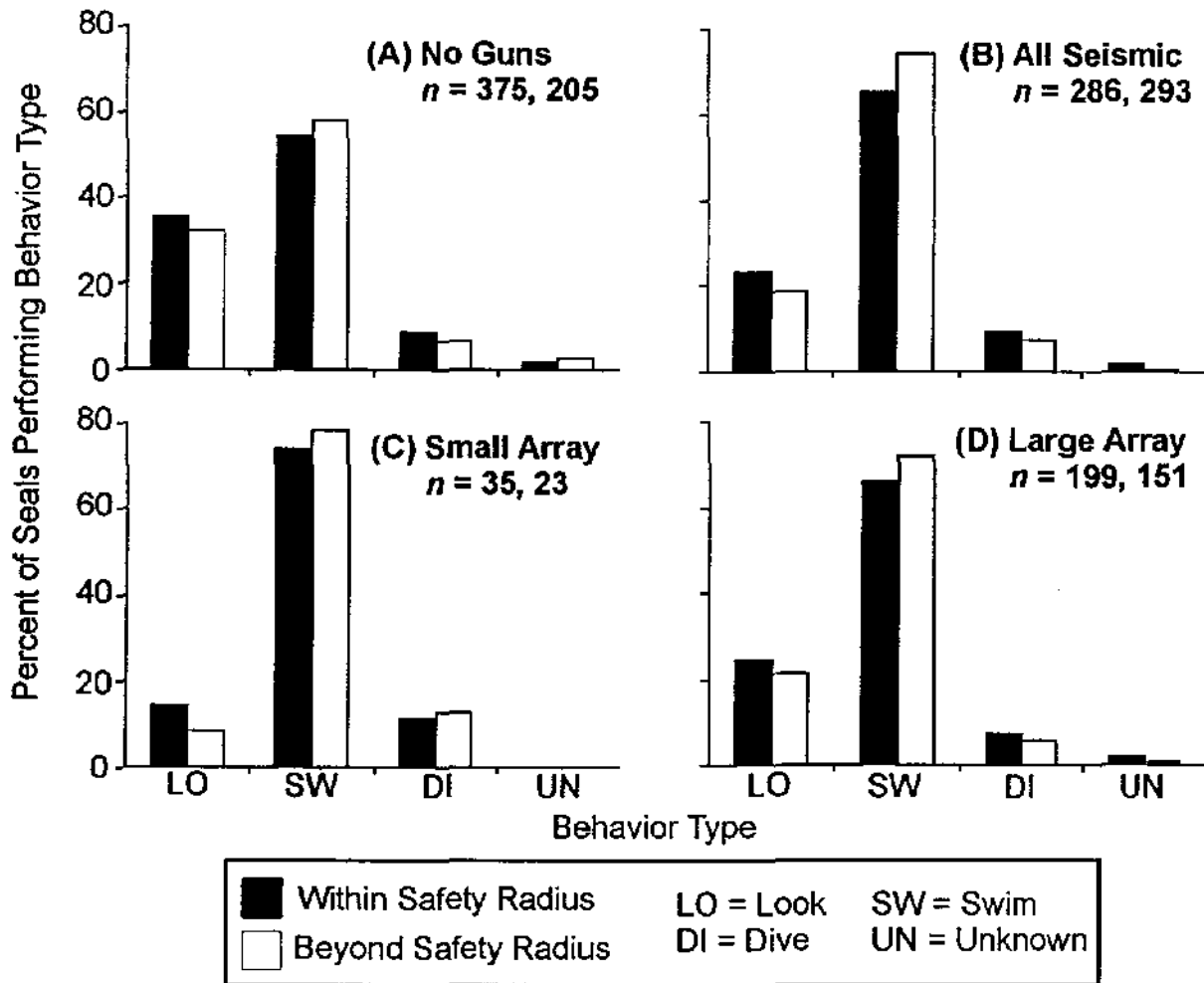


FIGURE 3.8. Percentages of seals showing various behavior types within vs. beyond the updated safety radius at times with no airguns vs. all seismic operations, as observed in 1996 to 2001. In (A)-(D), the two *n* values are the numbers of seals seen within vs. beyond the safety radius, respectively.

“Swim towards” was less common than “swim away”. “Swim towards” was about equally frequent with and without seismic operations but, contrary to expectation, was somewhat more frequent within the safety radius than beyond it during airgun operations.

Overall, the behavior of seals observed during the 1996-2001 seismic exploration operations in the Beaufort Sea was similar during non-seismic and seismic periods insofar as could be determined by visual observations from the source vessel. The relative frequencies of the behavior types were generally similar during both non-seismic and seismic periods. Of the various movement types, “swimming away” was the most common under all conditions but, during airgun operations, it was more common beyond the safety radius than within it. A slightly higher percentage of seals exhibited “no movement” during non-seismic periods, especially beyond the safety radius, than during seismic operations. There was no indication that seals were less likely to dive during seismic operations. Similar to results from the 2001 data alone, differences in the behavior of seals during non-seismic and seismic periods, whether inside the safety radii or not, were not distinctive or conspicuous.

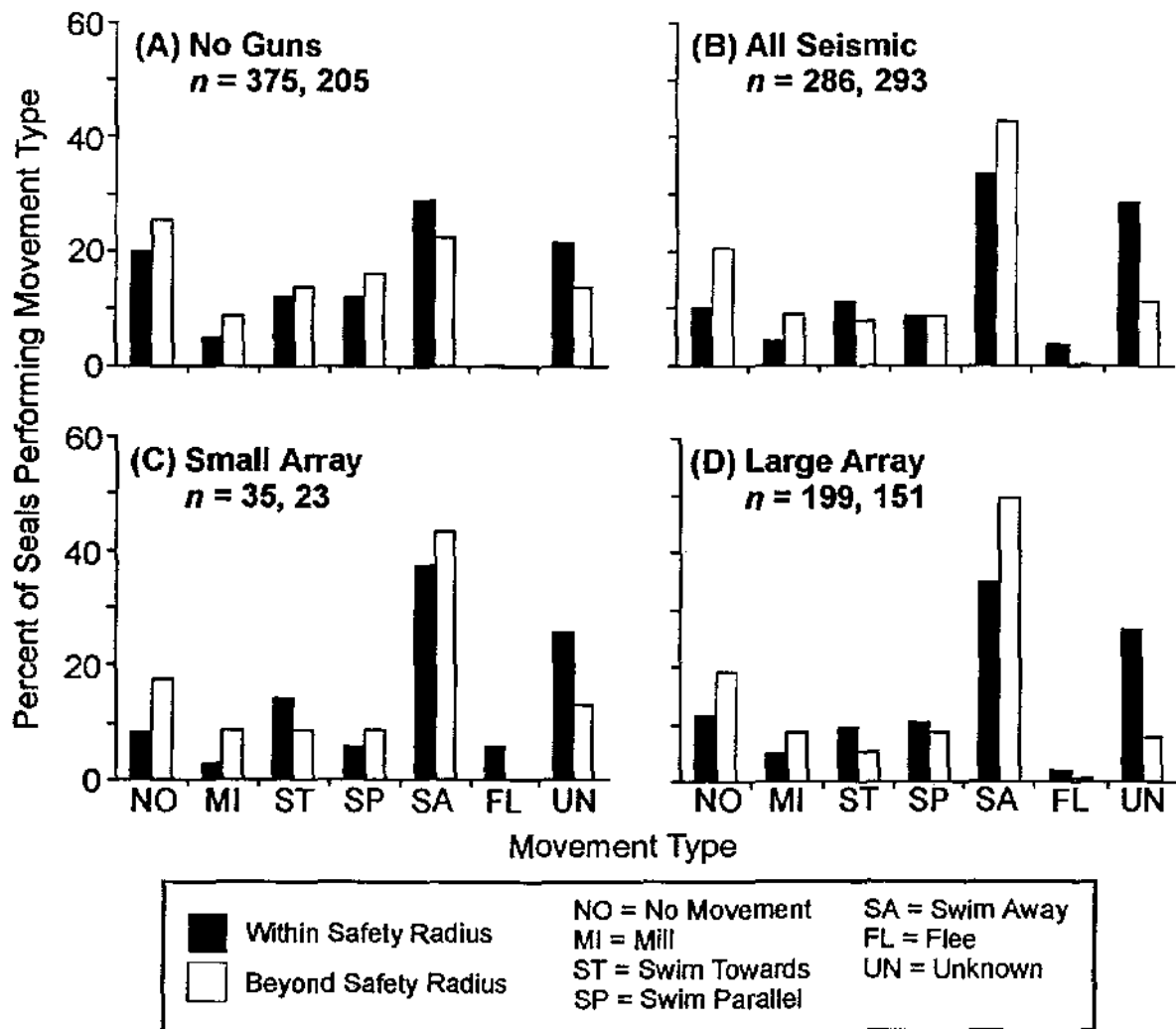


FIGURE 3.9. Percentages of seals showing various movement types within vs. beyond the updated safety radius at times with no airguns vs. all seismic operations, as observed in 1996 to 2001. In (A)-(D), the two n values are the numbers of seals seen within vs. beyond the safety radius, respectively.

“Pace” of Behavior During 2001 Operations.—In 2001, observers recorded a subjective measure of the “pace” at which seals were behaving (Table 3.10A). The proportion of the seals recorded as behaving at a “sedate” pace was higher during non-seismic periods (72.7%) than during periods of airgun operation (48.1%). Only a small proportion (7.4%) of the seals behaved at a vigorous pace even when airguns were active nearby, but the proportion with vigorous pace was higher with than without (0%) airgun operations.

“Pace” of Behavior During Combined 1998-2001 Operations.—For combined 1998-2001 data, similar results were obtained. Most seals did not behave vigorously when seismic operations were occurring nearby. However, the proportion doing so was slightly but significantly higher with than without airgun operations (test of goodness of fit; $G = 305.8$, $df = 1$, $P < 0.001$).

TABLE 3.10. "Pace" of behavior during 2001, subdivided by seismic state.

	Pace of Behavior	Seismic State			
		No Guns		All Seismic	
		No. of Sightings	%	No. of Sightings	%
A. 2001	Sedate	8	72.7	13	48.1
	Moderate	3	27.3	12	44.4
	Vigorous	0	0.0	2	7.4
	Unknown	0	0.0	0	0.0
	Total	11		27	
B. 1998-2001	Sedate	238	62.6	131	42.1
	Moderate	59	15.5	103	33.1
	Vigorous	29	7.6	58	18.6
	Unknown	54	14.2	19	6.1
	Total	380		311	

3.3.6 Detection of Seals

Sightability vs. Radial Distance.—In 2001, seals were first seen by observers at estimated radial distances ranging from 6 m to 750 m (20 ft to 2460 ft) from the seismic vessels. Most initial sightings were within a radial distance of 350 m (89.5% of all seals). The open bars in Figure 3.10 show the radial distances of the seals from the seismic vessels at times when the seals were first sighted. The radial distances to the initial sighting locations of seals averaged larger during non-seismic periods than during large-array seismic activity, but the difference was not statistically significant (details in §3.3.3).

The combined 1996-2001 data show that seal sightability declined rapidly with increasing radial distance from the source vessel (Fig. 3.11). Analyses of combined 1996-2001 data demonstrated that the radial distances at which seals were first sighted were significantly greater during airgun operations than during no-airgun periods (see §3.3.3).

The 50-m categories of radial distance considered in Figures 3.10 and 3.11 are annuli, and the areas of the annuli increase rapidly with increasing distance from the source vessel. If the density and detectability of seals were uniform, the numbers and percentage of sightings in the various 50-m categories should increase with increasing distance. In actuality, the percentages increased up to a distance of 150 m and then usually decreased with increasing distance (Fig. 3.11). This indicates that the probability of detecting seals diminished rapidly with increasing distance beyond 150 m.

Sightability vs. Lateral Distance.—Lateral distance was calculated based on the seal's radial distance and bearing relative to the bow of the source vessel. The shaded bars in Figure 3.10 illustrate, for 2001, the lateral distances relative to the tracklines of the source vessel of individual seals. Seals were initially sighted at estimated lateral distances ranging from 0 to 650 m (0 to 2133 ft) from the trackline of the vessels. The majority of seals were within a lateral distance of 200 m from the trackline of seismic vessels (71.1 % of all seals were within 200 m). Sighting rate declined more rapidly with increasing lateral distance than with increasing radial distance (shaded vs. open bars, respectively, in Fig. 3.10). The rapid decline in sightability with increasing lateral distances was probably attributable, in part, to the observers' tendency to scan forward of the vessel for seals entering or about to enter the safety zone.

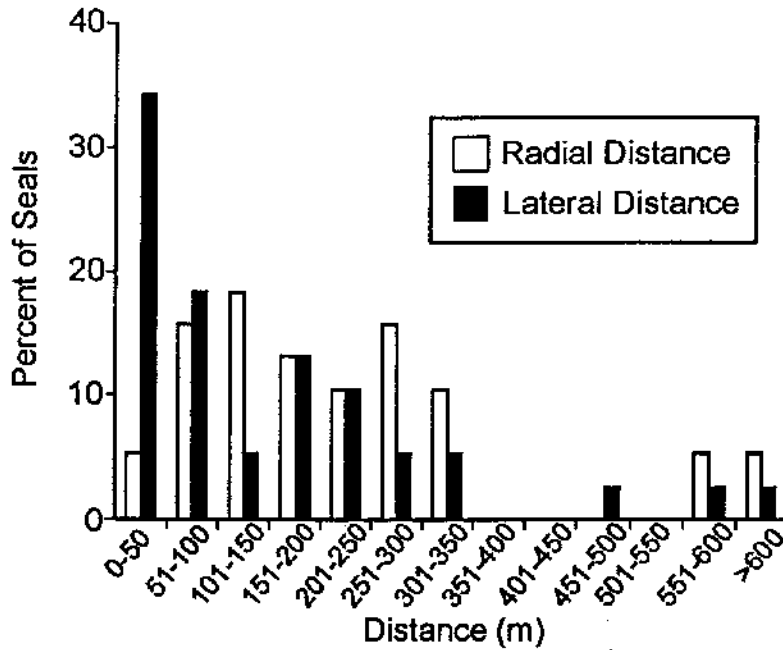


FIGURE 3.10. Percentages of seals ($n = 38$) seen by 50 m intervals of radial and lateral distance from *Peregrine* and *Arctic Star* in 2001. One meter equals 3.28 feet.

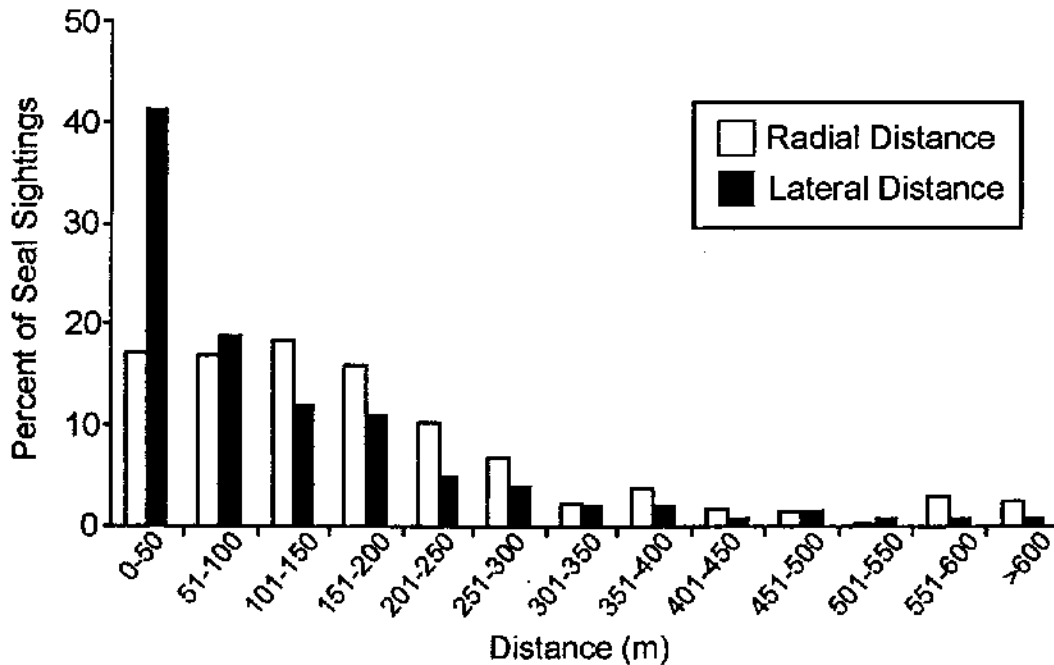


FIGURE 3.11. Percentages of seal sightings during daylight by 50 m intervals of radial and lateral distance from the source vessels for 1996 to 2001 combined. Groups of 2 or more seals are treated as “one sighting”. See Table 3.7 for a summary of yearly counts of seals sighted. One meter equals 3.28 feet.

Lateral sighting distances in 2001 were slightly less during non-seismic periods (mean = 114 m or 374 ft) than seismic periods (mean = 162 m or 531 ft), but the difference was not statistically significant (Mann-Whitney $U = 127.5$, $n = 10, 27$, $P = 0.399$).

Similarly, the combined 1996-2001 data showed that sighting rates diminished rapidly at lateral distances beyond 50 m during all six years (Fig. 3.11). Of all the seal sightings recorded in 1996-2001, 41% were within a lateral distance of 50 m, and 60% were within 100 m (Fig. 3.11). Based on combined 1996 to 2001 data, lateral distances were significantly greater during array seismic operations (mean 135 m or 443 ft; excluding sightings during one gun, ramp-up, and testing operations) than non-seismic periods (mean = 91 m or 299 ft; $U = 70,253$, $n = 501, 338$, $P < 0.0001$).

Sightability vs. Number of Observers.—The effect of the number of observers on watch on the number of seals seen per daylight hour during 2001 is shown in Figure 3.12, with additional details in Table 3.11. During daylight, one observer was on duty for 109.6 h and two observers were on duty for 142.8 h. In 2001, the overall average daylight sighting rate from the seismic vessels was higher with two observers vs. one observer (0.19 vs. 0.06 seals/h; Fig. 3.12, Table 3.11).

Considering 1997-2001 data combined, two observers also saw more seals than one observer (Fig. 3.13). This was statistically significant during all periods combined (0.28 vs. 0.19 sightings/h; $T_s = 177$, $n = 42$ weeks, $P < 0.005$), and all seismic periods (0.29 vs. 0.15 sightings/h; $T_s = 114$, $n = 32$ weeks, $0.0025 < P < 0.005$). The same pattern was observed during non-seismic periods but in that case the difference was marginally significant (0.26 vs. 0.24 sightings/h; $T_s = 323$, $n = 42$ weeks, $0.05 < P < 0.10$). There were no data from two-observer watches in 1996.

Distribution Around Vessel.—The combined 1997-2001 data from times with no airgun operations did not show a significant difference in the positions of seal sightings relative to the vessel with one vs. two observers ($T^2 = 4.66$, $n = 159, 99$, $0.25 > P > 0.10$). (There were too few data in 2001 to complete a single year analysis.) When both one and two observers were on watch, sightings were most commonly ahead of the vessels, with slightly more on the port than on the starboard side (Fig. 3.14A, B).

Sightability at Night.—The detectability of seals by observers on the source vessels undoubtedly varied with the level of ambient light, as affected both by time of day and meteorological conditions. Most importantly, darkness had a pronounced effect on the observers' abilities to detect marine mammals. No seals were observed during the relatively few periods of night observation (total 2.8 h, Table 3.4) during the 2001 field season. Similarly, no seals were observed during darkness in 1999 or 2000 (Moulton and Lawson 2000, 2001). Only one seal was seen at night during monitoring of BP's seismic operations in 1996-97 (Harris et al. 1997, 1998), and only one during monitoring of Western Geophysical's seismic operations in 1998 (Lawson and Moulton 1999). In view of the demonstrated ineffectiveness of an observer's ability to detect marine mammals in darkness, it would be appropriate to consider terminating the nighttime monitoring in the future.

Observers were equipped with third-generation light amplification devices in 1997 through 2001, and "generation 2+" devices in 1996, but these offered a relatively poor field of view, low contrast, and no means to estimate distance. Sighting ringed seals with these devices is difficult. We had hoped that sighting might be enhanced by the use of high-output floodlights oriented forward if these were positioned and aimed to minimize glare from the vessel superstructure. The new floodlights added to the *Arctic Star* during 1999 and again used in 2000 and 2001 illuminated distances out to approximately 100 m around the front and sides of the vessel. The *Peregrine* was also equipped with high-intensity crab lights mounted over its bow.

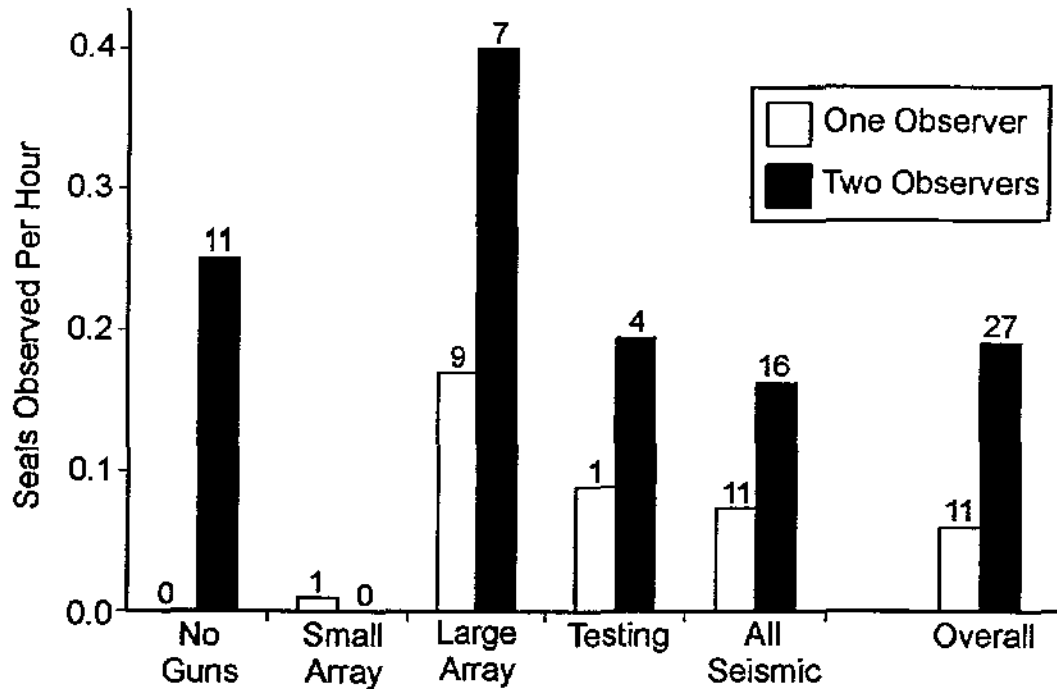


FIGURE 3.12. Numbers of seals seen per hour of daylight observation with one vs. two observers on duty, 2001, subdivided by seismic category. Values above columns show total numbers of individual seals seen.

TABLE 3.11. Numbers of seals seen per hour of daylight observation with one vs. two observers on duty in 2001.

	Seismic State					Total
	No Guns	Small Array	Large Array	Ramp-up	Testing	
A. One Observer						
Hours of Observation	41.4	89.2	53.9		6.2	190.6
No. of Seal Sightings		1	9		1	11
No. of Seals Observed		1	9		1	11
No. of Seals Observed/h	0.00	0.01	0.17		0.16	0.06
B. Two Observers						
Hours of Observation	43.8	62.0	17.4	10.3	9.3	142.8
No. of Seal Sightings	10		7	5	4	26
No. of Seals Observed	11		7	5	4	27
No. of Seals Observed/h	0.25	0.00	0.40	0.48	0.43	0.19

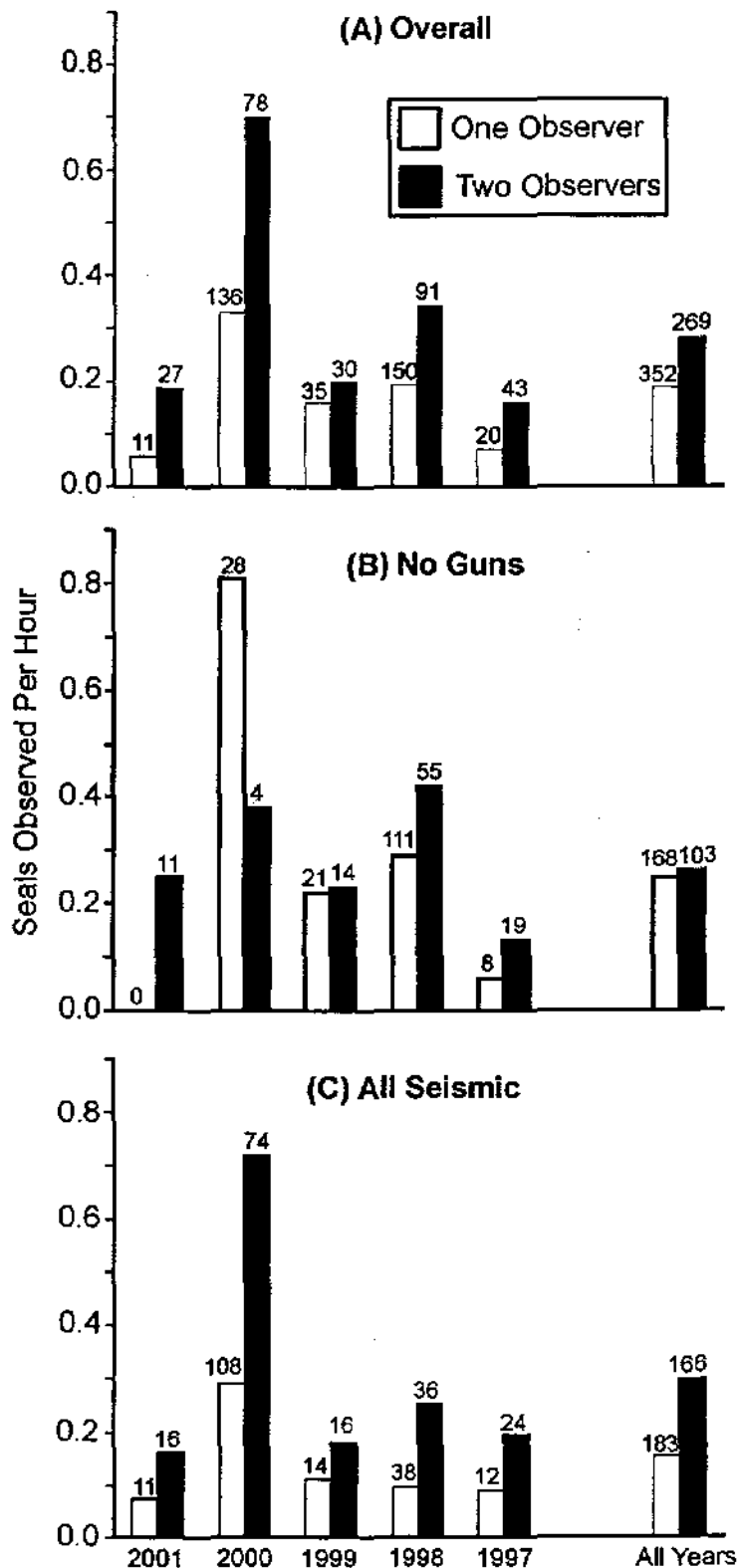


FIGURE 3.13. Numbers of seals seen per hour of daylight observation with one vs. two observers on duty, 1997 to 2001, subdivided by seismic category: (A) Overall (includes periods with and without seismic operations), (B) No Guns, and (C) All Seismic. Values above columns show total numbers of individual seals seen.

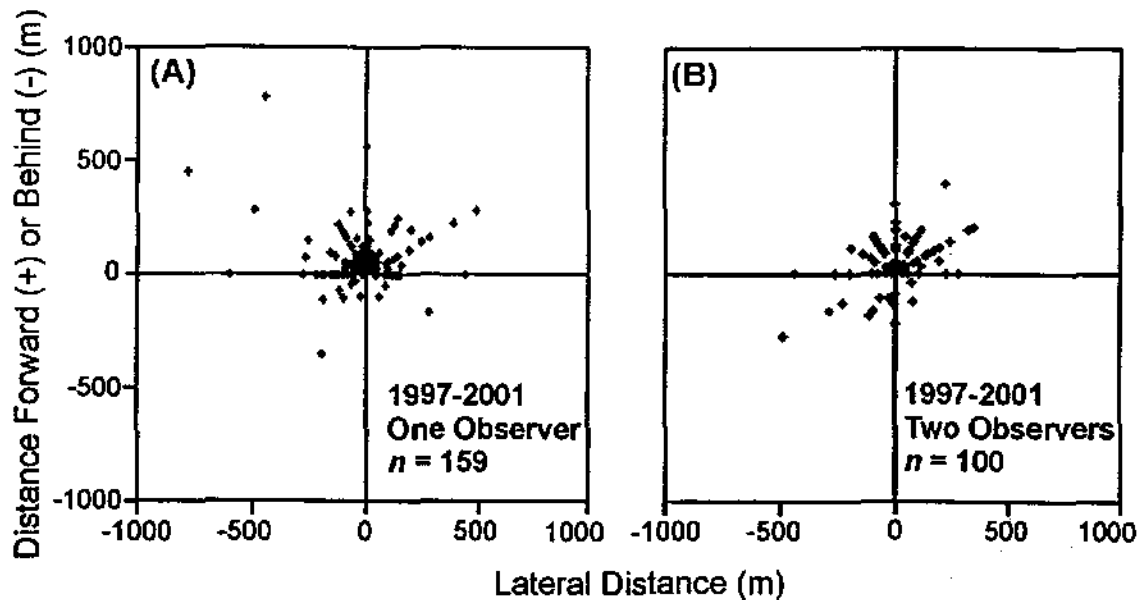


FIGURE 3.14. Effect of number of observers on relative bearings and distances to seal sightings during non-seismic periods in 1997 to 2001. One meter equals 3.28 feet.

3.4 Estimated “Take”

It is difficult, for several reasons, to obtain meaningful estimates of “take by harassment”: (1) The relationship between number of seals observed and number actually present is uncertain. (2) The most appropriate criteria for “take by harassment” are uncertain. (3) The distance out to which received sound level exceeds any given criterion such as 190 dB, 180 dB or 160 dB re 1 μ Pa (rms) is variable, depending on water depth, airgun depth, and perhaps aspect (Greene et al. 1997, 1998, 2000; Burgess et al. 1999; Greene and McLennan 2000; Greene in prep.). Also, the sounds received by seals vary depending on the depth of the seal in the water, and will be considerably reduced for seals at the surface (Greene and Richardson 1988). This section applies several methods to estimate “take by harassment” as a result of airgun operations. We do not attempt to estimate the numbers of seals disturbed by vessels participating in the seismic program but not firing airguns.

In this section, we assume that the sound levels received from both the 320 in³ and 1210 in³ airgun arrays were 190 dB re 1 μ Pa (rms) or more at distances up to 100 m in <10 m water depth and at distances up to 160 m in >10 m water depth. These were the distances specified in the IHA (see Table 1 in Appendix A) and were the safety radii implemented in the field. The received level of sound had almost always diminished below 190 dB re 1 μ Pa (rms) at the 100 m and 160 m distances, based on analyses completed in November 2000 (Greene and McLennan 2000). The assumed 190 dB radius is precautionary in the sense that it usually overestimates the actual 190 dB radius. Indeed, new analyses by Greene (in prep.) estimate that the 190 dB radii were much smaller than the safety radii implemented in the field, especially for the 320 in³ array (see Table 3.2). The safety radius for ramp-up, small-array, and seismic testing was also assumed (in a very precautionary manner) to be the same as that for the full array as then configured. In this section, seals that apparently remained at the surface, and thus received lower levels of sound, are not distinguished from those that dove.

3.4.1 Estimates Based on Direct Observation

In 2001, eight seals were seen within the safety radii (100 m or 160 m) during daytime seismic operations, including production seismic, standby shooting with large and small array, line changes, testing, and ramp-ups. The eight seals include

- 7 seals within 100 m of the arrays operating at 1 and 2.3 m gun depths in water depths <10 m,
- 1 seal within 160 m of the 1210 in³ array operating at 2.3 m gun depth in water depths >10 m

Repeat sightings of the same seal are not counted.

Seals Seen Within Safety Zones During Daytime.—For purposes of this discussion, it is assumed that all seals sighted within the applicable safety radii during airgun operations (see Table 3.2) were potentially disturbed. In total, eight seals (all ringed seals) were seen in these situations during daylight observations in 2001. (This includes six seals shown in Table 3.6 as being within the updated safety radii, plus an additional two that were within the larger safety radii specified in the IHA.) Observations were conducted during all daylight hours while seismic operations were underway. Almost all of the identified seals seen in 2001 were ringed seals (Table 3.6). Three spotted seals and no bearded seals were identified in 2001; the spotted seals were seen when the airguns were not firing.

Allowance for Seals Missed at Night.—No seals were seen from the seismic vessels during darkness in 2001. Seals undoubtedly were present during the limited amount of seismic activity in darkness, so an allowance should be made for seals that were present but not seen in these conditions. As in previous years, this number was derived by assuming that the rates at which seals were encountered during darkness were the same as those during daylight. For all types of airgun operations combined (single gun, large and small array, ramp-up, and testing), the number of hours of operations conducted in darkness was multiplied by the average sighting rate during corresponding conditions in daylight. There were 2.8 hours of airgun operations of all types during periods of darkness (Table 3.4). During the day, seals were encountered within the original safety radii (100 m and 160 m) around the source vessels at a rate of 0.02 seals/h (8 seals ÷ 333.4 h) during all seismic operations. Therefore, it is most likely that no seals were encountered within the safety radii during the 2.8 hours of nighttime seismic operations in 2001.

Thus, *eight seal takes* might have occurred within the original safety radii during nighttime and daytime operations. This represents the estimated maximum number of seals that would have been visible within the safety radii if all seismic operations had been conducted during daylight. The eight seal “takes” would all be ringed seals.

Strong Behavioral Reactions Beyond Safety Zones.—In addition to the numbers of takes quoted above, it would be reasonable to include as “taken” any additional seals beyond the applicable safety radii that showed strong behavioral reactions. To be conservative, we assumed that any seal for which behavior was recorded as “swim away”, “flee” or “thrash” was disturbed, regardless of the “pace” of the behavior (“vigorous”, “moderate” or “sedate”). We observed eight seals (five ringed seals and three unidentified seals) showing such “avoidance” of the seismic array at radial distances beyond the original safety radius during daylight seismic operations. Assuming similar avoidance rates by day and night, no additional seals were estimated to “avoid” the airgun array in darkness.

If these eight seals are added to the preceding estimates of take, the total estimated number of “takes by harassment” is 16. Some of these may have involved repeated takes of the same seal, given the proximity of adjacent seismic lines (500 m apart) and various overlaps in seismic source lines associated with adjacent lines, adjacent patches, line changes, etc. Almost all of these 16 seal takes would be ringed seal takes.

3.4.2 Indirect Estimate Based on Seal Density

Not all of the seals present within the safety radii were visible to vessel-based observers, even during daylight. Thus, the direct estimates of "take" described above do not account for all seals present. Indirect estimates can be made based on the estimated density of seals in the area (Harris et al. 1997, 1998; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001).

Estimating Density.—In 2001, as in 1996-2000, sightability became progressively lower in all lateral distance categories beyond 50 m than at lateral distances 0 to 50 m (Fig. 3.10). The seal density in the area was estimated from the number of individual seals seen in the 100-m (328 ft) strip centered on the vessel's trackline (i.e., at lateral distances 0 to 50 m), considering daytime periods when no airguns were firing and when two observers were on watch. During observations under these conditions in 2001, two ringed seals were seen during 43.8 h of watches from the seismic vessels. These seals were seen along about 394.8 km (213.2 n.mi) of vessel seismic trackline (see §2.2.5) or within an area of about 39.5 km².

Hence, the observed seal density within the central 100-m strip during daytime watches with no airgun operations and with two observers was about 0.051 seals per km². This estimate is not affected by the fall-off in sightability beyond 50 m, as it is based only on sightings within 50 m of the vessel's trackline. However, it does not allow for any seals that were not visible at the surface or that were at the surface but were not detected by two observers as the vessel passed close to their locations.

Estimated Number of "Takes" Within Safety Radii.—A total area of about 452.6 km² was within the various safety radii at one or more times during the season. Based on the estimated density value of 0.051 seals/km², as many as 23 seal takes are estimated to have occurred during the 2001 open-water seismic operation. Assuming that the percentages by species were the same as those documented for the 2001 season as a whole (Table 3.5 – 90 % ringed seals and 10% spotted seals), the estimated 23 takes consisted of 21 ringed seals and two spotted seals. These figures are undoubtedly overestimates because, for the majority of the time, the actual 190 dB (rms) radius was less than the nominal radii used in the above calculations. In addition, the estimates of total seismic distance shot, and therefore total areas within the safety radii, are overestimated because they are based on the nominal speed of the source vessel. It was not uncommon for the vessel to operate its seismic array at speeds less than 9.0 km/h due to mechanical or logistical limitations.³

Some of these "takes" involved repeated "takes" of the same individual seals because the source lines for each patch extended beyond the receiver cable boundaries (Fig. 2.13). Thus, parts of the source lines for one patch often overlapped source lines for adjacent patches, with the result that production shooting occurred frequently along line segments that had been shot previously during coverage of other adjacent patches. For these reasons, some seals were presumably "taken by harassment" more than once during the 2001 season. For this reason, as well as others mentioned above, the number of "takes" as estimated above (23) presumably exceeded the number of individual seals taken.

Estimated Number of Seals "Taken" Within Safety Radii.—The number of seals taken one or more times can be estimated based on the average density of seals derived above (0.051 seals per km²) and on the total water area that was within the safety radius (as defined in the IHA) one or more times during the field season.

³ The estimate of total length of seismic lines shot includes distances traveled during airgun operations on source lines, line changes, ramp-ups and testing, and assumes a constant source vessel speed of 9.0 km/h. The source vessel speed was slightly lower in 1999-2001 than in 1998 due the necessity of reducing array towing speeds during some operations in shallow water or amongst ice floes.

To estimate the potentially affected area, we first defined the area where WesternGeco conducted seismic surveys in 2001. This was done by drawing the appropriate buffer (100 or 160 m) around each source line. We excluded from the buffer all mainland and island areas, and all areas where the water depth was less than 3 m. The various areas were calculated by a Geographic Information System (MapInfo) based on digital maps of the "patches" shot during the 2001 seismic program. A total area of 124.3 km² (48.0 mi.²) was estimated to have been within the original safety radii, as defined in the IHA, at some time during the 2001 season.

Based on the estimated density value of 0.051 seals per km², as many as six individual seals (five ringed seals and one spotted seal) are estimated to have been taken during WesternGeco's 2001 open-water seismic operation. This figure is an approximation. For the majority of the time, the actual 190 dB (rms) radius was undoubtedly less than the nominal radius used in the above calculations. On the other hand, the assumed seal density was probably underestimated as it excludes seals below the surface or otherwise missed by observers. Also, because of the previously-described overlaps, some of these seals were probably "taken by harassment" more than once during the 2001 season.

Estimated Number of Seals Exposed to 160 dB Received Level.—The IHA did not include a formal requirement to estimate the number of seals exposed at levels other than ≥ 190 dB re 1 μ Pa (rms). However, the monitoring plan called for an estimate of the number exposed to received levels ≥ 160 dB re 1 μ Pa (rms).

For this discussion, we assumed that all seals within the estimated 160 dB (rms) radii around the active source vessels during array seismic (including ramp-up) may have been exposed to sound pulses with rms received levels as high as 160 dB re 1 μ Pa. These radii were estimated as averaging about 1770 m with airguns operating at ≤ 2.3 m depth in water < 10 m deep and 3590 m with airguns operating at ≤ 2.3 m depth in water > 10 m (see Chapter 3 in Greene and McLennan [2000]). Because the source lines normally were spaced 500 m apart, a seal at a given location within or near a patch would be exposed repeatedly to sounds exceeding 160 dB as the vessel moved back and forth along a series of adjacent lines.

The total area within which sound levels were ≥ 160 dB re 1 μ Pa (rms) at some time during the season was estimated from the area of the "patches" plus the appropriate buffer (which depends on the array operating depth and water depth—see preceding paragraph). This was done with MapInfo as described in the preceding subsection, but using the 1770 m and 3590 m buffers (maximum radius for 160 dB) rather than the smaller buffer corresponding to the 190 dB radius. Again, we excluded shallow waters as described above. The total area thus enclosed is 225.9 km².

Based on the estimated density of 0.051 seals per km², approximately 12 seals (11 ringed seals and one spotted seal) were exposed to sound pulses with rms received levels of 160 dB re 1 μ Pa.

3.4.3 Shutdown of Airguns

In all instances in 2001 when airguns were firing and seals were seen within the safety zones as then designated, the airguns were shut off within a few seconds. During WesternGeco's 2001 seismic program, the airgun(s) were shut down 10 times because of seals within or about to enter the safety radii. During 2001, the interval between seismic impulses was usually 8 to 24 s. In the majority of cases, the airguns were shut off during the interval between the first sighting of the seal and the next scheduled air-gun impulse. It is likely that no seals within the safety zone were exposed to more than one impulse after they were first sighted within the safety radius.

The number of shutdowns for seals within or near the safety zone in 2001 (10) was similar to the numbers experienced during open-water seismic work in 1997 (12; Harris et al. 1998) and 1999 (10; Moulton and Lawson 2000), and much lower than in either 1996 (112; Harris et al. 2001) or 1998 (57;

Lawson and Moulton 1999). The among-year differences in the required number of shutdowns were caused by year-to-year differences in number of hours of operations, seal density, and/or safety radius.

3.4.4 Summary of Take Estimates

The "direct observation" approach discussed above provided an estimate of number of seal "takes". Estimates of "takes" attempt to count each seal every time that it occurred within the safety radius during periods of airgun operations and each time a seal beyond the safety radius exhibited a strong reaction during periods of airgun operations. The estimated number of "seals taken", on the other hand, counts each individual seal once regardless of the number of times it was sighted within the safety radius or exhibiting a strong behavioral reaction.

The following tabulation summarizes the derivation of the "direct observation" estimate of the number of seal takes for 2001. For comparison, it also provides the corresponding 1996, 1997 (from Harris et al. 1997, 1998), 1998 (Lawson and Moulton 1999), 1999 (Moulton and Lawson 2000) and 2000 (Moulton and Lawson 2001) estimates:

<u>Direct Observation¹:</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>1999</u>	<u>2000</u>	<u>2001</u>
Seen within safety zone	160	8	60	14	16	8
Allowance for night	33	2	18	2	1	0
Strong reaction	17	16	12	14	91	8
Total takes	210	26	90	30	108	16

¹ These estimates are derived based on a number of assumptions discussed in the text.

In addition to these "direct" estimates of take, we have also calculated "indirect" estimates of take based on observed seal densities and the total area surveyed by WesternGeco, consistent with those derived for 1996 and 1997 by Harris et al. (1997, 1998) and for 1998 and 1999 by Lawson and Moulton (1999) and Moulton and Lawson (2000, 2001):

<u>Indirect Estimate¹:</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>1999</u>	<u>2000</u>	<u>2001</u>
Number of takes (190 dB)	648	68	940	91	122	23
Number taken (190 dB)	189	54	260	49	50	6
Exposure to 160 dB	404	97	365	146	140	12

¹ These estimates are derived based on a number of assumptions discussed in the text.

In comparison with the "directly" estimated 16 seal takes and the "indirectly" estimated six seals taken in 2001 (all ringed seals except one spotted seal), the Incidental Harassment Authorization issued to WesternGeco for 2001 authorized the taking of up to 400 ringed seals, 50 bearded seals, and 10 spotted seals (see Appendix A, §3[c]). The directly estimated number of seal takes in 2001 was similar to that in 1997 and 1999, and less than those in other years. Based on estimates of seal density, the number of seals "taken by harassment" in 2001 was relatively low, mainly because of the relatively short season, small area shot, small safety radii, and relatively low observed seal density in 2001 as compared with other years. Table 3.12 summarizes the species breakdown of three of the take estimates for 2001 and earlier years, based on the observed proportions of ringed, bearded, and spotted seals each year.

TABLE 3.12. Summary of estimated numbers of seals "taken by harassment" (regular typeface) and exposed to seismic pulses ≥ 160 dB re 1 μ Pa (rms) (italic typeface).

Species	Est. No. ¹ 1996 (BP Alaska)	Est. No. 1997 (BP Alaska)	Est. No. 1998 (Western)	Est. No. 1999 (Western)	Est. No. 2000 (Western)	Est. No. 2001 (Western)
Ringed seal ²						
Direct estimate ³	193	23	88	28	108	16
Indirect estimate (190 dB) ⁴	173	47	256	46	50	5
<i>Exposure to 160 dB</i> ⁵	370	85	359	136	140	11
Bearded seal ²						
Direct estimate ³	15	2	2	1	0	0
Indirect estimate (190 dB) ⁴	14	5	4	2	0	0
<i>Exposure to 160 dB</i> ⁵	30	9	6	6	0	0
Spotted seal ²						
Direct estimate ³	2	1	0	1	0	0
Indirect estimate (190 dB) ⁴	2	2	0	1	0	1
<i>Exposure to 160 dB</i> ⁵	4	3	0	4	0	1
Totals, all species ²						
Direct estimate ³	210	26	90	30	108	16
Indirect estimate (190 dB) ⁴	189	54	260	49	50	6
<i>Exposure to 160 dB</i> ⁵	404	97	365	146	140	12

¹ The 1996 values for particular species (not overall) are different than those cited in Harris et al. (1997) as they have been recalculated using the same method as for 1997, 1998, 1999, 2000, and 2001.

² Some individual seals may be "taken" more than once.

³ The "direct estimates" of numbers of seal "takes by harassment" are based on the number of individuals seen within the 190 dB re 1 μ Pa (rms) safety radii applied during airgun operations in the field; also allows for those present at night and those showing avoidance at distances beyond the 190 dB radii.

⁴ The "indirect estimates (190 dB)" are the numbers of seals estimated to have been within the safety radius at some time during that year's seismic program; these were calculated based on the average densities of seals observed at times when the airguns were not operating.

⁵ Numbers exposed to seismic pulses ≥ 160 dB are also estimated based on average densities of seals in the study area.

3.5 Effect on Accessibility to Hunters

The 2001 seismic operations may have caused small-scale displacement of some seals, as indicated by the lower sighting rates around the source vessel during periods when the airgun array was operating. The avoidance of the area close to the seismic vessel was only partial, as some seals were seen close to the operating seismic vessels in 2001 (as in earlier years). Thus, it is unlikely that the seismic operation caused displacement of seals to an extent that could affect accessibility to hunters.

In the past, hunters have also expressed concern that marine mammals (primarily bowhead whales rather than seals) exposed to industrial noise may become more “skittish” or otherwise difficult to harvest even if they are not physically displaced. In 2001, seals exposed to seismic pulses exhibited a tendency for increased “swimming away” (Fig. 3.7). It is unknown whether this behavioral effect (or other potential effects) would be long-lasting, or if they would reduce, increase, or have no effect on accessibility of seals to hunters. The one study that has examined the duration of effects on seals exposed to airgun pulses found that normal behavior resumed rapidly after the airgun operations ceased (Thompson et al. 1998). In any event, the effects were probably limited to a small area around the operating airgun array.

Hunters from Nuiqsut hunt for ringed and bearded seals at various times of the year, including the open-water season. Insofar as we are aware, no seal hunting was taking place within or near the areas of seismic operations during WesternGeco’s 2001 open-water seismic program. The most important seal hunting area for Nuiqsut hunters is off the Colville Delta, extending as far east as Pingok Island (149° 40’W), where the present seismic program was conducted. However, the Nuiqsut hunters did not notify WesternGeco or LGL of any situations when they felt that WesternGeco’s 2001 seismic program interfered with seal hunting.

3.6 Summary and Conclusions

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 in³) operated for 71.3 hours and the “small array” (normally 8 guns totaling 320 in³) 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 $\mu\text{Pa}_{\text{rms}}$) 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 $\mu\text{Pa}_{\text{rms}}$) radius around the operating airgun array were detectable by vessel-based observers. For the 320 in³ array, the conservatively-estimated 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$ radii were 15 m for airgun operations in <10 m water depth, and 50 m for >10 m water depth. For the 1210 in³ 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.

3.7 Acknowledgements

WesternGeco provided the logistical support needed for the 2001 monitoring work, and BP Exploration (Alaska) Inc. funded the monitoring program. We thank Peter Van Borssum of WesternGeco. The invaluable logistical support of WesternGeco's managers (particularly Doug Wyer), party manager (Michele Palatas), and operational supervisors in Anchorage (John Davis and Bret Schafer) was critical to the success of the monitoring program. We thank Allan Ross and Gwen Perrin of BP for sponsoring the monitoring work. We thank John Davis of WesternGeco and Allan Ross of BP for reviewing the report.

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The vessel-based field work was made possible by the enthusiastic participation of Inupiat observer-communicators Sally Brower, Martha Falk and Billy Adams, plus LGL biologists Peggy Hann, Jim Eddington, and Beth Haley. John Lawson of LGL supervised and participated in vessel-based fieldwork.

Bill Wilson, Shelly Schwenn, and Mike Williams of LGL Alaska Research Associates Inc. provided important and timely logistical support, and handled the administrative duties regarding the Inupiat observers-communicators. We also thank Ted Elliott (LGL, King City) who assisted with processing and analysis of the data. Drs. W. John Richardson and Arturo Serrano of LGL reviewed a draft of the chapter. Kathleen Hester helped keep the project on track and assisted with production of the report, as did Anne Wright. Trish Jarvie kept the project finances in order.

The 2001 work was done under NSB and Alaska State permits authorizing geophysical operations in state waters, and under an Incidental Harassment Authorization issued by the U.S. National Marine Fisheries Service (NMFS), Office of Protected Resources. We thank Rance Wall of MMS, and Ken Hollingshead and Brad Smith of NMFS. Additional general Acknowledgements pertaining to the entire project are given at the end of Chapter 1.

We are also grateful to all those who helped with the corresponding monitoring work during 1996-2000, as acknowledged in previous related reports. Data from the 1996-2000 projects, sponsored by BP Exploration (Alaska) Inc. and Western Geophysical, have been utilized extensively in the present report.

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APPENDIX A: INCIDENTAL HARASSMENT AUTHORIZATION FOR WESTERNECO'S 2001 OPEN-WATER SEISMIC OPERATIONS IN THE BEAUFORT SEA¹

DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE

Incidental Harassment Authorization

WesternGECO LLC, 351 East International Airport Rd., Anchorage, Alaska 99518, is hereby authorized under section 101(a)(5)(D) of the Marine Mammal Protection Act (16 U.S.C. 1371(a)(5)(D)) and 50 CFR 216.107, to take, by harassment, a small number of marine mammals incidental to conducting an ocean bottom cable seismic survey in the Alaskan Beaufort Sea, contingent upon the following conditions:

1. This Authorization is valid only during the open water season from the date of this Authorization through November 1, 2001.
2. This Authorization is valid only for activities associated with conducting ocean bottom cable seismic surveys in the Alaskan Beaufort Sea.

3. General Conditions

(a). The taking, by incidental harassment only, is limited to the species listed under condition 3 (b) below. The taking by serious injury or death of these species, the taking by harassment, injury or death of any other species of marine mammal, or the taking by harassment of a species listed under condition 3 (b) greater than authorized under condition 3 (c) is prohibited and may result in the modification, suspension or revocation of this Authorization.

(b). The species authorized for incidental harassment takings are: bowhead whales (*Balaena mysticetus*), gray whales (*Eschrichtius robustus*), beluga whales (*Delphinapterus leucas*), ringed seals (*Phoca hispida*), spotted seals (*Phoca largha*) and bearded seals (*Erignathus barbatus*).

(c). Limited to harassment, as defined in the Marine Mammal Protection Act, the following numbers of individual animals are authorized for incidental taking during the 2001 open water season: 1,965 bowhead whales; less than 10 gray whales; 250 belugas; 400 ringed seals; 10 spotted seals; and 50 bearded seals.

(d). Without an amendment to this Authorization, authorization for taking by harassment is limited to the following source vessels and acoustic sources during the 2001 open water ocean bottom cable seismic survey:

- (1). R/V *Arctic Star* - 1,210 in³ airgun array:
Twelve 40-150 in³ 2,000 psi sleeve airguns at
eight positions, including two 2-gun 300 in³

¹ NOTE: The style, formatting, and spelling of this Authorization are reproduced exactly as received from NMFS.

clusters and two 2-gun 160 in³ clusters.

- (2). R/V *Peregrine* - 640 in³ airgun array:
Sixteen 40 in³ 2,000 psi sleeve airguns in four
4-gun 160 in³ clusters.

(e). The taking of any marine mammal in a manner prohibited under this Authorization must be reported within 48 hours of the taking to Brad Smith at the Western Alaska Field Office, National Marine Fisheries Service, Telephone (907) 271-5006.

4. Cooperation: The holder of this Authorization is required to cooperate with the National Marine Fisheries Service and any other Federal, state or local agency monitoring the impacts of the activity on marine mammals. The holder must notify Brad Smith at the Western Alaska Field Office, (a) at least 48 hours prior to starting the seismic survey (unless constrained by the date of issuance of this Authorization); and (b) if the survey continues after August 31, 2001, at least 48 hours prior to that date.

5. Mitigation Requirements. The holder of this authorization must:

(a). Horizontally spread out the 640 in³ airgun array, such that the energy from the array will be directed downward as far as possible.

(b). 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 $\mu\text{Pa}_{\text{rms}}$) safety zone (see attached table).

(c). Immediately shut-down the seismic sources whenever any bowhead, gray, or beluga whales are sighted within the area delineated by the 180 dB (re 1 $\mu\text{Pa}_{\text{rms}}$) safety zone (see attached table).

(d). A ramp-up in air volume discharge is required when the source vessel speed is at least 4 knots and the array has been inactive for a period equal to or greater than 1 minute.

(e). A ramp-up in air volume discharge is required when the source vessel speed is reduced to 3 knots or less and the array has been inactive for a period equal to or greater than 2 minutes.

(f). Ramp-up of all seismic sources will begin with an air volume discharge not to exceed 80 in³ for the 1,210 in³ airgun array and 40 in³ for the 640 in³ airgun array. During ramp-up the rate of increase in source level will be no greater than 6 dB per minute.

(g). If seismic surveys occur after August 31, 2001, aerial surveys will be conducted daily, weather permitting (see Monitoring).

(h). To the extent possible, comply with any terms and conditions contained in a Conflict Avoidance Agreement signed by the Holders of this Authorization that would reduce the impact on bowhead whales and other marine mammals that are required for the subsistence of the villages and people of the Alaskan North Slope.

6. Monitoring.

(a). General.

(1) The holder of this Authorization must designate a sufficient number of biologically-trained, on-site individual(s), approved in advance by the National Marine Fisheries Service, to record the effects of the ocean bottom cable seismic survey operations and the resulting noise on marine mammals.

(2). The National Marine Fisheries Service must be informed immediately of any changes or deletions to any portions of the Marine Mammal and Acoustic Monitoring Plan submitted in April 2001 and agreed upon by the peer review panel on June 6, 2001, in accordance with condition 7 (a) of this Authorization.

(b). Vessel-based Visual Monitoring.

(1). Monitoring is to be conducted by biological observers, as described in condition 6 (a) (1) above, onboard both source vessels. At all times, either observers or wheelhouse personnel must be on active watch for marine mammals entering or within the designated safety zone.

(2). If operations continue after mid-August, image intensifiers and additional light sources will be made available and used by the source vessels to illuminate the safety zone.

(3). The R/V *Arctic Star* will have three marine mammal observers (two biologists and one Inupiat). Two observers must be on active watch 30 minutes prior to and during the start of seismic transmissions. A minimum of one observer must be on active watch aboard the *Arctic Star* whenever the seismic sources are operating during daylight hours in order to (a) ensure that no marine mammals enter their respective safety zones described under conditions 5 (b) and 5 (c) whenever the sources are operating, and (b) to record marine mammal activity as described in condition 6 (b) (5) below.

(4). The R/V *Peregrine* will have two marine mammal observers (one biologist and one Inupiat). A minimum of one observer must be on active watch 30 minutes prior to and during the start of seismic transmissions. A minimum of one observer must also be on active watch aboard the *Peregrine* for a total of 16 hours during any given 24 hour period when seismic operations are taking place in order to: (a) ensure that no marine mammals enter their respective safety zones described under conditions 5 (b) and 5 (c) whenever the sources are operating, and (b) to record marine mammal activity as described in condition 6 (b) (5) below. During the hours when a marine mammal observer is not on duty, wheelhouse personnel must actively watch for marine mammals, follow all shut-down procedures if a marine mammal is sighted within the designated safety zones, and notify the marine mammal observer(s) any time a shut-down occurs so that information in 6 (b) (5) can be recorded.

(5). Vessel-based monitoring will include recording the following information in a standardized format:

(a) the species, group size, age/size/sex categories (if determinable), behavior at time of sighting, heading (if consistent), bearing and distance from seismic source vessels, sighting cue, and apparent reaction of all marine mammals seen to the seismic source vessel and/or its acoustic sources;

(b) the location, heading, speed and activity of the vessel (transmitting or not), along with ice cover and sea state, at (i) any time a marine mammal is sighted, (ii) the start and end of each watch, and (iii) during a watch (whenever there is a change in one or more variables); and,

(c) the name of each vessel that is visible within 5 km of the seismic source vessel whenever a marine mammal is sighted, and the time, bearing, distance, heading, speed and activity of the other vessel(s).

(6). All biological observers must provided with appropriate reticulated binoculars.

(c) Aerial Surveys.

(1). If seismic surveys occur after August 31, 2001, aerial surveys will be conducted daily and until one day after the seismic operations end using two biological observers and one biological data recorder, as described in condition 6 (a) (1) above.

(2). Aerial monitoring will include recording the following information in a standardized format:

(a) Marine mammal species, number, age/size/sex class, behavior at time of sighting, heading (if consistent), swimming speed category (if traveling), sighting cue, ice conditions, and inclinometer reading.

(b) An estimate of the level of harassment takes and an assessment of the possible effects seismic operations have on the accessibility of bowhead whales for subsistence hunting.

(3). Survey aircraft must maintain a minimum altitude of 900 feet in areas where no whaling is occurring on that date, and a minimum altitude of 1,500 feet in areas where whaling is occurring on that date.

(4). Direct overflights of whaleboats and Cross Island must be avoided.

(d) Acoustic Monitoring.

(1). If seismic surveys occur after August 31, 2001, the holder of this Authorization is required to collect and analyze acoustic measurements of air guns, whale calls, and ambient noise levels as specified in the Marine Mammal and Acoustic Monitoring Plan. Approved methods for obtaining these measurements include:

(a) Autonomous seafloor acoustic recorders (ASAR) deployed in late August or September; and.

(b) Air-dropped sonobuoys deployed after September 1, 2001.

7. Reporting.

(a). Once monitoring begins, the lead contractor for the holder of this Authorization must consult weekly by telephone with Brad Smith, or his designee, at the Western Alaska Field Office, Alaska Region, National Marine Fisheries Service, Telephone (907-271-5006), providing a status report on the appropriate reporting items found under condition 7 (b), unless other arrangements for monitoring are agreed in writing.

(b). A report on the 2001 open water season must be submitted to the Western Alaska Field Office and the Office of Protected Resources, National Marine Fisheries Service, within 90 days after completion of the work described in this authorization. This report must contain the following information:

(1) Dates and specific locations of the seismic operations;

(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.).

(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 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.

(c). A draft technical report on the reporting items listed above must be submitted to the Western Alaska Field Office, and the Director, Office of Protected Resources, National Marine Fisheries Service, by March 1, 2002.

(d). A final technical report containing a description of the methods, results, and interpretation of all monitoring tasks will be provided to the Director, Office of Protected Resources, National Marine Fisheries Service, no later than April 30, 2002.

(e). Both 90-day and draft reports will be subject to review and comment by the National Marine Fisheries Service. Any recommendations made by the National Marine Fisheries Service must be addressed in the final technical report prior to acceptance by the National Marine Fisheries Service.

8. Activities related to the monitoring described in this Authorization and as described in the April 2001 Marine Mammal and Acoustic Monitoring Plan do not require a separate scientific research permit issued under section 104 of the Marine Mammal Protection Act.

9. The Plan of Cooperation (or Conflict Avoidance Agreement) outlining the steps that will be taken to cooperate and communicate with the native communities to ensure the availability of marine mammals for subsistence uses, must be implemented.

10. A copy of this Authorization must be in the possession of the operator of each vessel operating under the authority of this Incidental Harassment Authorization.

Donald K. Knowles
 Director
 Office of Protected Resources
 National Marine Fisheries Service

Aug 01 2001
 Date

TABLE 1.

SOURCE (in ³)	AIRGUN DEPTH (m/ft)	WATER DEPTH (m/ft)	SAFETY RADII (m/ft)	
			190 dB (Seals)	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	550/1,804
1210	5/16.4	<10/<32.8	160/525	350/1,148
1210	5/16.4	>10/>32.8	260/853	900/2,953
640	1/3.3	<10/<32.8	100/328	150/492
640	1/3.3	>10/>32.8	160/525	550/1,804

APPENDIX B: RECEIVED LEVELS VS. RANGE FOR THE 8-GUN, 320 IN³ SLEEVEGUN ARRAY USED IN 2001¹

Introduction

During its 2001 OBC seismic operations in the Beaufort Sea, WesternGeco employed half of a 640 in³ airgun array composed of 16 identical airguns. Four clusters of four 40-in³ airguns (total of 16) were swung out from two positions on the port and two positions on the starboard side of source vessel R/V *Peregrine* (see Fig. 2.8 in Chapter 2, SEISMIC PROGRAM DESCRIBED, 2001). Because only half of these airguns were fired during production seismic operations, the active array was actually 8 airguns with total volume 320 in³. This array was operated primarily in shallow waters inshore of the barrier islands at a gun depth of 1 m. Acoustic measurements to document levels, characteristics, and propagation of underwater sounds emitted by the 320 in³ source were not required in August 2001. For mitigation purposes, the safety radii for marine mammals employed by observers aboard the *Peregrine* were the same as used for the larger 12 gun, 1210 in³ array used by the R/V *Arctic Star* in 2001. These safety radii were based upon actual acoustic measurements near the 1210 in³ array in 1999, as presented by Greene et al. (2000).

As part of an analysis of sounds from airgun arrays used in the central Alaskan Beaufort Sea from 1996 to 2000, C.R. Greene (in prep.) derived new estimates of the distances within which received sound levels diminished to ≤ 190 dB re 1 μ Pa, averaged over the pulse duration. Results are summarized in Table 3.2 of the present report (in Chapter 3, SEALS, 2001). These revised safety radii were (when possible) based upon acoustical measurements of sounds from the specific arrays in question, supplemented by statistical derivations for situations in which direct acoustical measurements were not available. The revised radii account for array depth, water depth, number of airguns, array volume, and aspect (bow vs. stern). As there were no acoustic measurements for the 320 in³ array used in 2001, previous measurements of the sounds from different arrays were used to derive estimates of received levels vs. distance. This Appendix briefly describes the derivation of estimated distances within which sounds from the 320 in³ array diminished to ≤ 190 , 180 and 160 dB re 1 μ Pa rms, considering both shallow water (<10 m) and deeper water (>10 m). More details will be available in Greene (in prep.).

Methods

Greene (in prep.) derived a regression equation (least-squares fit) based on all acoustic measurements acquired from various airguns and arrays operated in the general Prudhoe Bay area during the open-water seasons of 1996-2000. These measurements were acquired at distances ranging from <100 m to several kilometers from the source, usually for both bow and stern aspects. In the recent re-analysis, only the data from distances >100 m were used in order to minimize the use of beam aspect data. In some cases the minimum distance had to exceed 500 m to be in a near end-fire situation. The airgun arrays used in 1996-2000 varied from year to year in terms of number of airguns and total volume. Also, arrays were deployed at different depths below the surface, and operated in different water depths. All of these variables influence sound levels and were included in the regression analysis. The independent variables in the regression analysis were number of airguns, total array volume, array depth, water depth, distance from the source, and whether the aspect was bow or stern. The dependent variable was the received sound pressure level (a root-

¹ By C.R. Greene Jr., Greeneridge Sciences Inc.

mean-square pressure level in decibels referred to one micropascal). Because the decibel is a logarithmic measure, logarithms were taken of all the predictor (=“independent”) variables. Received level (RL) varies inversely with distance, so a log(R) term is appropriate. However, sound absorption and scattering losses occur exponentially with distance, so a linear term in R was also appropriate.

The result of the least-squares regression was an equation with a negative coefficient for the log (volume) term. Such a result is not realistic; it is unrealistic to expect the received level to decrease with increasing array volume. We expect that this physically unrealistic result occurred because of strong correlations between some of the predictor variables, e.g., number of guns and total volume. Several of the arrays for which sound measurements were available were arrays involving different numbers of 120 in³ airguns. Thus, the least-squares fit was repeated with the volume term omitted. The result was the equation

$$\text{RL (dB re } 1 \mu\text{Pa)} = 180.2 - 17.7 \log (R) - 0.0039 R + 13.9 \log (N) + 9.4 \log (D_s) + 26.9 \log (D_w) + 1.7 \text{ Aspect} \quad (1)$$

Here R is the distance (m) from source to receiver, N is the number of airguns, D_s is the source depth in m, and D_w is the water depth in m (presumed the same or nearly so at source and receiver). Aspect was +1 for bow and -1 for stern; few measurements at other aspects were available and those few data were not used. The coefficient of determination (R^2) for this equation was 0.68 and the standard error was 8.7 dB, with 2892 degrees of freedom (nominally).² The regression accounted for 68% of the variation in the data, but did not account for the other 32%. However, it served to show some relationships between the received levels and the parameter values. In particular, it showed about 9 log (D_s) increase with increasing source depth and about 27 log (D_w) increase with increasing water depth. These relationships would not be expected to hold below water depths of about one-half wavelength, or 25 m for a dominant frequency of 30 Hz (an appropriate dominant frequency for these airguns).

From theoretical considerations, one generally expects the received sound pressure to vary directly with the number of airguns, i.e. received level proportional to 20 log (N), and to vary with the cube-root of the volume, i.e. received level proportional to 6.67 log (V).

Among the available acoustic measurements were several acquired in 1999 under different source and water depth conditions for a 12-gun, 1210 in³ array (Greene et al. 2000). Based on those data, equations were derived to predict received levels that would exceed 95% of the measured values, i.e., to predict received level vs. range curves that skim along the top of the scatter plot of measured data. These equations were derived for the purpose of calculating safety radii that would be conservative (precautionary) in nature, i.e., greater than might be necessary a high proportion of the time. Those results can be used, along with the above-described factors relating received level to number of airguns, array volume, water depth, and gun depth, to estimate received level vs. range equations appropriate for a 320 in³ array operating in various situations.

For the 12-gun, 1210 in³ array measured in 1999 at source depth 2.3 m and water depth 8 m (i.e., <10 m), the bow aspect data gave the greatest safety radius and the conservative least-square fit equation was

$$\text{RL (dB re } 1 \mu\text{Pa)} = 218.4 - 16.8 \log (R) - 0.0026 R \quad (2)$$

² It is recognized that data from sequential shots were not necessarily statistically independent, and thus that the true degrees of freedom (df) were less than the nominal df. For present purposes, this was not considered to be a problem, as did not attempt to assess the statistical significance of relationships.

for R in meters. Adjusting for a source depth 1 m, the correction factor is $9 \log (1/2.3) = -3.26$ dB; adjusting for 8 airguns vs. 12 airguns, the correction factor is $20 \log (8/12) = -3.52$ dB; adjusting for volume 320 in³, the factor is $6.67 \log (320/1210) = -3.85$ dB. The overall adjustment is -10.6 dB. The new estimated conservative equation for the 320 in³ array in water 8 m deep is

$$RL \text{ (dB re } 1\mu\text{Pa)} = 207.8 - 16.8 \log (R) - 0.0026 R \quad (3)$$

For the 12-gun, 1210 in³ array with source depth 2.3 m and water depth 23 m, the bow aspect data gave the greatest safety radius and the conservative least-square fit equation was

$$RL \text{ (dB re } 1\mu\text{Pa)} = 235.5 - 20.9 \log (R) - 0.0004 R \quad (4)$$

for R in meters. Using the same adjustments as for Equation (3), the new estimated conservative equation for the 320 in³ array in water 23 m (i.e., >10 m) deep is

$$RL \text{ (dB re } 1\mu\text{Pa)} = 224.9 - 20.9 \log (R) - 0.0004 R \quad (5)$$

Results

Equation (3) was used to solve for the distances where received sound levels were ≤ 190 , 180 and 160 dB re 1 μ Pa in the case of the 320 in³ array operating in shallow water. These distances were 15, 50 and 570 m, respectively.

Equation (5) was used to solve for the distances where received sound levels were ≤ 190 , 180 and 160 dB re 1 μ Pa in the case of the 320 in³ array operating in deeper water. These distances were 47, 140 and 1210 m, respectively. The 47 m value was rounded up to 50 m as a conservative estimate of the 190 dB distance. These values were all for bow aspect.

Discussion

The small 8-gun array used in 2001 was not towed behind the gun boat as was the case with the 12-gun array whose measurements were the basis of these predictions. In 2001, the airguns were suspended in pairs from four points around the gun boat, two on each side. Thus, there would be little basis for expecting a difference between bow and stern aspect. The bow aspect data from the 12-gun array provided the longest safety radii, so that seemed appropriate for deriving a conservative result in the case of the 8-gun array.

Acknowledgement

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