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 μPa 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 in^3. With the exception of 0.6 h of seismic testing involving the use of the full 640 in^3 array, all of the production seismic (154.0 h) was conducted with only half of this array in operation —

320 in^3. Hence, the array operated by the *Peregrine* is referred to hereafter as having a volume totaling 320 in^3. Alternating with the *Peregrine*, the second source vessel, *Arctic Star*, towed an array of 12 airguns with total volume 1210 in^3—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 in^3 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 walruses) 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 μPa_{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 ITT 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 in^3 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 "I" entered under the "First Substrate" and "W" in the "Second Substrate". If the seal remained on the ice, there would be two "I" 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 in^3 and 1210 in^3 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 µPa (rms):

- For the 320 in^3 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 in^3 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 in^3 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 in^3 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 μPa_{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 in^3. During 1997, the maximum array size was a "Small Array" of 6 airguns totaling 720 in^3 (aside from 1 hour of operations with a 810 in^3 6-airgun array and 1 min of operations with a 900 in^3 7-airgun array).

[c] In 1998, one airgun on the *Arctic Star* (used only at the start of ramp-up) equaled 80 in^3 and the 16-airgun array totaled 1500 in^3; one airgun on the *Saber Tooth* equaled 70 in^3 (used only at the start of ramp-up) and the 8-airgun array totaled 560 in^3.

[d] In 2001, one airgun on the *Peregrine* equaled 40 in^3 (used only at the start of ramp-up) and the 8-airgun array totaled 320 in^3 ; one airgun on the *Arctic Star* (used only at the start of ramp-up) equaled 80 in^3 and the 12-airgun array totaled 1210 in^3.

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.).

					Safety Radii (m) (190 dB)	
Year	Seismic Category	Source (in^3)	Operating Depth (m)	Water Depth (m)	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 in^3 airgun (primarily a 40 in^3) 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 in^3 (aside from 1 hour of operations with a 810 in^3 6-airgun array and 1 min of operations with a 900 in^3 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.).

					Updated Safety Radius Category (m)			
	Seismic Category	Operating Depth (m)	Water Depth (m)	Safety Radius (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.

	Hours of Observation During Weeks 1-4					
	Week One	Week Two	Week Three	Week Four		
Seismic State	2 Aug - 9 Aug	10 - 16 Aug	17 - 23 Aug	24 - 26 Aug	Total	%
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 in^3, but of these only half were operated for a total of 320 in^3; these guns fired at 1 m below the surface. The *Arctic Star* towed a "large array" of 12 airguns totaling 1210 in^3, 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 in^3. Most production seismic operations by the *Arctic Star* in 2001, as in 1999-2000, involved the use of 12 airguns with volumes totaling 1210 in^3. Harris et al. (1997, 1998) categorized array size in 1996-97 as "small array" ($\leq$840 in^3) and "large array" (>840 in^3, 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 in^3) 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 in^3) 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.

	Survey Effort													
	1996		1997		1998		1999		2000		2001		1996-2001	
Seismic State	**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	46.6	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.

	Number of Seals							
		Identified		Ringed Seal		Spotted Seal		Unidentified
Seismic State	Total No.	No.	% of Total	No.	% of Identified	No.	% of Identified	No.
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.

		Number of Seals									
			Identified		Ringed Seal		Bearded Seal		Spotted Seal		Unident.
Seismic State	Year	Total	No.	% of Total	No.	% of Identified	No.	% of Identified	No.	% of Identified	No.
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**	**12**
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	10.5	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**	**83**
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**					**11**
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**	**88.2**	**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**	**60**

[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).

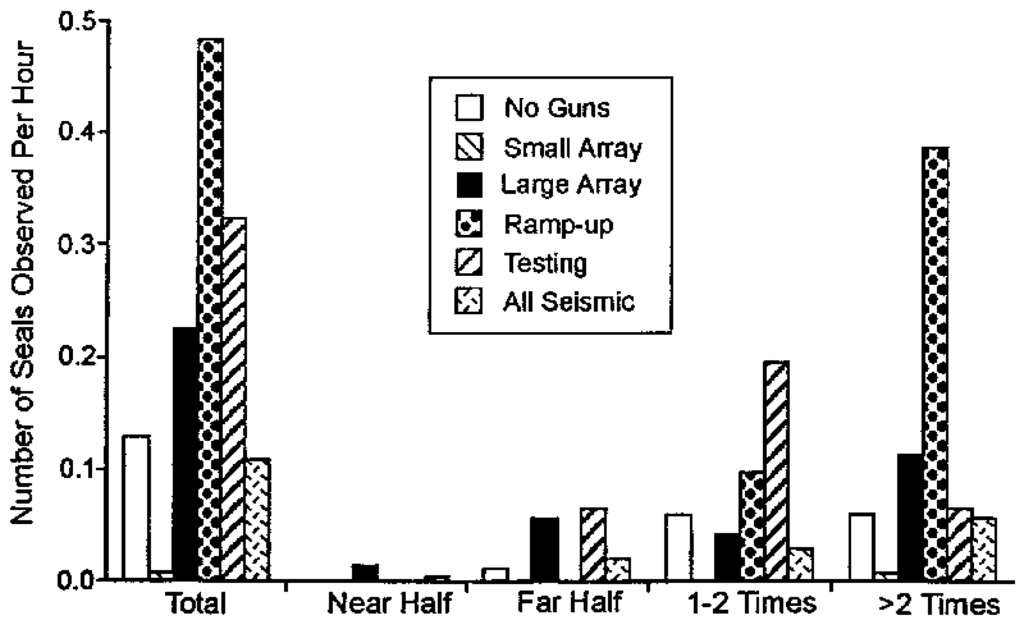

FIGURE 3.1. Numbers of seals seen in 2001 per hour of daylight observation by seismic state and distance from the source vessel relative to the updated safety radius. Safety radii defined as described in Table 3.3.

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; $T_s = 237$, $n = 43$ 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].

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[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.

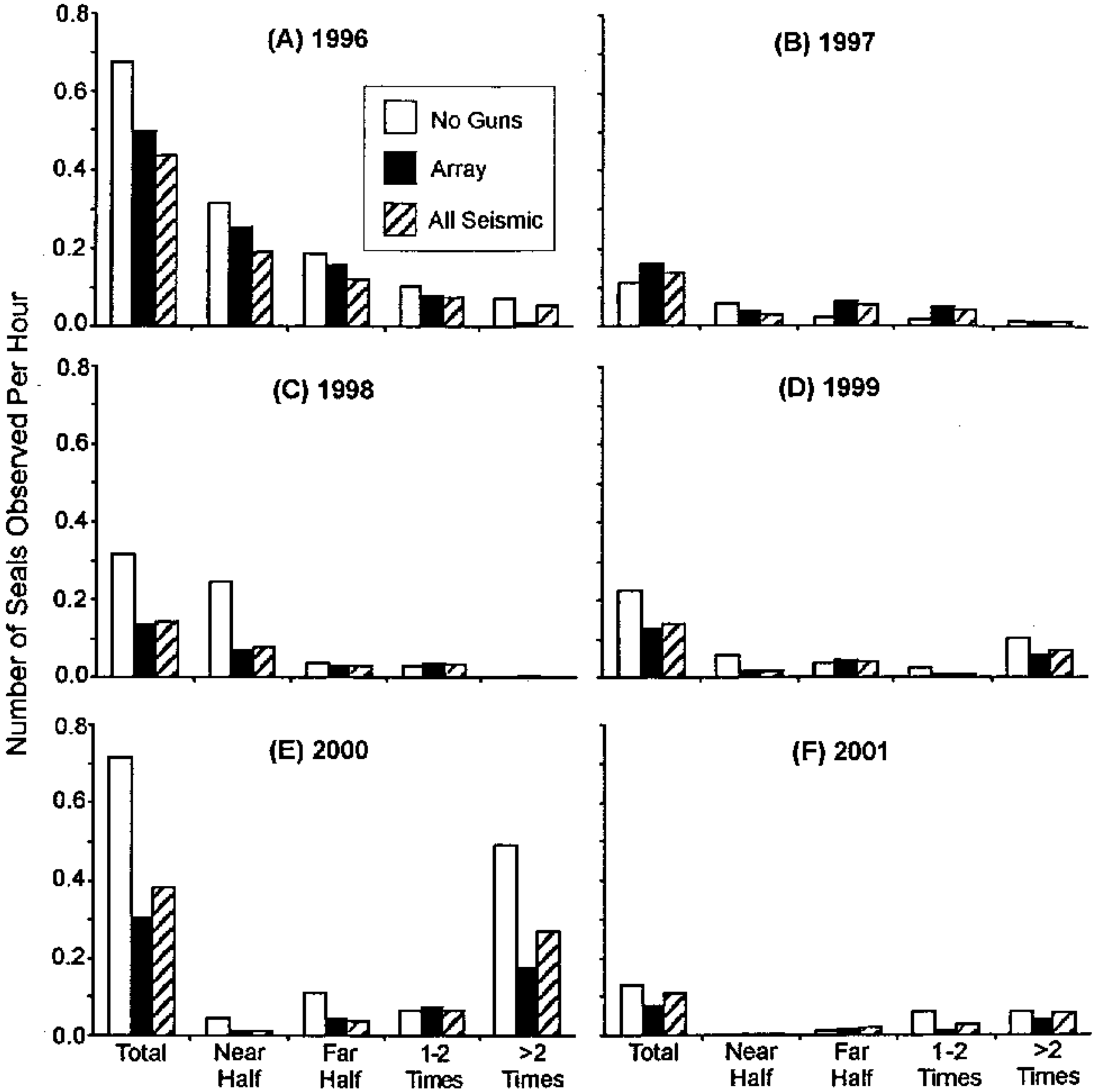

FIGURE 3.2. Numbers of seals seen per hour of daylight observation by seismic state and distance from the source vessel relative to the updated safety radius in 1996 to 2001. Table 3.3 lists the safety radius for each array and operating depth and the sizes of the four distance categories in each year.

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

		Within Safety Radius						Beyond Safety Radius						All Distances					
		Non-Seismic		Array Seismic				Non-seismic		Array Seismic				Non-seismic		Array Seismic			
Year	Test Type	Mean Dist. (m)	*n*	Mean Dist. (m)	*n*	*U*	*P* [a]	Mean Dist. (m)	*n*	Mean Dist. (m)	*n*	*U*	*P* [a]	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 stem. 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).

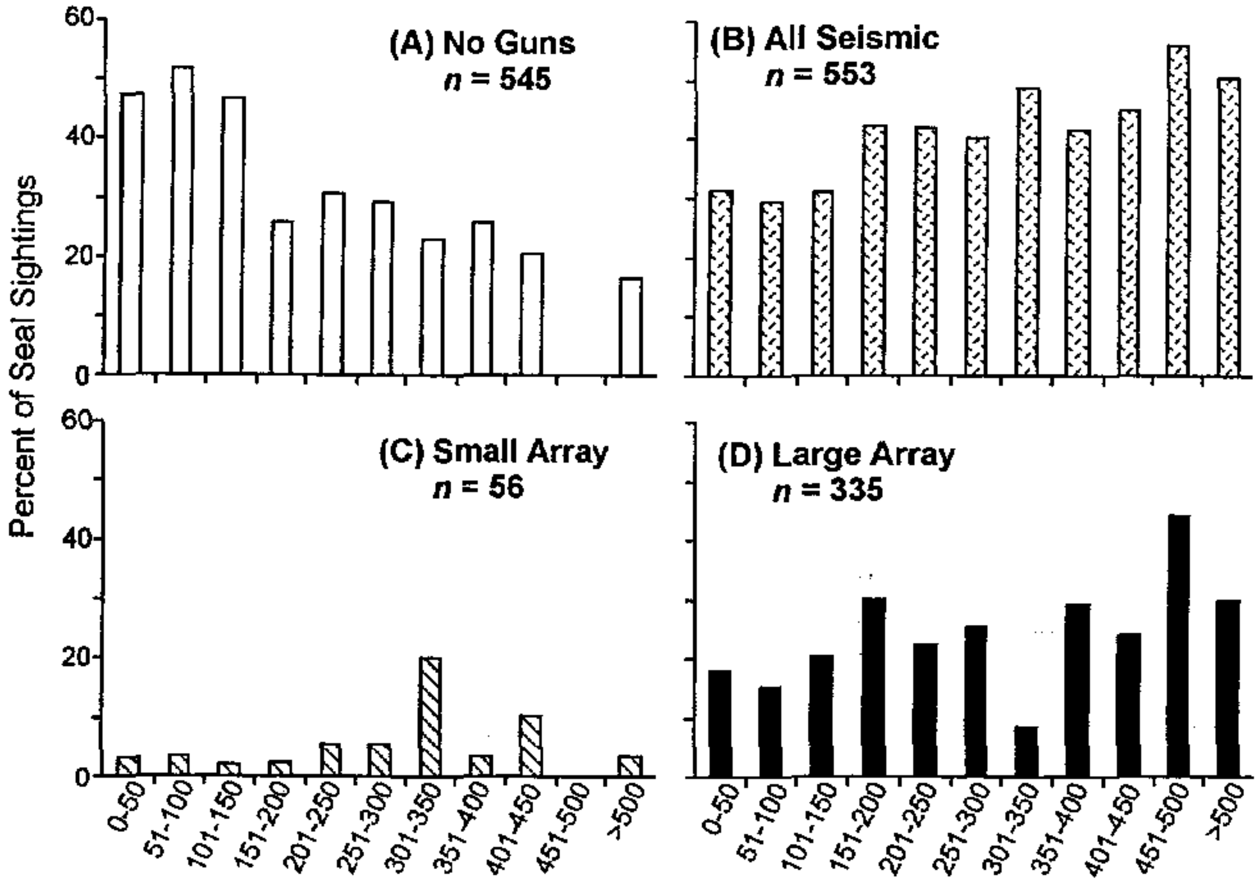

FIGURE 3.3. Percentages of seal sightings in daylight by seismic state and distance from the source vessel, 1996 to 2001 combined. The "All Seismic" category can contain seismic testing, ramp-ups, single-gun OBRL, and unknown seismic operations, and thus can represent up to 100% of the sightings in any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

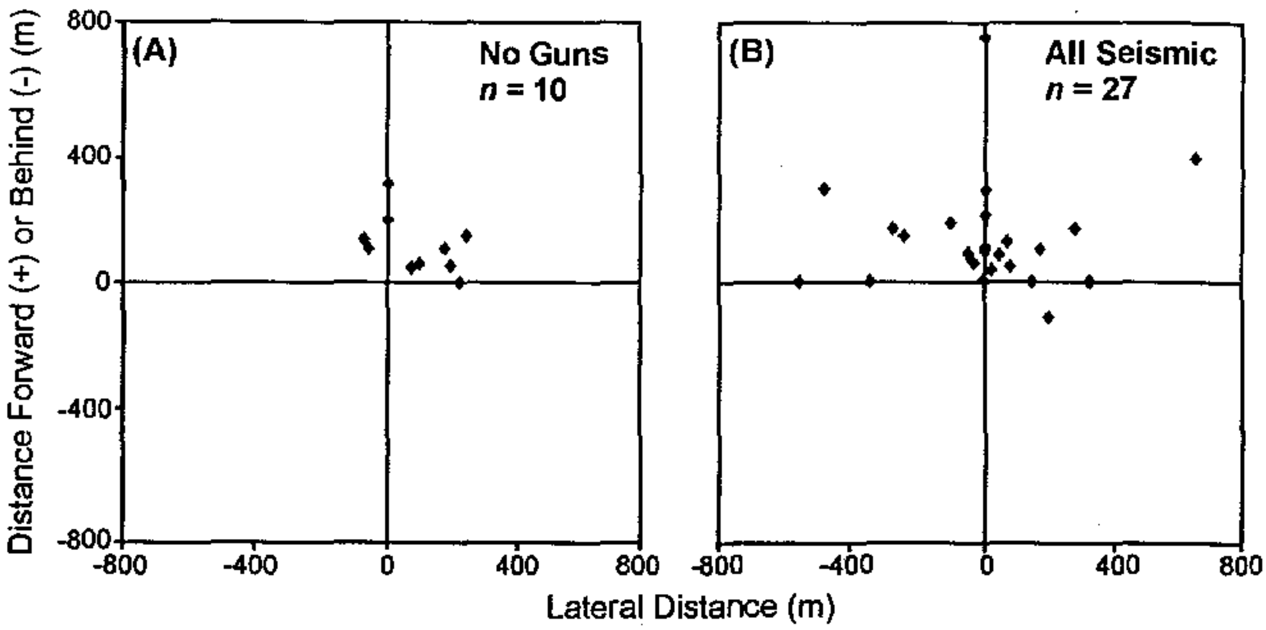

FIGURE 3.4. Relative bearings and distances to seal sightings during the 2001 seismic operations from *Arctic Star* and *Peregrine*. Bearings and distances are measured relative to the observation site on the bridge. One meter equals 3.28 feet.

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.

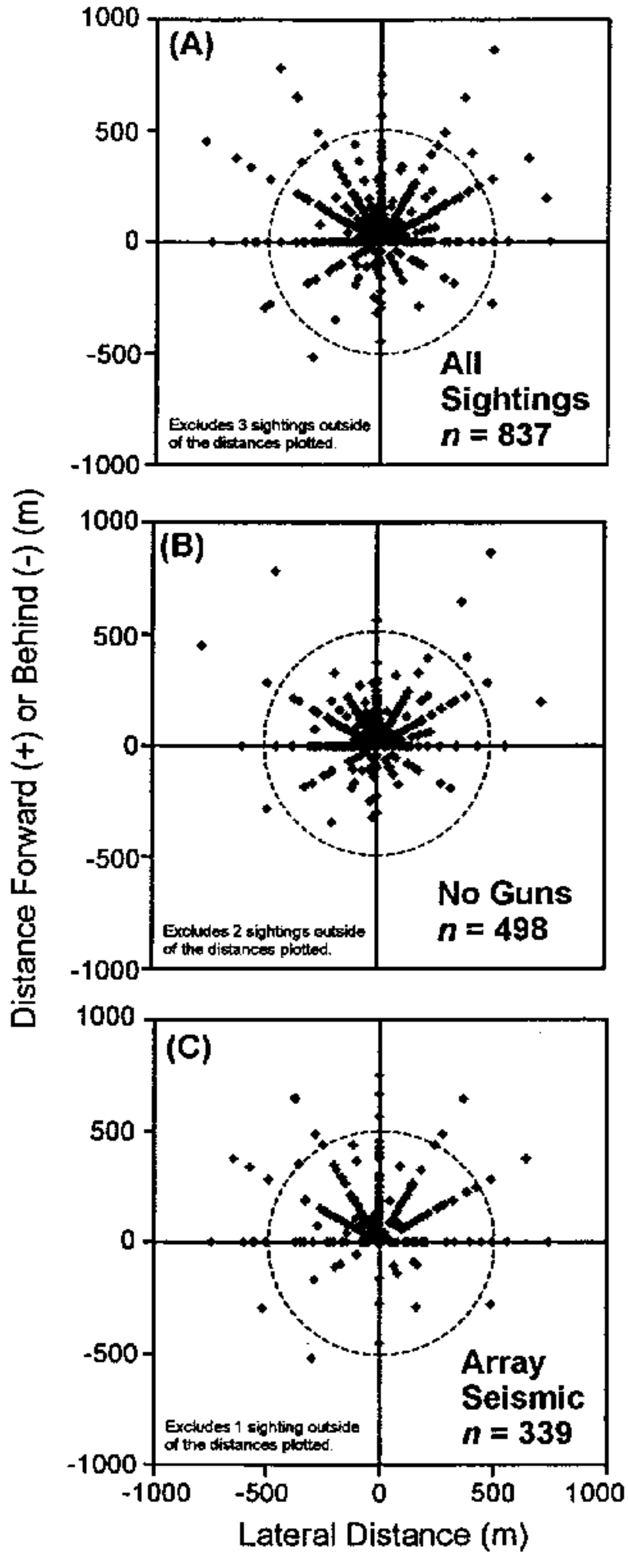

FIGURE 3.5. Relative bearings and distances to seal sightings during the 1996 to 2001 seismic operations combined. The "Combined Sightings" *(A)* and "Array Seismic" *(C)* categories do not include OBRL, testing, or ramp-ups. Dashed circle represents 500 m distance from the bridge of the source vessel.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

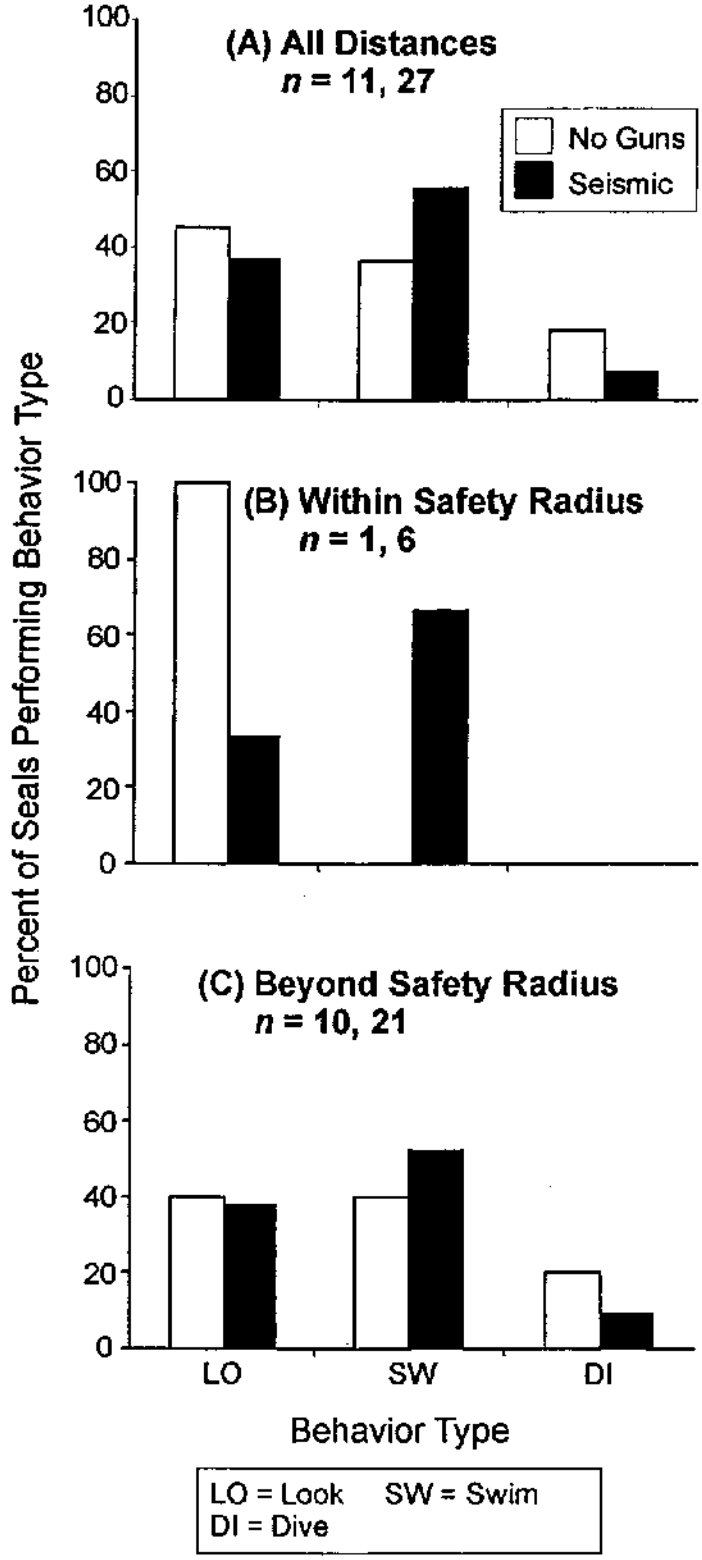

FIGURE 3.6. Percentages of seals showing various behavior types at all distances and within vs. beyond the updated safety radius (190 dB distances, Table 3.2) at times with no airguns vs. all seismic operations, as observed in 2001. The two *n* values in each panel are the numbers of seals seen with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

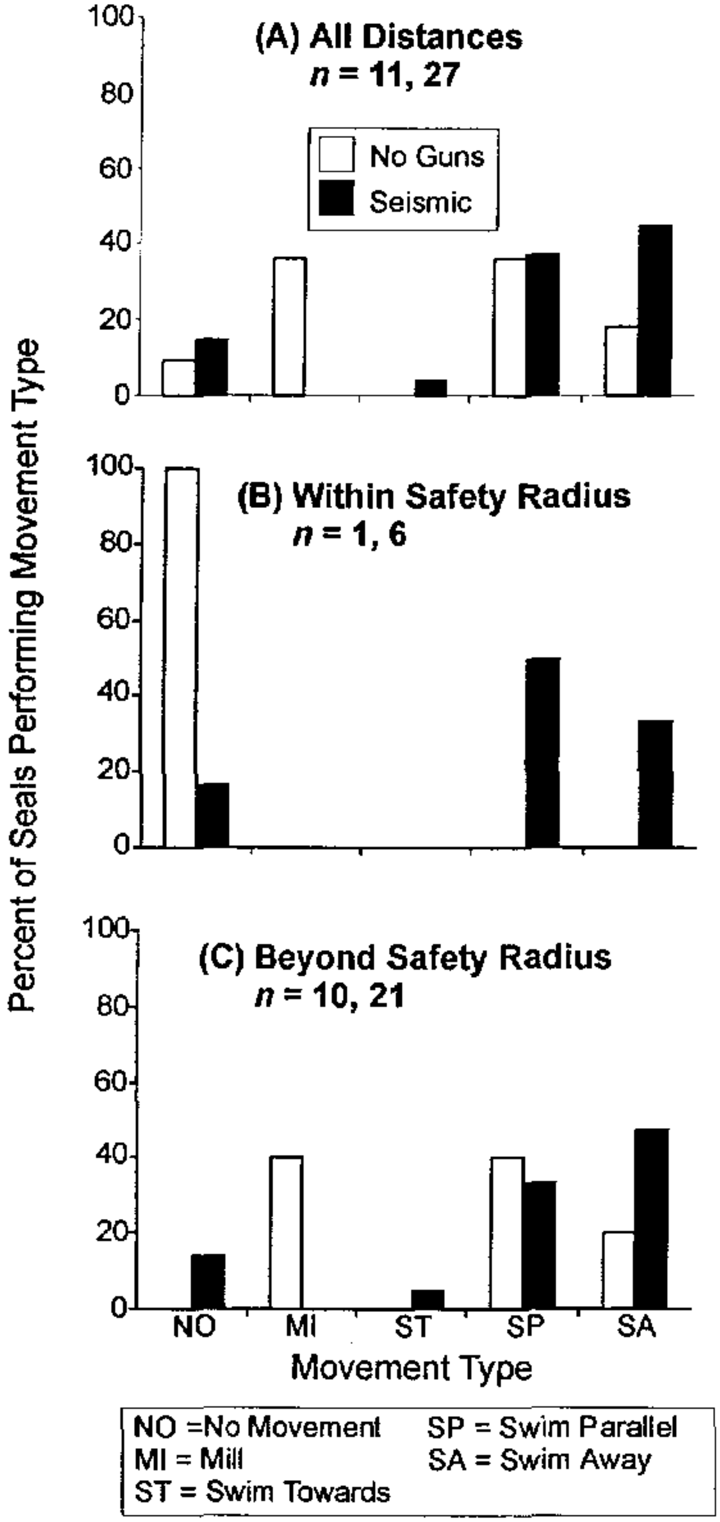

FIGURE 3.7. Percentages of seals showing various movement types at all distances and within vs. beyond the updated safety radius at times with no airguns vs. all seismic operations, as observed in 2001. The two *n* values in each panel are the numbers of seals seen with no guns vs. "all seismic" operations,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

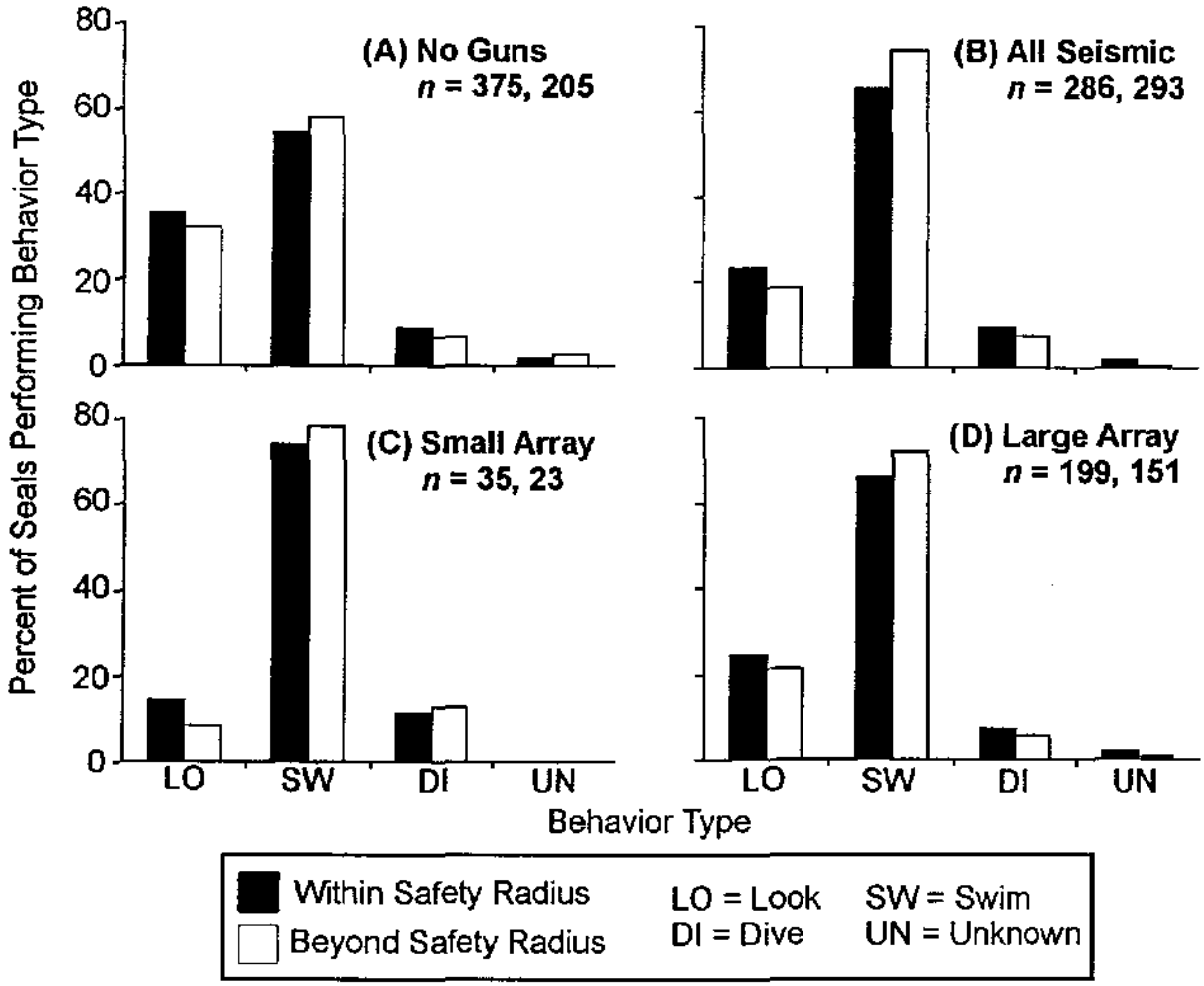

FIGURE 3.8. Percentages of seals showing various behavior types within vs. beyond the updated safety radius at times with no airguns vs. all seismic operations, as observed in 1996 to 2001. In (A)-(D), the two *n* values are the numbers of seals seen within vs. beyond the safety radius, respectively.

"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.

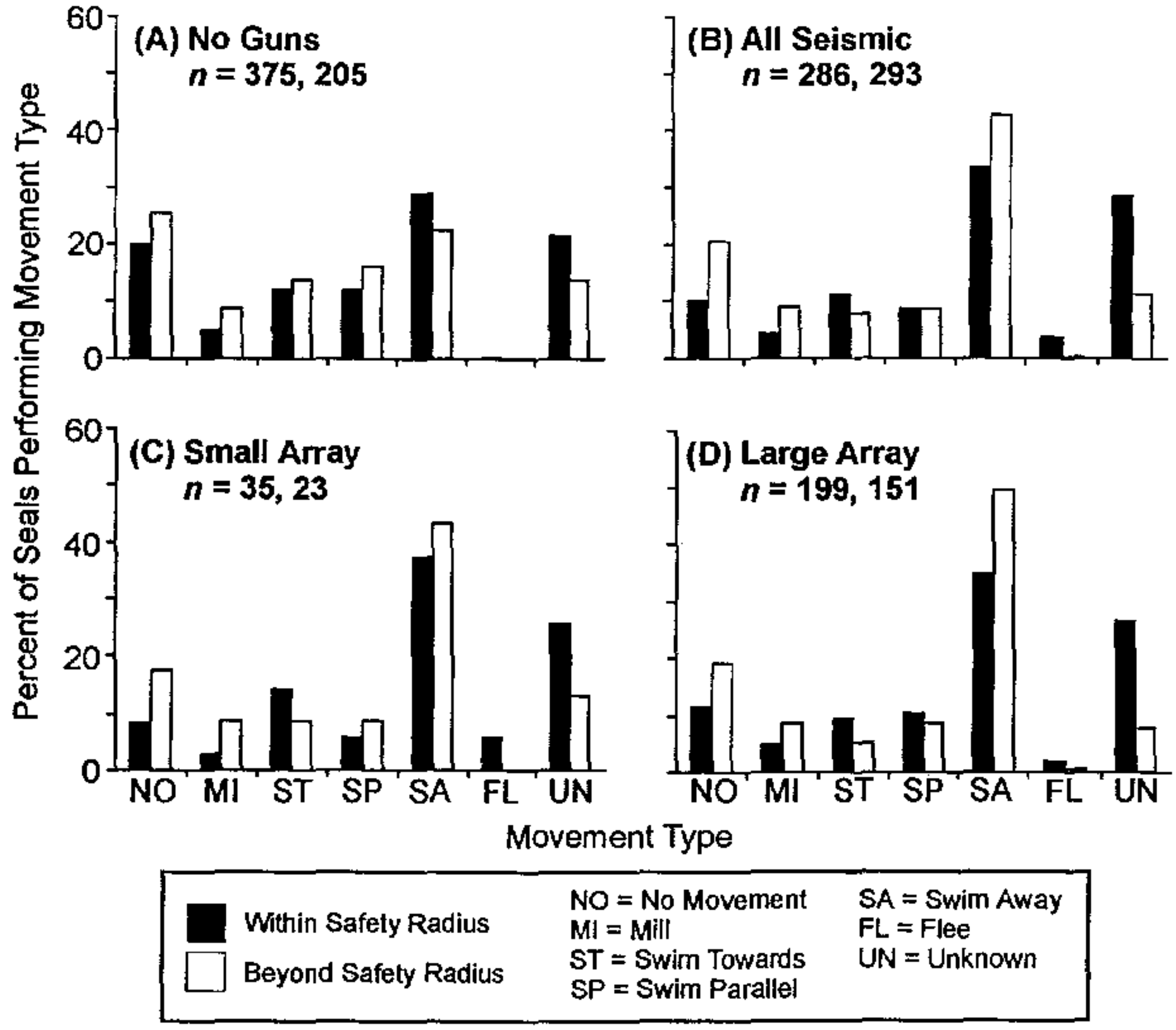

FIGURE 3.9. Percentages of seals showing various movement types within vs. beyond the updated safety radius at times with no airguns vs. all seismic operations, as observed in 1996 to 2001. In (A)-(D), the two *n* values are the numbers of seals seen within vs. beyond the safety radius, respectively.

"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.

		Seismic State			
		No Guns		All Seismic	
	Pace of Behavior	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.

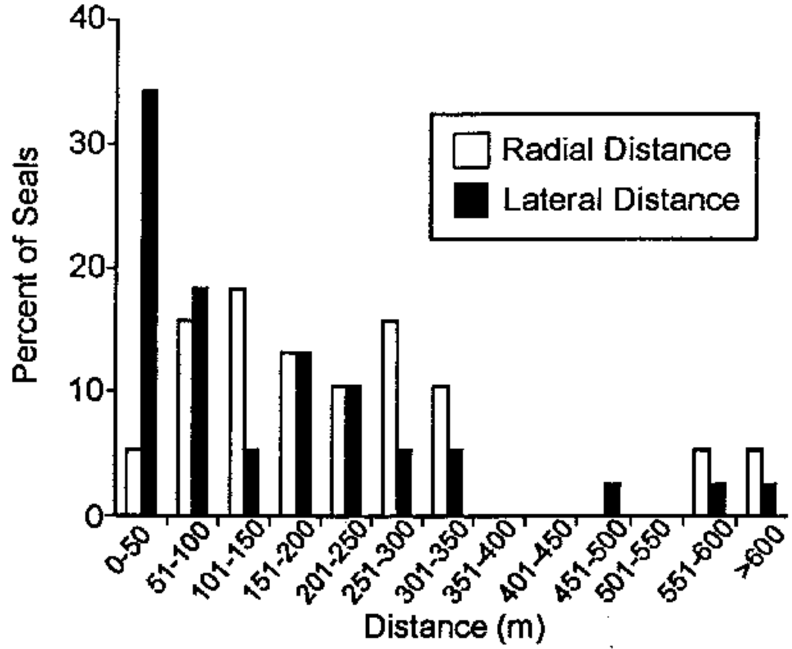

FIGURE 3.10. Percentages of seals (n = 38) seen by 50 m intervals of radial and lateral distance from *Peregrine* and *Arctic Star* in 2001. One meter equals 3.28 feet.

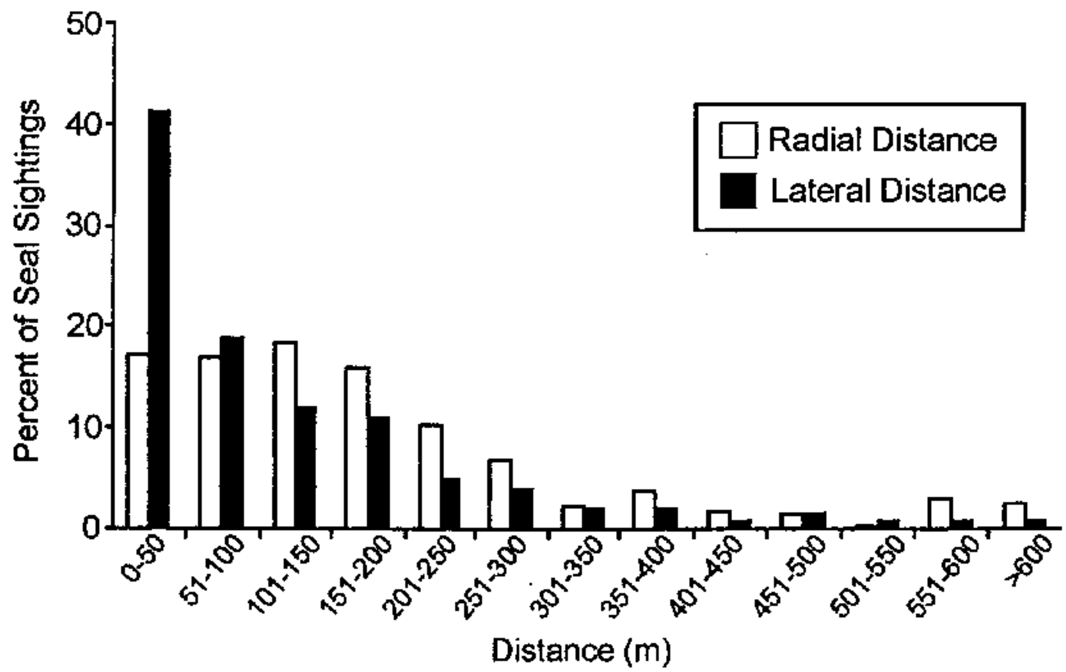

FIGURE 3.11. Percentages of seal sightings during daylight by 50 m intervals of radial and lateral distance from the source vessels for 1996 to 2001 combined. Groups of 2 or more seals are treated as "one sighting". See Table 3.7 for a summary of yearly counts of seals sighted. One meter equals 3.28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

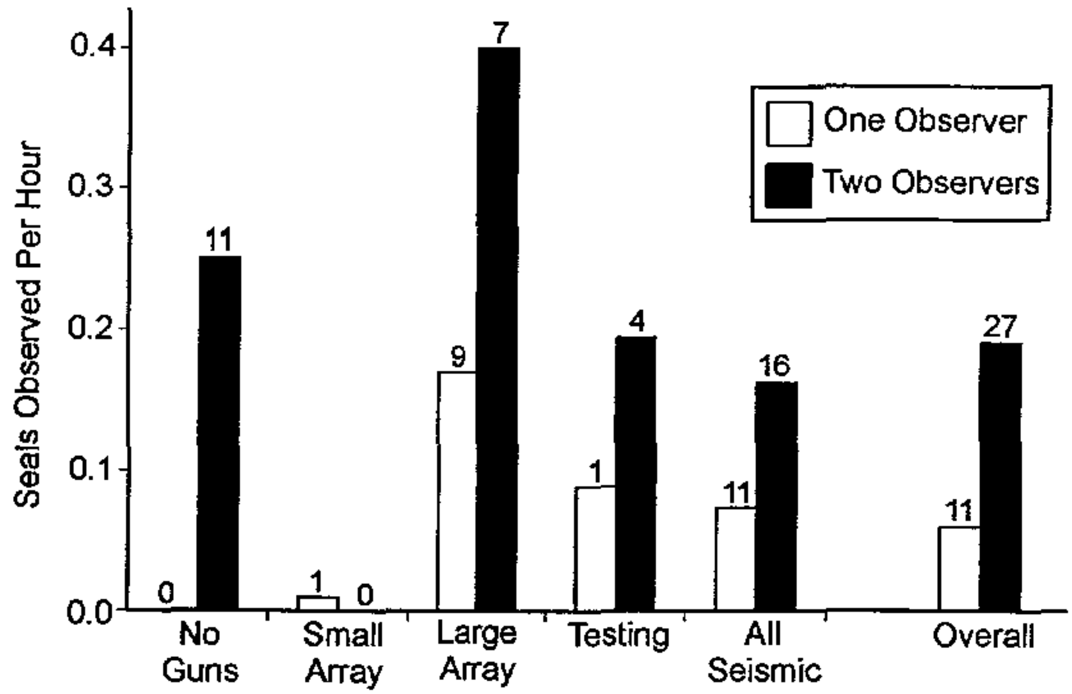

FIGURE 3.12. Numbers of seals seen per hour of daylight observation with one vs. two observers on duty, 2001, subdivided by seismic category. Values above columns show total numbers of individual seals seen.

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

	Seismic State					
	No Guns	Small Array	Large Array	Ramp-up	Testing	Total
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**

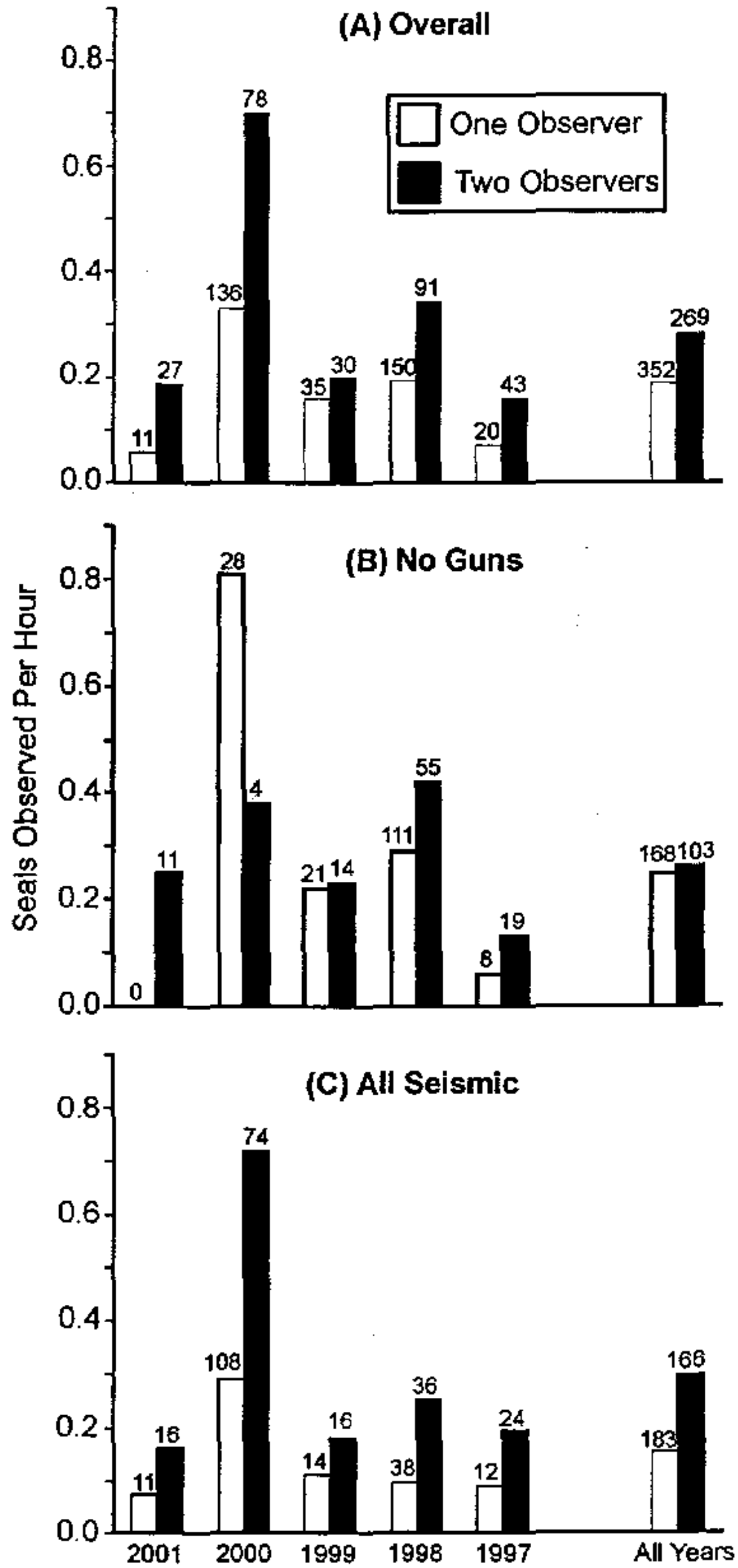

FIGURE 3.13. Numbers of seals seen per hour of daylight observation with one vs. two observers on duty, 1997 to 2001, subdivided by seismic category: *(A)* Overall (includes periods with and without seismic operations), *(B)* No Guns, and *(C)* All Seismic. Values above columns show total numbers of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

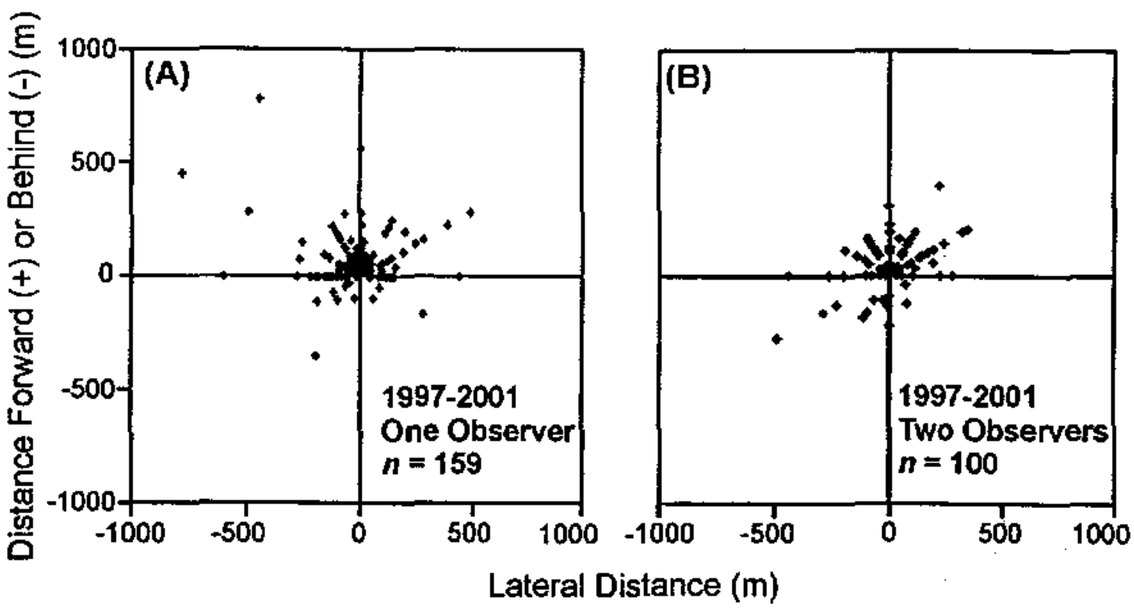

FIGURE 3.14. Effect of number of observers on relative bearings and distances to seal sightings during non-seismic periods in 1997 to 2001. One meter equals 3.28 feet.

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 μPa (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 in^3 and 1210 in^3 airgun arrays were 190 dB re 1 μPa (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 μPa (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 in^3 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 in^3 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 radiii 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 km^2.

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 km^2. 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 track-line. 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 km^2 was within the various safety radii at one or more times during the season. Based on the estimated density value of 0.051 seals/km^2, 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 km^2) 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.

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[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 km^2 (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 km^2, 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 µPa (rms). However, the monitoring plan called for an estimate of the number exposed to received levels ≥160 dB re 1 µPa (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 1µPa. 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 µPa (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 km^2.

Based on the estimated density of 0.051 seals per km^2, approximately 12 seals (11 ringed seals and one spotted seal) were exposed to sound pulses with rms received levels of 160 dB re 1 µPa.

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:

Direct Observation[1]:	1996	1997	1998	1999	2000	2001
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):

Indirect Estimate[1]:	1996	1997	1998	1999	2000	2001
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 μPa (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
Exposure to 160 dB [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
Exposure to 160 dB [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
Exposure to 160 dB [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
Exposure to 160 dB [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 μPa (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 in^3) operated for 71.3 hours and the "small array" (normally 8 guns totaling 320 in^3) operated for 154 hours. Of the 30 seals identified to species, 27 were ringed seals and three were spotted seals; no bearded seals were identified. Most seals (27 of 38) were sighted during seismic operations.

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

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

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

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

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

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

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

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

3.7 Acknowledgements

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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.

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APPENDIX A: INCIDENTAL HARASSMENT AUTHORIZATION FOR WESTERNECO'S 2001 OPEN-WATER SEISMIC OPERATIONS IN THE BEAUFORT SEA [1]

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 in^3 airgun array:
Twelve 40-150 in^3 2,000 psi sleeve airguns at
eight positions, including two 2-gun 300 in^3

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

clusters and two 2-gun 160 in^3 clusters.

(2). R/V *Peregrine* - 640 in^3 airgun array: Sixteen 40 in^3 2,000 psi sleeve airguns in four 4-gun 160 in^3 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 in^3 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 μPa_{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 μPa_{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 in^3 for the 1,210 in^3 airgun array and 40 in^3 for the 640 in^3 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 mare 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.

			SAFETY RADII (m/ft)	
SOURCE (in^3)	AIRGUN DEPTH (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	550/1,804
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 IN^3 SLEEVEGUN ARRAY USED IN 2001[1]

Introduction

During its 2001 OBC seismic operations in the Beaufort Sea, WesternGeco employed half of a 640 in^3 airgun array composed of 16 identical airguns. Four clusters of four 40-in^3 airguns (total of 16) were swung out from two positions on the port and two positions on the starboard side of 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 in^3. 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 in^3 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 in^3 array used by the R/V *Arctic Star* in 2001. These safety radii were based upon actual acoustic measurements near the 1210 in^3 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 μPa, 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 in^3 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 in^3 array diminished to ≤190, 180 and 160 dB re 1 μPa 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 in^3 airguns. Thus, the least-squares fit was repeated with the volume term omitted. The result was the equation

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

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 in^3 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 in^3 array operating in various situations.

For the 12-gun, 1210 in^3 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

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

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[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 in^3, 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 in^3 array in water 8 m deep is

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

For the 12-gun, 1210 in^3 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

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

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

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

Results

Equation (3) was used to solve for the distances where received sound levels were ≤190, 180 and 160 dB re 1 μPa in the case of the 320 in^3 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 μPa in the case of the 320 in^3 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.

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