Technical Plan for Marine Mammal and Acoustic Monitoring During Construction of BP's Northstar Oil Development in the Alaskan Beaufort Sea, 2000-2001

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INTRODUCTION

BP Exploration (Alaska) Inc. (BP) began construction of the Northstar project in nearshore waters of the Alaskan Beaufort Sea during the winter of 1999-2000. The Northstar production island was built at the Seal Island site, an artificial island constructed of gravel and located in water 12 m (39.4 ft.) deep about 5 km (3.1 mi.) offshore of the closest barrier islands. Seal Island was used for exploration drilling during the early to mid 1980s, then abandoned, and has been eroding for several years. It was re-constructed and enlarged during early 2000 for use as a production island. The main facilities required for Northstar include a gravel island work surface for drilling and oil production facilities, as well as two co-located buried subsea pipelines connecting the island to the existing production infrastructure in Prudhoe Bay.

The 1999-2000 winter-spring operations included constructing thickened ice-roads on the landfast ice, hauling gravel by truck to the island, and depositing it through an opening in the ice. Pipelines between Northstar and the mainland were also constructed in early 2000 from a thickened ice platform. After production begins in late 2001, one pipeline will transport crude oil from the island to Prudhoe Bay, and the other will transport natural gas to the island for injection purposes. Construction of the island is continuing during the open-water season of 2000; construction of the island itself is being completed, and various facilities are being emplaced on the island. Barges and aircraft are in use to support these construction activities. Some pre-fabricated facilities and a drilling rig are being transported to the island by sea-lift during the 2000 open-water season.

During the winter of 2000-2001, construction activities will consist of drilling the wells from the island, ice road construction along the pipeline right-of-way, and traffic along the road to support operations on the island.

Construction activities might disturb small numbers of seals and whales. However, planned mitigation measures are expected to limit effects on seals and whales to temporary changes in behavior or localized displacement, and to small numbers of animals. No serious injuries or deaths are expected.

During the ice-covered season, ringed seals are the only marine mammals under NMFS jurisdiction likely to be present in the Northstar construction area.

During the open-water season, ringed seals, lesser numbers of bearded seals, and a few spotted seals are present. In addition, during the latter part of the open water season, bowhead whales and beluga whales migrate westward, mainly in waters farther offshore than Northstar. Periodically, a few gray whales occur near Northstar during the open water season. Several gray whales were seen in the general area during late summer and autumn of 1998 (Miller et al. 1999).

On 25 November 1998, BP petitioned NMFS, under section 101 (a) (5) (A) of the Marine Mammal Protection Act, to issue regulations for the taking of small numbers of whales and seals during continued construction and operation of the Northstar and Liberty developments in the five-year period from 2000 through 2004. On 1 March 1999, NMFS published an advance notice in the *Federal Register* indicating its intention to issue these regulations. On 1 October 1999, BP submitted a revised petition for regulations considering Northstar alone, and taking account of changes in the Northstar project schedule and plan since the initial petition was submitted. On 22 October 1999, NMFS published the proposed rule in the *Federal Register*. On 25 May 2000, NMFS published the regulations for the incidental take of small numbers of whales and seals during construction and operation of Northstar. As of late August 2000, NMFS had not yet issued a Letter of Authorization (LoA) to authorize the take of whales and seals under the new regulations.

BP requested this LoA when the original petition for regulations was submitted. When this LoA is issued, it is expected to require marine mammal and acoustic monitoring work in 2000 and beyond.

A Communications Plan and Conflict Avoidance Agreement, as discussed in Section XII of BP's petition for regulations, was signed by BP and the Alaska Eskimo Whaling Commission on 17 March 2000. This agreement will ensure that the planned Northstar construction activities have no unmitigable adverse effect on the availability of marine mammals for subsistence harvests.

Section XIII of BP's Petition for Regulations, entitled "Monitoring and Reporting Plan", included an outline of the marine mammal and acoustic monitoring work proposed by BP. That outline was designed to respond to the following instruction to petitioners (from 50 C.F.R. sect. 216.104):

> "The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding."

In addition, Section XIV of BP's Petition for regulations, entitled "Coordinating Research to Reduce and Evaluate Incidental Take", responded to the instruction that applicants for regulations discuss

> "Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects."

A detailed "Technical Plan for Marine Mammal and Acoustic Monitoring" was prepared in August 1999, and submitted by BP to NMFS in September 1999. This plan provided additional details concerning the proposed monitoring over and above those given in BP's Petition for Regulations. That plan described monitoring measures proposed for the construction period in the winter and spring of late 1999 and early 2000, and in the open water season of 2000.

- Proposed monitoring tasks for the late 1999/early 2000 ice-covered season consisted of (Task 1) systematic aerial surveys of seals in spring, (Task 2) on-ice searches for seal lairs, and (Task 4) sound and vibration measurements. Task 3, a late-winter helicopter survey to assess abandonment rates of seal holes, was not included in the plans for spring 2000; such a survey had been attempted in spring 1999 with limited success.
- Proposed monitoring tasks for the 2000 open water season consisted of (Task 5) sound measurements, (Task 6) island-based visual monitoring for marine mammals, and (Task 7) acoustic monitoring of bowhead migration.

The monitoring plan dated August 1999 was discussed at workshops held at the National Marine Mammal Laboratory, Seattle, in October 1999 and May 2000. The former workshop focussed on the portions of the plan concerning the ice-covered season (Tasks 1-4), while the latter workshop discussed the portions concerning the open-water season (Tasks 5, 6 and especially 7).

All monitoring proposed for 2000 as part of the petition for regulations and the associated "Technical Plan" has been implemented on schedule. All monitoring work has been done despite the fact that the regulations were delayed to May 2000 and the LoA has not yet been issued. Tasks (1) and (4) were implemented in the winter-spring period in late 1999 and early 2000. A modified version of Task (2) was conducted in December 1999 (with follow-up in May 2000) to mitigate against potential injurious take in the absence of an LoA. A "90-day-report" on those winter/spring monitoring activities is in preparation for submission to NMFS in September 2000. Tasks (5) and (6) were implemented during the 2000 open-water season; task (5) is still underway. Preparations for Task (7) are well advanced, and fieldwork on Task 7 will begin by 1 September 2000.

Although this document provides the first formal update to the written monitoring plan since August 1999, procedures during the recent monitoring work have taken into account the results of the October 1999 and May 2000 workshops. For example, the procedures for Task (2), on-ice searches for seal lairs during late 1999 and early 2000, were amended to incorporate dog-based searches, as recommended by the October 1999 workshop. BP conducted on-ice searches for ringed seal breathing holes and lairs using dogs prior to road construction in December 1999, and rechecked the status of the previously detected structures in May 2000. Similarly, procedures for Task 7, the (imminent) monitoring of whale migration during the autumn of 2000, have been amended taking into account discussions and agreements made at the May 2000 workshop.

At the May 2000 workshop, it was agreed that following release by NMFS of the final Meeting Summary concerning that workshop the August 1999 version of the monitoring plan should be updated and resubmitted. It was agreed that the part of the monitoring plan concerning proposed efforts for the 2000 open-water season (Tasks 5-7) should be updated to describe final monitoring plans for the 2000 open-water season. It was also agreed that the part of the plan concerning the ice-covered season of late 1999/early 2000 (Tasks 1-4) should be updated to describe proposed monitoring plans for the early 2001 ice-covered season. The latter material would be reviewed at a further workshop tentatively planned for October 2000, whereupon revisions might be required. The final Meeting Summary for the May 2000 workshop, dated 8 August 2000, has recently been distributed. The present update of the monitoring plan takes account of the discussions at the October 1999 and May 2000 workshops.

- In summary, this revised monitoring plan describes efforts that BP is undertaking to assess, measure and mitigate the effects of Northstar construction activities on both seals and whales during the 2000 open-water season (Tasks 5-7). It also describes planned monitoring efforts for seals during the ice-covered season in early-mid 2001 (Tasks 1, 2 and 4). For consistency with previous documents and discussions, the Task numbers assigned previously to various monitoring tasks are retained in this document. The planned monitoring work will provide the data needed to determine
- the extent and nature of Northstar construction effects on seals and whales, and to assess
- whether effects are limited to disturbance and/or localized displacement ("Harassment"),
- whether effects on these mammals and their populations are no more than negligible, and
- if there are unmitigated adverse effects on availability of seals and whales for subsistence.

MONITORING DURING ICE-COVERED SEASON, EARLY 2001

Three types of ringed seal and acoustic monitoring are planned for the ice-covered season in early 2001:

- **Task 1**: systematic aerial surveys, using a fixed-wing aircraft, of seals hauled out on the ice in late May/early June (consistent with BP surveys of this type in 1997-2000);
- **Task 2**: on-ice searches using dogs to detect seal lairs in locations where construction is to begin after 19 March 2001 (during the seal pupping season);
- **Task 4**: measurements of underwater and in-air sounds, as well as ice vibration, produced by any construction, drilling, and operational activities occurring in early 2001 whose sounds were not measured in early 2000.

Details regarding these tasks are given in the following subsections. These three tasks are numbered and described in the same order as they are listed in Section XIII of the IHA Application and Petition for regulations. Chronologically, however, Task 4 and (if necessary) Task 2 will begin first, during late winter/early spring of 2001, followed by Task 1 during late May or early June 2001. In 1999, we determined that the helicopter survey of abandoned and active seal holes (Task 3) was not an adequate method to assess the abandonment rate of seal holes, and it is not proposed for 2001.

Task 1. Systematic Aerial Surveys of Seals, Spring 2001

Objective

The overall objective of Task 1 is to document the local distribution and abundance of ringed seals in the central Alaskan Beaufort Sea before and after construction of the Northstar Project. These data will be used to evaluate whether there is any localized change in seal distribution and abundance attributable to Northstar (or Liberty, when constructed) and, if so, to quantify the extent of this effect.

Background

BP has sponsored systematic aerial surveys of ringed seals in the Northstar and Liberty areas during the spring seasons of 1997, 1998, 1999, and 2000. These surveys were designed to provide up-to-date site-specific data on seal distribution and density. The initial surveys were to provide data on baseline distribution and density prior to construction of offshore oil production facilities. The subsequent surveys were to provide comparative data during and after construction.

More specifically, the ***1997-98 surveys*** were designed to comprise the "Before Development" component of a Before-After/Control-Impact (BACI) study of the distribution and abundance of ringed seals in relation to development of the offshore oil and gas resources in the central Alaskan Beaufort Sea. The BACI design is considered optimal for environmental field studies (Green 1979). The study design provides for systematic, replicated aerial surveys of ringed seals hauled out on the landfast ice during spring close to the planned development areas and in "reference" or "control" areas farther away from the development areas. The ***1999 surveys*** were expected to assess seal distribution and density after the first winter of construction. Ice roads were constructed near Northstar in early 1999, but island construction was postponed for 1 year. Thus, in 1999 the potential for disturbance was intermediate between that in the "baseline" years and that during active island construction. The ***2000 surveys*** were conducted after several months of intensive construction activities during the winter and early spring of 1999-2000.

Each year during late May/early June, there were four replicate surveys of the area shown in Figure 1. Each survey consisted of 40 closely spaced north-south transects extending from shore out to the edge of the landfast ice. These surveys were flown in a fixed-wing aircraft flying at an altitude of 300 ft and were conducted using procedures similar to those used by the Alaska Department of Fish and Game (ADF&G) for their spring seal surveys (e.g., Frost et al. 1997, 1998). The BP-sponsored surveys covered a much smaller area than the ADF&G surveys; however, the BP study area was covered four times each spring rather than once. This replicated coverage was designed to detect relatively small-scale effects; to detect and allow for the known and hypothesized effects of weather, temporal, and natural habitat factors on seals; and to distinguish these variations from potential industrial effects.

The 1997, 1998, and 1999 data are described by Miller et al. (1998a), Link et al. (1999), and Moulton et al. (2000), respectively. Excluding waters <3 m deep where seals were rarely seen, the overall observed density in 1999 was 0.63 seals/km^2 (Moulton et al. 2000). The overall observed density in areas ≥3 m deep was higher in 1999 than in either 1997 (0.43 seals/km^2; Miller et al. 1998a) or 1998 (0.39 seals/ km^2; Link et al. 1999). Analysis of the corresponding 2000 data has begun, and preliminary results for 2000 will be included in a 90-day report to be completed in September 2000.

Analyses of 1998 data in Link et al. (1999) and of 1997-1999 data in Moulton et al. (2000) suggest that Vibroseis and ice-road construction activities had some effect on the distribution and abundance of ringed seals before construction of the island and pipeline for Northstar began. In addition, Moulton et al. (2000) found that the numbers of seals seen within 0.64 km and 4 km of the 1999 ice road location were slightly higher in "non-industrial" years (1997-98) than in 1999. These data may suggest that a few seals might have been displaced in 1999. However, for the 0-0.64 km zone where displacement was most likely, the reduction from previous years was very small (12 and 7 seals seen in 1997 and 1998 vs. 6 in 1999) and explainable on the basis of an observed reduction in overall density in nearshore areas in 1999.

Ongoing analyses of the spring-2000 survey data will provide the first information concerning the extent of effects from intensive construction activities at Northstar. Also, LGL and biostatistical consultants at WEST Inc. are conducting a power analysis to determine the ability of this survey design to detect various percentage declines in seal abundance within a small area around the industrial development (e.g., within 5 km or less). Results are expected to be included in the 90-day report on the 2000 work, which is to be submitted in September 2000.

Approach

BP plans to continue the BACI study of the distribution and abundance of ringed seals in relation to development of offshore oil and gas resources in the central Alaskan Beaufort Sea. Collection of data during and after construction will provide a reliable method to assess the impact of oil and gas industry activities on ringed seal distribution and numbers in the area surrounding Northstar.

The close spacing and replicated coverage of the survey lines will provide the type and quantity of data needed to document the geographic extent of any zone of reduced seal density near the construction areas or areas of operations. The pre-construction baseline data (1997-98) from Northstar and nearby "reference" areas will provide a basis for testing for and quantifying changes in seal distribution around Northstar. The within-year replicate surveys will provide the data needed to distinguish local geographic differences in seal density from temporal variability resulting from seasonal, diel or weather effects on the proportion of seals hauled out. The results concerning temporal and weather effects will also be useful in interpreting other similar surveys where less information of this type has been obtained.

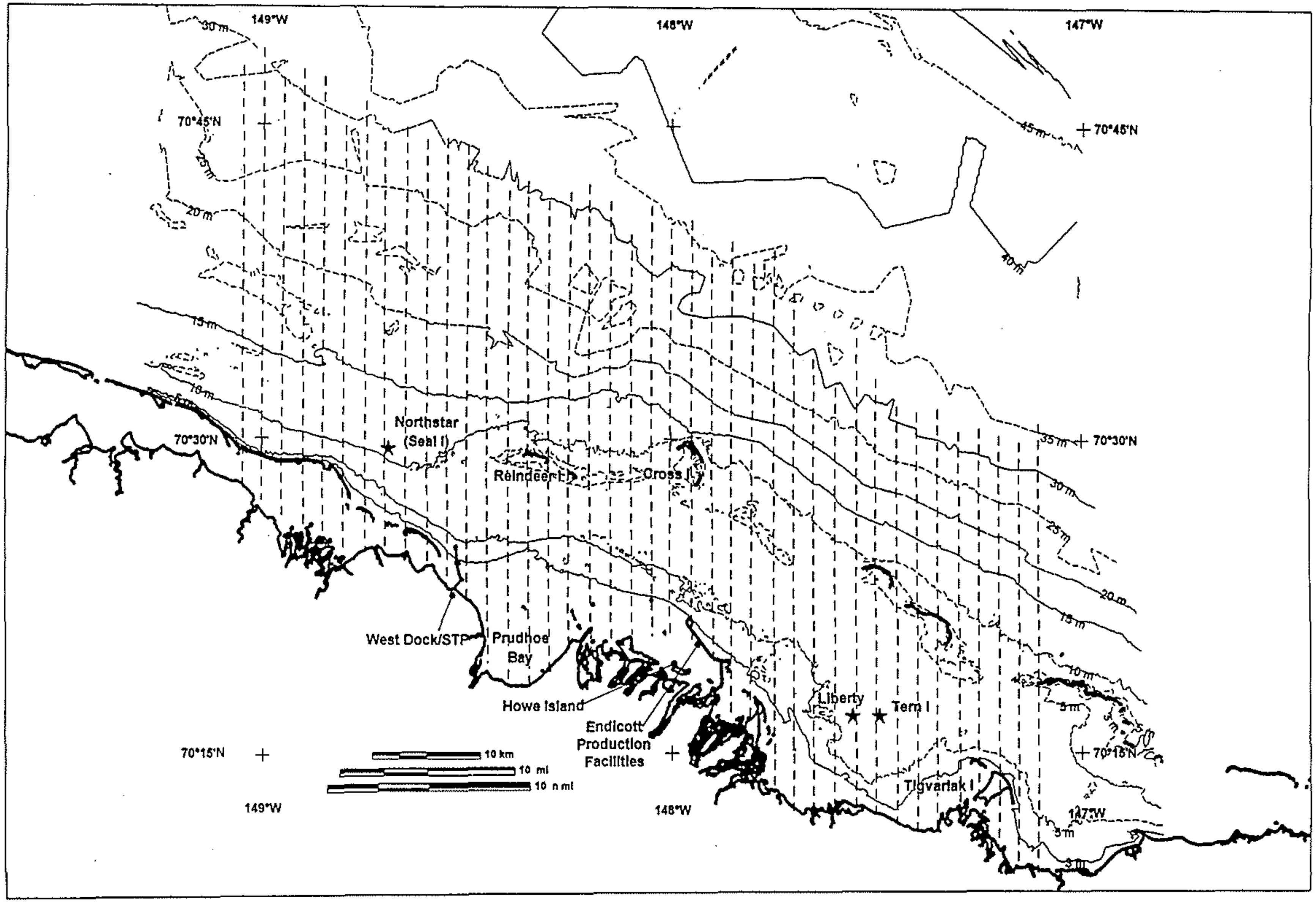

FIGURE 1. Aerial survey transects flown during BP's spring seal surveys. The 40 transects are spaced 1 n.mi. (1.15 mi. or 1.85 km) apart. For two of the four surveys each spring, the grid is offset 0.5 n.mi. (0.575 mi or 0.93 km) to the west from that shown here.

Study Area and Methods

Aerial surveys in 2001 will be conducted in the same manner as during 1997-2000, to ensure that "baseline", "construction", and "post-construction" results are directly comparable. The procedures are described in Appendix A, taken from the "METHODS" section of Moulton et al. (2000).

The study area as defined for the 1997-2000 surveys is approximately 75 km (47 mi) wide and extends about 40 km (25 mi) offshore (Fig. 1). Within this area, maximum water depths are ~30 m (98 ft) near the north ends of the survey transects, which are at the edge of the landfast ice. Barrier islands occur across much of the study area (Fig. 1). West of Prudhoe Bay, these barrier islands are fairly close to shore (2-7 km). In the generally shallower waters near and east of Prudhoe Bay, the barrier islands tend to be farther offshore, with some being as much as 20 km (12 mi) from shore.

Waters inside the barrier islands are shallow. West of Prudhoe Bay, maximum depths of about 4.5 m (15 ft) occur in the narrow lagoons formed by the barrier islands. In the broader areas south of the barrier islands east of Prudhoe Bay (e.g., Foggy Island Bay), water depths reach a maximum of about 9 m (30 ft). The water depth is 12 m (39 ft) at the Northstar development site (Seal Island), and 6.4 m (21 ft) at the planned Liberty development site in Foggy Island Bay. The 1997-98 baseline surveys showed that seal densities in the deeper portions of the lagoons are comparable to those on the landfast ice farther offshore (Miller et al. 1998a; Link et al. 1999).

In 1997 and 1998, the BP seal surveys were conducted by two observers plus a pilot. Aircraft positions were logged automatically by a GPS datalogger. Environmental and seal data were dictated into audio recorders by the two observers and transcribed later. In 1999 and 2000, we used two pilots plus three observers, including two biologists and one Inupiat. The Inupiat observer had experience in previous seal monitoring projects and was an experienced seal hunter. The observers rotated duties, with one of the three entering environmental and survey transect information into the datalogger. The other two observers recorded seal and environmental data onto audiotape. In 2001 and future years, we will use the same basic procedures as in 1999-2000.

Multivariate statistical methods will be applied to the 1997-2001 aerial survey data to assess the effects of industrial activities on ringed seal abundance and distribution. The general approach will be based on the Poisson regression method applied by Moulton et al. (2000) to the 1997-99 data, but with further refinements to improve the ability of the model to characterize and discriminate the effects of different factors on numbers of seals seen on the ice. These multivariate analyses will be in addition to the basic data summarization, analysis and mapping methods previously applied to the 1997-99 data (see Appendix A). Along with industrial factors, the multivariate analyses will take into account the effects of potential covariates, such as ice deformation, water depth, distance from the edge of the landfast ice, time of day, and weather conditions. All of these factors are known or suspected to affect seal density or the proportion of seals hauled out. In refining the analysis methods, we will take into account the procedures being used by ADF&G to analyze the results from their spring seal surveys. We will aim for consistency with their approach where possible. However, the among-day replication of the BP-funded surveys will require some changes in approach relative to those used by ADF&G, and will provide an enhanced ability to discriminate the effects of "distance from industry" vs. weather and time of day on the proportion of seals hauled out.

Field Schedule

The surveys will be conducted during late May and early June 2001, as in 1997-2000. Under good weather conditions, each of the four surveys requires two days of flying, i.e. a total of eight days. A 12-day field season is scheduled to provide allowance for up to four days of weather unsuitable for seal surveys. In

1997, 1998, and 2000, the fieldwork was completed in less than 12 days. In 1999, persistent foggy weather required 12 days to complete the surveys.

Related Projects

At present, it is not expected that ADF&G will continue their fixed-wing aerial surveys in 2001 or beyond. However, if they do, the BP surveys will be coordinated with ADF&G's surveys to avoid interference and to share data. The National Marine Mammal Laboratory (NMML) conducted an aerial survey program for ringed seals in the Chukchi Sea in 1999 and 2000. It is uncertain whether the work by NMML in the Chukchi Sea will be continued. Because the ADF&G surveys extended over a wider area than the site-specific surveys proposed here, their results will be useful to place the present results into a broader context. Conversely, because the BP surveys obtain replicate coverage of the same area on different dates, the results of the BP work may be helpful in interpreting whether any apparent geographic differences evident in the ADF&G data are actually a result of day-to-day differences in haul-out behavior. A meeting between LGL and ADF&G was held in June 2000 to discuss coordination of multivariate and other analyses. Additional coordination with ADF&G and NMML is anticipated.

In 1999 and 2000, Dr. B. Kelly of the University of Alaska Fairbanks (Juneau Center, SFOS) completed telemetry studies on the haulout behavior of ringed seals in the Prudhoe Bay area. In 1999 and 2000, we mounted a radio receiver on our survey aircraft, and the third observer was able to log data from the radio-tagged seals. We will assist with future projects again if logistically feasible. The data collected by Dr. Kelly's project will provide additional information on the haulout behavior of ringed seals during our surveys, and it will benefit both projects to coordinate and collaborate when possible.

In 1999 and 2000, Dr. Kelly's project was conducted within the study area that we had established in 1997. In 1999 and 2000, they requested that we fly at an altitude of 500 feet when over their study area. Frost and Lowry (1988) showed that sightability of ringed seals was significantly lower when aerial surveys were flown at 500 feet versus 300 feet, and suggested that future aerial surveys be flown at 300 feet for ringed seals. ADF&G has flown their recent surveys at 300 ft altitude. Our design was based on the standardized methodology proposed by Frost and Lowry (1988), and our 1997-98 baseline surveys were flown entirely at 300 ft. However, in 1999 and 2000, we did fly some transect lines over Dr. Kelly's study area at 500 feet. Although we accommodated Dr. Kelly's request, this use of a non-standard altitude during parts of our 1999-2000 surveys is, at best, an undesirable complication. This non-standard procedure might compromise BP's carefully designed long-term monitoring effort, which is required under the small take authorizations issued by NMFS (interim IHA in 1999; regulations in 2000). The possibility of future similar requests for changes to the field program should be discussed with all concerned in advance of the 2001 field season. If NMFS determines that we should fly at a non-standard (higher) altitude at certain times, it needs to be recognized that this could reduce the precision and accuracy of the monitoring effort, potentially reducing our ability to detect effects on ringed seals.

Research Permit

Monitoring studies that are required under incidental take exemptions are usually authorized by NMFS when the IHA or LoA is issued. In this case, the aerial surveys need to be conducted at an altitude of 300 feet (see above), which is lower than usually authorized under an IHA or LoA.

The proposed aerial surveys were approved under an authorization issued to LGL Ltd. by the National Marine Fisheries Service Office of Protected Resources. LGL requested this authorization via a letter dated 29 April 1997, which described the methods (including the fact that the surveys needed to be conducted at an altitude of 300 ft). On 19 May 1997, NMFS confirmed that these surveys were eligible to

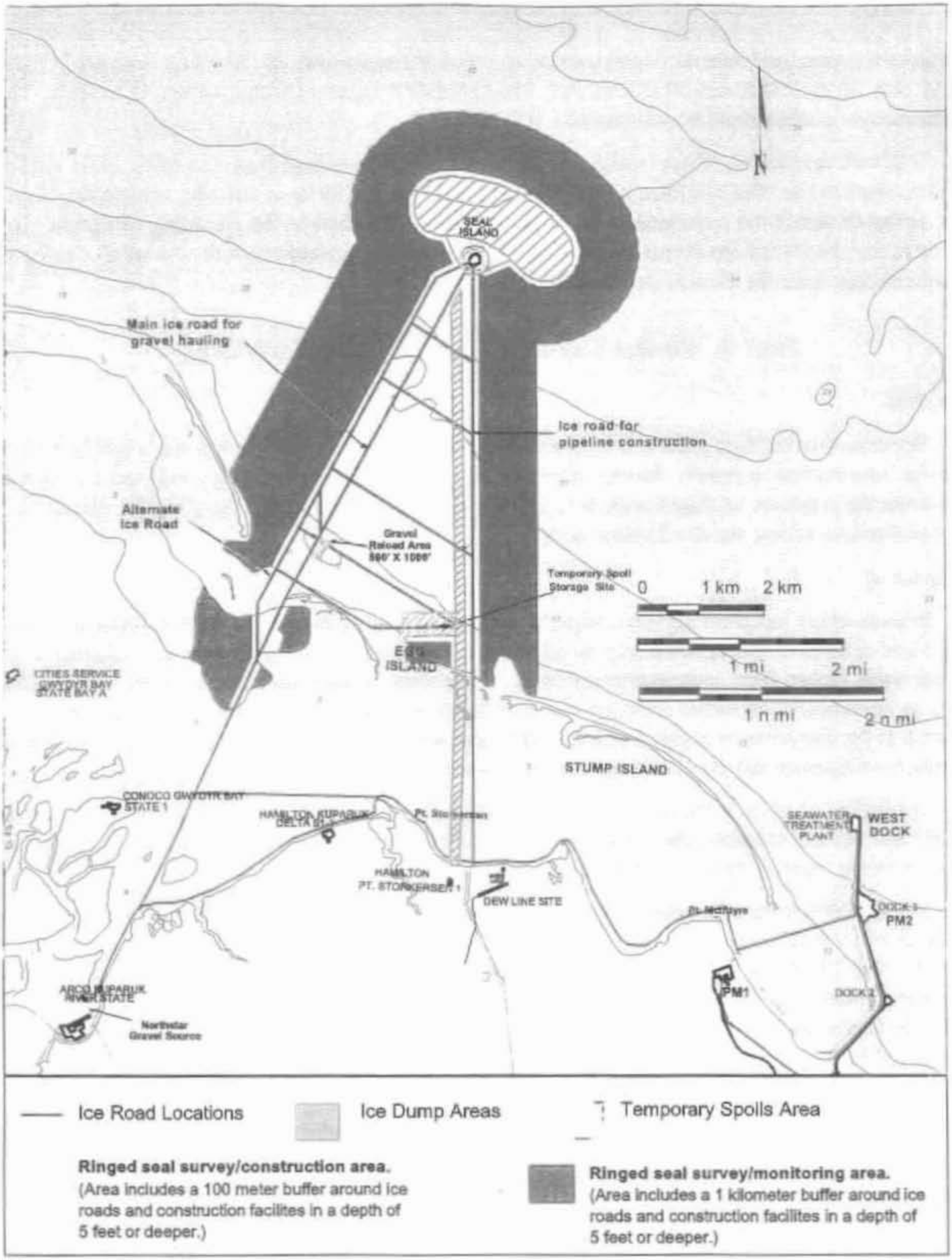

FIGURE 2. Location of the Northstar ice road complexes built to support island and pipeline construction during the winter of 1999-2000, and area where monitoring for ringed seal structures was conducted during December 1999 and May 2000.

be conducted under the "General Authorization for Level B Harassment for Scientific Research", as per MMPA sect. 104(c)(3)(C) and 50 C.F.R. sect. 216.45 (NMFS Letter of Confirmation 481-1382). This authorization is in effect for a five-year period (1997-2001).

LGL will, as required, advise NMFS that the project is being conducted again in 2001. LGL will also submit a report to the NMFS Office of Protected Resources within 90 days after the completion of each year's survey to satisfy the requirements of the authorization described in the preceding paragraph. It is anticipated that the 90-day report required to satisfy LoA reporting requirements will also satisfy the reporting requirements under the General Authorization.

Task 2. On-Ice Searches for Seal Lairs, Early 2001

Objectives

The objectives of Task 2 are: (1) to detect any seal birth lairs in areas where a pup might be harmed by on-ice construction activities, thereby allowing mitigation measures to be applied, and (2) to help characterize the responses of ringed seals to the Northstar development through detecting the presence and fate of seal structures near the development area.

Background

In areas where industrial activities begin by mid-March (before the start of the seal pupping season), some ringed seals at breathing holes may be disturbed by those activities. Such seals are expected to use alternate holes farther from construction activities. Temporary or permanent displacement of individual seals from holes near construction activities should be localized and is not expected to have significant consequences at the individual or population level. The fixed-wing aerial surveys (Task 1) will provide a basis to assess the occurrence and extent of displacement of seals away from industrial activities.

The outline of planned monitoring activities included as Section XIII of the Petition for regulations for 2000 and beyond indicated that no searches for seal lairs were proposed in areas where construction begins before the pupping season, i.e. before about 20 March.

In early 1999, as an additional precaution, BP decided to conduct on-ice monitoring for ringed seals in advance of ice-road construction and other Northstar construction activities even when these activities occurred before 20 March. This effort included on-ice searches for ringed seals, breathing holes, and seal lairs along portions of the road corridors that traversed potential ringed seal habitat. This on-ice monitoring work by biologists and Inupiat seal hunters began in January 1999 and continued until 8 April 1999 (see Williams and Perham (2000) for details).

The October 1999 on-ice monitoring workshop concluded that using dogs was the only effective way to detect ringed seal structures. It was suggested at the workshop that industry should use dogs to locate seal structures for mitigation purposes, and should also use dogs to help characterize the type and extent of taking of ringed seals by industrial activities.

In advance of ice road construction in December 1999, BP again conducted on-ice searches for ringed seal structures, this time using dogs trained by Dr. B. Kelly and L. Quakenbush and handled by L. Quakenbush. LGL participated in and coordinated this search for ringed seal structures, which occurred within a 1-km zone surrounding the construction area proposed for Northstar development (Fig. 2). Dr. Kelly and L. Quakenbush proposed that two initial searches of the entire area would be adequate to locate the majority of the seal structures. Dr. Kelly performed a follow-up search under subcontract to LGL in May 2000 to check the status and fate of the structures found in December, and to conduct a limited search for new structures. Given the delays in receipt of an incidental take authorization (which was expected to provide authorization for the dog-based surveys), this work was conducted under the provisions of Dr. Kelly's scientific research permit. Results will be described in the 90-day report to be submitted in September 2000.

During the 1999 and 2000 ice-covered seasons, BP did not initiate construction activities after 19 March in any additional areas not searched previously. However, if additional construction activities in previously-unsearched areas had been necessary, an additional on-ice seal survey was to be completed prior to the start of those activities. In 2000, this would have been done using dogs.

On-Ice Searches in 2001

During the ice-covered season of late 2000 and early 2001, no on-ice searches for seals are planned in areas where industrial activities are ongoing or where they are initiated prior to 20 March. It is assumed that, if industrial activities are ongoing before seals establish pupping lairs, seals will not do so in areas where pups could be physically harmed. Hence, surveys of these areas would not be needed for mitigation purposes. Monitoring for any displacement effects would be accomplished via Task 1 (aerial surveys).

If BP needs to initiate construction activities after 19 March in previously unsearched or undisturbed areas, an on-ice search would be conducted. The purpose of this search would be to locate seal lairs in previously-undisturbed areas where, subsequent to 19 March, BP plans to build ice roads or initiate construction or other industrial activities with the potential to disturb or injure seals. This search would be conducted before crews begin to remove snow and ice rubble from the right-of-way or construction site. This will ensure that seals, particularly young seal pups that may be unable to move to alternate lairs, are not injured. The search would include all potentially affected sea-ice habitats in areas where the water depth (in the open-water season) is greater than 1.52 m (5 ft). This is the same water depth criterion as specified in LoAs for on-ice seismic activities in 2000. The searches would include a buffer zone of at least 150 m around the areas where industrial activities are planned.

If an initial search of this nature is required, then a follow-up search to determine the fate of the seal structures would be conducted later in the season (e.g. May 2001). Methods to be used during the searches in late winter (after 19 March) would be based on those already applied during December 1999 and spring 2000, along with recommendations from future on-ice peer-review meetings. It is strongly recommended that the methodology be further discussed prior to the next field season. Coltrane et al. (in prep.) found 18 additional seal during May 2000 at the Northstar site over and above those found in the same area during the December 1999 searches. This has several implications. It may suggest that seals moved to adjacent areas or the initial (Dec. 1999) coverage of the area using dogs was not adequate to detect the majority of seal structures. If so, then an appropriate number of replicate searches needs to be determined and standardized.

Hammill and Smith (1990) suggest that four or more surveys are needed to obtain a reliable estimate of seal structures within a study area. In two to four km^2 plots surveyed six times, Hammill and Smith found only 61-81% of all structures during the first three searches. On the other hand, Frost and Burns (1989) suggest that a single survey detects 60-70% of the total structures present within 660 ft (200 m) of the transect line. However, as has been shown in previous studies, even searchers conducting multiple surveys with trained dogs cannot confirm that they have found every structure (Hammill and Smith 1990). In addition, the natural process of structure creation during winter could confound search results.

If four complete coverages were needed to determine the true number of seal structures present, then it would have taken 3-4 weeks to complete the search of the area in December 1999. Due to logistical and time constraints relative to the construction schedule, and the limited availability of trained dogs and their handlers, monitoring of this intensity may not be possible, especially if a substantial area of landfast ice needs to be searched. If adequate coverage via dogs is logistically impractical, then the objectives and approach need to be re-considered. If the objective is to locate some of the lairs present for purposes of (partial) mitigation and follow up concerning the fate of that sample of lairs, then incomplete coverage may have value. However, if the objectives require identification of all structures present, then it needs to be recognized that this may be impractical unless the area to be searched is small.

It is expected that the techniques to be used for any on-ice surveys will be discussed further with NMFS prior to March 2001. On-ice monitoring methods were discussed at meetings convened by NMFS at the National Marine Mammal Laboratory, Seattle, on 20-21 May 1998 and on 14-15 October 1999. To date, no specific monitoring procedures have been finalized by NMFS based on the May 1998 meeting, but the Minutes from the October 1999 workshop recommended using dogs. It is recommended that the planned workshop in October 2000 take up these questions again so as to provide further guidance regarding on-ice monitoring well in advance of March 2001.

Field Schedule

On-ice searches would occur just before or during the ringed seal pupping period during late March through May of 2001. These searches would occur if BP's Northstar construction activities needed to move into previously unaffected areas during that period. It is not proposed to conduct on-ice searches in areas where industrial activities are underway prior to 20 March. If it is evident before 20 March that industrial activities will need to move into a previously undisturbed area after 20 March, on-ice searches could begin in the mid-March period, slightly before 20 March.

Research Permit

It is anticipated that the Letter of Authorization that has been requested by BP will, when issued, include authorization for any disturbance to seals that could result from the monitoring activities associated with this Task.

Related Projects

If BP sponsors any on-ice seismic operations (Vibroseis) during the winter/spring, similar monitoring methods may be used to search for ringed seal lairs along or near Vibroseis lines. If on-ice searches for seal lairs are required in association with both Northstar construction and Vibroseis, the two closely-related efforts will be coordinated, using consistent methodologies and shared personnel.

In 1999 and 2000, Dr. B. Kelly of the University of Alaska Fairbanks (Juneau Center, SFOS) completed telemetry studies on the haulout behavior of ringed seals in the Prudhoe Bay area. Dog-based searches for seal structures were conducted as part of that project. In 2000, BP's on-ice searches near Northstar were closely coordinated with that project. We will coordinate and assist with any future related projects if logistically feasible. The data collected by Dr. Kelly's project will provide additional information on the use of the landfast ice by ringed seals. It will benefit both projects to coordinate and collaborate when possible.

Task 3. Abandonment Rate for Seal Holes

The objective of Task 3 was to document the abandonment rate for seal holes as a function of distance from construction activities.

Introduction

Kelly et al. (1986), Frost and Burns (1989) and Kelly and Quakenbush (1990) have documented natural abandonment of holes during winter and spring. However, a quantitative assessment of natural abandonment has not been undertaken. If ringed seals are displaced because of ice-road construction and use, or in the area near the island, the hole abandonment rate will be higher for breathing holes near the source(s) of disturbance than for those farther away. Information about the use and abandonment of breathing holes by ringed seals can be used to help assess the geographic scale of disturbance effects. These data would be useful to document the extent of "taking" of ringed seals during Northstar construction and to predict the impacts of future related construction activities on ringed seals in the Alaskan Beaufort Sea.

Approach

This approach was not proposed for 2000, and is also not proposed for 2001. The pilot study in 1999 identified a series of logistical and other difficulties in the methodology. The conclusion was that, although the methodology might be effective in some circumstances, it cannot be relied upon to produce meaningful results in any given year (see Lawson and Williams 2000).

Previous Approach.—In May 1999, participants at the on-ice monitoring workshop discussed and concurred with BP's plans to use a helicopter to assess local-scale population changes. In early July 1999, LGL used a helicopter in a pilot study to assess the usefulness of this approach in determining the relative number of abandoned and active seal holes. We flew a test flight in the Northstar development area, where ice roads had been constructed in winter, and in an otherwise-similar reference ("control") area with no known industrial activities. The purpose was to evaluate whether this method would be effective in detecting and distinguishing active and abandoned seal holes, and in determining the ratio of active to abandoned holes at different distances from industrial activities.

The helicopter surveys were scheduled to be conducted after snowmelt but before ice breakup. It was thought that at this time of the year it would be possible to differentiate open holes used throughout the winter vs. refrozen holes that were created in autumn or early winter but subsequently abandoned. It was recognized that, even from a helicopter, not all holes that are present would be detected, and abandoned holes would be less detectable than active holes. However, it was expected that the relative numbers of abandoned vs. active holes at different distances from the construction area would provide a useful index of the effects of industry activities on the distribution and habitat use of ringed seals.

Task 4. Sound and Vibration Measurements, Early 2001

Objectives

The objective of Task 4 in 2001 is to measure and document the levels, characteristics and range-dependence of sounds and vibrations produced by Northstar-related industrial activities occurring during the winter and spring of late 2000 and early 2001, excluding activities whose sounds and vibrations were adequately characterized in 2000. New operations may include some or all of the following:

- Drilling from the island;
- Power generation on the island during winter if a different power source is in use than was used in early 2000;
- New types of maintenance and construction activities, if they occur.

Approach

During any previously unstudied late winter or spring operations by BP on or near the island, sound and vibration measurements will be made for representative periods at several distances from the sound source. The acoustic work will be done by BP's underwater acoustics contractor and an Inupiat assistant employed via LGL. The new data will supplement related data on underwater sounds obtained during winter construction of Northstar Island in 2000 and Seal Island in 1982 at the same location (Greene 1983; Greene et al. in prep.). During the winter construction of Northstar Island in 2000, sound and vibration recordings were made of ice road, island, and pipeline construction activities. Recordings of sound, both in air and in water, and vibrations in the ice were also made of gravel hauling, ice cutting and dumping, and vibratory sheetpile driving. These measurements were made at various distances from the noise sources until they were no longer audible, and then a more distant location was visited when possible to verify the lack of propagation beyond the previous recording distance (Greene et al. in prep.). Similar recording methods will be employed during the ice-covered season in 2000-2001.

Nominal recording distances will be 1/8, 1/4, 1/2, 1, 2, and 4 n.mi (0.14 – 4.6 mi), and (if necessary) farther. If no construction-related sounds are detectable at a given distance, recordings will be made at the next planned distance if this is logistically feasible. However, recordings at distances beyond 2× the maximum audible distance may not be attempted. Precise recording locations and distances will be adapted to ice conditions. Whenever feasible, the duration of recording at each station will be sufficient to document the short-term variability in the sounds. When recording the operation of machinery engaged in repetitive operations on the island, the duration of recording at each distance will include at least three full cycles of machine operations.

Received sound and vibration levels will be measured by a microphone in the air above the ice, a geophone placed on the ice, and a hydrophone suspended through the sea ice to a location near the sea floor. These sensors will record the vibration and sound levels associated with the major new activities on the island not previously recorded, especially the sounds of drilling if that occurs in early 2001.

To help match specific tonal or other components with particular machines or operations, some recordings will be made at short distances from the sound sources. At these locations, their sounds will dominate the received sound field, and the specific source of the sound will be unambiguous.

Analyses of the recorded sounds will be designed to document sound and vibration levels, spectral and temporal characteristics, and transmission through the air, ice, and water. The analyses will be for both broadband and one-third octave levels. The recordings of the same sound made at different distances will provide the needed data on transmission loss. The analysis techniques will be based on techniques used in the recent past for similar work.

The results will be used to estimate the sound and vibration levels near animals that tolerated or avoided the various activities.

Access over the ice will be by two rolligons or similarly capable vehicles equipped with GPS for navigation, a powered ice auger for drilling holes (>6" diameter) in the ice, and a driver(s). The rolligon driver(s) will also be expected to assist with polar bear guard duties.

Field Schedule

One field trip is planned during the winter/spring period of 2001. The field crew will consist of one senior acoustician and one Inupiat assistant. In addition to having primary responsibility for the polar bear guard duties, the Inupiat assistant will help with the recording work and will receive training in the conduct of this type of fieldwork. On-ice operations are expected to require approximately 6 days.

Research Permit

The proposed acoustic monitoring work will not cause any significant disturbance to marine mammals beyond that caused by the general Northstar operations. The incidental take authorization (LoA) requested by BP should, when issued by NMFS, provide any necessary authorization to conduct this acoustic monitoring work.

MONITORING DURING OPEN-WATER SEASON, 2000

The primary activities associated with construction during the open-water season in 2000 are island shaping, placement of filter fabric and concrete slope protection, emplacement of foundations, emplacement of conductor pipes by impact methods, helicopter and vessel movement of personnel and supplies, and barge movement of living quarters, drilling supplies, and a drill rig to the island. Vessel transportation of production modules to the island is scheduled for the open-water season of 2000. During this phase of construction, ringed seals and a few bearded seals will be present, and possibly a few spotted seals. In most years, no gray whales occur near Northstar, but a few individuals could migrate through or (as in 1998) linger in the general area. Bowhead and beluga whales probably will not be present until mid to late August (belugas) or late August/early September (bowheads). Belugas are very infrequent as close to shore as Northstar. The main migration corridor of bowheads is also north of Northstar, but in some years a small proportion of the migrating bowheads approach within 10-15 km (6-9 mi). Subsistence whaling will occur east of the construction area, near Cross Island, during September.

During the open-water period of 2000, monitoring activities include acoustic measurement of sounds produced by construction activities (Task 5) and island-based visual observations of marine mammals (primarily seals) near construction activities (Task 6). Also, an additional task not mentioned in BP's original Petition for Regulations (as submitted in 1998) was added to the monitoring plan in 1999. This is Task 7, "Acoustic Monitoring of Bowhead Migration". Task 7 has been further refined in this updated monitoring plan based on (a) discussions at the peer review meeting held in Seattle in May 2000 and (b) statistical power analyses completed after that meeting. The monitoring of the bowhead migration corridor planned under Task 7 will address questions raised in the Northstar EIS, satisfy requirements of the North Slope Borough rezoning permit, and satisfy stipulations in the State of Alaska Consistency Determination.

Task 5. Sound Measurements/Open-Water Season, 2000

Objectives

The objective of Task 5 is to measure and document the sounds of island-related activities that occur when open water exists around the island. This includes "breakup", when a moat-like annulus of water was expected to appear around the island, and later periods when more or less open water exists at Northstar. The breakup period is important, because pile driving was expected to occur then, and some ringed seals might occur in the open water around the island. After breakup, levels, spectral characteristics, specific sources, and transmission loss will be determined.

Approach

Acoustical subcontractor Greeneridge Sciences Inc. will use three methods to obtain measurements of underwater sounds propagating from Northstar:

- Before general ice breakup, hydrophones and a microphone will be deployed (a) from a small boat or the ice edge in the localized area of water surrounding Northstar Island and (b) from the ice beyond the "moat". For the latter work, personnel will be transported to the ice by helicopter. These efforts will document underwater and airborne sounds from conductor pipe driving and other construction activities as they propagate into and beyond the limited area of open water around Northstar during breakup. [The field components of this task were completed in the early summer of 2000.]

- During the open-water period in summer, hydrophones and a microphone will be deployed from a boat at various distances from Northstar. This will obtain acoustic data at a variety of distances from Northstar Island at a few selected times in the open-water season, primarily to document levels vs. distance from the island. [This task is underway in August 2000.]
- Also during the open-water period in summer, a fixed, bottom-mounted hydrophone will be deployed 300-500 m (984-1640 ft) seaward of Northstar Island (actual distance 455 m) and connected to the island by a cable. This will obtain continuous data at one distance over a period of a week or more, primarily to document temporal variability. This effort will continue into the autumn as part of Task 7 (see later).

The fixed-hydrophone data will document a variety of construction sounds, allowing assessment of source variability. The boat-based samples are intended to provide information primarily on propagation characteristics. The fixed hydrophone will operate while boat-based measurements are acquired. Analysis of the data from this fixed recording site will allow us to recognize and quantify any changes in sound characteristics among the different periods when boat-based recordings are acquired. Propagation characteristics are unlikely to change significantly over periods of hours. In combination, the data from the brief recordings at various stations plus the "reference" data from the fixed hydrophone should be sufficient to characterize propagation on a given day. The monitoring plan includes a second day of recordings to characterize the variability in propagation characteristics.

Recordings During Breakup

It was anticipated that, during breakup in late June or early July, there would be an area of open water surrounding Seal Island. Conductor pipe driving and other construction activities were expected to occur during this time. To document underwater sounds produced by these operations, an acoustician used helicopter support to deploy two hydrophones through holes in the ice at various distances from the conductor pipe driving. A microphone was also used at these ice stations. In addition, it was planned that, in the event that there was a substantial "moat" of open water around the island, a small boat would be used to deploy a hydrophone and a microphone at various locations near the island. This boat was taken to the island over the ice road before the start of breakup. At each recording station, the boat was to drift with its engine off while the hydrophone and microphone signals are recorded onto a DAT recorder. Specific recording distances were to depend on the ice conditions. Distance from Northstar was to be determined by laser rangefinder and GPS.

These acoustic measurements were to be concentrated on the side of the island where conductor pipe driving or other potentially noisy activities are occurring, as that is where the highest sound levels were expected. This work was to be conducted with the assistance of LGL personnel, who were present at Northstar at the same time to monitor seal reactions to the construction activities (see Task 6). To help ascribe particular components of underwater sound to specific industrial activities, construction activities on the island were to be noted during the recording times, and in-air sounds near major sources of noise on the island were to be recorded.

Boat-Based Recordings in Open Water

More extensive boat-based recordings of sounds will be obtained in August 2000 after ice breakup. To document sounds levels and characteristics in relation to distance from Northstar, two hydrophones and a microphone will be deployed from a larger boat. The boat will drift with its engines off at distances of 1/8, 1/4, 1/2, 1, 2, 5 and 10 n.mi (0.14 – 11.5 mi) from Northstar Island, and farther if necessary. Recordings will, if logistically feasible, continue out to one station beyond where no Northstar sounds are heard.

Recordings at each distance will be for about five minutes. It is planned to make these boat-based recordings at each of these distances on two days to help assure recordings of the strongest sound sources. Island activities will be monitored on shore during the times of these recordings. Also, while the boat-based recordings are being made at various distances, the fixed hydrophone signal (see below) will be recorded continuously to document changes in the source levels that might otherwise confound interpretation of the results obtained sequentially at different distances. Specific sounds of interest include any of the following activities that occur during the open-water season: vibratory conductor pipe driving, operation of generators and construction equipment on the island, and movement of barges and other vessels to and from the island. When possible, sounds from the same operation will be recorded at several distances. This will provide information about received levels in relation to distance, and thus about transmission loss. All recording equipment will be calibrated, and both airborne and underwater sounds will be analyzed and described on both a narrowband and a 1/3-octave basis.

The boat used for the recording work will be equipped, at a minimum, with GPS navigation equipment and two-way radio. A laser rangefinder will be used to measure distances to the island at short ranges, and the GPS will be used at all stations. If Differential GPS equipment is available, it can be used at any distance. If radar is available on the vessel, it can also be used to determine or to verify distances from Northstar Island.

Underwater sound measurements from a boat will involve use of paired hydrophones suspended from a spar buoy tethered to the boat. The spar buoy is essential to decouple the hydrophone from wave-induced motion of the boat. Two hydrophones will be used: an ITC model 6050C low-noise hydrophone with built-in preamplifier, and a cylindrical ITC model 1104 hydrophone with no preamplifier. Both hydrophones are calibrated. The cylinder can tolerate higher sound levels without distorting, and is needed when the received level is high. The more sensitive 6050C is useful in low-noise environments, such as are often found in shallow water or ice-covered environments distant from any source of strong sound.

The hydrophone and microphone signals will be amplified to the degree necessary to provide good dynamic range. They will be recorded on a SONY model PC208Ax digital audiotape (DAT) recorder, which is an instrumentation-quality unit that automatically documents the recording date and time on the tape. The useful acoustic bandwidth will be from 10 to at least 10,000 Hz. (The upper frequency limit varies with the number of channels of acoustic data being recorded simultaneously.) Concurrent voice annotations will be made on a memo channel on the recorder.

Subsequent laboratory analyses will determine root-mean-square (rms) sound levels and sound spectral density levels. One-third octave band levels will be computed for band center frequencies from 20 to 8000 Hz. The result of the boat-based measurements will be data on sound levels and frequency composition vs. distance from the island for specific sounds of interest (especially the sounds from impact and vibratory conductor pipe driving) and for the composite sounds from Northstar.

Fixed Hydrophone

A single hydrophone with preamplifier (ITC model 8212 or similar) will be spliced to a double-armored cable for deployment from the island. After ice breakup, the hydrophone will be deployed by hand from a boat to a distance of about 500 m (1640 ft) north or north-northeast of the island. It will be mounted on a short steel stand to position the sensor just above the bottom. The island end of the cable will be connected to a postamplifier and thence to speakers (or headphones) and to a DAT recorder for long-term continuous recording. Alternatively, it may be connected to an autonomous recorder for continuous recording over the observation period, with the DAT recorder available for backup. An acoustician from

Greeneridge Sciences will monitor the sounds, maintain logs of industrial activities that could contribute to the underwater sounds, and keep the recording system operating.

The fixed hydrophone sounds will be recorded for a period of at least one week during the open-water season. This will include the days when boat-based measurements of sounds are being obtained at various distances from the island. A second complete hydrophone and cable system will be available for installation if the original system should fail prematurely, which is possible if ice keels drag over the cable. The Autonomous Seafloor Acoustic Recorders (ASARs) developed for BP in 1996 are also available if needed as backup recording devices at this location. The fixed hydrophone signals will continue to be recorded during bowhead migration in support of Task 7.

During laboratory processing, the acoustic recordings will be analyzed quarter-hourly to determine the levels, spectral characteristics, and statistical variability in the sound levels as received at a constant distance seaward of Northstar. In addition to the routine quarter-hourly analyses, the recorded signals will be analyzed at additional times when unusually strong or otherwise important industrial sounds are heard, and also at times when boat-based recordings were obtained. Sound analysis results will be related to records of the industrial activities occurring on or near the island at those times.

During the field season, in-air sound recordings will be obtained close to each piece of equipment operating on the island that might produce a significant contribution to the underwater sound. These recordings can be used to identify any specific tones or other sounds radiating from particular pieces of equipment. This information will assist in identifying the specific sources of sounds detected underwater seaward of the island

Task 6. Island-Based Visual Monitoring, 2000

In order to evaluate the effects of construction operations during the breakup and open-water seasons on marine mammals close to Northstar, it is necessary to monitor their occurrence and behavior near the island. By relating marine mammal observations (this task) to acoustic data from Task 5, the occurrence and nature of any "taking" can be further assessed. Also, by conducting visual observations around the island just before and during times with impact pile driving, BP can temporarily suspend impact pile driving, or any other activity that might produce very strong underwater sounds, at any times when marine mammals are close enough for hearing damage or other forms of injury to occur.

Objectives

The primary objective of this study was to suspend industrial activities (such as impact driving of the conductor pipes) if they had the potential to impair seal hearing. The secondary objective was to determine the distribution, abundance and behavior of seals around the island during times when construction activities emitted sounds strong enough that they might impair seal hearing or cause strong disturbance reactions.

Background

There are no specific data demonstrating that sounds of the types or levels emitted by Northstar construction activities will injure marine mammals. However, in the case of seals, a received sound level of 190 dB re 1 μPa (rms over duration of pulse) was planned as the threshold for requiring island-based visual monitoring and mitigative actions. Given the ice conditions and normal seasonal distribution of cetaceans in early summer, it was considered highly unlikely that cetaceans would occur near Northstar then. However, in the event that there was extensive open water near Northstar in the open-water season while impact piledriving was occurring, a 180-dB criterion would apply for cetaceans.

These exposure thresholds are sound pressure levels (SPL), which are based on the average sound pressure of a signal. When calculating SPL by averaging pressure measurements of a transient pulse, it is important to exclude from the average those times when the signal is absent; otherwise the result would be too low. The phrase "rms over duration of pulse" refers to the act of determining the time during which a transient sound is present and calculating the average (root-mean-square) pressure only over that time, thus avoiding underestimation.

The 190 and 180 dB re 1 μPa (rms) criteria were established by NMFS in 1995 for a seismic program off southern California (see NMFS 1995, *Federal Register* 60[200, 17 Oct.]: 53753-60). NMFS concluded that it would be safe to expose pinnipeds (and odontocetes) to sequences of low-frequency pulsed sounds with received levels as high as 190 dB[1]. At levels below 190 dB (rms), no effects on hearing sensitivity of seals were expected. The 190 dB re 1 μPa (rms) criterion has been used as the assumed safety criterion for seals in all open-water seismic projects conducted in the Beaufort Sea in 1996-99. In the Beaufort Sea, a 180-dB criterion has been used for all cetaceans, including belugas, as well as bowhead and gray whales.[2]

In June and July 2000, island-based observations were made during break-up when the well conductor pipes were being driven by impact hammering. Also underway at that time were grading of the island side slopes and placement of the concrete block slope protection. Preliminary analysis of acoustic measurements made simultaneously with the island-based visual observations was completed while the visual observations were still ongoing. This analysis indicated that received levels in the water near Northstar island did not exceed 150 dB re 1μPa (rms) — much less than the safety/shutdown criteria described above. Therefore, the potential to damage marine mammal hearing, as discussed in the petition for regulations, did not exist. Based on the results of the acoustic monitoring early in the 2000 open-water season, BP discontinued island-based visual watches for marine mammals. BP does not propose to conduct on-island visual observations for marine mammals in the future.

Specific information concerning the implementation and results of the on-island visual observations will be included in the 90-day report concerning the open-water monitoring in 2000, and in the draft final report on the 2000 monitoring activities. The rest of this section describes the island-based visual monitoring work as planned before the open-water season and as conducted during June-July 2000.

Monitoring and Mitigation Methods

Observations of marine mammals (primarily seals) will be conducted from an elevated platform on Seal/Northstar Island. These observations will provide information on marine mammal distribution, abundance, and behavior during periods with and without construction activities, particularly during emplacement of module foundation piles and conductor pipes. Observations will be conducted for 8 hours

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[1] Measured in the manner developed by C.I. Malme et al. (1983, 1984) during their studies of gray whale reactions to seismic pulses. Their measurement procedure entailed averaging the pulse pressure over the duration of the pulse

[2] Monitoring work during the 1996-99 seismic projects has shown that peak levels of seismic pulses are typically 10-12 dB higher than the rms levels at the same place and time. If disturbance or shutdown criteria were to be based on peak levels, then the criteria would be 10-12 dB higher than the criteria now used based on rms levels. The corresponding safety/shutdown radii would be unchanged relative to those now used based on rms levels. At least for seismic pulses, a 190 dB rms level and a 200-202 dB peak level are equivalent, and occur at the same distance from the sound source. Likewise, a 180 dB rms level and a 190-192 dB peak level are equivalent and occur at the same distance (which is larger than distance where a 190 dB rms or 200-202 dB peak level would be found).

per day for 2-3 days during each major type of construction activity, and during quiet periods before and/or after these activities occur. The sounds emitted by these activities will be recorded and analyzed at the same time as part of Task 5. If sounds strong enough to impair the hearing of nearby seals propagate into the water, island-based visual observations will occur whenever these sounds are being produced. It is assumed that, during early summer, ice-cover offshore from Northstar would prevent access of cetaceans to the area. Hence only the 190 dB criterion (for seals) is applicable at that time.

During all observation periods, observers will use binoculars to search continuously for marine mammals. To assist in estimating distances, binoculars with vertical reticles will be used from an observation site at known height. Observers will determine the locations of marine mammals relative to the observation site and any potential source of disturbance. If logistically practical, buoys or other objects at known distances in or near the water will also be used to help determine locations of mammals. The observers will record the following:

- construction activities occurring during each observation period,
- species and number of marine mammals seen,
- bearing and distance of the marine mammal(s) from the observation point,
- behavior of marine mammal(s), and
- any indications of disturbance or reactions to construction or other activities.

If marine mammals are seen within or approaching designated "safety radii" around operating equipment, the observers will advise the operators of the need to suspend operations temporarily until such time as marine mammals are believed to be no longer present within the safety radius.

This monitoring work involves only passive observations. It has no potential to disturb or otherwise "take" marine mammals.

Field Schedule

The island-based monitoring work in 2000 was to begin when open water began to form around the island. It was to continue at least until a minimum of 2-3 days of observations had been obtained during each type of construction activity that might produce underwater sounds exceeding the safety criteria. If acoustical measurements (Task 5) showed that sounds strong enough to impair the hearing of nearby marine mammals propagate into the water, observations were to occur whenever these sounds were being produced. As previously noted, it was assumed that, during early summer, only the 190-dB criterion (for seals) was applicable. If acoustic measurements indicated that underwater sound levels created by impact pile driving (and any other activity that might produce high sound levels) did not exceed 190 dB re 1 μPa (rms over duration of pulse) at any point in the water surrounding Northstar, then continued island-based visual monitoring was not proposed. It was expected that ice and open-water conditions would change continuously, and we proposed to maintain contact with NMFS staff in Anchorage to determine if this task is warranted, based on the conditions at the island.

For budgeting purposes, it was assumed that two observers (one biologist and one Inupiat) were required on the island for a period of three weeks during the early part of the 2000 open-water season. In addition to conducting the island-based marine-mammal monitoring, they assisted acoustics subcontractor Greeneridge Sciences with the acoustic tasks described in Task 5.

Task 7. Acoustic Monitoring of Bowhead Migration, 2000

Concern has been expressed that the autumn migration corridor of bowhead whales might be deflected farther offshore in the Northstar area in response to underwater sounds from construction, operations, and associated vessel and aircraft traffic. Previous studies, including work at Seal Island when it was constructed in the early 1980s (Hickie and Davis 1983), have shown that most underwater sounds propagating from a gravel island like Northstar are quite weak and usually not detectable beyond a few kilometers offshore of the island. Sounds from impact piledriving are a possible exception (Moore et al. 1984; Johnson et al. 1986), but BP does not expect to drive piles during the bowhead migration season. Also, vessel and aircraft traffic associated with Northstar construction will rarely if ever extend more than 1 km (0.6 mi) offshore of Northstar. A subsequent subsection provides additional details concerning the distances from Northstar within which industrial sounds are expected to be detectable. Assuming that these distances will be small, any effects of Northstar construction (or operations) on the autumn migration corridor are expected to be limited to the small minority of bowheads that move along the southern edge of the migration corridor. For this reason, any effort to monitor Northstar effects on bowhead migration in the Northstar area should concentrate on the southern part of the migration corridor, and should be designed to detect small-scale effects.

The two potential monitoring approaches that have been discussed by BP, the wildlife department of the NSB, NMFS and the peer/ stakeholder review group are aerial surveys and acoustic localization. BP has not proposed to use aerial surveys, on the rationale that even an intensive site-specific aerial survey would provide too few sightings of bowhead whales to detect and characterize a small-scale displacement of the southern edge of their migration corridor. Results of a power analysis supporting that view were presented at the peer/stakeholder meeting in Seattle in May 2000, and that power analysis is further documented in Appendix B. As noted in the final meeting summary, "There was general agreement that the monitoring plan should not include aerial surveys because aerial surveys will be very unlikely to detect even a large deflection away from the Northstar facility".

Instead, BP has proposed to use an acoustic localization technique to document the occurrence and locations of calling bowhead whales in the southern part of the migration corridor. In particular, this approach would determine whether the distribution of calling whales in that area is related to hour-to-hour variability in sounds emitted by Northstar operations. If so, this will suggest that Northstar sounds have an effect on migrating whales. The geographic scale of this effect should also be determinable, which (in turn) will provide much of the information needed to estimate the numbers of bowheads affected. This approach was discussed and provisionally accepted at the peer/stakeholder review meeting in Seattle in May 2000. This acceptance was subject to completion of a statistical power analysis addressing whether the proposed acoustic approach is likely to detect an effect of the anticipated magnitude if it occurs. That power analysis has been completed, and it confirms that the proposed approach does have the necessary statistical power (Appendix C).

One complication in monitoring effects of Northstar construction (and, in subsequent years, Northstar operations) on the bowhead migration corridor is the fact that the island will be present continuously. During recent (1996-98) seismic-monitoring projects, effects of the industrial activities on the bowhead migration corridor have been assessed by comparing the locations of migrating bowheads during times when the airguns have been operating vs. shut down (Miller et al. 1999). This approach, involving within-season comparisons between "seismic" and "control" periods, largely avoids the complications associated with the known year-to-year variability in the north-south location of the bowhead migration corridor. Within-season comparisons may be less effective in assessing effects of Northstar construction (and operation) on the migration corridor, given the continuous presence of the island. Nonetheless, at least during the construction phase, appreciable hour-to-hour variability in the industrial sounds is anticipated. This provides a basis to determine whether, and to what distance, the Northstar sounds affect the distribution of calling whales.

The following subsections (along with Appendices B and C) provide additional details concerning the objectives, anticipated sounds from Northstar, potential effectiveness of aerial surveys vs. acoustic localization, proposed specific methodology, and estimation of number of bowheads "taken by harassment".

Objectives and Hypothesis

BP is developing and will apply a new type of acoustic localization system during September-October 2000 and (if necessary) future years to monitor the autumn migration corridor of bowheads passing Northstar. The objectives are to document the occurrence of calling bowhead whales in the southern part of the migration corridor in relation to distance north of Northstar and to determine whether their distances from the island vary in direct relation to the sound levels emanating from the island. If so, this will indicate that Northstar affected the distribution and/or the calling behavior of the whales. If there is an effect, the geographic extent of the effect will be determined and will be used to estimate the number of whales that were apparently affected. More specifically, the objectives are:

1. to monitor the year 2000 bowhead migration past Northstar by acoustic localization methods, primarily to document the relative numbers of bowhead calls vs. distance offshore in the southern part of the bowhead migration corridor seaward of Northstar;

2. to document continuously the characteristics of the sounds propagating away from Northstar, as determined at a close-in monitoring site approximately 300-500 m (1000-1600 ft) offshore from the island, as well as the characteristics of the background sounds (industrial plus ambient) reaching the recording devices in the southern part of the migration corridor;

3. to assess the effects of Northstar activities on the migration corridor and calling behavior of bowheads by comparing the distances of calling whales from Northstar at times with varying levels of industrial noise;

4. to determine whether any individual bowheads or bowhead groups can be tracked acoustically. If so, the tracks will be analyzed to determine whether there is evidence of deflection as the whales approach Northstar and, if so, at what distances and received sound levels;

5. to compare the acoustic monitoring results with results from MMS or any other available aerial surveys to further assess the strengths and limitations of acoustic and aerial methods in documenting the bowhead migration corridor past Northstar and in detecting any change (probably small-scale, if at all) in the migration corridor near a site like Northstar;

6. to estimate the number of bowhead whales whose movements and/or calling behavior were affected by the presence of industrial activities at Northstar in autumn 2000.

The primary null hypothesis to be tested is that "the distribution of calling whales detected north of Northstar is not related to the level of industrial noise from Northstar". The associated alternative hypothesis is that "the calling whales detected north of Northstar tend to occur farther away with increasing levels of industrial noise from Northstar". This hypothesis relates principally to objective (3), above. It should be tested with a 1-sided test, and the test must allow for possible lack of independence among the whale calls received from nearby locations at short time intervals. To test this hypothesis, continuous data on the industrial sounds will also be required (objective 2).

The following subsections provide additional details on the proposed approach, rationale, and methods.

Anticipated Industrial Sounds and Reaction Distances

The types, levels and characteristics of sounds likely to be emitted by operations at Northstar during September-October 2000 have been discussed in BP's Petition for Regulations and request for an LoA, and in the Northstar EIS. Those documents cite the various relevant technical reports describing field measurements and models of underwater sounds that occurred during construction and operations at Seal and Sandpiper Islands during open-water seasons in the early-mid 1980s. Acoustical contractor Greeneridge Sciences Inc. has reviewed this work again for purposes of this updated Monitoring Plan. Greeneridge has concluded the following: Under typical ambient noise conditions, the distances offshore from Northstar at which industrial noise levels will diminish below ambient and become undetectable will be about

- 2 km or 1.24 statute miles for typical construction noise,
- 5 km or 3.1 mi for strong construction noise, excluding conductor pipe driving, which will likely not occur in Sept-Oct, and
- 15 km or 9.3 mi for a cavitating tugboat.

Under low (5th percentile) ambient noise conditions, corresponding distances are predicted to be about

- 9 km or 5.6 mi for typical construction noise,
- 15 km or 9.3 mi for strong construction noise, and
- 31 km or 19 mi for a cavitating tugboat.

In each case, this assumes a direct path from the source to the receiver, uninterrupted by the island or shoals. Also, it is emphasized that these are the maximum distances at which sounds will be *detectable*, and that reactions would not normally be expected at distances this large.

These figures are based on industrial sounds in the 20-1000 Hz band as compared with ambient noise in that same band. Data by 1/3rd octave band are generally not available from the measurements obtained in the early-mid 1980s. Sounds in the strongest 1/3rd octave band are likely to be slightly above the ambient level in that band (and thus detectable) out to distances slightly greater than those quoted above. However, even for the strongest 1/3rd octave band, received levels would almost always (if not always) be less than 10 dB above ambient at the distances quoted above. Industrial sounds with signal-to-ambient ratios up to 10 dB (and indeed up to 15 or 20 dB) generally do not elicit observable reactions by bowhead whales (Richardson and Malme 1993).

Observable reactions usually are limited to distances well inside the maximum detection distance. For example, the maximum distance at which bowheads have been observed to react to approaching boats, including supply ships, tugs, and outboard-powered vessels, is about 7 km (4.3 mi). More typical reaction distances to a directly approaching boat are about 2-4 km (1.2 - 2.5 mi). Bowheads (and other whales) are less sensitive to boats that do not approach directly (Richardson and Malme 1993; Richardson et al. 1995).

Based on the above, in the absence of tugboats, any reactions by bowhead whales will usually be limited to distances within 5-10 km (3-6 statute miles). There is a possibility of occasional reactions out to 15 km (9.3 mi) on days with low background noise and strong construction noise, or typical background noise and a cavitating tugboat. The one situation when whales might detect sounds at greater distances involves the case of a cavitating tugboat on a day with low background noise.

Aerial Surveys

Aerial surveys are the "traditional" method for studying the distribution and movements of bowhead whales in the Beaufort Sea. They have the advantage of providing direct observations of whales. Disadvantages include the fact that they are limited to periods of daylight and good visibility, to the transect area that can be traversed by an aircraft within a few hours of flying each day, and to the whales that are at the surface and detected as the aircraft passes over. Aerial surveys can be very valuable in many situations, but they have severe limitations in the present case.

The particular problems in this situation are that (1) the anticipated radius of influence of Northstar is no more than a few miles, (2) this zone of influence will be well south of the main migration corridor, and (3) good weather conditions for aerial surveys typically occur on only about half the days. Aerial survey data collected in the Northstar area annually since 1979 show clearly that, even in the absence of any Northstar effect, very few whales would be detected within that zone even by an intensive site-specific aerial survey.

(a) Combined MMS and LGL Site-Specific Surveys, 1979-98.—MMS has kindly made available the data from broad-scale aerial surveys that they have sponsored or conducted during autumn in the Beaufort Sea since 1979. In addition, LGL has conducted site-specific aerial surveys around various offshore oil and seismic industry activities in the general Prudhoe Bay area during parts of seven autumns (1982, 1984-85, 1995-98), including coverage of the Northstar area in each of those years. For purposes of assessing the numbers of whales detected near Northstar during aerial surveys, attention has been restricted to randomized (MMS) or systematic (LGL) north-south transects conducted near Northstar under periods of acceptable sightability and sea state. These are the data that would be useful in analyzing whale distribution around Northstar. The sightability and sea-state criteria used are the same as those used in analyses of whale distribution around seismic vessels during 1996-98 (Miller et al. 1999). The area considered is an area 88 km (55 st.mi.) from east to west, extending from the shore north to the 100 m depth contour. This area is consistent with the area typically surveyed during a site-specific aerial survey (12 north-south lines spaced 8 km or 5 mi apart).

Table 1 summarizes the numbers of bowhead sightings and survey effort vs. distance from Northstar in 1979-98. Overall, there were 128 MMS sightings in 22,400 st.mi. of surveys, and 324 LGL sightings in 39,000 st.mi. of surveys.

Very few of the 452 sightings, and relatively little of the survey effort, were within a few miles of Northstar. During randomized and systematic surveys by MMS and LGL over the 20-year period, there was only 1 bowhead sighting within 4 mi. of the Northstar, 13 sightings within 7 mi., and 31 within 10 mi. These low numbers are a result of two factors: the limited size of the annuli close to Northstar (and thus the limited survey effort within those annuli), and the fact that Northstar is south of the main migration corridor of the bowhead whales.

TABLE 1. Bowhead whale sightings vs. distance from Northstar island during all MMS and site-specific aerial surveys, 1979-98.

Number of Sightings at	Total Sightings	Statute Miles of Surveys	Sightings per 1000 st.mi
0-1 st.mi	0	171	-
1-2	1	245	4.1
2-4	0	773	-
4-7	12	2244	5.3
7-10	18	2656	6.8
10-20	135	14,551	9.3
>20 *	286	40,845	7.0
Total	**452**	**61,485**	**7.4**

* out to the boundaries of the area defined above (88 km or 55 mi east-west, offshore to 100 m contour).

(b) MMS Surveys, 1979-98.—Considering the MMS aerial surveys alone, and using the same criteria as described in (a), above, there were 90 MMS sightings of bowheads near Northstar in 1979-95, and an additional 38 sightings within that area in 1996-98 (total of 128 sightings over 20 years). The maximum number of MMS sightings within that area in any one year was 30 in 1995, with 21 in 1982, 19 in 1998, 12 in 1993, 12 in 1997, and ≤7 in all other years from 1979 to 1998. Over the 20-year period, none of the "systematic" MMS sightings were within 10 mi. (16 km) of Northstar. Eight MMS sightings were 10-15 mi. away, and 18 were 15-20 mi. away. The maximum number of MMS sightings within 15 mi. of Northstar in any one year was 5 (in 1995), and the maximum number within 20 mi of Northstar was 15 (also in 1995).

The MMS surveys are very useful in documenting the general timing of migration and the location of the main migration corridor relative to shore. However, they are obviously not adequate to monitor the numbers or proportions of whales passing within the short distances (5-15 km or 3 - 9 mi.) from Northstar where it is reasonable to hypothesize that some effect might occur.

(c) Site-Specific Aerial Surveys.—More intensive but localized site-specific aerial surveys were done in the general Prudhoe Bay area during the autumns of several years. Because of their design, these studies provide more aerial survey coverage and more sightings in the general Northstar area than are obtained from the wider-ranging MMS surveys. For example, site-specific studies in 1996, 1997 and 1998 recorded 33, 118 and 115 bowhead sightings within the area described in (a), above, as compared with 7, 12 and 19 sightings by MMS in that area during the same years. (Data are again restricted to systematic surveys conducted under periods with acceptable sightability and sea state.) Of these 33, 118 and 115 sightings during the 1996-98 site-specific studies, Table 2 shows that

- 0, 1 and 0 (respectively) were within 4 mi. of Northstar,
- 1, 9 and 2 (respectively) were within 7 mi of Northstar,

TABLE 2. Bowhead whale sightings near Northstar island during 1996-1998 site-specific surveys conducted to monitor bowhead reactions to BP and Western Geophysical seismic projects (Miller et al. 1997, 1998b, 1999).

Number of Sightings Within	1996	1997	1998
1-2 mi	-	1	-
2-4	-	-	-
4-7	1	8	2
7-10	-	12	6
10-20	15	56	31
Extra coverage possible*	x 3.5	x 2.4	x 1.7

* See text

- 1, 21 and 8 (respectively) were within 10 mi., and
- 16, 77 and 39 (respectively) were within 20 mi.

The numbers within 4 mi, 7 mi and 10 mi would be unchanged if the MMS results were combined with the site-specific survey results, as MMS systematic surveys detected no bowheads within 10 mi of Northstar in those years. The values for 20 mi would be 16, 81 and 41 based on the combined MMS and site-specific results. (There were four MMS sightings 10-20 mi away in 1997, and two in 1998.)

The number of sightings in the Northstar region in 1997 was unusually high, and indicative of the fact that the bowhead migration corridor was unusually close to shore that year (Miller et al. 1998b, 1999; Treacy 1998).

The site-specific studies in 1996-98 did not continue for the full bowhead migration season. If we assume the main bowhead migration period near Northstar to be 1 Sept to 20 Oct., the 1996 study covered about 42% of the migration (1-21 Sept.), the 1997 study covered about 56% of that period (1-28 Sept.), and the 1998 study covered about 90% (1 Sept. – 15 Oct.). There are further complications associated with the fact that, during parts of the 1996-98 seasons, the site-specific surveys were centered on seismic vessels operating far enough east or west of Northstar such that only partial coverage of the Northstar area was attained. Therefore, a site-specific survey centered on Northstar and occurring daily (weather permitting) throughout the 1 Sept. – 20 Oct. period would be expected to detect more whales near Northstar than were detected in 1996-98. We estimate that, if the site-specific aerial surveys had been centered on Northstar in 1996-98 and had been continued until 20 October, the amount of survey coverage near Northstar (and presumably the number of sightings there) would have been about 3.5 times higher than actually obtained in 1996, 2.4 times higher in 1997, and 1.7 times higher in 1998 (Table 2). If so, the expected numbers of sightings in 1996-98 would have been

- 0 in 1996, 2 or 3 in 1997, and 0 in 1998, within 4 st.mi. of Northstar,
- 3 or 4 in 1996, 22 in 1997, and 3 or 4 in 1998, within 7 mi. of Northstar,

- 3 or 4 in 1996, 50 in 1997, and 14 in 1998 within 10 mi., and
- 56, 185, and 66 (respectively) within 20 mi.

Again, the 1997 figures reflect the unusual numbers of whales migrating close to shore that year. The 1996 and 1998 figures are more representative of those likely to be found in a future site-specific aerial survey project centered on Northstar and extending through the full migration season.

(d) Statistical Power Analysis: Biometrician Dr. Trent McDonald of WEST Inc. has conducted an analysis of the statistical power of aerial surveys to detect avoidance by bowheads of the area within various relevant distances of Northstar (Appendix B). The analysis shows that power to detect an effect was low given typical whale sighting rates of 3 or 5 sightings per 1000 km of survey effort. With those typical sighting rates, power to detect an effect was low regardless of the size of the impact area (1-20 mile radius), even in the case of near-total avoidance of the impact area. With typical whale sighting rates, power would be low even with three years of post-construction surveys and a liberal $\alpha = 0.20$ criterion.

Results of this analysis were summarized at the peer/stakeholder review workshop in Seattle on 24-25 May 2000, and are given in more detail in Appendix B. Participants at the Seattle workshop concurred with the conclusion from these analyses that a full-season, intensive, site-specific aerial study is unlikely to detect enough whales close to Northstar for a meaningful test of an "avoidance hypothesis", assuming that effects are limited to distances within 4 - 7 miles (6 - 11 km). The numbers that would be detectable within those distances over a full migration season are very low in "typical" years as exemplified by 1996 and 1998. Even when site-specific plus MMS data are compiled across many years of surveys in the Northstar area, the numbers of sightings within 4 – 7 miles are low (e.g., Tables 1, 2). For this reason, aerial surveys are not proposed as part of this monitoring project.

Acoustical Localization Approach

Localization of calling bowhead whales via an array of hydrophones is planned to document the locations of many of the bowheads migrating past Northstar. A variety of array designs have been applied to detect and localize whale calls (Richardson et al. 1995, p. 40; Richardson 1999). For example, U.S. Navy SOSUS arrays were used to track a blue whale over 43 days and 2500 km (1,554 mi) in the Atlantic Ocean (Nishimura and Conlon 1993). Other array approaches have involved hydrophones suspended from the ice edge and cabled to attended recording and processing equipment (Clark and Ellison 1988). Another approach used bottom-moored hydrophones with surface buoys that used radio telemetry to transfer the acoustic signals to a ship for recording and processing (Greene 1987). These last two approaches were based on hyperbolic localization, i.e. differences in the time of arrival of a call at several hydrophones (Greene and McLennan 1996).

Acoustical localization methods are well established, and their capabilities and limitations are well understood. Only the whales that call can be detected and localized. Silent whales are missed. There are limits on the distance to which a given call detection and localization system can be effective. Also, there is no direct relationship between the number of calls detected and the number of whales present. Noise-induced changes in calling rate can also complicate interpretation. On the other hand, an acoustical system (unlike aerial surveys) detects whales when they are below the surface, and can do so day or night, in good weather or bad, in open water or under ice. Bowhead whales are known to call frequently during autumn migration (e.g., Greene et al. 1997, 1999).

Sample Size Considerations.—One of the main advantages of acoustical localization for the detection of small scale changes in the southern extent of the bowhead migration (or at least of the distribution of calling bowheads)[3] would be the large number of whale calls that are expected to be detectable. For example, during 1996, a bottom-mounted acoustical recorder about 17 km (10.5 mi) offshore of Northstar received 7018 calls during a 15.5-day period, and a similar unit about 13 km (8 mi) farther offshore received 28,592 calls over 22.6 days (Greene et al. 1998) (Table 3). To localize whales, a higher signal-to-noise ratio is necessary than for the simple detection of whales. Hence, not all of these calls would have been localizable if an acoustic system with localization capability had been in use. However, even if only 25-50% of the 7018 calls heard at the closer site had been localizable, the sample size would have been far larger than attainable with aerial surveys. There were only 58 bowhead sightings during daily [weather permitting] site-specific aerial surveys in the same area during a 21-day period in September 1996 (Miller et al. 1997). Also, for present purposes, monitoring would be continued for more than the 15.5-day period within which those 7018 calls were heard.

An acoustical localization system, as compared with aerial surveys, would provide a more effective method of site-specific long-term monitoring of an effect that is expected to occur on only a small scale (if at all). The use of an acoustical localization program to detect small scale changes in the southern extent of the bowhead migration corridor is expected to be a more effective monitoring tool than aerial surveys because of the increased statistical power afforded by the much larger sample size (Appendices B and C).

Effective Monitoring Range.—The distances over which bowhead calls can be detected and localized are important in designing an acoustic localization system. Call detection range will depend strongly on both the source level of the calls and the ambient noise level, both of which are variable. The NSB's acoustic studies in spring near Barrow (e.g., Zeh et al. 1988) have shown that many calling bowheads can be localized at distances out to at least 6 st.mi. (10 km), with smaller numbers to 9 mi (15 km) and a few to 12 mi (20 km). Localization distances in autumn should be at least as large as those in spring, and possibly larger, given the following:

- At Barrow, the fall-off in detection beyond 6 mi may be partly a result in fall-off in number of whales at distances >6 mi from the ice edge, not simply a result of limitations in detection range.
- As compared with the systems used at Barrow, the localization system planned by BP will employ a larger number of sensors spread over a much larger area.
- Ambient noise levels may be lower and/or less variable in autumn because of the much reduced level of calling by bearded seals in autumn vs. spring, and the less-frequent occurrence of moving ice close to the study site in autumn. Lower ambient noise levels would allow for larger localization distances, other factors being equal.

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[3] Acoustical results could be confounded if the rate or source levels of bowhead calls were affected by the presence of noise from Northstar. Some "bias" of this type is possible. However, results from numerous studies in the Beaufort Sea show that, in the presence of industrial sounds, bowhead calls of the usual types are detected at rates at least on the same order of magnitude as detected in the absence of industrial noise. Even with strong seismic noise, bowhead calls are detected (Richardson et al. 1986; Greene et al. 1999), though detection rate (and possibly calling rate) is sometimes reduced in the presence of seismic pulses. Given the lower source lower levels of the anticipated Northstar sounds as compared with seismic pulses, the distribution of call locations in the southern part of the bowhead migration corridor is expected to provide a good index to the distribution of whales there.

TABLE 3. Bowhead whale call counts recorded by Autonomous Seafloor Acoustic Recorders (ASARs) deployed in the general Northstar area during September of 1996 and 1998.

	Total Number of Calls	Days of Data	Calls per Hour
1996			
Northstar Island, north	9,023	20.0	18.8
Northstar Island, center	28,592	22.6	52.7
Northstar Island, south	7,018	15.5	18.8
Narwhal Island	17,620	14.6	50.2
1998			
Jones Island, North	2,013	10.5	7.9
Jones Island, South	8,138	10.5	32.3
Jones Island, East	4,458	10.5	17.7

- Industrial noise from Northstar is expected to diminish below natural background noise levels within a few miles of Northstar on most occasions, so it will be undetectable (or at most weak) at the DASAR locations, and will have little if any effect on detection and localization distances.

Calculations by Greeneridge Sciences indicate that a "loud" bowhead call with source level 180 dB re 1 µPa-m should be at least faintly detectable out to the following approximate distances: 9 mi at times of high (95th percentile) ambient noise, 22 mi with typical ambient noise (50th %ile), and 34 mi with low ambient noise (5th %ile). With lower source levels of 170 or 160 dB, the detection range under typical (50th %ile) ambient conditions would be reduced to about 14 and 7 mi, respectively (vs. 22 mi for 180 dB source level). Maximum localization distance would be somewhat less than maximum detection distance.

"Dose-Response" Approach.—One complication in monitoring effects of Northstar on the bowhead migration corridor is the fact that the island and the associated sounds will be present continuously. Thus, comparatively simple comparisons of the whale migration corridor at times with and without industrial activity (as done during recent seismic monitoring projects) is not an option. However, at least during construction, there is expected to be considerable variability in the sounds emanating from Northstar. (Once routine drilling and production operations are underway, less day-to-day variability is expected.) If the Northstar sounds do affect the use of the southern part of the migration corridor by bowheads, then there is expected to be noise-related day-to-day variation in the proportion of calling whales occurring close to vs. farther away from Northstar. This provides an opportunity to test for Northstar effects on the migration corridor based on a "dose – response" approach. (Two additional approaches involving acoustic tracking of individual bowheads and analysis of bowhead call types in relation to noise exposure are discussed in the next two subsections.)

Ambient noise levels vary naturally from day to day. This variability in natural ambient noise, combined with variability in industrial noise, could result in substantial variability in industrial-to-ambient noise ratios at specific distances offshore of Northstar, especially during construction. Even in later years when there is expected to be little variation in industrial noise, the industrial-to-ambient ratios at specific distances offshore will vary because of the naturally variable ambient noise levels. Likewise, there will be day-to-day variations in the distance from Northstar where the industrial sound will diminish below the threshold of detectability or responsiveness (Richardson et al. 1995).

One of the most promising methods to test for effects of Northstar on the location of the migration corridor is to analyze day-to-day variability in the distances of whales from shore vs. variability in the received level of industrial noise (or the industrial-to-ambient ratio) at a standard distance offshore. If distances from shore are positively related to noise exposure, this could be an indication of an effect from Northstar. If a clear effect is demonstrated, then we can assess the sound level ("dose") and distance at which effects become evident. This analysis would need to concentrate on the southern part of the migration corridor, as any effects would be most evident there. This analysis would require a large number of whale localizations in order to be meaningful. An acoustical localization system can obtain large sample sizes; aerial surveys cannot.

Tracking of Individual Whales Passing Northstar.—If the migration paths of individual whales passing Northstar could be followed over a sufficient east-to-west distance, individual whales could effectively serve as their own controls. For example, if most whales moved west-northwest (WNW) parallel to shore until they approach within some distance of Northstar, but then deflected to the northwest, this could be indicative of an industrial effect. Ideally, one would want to compare the proportions deflecting before and after Northstar is constructed. However, no such "before" data are available. Another approach could be to assess the occurrence and distance of deflection in relation to industrial sound levels or industrial-to-ambient ratio. If deflections were more frequent, or began farther away, at times with comparatively high industrial sound levels (or high industrial-to-ambient ratios), this could be interpreted as an effect of Northstar even in the absence of pre-construction control data.

Acoustical tracking of those bowheads that call repeatedly might be possible if an acoustical localization system with sufficient geographic range were deployed (Clark 1989). However, it is not known what proportion of the bowheads (if any) call often enough, and over an extended period, to allow acoustic tracking. This proportion is probably small. Also, displacement effects would need to be confined to an area smaller than the effective range of the acoustic tracking system in order for this method to work. Furthermore, there will always be ambiguity as to whether a given sequence of calls comes from one whale or a close grouping of whales. Despite these limitations, when the number of whales in the area is low, it may be possible to conclude that a sequence of similar calls from a logical progression of locations represents a single whale or a single, closely-associated group of whales.

No systematic attempt to "track" whales acoustically is proposed for 2000. However, if any such sequences of calls are recognized, they will be plotted to check for any consistent pattern of change in heading or location as the whales approach Northstar. If there is evidence of this pattern, it may be appropriate to place more emphasis on this approach in subsequent years.

Call Characteristics vs. Noise Exposure.—The calls of bowhead whale are variable in frequency, modulation properties, and other characteristics. A classification system for bowhead calls was developed in the 1980s by Dr. C.W. Clark (e.g. Clark and Johnson 1984), and has been used in various studies. There is no specific information demonstrating that the types of calls emitted by bowheads differ depending on exposure to man-made noise. In one study of bowhead call types in the presence and absence of seismic pulses, it was shown that the proportional occurrence of the various call types was almost identical in the two situations (Richardson et al. 1986). Nonetheless, it is possible that the relative frequency of different call types, or the more specific characteristics of the calls, might be affected by noise exposure. It was suggested at the 2000 peer/stakeholder review meeting that this approach might be useful. No detailed analysis of this type is planned for 2000. However, the acoustical data to be collected in 2000 will be suitable for this type of analysis if it is later determined to be desirable to pursue this approach.

"Reference" Area.—As discussed in the August 1999 version of this monitoring plan and at the Seattle workshop in May 2000, it would be very desirable to have data on the relative numbers of bowheads (or bowhead calls) at various distances offshore under quiet conditions, i.e. without any possible Northstar effect. Because Northstar will be present continuously, this type of information will not be available from the Northstar area itself.

An additional "control" or "reference" monitoring zone to the east or west of Northstar would, in theory, provide very helpful data for comparison. However, the relative numbers of whale sightings or whale calls at various distances offshore cannot be assumed to be the same in a "reference" area as at Northstar. It is already known, from aerial surveys, that distances from shore tend to increase in areas west of Northstar, and to decrease in areas to the east. Also, on a geographical basis alone, the Cross Island area east of Northstar might be the most comparable "reference" area. However, the occurrence of bowhead hunting around Cross Island may affect whale distribution and behavior there, confounding use of that area as a "reference" area. Given these complications, there is no plan to conduct acoustical monitoring in a distinct "reference" area.

Acoustic Localization Procedures

As discussed and agreed at the review workshop in Seattle on 24-25 May 2000, the spatial distribution of calling whales in the southern part of the bowhead migration corridor will be monitored via an array of hydrophones deployed seaward of Northstar during September 2000 by acoustical subcontractor Greeneridge Sciences Inc. This subsection describes the methodology planned for detection of bowhead whale calls and localization of the positions of the calling whales.

Design Considerations.—There are significant environmental and logistical challenges to the design and operation of an effective hydrophone array in this area. The main migration corridor of bowhead whales passes approximately 15-50 km (9-31 mi) offshore from Northstar. The main region of interest (where deflection might occur) is the southern portion of this corridor, up to approximately 25 km (15.5 mi) from Northstar:

- That distance is too far for hydrophones deployed near Northstar or any other land area to record whale calls clearly.
- These distances are (at best) marginal for the use of a radio-telemetry system from the array to Northstar. The likelihood of drifting ice poses additional severe challenges for any approach based on radio telemetry. At the least, the radio link would be interrupted when ice is present.
- The location of the pack ice during the September-October migration period is unpredictable, and frequently too far north to be useful as a hydrophone deployment base. Also, pack ice moves, which would cause severe complications in using it as a platform for deploying hydrophones.
- Cables from land, 10–20 km (6-12 mi) long and trenched over part of that length to avoid damage from ice scour, would involve significant permit, acquisition, and installation expense.

Proposed Localization Approach.—The circumstances listed above suggest that the optimum approach will be to use multiple autonomous acoustic recorders placed on the seafloor within the southern portion of the bowhead migration corridor. Autonomous recorders can be synchronized and placed for best advantage with no cabling and little risk of damage by drifting ice. Redundant placement would reduce dependence on any given unit, reducing the probability of system failure. In addition, the planned design includes provision to check periodically (weekly) on the status and functionality of each of the deployed recorders, either by retrieving them from the bottom and downloading the data, or by interrogating a transponder that will report on the status of the recorder without retrieving it. Provision for the transponder system has been built into the units to be deployed in 2000, but in 2000 it is currently planned to retrieve the recorders weekly rather than to activate the transponders. This will allow each week's data to be retrieved and checked, avoiding the risk that the entire season's data will be irretrievable due to ice or unusable because of some problem not reported by the transponders.

The technology proposed for these recorders is based on Directional Frequency And Ranging (DIFAR). By using a DIFAR sensor in each seafloor recorder, each recorder will determine the bearings to calling bowheads. The specific location of a calling bowhead will be determined by triangulation of the bearings obtained when the same call is detected by two or more seafloor recorders. DIFAR was developed for a sonobuoy design and has been used widely by the U.S. Navy. The technique uses an omnidirectional sensor in combination with two dipole directional sensors mounted at right-angles to each other and aligned automatically with the earth's magnetic field. Thus, N-S, E-W and omni sensor channels are available for processing. At any time, any received signal can be determined to have come from an unambiguous direction. The bandwidth of each DIFAR sensor is 10-2400 Hz, adequate for bowhead whale calls and for most industrial sounds that may come from Northstar Island and the surrounding waters. The DIFAR response is not flat with frequency, rising as frequency increases to a peak sensitivity at about 1.5 kHz, then falling off. The rising response compensates for the general decrease in ambient noise spectral density levels with increasing frequency, helping to flatten the overall noise response.

DIFAR hydrophone systems are readily available by disassembling AN/SSQ-53B sonobuoys, which Greeneridge and LGL have used often. Greeneridge has developed and tested signal processing equipment necessary to extract acoustical and directional data from DIFAR signals, and has shown that it can determine the bearing from which a bowhead call is received. Bearings to calling bowhead whales have also been determined by U.S. Navy DIFAR equipment (Ljungblad 1986). Tests by Greeneridge have shown that the DIFAR process is functional in the Beaufort Sea despite the high latitude and large magnetic declination.

Data recorded by the seafloor recorders will also be suitable for determining the locations of calling bowheads based on differences in times of arrival of each call at different seafloor recorders. The "time of arrival" method does not require the directional components of the DIFAR data, but does require more precise synchronization of the clocks in the different recording units. To provide for this backup method of localization, the clocks in each recorder will be stabilized and synchronized, and then calibrated by detecting light-bulb implosions at known times and locations near the seafloor recorders. Cross-correlation or other techniques can be used to measure the difference in travel times from a source to three or more pairs of receivers. Based on these data, "hyperbolae of position" are computed; their intersections define the estimated source location. This is a well-established procedure that has been used to localize calling bowheads during several previous projects (e.g., Greene 1987; Clark and Ellison 1988; Greene and McLennan 1996).

Design of Individual Seafloor Recorders.—Each individual seafloor recorder will be a further development of the Autonomous Seafloor Acoustic Recorder (ASAR) concept as used for BP in 1996 and 1997 during monitoring of seismic survey sounds and ambient noise (Greene et al. 1997; Greene 1998). The new design will incorporate a directional (DIFAR) hydrophone and on-board signal processing (Fig. 3). The directional hydrophone will allow two or more units to obtain position information on whale calls, in addition to recording call characteristics and received noise levels as in the past. The design provides for compression of data so that units could operate for about 45 days–most of a migration season–without requiring service. However, for 2000, when the units will be retrieved weekly to download the data, a simpler data recording scheme will be used that will allow 9.2 days of continuous recording before the hard disk in the recorder is filled. Reliability of the new design will be ensured through software testing using data recorded in previous seasons, and through hardware testing in the Santa Barbara Channel, California. The new unit will be called a Directional ASAR, or DASAR.

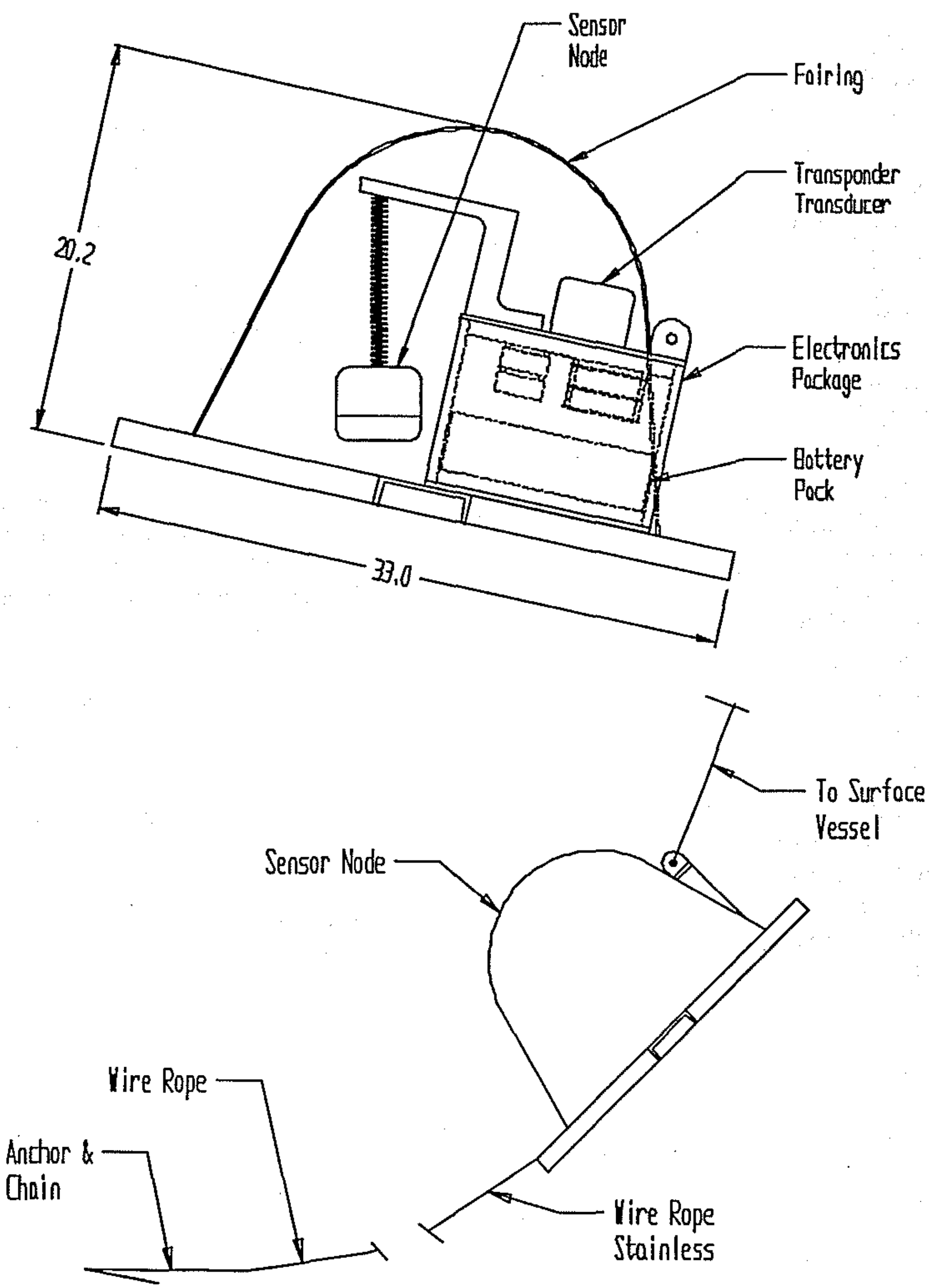

FIGURE 3. *(A)* Directional Autonomous Seafloor Acoustic Recorder (DASAR) incorporating a directional (DIFAR) hydrophone and on-board signal processing; dimensions are in inches. The unit's weight in air is estimated to be 100 lbs (45.3 kg), and in water 50 lbs (22.7 kg). The design is to be tolerant of a bottom slope up to 15 degrees. *(B)* The recorder is lowered toward the sea floor and later recovered by dragging a grappling hook across the length of wire rope between the recording unit and its anchor.

The DASAR will ultimately include an intelligent acoustic transponder to verify proper operation without requiring recovery. Once near a unit, a vessel will be able to interrogate the transponder to quickly assess the recorder's status by the presence and frequency of its transponder response. This transponder will also aid in recovery of the units at the end of the season. As noted above, the transponder subsystem will not be activated in 2000.

Recording Array.—To localize the source of a sound, directional bearings from two or (preferably) more receivers to the sound source are required. For optimal localization ability, six DASARs will be placed within the southern portion of the bowhead migration corridor in a hexagonal pattern (Fig. 4). Two additional units (the second for redundancy) will be placed in the center of the hexagonal pattern to improve our ability to obtain position fixes, especially at times of high ambient noise, or at any times when some units may have failed, or at any times when the backup time-of-arrival (hyperbolic localization) signal processing method might need to be used. The array center as drawn in Figure 4 is about 18 km (11 mi) from Northstar. Two additional units will be placed south of the hexagon and nearer to Northstar Island (Fig. 4) to provide improved ability to detect and localize the small number of calling whales anticipated to occur within several miles of Northstar.

Figure 4 also shows the maximum location errors expected for calling whales at different locations around the array. These contours are based on the fact that most DIFAR bearings are expected to have an error of no more than ±2 degrees.[4] By placing the array closer to shore, improved positional accuracy could be obtained close to Northstar along the southern edge of the bowhead migration corridor (where any effects of island noise are most likely). This improved accuracy close to Northstar would, to a degree, be at the expense of reduced accuracy farther offshore in the main migration corridor.

Twelve DASARs are being built and tested. Ten DASARs will be deployed, and two spare recorders will be available as backups. Some of the backup units would be used if any problems are detected or suspected before deployment, or during the weekly retrieval of the units in 2000, or during the periodic interrogations of the transponders when this capability is activated.

Deployment and Retrieval.—The DASARs will be deployed (ice permitting) at the pre-selected locations during late August 2000 using a boat equipped with Differential GPS. To allow subsequent retrieval by grappling, a tag line and anchor will be placed on the bottom extending outward from the DASAR. This approach has been proven during several deployments of ASARs in the same area during 1996-98 (e.g., Greene et al. 1997, 1999). The units will be programmed to commence recording on 1 September

[4] A standard azimuth error of ±2° was assumed for each DASAR. It was further assumed that any given whale call could be detected at all nine DASAR stations (the two DASARs at the central location are co-located and treated as a single station). A given whale call would provide 36 position fixes from 36 pairs of stations (nine stations taken two at a time). Position-fixing was assumed to take place using the best-located pair of these nine stations, i.e. using a deterministic solution from two stations rather than an overdetermined solution from three or more stations. [Some improvement in localization would probably be possible by using a weighted average of all fixes, with highest weighting applied to the best-located pair(s) of stations.] To derive the contours shown in the Figure, calls were assumed to originate at the intersections of a 250 m by 250 m grid covering the monitoring zone. For each assumed source location, a "standard" position error was determined assuming both of the best-located DASAR stations provided bearings with azimuth error of 2°. In most case, actual uncertainty is expected to be less than the error depicted by the contours.

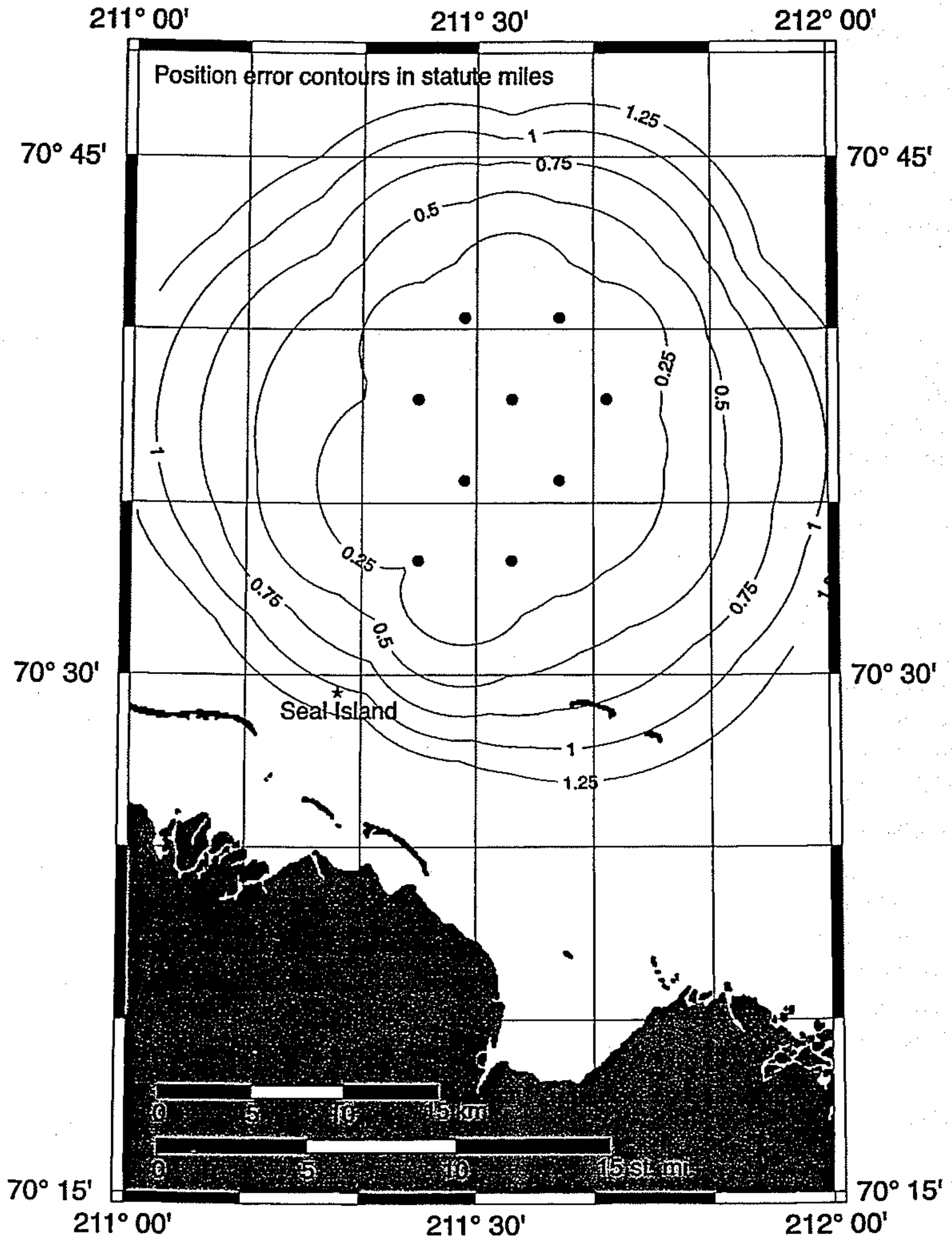

FIGURE 4. Planned configuration of seafloor acoustic recorders deployed to determine locations of calling bowhead whales in the southern part of the bowhead migration corridor. Maximum location errors expected from the DASAR array are shown by contours, assuming that DIFAR bearing errors are typically no more than 2 degrees. The contours indicate the maximum distance a sound source might be away from its nominal location as reported by the DIFAR array.

During September, on an approximately weekly schedule, each unit will be retrieved and checked for functionality; the data will be retrieved, and the units will be re-deployed ready to operate for another 7-9 days. This weekly cycle will continue until approximately mid-October if ice conditions allow. However, if ice threatens to encroach and block access by the boat, all units will be retrieved.

In the event that ice or logistical problems prevent retrieval of some or all units in autumn 2000, an attempt will be made to retrieve them in winter by ROV deployed through the ice, or during the next summer by boat. The possibility of using an ROV to retrieve them from below the ice in winter (i.e., early 2001) is an untried procedure involving complex logistics, and is not a preferred option.

Ice conditions are an important consideration in determining when to retrieve the acoustical recording units (DASARs) and to terminate acoustical monitoring. There is a trade-off between wanting to monitor as much of the bowhead migration as possible vs. wanting to recover the equipment and data before ice prevents this. If the waters where the DASARs are deployed remain ice free well into October 2000, as occurred in 1997-99, and if a vessel suitable for retrieval of DASARs remains available on short notice into October, then a decision to continue operations into October would probably be made. If ice threatens to cut off access to the DASARs in late September, current plans are to retrieve them then and to terminate acoustic monitoring. If the DASARs are still deployed when the ice moves in, they and the data they contain will probably still be retrievable, but most likely not until July or August 2001, long after the time when analysis and reporting of those data should take place.

The periodic vessel operations during September within the area being monitored by the DASARs will provide acoustic signals (boat noise and possibly light bulb implosions) at precisely known locations and times. Some of these sounds will be detected and recorded by the DASARs. During subsequent analysis of the data, vessel and light bulb locations computed from the acoustic data will be compared with the actual known locations as a check on the accuracy of the internal DASAR clocks and of the acoustic localization process. If systematic biases are found, the calibration data will allow at least partial compensation.

Analysis and Interpretation of Acoustical Data

Greeneridge Sciences will determine locations of calling whales detected by the DASARs by triangulation of DIFAR bearings, or alternatively by analysis of time-of-arrival differences if necessary.

To determine the accuracy of the localization system, we will compare locations of vessels as determined by the acoustical system with the known actual locations based on Differential GPS, as previously described. These data on position errors will be summarized for various distances from the center of the DASAR array, and will be compared with the position uncertainty estimated prior to the fieldwork (Fig. 4).

Detection range will be assessed based on the calculated positions of whales whose calls were detected, and the fall-off in number of calls detected with increasing distance from the array. For comparison, the MMS aerial survey data will provide an independent source of data (albeit with much smaller sample size) on the relative numbers of bowheads occurring at various distances offshore.

Procedures for addressing the objectives for Task 7 will be as follows:

(1) Monitor the year 2000 bowhead migration past Northstar by acoustic localization methods, primarily to document the relative numbers of bowhead calls vs. distance offshore in the southern part of the bowhead migration corridor seaward of Northstar...

Acoustic location data will be mapped and tabulated in relation to distance offshore to document the actual and relative numbers of calls detected at various distances offshore. These will be interpreted taking into account the results on localization accuracy and detection range.

(2) Document continuously the characteristics of the sounds propagating away from Northstar, as determined at a close-in monitoring site approximately 300-500 m (1000-1600 ft) offshore from the island, as well as the characteristics of the background sounds (industrial plus ambient) reaching the recording devices in the southern part of the migration corridor...

Levels and spectral characteristics of the sounds recorded at the close-in monitoring site will be determined at intervals consistent with those required for analysis of the whale call data, probably every 15 minutes (same as in Task 5).

(3) Assess the effects of Northstar activities on the migration corridor and calling behavior of bowheads by comparing the distances of calling whales from Northstar at times with varying levels of industrial noise...

We will test the relationship between distances offshore and the received sound level at the close-in monitoring site using a quantile regression approach, as described in Appendix C. This analysis method will determine whether there is a significant positive relationship between the distances of the closest calling whales and sound level. If not, a power analysis will be conducted to determine how small an effect could have been detected had it occurred. Conversely, a significant positive relationship will indicate that noise from Northstar influences the distribution of whales, or their calling behavior, or both. In that case, the geographic extent of the effect at times with high vs. low noise levels will be determined from the quantile regression results. Prior to running the quantile regression, the data will be analyzed to test for lack of independence of calls that are close in space and time. If autocorrelation is detected, the data will be subsampled to obtain independent observations.

The study's primary goal is not to census the whales, but rather to monitor the relative numbers of calls at various distances from Northstar, and to assess whether Northstar operations affect the pattern of calling. A reduction in the proportion of calls occurring close to Northstar at times with higher-than-average noise emissions could occur as a result of either an offshore displacement of whales or a reduction in call rate when exposed to noise, or both. Either possibility would be indicative of a Northstar effect on the migrating bowheads. These two possible explanations could be distinguished if there were an effective independent method to determine the relative numbers of whales at various distances offshore. However, no such method is available, given the low sample size achievable even with intensive site-specific aerial surveys. Interpretation of the acoustical data will need to acknowledge the possibility of biases associated with differences in the calling rate or source levels of calls at different distances from Northstar.[5] Even so, the proposed acoustical method is expected to determine, with good statistical power, whether (and to what distance) the occurrence of calls is affected by sounds from Northstar. As noted under (6), below, that information will be a key component of the planned procedure to estimate the number of bowhead whales whose distribution or behavior (or both) are affected.

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[5] Aerial survey results from different distances offshore could also be biased, e.g. if proportion of time at the surface were affected by exposure to noise, or if sightability is related to distance from shore because of associations between distance from shore and sea state or ice cover (both of which are common). Aerial surveys would suffer from the additional severe limitation of low sample size.

(4) Determine whether any bowheads or bowhead groups can be tracked acoustically; if so, the tracks will be analyzed to determine whether there is evidence of deflection as the whales approach Northstar and, if so, at what distances and received sound levels...

The acoustic localization results, in map format, will be examined to see if there are obvious temporal and spatial sequences of localizations consistent with the movement of a whale or whale group along a consistent track at a reasonable speed. If so, these "acoustic tracks" will be examined to see if there are obvious offshore deflections as the whale(s) approach Northstar. If informal examination of the data indicates that unambiguous "acoustic tracks" are commonly detected, then a formal analysis will be devised to determine the distance (and sound level) at which deflections occur.

(5) Compare the acoustic monitoring results with results from MMS or any other available aerial surveys to further assess the strengths and limitations of acoustic and aerial methods in documenting the bowhead migration corridor past Northstar and in detecting any change (probably small-scale, if at all) in the migration corridor near a site like Northstar...

Based on aerial survey data obtained by MMS (and any other available sources) in the Northstar area during 2000, we will determine the number of whales detected during systematic aerial surveys, and their distances from shore. From the aerial survey data, we will determine the number and proportion of the whales seen (a) within the nearshore zone where the acoustical system detected avoidance, and (b) in the zone too far offshore to be monitored acoustically. Within the distance-from-shore range covered by both methods, we will test whether the shapes of the "numbers detected vs. distance-from-shore curves" were consistent. If not, this could be indicative of a bias in one or both methods.

The acoustic localization system is expected to detect far more bowheads than are seen by aerial surveyors. It is common for a single ASAR to detect more than 100 bowhead calls per hour (e.g., Greene et al. 1997, 1999). In contrast, one day of aerial surveying in the Northstar region during the peak of bowhead migration usually detects on the order of 5-15 bowheads. We will compare the acoustical localization results with the year 2000 MMS aerial survey results to assess their relative strengths and weaknesses in monitoring the bowhead migration past a specific site such as Northstar. Based on these data, we will evaluate the various alternatives for monitoring the bowhead migration past Northstar in subsequent years.

(6) Estimate the number of bowhead whales whose movements and/or calling behavior were affected by the presence of industrial activities at Northstar in autumn 2000.

Several figures will be needed to estimate the number of bowheads affected.

- The quantile regression method listed under (3) above and described in Appendix C will provide an objective measure of the extent of offshore deflection. This will be a function of increasing sound level at the close-in acoustic monitoring site (i.e., x km per 1 dB increase in sound level).
- The close-in hydrophone will also document how often each sound level occurred during the study period.

In combination, those two sets of results will tell us what proportion of the calling whales detected by the localization system were close enough to be deflected offshore. For example, acoustical monitoring might indicate that the percentage of the acoustically-monitored whales that were close enough to be deflected ranged from 0% at quiet times to (perhaps) 5% or 6% at the noisiest times, and averaged 2%.

- The 2% figure will be an overestimate of the percentage of the bowheads that are deflected, as the acoustical system will not monitor the offshore portions of the migration corridor. The MMS aerial survey data from 2000, plus historical aerial survey data, will be used to estimate what percentage of the total whale migration was within the area that was monitored acoustically. For example, aerial surveys might indicate that 50% of the whales passed through the area where acoustical monitoring was effective. If so, and if 2% of the acoustically-monitored whales were close enough to be deflected, then about 1% of the total whales might have been deflected. The MMS aerial survey data will be too sparse to characterize the (anticipated) small proportion of the whales that pass close enough to Northstar to be deflected. However, the aerial survey data are likely to be adequate to characterize the larger proportion that pass through the area where acoustical monitoring is effective.
- The total number of whales affected can then be estimated by applying the percentage calculated above (1% in our example) to the best estimate of the number of bowheads that migrate into the Beaufort Sea.

In summary, BP will measure the levels of industrial sounds originating from the island, record whale calls using an array of direction-finding hydrophones, and localize the sources of whale calls. Among other results, the monitoring program will test the following null and alternate hypotheses:

- **Null:** The distribution of whale calls detected north of Northstar is not related to the level of industrial noise from Northstar.
- **Alternate:** The whale calls detected north of Northstar tend to occur farther away with increasing levels of industrial noise from Northstar, indicative of avoidance, a change in calling behavior, or both.

This hypothesis can be assessed with a 1-tailed statistical test (quantile regression), but the test must adjust for autocorrelation among whale calls, and requires continuous, concurrent measurement of underwater sound close to Northstar.

PERSONNEL

Biological aspects of this monitoring project are being conducted by LGL Alaska Research Associates Inc. of Anchorage and its affiliate LGL Ltd., environmental research associates, of King City, Ontario. Subcontractor Greeneridge Sciences Inc., Santa Barbara, CA, is responsible for the acoustical measurements and the acoustical localization of calling bowhead whales (Tasks 4 and 5 and much of Task 7).

LGL's Anchorage-based Project Coordinator is **Michael T. Williams.** He is responsible for coordination of fieldwork and for day-to-day liaison with BP, and will be field crew leader for some of the biological fieldwork. Mr. Williams is assisted in the project coordination tasks by **William J. Wilson** of LGL Alaska. Field crew leaders are expected to include Mike Williams, **Dr. John W. Lawson, Valerie Moulton, Jessy Coltrane**, and **Craig Perham** of LGL for the biological tasks, and **Drs. Charles R. Greene, William C. Burgess** and **Susanna Blackwell** of Greeneridge for the acoustical tasks.

Dr. W. John Richardson of LGL Ltd. is the overall Project Director, with assistance from Michael Williams and J.W. Lawson. Charles Greene is responsible for the acoustical components. **John J. Burns**, formerly of ADF&G and well known for his expertise on ringed seals, assisted with the project design in 1999-2000 on Tasks 2 and 3, and may act as a senior advisor on future ringed seal projects as needed.

There will be **Inupiat** participation in the fieldwork for all Tasks, and in some cases in the analysis work as well.

LGL Personnel

LGL Management Personnel

W. John Richardson, Ph.D., Executive Vice President of LGL Ltd., is the project director. An animal behaviorist by training, he was project director for the 1995-2000 seal and whale monitoring programs for BP and Western Geophysical. Since 1980, he has conducted many field studies, reviews and environmental assessments of noise effects on marine mammals, working closely with physical acousticians. He was project director for a major 4-year field test of industrial noise effects on bowhead and beluga whales near Barrow, AK (completed in 1995). In 1980-85 he directed the first experimental study of noise effects on bowheads. From 1985-86 and from 1997 to date, he directed bowhead feeding ecology projects in the eastern Alaskan Beaufort Sea. In 1984-86, he also helped supervise several industry-funded monitoring programs in the Alaskan Beaufort. He has been field crew leader during about 1000 hours of aerial survey/aerial observation work over the Beaufort Sea, mainly concerning disturbance effects on marine mammals.

Dr. Richardson is knowledgeable about U.S. permitting processes for scientific research on marine mammals and for "incidental takes" of marine mammals by industrial activities. He has much experience in coordinating marine mammal projects with agency requirements and Inupiat groups. He is author of numerous refereed papers and technical reports on marine mammals and noise, and is senior author of the book *Marine Mammals and Noise*, published in 1995 by Academic Press (reprinted 1998).

Michael T. Williams, M.S., of LGL's Anchorage office is Project Coordinator for this work. He conducted his Masters thesis research on the impact of aircraft activity on the behavior and productivity of northern fur seals on St. George Island, Alaska. He has worked with NMFS on fur seal and Steller sea lion issues, liaison with native groups, hazardous waste cleanup, and other conservation issues. Mr. Williams joined the staff of LGL Alaska in the spring of 1998. At LGL, he has been the main point of contact between BP and LGL for much of LGL's recent marine mammal work on behalf of BP. He has worked on marine mammal permitting for the Northstar and Liberty developments, including an IHA Application, petition for rulemaking, Environmental Assessments, various LoA requests, and associated reports. He participated in the 1998, 1999 and 2000 aerial survey programs for ringed seals, and in vessel-based seal monitoring work associated with a 1998 open-water seismic program. He has also organized and participated in various on-ice seal monitoring projects and associated acoustical studies.

William Wilson, M.S., Regional Manager for LGL Alaska, is assisting with project coordination duties, especially at times when Mr. Williams is in the field or otherwise unavailable. Bill Wilson was responsible for coordinating the field observers for LGL's 1996-99 seismic monitoring projects. He has many years of experience in organizing and managing major field programs near Prudhoe Bay. He has also been involved in environmental assessment and permitting work relating to Northstar, Liberty, and other North Slope developments, including marine mammal issues.

Field Leaders/Senior Biologists

William R. Koski, M.Sc., a senior wildlife biologist on LGL's staff, was field crew leader for many of the 1996-98 aerial surveys conducted for BP and Western Geophysical. Mr. Koski has been with LGL since 1973. Since 1977, he has been a field supervisor and/or participant in most of LGL's major marine mammal projects in the Arctic. He has over 3500 hours of aerial survey or aerial observation experience, mostly Arctic. Besides systematic surveys, this includes several seasons of experience in conducting systematic behavioral observations of bowheads. Sonobuoys were dropped and monitored during several of those projects. Also, beginning in 1981, he developed the vertical photography method used by LGL, NMFS, and others to measure and re-identify bowhead whales. Mr. Koski has much experience with the permitting process for "incidental takes" of marine mammals. In 1991-92 he assisted an industry consortium to obtain the USFWS Incidental Take Regulations for walruses and polar bears. In 1997-98, he assisted industry groups in renewing the NMFS Incidental Take Regulations for ringed seals and on-ice seismic activities. He has also helped write IHA Applications and the associated Monitoring Plans and Environmental Assessments. He has prepared many reports and papers on arctic mammals, including the "Reproduction" chapter in the 1993 book, *The bowhead whale.*

Stephen R. Johnson, Ph.D., a senior wildlife ecologist with LGL since 1975, was aerial-survey crew leader during the August 1995 and most of the September 1997 marine mammal monitoring work for BP. Dr. Johnson has conducted over 2000 hours of aerial surveys for seals, whales, and birds in many parts of the Arctic, including much work in Alaska. For example, he was field leader for aerial monitoring of marine mammals near Seal Island in 1982, Sandpiper Island in 1985, and the Corona and Hammerhead drillsites in 1986, including surveys, sonobuoy drops, and behavioral monitoring.

John W. Lawson, Ph.D., a marine biologist specializing in pinnipeds, joined LGL's staff during the spring of 1998. At LGL, he has been in charge of a vessel-based seal monitoring programs associated with the 1998, 1999 and 2000 seismic projects in the Beaufort Sea. In 1998-2000, he also prepared parts of two EISs and one EA concerning acoustic disturbance and other effects of military operations on pinnipeds and cetaceans off southern California and in the Gulf of Mexico. Dr. Lawson has much experience in studies of seal behavior, ecology, diet and digestive physiology in the North Atlantic in both Canada and Europe. He has experience in aerial, shipboard, and shore-based techniques as applied to seals, including radio and satellite telemetry methods. He has done about 250 hours of aerial surveys of seals on the ice offshore of Newfoundland. Dr. Lawson has published numerous papers on harp, harbor, gray, and ringed seals. Although employed full time at LGL, he retains an adjunct faculty appointment at Memorial University of Newfoundland and has access to facilities for research on captive seals there.

Gary W. Miller, B.S., a wildlife biologist with LGL since 1977, participated in or led many aerial surveys in the Beaufort Sea region during 1995-98 on behalf of BP and Western Geophysical. He was also a marine mammal observer and crew leader for some of the vessel-based marine mammal monitoring in 1996-2000. He was senior author of the portions of the 1996-98 seismic monitoring reports concerning whales. A large proportion of his work over the past 20 years has been on studies of arctic marine mammals, including aircraft-, vessel-, ice- and shore-based surveys, behavioral observations, photo-identification, and acoustical work in the Beaufort Sea, Bering Sea, and Canadian High Arctic. Mr. Miller has worked closely with subsistence hunters and other native people in several of his past projects, documenting their harvests, collecting biological samples, and involving the hunters in the research. He is an author of about 12 journal papers on seals and whales.

Valerie D. Moulton, M.Sc., conducted her Masters thesis research on activity and haul out behavior of harp seals. Before joining LGL in 1998, she worked with the marine mammal branch of the Canadian Dept of Fisheries and Oceans; there she worked on field surveys of seals, diet analysis, photoidentification, and reproductive analysis. Since joining LGL, she has participated in ship-based and aerial monitoring of seals and whales in the Prudhoe Bay region in association with the 1998 and 1999 seismic programs. She also conducted much of the analysis of the seal data for the resulting reports. In 1999 and 2000, she was one of the observers for BP's fixed-wing surveys of seals on the ice, and she is the senior author of the resulting reports.

Jessy Coltrane, M.S., is a wildlife biologist who joined LGL Alaska in 1999. Ms. Coltrane participated in Western Geophysical's 1999 vessel-based monitoring program as a marine mammal observer. Since joining LGL, Ms. Coltrane has also conducted a behavioral study of caribou on the North Slope of Alaska, and participated in on-ice ringed seal monitoring. Previously, she worked for the New England Aquarium, monitoring the North Atlantic right whale population. In addition, she worked as a consultant, monitoring endangered species harassment due to dredge vessels.

Craig Perham, M.S., is a wildlife biologist who participated in LGL's 1998 vessel-based seismic monitoring programs in the Beaufort Sea. He was field crew leader during the Northstar ice road monitoring (Task 2) in 1999 and during additional seal monitoring work near Northstar in early 2000. He also has many years of experience flying aerial surveys for terrestrial mammals in Alaska, and in capturing and handling many species of furbearers.

Other LGL Personnel Available

Robert Elliott, B.Sc., a data analyst/GIS specialist at LGL, has assisted with the analysis of results from the 1997-2000 aerial surveys of seals (Task 1), and will also provide analysis and mapping support for other Tasks. Mr. Elliott has much experience as a programmer, database manager, statistical analyst, and GIS/mapping specialist for environmental monitoring, research, and assessment projects. Recently, he has filled this role in the MMS/LGL study of the responses of spring-migrating bowhead and beluga whales to simulated human activities off northern Alaska, in the 1995-98 BP and Western Geophysical marine mammal monitoring projects, and in a retrospective analysis for MMS of bowhead distribution in the eastern Alaskan Beaufort Sea during 1979-97.

Beth Haley, B.A., is a fisheries biologist who participated in LGL's 1996-98 and 2000 vessel-based seismic monitoring programs in the Beaufort Sea. She also has many years of experience as a fisheries and marine mammal observer for Alaska Dept. of Fish & Game and NMFS.

Ross E. Harris, M.Sc., is a wildlife biologist who has worked with LGL since 1977. He was one of the marine mammal observers and crew leaders during the 1996-97, 1999 and 2000 vessel-based seismic monitoring programs in the Beaufort Sea. He was senior author of the portions of the 1996 and 1997 reports concerning seals. In prior years, he has conducted aerial surveys for marine mammals in the Alaskan Beaufort Sea, the Canadian High Arctic, and the northwest Atlantic off Newfoundland and Labrador. He has also conducted bird surveys in the Prudhoe Bay area.

Larry Martin, B.S., a marine biologist on LGL's staff, has participated in several LGL marine mammal projects in the Beaufort and Bering Seas, including the 1996 vessel-based marine mammal monitoring at Northstar, the 1997 BP shallow-hazards program, bowhead whale feeding ecology studies in the eastern Alaskan Beaufort Sea in the 1980s and in 1998-2000, and a gray whale study in the northern Bering Sea. He also has many years of experience in conducting marine fisheries projects in the Prudhoe Bay area.

Tannis Thomas, M.Sc., has recently completed her Masters degree on habitat selection and feeding by bowhead whales in the northern Hudson Bay/Foxe Basin area. Since joining LGL in 1998, she has participated in two aircraft-based projects on bowhead whales and other marine mammals in the Alaskan Beaufort Sea: a bowhead feeding ecology project, and a seismic monitoring project. She was also responsible for much of the data analysis and report preparation work concerning bowhead whale distribution and behavior as documented during the 1998 and 1999 feeding ecology projects.

Various other biologists with experience in conducting marine mammal observations may be assigned if needed. If any additional biologist observers not involved in the 1996-99 BP and Western Geophysical marine mammal monitoring work are employed in 2000-01, their résumés will be submitted to the Anchorage office of NMFS in advance.

Greeneridge Personnel

Charles R. Greene, Jr., Ph.D., president and principal scientist with Greeneridge Sciences Inc., is in charge of the acoustical work, as he was for the 1995-98 BP and Western Geophysical acoustic measurement programs. Dr. Greene's training was in electrical engineering, and he has specialized for over 30 years in arctic underwater acoustics. He has done arctic fieldwork in all seasons and many regions, from vessels, ice, aircraft, and shore. He has expertise in the design and implementation of acoustic signal analysis systems. Before 1980, most of his acoustical work was for the U.S. Navy, mainly in the Arctic. He studied ambient noise and underwater sound propagation, and he designed and implemented various complex acoustical measurement and display systems. Since 1980, he has continued to do some military acoustics work, but has concentrated on studies of oil and seismic industry noise as it may affect marine mammals, mainly in association with LGL.

Dr. Greene was responsible for the physical acoustics fieldwork and analysis for several LGL studies on the disturbance responses of bowhead whales, white whales, and narwhals. He has recorded and analyzed sounds emitted from most types of offshore oil industry activities. He is coauthor of the 1995 book *Marine Mammals and Noise* for which he wrote most of the physical acoustics sections. Recently he was elected a Fellow of the Acoustical Society of America in recognition of his contributions regarding noise effects on arctic marine mammals.

William C. Burgess of Greeneridge Sciences received his B.S., M.S., and Ph.D. in Electrical Engineering from Stanford University. Following his graduation in 1993, he conducted ocean acoustic research under postdoctoral scholarships at the Woods Hole Oceanographic Institution and the Monterey Bay Aquarium Research Institute. During these appointments Dr. Burgess designed, built, and applied an acoustic recording tag to directly measure noise exposure of migrating northern elephant seals. His technical background includes geophysical remote sensing with low-frequency radio, bioacoustics, instrumentation, audio-frequency signal processing, and systems programming. His field experience includes a total of seven months at sites in Antarctica, northern Québec, and the Alaskan Arctic, and over two months at sea on research vessels in Arctic, Antarctic, and Atlantic waters. Since joining Greeneridge in early 1998, Dr. Burgess has acquired and analyzed acoustic data to determine exposure of protected species to sounds from jet aircraft, rockets, missiles, vessels, airguns, and shallow-hazard surveys. Dr. Burgess is the first author of three refereed journal articles and ten papers presented at scientific conferences. He is a member of the Acoustical Society of America, the American Geophysical Union, and the IEEE.

Susanna B. Blackwell, Ph.D., of Greeneridge Sciences will conduct some of the fieldwork and analysis on the acoustical monitoring tasks. She received her undergraduate degree from the University of Neuchâtel (Switzerland) in Zoology, and her graduate degree from the University of California in Santa Cruz, in Biology. She has held postdoctoral appointments at UCSC (ecology and diving behavior of northern elephant seals), at the University of Stockholm, Sweden (grey seal ecology in Estonia), and at Hopkins Marine Station of Stanford University (bluefin tuna ecology and migratory behavior). At UCSC she was involved in the design and manufacture of data loggers which record underwater sounds during elephant seal migrations, in addition to variables such as depth, temperature, swim-speed, and heart rate. As a postdoc at Stanford, she spent several weeks tracking Pacific bluefin and albacore tuna acoustically. Since joining Greeneridge she has been involved in several field trips, making acoustic recordings at the Northstar project (Prudhoe Bay, AK), Red Dog mine (Kivalina, AK), and with the US Geological Survey (Pt

Hueneme, CA), in addition to analyzing collected data. Dr. Blackwell is a first author (twice) or co-author of nine refereed journal articles. She is a member of the Acoustical Society of America, the International Society for Bioluminescence and Chemiluminescence, and the Society for Marine Mammalogy.

Robert G. Norman, consulting engineer at Greeneridge Sciences Inc., has a B.S. in Electrical Engineering from California State University at Long Beach, and an M.S. in Electrical Engineering, emphasis in signals and systems, from University of California , Santa Barbara. Mr. Norman has 20 years of experience in electrical and electro-mechanical engineering programs. This experience encompasses system design, hardware/software partitioning, digital signal processing, control systems, and detailed analog circuit and interface design. His work has included development of software for design simulation and verification, and for execution in real-time systems. At Magnavox, Mr. Norman developed analog baseband signal processing circuitry for military and space-based GPS receivers and spread-spectrum communication systems. This work included custom linear IC design and layout. At Delco Electronics, Mr. Norman was technical lead for the development and delivery of a high accuracy single-axis inertial measurement gyroscope. At SAIC MariPro, Mr. Norman was project engineer for a full-field processing system consisting of five vertical hydrophone arrays coupled to shore by means of an electro-optical cable. The system was successfully installed on schedule in the Santa Barbara Channel. Each vertical array included 30 sensors, each consisting of an active hydrophone element, low-noise preamp, dual axis inclinometer, and temperature sensor. Additionally, 4 magnetic compasses and 4 high-frequency phones were employed on each vertical array for attitude determination. For Greeneridge, Mr. Norman developed the signal processing tools for analyzing the airgun pulses received simultaneously from 600 to 1300 hydrophones in ocean bottom cables. Also for Greeneridge, he developed the software code for demultiplexing the composite signal from DIFAR (Directional Frequency and Recording) sonobuoys.

Bob Blaylock of Greeneridge will conduct much of the laboratory analyses of recorded sounds. He is a computer programmer and digital signal analyst who has performed acoustic signal analysis at Greeneridge for over 10 years, including many of the acoustical analyses for the 1996-99 BP and Western Geophysical acoustical monitoring projects. This work routinely includes A/D conversion, reformatting and scaling, fast Fourier transformations, various types of averaging, and derivation of band levels. He programs in C and C++, Pascal, BASIC and Postscript, and he is an advanced user of several operating systems and many types of application software.

REPORTS

During the periods of field operations, reports concerning recent construction activities, marine mammal and acoustic monitoring work, and such other information as NMFS may specify in the Letter of Authorization (LoA), will be provided to NMFS on the schedule specified in the LoA. Any significant observations concerning impacts on marine mammals will be transmitted to NMFS within 48 hours.

BP has received an LoA from the U.S. Fish & Wildlife Service (FWS) for incidental "taking" of walruses and polar bears during the 2000 phase of Northstar construction. Walrus and polar bear sightings will be reported to FWS in the manner that FWS requires.

Two 90-day reports and a final technical report will be submitted annually to document the monitoring work conducted under the Letter of Authorization that has been requested from NMFS. It is assumed that the schedule for these reports will be as specified in the Regulations issued by NMFS on 25 May 2000 concerning Northstar:

- A 90-day report will be submitted to NMFS within 90 days after the end of the ice-covered season. For example, a report describing monitoring activities during the late 1999/early 2000 ice-covered season will be submitted to NMFS on approximately 15 Sept 2000. A report describing the monitoring activities planned for early 2001 (Tasks 1, 2 and 4 of this document) will be submitted to NMFS on or about 15 Sept. 2001. More specifically, the 90-day reports on monitoring during the ice-covered season will be completed 90 days after the ice roads are no longer usable or the spring aerial surveys are completed (whichever is later).
- Another 90-day report will be submitted within 90-days after the conclusion of open-water construction and monitoring activities. The first of these reports, describing the work conducted under Tasks 5, 6 and 7 of this document, will be submitted to NMFS by 1 February 2001.

The 90-day reports will provide summaries of the dates and locations of BP's construction operations, details of marine mammal sightings (dates, times, locations, activities, associated construction activities), estimates of the amount and nature of marine mammal "take" by harassment or in other ways, and any apparent effects on accessibility of marine mammals to subsistence hunters.

In addition, a draft annual technical report will be submitted to BP by 10 April 2001, and to NMFS by 1 May 2001. This report will provide full documentation of methods, results and interpretation pertaining to all monitoring tasks completed in 2000 (i.e., Tasks 1, 2 and 4 from late 1999/early 2000; Tasks 5-7 from the 2000 open-water season). Detailed analyses of the early 2001 work (Tasks 1, 2, 4) will appear in the draft annual report to be submitted to NMFS by 1 May 2002. If statistical analyses of key questions reveal no statistically significant differences, statistical power analyses will be included to assess the minimum size of effect that would have been detectable with the monitoring effort that was achieved. It is assumed that this draft final report will be subject to a peer review process, and will then be finalized.

COORDINATION OF RESEARCH

The Minerals Management Service has been supporting aerial surveys of endangered whales in the Alaskan Beaufort Sea since 1979. Western Geophysical conducted a marine mammal monitoring program during the summer and fall of 1998, and during the summer of 1999, and is continuing this work in the summer and possibly the fall of 2000. BP and its monitoring contractors LGL and Greeneridge will coordinate the Northstar open-water monitoring program with MMS, Western Geophysical, and any other industrial groups conducting related work in 2000. The objective will be to share data and to utilize the experience and results gained from all relevant surveys in this region.

The Alaska Department of Fish and Game (ADF&G) conducted MMS-funded aerial surveys for ringed seals in the Beaufort Sea during recent spring seasons up to 1999, but did not continue this work in 2000. LGL is coordinating with ADF&G regarding analysis of the data from the BP-funded surveys during 1997-2000 with the related analyses being conducted by ADF&G.

In 1999 and 2000, MMS funded a cooperative study with Dr. Brendan Kelly and Lori Quackenbush to determine a correction factor for the above-mentioned ADF&G aerial survey of the ringed seal population in the Alaskan Beaufort Sea. By capturing and attaching radio transmitters to ringed seals, Dr. Kelly and L. Quackenbush are studying the haul out behavior of ringed seals in the central Alaskan Beaufort Sea. BP and LGL assisted this study in 1999 and 2000. As part of their study, Dr. Kelly and Ms. Quackenbush, used trained dogs to locate seal structures on the landfast ice. In late 1999 and early 2000, as part of the Northstar monitoring work, they used their dogs to locate and check structures in the area of Northstar construction (2000 phase of Task 2). It is not known whether their study will continue in 2001; if it is, the 2001 phase of Tasks 1 and 2 will be coordinated with their work.

BP will also coordinate its proposed seal and acoustic monitoring during the ice-covered season with any monitoring of on-ice seismic work or any other related research on seals in the area surrounding Northstar. It is possible that research or monitoring programs related to those described under Task 2 (On-ice Searches for Seal Lairs) and Task 4 (Sound and Vibration Measurements) will be conducted in relation to Vibroseis exploration during the spring of 2001.

The MMS-funded ANIMIDA project is underway in the Northstar area during 2000 and is expected to continue in 2001. This may include acoustical measurement work and possibly other studies that are related to some of the work described in this plan. BP, LGL and Greeneridge will coordinate with MMS and the investigators conducting the ANIMIDA studies to avoid unnecessary duplication and interference, and to maximize the value of the data collected by both groups for addressing impact questions.

PEER AND STAKEHOLDER REVIEW

BP is participating in a peer review process for the Northstar monitoring work in response to (1) a North Slope Borough zoning stipulation requiring peer review and (2) the requirements of the NMFS incidental take authorization. BP offered to establish a peer-review process specifically for the Northstar project. However, as events have evolved, peer review for this project has been incorporated into an expanded version of the process convened by NMFS. The NMFS process now deals with on-ice as well as open-water activities in the Alaskan Beaufort Sea.

Two workshops are held each year in Seattle, one in autumn to deal with on-ice activities and one in late spring to deal primarily with open-water activities. The due-date for the 90-day report on winter-spring activities (approx. 15 Sept.) precedes the autumn meeting, so participants in that meeting can review the 90-day report before and at the meeting. The due-date for the draft final report on each year's activities is 1 May, so this report will be available for review at the spring meeting. The meeting participants include representatives from the National Marine Fisheries Service, North Slope Borough, Alaska Eskimo Whaling Commission, Minerals Management Service, other industrial operators conducting offshore activities in the Beaufort Sea, contractors conducting the marine mammal and acoustical monitoring work, and other interested agencies and individuals with relevant expertise on topics such as seals, whales, acoustics, and study design/statistics. Reviewers are asked to comment on monitoring plans, 90-day reports, and draft final reports, and to do so on a schedule that will allow their comments to be fully considered in a subsequent version of the monitoring plan or report.

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APPENDIX A: METHODS FOR AERIAL SURVEYS OF SEALS

The following is an almost-verbatim copy of the METHODS section of the draft final report on the 1999 aerial surveys of ringed seals conducted for BP by LGL. Methods for the planned 2001 surveys will be very similar to the 1999 methods described below. The report from which this section is taken is

> Moulton, V.D. and R.E. Elliott, with T.L. McDonald, G.W. Miller, W.J. Richardson and M.T. Williams. 2000. Fixed-wing aerial surveys of seals near BP's Northstar and Liberty sites, 1999. p. 3-1 to 3-72 *In:* W.J. Richardson and M.T. Williams (eds.), Monitoring of ringed seals during construction of ice roads for BP's Northstar oil development, Alaskan Beaufort Sea, 1999. Rep. from LGL Ltd., King City, Ont., and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Int., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. DRAFT, March 2000.

References to Figures and Tables included in the 1999 report but not in this extract have been deleted. The few notable changes anticipated in 2001 relative to 1999 are identified by *[bracketed editorial inserts]*. References cited in this section are listed at the end of this Appendix.

Survey Design

In 1999, as in 1997-98, two "grids" of aerial survey transects were flown between longitudes 147°06'W and 149°04.5'W, an east-west extent of about 75 km or 40 n.mi. (46 mi). Each grid consisted of 40 north-south transects spaced 1.85 km (1.15 mi, 1 n.mi.) apart. Each transect extended from the Beaufort Sea shoreline to roughly 37 km (23 mi) offshore or to the edge of the land-fast ice if it was encountered and recognizable <37 km offshore *[see Fig. 1 under Task 1]*. One of the grids that we surveyed includes some of the same transects flown by ADF&G during their wider-ranging ringed seal surveys. *[ADF&G's last year of surveys was 1999.]* The second or alternate grid was offset from the first by 0.9 km (0.6 mi) to the east. In this report, we define a *survey replicate* as a complete survey of the 80 unique transects. In 1999, as in 1998, two complete survey replicates were completed. Survey replicate 1 was flown on 4-8 June 1999 and replicate 2 was flown on 8-13 June 1999. In total, 5486 linear kilometers (3409 mi) of surveys were flown over land-fast ice by LGL during the 10-day survey period. The BP/LGL surveys were flown later in the season in 1999 than in 1997-98. However, snowmelt and breakup were late in 1999, and surface conditions were generally consistent with those during the 1997-98 surveys.

A 40-transect grid usually required two days to complete and an 80-transect survey replicate took four days to complete. Ideally, the 20 odd-numbered transect lines from one grid were flown on one day, and the 20 even-numbered lines from that grid were flown on the next day. The odd and even numbered lines from the alternate grid were then (ideally) flown on the third and fourth days. Each day's flight was designed to sample 20 of the 80 distinct transects within the study area, rather than sampling the eastern portions one day and the western portions the next. Thus, the entire study area was to be sampled four times during each replicate survey, and eight times during each year. Fog or low cloud prevented the timely completion of transects during many survey days, and it was often not possible to cover 20 full transects on one day. Sometimes it was necessary to cover parts of two 20-transect groups on the same day, and to complete the coverage of those 20-transect groups on another day. No transects were surveyed on 11 June 1999 because of fog.

The northern ends of repeated transects varied somewhat from day to day. Northbound transects were usually terminated when we had flown at least 37 km (23 mi) or when it was apparent that we had reached the northern edge of the fast ice. In 1999, the fast ice edge (Fig. 1) was often easy to recognize because of large open leads in the ice.

The southern ends of transects were usually defined by the coastline. However, we sometimes avoided flying over narrow nearshore bands of deteriorated ice. Near the Endicott production facilities, we started or ended some transects 1-2 km (0.6-1.2 mi) north of Howe Island to avoid flying close to bird colonies located there.

Survey Procedures

The 1999 surveys were flown in a DHC-6 Twin Otter operated by Corporate Air of Billings, Montana. This twin-engine high-wing aircraft was equipped with turbo-prop engines, a GPS navigation system, and large bubble windows installed in the emergency exits. Two pilots were present during the entire survey. *[In 2000, a TurboCommander operated by Commander Northwest of Wenatchee, WA, and Anchorage, AK, and specially modified for survey work was used. It is anticipated that the TurboCommander will be used again in 2001.]*

The survey procedures generally followed those of Frost and Lowry (1988). We used strip transect methodology, which has been standard for previous aerial surveys of ringed seals in Alaska. Surveys were usually conducted at an altitude of 91 m (300 ft) above sea level (ASL) and a ground speed of 222 km/h (120 knots). Transect numbers 14-16 and 54-56 near Reindeer Island were flown at altitude 152 m (500 ft) on 6-9 June 1999 to accommodate researchers studying ringed seal haulout behavior in that area. There was concern about radio-tagged seals returning to the water during aircraft overflights at 91 m ASL.

We surveyed transect strips 411 m (1350 ft) in width on each side of the aircraft. These strips extended from 135 m (443 ft) to 546 m (1791 ft) from the centerline. Strip boundaries were marked on the aircraft's windows with tape at the appropriate inclinometer angles, which were 9.5° and 34° below the horizontal for surveys at 91 m altitude and 15.6° and 41.5° for surveys at 152 m altitude. Sightings of seals inside 135 m or beyond 546 m were recorded as off-transect sightings. For consistency with previous ringed seal surveys, we have *not* attempted to adjust the strip boundaries or calculated densities to take account of the "earth curvature" corrections described by Lerczak and Hobbs (1998).

The two primary observers occupied the right seat behind the co-pilot and the left seat behind the pilot. A third observer operated a computerized data logger and recorded polar bear sightings and tracks. This third observer did not record seal sightings and was positioned behind the right observer. The two primary observers sat at large bubble windows that allowed greater downward visibility than standard windows. The surveys were usually flown between 8:00 and 16:00 h true local time (10:00-18:00 Alaska Daylight Time) when numbers of seals hauled out on the ice were expected to be highest. When sightability was severely impaired for more than approximately 5 of the 1-min time periods along a transect, that transect was generally re-surveyed later, and the data from the initial incomplete survey were discarded.

Data Recording Procedures

A GeoLink data logger automatically recorded time and aircraft position (latitude and longitude) at 2-s intervals throughout the flights. The GeoLink system consisted of a portable computer, Garmin GPS unit, and GeoLink data logging software (Version 6.0). At keystrokes initiated by the computer operator, the time and position of the aircraft were automatically logged at the start and end of each transect. Polar bear sightings and tracks were also logged via GeoLink.

The two primary observers recorded the time, visibility (n.mi.), ice cover (%), ice deformation (%), meltwater (%), sunglare (none, moderate, or severe), and overall sightability conditions (ranging from "excellent" to "impossible") onto audio tape at the end of each 1-minute (~3.7 km or 2.3 mi) time period. An electronic timer signaled the observers at 1-min intervals. Ice deformation was estimated by the observers on each side of the aircraft. At the end of each 1-min interval, the observers estimated the percent of the on-transect ice surface surveyed during the preceding minute that was deformed rather than smooth ice. The ice deformation estimates were categorized by intervals of 10%. Cracks and leads in the ice were also noted by the observers at the specific times when seen, allowing their locations to be extracted subsequently from the GeoLink files.

Environmental parameters were recorded by the computer operator (with the assistance of the pilots) at the start of each transect. These variables included cloud cover (in tenths), ceiling height (ft), visibility (n.mi.), wind speed (knots), wind direction (° T), and air temperature (°C).

For each seal sighting, the observer dictated onto audio tape the species, number, habitat (hole or crack), and behavior (look, move, dive, or none) of the seal(s), and noted whether the sighting was on or off transect.

When polar bears were sighted, the observer recorded size/age/sex class when this was determinable, behavior, and direction of movement.

The observers also recorded the time of any sightings of industrial sites or activity, including ice roads or artificial islands.

Analysis Procedures

The location of each seal sighting was determined by matching the time of the sighting with the position recorded for that time in the GeoLink GPS logs. Time periods with severely impaired sightability conditions were excluded from all analyses. Each sighting was also linked to the environmental variables recorded for the corresponding one minute (3.7 km) time period. The fast-ice edge was subjectively located by mapping open leads; areas with leads were classified as pack ice and were excluded from analyses.

Hourly (or more frequent) temperature and wind speed data for Deadhorse airport at Prudhoe Bay were obtained from the National Climatic Data Center (Asheville, NC) for the entire study period. Each one-minute time period was assigned a wind speed and air temperature value by interpolating from the values obtained from the nearest preceding and following airport weather records. Airport data and data collected from the plane were highly correlated in all survey years (Pearson's $r > 0.8$ for air temperature and wind speed). The airport data, with the exception of cloud cover, were used in analyses because they provided finer temporal coverage. Cloud cover data collected from the survey aircraft were used in analyses because it differed from the airport data. From the airport data, an index of wind chill called heat loss was calculated by using the following formula (Siple and Passel 1945):

$$H = (12.1452 + 11.6222\,(v^{1/2}) - 1.16222\,(v))\,(33\text{-}t)$$

where H is the heat loss in Watts/m^2, v is the wind speed in m/s, and t is the temperature in °C. Wind chill in °C was also calculated based on the following formula (Siple and Passel 1945):

$$T_{wc} = 33 + (t\text{-}33)\,(0.474 + 0.454\,(v^{1/2}) - 0.0454\,(v))$$

Weather conditions experienced by seals on the ice undoubtedly varied from weather data collected at the Deadhorse airport. However, we feel the airport data provide a good approximation to "on-ice" weather.

The percent ice deformation data collected at one-minute intervals during all surveys were, for corresponding locations, averaged across days and plotted at the midpoint of the one-minute time period. The averaging procedure involved comparing the GPS coordinates for the midpoints of replicated time periods. If the midpoints were within 800 m of each other, the ice deformation data were averaged. If they were more than 800 m (2625 ft) apart, they were treated as independent values. These data were contoured at 5% intervals using Vertical Mapper for MapInfo (Version 5.0.1). The contoured data were used as a GIS layer showing ice deformation. MapInfo was used to compute the portions of the surveyed area that occurred within the various ice deformation categories. Seal sightings were overlaid on the ice deformation layer, and the numbers of on-transect seal sightings/km^2 and individuals/km^2 were determined for each ice deformation category using MapInfo supplemented by specially written MapBASIC computer code.

In a similar manner, water depth contours were developed based on all available depth soundings. Sounding data, obtained on CD-ROMs from NOAA, included Hydrographic Survey Data, Vol. 1, vers. 3.1, and Marine Geophysical Data/Bathymetry, Magnetics, Gravity, vers. 3.2. The 3-m, 5-m, and additional contours by 5-m intervals out to 45 m were derived using Vertical Mapper for MapInfo. These depth contours were used as a GIS layer. MapInfo was used to calculate the surveyed areas within each contour interval. Seal sightings were overlaid onto the depth GIS layer, and densities for both on-transect sightings and individual seals were calculated.

Five kilometer "bins" of distance as measured from the ice edge shoreward were also plotted and used as a GIS layer. The on-transect surveyed area in each bin was calculated. In the same manner as described above, seal sightings were overlaid onto this layer, and seal sightings/km^2 and individuals/km^2 were calculated for each 5-km interval.

A seal density contour map was created using Vertical Mapper for MapInfo by contouring the ringed seal density (seals/km^2) calculated for each time period segment midpoint. More specifically, the density contours were created from the irregularly spaced midpoints of time period segments by using the inverse distance method (Vertical Mapper) with the following parameters: 1 zone, minimum 1 point, maximum 25 points, 200 m cell size, 18,660 m search and display radius, exponent 1.

Date, time-of-day, and weather effects were analyzed using the 1-minute time periods as the common unit of observation. For example, to compare ringed seal densities with respect to time-of-day, all 1-min time periods surveyed at a particular hour were combined in one bin. The number of on-transect seals was divided by the on-transect area surveyed to calculate the density for that hour.

To investigate potential changes in size of ringed seal groups during the survey period, group size (number of individual seals/number of seal sightings) was calculated for every sighting in 1999 and averaged by date. Group size was further divided by sightings at cracks and those at holes. The percent of the total individual seals (and also sightings) observed hauled out along cracks (vs. holes) in the ice was also calculated for each survey date. These procedures were repeated for data from the 1997-98 surveys to permit interannual comparisons.

For the 1999 data, we examined seal sightings in relation to distance from the Northstar ice road. Ten 1-km "bins" of distance from the edge of the ice road (including the ice dump area north of Seal Island) were plotted and used as a GIS layer. (No seals were observed directly on the ice road.) The on-transect area per bin was calculated and the number of seal sightings and individuals were overlaid onto this layer, which permitted density calculations. The results from replicates 1 and 2 were combined because of the relatively small areas and numbers of sightings involved in this localized analysis. Water depths <3 m were excluded from these calculations.

As part of a multiyear analysis (see "Poisson Regression" section, later) to examine the potential influence of industry, a similar approach was taken for examining seal sightings in relation to distance from Tern Island in 1997 and 1998 and two areas of vibroseis operations in 1998. Data were organized in ten 1-km bins around these industrial areas even during non-industrial years to permit comparison of seal densities between industrial and non-industrial years (while controlling other variables).

Statistical Tests

Univariate Tests

We used the chi-square (χ^2) goodness-of-fit test to assess the significance of observed differences in ringed seal densities with respect to physical (e.g., % deformation), weather (e.g., air temperature), and temporal (e.g., time of day) variables. Simultaneous Bonferonni-corrected 95% confidence intervals were calculated for the observed proportions by strata. An expected proportion (based on available survey area) falling outside the confidence interval for the observed proportion for that stratum was considered significantly different (Manly et al. 1993). All tests were done based on numbers of seal sightings (singletons or groups) rather than numbers of individual seals. The different seals within a closely spaced group are not statistically independent. The expected numbers of seal sightings in the various strata (if seal density were unrelated to the variable in question) were assumed proportional to the surveyed amounts of land-fast ice within those strata. Although the statistical tests were always conducted on the basis of seal sightings (total number of singletons or groups seen), we discuss the results in terms of observed seal densities (individuals/km^2).

Two complete survey replicates were conducted in 1999. All 80 transects were surveyed twice. For comparisons of seal densities with respect to physical factors that did not change during the course of the study, such as water depth, we considered the two survey replicates to be non-independent. At any given location along each of those transects, these variables would be the same during each survey, and some of the same seals may have been seen repeatedly. To avoid pseudoreplication problems associated with the lack of independence of these "repeated measures", we examined each survey replicate (group of 80 unique transects) separately whenever possible. It should be noted that the location of survey lines varied somewhat from replicate to replicate. For the analysis of the relationships of observed seal densities to weather and temporal variables, we pooled the data across replicates. We assumed that numbers of seal sightings at a given location would vary as a result of variation in the temporal and weather factors between replicate surveys. This would make each replicate partially independent with respect to these variables. However, there is still concern about interdependence of results given the presumably fixed number of seals in the area and the close spacing of adjacent transects.

The non-parametric Page's L test (Page 1963) was used to test for progressive seasonal trends in group size (at cracks, holes, and overall) and in percent of total ringed seal sightings that were at cracks in the land-fast ice. We hypothesized that group size and percent of seals observed at cracks would increase during the survey period. These analyses were performed separately for each of the three survey years.

Poisson Regression

Poisson regression models (McCullagh and Nelder 1989; Cameron and Trivedi 1998) were used to assess the relationship between seal counts in small segments of the survey transects and several variables known or expected to influence seal abundance and haul-out behavior. The ultimate objective is to quantify any influence of oil industry activities on the number of seals hauled out, after allowing for natural factors that also influence the number of seals seen. (Additional data from years with more intensive construction operations will be needed before this analysis can be completed.) The remainder of this subsection includes a technical description of the Poisson regression procedures.

Prior exploratory analysis had revealed that the ringed seal count data exhibited a Poisson distribution. The Poisson distribution is a positive discrete distribution in which only positive integers are acceptable values. Tests based on this distribution were more appropriate for the ringed seal count data than tests assuming a normal distribution, where non-integers and negative values would also be assumed to be permissible. Separate Poisson regression models were fitted to the 1999 data alone and to combined data from the years 1997 to 1999.

The unit of observation in these analyses was normally the segment of a survey transect covered within a 1-min period of observation. This was approximately a 3 km^2 area, i.e. a segment about 3.7 km long (the distance traveled in 1 min) $\times$ 0.822 km wide (411 m on each side of the aircraft). However, if environmental conditions remained relatively constant during consecutive 1-min time periods, the data were pooled over these time periods; seal counts and segment areas were summed. This was done to reduce concern about possible lack of independence and to reduce the potential for autocorrelation. To account for the fact that larger survey areas would likely contain more ringed seals than smaller areas, the logarithm of the survey area was fitted as an offset variable in all regression models.

The values for environmental parameters, including percent ice deformation, percent melt water, and visibility, were averaged for combined right and left observer data. Treating data from left and right observers separately would have resulted in pseudoreplication, as environmental conditions were highly correlated between left and right sides of the plane. Also, seal sightings by left and right observers were not always independent of each other, e.g., when ringed seals were counted at an ice crack extending across both observers' fields of view beneath the aircraft. Although the same seals were not counted by both observers (their fields of view were separated by a 270-m-wide strip underneath the plane that was considered off-transect), the seals hauled out at the crack were not entirely independent of each other.

The names of the covariates and factors used in the analyses are listed in Table A-1. All covariates were required in order for a transect segment to be included in the Poisson regression analyses. All variables in the Poisson regression, except survey replicate number and year, were continuous. The survey replicate and year were considered discrete and treated as factors in the models. Quadratic terms were included for the covariates time of day and date to investigate possible non-linear trends. The response variable was the number of observed ringed seal sightings (singletons or groups) in a transect segment, with log (segment area) as an offset variable. The number of seals was not used as the response variable because different seals within a closely-spaced haul-out group should not be treated as statistically independent. Aside from the influences of the various factors and covariates that were analyzed explicitly, the probability of detecting a seal from the survey aircraft was assumed to be constant throughout the study period, and over the length and width of each transect. Data collected during conditions of poor sightability, in water depths < 3 m, and over pack ice were excluded from analyses.

Backward model selection (Rawlings et al. 1998) was employed to derive the final model. Backward model selection is an objective variable selection technique that sequentially eliminates the least significant variables from a candidate model until all variables remaining in the model are significant at the $\alpha = 0.05$ level. Significance of terms in the model was assessed by approximate *F*-tests, which account for overdispersion of the raw data using a quasi-likelihood approach. Overdispersion occurs when the variance of the response variable exceeds its mean. If this occurs and no adjustment is done, test statistics and standard errors will be erroneously inflated (Cameron and Trivedi 1998). Calculations were done with S-Plus Version 2000 (Venables and Ripley 1999).

TABLE A-1. List of variables included in the Poisson regression models of seal sightings in relation to environmental parameters; for 1999 and 1997-99 combined. The response variable in both models was the number of seal sightings.

Data Set		Factors	Covariates
A.	1999	Survey replicate	Water Depth (m)
			Distance from Ice Edge (km)
			Ice Deformation (%)
			Melt Water (%)
			Time of Day (hr-ADST)
			Time of Day^2 (hr-ADST)
			Date
			Date^2
			Air Temperature (°C)
			Wind Speed (m/s)
			Heat Loss (W/m^2)
			Cloud Cover (%)
			Visibility (n.mi.)
			Distance from Northstar Ice Roads (1 km bins) [a]
B.	1997-99	Year	Water Depth (m)
			Distance from Ice Edge (km)
		Survey replicate nested within year	Ice Deformation (%)
			Melt Water (%)
			Time of Day (hr-ADST)
			Time of Day^2 (hr-ADST)
			Date
			Date^2
			Air Temperature (°C)
			Wind Speed (m/s)
			Heat Loss (W/m^2)
			Cloud Cover (%)
			Visibility (n.mi.)
			Distance from Industry (1 km bins) [b]

[a] The distance of an observation from the Northstar ice road in ten 1-km bins (see Fig. 3.2). Observations >10 km from the ice road were coded as "11".

[b] This composite variable accounts for distance to industrial areas in all three survey years. It is composed of "Distance from Northstar Ice Roads" for observations in 1999, the minimum of the distance values for distance from "Tern Island", "Eastern Vibroseis Area", and "Prudhoe Bay Vibroseis Area" for observations in 1998, and "Tern Island" for observations in 1997. See Fig. 3.2 for location of these areas. Distances were recorded as ten 1-km bins from the edge of the industry zone. Observations >10 km from industry were coded as "11" and those within the industrial zone were coded as "0".

The initial model for the backward selection process using 1999 data alone included all variables listed in Table A-1A plus the interaction of survey replicate (1 or 2) with each of the other variables. The initial model for 1997-99 data contained all variables listed in Table A-1B plus the interaction of year and each of the other variables. In the 1997-99 model, survey replicate was nested within year and within all year interactions; however, in the model fitted to these data, the nested effects were not significant and were dropped from further consideration. Main effects were not considered for elimination from the model if they were involved in a statistically-significant interaction.

Due to the potential for temporal correlation among seal counts collected on successive 1-min transect segments, the deviance residuals of all final models were checked for correlation (Pearson's *r*) within each transect line (T.L. McDonald, WEST Inc., pers. comm.). Average correlation between residuals separated by less than 5 min of flight time (about 18.5 km) was calculated for each model. Moran's *I* statistic (Moran 1950) was computed on residuals of the final model. Assuming *n* observations existed in a given 5-min interval of flight, Moran's *I* computed correlation and standard error among the $n(n-1)/2$ pairs of residuals. Five min intervals were chosen for testing because at a minimum, each 5-min interval contained 5(4)/2 = 10 pairs of points. Intervals less than 5 min might not contain a sufficient number of pairs for testing using Moran's *I*. An estimate of overall temporal correlation was computed by averaging correlation estimates across all transects present in the analysis. When this overall correlation estimate was non-significant or negative, temporal correlation was deemed to have an insignificant influence on model estimation.

Model fit was examined by computing the minimum, lower quartile (25^{th} percentile), median, upper quartile (75^{th} percentile), and maximum deviance residual for each model. The absolute value of the lower and upper quartile was compared to 2.0 and, if greater, model fit was further examined for systematic factors producing the large number of high residuals. In addition, deviance residuals were plotted against key environmental variables and examined for trends. These tests revealed that there were no residual quartiles greater than 2.0 in absolute value. No trends were observed when deviance residuals were plotted against key variables. This examination of residuals was deemed to validate all final models.

Results from these analyses include the following: estimates and standard errors of the coefficients, approximate *F*-values, *P*-values, overdispersion estimates, and Pearson's *r* values for temporal correlation. The Tables also show the expected percent increase or decrease in the number of seal sightings (with 95% confidence intervals) for a 1-unit change in the value of each covariate. Degrees of freedom (sample size – number of terms in the model) are also reported for each model.

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APPENDIX B: STATISTICAL POWER OF AERIAL SURVEYS OF BOWHEAD WHALES [6]

This report briefly describes methods used in a power analysis designed to determine the ability of intensive aerial surveys to detect a reduction in number of whales near the Northstar Island (NSI) if there was such a reduction. This Appendix presents methods used to conduct the power analysis, and a summary of the results.

It is assumed that the aerial surveys to be conducted near Northstar during one or more post-construction years would include daily (weather permitting) site-specific aerial surveys of the type conducted in 1996-98 around seismic operations, but in this case centered on Northstar Island. In addition, it is assumed that the broad-scale MMS aerial surveys would continue, and that the MMS data from the area around NSI would also be used in the analysis.

Methods

To evaluate the statistical power of aerial surveys, two areas surrounding NSI were defined. One area was called the *impact* zone and consisted of ocean habitat within a certain distance of NSI. The impact zone was hypothetical for this power analysis exercise and varied from 1 mile to 20 miles in radius. The second area was called the *control* zone and consisted of ocean habitat beyond the impact zone to the boundary of the anticipated aerial survey coverage that might be achievable on a daily basis in 2000-2002. NSI was defined to have an impact on whales when the time trajectories of sighting rates in the impacted and control areas were significantly non-parallel.

To clarify the type of NSI impact that the analyses described in this report detect, consider the situation depicted in Figure B-1 where NSI is assumed to reduce the number of whale sightings within 10 miles. In Figure B-1, average sighting rate estimated from historical data on the control area (outside 10 miles) was 3.5 whales per 1000 km of survey effort prior to NSI. Average sighting rate estimated from historical data on the potentially impacted area was 1.6 whales per 1000 km based on survey effort prior to NSI. Assuming 15 whales per 1000 survey km will be seen in the control area each year after construction, and that NSI produces no effect on whales, the analysis expects average sighting rate in the potentially impacted area to be 13.07 whales per 1000 survey km. This expected number of whale sightings, 13.07, was computed assuming perfect "parallelness" of the two average sighting trajectories displayed in Figure B-1. Expected "parallelness" in the absence of an NSI effect has been marked in Figure B-1 with a triangle. The solid lines displayed in Figure B-1 assume a 50% reduction in sighting rate on the impacted area over what would have been expected under perfect "parallelness". In this case, the 50% reduction equates to a sighting rate of 6.53 whales per 1000 km in the impacted area after construction, i.e. 0.5(13.07).

Hypothetical whale sighting rates in the control and impact areas before and after construction of NSI were compared using a two-sample t-test procedure. The t-test procedure tested for differences among yearly sighting rate differences before and after construction. For example, suppose three years of aerial survey data were available prior to construction and that the impact - control differences were -1.2, 0.5, and 0.2 sightings per 1000 kilometers of survey. Suppose further that a single year of survey data after construc-

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tion resulted in a impact - control difference of 1.5. The t-test procedure would test for a difference between the true underlying differences using observed (yearly) differences as a basis for replication. In this example, the estimated mean difference prior to construction was -0.16 while the estimated mean difference after construction was 1.5. All historical data from 1978 through 1998 aerial surveys (both MMS and site-specific) were used to establish reasonable hypothetical sighting rates, historical variation in sighting rate across years, and historical differences across impacted and control areas.

For each set of simulation conditions, 500 random sets of data were generated randomly assuming the number of whale sightings followed a Poisson distribution with mean proportional to survey effort. Effort in past years was fixed at the levels that actually occurred. Effort for post-construction monitoring was assumed to be the average of 3.5 times effort in 1996, 2.5 times effort in 1997, and 1.7 times effort in 1998. (These factors represent the amount of additional effort expected to be achievable with a site-specific aerial survey centered on Northstar relative to the amount of effort obtained near Northstar in 1996-98 when the site-specific surveys were usually not centered specifically on Northstar.) The assumed values for post-construction survey effort appear in Table B-1. For each randomly generated data set, lack of "parallelness" was measured by the two-sample t-test procedure. Expressing the situation in terms of means, rather than differences, the t-test procedure tested the hypothesis,

$$H_0: \mu_{i,b} - \mu_{c,b} - \mu_{i,a} + \mu_{c,a} = 0$$

where $\mu_{i,b}$ was the mean sighting rate on the impacted area before NSI, $\mu_{c,b}$ was the mean sighting rate on the control area prior to NSI, $\mu_{i,a}$ was the mean sighting rate on the impacted area after NSI, and $\mu_{c,a}$ was the mean sighting rate on the control area after NSI. By definition, a significant NSI impact was detected when H_0 was rejected in favor of the alternative $\mu_{i,b} - \mu_{c,b} - \mu_{i,a} + \mu_{c,a} \neq 0$. H_0 was rejected when the observed t-statistic exceeded the $\alpha = 0.05$ and $\alpha = 0.20$ quantile from a Student's t distribution. Two α levels of significance were used to assess power under "liberal" and "conservative" evidence requirements. The $\alpha = 0.05$ level of significance requires strong evidence in favor of the alternative hypothesis in order to reject the null hypothesis of no effect. The $\alpha = 0.20$ significance level requires less evidence than the $\alpha = 0.05$ level in order to reject the null hypothesis. If one-tailed tests were used to detect impacts, significance levels would then be $\alpha = 0.025$ and $\alpha = 0.10$. Degrees of freedom for the t-test were (number of years of surveys prior to construction) + (number of years after construction) - 2. The proportion of NSI impacts detected out of 500 randomly generated data sets was computed and reported as power.

Power to detect a 0%, 50%, 75%, and 99% reduction in whale sightings on impacted areas was computed for impact radii of 1, 2, 4, 10, and 20 miles. For comparative purposes, sighting rates on the control area were assumed to be 3, 5, 10, 15, and 20 whales per 1000 km of survey effort. (In fact, the average sighting rate in the control area in prior years has been less than 5 regardless of the assumed size of the impact zone — see dashed horizontal lines in Figures B-1 to B-5.) Both one year of post-construction monitoring (2000) and three years of post-construction monitoring (2000 – 2002) were evaluated at the $\alpha = 0.05$ ($\alpha = 0.025$ one-tailed) significance level. The three years post-construction situation was also evaluated using $\alpha = 0.20$ ($\alpha = 0.10$ one-tailed). This latter case assumes the longest post-construction survey effort among all assessed situations, and requires the least amount of evidence before an impact is detected.

Results

Figures B-1 through B-5 graph historical and hypothetical data for impact radii of 10, 1, 2, 4, and 20 statute miles, respectively. Three hypothetical years of post-construction monitoring are shown in the Figures. Situations involving one year of post-construction monitoring were identical to the three-year post construction situations except that the hypothetical information from 2001 and 2002 was deleted.

Results of the power analysis assuming one year of post-construction monitoring appear in Table B-2. Results assuming three years of post-monitoring data and $\alpha = 0.05$ appear in Table B-3. Results assuming three years of post-monitoring data and the less conservative $\alpha = 0.20$ criterion appear in Table B-4. The half-width of an approximate 95% confidence interval on the values in Tables B-2 through B-4 is 0.033.

In general, power to detect an effect was low given typical whale sighting rates of 3 or 5 sightings per 1000 km of survey effort in the control area. With those typical sighting rates, power to detect an effect was low regardless of the size of the impact area (1-20 mile radius), even in the case of near-total avoidance of the impact area. With typical whale sighting rates, power would be low even with three years of post-construction surveys and an $\alpha = 0.20$ criterion (Table B-4).

For assumed sighting rates of 10 or more sightings per 1000 km of survey effort in the control area, the power of the aerial surveys to detect an effect was higher. In general, power was positively related to the sighting rate, to the size of the impact area, and to the number of years of post-construction surveys (Tables B-2 to B-4). On average, power of three years post-construction monitoring to detect an effect was approximately 84% higher than the power of a single year of post-construction monitoring. With three years of post-construction surveys, reasonable power (0.80 or higher) might be achievable if the impact radius were 10 miles or more, if a high proportion of the bowheads avoided the impact zone, and if the sighting rate (in the control area) were 10 or more sightings per 1000 km of surveys (Tables B-3 to B-4). However, this sighting rate and impact radius are both higher than can reasonably be expected. With realistic sighting rates of 3 – 5 sightings per 1000 km, power would be low even if the impact radius were as much as 10-20 miles and surveys continued for 3 post-construction years.

TABLE B-1. Assumed kilometers of survey effort in the control and impact areas each year post-construction.

Impact Area Size	Assumed Effort in Control Area (km)	Assumed Effort in Impact Area (km)
1 km	28,568	83.4
2 km	28,468	183.7
4 km	28,132	520
10 km	26,067	2585
20 km	19,645	9007

TABLE B-2. Power of **1 year** post-construction aerial surveys to detect varying reductions in whale sightings within various radii impact areas using α = **0.05** and assuming different sighting rates in the control area. For one-tailed tests, significance level requirements would be α = 0.025. Power assessed under simulation using *t*-test for differences of differences. The bound on the simulation error was ±0.033.

Impact Area Size (mi)	Effect Size	Sighting rate in control area (per 1000 km)				
		3	5	10	15	20
1	0	0.006	0.006	0.038	0.058	0.142
	0.5	0.004	0	0.012	0.014	0.154
	0.75	0.01	0	0	0.006	0.206
	0.99	0.008	0	0	0	0.294
2	0	0.004	0.006	0.014	0.038	0.062
	0.5	0.002	0.002	0.012	0.052	0.108
	0.75	0	0	0.004	0.072	0.154
	0.99	0	0	0.008	0.158	0.254
4	0	0	0.002	0.008	0.014	0.036
	0.5	0	0	0.014	0.086	0.16
	0.75	0	0	0.02	0.172	0.33
	0.99	0	0	0.04	0.332	0.472
10	0	0	0	0	0	0.002
	0.5	0	0	0	0.028	0.202
	0.75	0	0	0.01	0.268	0.68
	0.99	0	0	0.076	0.648	0.886
20	0	0	0	0	0	0
	0.5	0	0	0	0	0.034
	0.75	0	0	0.002	0.076	0.682
	0.99	0	0	0.016	0.678	0.996

TABLE B-3. Power of **3 years** post-construction aerial surveys to detect varying reductions in whale sightings within various radii impact areas using and α = **0.05** and assuming different sighting rates in the control area. For one-tailed tests, significance level requirements would be α = 0.025. Power assessed under simulation using *t*-test for differences of differences. The bound on the simulation error was ±0.033.

Impact Area		Sighting rate in control area (per 1000 km)				
Size (mi)	Effect Size	3	5	10	15	20
1	0	0.004	0.004	0.02	0.05	0.068
	0.5	0.004	0	0.002	0.092	0.154
	0.75	0.002	0	0.008	0.21	0.288
	0.99	0.008	0	0.006	0.366	0.434
2	0	0	0.004	0.036	0.036	0.052
	0.5	0	0.002	0.06	0.088	0.172
	0.75	0	0	0.098	0.242	0.35
	0.99	0	0	0.188	0.332	0.432
4	0	0	0	0.006	0.018	0.034
	0.5	0	0	0.066	0.222	0.372
	0.75	0	0	0.188	0.42	0.468
	0.99	0	0.006	0.374	0.468	0.47
10	0	0	0	0	0	0
	0.5	0	0	0.072	0.514	0.858
	0.75	0	0	0.372	0.876	0.906
	0.99	0	0	0.808	0.912	0.918
20	0	0	0	0	0	0
	0.5	0	0	0.01	0.418	0.97
	0.75	0	0	0.404	0.998	1
	0.99	0	0.008	0.964	1	1

TABLE B-4. Power of **3 years** post-construction aerial surveys to detect varying reductions in whale sightings within various radii impact areas using α = **0.20** and assuming different sighting rates in the control area. For one-tailed tests, significance level requirements would be α = 0.10. Power assessed under simulation using *t*-test for differences of differences. The bound on the simulation error was ±0.033.

Impact Area		**Sighting rate in control area (per 1000 km)**				
Size (mi)	**Effect Size**	3	5	10	15	20
1	0	0	0	0.102	0.062	0.116
	0.5	0	0	0.182	0.244	0.348
	0.75	0	0	0.29	0.398	0.428
	0.99	0	0	0.45	0.47	0.548
2	0	0	0.004	0.032	0.04	0.086
	0.5	0	0.012	0.142	0.294	0.366
	0.75	0	0.016	0.256	0.462	0.502
	0.99	0	0.026	0.4	0.542	0.56
4	0	0	0.002	0.044	0.066	0.058
	0.5	0	0.012	0.246	0.442	0.516
	0.75	0	0.022	0.408	0.574	0.718
	0.99	0	0.048	0.49	0.712	0.754
10	0	0	0	0	0.01	0.032
	0.5	0	0.004	0.658	0.912	0.892
	0.75	0	0.058	0.894	0.926	0.92
	0.99	0	0.238	0.916	0.916	0.892
20	0	0	0	0	0	0
	0.5	0	0.002	0.656	0.998	1
	0.75	0	0.12	1	1	1
	0.99	0.002	0.692	1	1	1

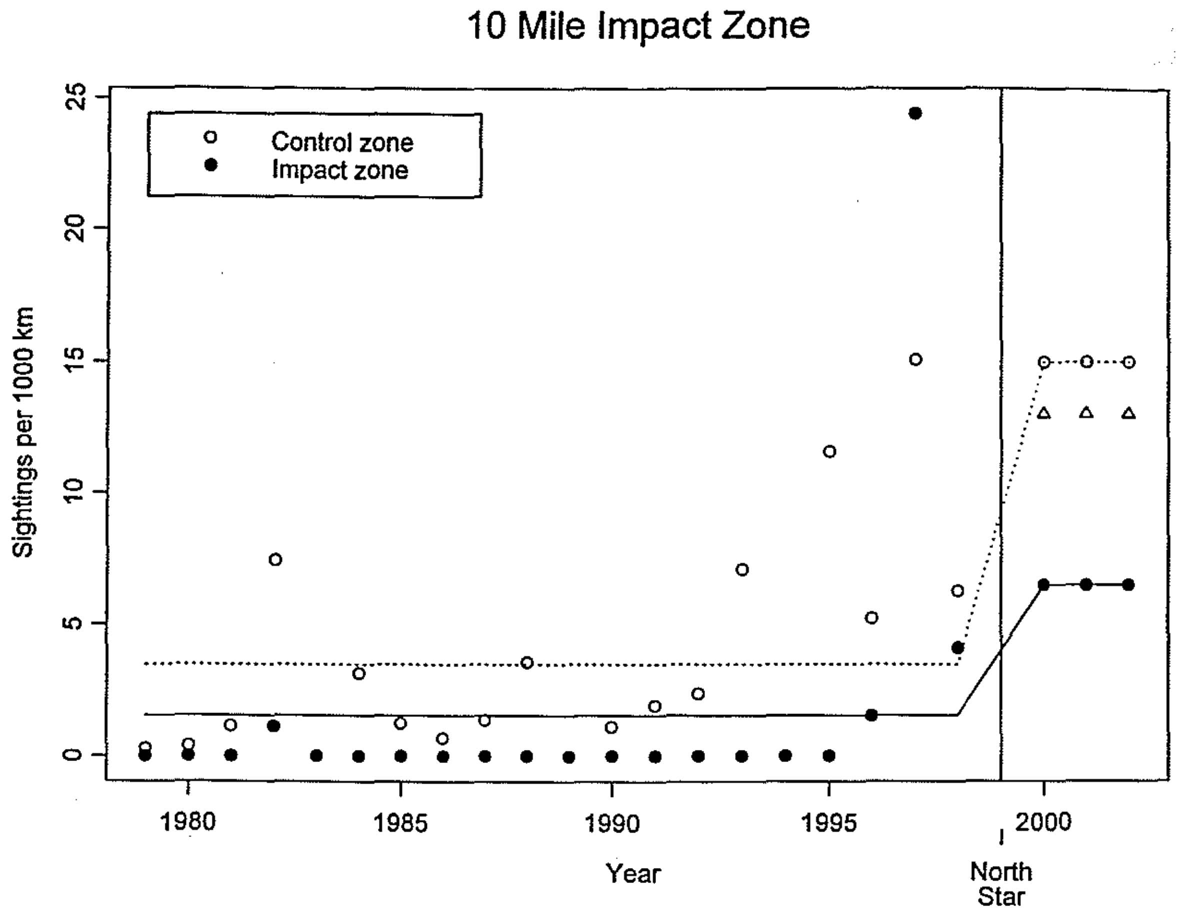

FIGURE B-1. Historical and hypothetical data used to assess power assuming a 10 mile impact zone, 15 sightings per 1000 km in the control area after construction, and assuming a 50% reduction in sightings over what would be expected under the hypothesis of no North Star effect. Filled circles represent sighting rates (per 1000 km) in the potentially impacted area. Hollow circles represent sighting rates on the control area. Expected sighting rates in the impact area under the hypothesis of no effect are shown as triangles.

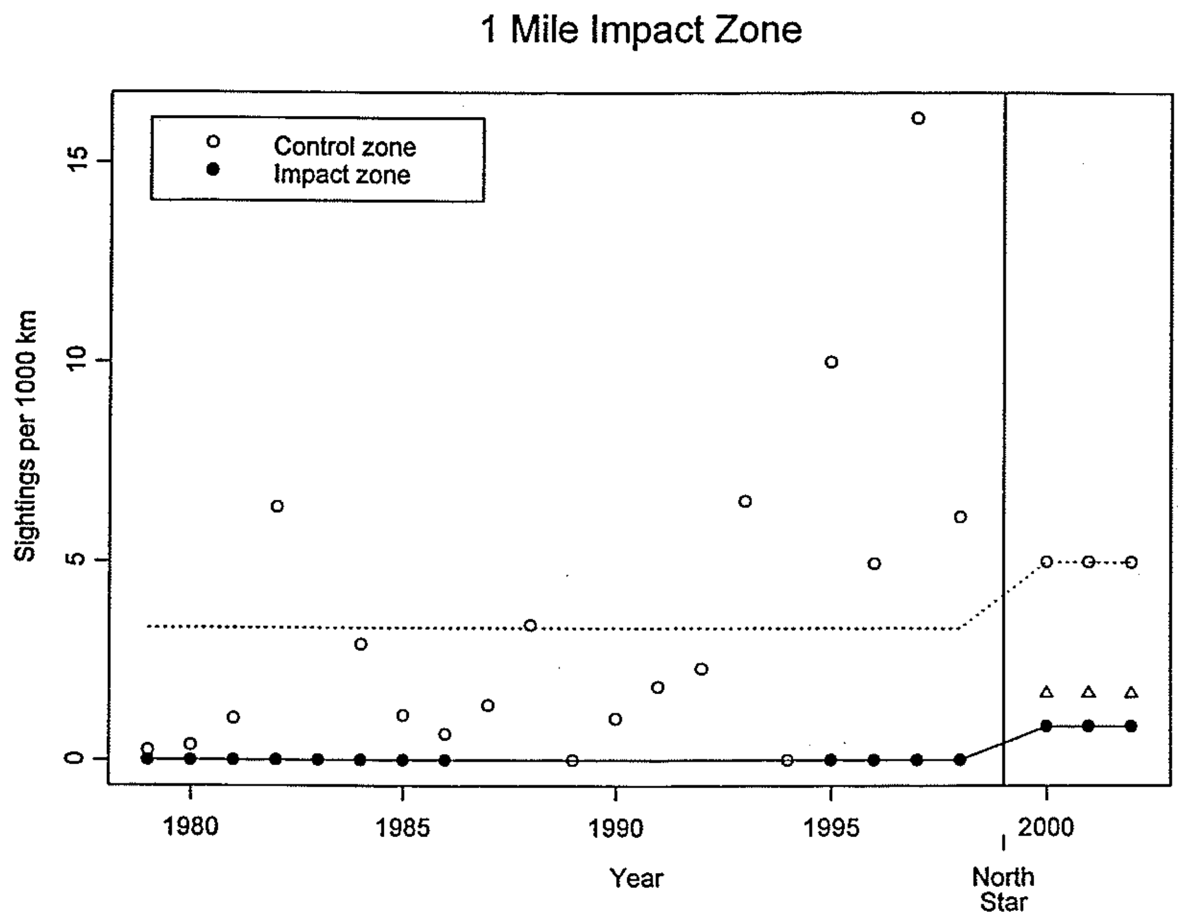

FIGURE B-2. Historical and hypothetical data used to assess power assuming a 1 mile impact zone, five sightings per 1000 km in the control area after construction, and assuming a 50% reduction in sightings over what would be expected under the hypothesis of no North Star effect. Filled circles represent sighting rates (per 1000 km) in the potentially impacted area. Hollow circles represent sighting rates on the control area. Expected sighting rates in the impact area under the hypothesis of no effect are shown as triangles.

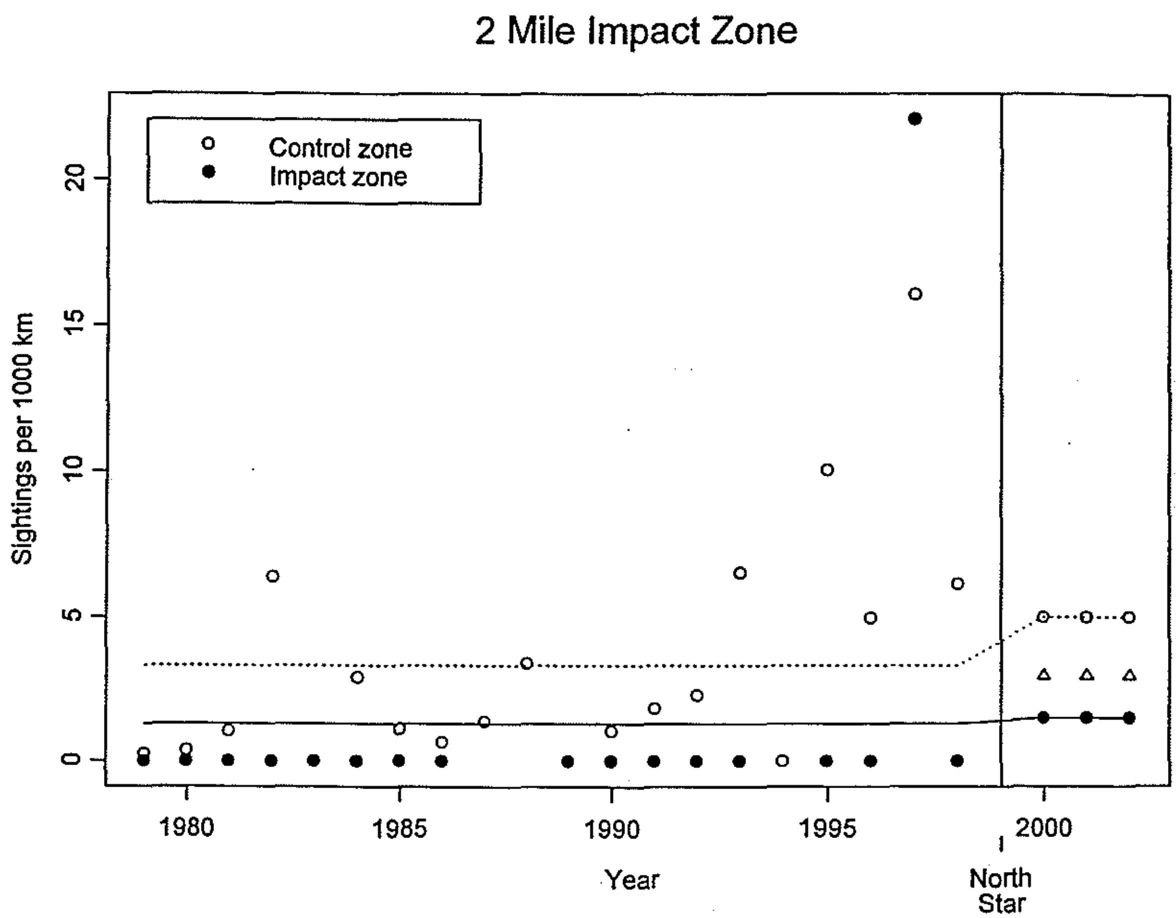

FIGURE B-3: Historical and hypothetical data used to assess power assuming a 2 mile impact zone, five sightings per 1000 km in the control area after construction, and assuming a 50% reduction in sightings over what would be expected under the hypothesis of no North Star effect. Filled circles represent sighting rates (per 1000 km) on the potentially impacted area. Hollow circles represent sighting rates on the control area. Expected sighting rates in the impact area under the hypothesis of no effect are shown as triangles.

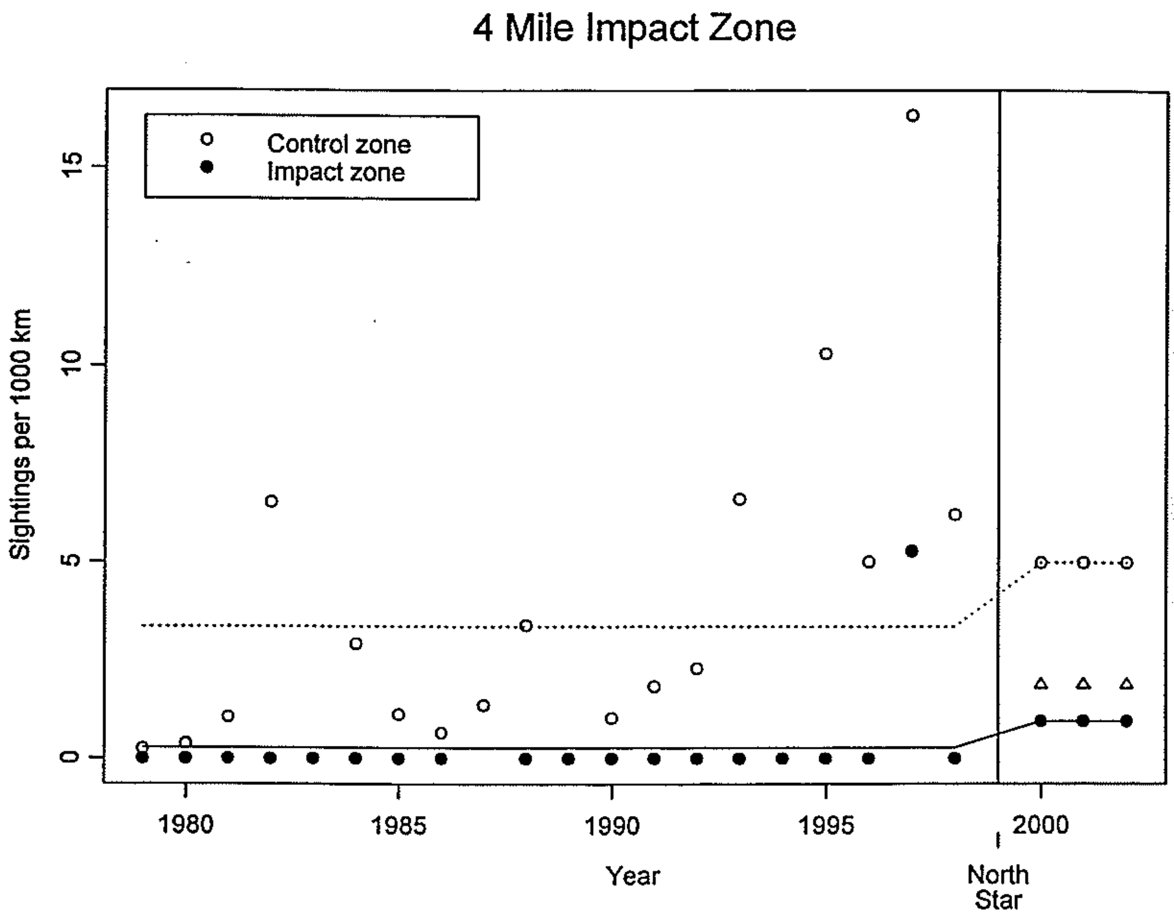

FIGURE B-4: Historical and hypothetical data used to assess power assuming a 4 mile impact zone, five sightings per 1000 km in the control area after construction, and assuming a 50% reduction in sightings over what would be expected under the hypothesis of no North Star effect. Filled circles represent sighting rates (per 1000 km) on the potentially impacted area. Hollow circles represent sighting rates on the control area. Expected sighting rates in the impact area under the hypothesis of no effect are shown as triangles.

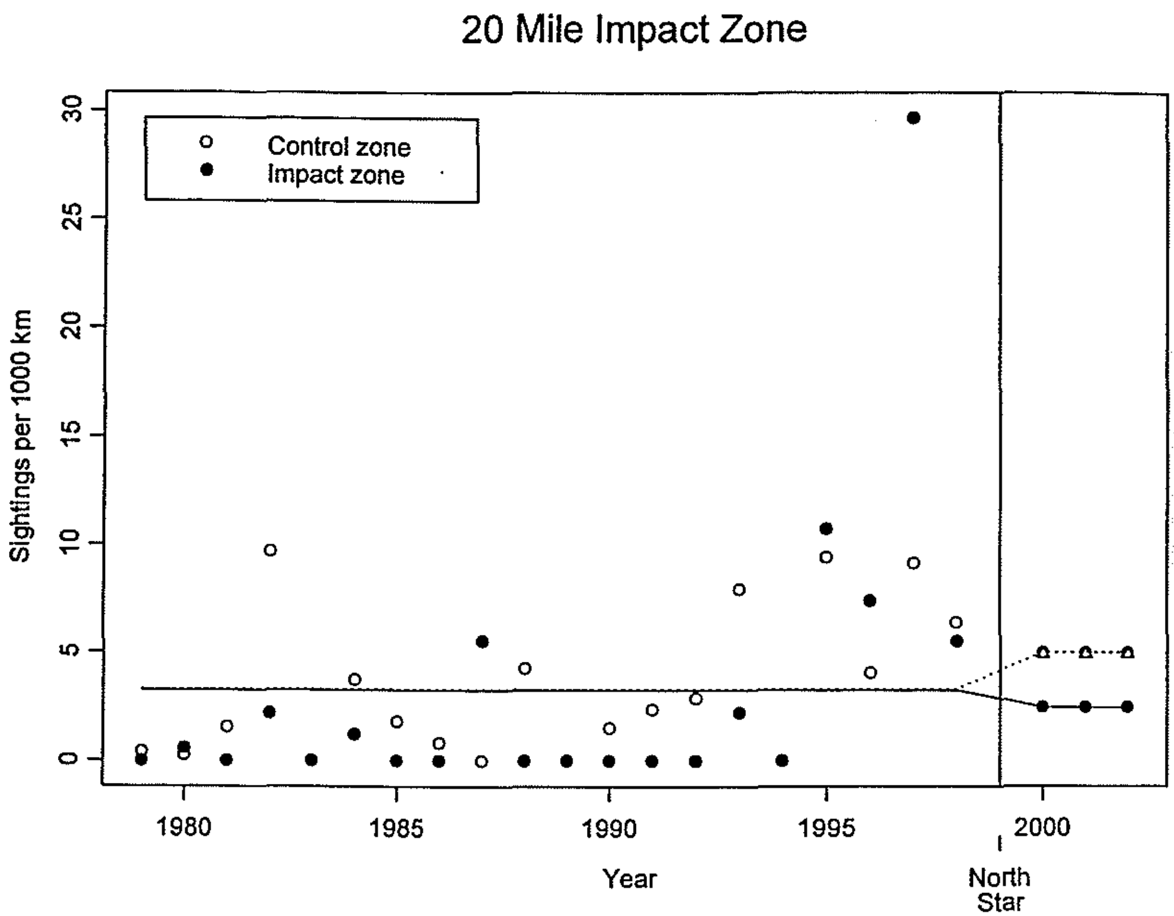

FIGURE B-5. Historical and hypothetical data used to assess power assuming a 20 mile impact zone, five sightings per 1000 km in the control area after construction, and assuming a 50% reduction in sightings over what would be expected under the hypothesis of no North Star effect. Filled circles represent sighting rates (per 1000km) on the potentially impacted area. Hollow circles represent sighting rates on the control area. Expected sighting rates in the impact area under the hypothesis of no effect are shown as triangles.

APPENDIX C: STATISTICAL POWER OF ACOUSTIC SURVEYS FOR CALLING BOWHEAD WHALES [7]

In this report, we describe methods used in a power analysis designed to determine the ability of an acoustic localization technique to detect a reduction in the number of whale calls originating near Northstar Island (NSI) at times when NSI produces substantial underwater noise. We present Methods and a summary of Results, but no discussion is given (see Task 7 section of Monitoring Plan for discussion). The Methods section is organized as follows: First, we discuss a simulation of the expected data, including anticipated distributions of both NSI noise and distance to whales, and a model for the effect of noise on distance. Next, we describe quantile regression as a method of estimating the noise effect, and provide some background on this methodology. Finally, we discuss a power analysis concerning the ability of the proposed methodology to detect and quantify effects of relevant magnitude, including the factors affecting power and our approach to estimating power.

Methods

Data Simulation

Distributions of Noise and Distance to Whales.—In all that follows, we consider noise expressed on a decibel scale, recognizing that this is a logarithmic scale. It is assumed that NSI noise will be measured at a fixed hydrophone located about 500 m offshore of NSI. We assume that the frequency distribution of this noise can be approximated by a gamma distribution. We generated random observations from a gamma distribution with shape parameter 5.6 and scale parameter 2.5, truncated the upper tail of the distribution at 35.5 (less than 0.4% of the distribution was truncated), and translated all remaining observations by adding 86.8. The result was a right-skewed distribution (Fig. C-1) with both mean and median of 100 dB, and range of 88 – 122 dB. The percentiles of our simulated noise distribution closely approximated those from empirical data collected by a fixed hydrophone located 450 m from Sandpiper Island during drilling and other operations in autumn 1985 (data provided by Charles Greene, Greeneridge Sciences Inc.).

Under conditions of no noise from NSI, we assumed that the distribution of distance from NSI to detectable calling whales would be roughly uniform between 17 and 33 km, centered at 25 km, with roughly normal tails below 17 and above 33 km. That is, the probability distribution of whale locations ought to increase as a normal density function between 0 and 17 km, be relatively constant between 17 and 33 km, and then decrease as a normal density function beyond 33 km. This fall-off beyond 33 km offshore is expected because the acoustic monitoring system is designed to cover only the southern portion of the bowhead migration corridor. For calls originating farther offshore, the system will detect and localize a diminishing proportion of the calls at increasing distances beyond 33 km.

We generated such a distribution by simulating observations from a mixture of normal and uniform distributions. Seventy percent of the observations in our mixture distribution came from a normal distribution with mean 25 and standard deviation 6.67, while 30% of the observations came from a uniform

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distribution with minimum 17 and maximum 33. We truncated the lower tail of the mixture at 0 km, since a very small percentage (less than 0.01%) of the distribution is negative, and bowheads are not expected to occur inshore of NSI. Figure C-2 depicts 1000 simulated observations of distance to whale calls under the assumption that NSI noise level has no effect on distance from NSI.

Modeling Whale Response to Noise.—Whales might respond to noise from NSI in variety of ways. A simple model of noise avoidance posits that whales will increase their distance from NSI in direct proportion to the noise. At any given noise level, we would expect the effect to be maximum at the noise source and diminish at greater distances from the due to decay in sound level with increasing distance. Irrespective of both the form of the sound decay and the effect of noise on very distant whales, the noise effect should be most apparent on nearer whales. We would be surprised if whales far from a noise source moved more in response to the noise than whales close to the noise.

We simulated the effect of noise by "moving" the whales closest to NSI offshore by a distance proportional to the noise level, so that whales exposed to the minimum noise (88 dB) had no response and whales experiencing the maximum noise (~122 dB) moved the greatest distance offshore. We defined "close" based on the 0.05 quantile line, the line that separates the lower 5% from the upper 95% of the distribution of distance conditioned on noise. If there were truly no noise effect, the quantile line would be perfectly horizontal. For any particular noise effect, say, movement of 0.15 km offshore per 1 dB increase in noise, whales were assumed to move offshore such that 5% of the distribution remained below the line with slope 0.15 km/dB. That is, the "true" 0.05 quantile line would have slope 0.15. For a simulated data set (such as that shown in Figures C-2 and C-3) all observations below the theoretical line with slope 0.15 were moved a distance sufficient to guarantee that 5% of the true distribution remained below the line. This distance, d, was calculated as: $d = \text{slope} \times (\text{Noise Level} - 88)$. As an example, consider a whale close to NSI (below the 0.15 km/dB line). At a noise level of 120 dB, that whale would move $0.15 \times (120 - 88) = 4.8$ km. Another close whale at the median noise level (100 dB) would move 1.8 km. Figure C-3 depicts 1000 simulated observations under the assumptions described in this example.

It might be argued that noise should have some effect on more distant whales in addition to the effect on those closest to NSI. However, our method of assessing the noise effect, quantile regression (see below), is insensitive to changes in whale location for distant whales. That is, because we expect the greatest effect among the nearest 5% of whales, we focus on detecting a shift in location among these nearest 5% of whales. In estimating the 0.05 quantile line, it is immaterial whether the more distant whales move 0, 1, or 10 km. In other words, our method is robust to changes in the shape of the distribution of distances larger than the quantile of interest.

The important consequence of this robustness is that, as long as 5% of observations remain below (south of) the estimated line and 95% remain above it, the line is completely unaffected. For this reason, we determined that it was unnecessary to simulate decreasing detectability of whale calls at large distances from the hydrophone array. Our simulated distribution of large distances may be unrealistic; however, quantile regression for lower quantiles is not affected by details in the upper tail of the distribution.

Estimation

Quantile Regression: Assessing the Relationship between Noise and Distance.—If there is any effect of noise on the distribution of calling whales, we assume that the lower portion of the distribution of distance, i.e., the nearest distances to NSI, ought to shift upward (offshore) as noise increases, as in the example in Figure C-3. We let the 5^{th} percentile represent this lower part of the distribution. Thus, positive slope of the line through the 5^{th} percentile indicates a noise effect, while zero or negative slope is taken as evidence of no noise effect. Quantile regression (Koenker and Bassett 1978) provides the methodology to assess slope through any percentile of a conditional distribution (here, the distribution of distance offshore is conditional on noise). As with the quantiles of a univariate distribution, quantile regression estimates are less sensitive to assumptions of normality and constant variance than is standard regression through the mean.

Background on Quantile Regression.—Estimation procedures for quantile regression and standard linear regression are similar in some respects. Linear regression estimates, $\hat{\beta}$, may be obtained from minimizing the sum of squared residuals, i.e.,

$$\hat{\beta} = \min_{\beta}\left\{\sum_{i=1}^{n}(y_i - \mathrm{X}_i\beta)^2\right\}$$

where y_i is the observed value of the response variable, X_i is the vector of explanatory variables, and β is the unknown parameter vector. Likewise, quantile regression estimates may be obtained by minimizing a sum of weighted residuals. If $r_i = (y_i - \mathrm{X}_i\beta)$ are residuals and τ represents the desired quantile with $0 < \tau < 1$, then the regression estimates for the τ quantile are

$$\hat{\beta}_\tau = \min_{\beta}\left\{\sum_{i=1}^{n} r_i\left[\tau - I(r_i < 0)\right]\right\}.$$

Here, I(A) represents the indicator function constructed such that all observations below the fitted line receive a constant negative weight of $1-\tau$ and all observations above the line receive a constant positive weight of τ. For example, if $\tau = 0.05$ (the 5th percentile), then observations below the line receive a weight of -0.95 while observations above the line receive a weight of $+0.05$. Most, if not all, of the literature on estimation for quantile regression focuses on performing this minimization through linear programming (e.g., Buchinsky 1998; Portnoy and Koenker 1997); however, we obtained estimates using widely available nonlinear optimization routines implemented in Matlab (MathWorks 1999). Identical estimates of $\hat{\beta}_\tau$ are obtained by both procedures. The fitted line in Figure C-3(b) represents the regression through the 5th percentile. Significance of $\hat{\beta}_\tau$ was assessed using a randomization test (see below) that did not require the distribution of $\hat{\beta}_\tau$ to be known.

Power Analysis

Factors Affecting Power.—Power to detect an effect will depend on the size of the hypothesized effect, in this case, the slope of the underlying relationship between the 5th-percentile distance offshore and noise. We considered a range of possible effect sizes, simulating data with true slopes of 0, 0.0075, 0.015, 0.03, 0.06, 0.15, and 0.3 km/dB. These slopes for the 5th-percentile distance offshore correspond to a minimum of no noise effect and a maximum increase in 5th-percentile distance of 10.2 km for a noise increase of 34 dB from 88 dB to 122 dB re 1 μPa, as measured a few hundred meters from NSI.

Similarly, we considered sample sizes of 100, 300, 1000, and 3000 localized, independent calls. The largest sample size is a conservative estimate of the total number of calls expected to be localized in a one-month period (Charles Greene, personal communication). However, frequent whale calls may be autocorrelated in time and location. We plan to test for autocorrelation and, if necessary, subsample the available data to obtain independent observations. For example, it may be necessary to take a subsample of every 10th observation to achieve independence; in that case, 300 observations would remain if 3000 calls were localized in one season. We feel that 100 observations is likely a lower limit on the number of useable observations, given that fewer than 3000 observations may be available and that subsampling may still be necessary. It is also possible that more than 3000 observations will be available. Still, given the estimated power for a sample size of 3000 (see Results), we would expect larger samples to result in very high power to detect even rather small effects.

For testing, we selected $\alpha = 0.10$, a value that requires moderate evidence against the null hypothesis of no effect in order for it to be rejected. Estimated power would have been lower had we used $\alpha = 0.05$.

Estimating Power.—If there were no effect of NSI noise on distance to the closest vocalizing whales, the slope of the quantile regression through the 5[th] percentile, denoted $\hat{\beta}_{0.05}$, ought to be zero. Conversely, if there is a noise effect, $\hat{\beta}_{0.05}$ ought to be positive. Thus, the null and alternative hypotheses of interest were

H_0: $\beta_{0.05} = 0$ and H_a: $\beta_{0.05} > 0$.

To estimate power, we conducted simulations in two stages, involving primary and secondary data sets. At each of the 24 combinations of sample size and slope, 500 primary data sets were generated. Each primary data set fulfilled the assumptions of the alternative hypothesis, that is, each contained a positive relationship between noise and distance; however, one set of primary data sets was generated based on the assumption of no relationship between noise and distance. For each primary data set, $\hat{\beta}_{0.05}$ was calculated. To calculate a significance level under the null hypothesis of $\hat{\beta}_{0.05} = 0$, a randomization test (Manly 1998) was performed on each primary data set. The randomization test randomly permuted distance values and reassigned these to noise levels. Each random permutation of distance values was called a secondary data set. One hundred secondary data sets were produced for each primary data set. Each secondary data set fulfilled the assumption of the null hypothesis, that is, of no relationship between noise and distance. The proportion of slopes computed on secondary data sets that were greater than the slope calculated from the primary data set provided an estimate of significance.

If the P-value computed via randomization was less than α, then the null hypothesis was rejected in favor of the alternative hypothesis. Since the 500 primary data sets were generated under the assumption of the alternative, the number of times the null hypothesis was rejected (out of 500) constituted an estimate of power. That is, power was calculated as the proportion of P-values less than α.

Results

As shown in Table C-1 and Figure C-4, power increased with both sample size and effect size (i.e., magnitude of slope). As expected, the probability that the testing procedure led to the conclusion that $\beta_{0.05} > 0$ when in fact $\beta_{0.05} = 0$ (i.e., Type I error) was roughly equal to $\alpha = 0.10$, irrespective of sample size. The power was 0.99 with an expected sample size of 3000 and a slope of 0.15 km/dB, corresponding to a displacement of the 5[th]-percentile by 4.8 km when received level a few hundred meters from Northstar is 120 dB. For this slope, the power was still high (0.92) for sample size 1000, and 0.65 for sample size 300. With a larger slope of 0.3 km/dB (i.e., a displacement of 9.6 km at 120 dB), the probability of detecting a noise effect was ≥0.95 for sample sizes of 300 or greater.

Other factors that might affect the estimated power to a lesser extent than sample and effect size include (1) distribution of noise (e.g., normal rather than gamma); (2) heteroscedasticity in the conditional distribution of distance (e.g., increased variation at high noise levels); and (3) nonlinear relationship between noise and distance. We have not examined these other factors.

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TABLE C-1. Power of acoustic surveys to detect increases in distances to whale vocalizations. The 5th percentile of distance was assumed to be a linear function of noise as measured a few hundred meters offshore of Northstar Island (expressed in dB re 1 µPa, 20-500 Hz band). Power was estimated at 7 different effect sizes (slopes relating distance and noise) and 4 different sample sizes. Significance level was $\alpha = 0.10$ in all cases.

		Sample Size			
Slope (km/dB)	Displacement (km)[1]	100	300	1000	3000
0	0	0.1040	0.1127	0.1134	0.1127
0.0075	0.24	0.1068	0.1258	0.1182	0.1408
0.015	0.48	0.1168	0.1165	0.1014	0.1469
0.03	0.96	0.1095	0.1174	0.1956	0.3448
0.06	1.92	0.0949	0.1956	0.3567	0.6840
0.15	4.80	0.3783	0.6538	0.9175	0.9940
0.30	9.60	0.7699	0.9479	1.0000	1.0000

[1] Projected offshore displacement of 5th-percentile calling whale when received noise level a few hundred meters from Northstar Island is 120 dB re 1 µPa in the 20-500 Hz band.

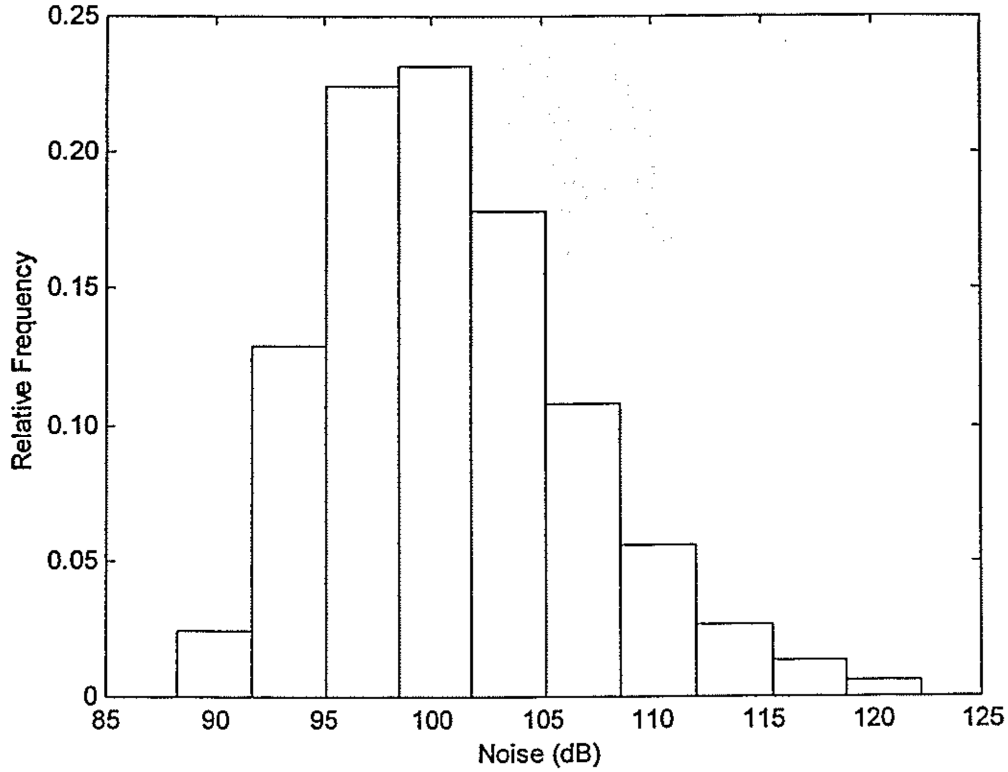

FIGURE C-1. Empirical distribution of noise (in dB re 1 μPa, 20-500 Hz band), based on simulation of 10,000 simulated observations from a gamma (5.6, 2.5) distribution, upper tail truncated at 35.5, and transformed by adding 86.8 to all values.

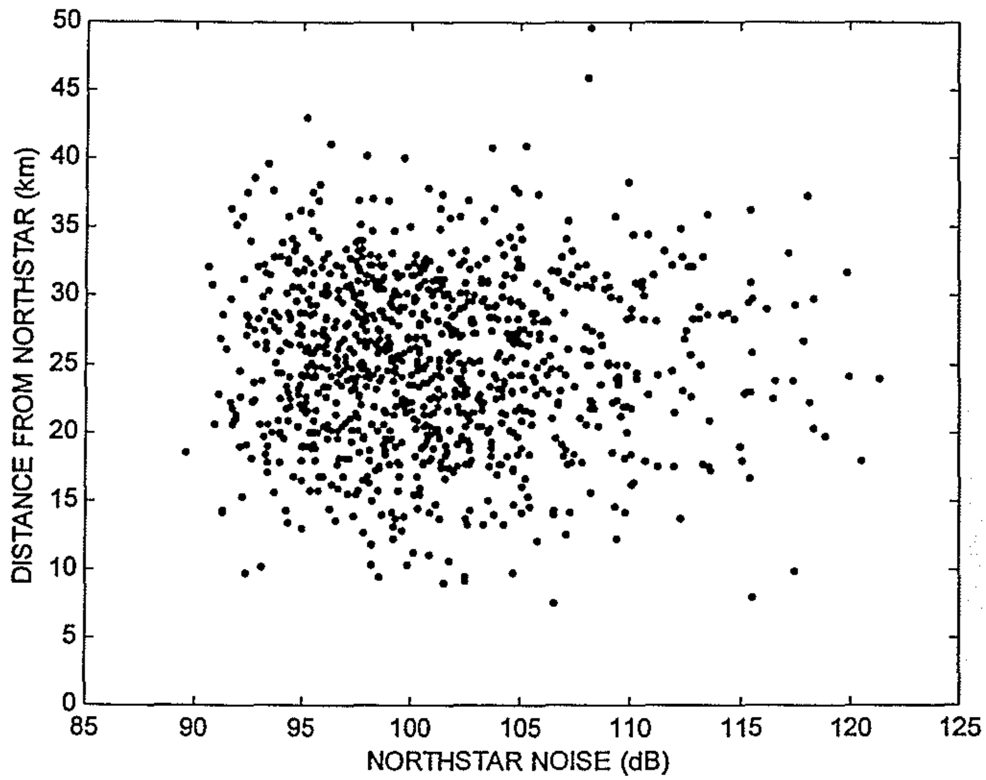

FIGURE C-2. Simulation of 1000 localizations of calling whales under the null hypothesis of no relationship between Northstar noise and distance from Northstar to vocalizing whales. Noise was distributed as a transformed gamma with a mean of approximately 100 dB re 1 μPa in the 20-500 Hz band (as shown in Fig. C-1). Distance was distributed as a mixture of normal and uniform distributions (see text for details), with a mean of 25 km.

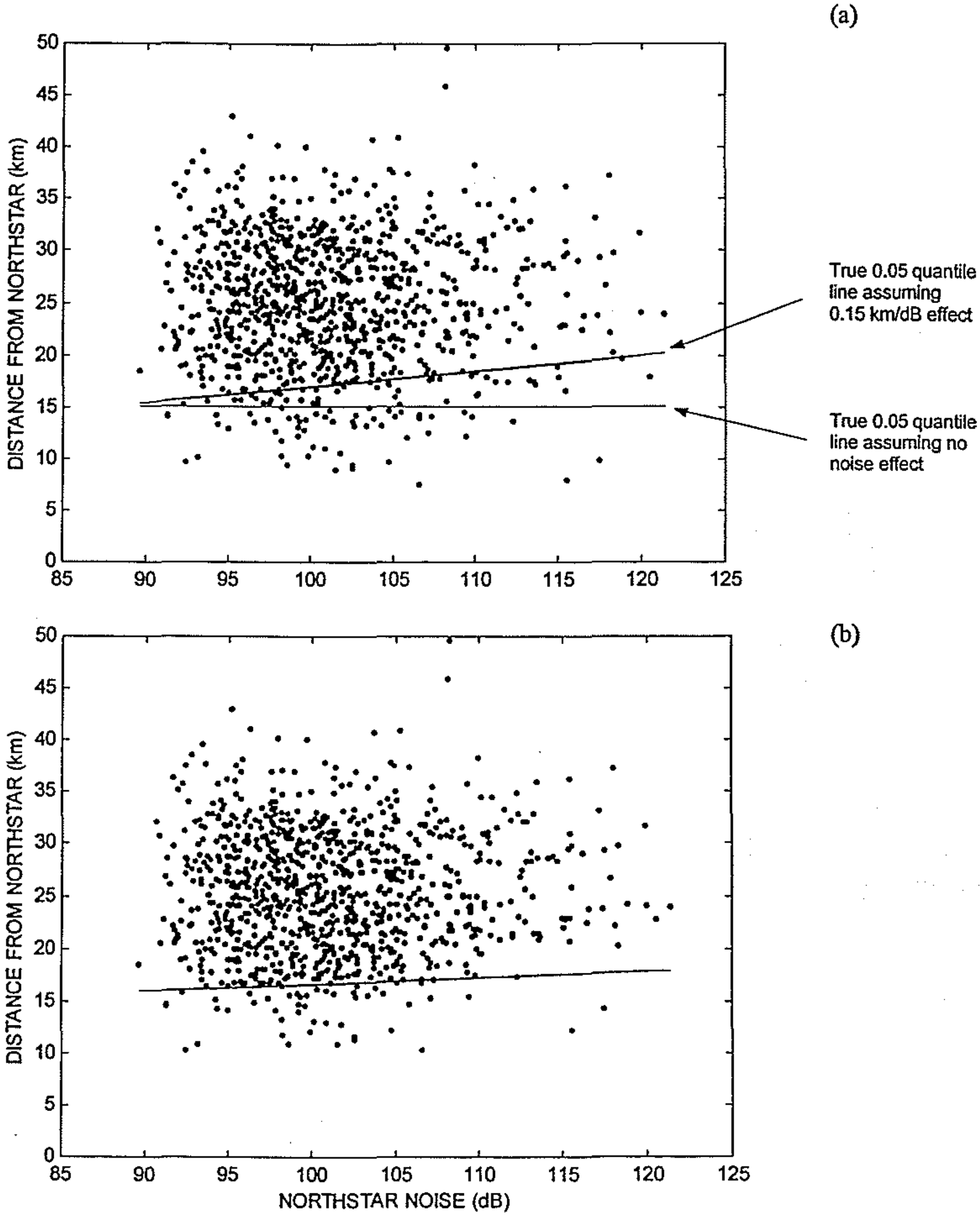

FIGURE C-3. Simulation and subsequent estimation of noise effect. (a) Same data as shown in Figure C-2. Horizontal line represents true 0.05 quantile line for no noise effect. Upper line with positive slope represents a hypothetical effect size of 0.15 km/dB (i.e., 4.8 km farther offshore for 120 dB than for 88 dB). (b) Same data, but with observations below the upper line moved offshore based on the 0.15 dB/km assumption (see text). The line in (b) is the estimated 0.05 quantile line for the altered distribution.

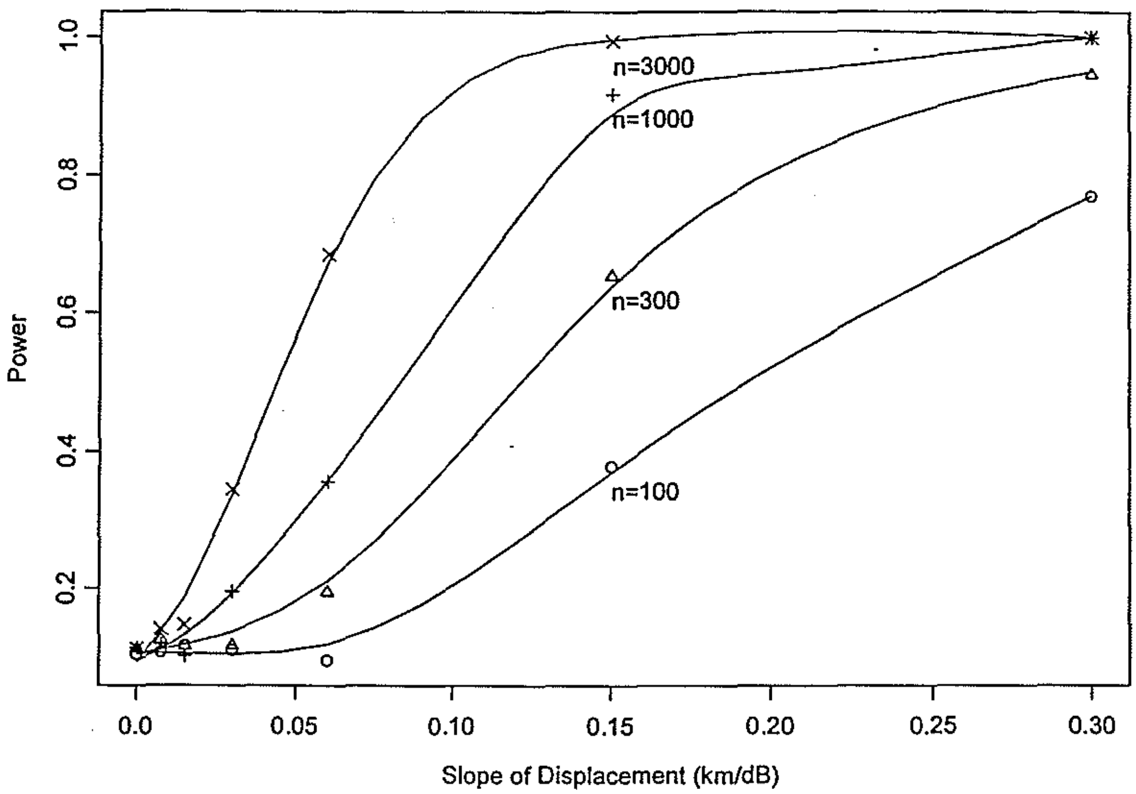

FIGURE C-4. Estimated power as a function of both sample size and magnitude of the slope relating 5th percentile distance offshore and noise. Symbols represent data contained in Table 1. Lines represent a smoothed estimate of the power curve for each sample size.