

Calibrating and monitoring the western gray whale mitigation zone and estimating acoustic transmission during a 3D seismic survey, Sakhalin Island, Russia

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Received: 26 April 2006 / Accepted: 11 May 2007 / Published online: 29 August 2007
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Abstract A 3D marine seismic survey of the Odoptu license area off northeastern Sakhalin Island, Russia, was conducted by DalMorNefteGeofizika (DMNG) on behalf of Exxon Neftegas Limited and the Sakhalin-1 consortium during mid-August through early September 2001. The key environmental issue identified in an environmental impact assessment was protection of the critically endangered western gray whale (*Eschrichtius robustus*), which spends the summer–fall open water period feeding off northeast Sakhalin Island in close proximity to the seismic survey area. Seismic mitigation and monitoring guidelines and recommendations were developed and implemented to reduce impacts on the feeding activity of western gray whales. Results of the acoustic monitoring program indicated that the noise monitoring and mitigation program was successful in reducing exposure of feeding western gray whales to seismic noise.

Keywords Western gray whale · 3D seismic survey · Noise monitoring and mitigation · Sakhalin Island, Russia

Introduction

Exxon Neftegas Limited (ENL) and its Sakhalin-1 consortium partners are developing oil and gas reserves on the shallow continental shelf of northeast Sakhalin Island in Far East, Russia. DalMorNefteGeofizika, on behalf of the Sakhalin-1 consortium conducted a 3D seismic survey in the consortium's Odoptu license area off northeastern Sakhalin Island from 17 August–9 September 2001 (Fig. 1).

The seismic survey was preceded by an environmental impact assessment (EIA) which identified as an important issue the protection of the Western North Pacific population of gray whale, *Eschrichtius robustus* (hereafter western gray whale) which feed near the Odoptu license area. These whales are listed as endangered in the Russian Red Book (Anonymous 2001) and critically endangered by IUCN—The World Conservation Union (Hilton-Taylor 2000). In addition, starting in 1999 some individual western gray whales were reported to be emaciated (Weller et al. 1999, 2001).

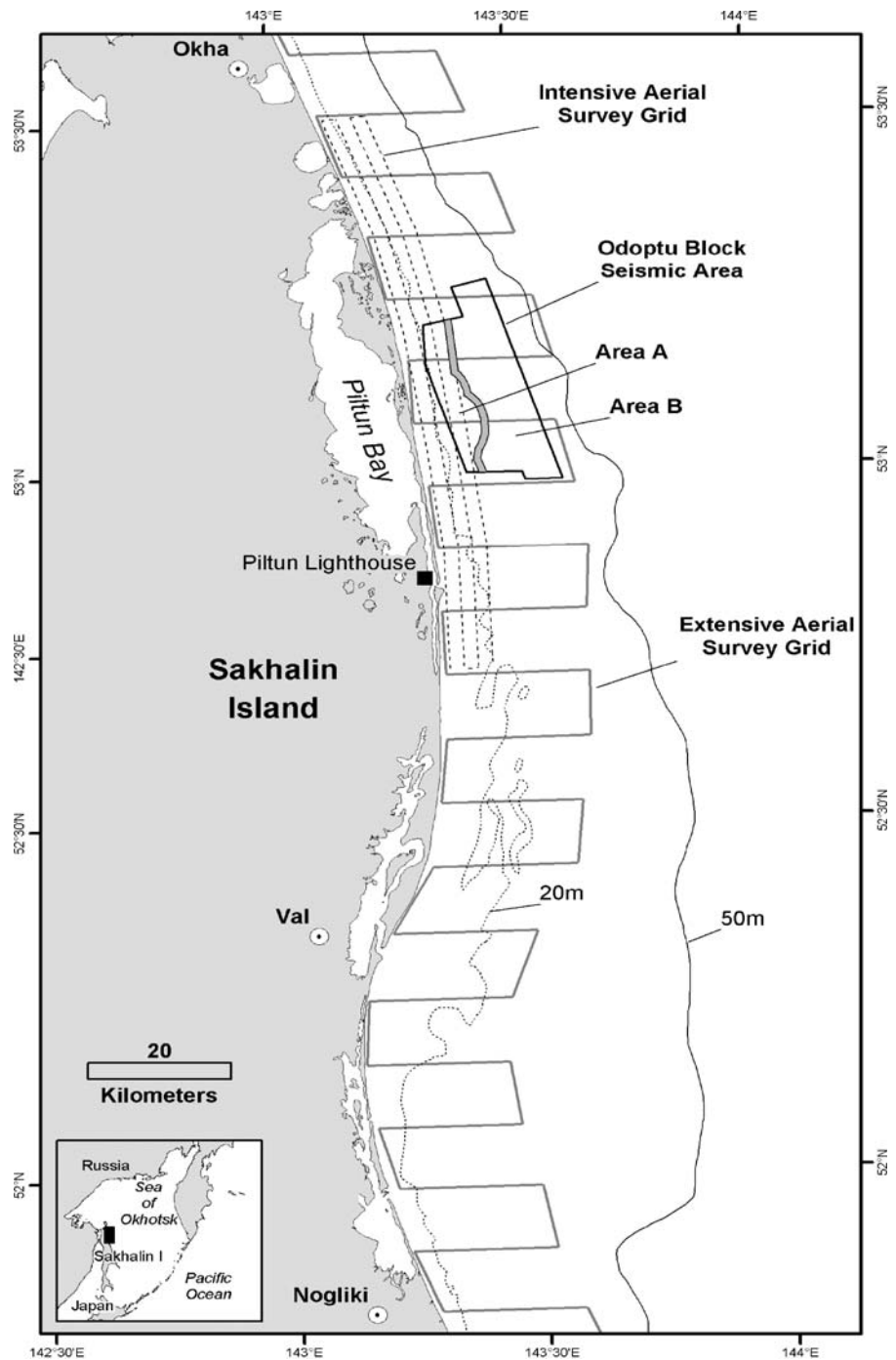
Previous observations of western gray whale activity

In the two years preceding the 2001 seismic survey, feeding western gray whales were predominantly

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Fig. 1 Intensive and extensive aerial survey grids, and subdivisions of the Odoptu seismic block relative to the 20 m isobath offshore from Piltun Bay, Sakhalin Island, Russia, 2001. The band dividing area A and area B represents the 4 or 5 km outer boundary of the feeding buffer (see Johnson et al. 2007)



sighted in a localized area near the mouth of Piltun Bay and northward along the northeast Sakhalin coast (Sobolevsky 2000, 2001). Over 95% of all gray whale observations in this area were located shoreward of the 20 m water depth contour (Fig. 2). Because of this localized distribution near the Odoptu

seismic survey area, it was necessary to design a seismic noise mitigation strategy that would reduce impacts on the feeding activity of the whales.

This paper describes the Odoptu seismic program and the objectives, methods, rationale, and effectiveness of the acoustic mitigation and monitoring

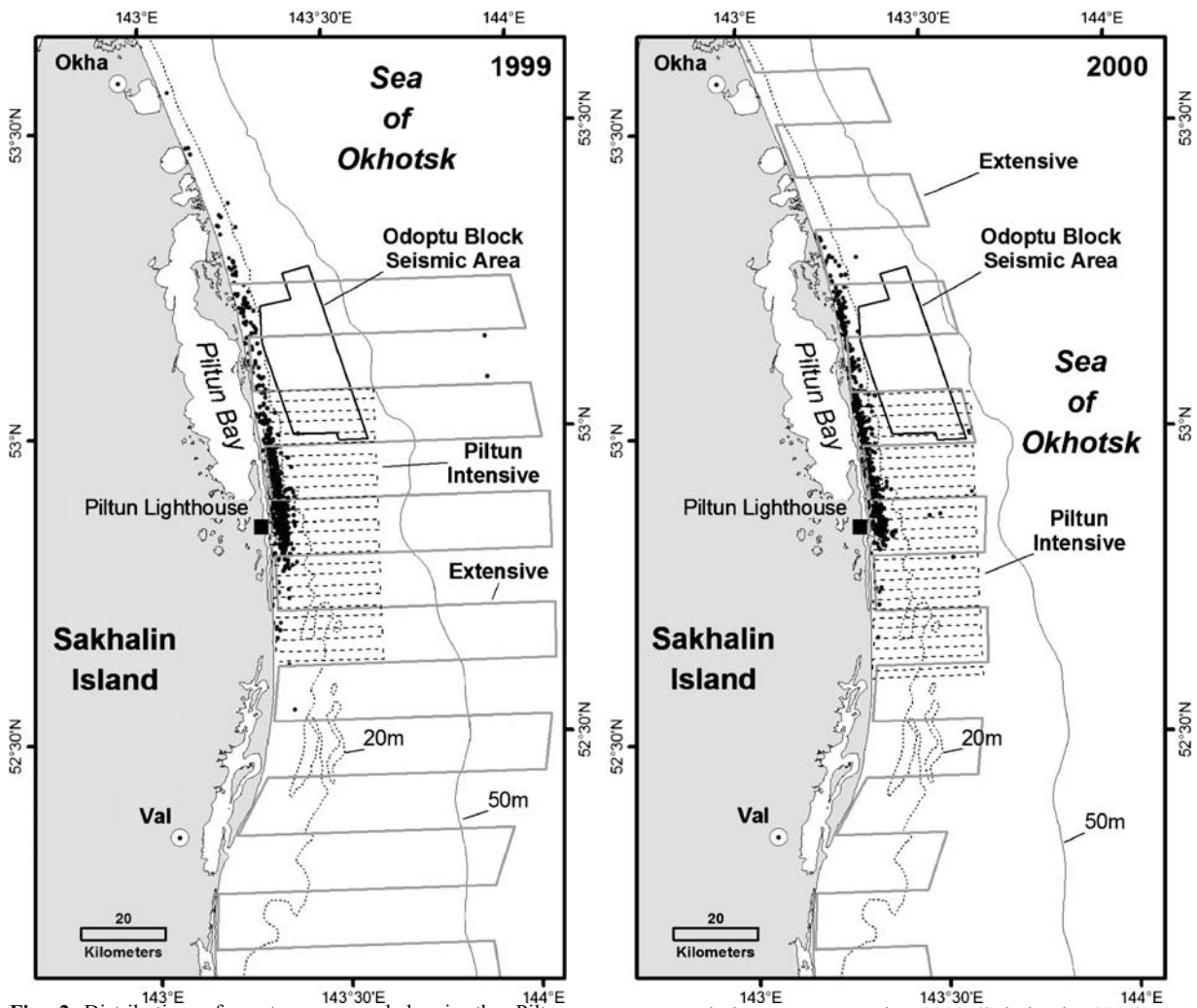


Fig. 2 Distribution of western gray whales in the Piltun feeding area, Sakhalin Island, Russia, as determined from systematic aerial (helicopter) surveys conducted during 1999–2000. Survey effort was similar in both years: 13 surveys during July–November 1999 (Sobolevsky 2000) and 14

surveys during June–November 2000 (Sobolevsky 2001). An additional coastal transect, located approximately 2 km seaward of and parallel to the Sakhalin coastline from approximately 52°40'N to 53°30'N was also surveyed during each aerial survey in 1999 and 2000

program adopted by ENL to reduce impacts of the seismic survey on the feeding activity of western gray whales.

Known reactions of gray whales to seismic survey noise

It has been commonly assumed that baleen whales would not suffer permanent hearing effects at noise levels below 180 dB_{rms} re 1 μPa (Richardson et al. 1995). However, previous studies indicated that behavior could be affected at significantly lower

sound intensities than those causing hearing or other physical damage (Richardson et al. 1999).

Previous behavioral studies conducted in association with seismic experiments (Malme et al. 1983, 1984, 1986, 1988; Malme and Miles 1985) have provided the best information available on the effects of seismic surveys on gray whales. An overview of these and other studies is given in sections 9.7 and 9.8 of *Marine Mammals and Noise* (Richardson et al. 1995). These studies included experiments in the Bering Sea on feeding gray whales and off California on migrating gray whales. These studies indicated that

10% of the gray whales ceased feeding and were displaced when the received impulsive sound levels generated by a seismic vessel were greater than 163–164 dB_{rms} re 1 μPa as measured in the water column. For feeding gray whales, the noise threshold below which 90% of gray whales were not displaced by seismic air gun noise was 164 dB_{rms} re 1 μPa, and for migrating whales it was 163 dB_{rms} re 1 μPa. Most displaced whales in the studies of feeding gray whales in the Bering Sea returned to their original location and resumed feeding within 1 hour after the seismic source was shut down (Malme et al. 1986). These studies found the sound to be attenuated to 163 dB_{rms} re 1 μPa at a distance of 4 to 5 km from the seismic vessel. We acknowledge that for some of these previous studies only a single air gun was used, and the distance to the whales was short, therefore the gray whales could have been reacting to visual rather than acoustic cues. For the purposes of our mitigation program, a received level of 163 dB_{rms} re 1 μPa at a distance of 4 to 5 km was considered a conservative threshold that would mitigate both sound and visual cues.

Acoustic mitigation and monitoring goals

The primary goal for the acoustic mitigation and monitoring programs associated with the Odoptu seismic survey was to reduce the impact of underwater noise generated by the seismic survey on the feeding activity of western gray whales. By protecting the feeding activity of the whales, the whales would also be protected from any direct physical harm (e.g., direct impacts to hearing) from the seismic survey. This paper describes the key measures implemented by ENL to eliminate or reduce noise impacts on feeding western gray whales. Johnson et al. (2007) describes in more detail the rationale and design of the mitigation and monitoring programs conducted during the Odoptu seismic survey.

Acoustic mitigation plan

The localized depth distribution of gray whales allowed ENL to design an effective mitigation strategy. The key to this mitigation strategy was to

determine a buffer distance between feeding gray whales and the operating seismic vessel that would not disrupt the feeding activity of the whales. ENL conducted an acoustic calibration study prior to the start of the seismic survey and determined that the received sound levels at the 20 m contour dropped below 163 dB_{rms} re 1 μPa at a distance of 4 km. The monitoring program would ensure that the seismic vessel would stay at or beyond the buffer distance from feeding gray whales (Johnson et al. 2007). Since the whales were known to feed primarily shoreward of the 20 m water depth contour, the area designated for seismic activity was divided into two areas to facilitate maintenance of the buffer zone throughout the seismic survey. Area A was the area within the Odoptu seismic block extending 4 or 5 km seaward from the 20 m isobath. The seaward edge of area A represents the buffer distance beyond which sound from the seismic survey would attenuate below the 163 dB_{rms} re 1 μPa threshold at the edge of the feeding area. Seismic surveys in area A (Fig. 1) were restricted to daylight hours and periods of unrestricted visibility. With the help of aerial and vessel-based surveillance, shooting of seismic lines in area A was timed and conducted to avoid operations within 4 or 5 km from all observed western gray whales. Area B was the area within the Odoptu seismic block boundary that was 4–5 km or greater seaward of the 20 m isobath. Therefore, seismic sound transmission from area B into the Piltun feeding area would always be below the target threshold of 163 dB_{rms} re 1 μPa.

Using aerial and vessel-based survey data, acquisition in area A was carefully planned to maintain the established buffer distances from all observed whales (Johnson et al. 2007). While shooting in area A, continuous observations were made by vessel-based marine mammal observers (MMOs) aboard the seismic vessel *M/V Nordic Explorer* and two support vessels, *M/V Rubin* and *M/V Atlas*. Each MMO observer group was equipped with satellite phones to relay any concerns if whales appeared to be affected by the seismic activity. Operational plans called for the number of operating air guns to be reduced if a whale came within the applicable buffer distance of the seismic vessel. In practice, if a whale was sighted within the respective buffer distance, all of the air

guns were shut down. There were five shut downs for gray whales observed within the 4 to 5 km buffer in area A (Meier et al. 2002). The MMOs enforced the same buffer distances (1 km and 4–5 km) while the *Nordic Explorer* was actively shooting in area B. However, because few gray whales (and no other endangered whales) had been previously documented in area B (Figs. 1 and 2), shooting in area B was not restricted to daylight hours or periods of unrestricted visibility (Johnson et al. 2007).

Acoustic recording and processing equipment

Two acoustic recording systems were used to record acoustic data for the 2001 field program. This section describes their calibration and operational deployment. It also includes a description of the tools and methodology for analyzing the data.

Acoustical sonobuoy

Individually deployed autonomous sonobuoys were used to measure acoustic signals in the frequency band from 10 to 5 kHz and to transmit them to a shore station. These systems were placed throughout the survey area to most effectively monitor the seismic signal. Figure 3 shows the major components of a sonobuoy and how the sonobuoy and hydrophone were anchored when deployed at sea.

Practical experience has shown that at shallow deployment depths (10–20 m), wave action can create significant noise at the hydrophone. Movement of the sonobuoy due to surface waves is mechanically

conducted down the cable to the hydrophone, where this mechanical movement is recorded as acoustic noise. To reduce this noise the hydrophone is deployed 70 m from the anchor, thus reducing the mechanical coupling between the surface buoy and the hydrophone.

The subsea component of the system consists of a hydrophone, pre-amplifier and filter. The hydrophone is deployed inside a pyramid shaped wire frame and attached by rubber bands to the corners of the frame, isolating it to the greatest extent possible from the sea floor. The pre-amplifier and filter are housed in a small cylinder close to the hydrophone. The pre-amplifier amplifies the signal prior to transmission along the 100 m connector to the sonobuoy. By amplifying the signal as close as possible to the hydrophone the signal level is maximized relative to any noise picked up in the cable. The filter amplifies the low frequency components of the signal, compensating for the lower low frequency response of the pre-amplifier. This equalization of amplitudes across the frequency band optimizes the use of the dynamic range of the radio receivers and transmitters.

The signal travels through the cable to the sonobuoy. At the sonobuoy it is low-pass filtered (cut-off frequency 5 kHz), converted into an ultra high frequency (UHF) band frequency modulated (FM) radio signal, and transmitted to the shore station by FM transmitter. The sonobuoy is powered by an external battery pack that can be changed at sea.

The frequency dependent hydrophone sensitivity over the frequency band 3–630 Hz was measured in an acoustical calibration chamber at SMCHM (State Meteorological Center of Hydro-acoustical Measurements), located at RSSRIPRTM (Russian State Scientific Research Institute of Physical Radio Technical Measurements) in Moscow. The sensitivity measurements have a relative error of less than 1.5 dB (95% probability), including the approximately 1 dB error associated with estimation of absolute pressure for the calibration of the reference hydrophone. A second calibration was made in the Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (POI FEB RAS), for frequencies greater than 700 Hz.

Radio receivers at the two coastal acoustic stations (Piltun lighthouse and an acoustics camp approximately

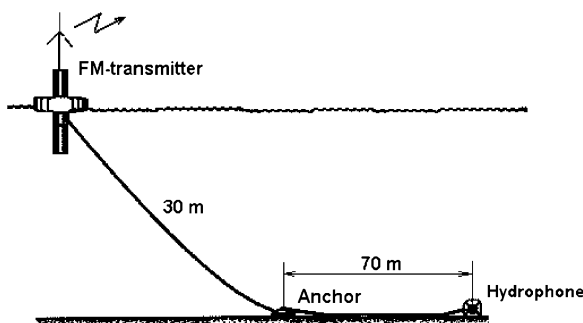


Fig. 3 Diagram showing the components of the sonobuoy when deployed at sea

20 km north of the Piltun lighthouse, Fig. 1) received the radio-telemetry signals transmitted by the sonobuoys. The output from these receivers was filtered to correct for the filter applied to the low frequencies prior to transmission. This inverse filter made the response of the system flat across the spectrum above 10 Hz; frequencies below 10 Hz were not amplified to avoid preferentially amplifying the noise. This output was input to one channel of a multi-channel amplifying, filtering and digitizing unit prior to storage on a computer. The frequency–amplitude characteristics of the six (post-radio) filters and the pre-amplifier filters were determined. The variation in the transfer functions of the six post-radio filters did not exceed 0.2 dB and of the six pre-amplifier filters, 0.5 dB.

Recording system for acoustic measurements from the vessel *M/V Grif*

A two channel digital audio tape (DAT) recorder was used to record acoustic signals from hydrophones deployed by the vessel *M/V Grif*. The system was constructed to record acoustic signals from two hydrophones deployed 10 m vertically apart. While acoustic data were being recorded, the vessel's depth finder was used to maintain a distance of 1 m between the bottom and the deeper hydrophone (in low current conditions). The horizontal displacement of the cable was monitored visually from the vessel. If the displacement was significant (due to strong currents), the data were disregarded. To reduce the mechanical noise generated by the vibration of the cable and motion of the vessel, the hydrophones were attached to the cables by rubber bands. Pre-amplifiers conditioned the signal from both hydrophones. To reduce leakage between the hydrophone power and signal lines they had separate four-wire shielded cables. The pre-amplifiers were powered by external batteries and the digital tape recorder by its own internal battery.

As with the sonobuoy, the output signals from both hydrophones were amplified, filtered and then transmitted through the cable to the input of a two-channel DAT recorder. The sample rate of the tape recorder's analog-to-digital converter was 48 kHz. During the initial testing of the recorder, trimpots were adjusted to ensure that the input-output relationship of the recorder was unity; this relationship was maintained for all future recordings and calibrations.

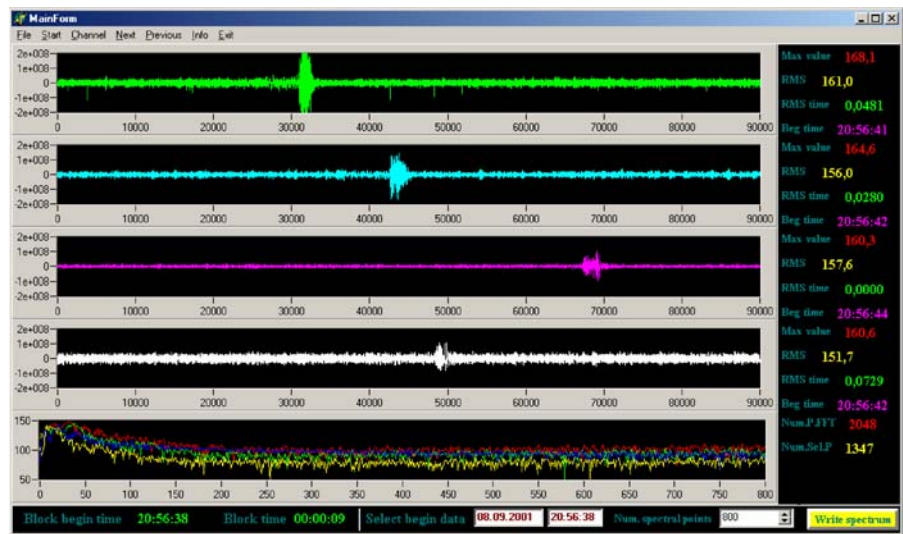
Calibration of the digital tape recorder included determination of the amplitude-frequency characteristics of each channel and confirmation of the dynamic range, cross-feed linearity and transfer function for the recorder. The differential deviation in the input/output frequency-amplitude relationships of both channels in the frequency band from 20 Hz to 20 kHz did not exceed 0.5 dB. This relationship can reach -3 dB at a frequency of 3.25 Hz. The deviation of each channels' input/output relationship was less than ± 0.4 dB in the frequency band from 80 to 630 Hz. These inaccuracies in the preliminary adjustment of the tape recorder were accurately calibrated and corrected digitally during data analyses. Instrument tests showed that the signal/noise ratio at the minimum input signal level was 9 to 12 dB and that in the frequency band from 3 to 200 Hz the values of cross-feed were below the lower noise threshold of the DAT recorder.

Data storage and processing

A recording unit (based on National Instruments equipment housed in a power chassis) was built for the storage and pre-processing of the acoustic data. The output from each active radio receiver was connected to an eight channel terminal block and input to a low pass filter module containing eight pre-amplifiers and Bessel filters. These filters were used to limit the frequency range of the input signal to within the Nyquist frequency for the sample rate of the analog to digital converter (ADC). The analog data from all active receivers and their filters was then simultaneously digitized by a multi-channel gain ranging 16 bit ADC data acquisition card housed in a notebook computer and stored on the hard drive of the computer. At the end of a recording period a CD writer was used to archive the data to CD from the hard drive of the computer. This unit filtered, digitized, stored and displayed data for up to eight separate channels. System parameters, including the name, water depth, and coordinates of the sonobuoy deployment locations are also stored in an initialization file.

The data were processed in 6.5 s blocks. The program looked for an impulse within this block and if registered, calculated rms, rms time (time period over which rms of pulse was calculated) and peak amplitude of the pulse. The data for each channel

Fig. 4 Main display window for the recording computer



were plotted separately in dB re 1 μPa , with the pulse data shown on the right (Fig. 4).

System calibration and cross-calibration error analysis

Previous work (Malme et al. 1983, 1984, 1986, 1988; Malme and Miles 1985) described the effect of seismic sound energy on the feeding and behavior of gray whales. In order to compare the acoustic measurements made in the Odoptu area to this previous work, the data had to be calibrated to an absolute standard pressure. The hydrophones were manufactured with nominal sensitivities of 180 and 300 $\mu\text{V}/\text{Pa}$, and the gains were set in the field by the variation of trimpots. It was possible, however, that the pre-amplifiers and filters had a response that was different from their nominal response. In order to confirm the calibration of the equipment, a field cross-calibration was conducted.

The hydrophones, pre-amplifiers, filters and digital tape recorders were calibrated at SMCHM located at RSSRIPRTM (Moscow) as described earlier. The sensitivities of the hydrophones were determined by comparative calibration against a reference hydrophone in an acoustic calibration chamber and had a relative error of less than 1.5 dB (95% probability). On completion of these calibrations a further cross calibration was conducted by POI to determine the absolute calibration errors. The maximum absolute error from the mean for any remaining sonobuoy was

<1.43 dB, which was within the expected relative error limits for the equipment, thus confirming the absolute calibration of the data.

Software for acoustic data analysis

Software was specifically designed for the real-time experimental data processing required for this work and was modified throughout the field program to more efficiently evaluate the acoustic data. The main features of the acoustic impulses (peak, rms, and rms window time) were computed for all the data. Figure 4 depicts the main display window of the program. Every channel was displayed in a separate window and in a different color. The pulse data (peak, rms, and time_{rms}) were displayed in a window to the right of the main data window. Control options and time information for the data were displayed at the bottom of the screen.

Methodology for analyzing the acoustical data

For the real-time system every impulse was detected using an event trigger. The computer automatically estimated the beginning (N_1) and end (N_2) of each impulse (Fig. 5). The beginning estimate was satisfactory if the noise levels were low, however the end was more ambiguous because of the low signal to noise at the end of the impulse. The previously accepted procedure for rms calculations was to compute

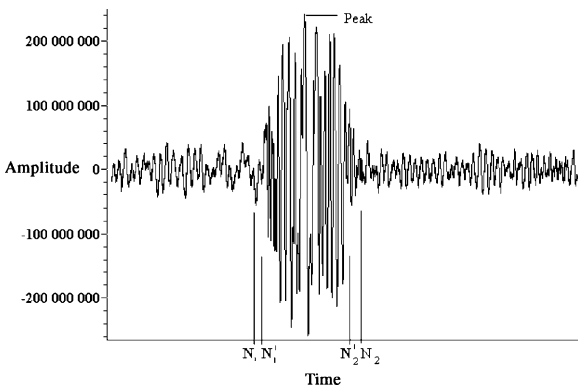


Fig. 5 Seismic impulse showing the manually selected (N_1 , N_2) and computed (N'_1 , N'_2) limits of the rms calculation. Time selections N_1 and N_2 have been shown away from the start and end of the impulse for illustration

the total energy between the automatic pick times (N_1 and N_2), then compute two new times N'_1 and N'_2 , which corresponded to 5 and 95% of the total sound energy. These new times were used as the time limits for rms calculations, stabilizing rms calculations and making them less sensitive to pick errors. The peak value was computed by determining the maximum absolute value present between times N'_1 and N'_2 . This value was logged in dB re 1 μPa . The rms value was also computed between times N'_1 and N'_2 using the following equation:

$$\text{rms} = 20 \log_{10} \left[\frac{1}{N} \left[\sum_{i=N'_1}^{N'_2} X_i^2 \right] \right]^{\frac{1}{2}} \tag{1}$$

where:

- X_i is the amplitude of input signal ($\mu\text{V}/\text{Pa}$),
- N is $N'_2 - N'_1$,

The time in seconds of the extent of the pulse was also computed using:

$$\text{Time}_{\text{rms}} = \Delta t (N'_2 - N'_1) \tag{2}$$

where:

Δt is the sample interval (s)

Most of the data in this study were cosine filtered with a filter length $<10\%$ of the distance from source to receiver. The theory behind the use of cosine

filtering is that the signal level is unlikely to change significantly over short distances, but the noise level can change over short distances. Also any multipathing can cause short-term variations in the signal level. A short rolling filter will therefore have little effect on the signal estimation, but it can significantly reduce the impact of the variation in the noise on the signal estimate (Harrison and Harrison 1995). A nine-point cosine filter with a length of 150 m was applied to all acquisition data in this study. This cosine window is a simplified approximation of the Gaussian window used by Harrison and Harrison (1995). Since the western gray whale buffer distance was 4–5 km (Johnson et al. 2007), the filter length would never be greater than 4% of the overall range; the range filtering applied was therefore considered conservative. The direction of shooting in this study was broadside to the receivers and the closest point of approach from source to receiver was almost constant. The range smoothing effect of the filter on the signal was therefore very small. For data acquired for the buffer distance determination (see “Acoustic calibration of the buffer distance” below), where the array sizes and ranges were lower, five or seven-point cosine filters were used.

Temporal and spectral methods for estimating rms with varying signal/noise levels

According to Parseval’s theorem, the time average energy of an acoustic pulse calculated using the following formulation:

$$\frac{1}{T} \int_0^T |A(t)|^2 dt \tag{3}$$

Where:

- T is time of the pulse (s),
- $A(t)$ is the amplitude of the signal at time t (μPa),
- t is the integration variable—time in the pulse (s),

is equal to the sum of squares of the absolute spectral amplitude values (S_k):

$$\sum_{k=0}^{N-1} |S_k|^2 \text{ where } : S_k = \frac{1}{T} \int_0^T A(t) e^{-i\omega_k t} dt \tag{4}$$

Thus:

$$\begin{aligned} \text{rms} &= 20 \log \left(\frac{1}{N\Delta t} \sum_{k=0}^N |A_k|^2 \right)^{\frac{1}{2}} \\ &= 10 \log \left(\frac{1}{N\Delta t} \sum_{k=0}^N |A_k|^2 \right) \end{aligned} \tag{5}$$

$$\begin{aligned} \text{rms} &= 10 \log \left(\frac{1}{N\Delta t} \sum_{k=0}^N |A_k|^2 \right) \\ &= 10 \log \left(\sum_{k=0}^{N-1} |S_k|^2 \right) \text{ (dB re } 1 \mu\text{Pa)} \end{aligned} \tag{6}$$

If the signal to noise level is high the rms estimate of a pulse using either method makes an accurate estimate of the signal level in a pulse. This is shown in Fig. 6 where the temporal and spectral rms estimates are equivalent to the third decimal place.

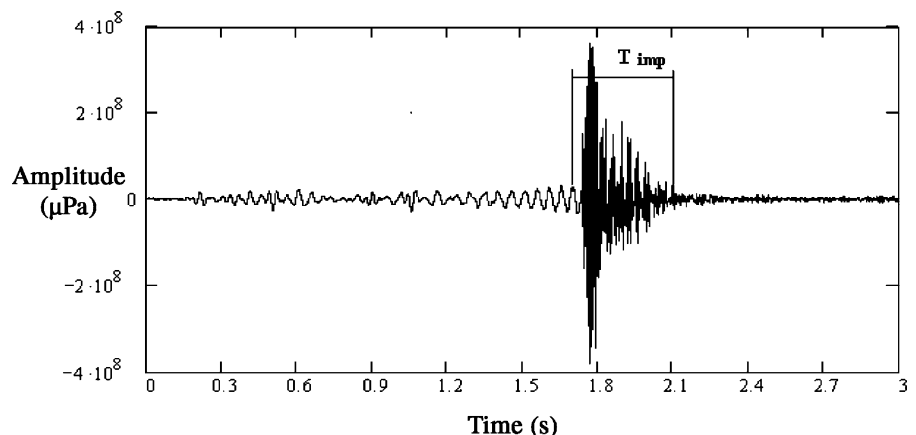
Figure 7 shows signal and noise spectra (the ‘noise’ spectrum was recorded at a time when the *Nordic Explorer* was not shooting) recorded in 25 m of water by sonobuoy T.9; these data have a low S/N ratio.

Figure 8 shows that for frequencies below 80 Hz and above 600 Hz the spectral density of the signal is

only slightly greater than that of the noise. In these low S/N cases the rms level of the signal in the pulse can be overestimated because of addition of noise at low frequencies; this is illustrated in Fig. 8. If the integral is calculated for the whole frequency band the temporal and spectral rms estimates will be equal. However, if the bandwidth is limited to the zone where the signal is stronger than noise, the rms spectral estimate will be 2.6 dB less than that calculated with time integral. The time domain estimate (rms, Eq. 1) was used for the 2001 monitoring program and in this paper.

During the field program the signal/noise ratio varied dramatically. Automatic detection of the beginning and end of an impulse was therefore very difficult. The start could normally be picked fairly accurately, but the end of the impulse could not be estimated effectively, and this pulse length estimation error could potentially lead to dramatic variations in rms estimation. Thus, the beginning and end of the pulses were manually picked, which greatly increased data processing time. All the acoustic data recorded during the Odoptu 3D seismic program was written to CD and brought to POI (Vladivostok) for analysis. Every impulse was re-picked with an operator manually selecting the beginning (N_1) and end times (N_2) of each impulse, and recomputing the peak, rms, $\text{rms}_{\text{filtered}}$ and time_{rms} values (Borisov et al. 2002).

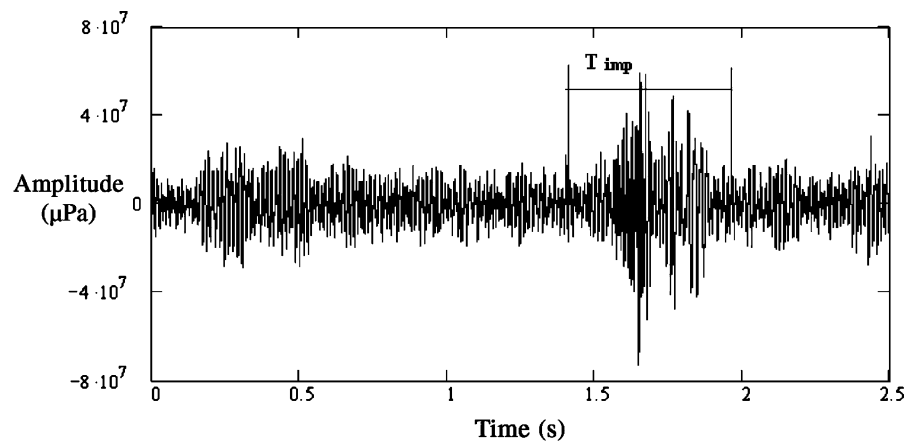
Fig. 6 Temporal and spectral methods for estimating rms



$$\text{RMS1} = 10 \cdot \log \left[\frac{1}{N} \sum_{k=0}^{N-1} (A_k)^2 \right] \qquad \text{RMS1} = 158.830294260444$$

$$\text{RMS2} = 10 \cdot \log \left[2 \cdot \left[\sum_{j=0}^{\frac{N}{2}-1} (|S_{Pj}|)^2 \right] \right] \qquad \text{RMS2} = 158.830453950987$$

Fig. 7 Spectral and temporal rms estimates. The frequency sampling in the spectral estimate ($\Delta f=2.44$ Hz) is such that summing between spectral indices of 33 and 410 is equivalent to summing between frequencies of 80.6 and 1001 Hz



$$\text{RMS1} := 10 \cdot \log \left[\frac{1}{N} \sum_{k=0}^{N-1} (A_k)^2 \right] \quad \text{RMS1} = 145.197062076286$$

$$\text{RMS2} := 10 \cdot \log \left[2 \cdot \sum_{j=33}^{410} (|S_{Pj}|)^2 \right] \quad \text{RMS2} = 142.582858365286$$

Calibration and monitoring the buffer distance

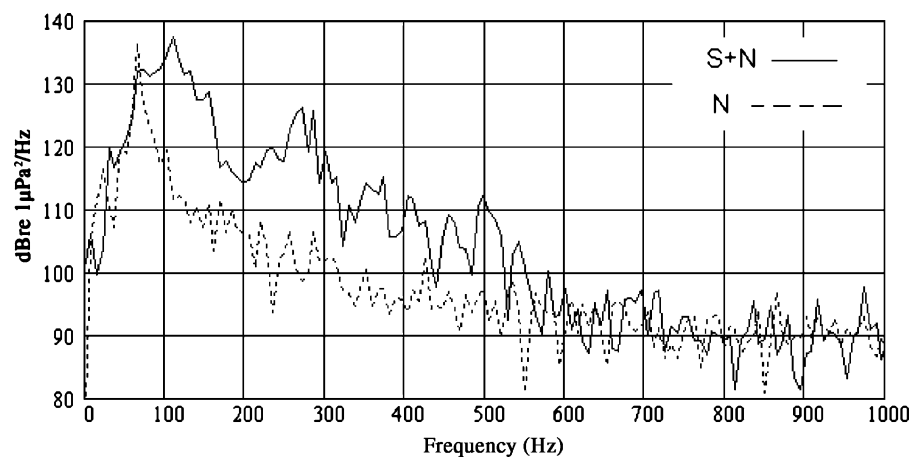
Acoustic calibration of the buffer distance

The 4–5 km buffer used for the Odoptu mitigation and monitoring program (Johnson et al. 2007) was determined through a series of acoustic experiments taken in conjunction with previous work on the effect of seismic acquisition on gray whales.

Previous experiments were conducted in the Bering Sea for feeding gray whales and off California

for migrating gray whales. These studies indicated that 10% of the gray whales modified their behavior when the received seismic sound levels were greater than 163–164 dB_{rms} re 1 μPa as measured in the water column (Malme et al. 1983, 1984, 1986, 1988; Malme and Miles 1985). ENL proposed to shoot a series of acoustic calibration lines to determine the distance at which the received sound levels (RL) would drop below the 163 dB_{rms} re 1 μPa level. The received sound level close to the sea floor at the 20 m bathymetry contour was monitored and analyzed to

Fig. 8 Signal and noise spectra for sonobuoy T.9



determine at what distance the transmission loss was sufficient to meet this criterion. This distance would then be used to determine the appropriate buffer distance for the Odoptu area. Previous studies indicated that this distance was expected to be 4 to 5 km; this distance range was used in the preliminary planning for the 2001 Odoptu seismic survey. However, the degree of underwater sound attenuation at different distances is dependent on a number of factors (e.g., water temperature and salinity, water and sub-bottom velocity, sub-bottom density) that can differ from area to area. Consideration of this fact, along with the potential behavioral modifications noted by Würsig et al. (1999) in the Piltun area in 1997, influenced the planning for the calibration study.

Hydrophone signals were continuously relayed to shore and the received acoustic levels were monitored and recorded. During the calibration, regular communication was maintained with the seismic vessel *Nordic Explorer* to facilitate a reduction in output or shutting down of the air guns as the target sound levels were approached.

At the beginning of the survey, the proposed seismic source was a 3,090 in.³ (50.6 l) G-gun array (Fig. 9).

This array has a ‘notional’ peak output level (vertically down, back calculated to 1 m) of 72.6 bar-m (257.2 dB_{peak} re 1 μPa; Fig. 10). It is important to note that ‘notional’ output is not a physical quantity, but rather a mathematical formulation of a point-source representation of the array, back-calculated to 1 m. In the far field the sound propagates as if it were generated by a single point source at the specified level. However, there is no physical point at which these nominal source levels are reached, actual near-field pressure is less due to array and divergence effects.

Acoustic calibration tests were conducted in the northern and southern part of the Odoptu 3D-survey area to calibrate the acoustic properties of the northeast Sakhalin shelf near the Odoptu block. Real-time acoustic measurements were made at the 20 m isobath to ensure that the test could be shut down if the noise levels became too high.

In order to accomplish the buffer distance calibration the received levels at the 20 m contour were monitored using a bottom referenced hydrophone and sonobuoy deployed at location T.4 (53°09′01.5″N, 143°19′01.4″E; Fig. 11) on the 20 m contour. The first shot line was acquired perpendicular to the coast (not

Fig. 9 Air gun (3,090 in.³) array diagram (full array) showing distances (m) between air guns

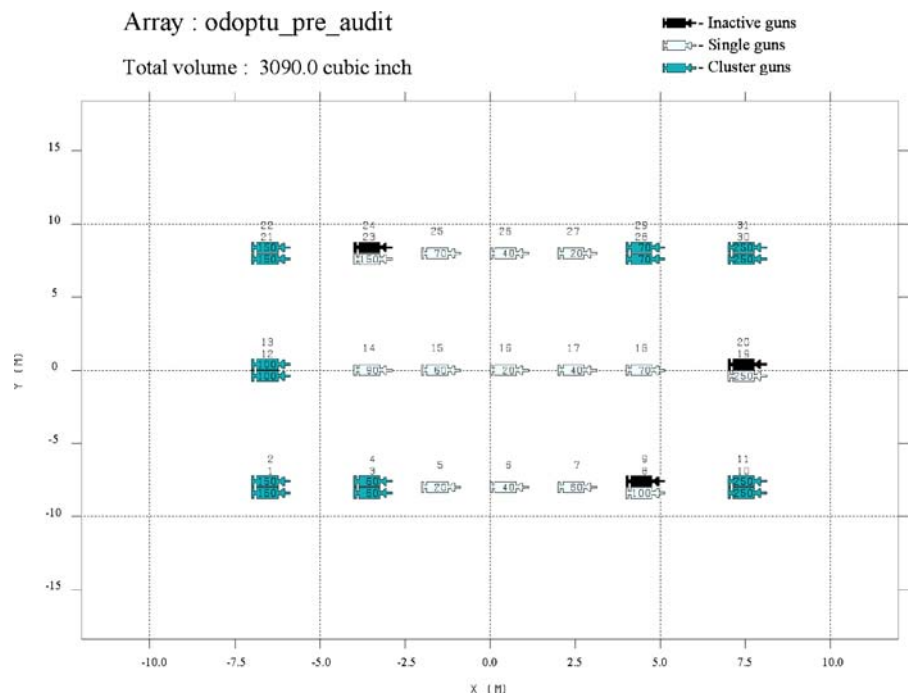
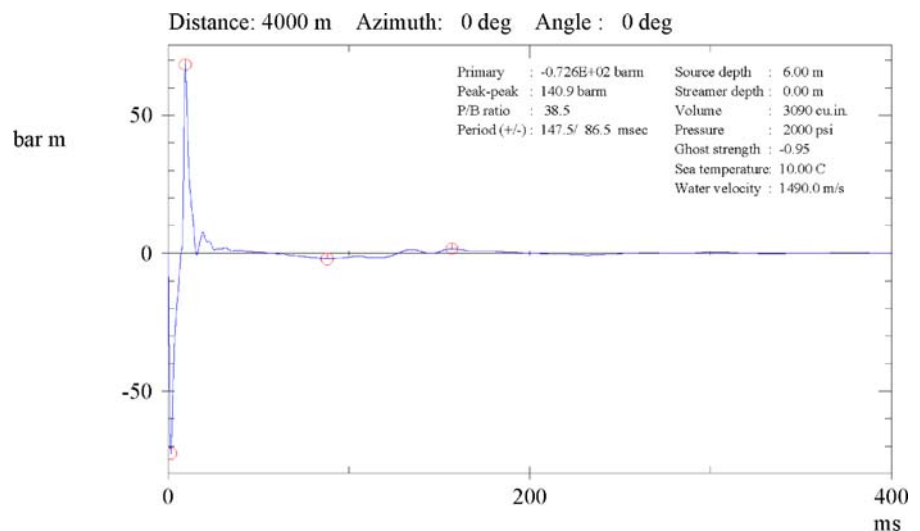


Fig. 10 Air gun (3,090 in.³) signature (full array)



shown) allowing an initial determination of the buffer zone distance to be made. A seismic source line was then acquired parallel to the shooting direction of the survey approximately 7 km offset from monitoring buoy T.4 and shot such that the range started at 11.4 km and at the closest point of approach reached 6.9 km (Fig. 11). The times shown are the start and end shooting times for the seismic survey line. The vessel alternately shot two sources 50 m apart; the shot point interval was 18.75 m. For each shot the location of the center of the active source was calculated. These calibration data were recorded at the acoustics camp located about 20 km north of Piltun Lighthouse. The range from the source to the sonobuoy and the time domain rms level of the received signal were calculated.

Figure 12 shows the received level (dB_{rms} re 1 μPa) at the 20 m contour (red), the data filtered with a nine-point cosine filter (azure), and the range from source to hydrophone (blue). Previous discussions with Charles I. Malme (Engineering and Scientific Services, personal communication) indicated that a cosine filter with a length of approximately 10% of the overall range could be used to smooth the results from acoustic models when the wavelength scale of the noise is greatly different from the wavelength scale of the data. In the calibration study, the change in range over the filter length was never more than 6% of the overall range. The 163 dB_{rms} re 1 μPa level is shown in green. Figure 12 shows that the cosine filtered rms received level at the 20 m contour never exceeded 163 dB_{rms} re 1 μPa.

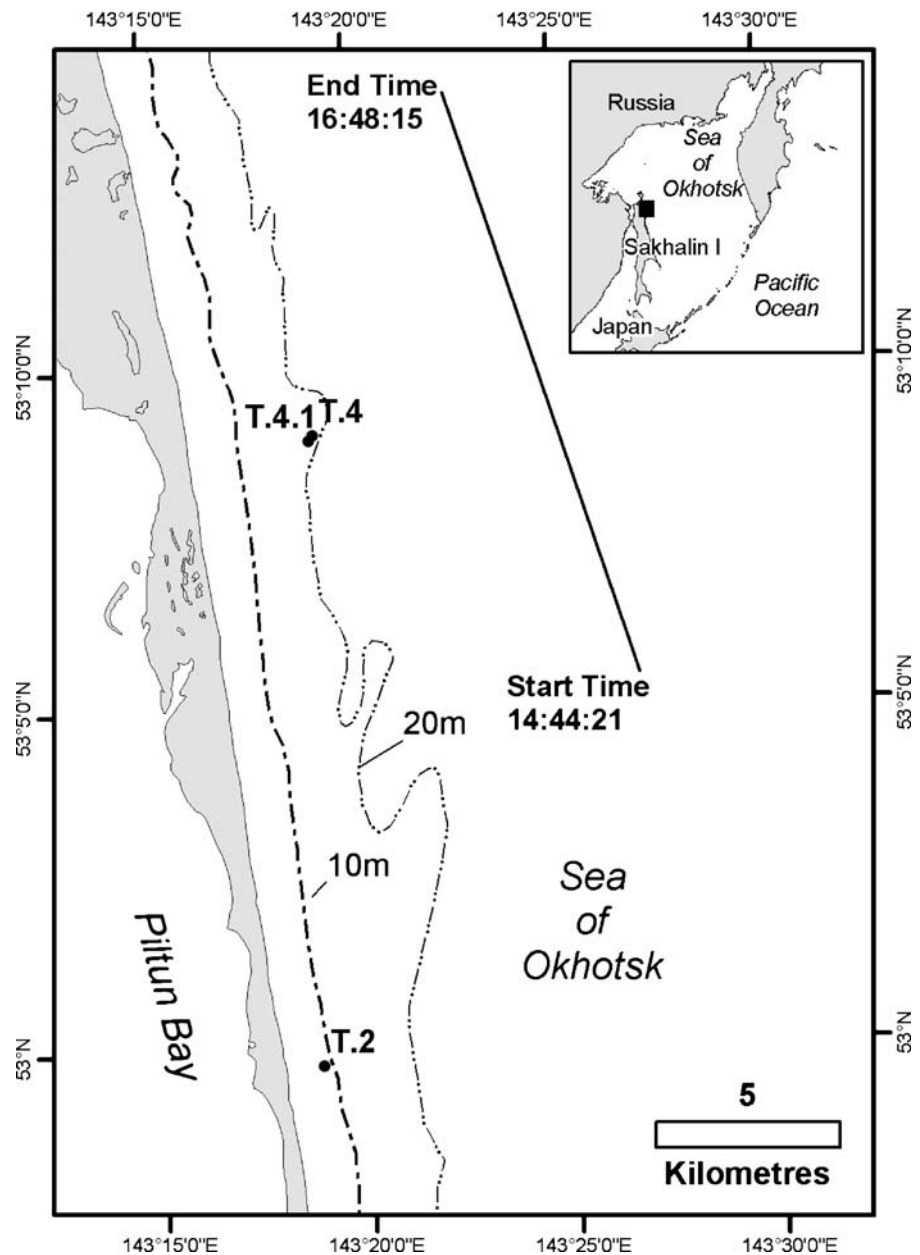
However the distance at which the seismic sound level of 163 dB_{rms} re 1 μPa was measured was considerably greater than that expected (7 km vs 4–5 km). It was recognized that a buffer distance of 7 km would be very difficult to implement and that maintaining a buffer of this magnitude could significantly impact the probability of conducting the seismic survey.

The only effective way to reduce the buffer distance to more manageable levels was to reduce the output amplitude of the seismic source array, thereby reducing the received levels at the 20 m depth contour. A modeling study indicated that the smaller 1,640 in.³ (26.9 l) gun array (Fig. 13) would result in approximately half the output amplitude of the 3,090 in.³ array. The 1,640 in.³ array was configured by turning off specific guns in the 3,090 in.³ array.

The 1,640 in.³ air-gun array has a 'notional' peak output level (vertically down and back calculated to 1 m) of 37.5 bar-m (251.5 dB_{peak} re 1 μPa; Fig. 14). A comparison of the two signatures is shown in Fig. 15. The output of the 1,640 in.³ array (red) was approximately half that of the 3,090 in.³ array (blue).

As part of the acoustic calibration, the degradation in seismic survey data quality caused by the output reduction was evaluated. It was determined that the 1,640 in.³ array would produce acceptable, though degraded, data quality. The possibility of double shooting critical seismic lines in order to double the fold of the seismic data where possible (i.e., considering proximity to western gray whales and weather conditions) was considered to partially offset this

Fig. 11 Position of acoustic sonobuoys T.2, T.4 and T.4.1 relative to the 20 m isobath and the trackline (showing start and end times) of the seismic vessel *Nordic Explorer* during air gun calibration tests on 5 August 2001. During this test the vessel at its closest point of approach was 6.9 km from sonobuoy T.4



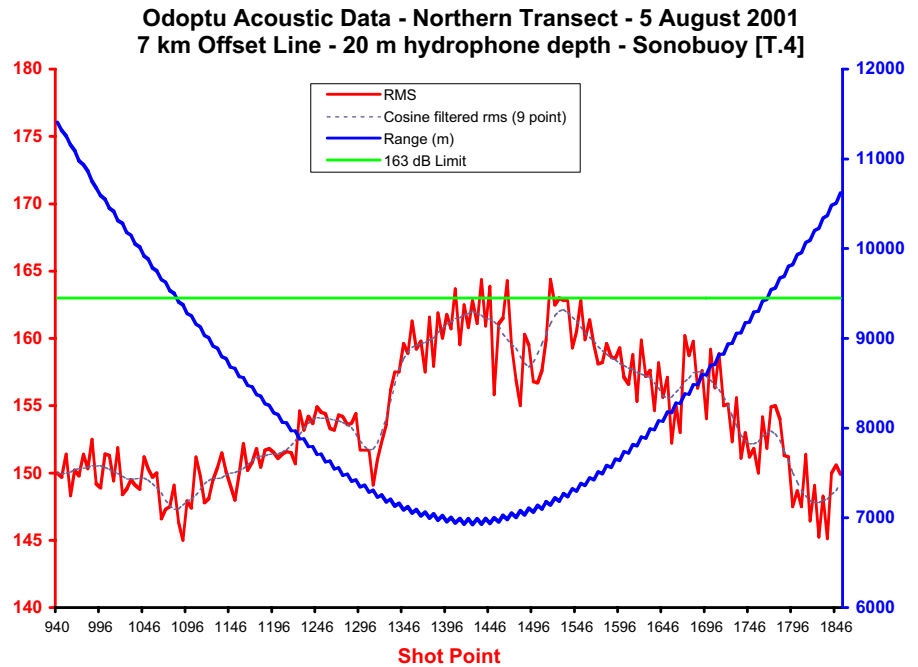
effect. However, it was recognized that this would increase the sound exposure duration for the gray whales, thus lines were not double shot during the survey.

To calibrate the buffer distance for the 1,640 in.³ array, a line was shot parallel to the shooting direction of the survey approximately 4 km offset from monitoring buoy T4 (Fig. 16). The line was shot such that the range started at 6.5 km and at the closest point of approach reached 3.8 km. Again the vessel used the production shot point interval and the range

from the source to the sonobuoy and the rms level of the received signal were calculated.

Figure 17 shows the received level in dB_{rms} re 1 μPa at the 20 m contour (red), the same data filtered with a five-point cosine filter (azure) and the range from the source to the hydrophone (blue). A five-point filter was chosen for this data as the ranges were smaller. The cosine filtered rms received level at the 20 m contour never exceeded 163 dB_{rms} re 1 μPa at ranges of 4 km or greater. The received level reached 163 dB_{rms} at a range of approximately 3.9 km [the

Fig. 12 Received level at the T.4 sonobuoy during the calibration experiment conducted on 5 August 2001 and shown in Fig. 11. During this test the vessel at its closest point of approach was approximately 7 km from sonobuoy T.4



X-axis is shot point]. These data indicate that the received level would not exceed 163 dB_{rms} re 1 μPa at distances of 4 km or greater. Therefore, a buffer distance of 4 km was determined to be sufficient to

protect against significant disturbance to feeding or migrating gray whales.

These initial calibration experiments showed that the received level (RL) of data from lines shot parallel

Fig. 13 Air gun (1,640 in.³) array diagram (half-amplitude array) showing distances (m) between air guns

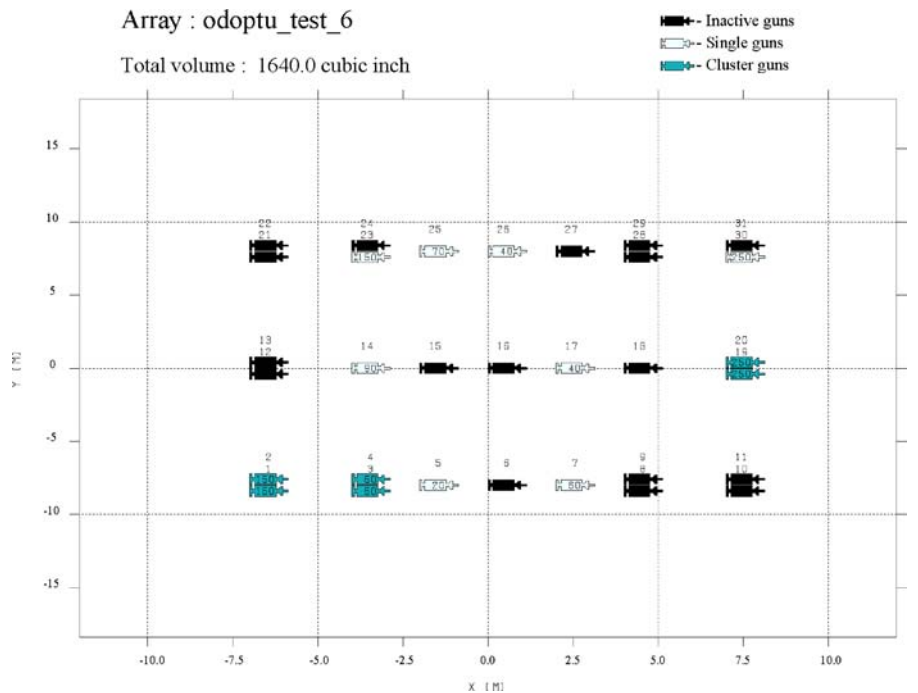
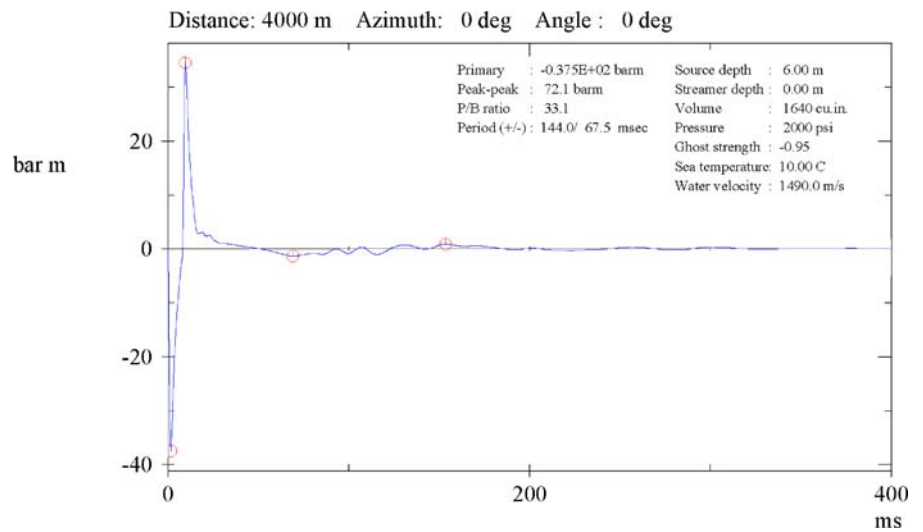


Fig. 14 Air gun (1,640 in.³) signature (half-amplitude array)



to the shore (e.g., broadside to the array) were higher than those from lines shot perpendicular to the shore (end-on to the array) for the same distance from the source. This unexpected phenomenon was investigated to ensure that the buffer zone was correctly calibrated. The peak spectral amplitudes of the data recorded at the 20 m contour were between 100–200 Hz (see Fig. 8). If the array response of the 1,640 in.³ array is analyzed it can be seen that there is a 6 dB difference in the crossline and inline response of the source array at these frequencies. Figure 18 shows the inline and

crossline array responses for frequencies from 0–500 Hz and takeoff angles from 0° (vertically down) to ±90° (horizontal). If the sub-horizontal propagation angles (±70–90°) are evaluated for frequencies from 100–250 Hz, the crossline response was 6 dB higher than the inline response at those frequencies. Since the 3D seismic program was to be shot parallel to the coast, the broadside test results (more conservative than end-on) were used to establish the buffer zone. Since the survey was designed to follow sail lines sub-parallel to the bathymetry, most

Fig. 15 Comparison of 1,640 in.³ (red) and 3,090 in.³ (blue) air gun signatures

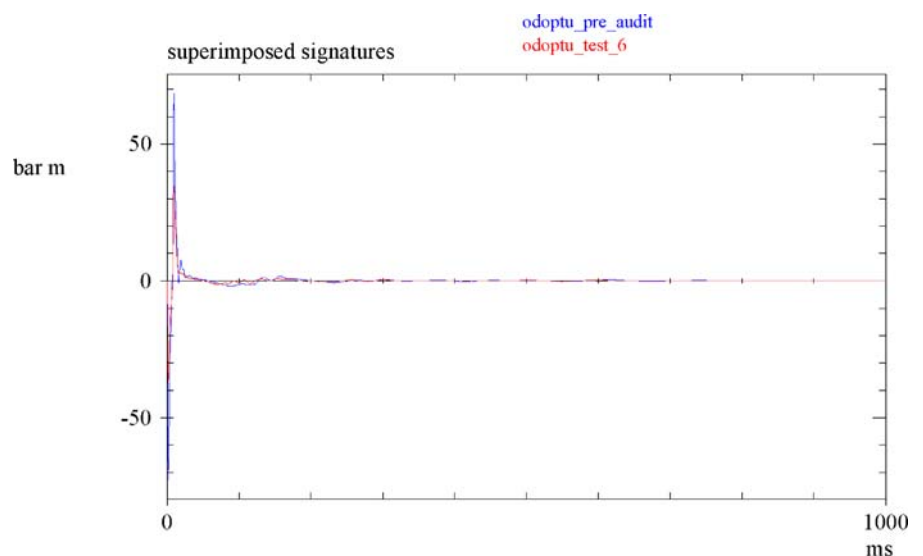


Fig. 16 Position of acoustic sonobuoys T.4 and T.4.2 relative to the 20 m isobath and the track line (showing start and end times) of the seismic vessel *Nordic Explorer* during air gun calibration tests on 12 August 2001. During this test the vessel at its closest point of approach was approximately 4 km from sonobuoy T.4

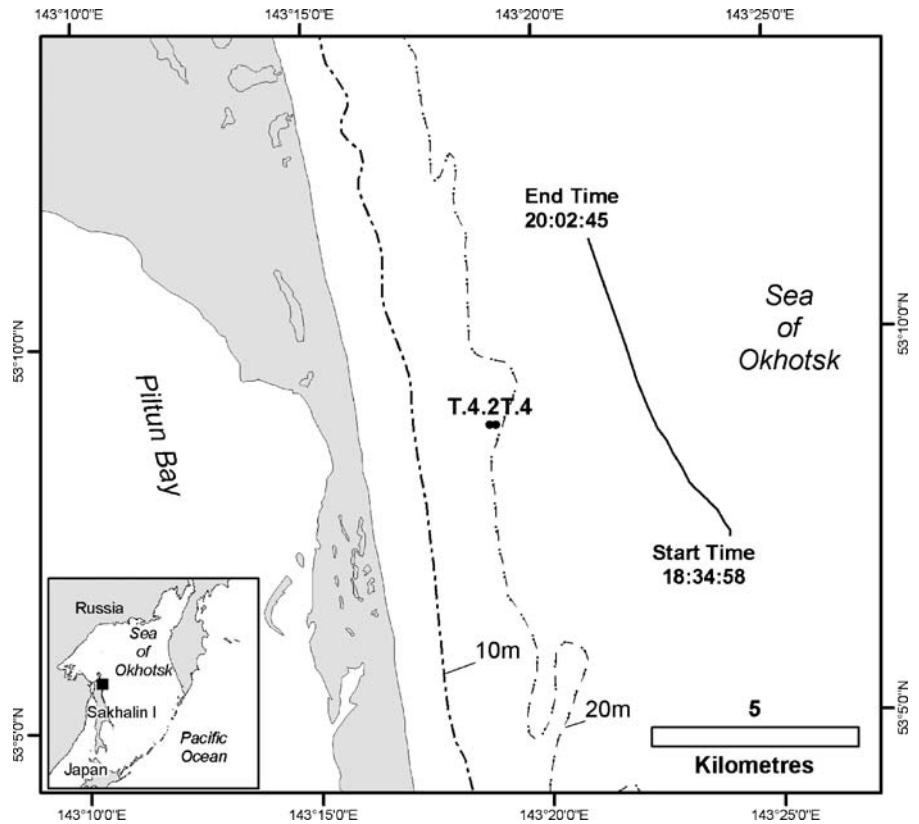


Fig. 17 Received level at the T4 sonobuoy during the calibration experiment acquired on 12 August 2001 and plotted in Fig. 16. During this test the vessel at its closest point of approach was approximately 4 km from sonobuoy T.4

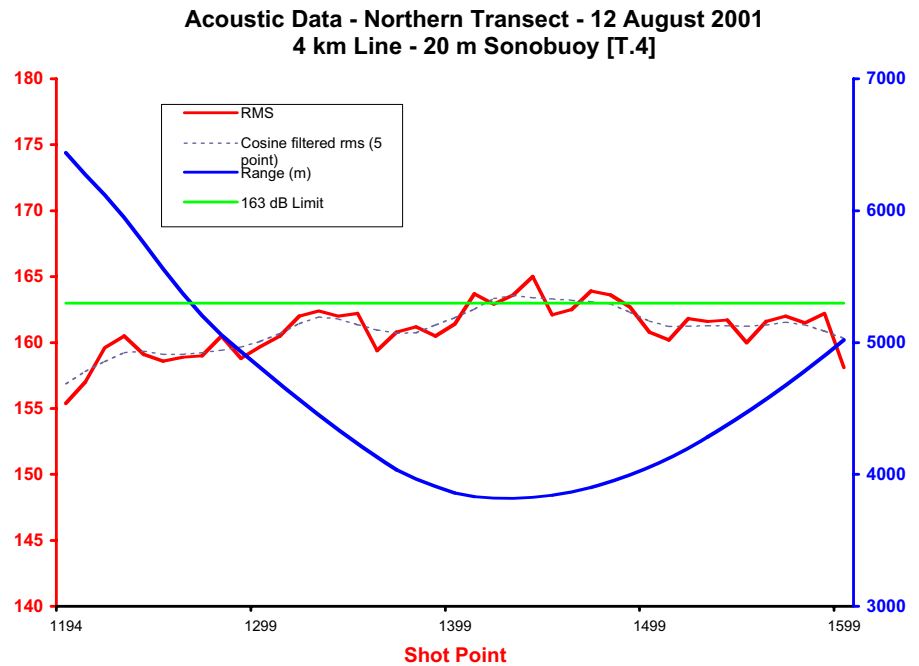
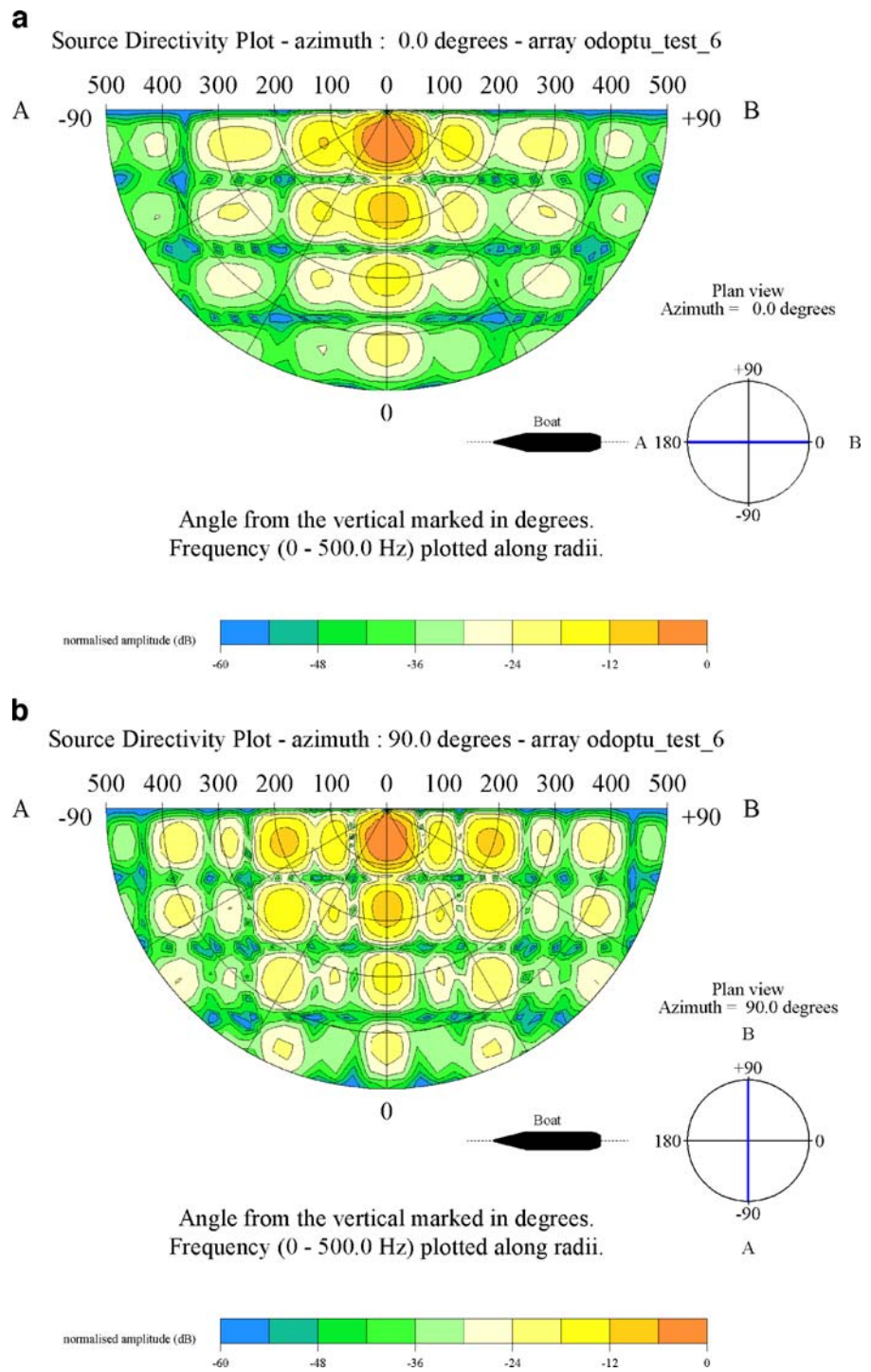


Fig. 18 a–b Array responses for the 1,640 in.³ air gun array. The responses show the variation in the output for the array with frequency (*top axis*) and takeoff angle (*radial lines*). **a** Inline array response (parallel to the sailing direction), **b** the crossline array response (perpendicular to the sailing direction)



of the exposure that would be experienced by the whales would be in a direction broadside to the vessel. This aspect was therefore chosen in determining the buffer distance.

With a level of 163 dB_{rms} re 1 μPa at 4 km, a received level of 180 dB_{rms} re 1 μPa would be reached at approximately 565 m (applying divergence {1/r}). The safety buffer distance of 1 km was therefore more

than sufficient to protect the hearing of other whales that inhabit the area (e.g., minke whales *Balaenoptera acutorostrata*).

Acoustic monitoring of the buffer zone

A comprehensive acoustic monitoring program was implemented to measure the received level of air gun sounds reaching the near shore waters

where gray whales feed. This program consisted of the deployment of sonobuoys along the outer edge of known gray whale feeding areas. To monitor the effectiveness of the 4 km buffer, sonobuoys were deployed at six locations along the 20 m contour and monitored during acquisition of the zone B lines closest to the buffer zone (lines S012163, 2175, and 2187). Monitoring confirmed that the received sound level at the 20 m contour

Fig. 19 Locations of the six sonobuoys (T.7 through T.12) deployed during acoustic monitoring of a line from the Odoptu seismic survey (also shown) on 8 September 2001. Also shown is the 20 m isobath and the start and end times of the acquisition of the seismic line. This was the closest zone B seismic survey line to zone A

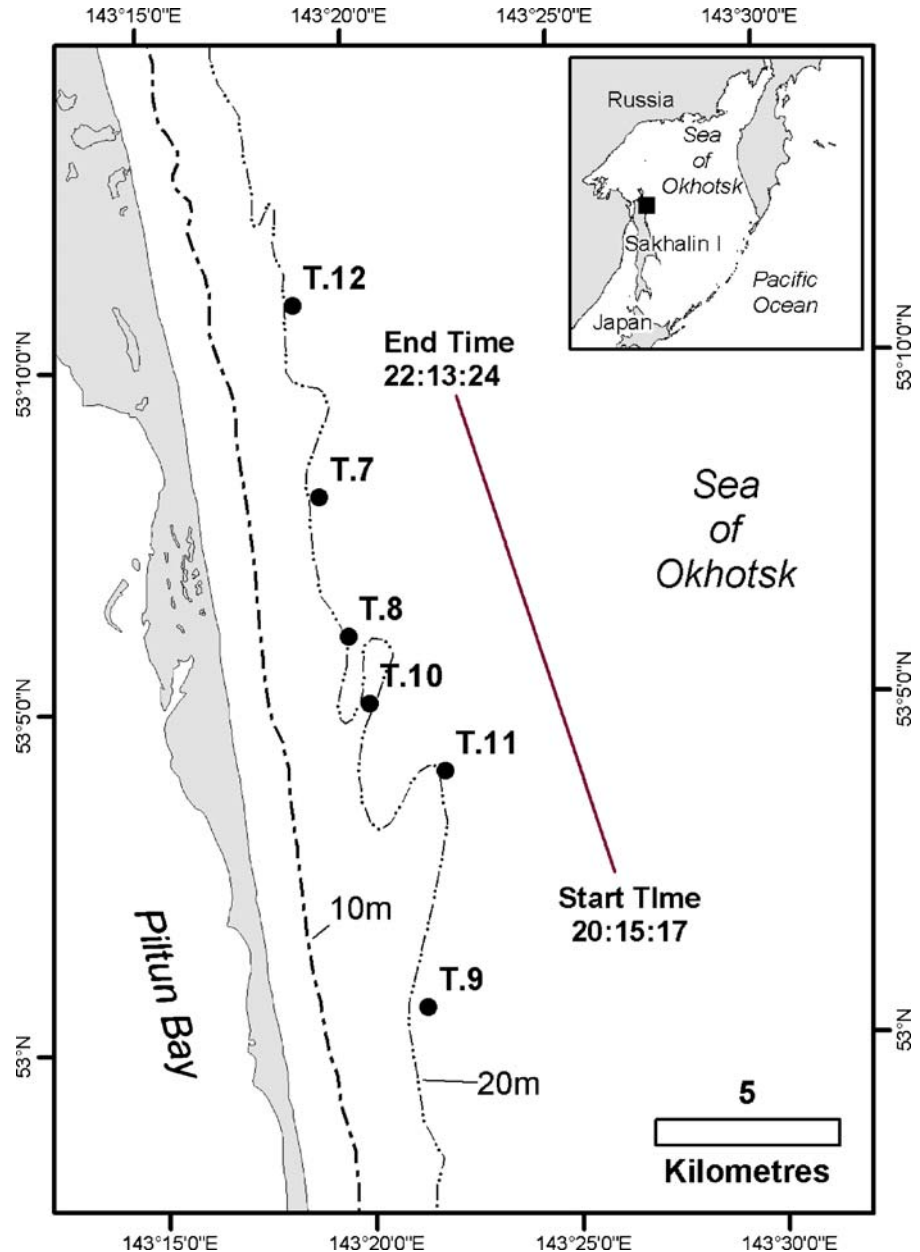
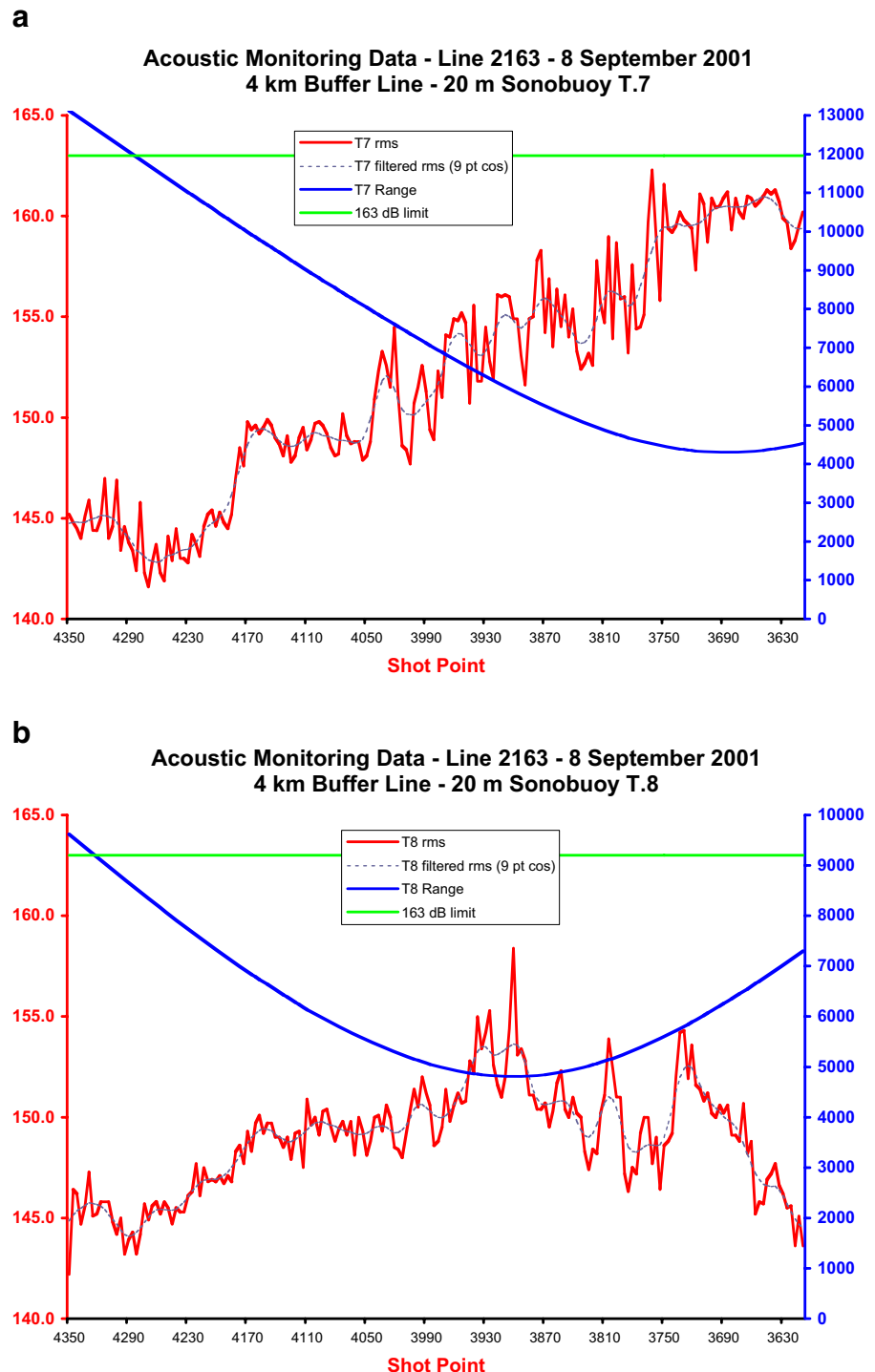


Fig. 20 a–f Shot point along seismic line 2163 vs range from the seismic source to the 20 m contour and received level at the six sonobuoys (T.7 through T.12) deployed during acoustic monitoring of the seismic line acquired on 8 September 2001 and plotted on Fig. 19. During this monitoring the vessel was just seaward of the boundary between area A and area B (Fig. 1), approximately 4 km from the 20 m isobath, and at its closest point of approach was ~4 km from the sonobuoys. **a** Sonobuoy T.7; **b** sonobuoy T.8; **c** sonobuoy T.9; **d** sonobuoy T.10; **e** sonobuoy T.11; **f** sonobuoy T.12

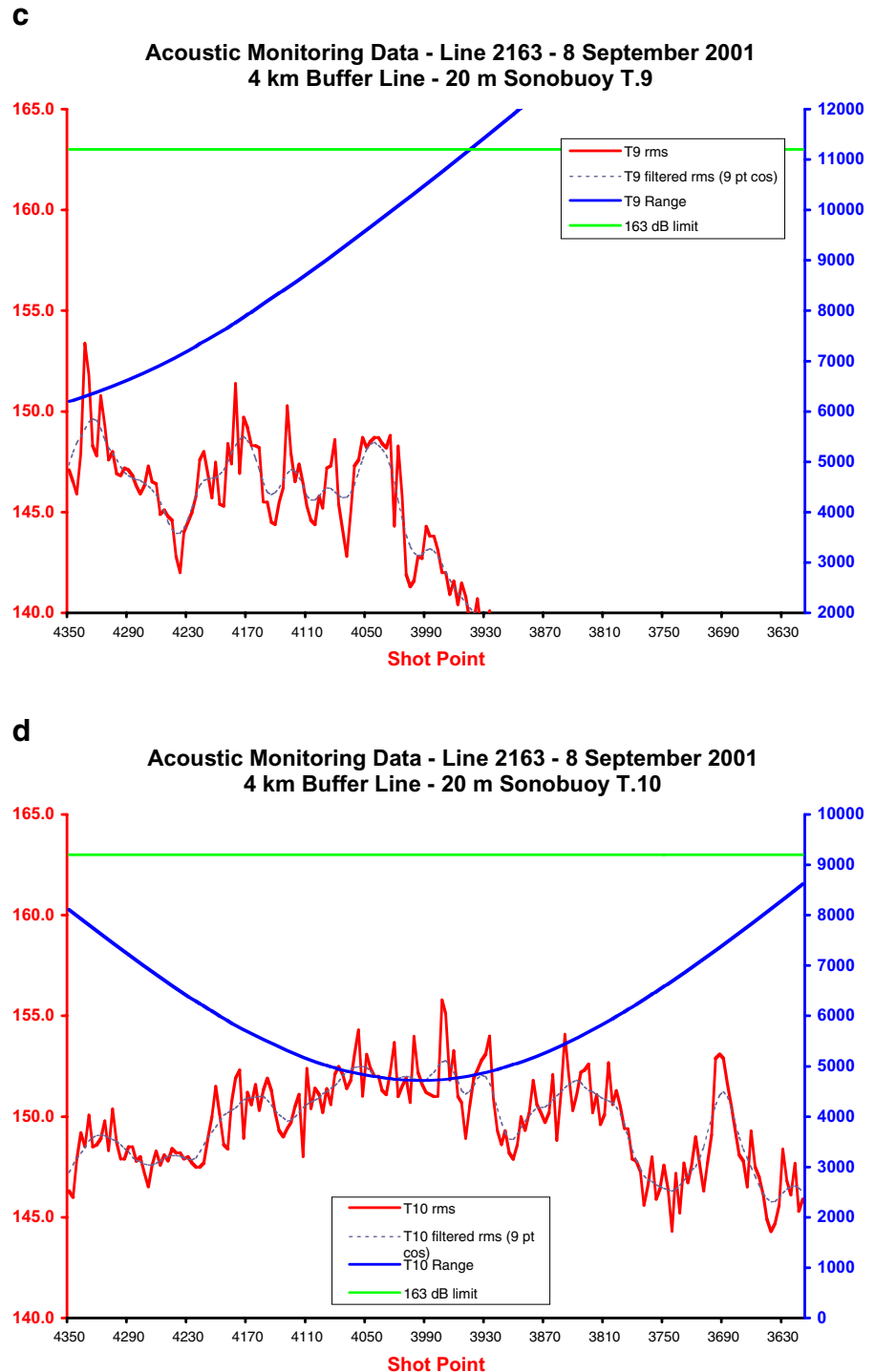


was not greater than 163 dB_{rms} re 1 μPa. Figure 19 shows the distribution of the sonobuoys used for the monitoring of the buffer zone.

This distribution of sonobuoys was limited by the radio reception. The sonobuoys could be monitored

from the Piltun lighthouse or the acoustics field camp located 20 km north of the lighthouse. However, there was a zone between 53°0.5'N to 53°04'N (sonobuoy locations T.9 and T.11) that could not be monitored from either location. Between these two points, the

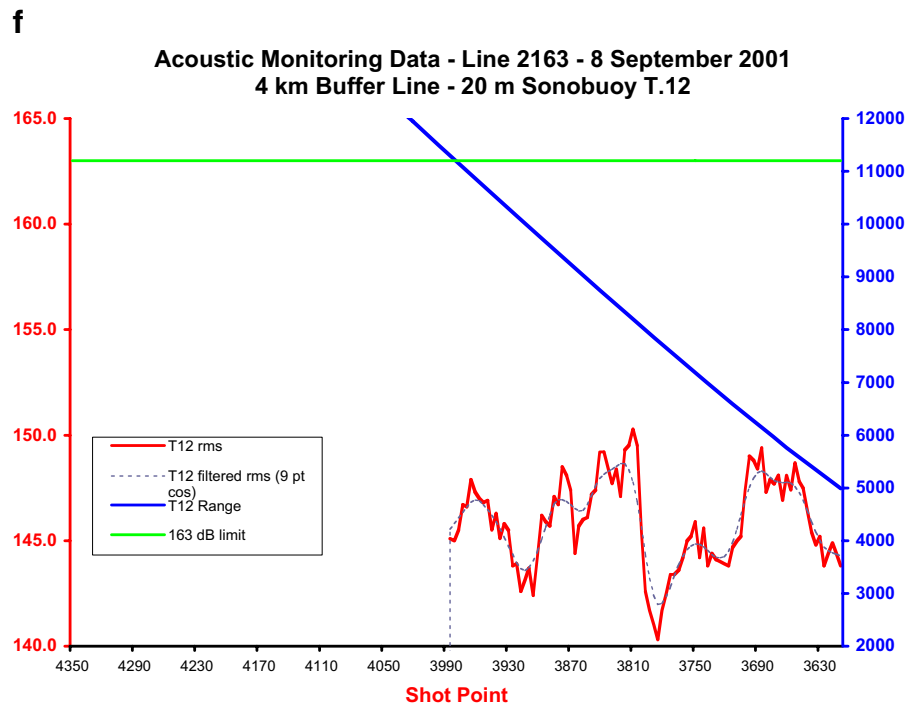
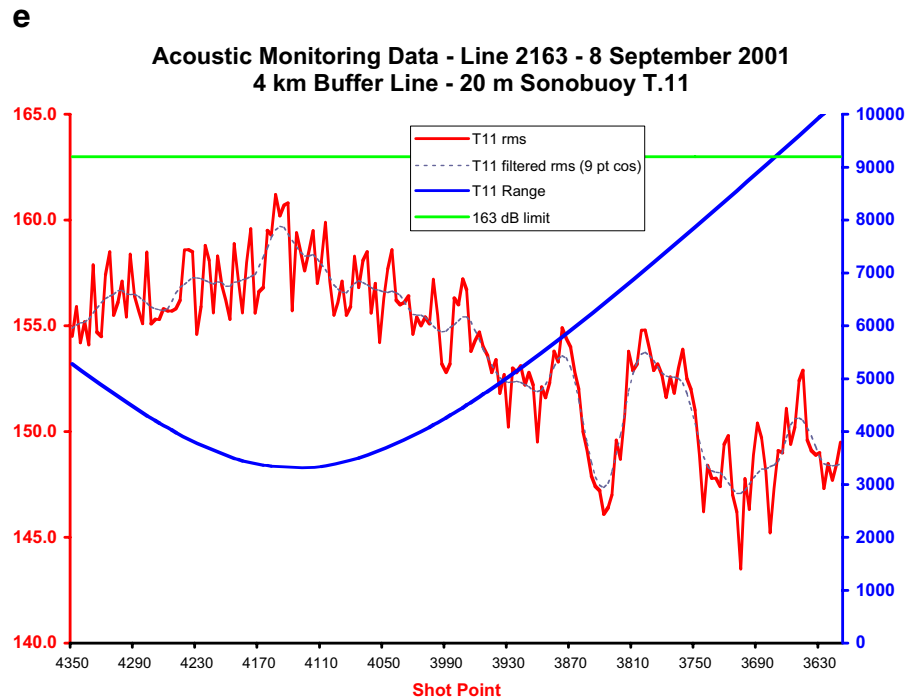
Fig. 20 (continued)



20 m contour is further from the seismic line than location T.11, therefore this gap did not materially affect the real-time monitoring. Apart from this zone, the sonobuoys were distributed evenly between shot

points 3600 to 4400 on the seismic lines. Special attention was paid to the two fingers of shallow bathymetry that extended towards the buffer (although these areas were monitored visually before

Fig. 20 (continued)



acquisition closer than 4 km). In the southern part of the survey the distance from the buffer to the 20 m contour extended to beyond 5 km and only buoy T9 monitored this area.

Line 2163 (full line name S012163) was the closest line to the 4 km buffer; being located approximately 50 m outside zone A. Figures 20a–f are plots of the rms received level at sonobuoys T7 to T11 during the

acquisition of this line. Buoy T12, which was located in the northern part of the prospect, was only active for the northern part of the line. Buoy T.9 located in the southern part of the prospect was active for the southern part of the line. In each of the plots the red line shows the received level (dB_{rms} re $1 \mu\text{Pa}$) at the specified sonobuoy, the azure dotted line is the nine-point cosine filtered result. The $163 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ level is marked in green, the blue line shows the range in meters to the specified sonobuoy.

The closest points of approach (CPA) were sonobuoys T7 and T11. Buoy T7 was located at the northern end of the survey, where the survey line was closest to the 20 m depth contour. The closest range was 4,300 m and the highest sound level received was $162.3 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ (instantaneous), $161.0 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ (filtered). Sonobuoy T11 was in the southern part of the field, however, it was on a finger of shallow bathymetry inside the nominal 20 m contour and therefore was only 3,320 m away from the 4 km buffer. The highest sound level received was $161.2 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ (instantaneous), $159.7 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ (filtered).

As discussed earlier, the data could be subject to two possible errors related to the calibration of the acoustic equipment. A $\pm 1.5 \text{ dB}$ error associated with the sonobuoy hardware and a $\pm 1.0 \text{ dB}$ error associated with the determination of absolute pressure.

Discussion

A marine 3D seismic survey was conducted by DalMorNefteGeofisika (DMNG) on behalf of Exxon Neftegas Limited and the Sakhalin-1 consortium in the Odoptu license area northeast of Sakhalin Island, Russia, from 17 August to 9 September 2001. The key environmental issue identified in an environmental impact assessment was protection of the critically endangered western gray whale, which spends the summer-fall open water period feeding off northeast Sakhalin Island in close proximity to the seismic survey area.

Seismic mitigation and monitoring guidelines and recommendations were developed and implemented to reduce impacts on the feeding activity of western gray whales (Johnson et al. 2007). Controlling exposure to sound levels below the threshold known to impact feeding activity ($\sim 163\text{--}164 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$)

ensured that the whales would also be protected from any direct physical harm (e.g., direct impacts to hearing). Earlier gray whale sightings (Fig. 2) indicated that over 95% of all observed feeding gray whales in the Piltun area were located shoreward of the 20 m water depth contour. The objective of the mitigation strategy was to employ a buffer distance between feeding gray whales and the operating seismic vessel so as to not decrease the feeding activity of the whales (Johnson et al. 2007).

ENL conducted an acoustic calibration study prior to the seismic survey to determine at what distance from the 20 m contour the received sound levels dropped below $163 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$. This distance was 4 km for the reduced volume $1,640 \text{ in.}^3$ air gun array. Therefore, a buffer distance of 4 km became the basis for the entire survey. An acoustic monitoring program was developed based on the buffer distance determined during the calibration studies.

This acoustic monitoring program evaluated the sound levels received at the 20 m contour as the most westerly seismic lines from Area B were acquired. Results from this acoustic monitoring program showed that the sound level at the 20 m contour did not exceed a level of $163 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ even when the calibration errors are considered. The noise monitoring and mitigation program was therefore successful in reducing the exposure of feeding western gray whales to seismic noise (Yazvenko et al. 2002, 2007a,b).

Acknowledgements The authors would like to thank the V.I. Il'icev Pacific Oceanological Institute, Far East Branch or the Russian Academy of Sciences (POI, FEB, RAS), (Tikhookeanskij okeanologicheskij institut im. V.I. Il'icheva DVO RAN), for their assistance in conducting this work. We would also like to thank Exxon Neftegas Limited for supporting this work. The authors would also like to acknowledge the following personnel from POI, who while they did not contribute to the report, contributed significantly to the success of the program in the field. Sc. R.A. Korotchenko; engineers: Sc. A.V. Hodzevich, E.A. Maslennikov, V.V. Lihachev, D.G. Kovzel'. The authors also wish to thank the crew of the *Nordic Explorer*, *Grif* and the ExxonMobil representatives on board these vessels, including Peter Napier, Razak al Nuhr Mohammed, and Joe Scarlett. The authors would like to thank Mat Walsh and Vinny Buffenmyer of ExxonMobil and Peter Wainwright of LGL Limited for contributing data to this report. Finally the authors would like to thank Dr. Sc. G.I. Dolgih (Pacific Oceanological Institute), Dr. Richard T. Houck and Dr. H. Rodger Melton (ExxonMobil Upstream Research Co.), and

Dr. Kenneth D. Andersen (ExxonMobil Exploration Co.) for reviewing this paper, Dr. Charles I. Malme (Engineering and Scientific Services) for valuable assistance and consultation on acoustic issues and for reviewing this paper, Dr. Stephen R. Johnson (LGL Limited) for review and assistance in preparation of this paper, and Dr. W. John Richardson (LGL Limited) for assistance in planning this study.

References

Anonymous (2001). *Krasnaya Kniga Rossiiskoi Federatsii. Zhivotnye*. [“The Red Book of the Russian Federation. Animals”]. Ast and Astrel, Balashikha, Aginskoe, 862 pp. Available at <http://www.nature.ok.ru.redbook.htm>.

Borisov, S. V., Gritsenko, A. V., Jenkerson, M. R., Rutenko, A. N., & Hodzevich, A. V. (2002). Evaluating and monitoring acoustic transmission from the Odoptu 3D seismic survey, 5 August–9 September, 2001. Report by V.I. Il'icev Pacific Oceanological Institute, Far East Branch, Russian Academy of Sciences, Vladivostok, Russia, and ExxonMobil Upstream Research Company, Houston, TX, for Exxon Neftegas Limited, Yuzhno-Sakhalinsk, Russia. Available from Exxon Neftegas Limited, c/o ExxonMobil Development Company, 17001 Northchase Drive #466, Houston, TX 77060, Attn: Daniel Engging.

Harrison, C. H., & Harrison, J. A. (1995). A simple relationship between frequency and range averages for broadband sonar. *Journal of the Acoustical Society of America*, 97(2), 1314.

Hilton-Taylor, C. (2000). *2000 IUCN red list of threatened species*. Gland, Switzerland and Cambridge, United Kingdom: IUCN/SSC.

Johnson, S. R., Richardson, W. J., Yazvenko, S. B., Blokhin, S. A., Gailey, G., Jenkerson, M. R., et al. (2007). A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. *Environmental Monitoring and Assessment* (this issue).

Malme, C. I., & Miles, P. R. (1985). Behavioral responses of marine mammals (gray whales) to seismic discharges. In G. D. Greene, F. R. Engelhardt, & R. J. Paterson (Eds.), *Proc. Workshop on effects of explosives use in the marine environment*, Jan. 1985, (pp. 253–280). Halifax, NS, Tech. Rep. 5, Can. Oil & Gas Lands Administration, Environmental Protection Branch, Ottawa, ON, 398 pp.

Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P., & Bird, J. E. (1983). *Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior*. BBN Report 5366, Bolt Beranek & Newman Inc., Cambridge, MA, for U.S. Minerals Management Service, Anchorage, AK. NTIS PB86-174174.

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

Malme, C. I., Würsig, B., Bird, J. E., & Tyack, P. (1986). *Behavioral responses of gray whales to industrial noise: Feeding observations and predictive modelling*. Outer Continental Shelf Environmental Assessment Program, Final Report of Principal Investigators, 56(1988):393–600. NTIS PB88-249008.

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

Meier, S., Lawson, J., Yazvenko, S., Perlov, A., Maminov, M., Johnson, S. R., et al. (2002). *Vessel-based marine mammal monitoring during the 2001 3-D seismic survey of the Odoptu block, northeast Sakhalin Island, Okhotsk Sea, Russia*. Report by LGL Limited, Sidney, BC, for Exxon Neftegas Limited, Yuzhno-Sakhalinsk, Russia, 38 pp. Available from Exxon Neftegas Limited, c/o ExxonMobil Development Company, 17001 Northchase Drive #466, Houston, TX 77060, Attn: Daniel Engging.

Richardson, W. J., Greene, C. R. Jr., Malme, C. I., & Thomson, D. H. (1995). *Marine mammals and noise* (576 pp.). San Diego, California: Academic.

Richardson, W. J., Miller, G. W., & Greene, C. R. Jr. (1999). Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. *Journal of the Acoustical Society of America*, 106(4, Pt. 2), 2281.

Sobolevsky, E. I. (2000). *Marine mammal studies offshore northeast Sakhalin, 1999*. Final Report by the Institute of Marine Biology, Far Eastern Branch of Russian Academy of Sciences, Vladivostok, for Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russia, 149 pp.

Sobolevsky, E. I. (2001). *Marine mammal studies offshore northeast Sakhalin, 2000*. Final Report by the Institute of Marine Biology, Far Eastern Branch of Russian Academy of Sciences, Vladivostok, for Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russia, 199 pp.

Weller, D. W., Burdin, A. M., & Brownell, R. L. (2001). *The western North Pacific gray whale: A review of past exploitation, current status, and potential threats*. International Whaling Commission Scientific Committee Report SC/53/BRG 12, 16 pp.

Weller, D. W., Würsig, B., Bradford, A. L., Burdin, A. M., Blokhin, S. A., Minakuchi, H., et al. (1999). Gray whales (*Eschrichtius robustus*) off Sakhalin Island, Russia: Seasonal and annual occurrence patterns. *Marine Mammal Science*, 15, 1208–1227.

Würsig, B. G., Weller, D. W., Burdin, A. M., Blokhin, S., Reeve, S., Bradford, A. L., et al. (1999). *Gray whales summering off Sakhalin Island, Far East Russia: July–September 1997, a joint U.S.–Russian scientific investigation*. Report by Texas A&M University, College Station, TX and Kamchataka Institute of Ecology and Nature Management, Russian Academy of Sciences, Petropavlovsk, Russia, for Sakhalin Energy Investment Company Limited and Exxon Neftegas, 103 pp.

Yazvenko, S. B., MacDonald, T., Blokhin, S. A., Johnson, S. R., Meier, S. K., Melton, H. R., et al. (2007a). Distribution and abundance of western gray whales during a seismic survey near Sakhalin Island, Russia. *Environmental Monitoring and Assessment* (this issue).

Yazvenko, S. B., MacDonald, T., Blokhin, S. A., Johnson, S. R., Melton, H. R., Newcomer, M., et al. (2007b). Feeding

activity of western gray whales during a seismic survey near Sakhalin Island, Russia. *Environmental Monitoring and Assessment* (this issue).

Yazvenko, S., MacDonald, T., Meier, S., Blokhin, S., Johnson, S. R., Vladimirov, V., et al. (2002). *Aerial marine mammal monitoring during the 2001 3-D seismic survey of the*

Odoptu block, northeast Sakhalin Island, Okhotsk Sea, Russia. Report by LGL Limited, Sidney, BC, for Exxon Neftegaz Limited, Yuzhno-Sakhalinsk, Russia. 163 pp. Available from Exxon Neftegaz Limited, c/o ExxonMobil Development Company, 17001 Northchase Drive #466, Houston, TX 77060, Attn: Daniel Egging.