WESTERN GRAY WHALE ADVISORY PANEL **WGWAP:**

Seismic Survey Task Force

1st meeting of the task force **25-28 June 2007**

Den Haag, The Netherlands

REPORT OF THE TASK FORCE

CAUTION !

The monitoring and mitigation measures have been refined in the report of the second meeting of the Seismic Task Force.

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1 INTRODUCTION

The Task Force on Seismic Surveys of the WGWAP held a workshop in Den Haag, The Netherlands, during June 25-28 2007 in order to:

- Review and analyze noise predictions and estimated whale densities for the 2008 Astokh Seismic Survey in the context of potential effects on the Western Gray Whale (WGW) population.
- Develop recommendations for mitigating the impact of the survey on Gray Whales;
- Develop recommendations for Gray Whale monitoring during the survey to both minimize effects on the whales in "real time" and contribute to the body of scientific knowledge regarding the effects of seismic surveys on whales. These recommendations will be aimed at helping to ensure that the effects of this and any future seismic surveys offshore Sakhalin are minimized.

The Task Force on Seismic Survey and its terms of reference were established by the WGWAP at its 2nd (St Petersburg) meeting (see section 12.2 of WGWAP 2007) to provide input to the Sakhalin Energy Investment Company Ltd (SEIC)'s Environmental Impact Assessment (EIA) for the proposed 2008 seismic survey. The Task Force had been working by email and phone since April, and this was its first and only scheduled meeting.

The Task Force is a joint, collaborative effort, and in that respect differs from the formal WGWAP process. The Task Force agreed that the report and recommendations would be developed jointly by all participants, including designated SEIC representatives and contractors, Panel members and associated scientists. The Workshop report was circulated to SEIC and WGWAP for comment before being finalised, but responsibility for the report and any views expressed therein remains with the Task Force members, because the report has not been formally endorsed by the Panel, SEIC or IUCN.

It was agreed that the report did not need to document the full course of discussions, but should contain the recommendations, and sufficient discussion and background information to show how the recommendations were arrived at. Apart from the report and its Annexes, there would be no other formal meeting documents. The Terms of Reference, including a list of Task Force members, are attached as Annex A.

2 REVIEW OF SEIC PLANS FOR SEISMIC SURVEYS – UPDATES

2.1 Overview and update to survey plans

The Piltun-Astokh (PA) field was discovered in 1986 ca 12-15 km offshore at water depths between 30 and 50 m. Since then, 17 E&A (Exploration and Appraisal) wells have been drilled, of which 4 reside in the producing Astokh area. The Astokh portion of this field started its production from the PA-A (Molikpaq) platform in 1999. Between 1999 and 2001, 13 production wells were drilled and brought on line. Production has been seasonal thus far, but with the planned hook-up to the pipeline there will be year-round production.

In 2003-2005, the pressure-maintenance project was carried out, entailing the drilling of four dedicated water-injection wells on the periphery of the field. This project was undertaken to increase reservoir pressure and enhance recovery by water drive. The fourth injection well was brought on line in April 2005. In 2006, pressures have been restored to levels close to original. The location of the injection-related waterfront is unknown, and no water-breakthrough has occurred in production wells to date.

The Astokh Further Development project will entail infill drilling from the existing Molikpaq platform to increase the recovery from the field and meet levels of recovery that are commitments to the Russian Authorities. Because of the complex reservoirs at Astokh however, efficient development of this large resource cannot be undertaken without some means of monitoring the area changes in water and oil movement across the structure. The availability of a seismic-based map of reservoir changes will allow recovery commitments to be met with fewer production wells.

At Astokh, efficient recovery of oil and gas from this large reservoir is dependent upon reliable information regarding production-related spatial pressure and fluid changes in the reservoir and surrounding formations. Such information enables a given recovery fraction to be achieved with fewer wells, thus potentially reducing the risk to the environment.

An evaluation by SEIC of all available techniques for spatial field monitoring that was presented to the Task Force concluded that unproven, non-conventional methods including Time Lapse Electromagnetics and Gravity will not yield the horizontal and vertical resolution required to image production-related effects within the Astokh reservoirs. 3D seismic profiling is the only spatial reservoir monitoring technique with the potential to aid field development offshore Sakhalin.

In 1997, the full PA license area was surveyed with a 3D seismic system. This "baseline survey" was acquired by the PGS vessel "Nordic Explorer" between the months of July and August. These data were reanalysed in 2001 resulting in a higher quality map and are deemed suitable by SEIC as a base survey for reservoir monitoring purposes. Because the Astokh Field has been under production for several seasons, a repeat of the original 3D streamer seismic data is considered to be the only technically feasible time-lapse method that can be used to prevent the drilling of unnecessary wells.

The technical feasibility of imaging production-related changes at Astokh has been assessed using a forward modeling approach. These models indicate that acoustically subtle production-related changes can be imaged. However, during a repeat 3D survey (often called a 4D survey in the industry, where the fourth dimension is time), the original pre-production survey design and acquisition specifics, particularly source size and array geometry and source-to-receiver positioning, will need to be matched as closely as possible with those of the 1997 survey. Accordingly, a repeat 3D survey is planned over Astokh during the summer of 2008. This timing is determined by SEIC's plans to use the results in planning the further development drilling campaign that is due to commence in 2009.

2.2 Survey design specifics

Production-related effects in the reservoir are acoustically subtle. Therefore, to measure changes over time, it is critical that the original 1997 survey be repeated exactly.

Specifically, source-to-receiver position and source level must be identical. Though the source level requirement has been and is being investigated *vis-à-vis* reducing the exposure of gray

whales to noise in future surveys, such a reduction is not an option for the proposed 2008 survey. To ensure consistency between the 1997 and 2008 surveys, baseline orientations and acquisition directions must be repeated exactly. There is however no requirement to re-acquire the full area of the original data: the repeat survey can be limited to areas where the production-related effects are expected.

The key parameters of the original 1997 survey are indicated below:

1. Mode

    - 6 Streamers /dual source
    - Shot interval – 18.75m (flip-flop), corresponding to approximately 7.2 seconds between pulses during normal survey at 5 knots

2. Receivers/cables

    - 4500m long, 100m separation and 8m depth

3. Source

    - 2 x 2620 cu in sleeve guns
    - 3 Sub arrays with 10m separation
    - Depth 6m
    - Length 14m
    - 2000 psi pressure.

The survey target area has been trimmed and limited as much as possible to only the sector of the field where production-related effects are expected – an area of approximately 90 km^2. To acquire seismic data and image the area of interest, the actual 1997 line orientation and source-to-receiver position will have to be replicated exactly. This will require acquisition of an area of approximately 170km^2 (Fig. 2.1). A seam exists in the 1997 data exists at the boundary between N-S and S-N lines. The lines are spaced approximately 400m apart.

It is expected that to acquire data over the significantly reduced survey area, a seismic vessel will be active for approximately 21 days. However of these 3 weeks, only 4-5 days of full seismic source activity will be undertaken. This period of fully active pulsed seismic source will be non-continuous and interspersed with frequent intervals of reduced activity (such as during line changes) or complete inactivity (vessel downtime during rigging-up, poor weather conditions or nearby gray whales).

At least 3 vessels are likely to be involved with the acquisition, a master seismic vessel, a guard vessel and a supply vessel. The guard vessel follows the array to ensure that it is properly deployed and not compromised by other vessels.

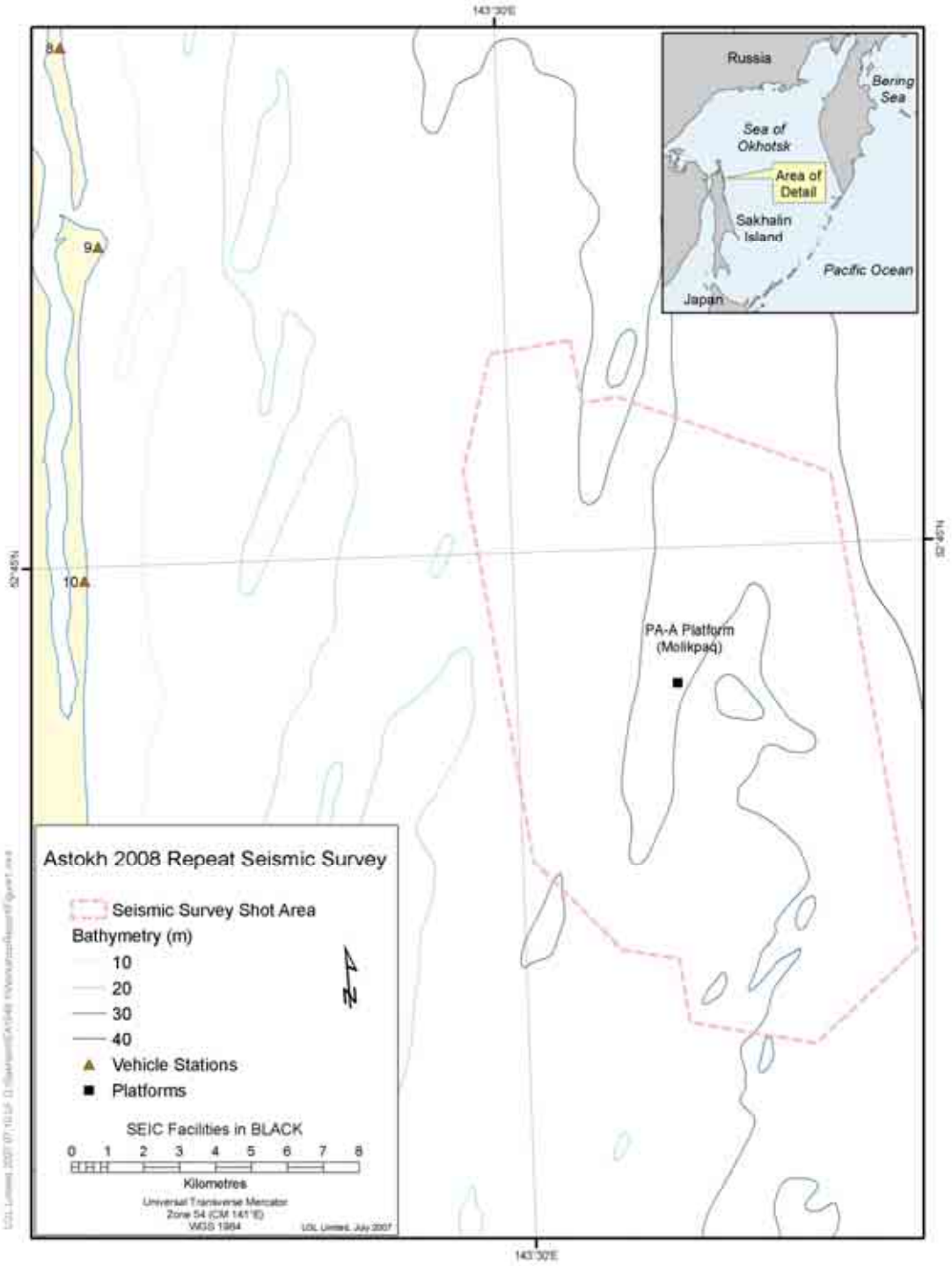

Fig. 2.1. Map of Astokh 2008 survey shot area with coastline and bathymetry shown.

2.3 Shell Arctic Research on feasibility of ice-based surveys offshore Sakhalin

The option of acquiring a new baseline survey (for time-lapse imaging of the Astokh reservoir) has been raised. Ideally, this new baseline survey and future repeats of the survey would be conducted during periods when the WGW population is absent, therefore reducing the impact on the WGW population.

Winter ice conditions in the vicinity of Piltun and Astokh are complex, variable and are markedly different from those areas of land-fast ice where trials of winter seismic acquisition have been undertaken (eg. Alaska). Conditions typically entail a thin strip of ridged landfast ice along shore extending up to 8km seaward, often bounded by a coastal flaw lead or polynya of open water or thin, very mobile ice, typically 6-18 km wide, beyond which there is commonly mobile offshore pack-ice with thick keels, of 10-15m in depth, but up to 20-25m.

There are no technically proven options for the acquisition of reliable seismic data in the ice conditions encountered over Piltun Astokh during the winter months. Of the potential techniques examined, the use of ocean bottom receivers offers the greatest potential for technical success although this approach is frequently not commercially feasible under benign open water conditions. This approach faces several additional technical and environmental hurdles and is yet to be tested in arctic conditions.

To further explore the feasibility of winter acquisition, Sakhalin Energy has initiated and is co-funding a long-term research program with the Shell Arctic Research Group. The short-term aim of this program, in conjunction with the Shell Alaskan Group, is a detailed assessment of existing vendor technologies. After this initial feasibility stage it is hoped that one or more field trials could be conducted offshore Sakhalin with the aim of being ready for implementation by 2011 at the earliest. Clearly, achieving this goal will depend on the success of interim steps. The Task Force agreed that survey in winter, when no WGW are present, would be desirable if it were possible, but recognised that it is too early to assess the prospects for the successful development of a winter survey method.

3 REVIEW OF LEBEDENSKOYE AND OTHER SURVEY PLANS IN 2008

The seismic vessel market is tightening globally and there is continued upward market pressure on production day rates and mobilization fees. Sakhalin is an isolated location and the operator may face the costs of mobilizing vessels from distant ports in areas such as Singapore, India or Australia.

Sakhalin Energy has no details on the future activities of other operators who may wish to commission seismic surveys, but in view of the above consideration, it seems unlikely that a survey involving a comparably large seismic vessel would be conducted in the Sakhalin area concurrently with the SEIC survey. It can also be assumed that no other survey would be conducted in 2008 prior to the SEIC survey near or northward of the Astokh area, because of ice conditions (the SEIC survey is scheduled to start as soon as ice conditions allow).

It therefore seems reasonable to assume that the potential impacts of the SEIC survey on the WGW population will, within a single season, not be confounded by impacts of preceding or concurrent seismic surveys.

According to information received by WGWAP (see section 12.2 of WGWAP-2 report (WGWAP 2007)), it is possible that a seismic survey is planned for the Lebedenskoye area in 2008 or later. In view of the shallow water in the Lebedenskoye area, it is presumed that the survey would involve a different kind of vessel than the one used for the SEIC survey. Also, due to ice cover, it would likely be conducted later in the season than the SEIC survey.

A survey of the Lebedenskoye area could have a greater impact on the WGW population, if it impinges on a greater part of the feeding ground and takes place later in the season when more whales are present. It is therefore especially important that adequate mitigation and monitoring measures be implemented for such a survey.

4 REVIEW OF DATA AND DISCUSSION OF "SAFE" EXPOSURE LEVELS

4.1 Measures of sound exposure

In this report, sound "levels" are sometimes expressed in terms of "dB_{RMS}" (root-mean-square sound pressure level, expressed in decibels re 1 μPa) and sometimes in terms of "dB_{SEL} or "SEL" (sound energy level, expressed in decibels re 1 $(\mu Pa)^2s$). The SEL is not a direct measure of the energy in a sound, but correlates highly with it (NRC 2001). For a sound pulse of 1 second in duration, the two measures are numerically equal. For shorter pulses, the dB_{SEL} measure is numerically smaller than the dB_{RMS} level and vice-versa.

Both measures have their advantages and disadvantages as indicators of sound exposure. Since dB_{RMS} is an average intensity over the duration of a pulse, its use requires specification of the duration of the pulse, which is to some extent arbitrary. Usually the tail end of the pulse is not included in the average. The dB_{RMS} level usually attenuates faster than the dB_{SEL} level with increasing distance from the source, because a pulse of sound spreads out in time as well as in space as it is transmitted through a medium.

The dB_{SEL} level, being a measure of the total rather than the average energy in a sound, is, for a sound of constant intensity, a function of the duration of the sound: other things being equal, a doubling of the duration adds approximately 3 dB to the dB_{SEL} level. Likewise, the SEL from a series of 100 identical pulses is 20 dB higher than the SEL from just one such pulse. In the case of a seismic survey, it is important to distinguish between the SEL that a whale receives from a single pulse, and the combined SEL that the whale receives from the series of pulses to which it is exposed as the seismic vessel passes.

Research since 1995 (especially Schlundt *et al.* 2000, reviewed below) has provided some support for the applicability to small cetaceans of the "equal-energy" approach used to develop damage risk criteria for human hearing (Lataye and Campo 1996). Under the equal energy rule, a doubling of exposure time is considered equivalent to a 3dB increase in the sound level. However, not all published results for marine mammal are consistent with the equal energy rule. Kastak *et al.* (2005) found that for three pinnipeds (one harbour seal, one California sea lion and one northern elephant seal), sounds of longer duration caused more TTS than shorter-duration sounds of higher intensity and higher total energy: doubling the duration from 25 minutes to 50 minutes had a greater effect than increasing the exposure from 80 to 95 dB_{RMS} (which corresponds to an approximately 30-fold increase in intensity).

The Interim Independent Scientists Group (IISG) had recommended a 5 dB exchange rule, which has been used in some standards for noise exposure in humans (e.g. US Occupational Safety and Health Administration standard 1910.95, see www.osha.gov). This rule is that doubling the exposure duration is considered equivalent to an increase of 5 dB in sound intensity. For its 2006 construction noise management plans, SEIC had employed the equal energy approach (WGWAP, 2006). It appears that most noise exposure standards now in effect use a 3 dB (equal energy) exchange rule.

The Task Force agreed that in the absence of a widely accepted alternative, it was appropriate to use, where possible, the equal energy rule and hence the dB_{SEL} scale for computing effective noise exposures.

4.2 Summary of Available Data

4.2.1 Abandonment of favored habitat

Gray whale responses to cumulative vessel traffic and disturbance over the long term (more than a decade) have been examined once. Bryant et al. (1984) reported abandonment by wintering gray whales (calving females, breeding whales) in Laguna Guerrero Negro in Baja California. The whales were exposed to heavy and uncontrolled commercial shipping and dredging activities from a salt mining operation starting in 1957. They had largely abandoned the lagoon as a breeding area by 1964. Once the vessel traffic and dredging activity were stopped in 1967, the whales began to use the lagoon again and were present in numbers by the time Bryant et al. began surveys in the 1980s.

The unplanned 'experiment' conducted in Laguna Guerrero Negro provides the only documentation of abandonment of favored habitat by gray whales as a consequence of disturbance.

Dredging and heavy vessel traffic are not necessarily good models for activity of oil industry sources in the vicinity of WGW feeding grounds. However, the experience in Mexico and California does suggest that caution should be exercised when conducting extensive and disturbing activities within favored habitat because it is possible that gray whales will move away temporarily or abandon it completely.

The cumulative effects of repeated exposure to seismic sources are unknown. Johnson (2002) reported the results of seismic surveying inshore of the Odoptu License Area off Sakhalin Island in August and September 2001. Survey lines came within the current boundary of the near-shore feeding area, extending inshore to the 20 m isobath. The available report did not provide detailed information on behavioral observations. On the basis of distribution surveys, WGWs may have moved away from the immediate vicinity of the surveying during active shooting. According to Johnson (2002), these apparent movements were not distinguishable from shifts in distribution observed at other times, so they could have been explained by natural factors. However, Weller *et al*. (2002) documented a significant increase in the numbers of whales and whale pods sighted in their research area, which was south of the Odoptu seismic survey area, during the survey period as compared to before and after it. Weller *et al*. suggest that this shift was likely in response to the Odoptu seismic survey. Whatever the interpretation, the whales did not completely abandon the feeding area and were observed using the affected areas in the two months after the surveying had been completed. If the shift southward was the result of seismic surveys, it could represent a significant energetic impact on gray whales, particularly lactating

mothers, but the magnitude and consequences of such a potential impact have not been estimated.

4.2.2 Hearing Damage

Effects on mysticete hearing: Due to the difficulty of measuring the auditory capabilities of large whales, there are no direct data on thresholds of noise-induced temporary or permanent threshold shift (TTS or PTS) in gray whales or any other large whale. The range of mysticete hearing has been estimated to lie between 7 Hz and 22 kHz based on anatomical characteristics of a limited sample of mysticete ears collected from freshly dead specimens (Ketten 1994) (one each bowhead, fin, humpback, blue, right, and minke whales). The estimated best frequency was below 5 kHz in every case. One attempt was made to estimate the hearing thresholds of an orphaned gray whale in captivity using electrophysiological measures (Ridgway *et al*., unpub.) The data obtained had severe limitations, but were consistent with the range estimated on anatomical grounds. It has been estimated that mysticetes are likely most sensitive to sound from perhaps 10's of Hz to ~10 kHz (Richardson *et al.*, 1995; Wartzok and Ketten, 1999; Clark and Ellison, 2004).

A few authors have attempted to estimate thresholds of mysticetes using the lowest level at which individual whales responded to sounds of known frequency. Dahlheim and Ljungblad (1990) exposed eastern gray whales in the calving lagoons to tones and observed reactions to tones at frequencies from 200 Hz to 2500 Hz. These experiments were very limited in scope (they were only collected to show the feasibility of the playback method) and could not be used to estimate behavioral thresholds using accepted psychophysical techniques. However, the whales were observed to make abrupt changes in behavior at levels below 95-108 dB_{RMS} re 1µPa at test frequencies of 800-1000 Hz. Mobley *et al*. (1988) observed responses of humpback whales to playback of natural calls, which have their greatest energy in the range from 50 Hz to 8 kHz, and synthetic sounds. They also found that the whales responded down to the ambient noise floor. Bowles *et al*. (2001) showed that an orphaned, rehabilitated gray whale calf detected and responded to natural gray whale calls with estimated broadband levels of 95 dB_{RMS} re 1µPa, close to the noise floor in the pool at low frequencies. Finally, Frankel (2005) reported that gray whales responded to the pings from a 21-25 kHz sonar suggesting that they were capable of hearing at these frequencies. Frankel has not yet reported estimated received levels at the whales for these data.

In conclusion, these very limited experimental and quasi-experimental studies cannot be used to model the auditory threshold function for the gray whale or any other mysticete, but they do suggest that the whales can hear in the range estimated on anatomical grounds (i.e. 7Hz – 22kHz) and that they will be able to hear sounds from seismic surveys down to the local ambient at the low end of the range.

Effects on odontocete hearing: Given that effects of noise on the hearing of mysticete whales has not been measured directly, an alternative method for estimating damage risk is make inferences using data available for odontocete cetaceans.

Finneran *et al*. (2000) exposed two bottlenose dolphins and one beluga to pulses from an array of piezoelectric sound projectors that generated pressure waveforms resembling distant underwater explosions. The sounds had substantial energy in the subjects' midrange. No measurable (*i.e*., 6 dB or larger) threshold shifts, either temporary or permanent, were observed in any of the subjects at the highest received exposure levels (70 kPa (10 psi); 221 dB_{p-p} re 1µPa; and 179 dB_{SEL} re $1(\mu Pa)^2s$).

Finneran *et al*. (2002) repeated this experiment with one beluga and one dolphin using a slightly different source, single pulses from a seismic watergun. Values of TTS measured two seconds after exposure to pulses a few ms in duration were 7 and 6 dB in the beluga at 0.4 and 30 kHz, respectively (160 kPa (23 psi); 226 dB_{p-p} re 1µPa; and 186 dB_{SEL} re 1$(\mu Pa)^2$s). Thresholds could not be distinguished from the pre-exposure value within four minutes of exposure. No TTS was observed in the bottlenose dolphin at the highest exposure conditions (207 kPa peak pressure, 228 dB_{p-p} re 1µPa, and 188 dB_{SEL} re 1$(\mu Pa)^2$s).

Schlundt *et al.* (2000) reported TTS in five bottlenose dolphins and two belugas exposed to 1-sec pure tones. At frequencies of 3, 10, and 20 kHz, levels necessary to induce measurable amounts (6 dB or more) of TTS were between 192 and 201 dB_{RMS} re 1µPa (192 to 201 dB_{SEL} re 1$(\mu Pa)^2$s because of the 1 sec duration). The mean level for TTS onset was 195 dB_{RMS} re 1µPa (195 dB_{SEL} re 1$(\mu Pa)^2$s). At 0.4 kHz, no subjects exhibited shifts after exposures up to 193 dB_{RMS} re 1µPa. The data at 75 kHz were inconclusive - one dolphin exhibited measurable TTS after exposure at 182 dB_{RMS} re 1µPa but not at higher exposure levels. The other dolphin did not show any shift after exposure to maximum levels of 193 dB_{RMS} re 1µPa.

Finneran *et al.* (2003, 2005) measured TTS in bottlenose dolphins exposed to 3 kHz tones with durations of 1, 2, 4, and 8 seconds. Small amounts of TTS (3-6 dB) occurred in one dolphin after exposure to between 190 and 204 dB_{SEL} re 1$(\mu Pa)^2$s. These results were consistent with those of Schlundt *et al.* (2000). They also confirmed that for tonal noise of variable duration, the amount of TTS was best correlated with exposure SEL, rather than RMS sound pressure level.

Additional research on odontocete TTS was performed by Nachtigall *et al.* (2003) using continuous noise. They exposed a bottlenose dolphin to octave-band noise with 7.5 kHz center frequency and maximum sound pressure level of 179 dB_{RMS} re 1µPa and ~212 to 214 dB_{SEL} re 1$(\mu Pa)^2$s for 30 min. They measured TTS 10-15 min after exposure. They found shifts of approximately 11 dB. The total experimental time exceeded the net exposure time because the subjects had to surface to breathe during experiments. This time was measured and factored into the SEL measurement. No TTS was observed after exposure at a maximum sound pressure level of 165 and 171 dB_{RMS} re 1µPa (~ 198 to 200 dB_{SEL} re 1 $(\mu Pa)^2$s and 204 to 206 dB_{SEL} re 1$(\mu Pa)^2$s respectively). The same researchers also measured TTS five minutes after exposure using evoked potentials (Nachtigall *et al.* 2004) (maximum SPL: 160 dB_{RMS} re 1µPa and ~193 to 195 dB_{SEL} re 1$(\mu Pa)^2$s). The difference in results (slightly lower TTS for exposures of much lower exposure energy) was attributed to faster post-exposure threshold measurement, and thus less opportunity for recovery in the Nachtigall *et al*. (2004) study.

The lowest levels for which TTS has been observed in odontocetes is about 190 dB_{SEL} re 1$(\mu Pa)^2$s. The shifts were of short duration and small (3-11 dB). In the case of the pulse from a seismic watergun, the shifts were from 1-7 dB and recovery occurred within 4 min. Low to moderate TTS results primarily from the fatigue of cochlear hair cells and supporting structures, rather than damage (Nordmann *et al*., 2000). Therefore the possibility of small effects accumulating over time is low. An estimated threshold of injury of 190 dB_{SEL} re 1$(\mu Pa)^2$s should be considered conservative because it does not include a correction factor for the substantially higher levels required to produce permanent threshold shift, PTS. In humans, when threshold shift magnitudes for single exposures exceed approximately 40 dB, the likelihood of PTS begins to increase substantially (Kryter 1994), whereas no permanent loss is expected after shifts of the sizes reported above.

A received level of 180 dB_{RMS} re 1 µPa has been used for some years as an *ad hoc* limit to prevent auditory injury (such as PTS) to mysticetes exposed to seismic survey pulses (National

Marine Fisheries Service [NMFS] 1995). At the time the limit was set, there was no specific evidence that exposure to higher levels of pulsed sounds would cause auditory or other injury in mysticetes (and no direct measurements are available to date). Instead, the value was a conservative (i.e. risk-averse), informed estimate made by experts based on experience with terrestrial animals.

4.2.3 Behavioral Responses

Background: Available data on mysticete responses to seismic surveys include reactions to opportunistic and controlled exposures of non-migrating bowhead whales (Ljungblad *et al*., 1988), humpback whales (Malme *et al*., 1985; McCauley *et al*., 1998, 2000a; Todd *et al*., 1996), and gray whales (Malme *et al*., 1983; 1984; 1986; 1988; Moore and Clark, 2002). Reports by Ljungblad *et al*. (1988), Malme *et al*. (1983; 1984), and McCauley *et al*. (1998, 2000a) contain sufficient information on exposures and individual responses for detailed examination. This information has been previously discussed by the WGWAP and its predecessors (WGWAP 2006).

Received SEL is likely to be the best measure of responses to noise of different types. However, the available data on exposures to seismic noise have been limited to estimation of the average level of pulses, expressed as RMS sound pressure level, and peak pressure level (peak-to-peak, 0-to-peak). In every case, the received level at the whale was estimated based on some type of propagation modeling and the duration of exposure was relatively short (e.g., the duration of a playback experiment or the time it took a whale to cross the path of a seismic vessel). Therefore, the available data describe short-term responses only and are not completely comparable because the sources, observation ranges, and environmental conditions varied from study to study, which would have affected received levels (RL) substantially.

In addition, the following review must be read with the understanding that no adequate experimental study has directly measured the relationship between exposures and gray whale responses to seismic sources either on the feeding grounds or in calving areas. Therefore, the available data must be interpreted with caution because social or behavioral context has been important in studies with both gray whales and other mysticetes. For example, migrating gray whales responded at greater ranges for the equivalent received level when the experimental source was within the migration path as opposed to offshore of it (P. Tyack, pers. comm.). McCauley et al. (1998, 2000a) reported that single migrating humpback whales (most likely males) altered course to move towards an experimental airgun and a working seismic vessel, approaching within a few hundred meters during experiments, apparently mistaking the pulses for the surface-active behaviors of rival males. Cows with calves, on the other hand, avoided both the vessel and airgun at greater ranges and lower received levels than other age/sex classes.

Also, it is important to recognize that although studies with experimental sources (e.g. a single airgun, playback) provide valuable information on specific responses of whales to a controlled noise source, they are hampered by the limitations of the sound projector and rarely simulate exactly the noise that would be projected from a working vessel, especially at low (<100Hz) frequencies. For example, a single airgun fails to simulate a long array in either transmission loss with distance or directional cues.

Summary of Available Research: Ljungblad *et al*. (1988) conducted a series of controlled experiments to assess behavioral reactions of non-migrating bowhead whales to noise from a single airgun. The results indicated that bowheads are relatively sensitive to seismic exposures.

Experiment 1 was conducted on a group of 8 whales. When the experimental vessel approached to within 3.5 km (maximum received level measured at the site where individuals passed was 142 dB_{RMS} re 1µPa), the whales congregated and moved in a tight group away from the approaching vessel. Experiment 2 involved a group of 3 whales that startled at the activation of the source 7 km away (maximum measured received level was 165 dB_{RMS} re 1µPa). Behavior returned to pre-exposure values shortly after operation ceased. Experiment 3 involved a group of 7 bowhead whales that avoided the source at ranges of approximately 3.5 km (maximum measured received level as 178 dB_{RMS} re 1µPa). Experiment 4 involved a group of 50 whales. Behavioral reactions were first observed at about 8 km distance (maximum measured received level was 157 dB_{RMS} re 1µPa) and consistent avoidance was noted at ~3 km (received levels ~165 dB_{RMS} re 1µPa). The whales stopped swimming away shortly after shooting ceased. Total exposure levels in dB_{SEL} have not been computed for these experiments.

Malme *et al*. (1983, 1984) documented behavioral reactions of migrating gray whales to seismic pulses from both single airguns (100 in^3) and an airgun array (number of guns and frequency of pulses were not known to the Task Force). An important methodological distinction relative to the other studies was that only land-based observers were used, which limited observational range but eliminated the potential bias of having a vessel present. Based on two years of experimentation on a large number of pods, Malme *et al*. found that migrating gray whales began to avoid seismic pulses at levels >160 dB_{RMS} re 1µPa. Based on a dose-response model developed using these data, Malme *et al*. (1984) calculated 10%, 50%, and 90% probabilities of gray whale avoidance reactions to be 164, 170, and 180 dB_{RMS} re 1µPa respectively. Exposure levels in dB_{SEL} have not been computed for these exposures.

McCauley *et al*. (2000a, b) conducted behavioral observations of migrating humpback whales near Exmouth Gulf in Australia during experiments using a single airgun (20 in^3) and a seismic array (2,678 in^3). Seismic track lines were oriented perpendicular to the migration path of the whales. McCauley *et al*. (2000b) provide acoustic measurements and detailed observational data from individuals and groups of whales. The seismic survey did not appear to grossly affect the migration of humpback whales (*i.e*., by halting the migration). However, avoidance behavior was observed close to the seismic vessel and experimental airgun. Whales began to avoid the sources at ranges from 5-8 km and nearly all avoided them at ranges of 1-4 km. Controlled exposures to the single airgun (20 in^3) were extrapolated to equivalent ranges for exposure from the full array. The data indicated onset of behavioral avoidance at 157-164 dB_{RMS} re 1µPa for the population on average, roughly equivalent to the received level from the full array at 3-4 km. McCauley *et al*. did not calculate a dose-response function for the proportion of the population responding by level.

Their observations included instances of whales hanging at the surface during trials, possibly taking advantage of the surface layer to avoid noise. A few large adults approached the sources at short range, 100-400 m, corresponding to received levels of 179 dB_{RMS} re 1µPa. McCauley *et al.* hypothesized that these were males actively investigating the source because the airgun pulses were very similar to those recorded during surface-active behaviors (pectoral slaps, tail slaps, breaching), which are associated with male-male competitive interactions. Cows with calves avoided the experimental source at levels down to 140 dB_{RMS} re 1µPa (McCauley *et al.* 2000a). The cows could have been avoiding the seismic pulses because they mistook them for signals of competitive males. However, it is also possible that mothers with calves are generally more sensitive than other age/sex classes to noise disturbance. The Task Force did not have the published papers to hand, and could not determine whether effective exposure levels in dB_{SEL} could be computed for these exposures.

The research on migrating gray whales by Malme and his coworkers (Malme *et al*. 1984) potentially represents a basis for predicting avoidance behavior by WGWs, but some individuals can be expected to be more sensitive. No direct measurements of effects on feeding gray whales have been made, but the data from Malme *et al.* have been used previously to predict sensitivity of feeding eastern gray whales and WGWs (Reeves et al.2005) . The Malme *et al*. data lead to estimated 10%, 50%, and 90% probabilities of gray whale avoidance reactions at 164, 170, and 180 dB_{RMS} re 1μPa, respectively. The RMS measurements reported by Malme *et al*. (1984) cannot be compared directly with predicted values for Astokh 4-D pulses because the seismic sources, pulse propagation, bottom topography, spectral characteristics etc. differ substantially between the two scenarios. In particular, information on the rate and number of pulses to which the whales in the Malme *et al*. study were exposed would be required in order to determine their total sound exposure in units of dB_{SEL}.

In summary the Task Force was not in a position to draw any firm conclusions from this brief review of the published literature relating to behavioural responses to noise. It **recommends** that a more detailed review of the available information be conducted: in particular, the temporal pattern and nature and duration of exposures in each study should be ascertained where possible, such that the results of each study can be directly compared both across studies and with respect to their implications for the proposed Ashtok and future seismic surveys. The Task Force was unable to conduct this review in the time available. Neverheless it noted the results of Malme *et al.* indicating that exposure to 164 dB_{RMS} or less might be expected to produce an avoidance response by some gray whales (albeit probably fewer than 10% of those exposed), at least for sounds of nature and duration similar to those used in the Malme *et al.* study. The Task Force did not have at its disposal the information on the duration and total sound energy to which the whales in that study were exposed.

4.3 Recommended Exposure Guidelines

4.3.1 Guidelines for Preventing Auditory Damage

As described in Section 4.1, there is very little data on the potential for seismic surveys to cause hearing damage, either TTS or PTS, in mysticete whales. The Task Force was therefore unable to recommend a specific maximum acceptable sound level exposure for individual whales. In this situation, the Task Force agreed that at a minimum, the current practice should be retained of establishing an "exclusion zone" around the seismic vessel that completely encloses the 180 dB_{RMS} re: 1 μPa isopleth. A180 dB_{RMS} re: 1 μPa shut-down limit is consistent with current industry guidelines and previous authorizations of the National Marine Fisheries Service of the United States (the government agency responsible for authorizing potential impacts of seismic surveys on marine mammals) (NMFS, 1995).

It should be noted that operation of an exclusion zone based on 180 dB_{RMS} does not ensure that no whale will be exposed to greater than this level. As discussed below, whales will not necessarily be immediately detected on entering the zone. The motivation behind the180 dB_{RMS} threshold is that it should be sufficiently precautionary to trigger a mitigation response (such as shut-down of source activity) in time to ensure that the actual maximum sound levels to which a whale might be exposed do not approach injurious levels.

The expected number of whales liable to be exposed to different sound levels needs to be examined in each specific seismic survey, because it depends on factors related to the detectability of whales, such as observer effort, sighting conditions, etc. For the planned Astokh

survey, this issue is examined in section 7. Furthermore, the total amount of sound energy, expressed in units of dB_{SEL}, to which whales at different distances of "closest approach" will be exposed during a passage of the seismic vessel depends not only on the loudness of each pulse, but also on the frequency of the pulses, and the speed of the vessel. This is examined in section 5.

In accordance with current practice, the 180 dB_{RMS} safety zone also determines the area that should be clear of whales when the air guns are started up (in the sense that no whales have been detected within this area during a specified period prior to start-up). The common industry practice of 'ramp up', whereby gun volume is added over several minutes, is premised on the hypothesis that any animals within range of the guns will move away as the intensity of the sound increases. This hypothesis has not been tested, and ramp-up could result in additional exposure, as animals may tolerate a sound that is initially non-injurious but that reaches damaging levels gradually. Without evidence to the contrary, however, the Task Force agreed that ramp-up should still be used. Another, similarly unproven industry standard practice is to leave a single, small-volume gun operational during turns between acquisition lines. This practice is based on the unverified assumption that whales will hear the single small gun and will thus not approach the array where they might later be exposed to injurious levels of sound. It is also presumed that by alerting a whale to the position of the gun array, continuous operation of the single small gun reduces the risk that a whale will become entangled in the array or streamers. The merits of this practice are especially uncertain given that it can increase a whale's overall exposure to air gun sounds. Again, however, the Task Force agreed that it had insufficient information to recommend any departure from the industry standard practice.

4.3.2 Guidelines for limiting behavioral disturbance

The Task Force agreed that behavioral disturbance to whales in the feeding ground sufficient to have a significant energetic impact on individuals, especially females with calves, should be avoided. However, the Task Force agreed that it had insufficient information at its disposal to set a specific exposure threshold that would ensure that no such disturbance occurred.

Pending the availability of more information, the Task Force agreed that SEIC's plan to limit maximum noise exposure at the edge of the feeding ground to 165 dB_{SEL} re 1 $(\mu Pa)^2s$ per pulse, was a reasonable mitigation measure, on the understanding that it would be expected to result in maximum exposures of less than 164 dB_{RMS} over at least 95% of the feeding ground (see section 5). As discussed in section 5, the threshold of 165 dB_{SEL} per pulse corresponds to approximately 175 dB_{RMS} at the edge of the feeding ground.

The Task Force recognized that, even with enforcement of this threshold, a part of the feeding area could still be ensonified at levels that would cause temporary behavioral disturbance and that may or may not be biologically significant. It is therefore important that sufficient acoustic and behavioral monitoring resources are in place to detect possible responses to sound levels so that the guideline can be refined in future.

The Task Force **recommends** that if 165 dB_{SEL} re: 1 $(\mu Pa)^2s$ is exceeded at the edge of the feeding ground, mitigation measures be triggered to ensure that no whales within the feeding ground are exposed to greater than this sound level. Details of the proposed measures are given in section 7.

The Task Force emphasises that the recommendation for a threshold of 165 dB_{SEL} per pulse is based on limited information and should not set a precedent for future surveys.

5 REVIEW OF ACOUSTIC MODEL TRIALS

As discussed at the 2nd WGWAP meeting (WGWAP 2007) and as reflected in the Task Force's terms of reference, a principal objective was to obtain information on the likely exposure of gray whales to sound within the feeding areas, taking into account relevant uncertainty (i.e. both model uncertainty and uncertainty associated with input parameters).

The principal mathematical tool used to estimate levels of exposure to sound energy from the planned Astokh 4D survey is a Parabolic Equation (PE) acoustic model developed by JASCO Research. Roberto Racca of JASCO began the formal discussion of numerical modelling at the workshop with a presentation of the progress made since the preliminary results were presented at the St Petersburg WGWAP meeting in April 2007. The revisions and advancements of the modelling fell primarily along three lines: i) the airgun array configuration and exact geometry of the survey area had been updated to reflect the definitive specifications from Sakhalin Energy including a slightly lower array volume; ii) the sensitivity of the model output to variations or uncertainties in the input parameters had been investigated; and iii) full waveform modelling had been carried out along some selected radials to estimate the precise wave shape of the received airgun pulses at different ranges to permit derivation of the numerical relationship between the sound exposure level, root mean square and peak-to-peak metrics.

JASCO presented the sensitivity analysis outcome in the form of a table (below) listing the ranges of various parameters explored and the resulting variation in the predicted propagation distance to a test level of 150 dB_{SEL} re 1(µPa)²s per pulse. This test level was chosen for its approximate equivalence to the 160 dB_{RMS} threshold cited by regulatory agencies in terms of onset of behavioral response in some cetaceans.

The key configuration and criteria used in this sensitivity analysis are listed below:

- Airgun source modeling location was at the most inshore NW corner of the optimized Astokh survey area outline, i.e. the closest point of the survey to the near-shore feeding area.
- Three sample radials were considered; their orientations relative to the airgun array tow axis heading (-10° to North) and topographical features were:
  - Broadside shoreward (-100°)
  - Endfire southward (170°)
  - Broadside seaward (80°).
- The nominal values for each parameter were based on the optimized set obtained from model validation and tuning (JASCO 2005) against available transmission loss (TL) measurements, and later refinements. These values had been used by JASCO throughout the initial acoustic modelling of the Astokh 4D survey as well as in all industrial acoustic levels forecasting for SEIC Piltun offshore construction for the 2005, 2006 and 2007 seasons.
- Propagation modelling was carried out in individual third-octave bands from 5Hz to 2000Hz, ultimately summing the received levels in the various bands to yield broadband values. Third-octave band modeling, which JASCO has used in all its numerical estimation of acoustic levels for the Astokh survey, considers source and propagation properties at 27 centre frequencies.
- For most of the parameters JASCO defined a variability range extending both above and below the nominal value, unless the latter was considered to be already at the upper or lower limit of its physically realizable range. The parameters were varied independently of each other.

					Resulting range to 150 dB re µPa SEL								
	Parameter	Minimum	Nominal	Maximum		Broadside shoreward			Endfire southward			Broadside seaward	
					r(min)	r(nom)	r(max)	r(min)	r(nom)	r(max)	r(min)	r(nom)	r(max)
Sediment	P-wave speed	1612 m/s-2112 m/s (0-500m); 2112 m/s (>500m)	1652 m/s-2152 m/s (0-500m); 2152 m/s (>500m)	1692 m/s-2192 m/s (0-500m); 2192 m/s (>500m)	8.1km	8.4km	8.7km	5.7km	6.8km	7.4km	9.4km	9.8km	10.9km
	P-wave gradient	1652 m/s 0.8 m/s/m to 500m	1652 m/s 1.0 m/s/m to 500m	1652 m/s 1.2 m/s/m to 500m	8.4km	8.4km	8.4km	6.6km	6.8km	6.9km	9.8km	9.8km	10.0km
	P-wave attenuation		0.14 dB/λ	0.5 dB/λ		8.4km	5.3km		6.8km	3.5km		9.8km	6.0km
	Density	1.722 g/cc	1.772 g/cc	1.822 g/cc	8.5km	8.4km	8.3km	6.6km	6.8km	6.8km	9.8km	9.8km	10.2km
	S-wave speed	50 m/s	150 m/s	250 m/s	9.8km	8.4km	5.5km	9.0km	6.8km	4.9km	12.9km	9.8km	6.4km
	S-wave attenuation	2.6 dB/λ	13.6 dB/λ		9.8km	8.4km		8.2km	6.8km		12.0km	9.8km	
Water column	Sound speed profile gradient	0m: 1480m/s 30m: 1480m/s	0m: 1482m/s 6m: 1481m/s 10m: 1480m/s 30m: 1462m/s		9.4km	8.4km		7.1km	6.8km		11.8km	9.8km	

Table 5.1. Sensitivity of predicted attenuation (expressed as range to 150 dB re 1 (µPa)²s per pulse) to various parameters of the JASCO model

The sensitivity analysis showed a markedly stronger response of the test metric to changes in certain parameters than to others. JASCO highlighted in particular the sensitivity to the shear wave geo-acoustic properties of the sediment (shear velocity and shear attenuation profiles, evidenced by shading in the table). Because these parameters were considered by JASCO to be poorly defined in terms of available geophysical data, their approach was to eliminate these quantities from the search space by fixing them at optimized values. These were obtained by minimizing the total residual over a range of frequencies between model predicted TL and corresponding experimental measurements conducted in Piltun in 2004 for a number of transects, each several kilometers long and spanning different areas in the Piltun region relevant to the Astokh 4D survey sound propagation. To perform this optimization JASCO held all non-shear modeling parameters fixed at their nominal values and minimized the cost function (discrepancy) by varying the shear wave velocity. The shear wave attenuation was set to its nominal value, which yielded well-defined minima. The plots of cost function presented by JASCO showed that each transect gave a somewhat different optimal shear velocity, with the aggregate difference having a single minimum at 150m/s.

The Task Force discussed at length the sensitivity analysis approach presented by JASCO and in particular the assumptions on which the fixing of the shear wave parameters was based. This discussion expanded to a broader debate of the relative merits of estimating model parameters through a process of optimization against TL measurements for unavailable or poorly defined physical quantities, versus the more direct approach of securing geophysical data of the highest quality for input into models. The Task Force agreed that better geophysical data should be used where available and where it is practical to include them into models, but that even with the best input data some tuning of parameters values to match TL measurements from the field would likely be needed.

The Task Force noted that the fitting of the model to observed TL measurements had been performed in a relatively informal, *ad hoc* manner to date. It **recommends** that in future work, attention be paid to placing the comparison of prediction and measurement on a more orthodox statistical footing, so that the variability (e.g. between different locations and times) in the discrepancies between model and predictions can be accounted for in a statistically appropriate

manner. For example, in the above results it was not obvious how the results from the different transects should be combined, and how the variability between them should be handled.

On the basis of the sensitivity analysis after exclusion of the shear wave parameters, JASCO singled out the compressional sound speed profiles in the substrate and the water column as the parameters having greatest influence on model results. Of the two, the former is temporally invariant but has a range of feasibility due to imprecise knowledge of the geophysical properties of the seafloor whereas the latter can actually exhibit considerable temporal variability on a scale of days to weeks. Most measurements of sound velocity profile taken in the Piltun region during the summer ice-free period show the water column to have a downward refracting profile, which tends to induce greater attenuation of propagating sound by causing it to impinge onto the absorptive sediment. The nominal condition in the JASCO modeling parameters is a downward refracting profile based on an average of measured properties. Because of the potential early-season start of the Astokh 4D survey, however, the Task Force concluded that an isovelocity profile – in which the sound propagates more linearly through the water column with fewer interactions with the bottom – **should be considered** as a precautionary limit for the water temperature conditions that could exist.

Some results of JASCO's full-area modeling of sound levels from four locations along the inshore edge of the seismic survey navigation area are shown in Fig. 5.1 below. The source was positioned at a depth of 6 m, the mandatory operational depth for the Astokh 4D survey. The modeling was repeated using, in one case, the nominal values for all parameters and, in a second case, the precautionary combination of isovelocity water column profile and sediment compressional speed profile at the top of its assumed range. The contours were computed from the maximum sound level estimated over all receiver depths, based on a vertical sample spacing of 2m from surface to sea floor.

JASCO also demonstrated the operation of their model in full waveform mode, whereby the modeling of the propagated signal is performed not in relatively wide frequency bands but at 1Hz resolution between 2Hz and 2000Hz. This computationally intensive operation allows the synthesis of essentially perfect renderings of an evolving airgun array pulse shape as it propagates in the specified environmental conditions. This enables the precise estimation of sound level metrics that, unlike the SEL, are directly dependent on the received primary pulse amplitude (peak to peak) and its effective duration (rms). JASCO presented level versus range plots in all three metrics for the impulsive sound from the Astokh 4D array propagating along variously oriented radials. Although full wavefront modeling is the only rigorous way to estimate all metrics, results computed along a certain radial may be effectively used to convert the SEL output of third octave band modeling over a reasonable spatial neighborhood. The full waveform runs have shown that, for the particular pulse shape and propagation conditions of the Astokh 4D survey, using a conversion factor of 10 dB to convert from SEL (per pulse) to RMS levels is approximately valid near the edge of the feeding ground. The Task Force noted that the relationship is potentially sensitive to the convention used to define the envelope and duration of a pulse.

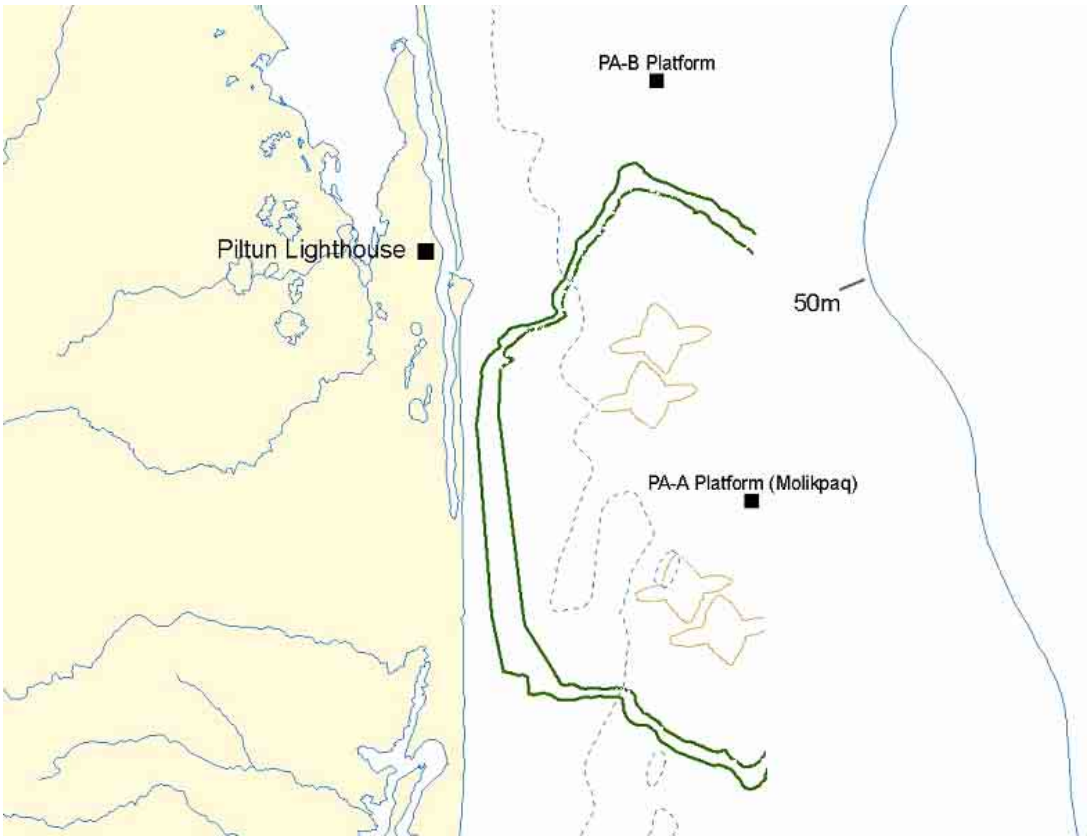

Fig. 5.1. The four somewhat rhomboidal outlines north and south of PA-A are the 165 dB_{SEL} (per pulse) contours for the individual shot points; their shape is indicative of the directionality of the laterally propagating sound front from the airgun array. Only the results obtained with the nominal parameters are shown; the small difference in the contours for the precautionary limit is nearly imperceptible at the map scale. The two outlines extending shoreward are the nominal (inner) and precautionary (outer) renditions of the 150 dB_{SEL} (per pulse) sound level fronts, obtained by merging the outlines of the contours for the four shot points and defining a linear tangent to their most shoreward lobes. The propagation contours in the offshore direction were not computed in these runs. It bears repeating that these contours are based on shot points nearest to the feeding area.

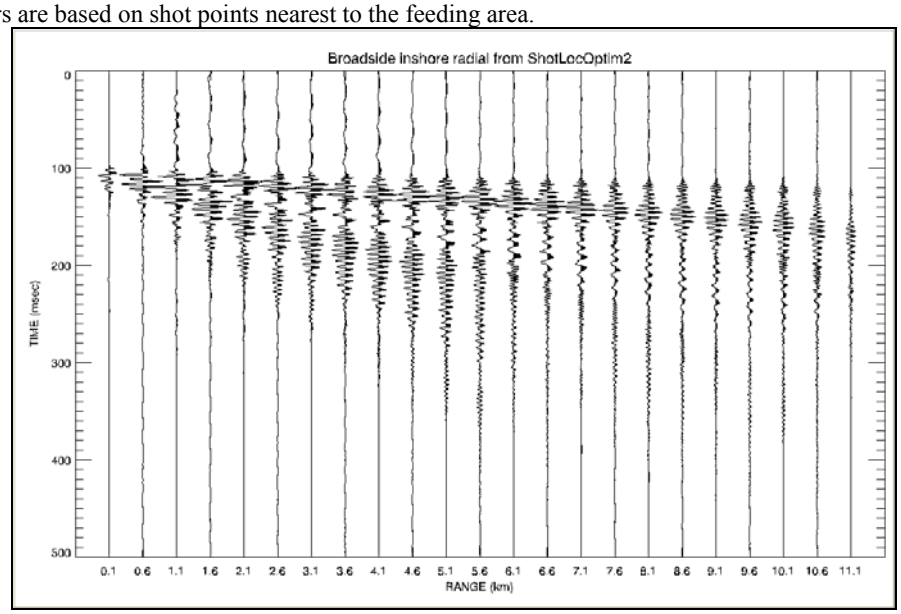

Fig. 5.2. Synthesized pulse shapes for a single airgun pulse at increasing distance along an inshore radial traverse.

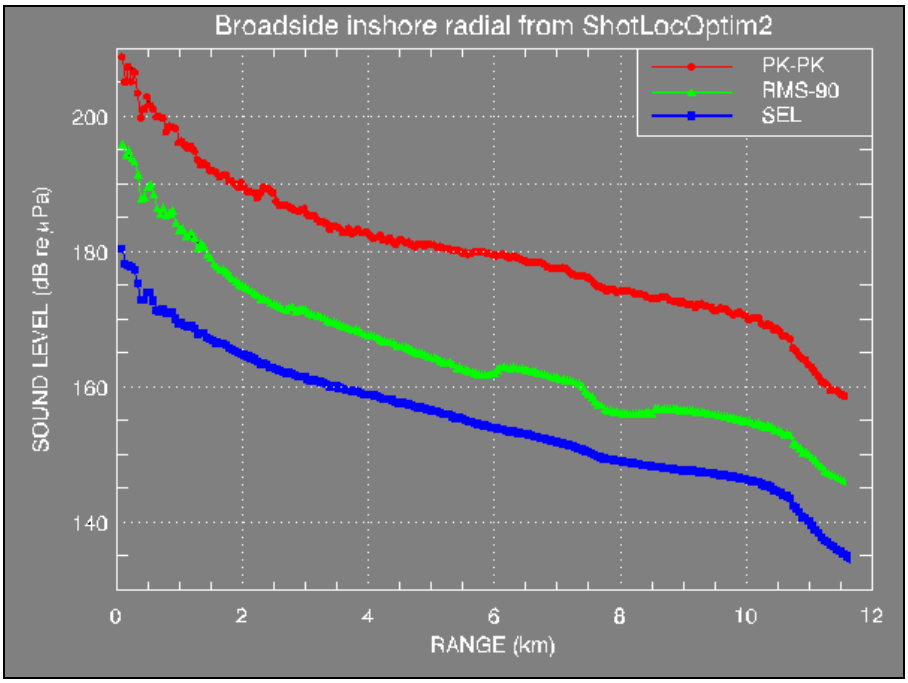

Fig 5.3. The corresponding sound level vs. range curves for the SEL per pulse, RMS and Peak-to-Peak metrics.

Alexander Vedenev of the Institute of Oceanology of the Russian Academy of Sciences (IO-RAS), also on behalf of his colleagues K. Avilov and V. Goncharov, presented results of parallel work that complemented the modeling effort performed by JASCO but also opened up an intense and productive dialogue on the relative merit and weaknesses of different approaches to defining the modeling environment. While the IO-RAS model and the JASCO model are based on the same fundamental approach to solving the wave equation, they implement different mathematical approximations in the process. The technical details of the two methods transcend the scope of this report, but there are unique aspects to the two approaches that would warrant a properly designed and executed comparison between the outputs of the two models for a given set of parameters, specifically related to the Astokh 4D survey source and environment. Aside from the overall agreement in results, the stability of each model in terms of sensitivity to changes in inputs would be a very important factor to consider.

Vedenev presented an assessment of the IO-RAS model performance and the results of various benchmark comparisons against experimental measurements and adiabatic normal mode modeling. All of these examples showed excellent cross-agreement. He then addressed the directly relevant matter of agreement of model results with the TL measurement studies carried out in the Piltun region in 2004 which form the basis for the JASCO model validation and tuning. Starting with a finely resolved geological profile of the seafloor from studies reported in the SEIC TEO 1997, they defined a detailed, multi-layer template of the properties of the sediment. The conversion from geological to acoustic parameters was performed in accordance with the theory in a recent paper by Buckingham (2005). The matching of model results and TL measurement data was then performed at selected frequencies for each of the study transects, and in each case the geological stratification model was carefully adjusted from the base case to give optimal match. The underlying premises in this approach are that the composition of the seafloor even on a relatively small area like the Piltun region is intrinsically varied to the extent of affecting significantly the acoustic propagation in different zones, and furthermore that the geo-acoustic properties for a given sediment composition are frequency dependent. Vedenev stressed

the importance of direct measurement of the geological properties of the seafloor at a number of locations. Specifically he indicated that in studies performed by Avilov the properties of the top 10m of sediment, which can be quite varied even on a small geographical scale, are crucial to determining the sound propagation. From this standpoint Vedenev and his colleagues argue that any modeling approach that uses a generalized seafloor model for the Piltun area, regardless of how well tuned it might be through global matching to TL measurements, will be subject to significant error. The potential magnitude of this error, for a model using reasonably well selected geo-acoustic parameters but not specifically matched to local variations in the upper bottom properties, has been estimated by the Russian subgroup to be in the order of 6-10 dB. This implies that effort should be made to obtain any previously collected geophysical data especially for the superficial layers (such as might be routinely measured as a preparatory step prior to underwater construction), and these data should be used to increase the accuracy of the geo-acoustical parameter estimates.

The Task Force agreed in principle that the use of more detailed geophysical data would be desirable, but did not have sufficient information on the nature of the data that have been gathered for this area to determine how much extra work its use would involve and how much it could improve the accuracy of predictions.

In the course of the workshop Avilov was contacted by telephone and follow-up email at his institute in Moscow and asked to provide two representative geo-acoustic profiles based on the TEO geophysical information that would bracket in his opinion the range of top-layer geological variation that could be expected in the Astokh area. Avilov provided two realizations of geo-acoustic profiles (Table 5.2). One of them (Case B) was closely related to the original geophysical description; the other (Case A), however, had significant departures in the top layer properties that arguably exceeded any reasonable geological variation, but this realization was nevertheless used as a sensitivity test for the model.

The JASCO model was run using both of these parameter sets along the same shoreward propagation radial that had been used for the original sensitivity study. As shown in the table below, the results for the profile that reflected the true geophysical properties (Avilov B) matched to within about 1 dB the levels obtained using the nominal parameters from the JASCO validation study, despite the fact that the latter used a much less finely resolved geo-acoustic profile.

Parameter		Case A	Case B
P-wave speed		z=0, cp=1541.6m/s	z=0, cp=1644.7m/s
		z=150, cp=1848.3m/s	z=150, cp=1971.5m/s
S-wave speed		z=0, cs=0	z=0, cs=104.9m/s
		z=150, cs=439.7m/s	z=150, cs=557.2m/s
Density		1.90 g/cc	2.00 g/cc
P-wave attenuation		z=0, bp=0	z=0, bp=0.27dB/λ
		z=150, bp=1.12dB/λ	z=150, bp=1.30dB/λ
S-wave attenuation		z=0, bs=3.66dB/λ	z=0, bs=3.66dB/λ
		z=150, bs=3.66dB/λ	z=150, bs=3.66dB/λ

Table 5.2. Parameters of two alternative geo-acoustic profiles used for testing the sensitivity of the JASCO model

SEL (r)	1km	2km	3km	4km	5km	6km	7km	8km
JASCO	170 Db	166 dB	162 dB	159 dB	157 dB	154 dB	152 dB	150 dB
Avilov B	170 dB	165 dB	162 dB	159 dB	156 dB	154 dB	153 dB	152 dB
Avilov A	170 dB	167 dB	163 dB	161 dB	160 dB	158 dB	156 dB	156 dB

Table 5.3 Comparison of predicted received sound levels (dB_{SEL} re 1 $(\mu Pa)^2s$) as a function of distance (in the broadside, inshore direction) from the JASCO model using the base-case parameters and the two alternative geo-acoustic profiles

The modeling results for the mismatched profile (Avilov A) were uncharacteristic of any of the other sensitivity analysis runs performed. The discrepancy along the test traverse relative to the JASCO parameters run, although moderate for distances up to a few km, built up at longer ranges where the upward-sloping seafloor played a more prominent role and reached 6 dB by the 8km range.

Part of the uncertainty in sound propagation modeling stems from the inability of most present algorithms to account fully for three-dimensional deflection of acoustic energy including horizontal refraction, which in the Astokh survey case could lead to alongshore propagation of sound initially directed toward the shoreline. The Russian subgroup used a 3D ray trace model to explore the influence of horizontal refraction on the sound levels reaching WGWs in the feeding grounds. The 3D model predicted slightly lower TL than an equivalent 2D algorithm as the range increased, but only to a maximum difference of 2 dB at 12 km. The task force **concluded** that for the Astokh survey the current 2D models are not significantly hampered in forecasting accuracy because of 3D effects. Should 3D modeling capability be required in other environments with more complex topography, a 3D Parabolic Equation code or similar would have to be used since ray trace algorithms cannot handle the low frequency components that are prominent in the acoustic signature of airguns.

In conclusion, the Task Force recognised that the analyses conducted to date did not necessarily characterise the full range of uncertainty in the model predictions of noise levels. It therefore **emphasized** the importance of empirical re-calibration of the models during the actual survey, to correct any major mismatch between predictions and observations, and developed recommendations accordingly, as detailed in section 7.

The Task Force did not address the issue of total SEL exposure arising from multiple pulses emitted during the passage of the seismic vessel using either of the above models, partly because there are currently no established standards for behavioural influence based on cumulative SEL.

The expected distribution of sound energy levels experienced by whales that may be present in the sesmic survey area is examined in section 7.

6 WHALE DENSITY DISTRIBUTION DATA

6.1 WGW Density Analysis

Systematic aerial, vessel, and two (behavior and vehicle) shore-based scan surveys to monitor the seasonal distribution and number of western gray whales (WGWs) along the NE Sakhalin coast have been conducted on an annual basis since 2002 (Würsig et al. 2003; Blokhin et al. 2003a, 2003b; Maminov 2004; Gailey et al. 2005, 2006, 2007; Vladimirov et al. 2005, 2006, 2007). These surveys have been designed to provide quantitative information on:

i) The distribution and number of WGWs (all surveys) and WGW feeding plumes in the Piltun feeding area (aerial surveys).

ii) The distribution and number of WGWs in the Offshore feeding area and over a broader area of the NE Sakhalin shelf (aerial and vessel surveys).

The WGW distribution data from these systematic surveys have been analyzed to produce estimates of whale densities at a 1 km^2 resolution. The analysis involves a new method developed by LGL Limited in consultation with Trent McDonald, a statistician with West Inc., and the University of St. Andrews, developers of the Distance Sampling software (Thomas et al. 2006) used in the analysis. The study area is divided into a grid of 1.0 x 1.0 km cells with a WGW density estimated for each cell that has been sampled by the systematic surveys. Survey data from the period 26 September to 19 October 2004, when non-SEIC geophysical seismic surveys were underway were excluded from the calculation of average density estimates because of the possibility that whale distribution was affected. Before performing the density calculations, WGW sightings are corrected for two types of bias that typically result in underestimation of animal abundance (Marsh and Sinclair 1989):

i) Availability bias: The probability that WGWs are available to be seen at the surface during a particular survey based on the amount of time an area of water is observed during the survey (dependent on the size of the area in view, and the aerial/vessel survey speed or binocular scanning rate at shore-based stations), and the WGW surface-respiration-dive cycle in the survey year (Wursig et al. 2003; Gailey et al. 2004, 2005, 2006, 2007).

ii) Perception bias: The probability that an observer will perceive an available gray whale. Distance sampling (Buckland et al. 2001, Buckland et al. 2004) is used to analyze the effects of distance and other factors (e.g. sea state and WGW group size) on the probability of detecting an available gray whale. Distance 5.0 (Thomas et al. 2006) was used to model detection functions for the aerial and vessel-based surveys. The shore-based detection function was assumed to be flat (i.e. the detection probability does not decrease with increasing distance from the observation station) for up to 0.1 reticle radial distance (range 4.5 to 10.8 km) from each shore station, to a maximum of 8 km distance. This detection function is based on an analysis conducted by the University of St. Andrews. The model they fitted included both shore-based and ship-based sightings in a joint analysis to estimate parameters of a shore-based detection function. An important assumption of the analysis is that the detectability of whales from the ship does not depend on distance from shore. In addition, the effects on the shore-based detection

function of variables other than distance were not considered. WGW sightings beyond the maximum distance assumed for a flat detection function at a shore-based observation station were excluded from the density analysis.

A WGW density is estimated for each grid cell that was sampled during a particular survey by summing that survey's corrected WGW sightings in that grid cell, and then dividing by the area that was surveyed in the grid cell. An estimated density of zero is assigned to a grid cell if no WGWs were sighted within it. The grid cell WGW densities estimated for each survey are maintained in a database that allows them to be extracted for selected combinations of survey type and time period. These estimates are then averaged within each grid cell to create WGW density surface maps at several temporal scales (e.g., monthly, yearly) that depict the WGW spatial distribution and abundance at a resolution of 1.0 km^2 for the surveyed area off the northeast Sakhalin Island coastline. For example, Fig. 6.1 shows the average WGW density in each surveyed grid cell based on all distribution data from the 2002 to 2006 aerial, vessel and shore-based vehicle surveys.

6.2 WGW density analysis sensitivity tests

As requested in Appendix 2 of the Task Force's terms of reference, sensitivity tests were conducted by LGL Limited to investigate the potential effects of parameter values, specifically grid cell size, grid cell shape, and length of the time period used to sample the survey data, on density estimates and consequently on the number of WGWs estimated to be within a study area for the years 2004 to 2006. All sensitivity tests used the same spatial and temporal boundaries. For the purpose of these tests, the Piltun feeding area was divided into 15 equal-sized blocks, with the number of WGWs estimated within a study area delineated by blocks 7 to 12 (approximately 385 km^2, Fig.6.2). Only the data from shore-based vehicle scan surveys during the month of September were used for the sensitivity tests, with survey data pooled across all 3 years that these surveys were conducted (2004 to 2006). These survey data and this time period were selected for the sensitivity tests because weather conditions were usually good, surveys were frequently conducted, and WGW abundance generally was high during this month. This meant that sample sizes were higher than they would have been for other months of the feeding season (June-October). A variety of grid cell sizes of both square and rectangular shapes were tested first. Then the results of these tests were used to select a single grid cell size for the time interval test. The following statistics were determined for each sensitivity test:

1) Average, maximum and standard deviation of the average WGW density for each grid cell in the study area pooled across all three years (2004 to 2006).
2) Average, maximum and standard deviation of the number of WGWs within the entire study area estimated by each test pooled across all three years (2004 to 2006).

Ten square and rectangular grid cell shapes from 1 to 25 km^2 in size were tested. The average grid cell density ranged from 0.14 to 0.20 whales/ km^2 (Fig. 6.3), with all grid cell configurations other than 8x2 (8 km wide, i.e. east/west, by 2 km high, i.e. north/south) having similar values. The 8x2 grid cells had the highest average density across all the grid cell configurations. Both the maximum grid cell density and the standard deviation of the average grid cell densities declined with increasing grid cell size, except for the 8x2 grid cells that had higher than expected values. The number of WGWs that were estimated in the study area was quite consistent across most grid cell sizes and shapes (Fig. 6.4), ranging from 43 to 48 WGWs. Again, the 8x2 grid cells were an exception, with 60 WGWs predicted to be in the study area.

The results of the sensitivity tests for grid cell size and shape clearly show that the wide 8x2 grid cells produce quite different results compared to other grid cell configurations. The remaining grid cell sizes and shapes produced average densities similar to the currently used 1x1 grid cell configuration. The decreasing values for maximum and standard deviation of grid cell average WGW densities with increasing grid cell size are a reflection of the increased smoothing across the WGW density gradient with respect to shore as the grid cell size increases. Based on these sensitivity tests, the Task Force agreed that the 1 km x 1 km grid cell configuration presently used in the WGW density analysis provides an adequate estimation of density and associated estimates of the number of WGWs present in a study area.

The time interval sensitivity test was conducted using the 1 km x 1 km grid cell configuration that was demonstrated in the first sensitivity test to provide adequate estimation of WGW density and numbers of WGWs in a study area. Three temporal intervals that have different WGW population trends in the Piltun feeding area were tested, with WGW densities and number of WGWs estimated for each temporal interval using time periods at 1 day increments from 3 to 31 days (Table 6.1).

Temporal Interval	**WGW population trend in Piltun area**	**Time window center**
Early Season	Increasing	7 July
Mid Season	Stable	21 August
Late Season	Decreasing	1 October

Table 6.1. Time interval sensitivity tests were conducted for the three temporal intervals in the feeding season. Time periods were centred on the day indicated for each temporal interval, with successive time periods constructed by adding 1 day to each end of the current time period.

The time interval test results for the early season showed the average of the grid cell average densities first declining as the time interval increased from 3 to 13 days, and then stabilizing (Fig. 6.5). The maximum and standard deviation of the grid cell average densities during the early season also declined until approximately the 15-days interval, then showed a small decreasing trend for the remaining time intervals that were tested (Fig. 6.5). The average of the grid cell average densities during the mid season, when the WGW population was relatively stable, showed little variation across all time intervals while the maximum and standard deviation stabilized at the 7-day time interval (Fig. 6.6). The averages of the grid cell average densities during the late season were fairly stable for time intervals from 3 to 11 days, and then steadily increased (Fig.6.7). The maximum and standard deviation of the grid cell average densities during the late season generally declined as time intervals increased to approximately 13 days, then were more stable for the remaining time intervals that were tested.

The number of WGWs estimated by the 1x1 grid cell configuration using different time intervals in the early season decreased from a maximum of 57 WGWs to approximately 34 WGWs at a time interval of 15 days, then remained quite stable at between 34 to 35 WGWs for longer time intervals (Fig. 6.8). During the mid season the number of WGWs increased until a 9-day time interval, then remained at between 51 to 55 whales (Fig. 6.9). Estimated numbers of WGWs during the late season showed greater variability, first decreasing to approximately 24 whales,

then increasing and remaining fairly constant at between 35 to 37 whales for time intervals of 19 to 31 days (Fig. 6.10).

Results of the time interval tests demonstrated that using fewer than 15 consecutive days to sample the WGW density data can introduce bias in the average grid densities and the number of WGWs estimated to occur in a study area.

6.3 Use of WGW density data to assess potential impacts from the 2008 SEIC seismic survey

The estimated number of WGWs within a predefined study area during a specific time period is a useful metric for a variety of management applications. SEIC presently derives this metric using average WGW densities estimated at a 1 km^2 resolution from systematic aerial, vessel and shore-based survey data collected from 2002 to 2006. Estimation is a 4-step process, as follows: (1) A WGW density is estimated for each grid cell that has been sampled by a given survey; (2) The density estimates from all surveys within a time period of interest are averaged for each grid cell in the study area; (3) The number of WGWs within each grid cell is estimated by multiplying the cell area by the average density in that cell; (4) Estimated numbers of WGWs are summed across all grid cells to determine the number of WGWs in the study area.

The seismic survey is planned to commence in late June/early July 2008. Since few surveys have been conducted in June, WGW average density estimates for a two week time period from 25 June to 9 July will be used instead to create a density map that displays the average estimated number of whales per km^2 for all 1.0 km^2 cells sampled within the Piltun feeding area during that time period. The Task Force was informed that, for the purpose EA, noise contour maps at different sound levels will be modeled for the seismic survey and used to estimate exposures of WGWs using the methods described above. The results of the sensitivity tests requested by the Task Force indicated that the grid cell size and time period used in this analysis are reasonable.

In summary, the Task Force considered that the data presented provided a useful indication of the average density of gray whales in the feeding grounds for the areas and time periods considered. The Task Force recognised that, in principle, a more orthodox statistical analysis of the data, that would yield quantitative probabilistic predictions of the ranges of numbers of whales expected to occur in different ensonification bands, including upper and lower confidence limits, could in principle have been considered. It nonetheless accepted that the information presented satisfactorily answered the requests contained in it the Task Force's terms of reference.

6.4 Proposed Piltun feeding area perimeter monitoring line

The Task Force **recommends** that sound levels at the edge of the Piltun feeding area be monitored in real-time using acoustic receivers stationed along the feeding area boundary (see section 7.2.3). A perimeter monitoring line for the Piltun feeding area was delineated using the following steps:

1) A 1.0 km by 1.0 km grid of average estimated WGW densities was produced for the Piltun feeding area based on the 2002 to 2006 systematic aerial, vessel and shore-based survey data using the methods described in section 6.1, above.

2) A 95% kernel density contour for the Piltun feeding area WGW density grid was determined using the ArcView 3.2 Animal Movement extension (Hooge and Eichenlaub 2000). Kernel density methods are statistical techniques to estimate a probabilistic density surface of an animal's or population's distribution (Seaman et al. 1998). The probabilities indicate the relative amount of time spent at a location (Seaman *et al*.1996).

3) The 95% kernel density contour was manually smoothed to reduce the effect of isolated non-zero density grid cells. The offshore segment of the smoothed contour that extended 10 km north and 10 km south of the shot area center was then extracted to delineate the Piltun feeding area perimeter monitoring line.

The resulting boundary is plotted in Figs 6.11-12. The densities of WGW by square, based on the entire data set (Fig. 6.11), or the data from 25 June to 9 July only (Fig. 6.12), are overlain, along with the predicted maximum noise isopleths in terms of dB_{SEL} per pulse from the 2008 Ashtokh seismic survey.

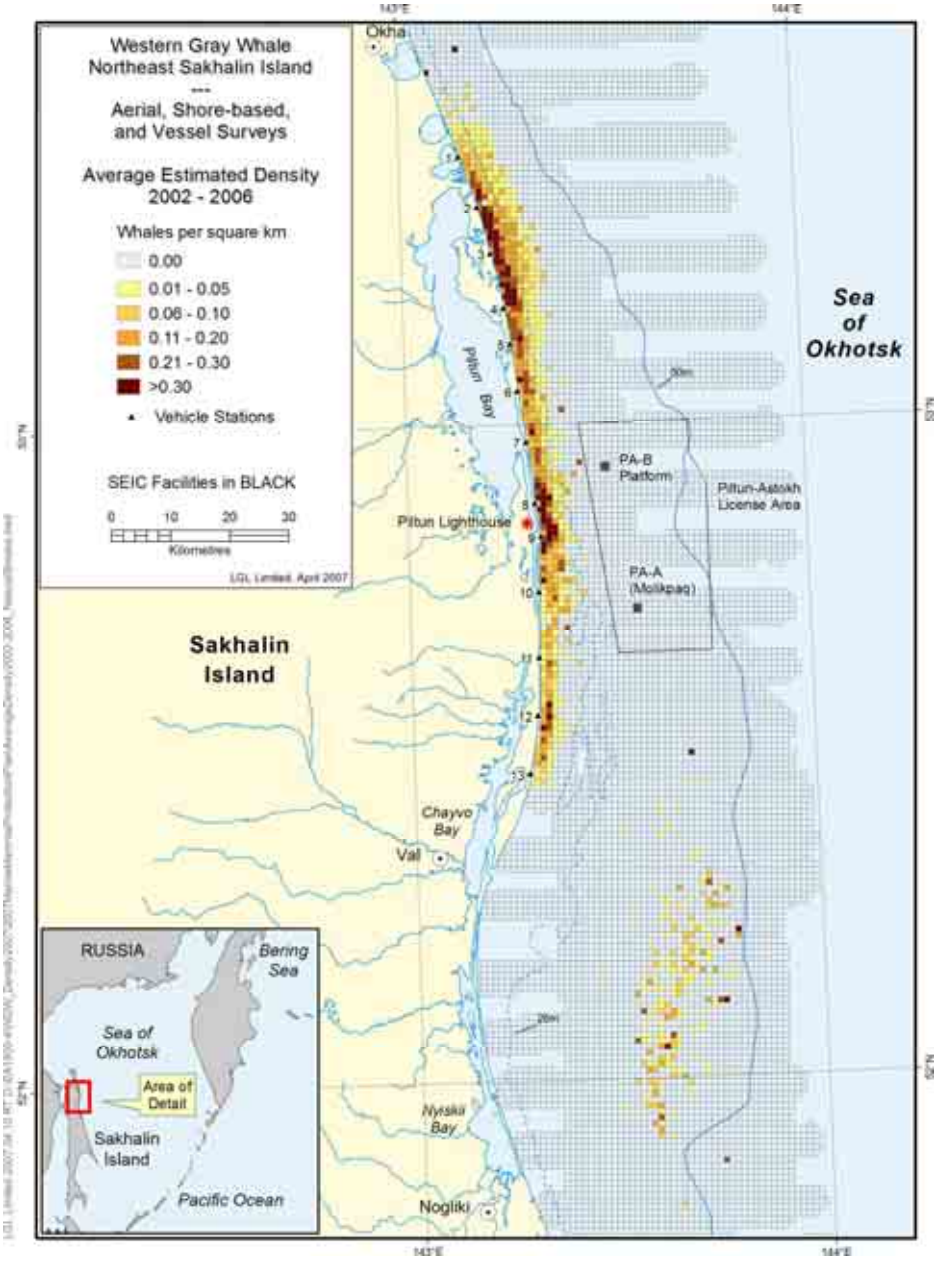

Fig. 6.1. WGW average estimated density at a 1 km^2 resolution on the north-east Sakhalin shelf based on 2002 to 2006 aerial, vessel, shore-based behaviour scan and shore-based vehicle scan survey data.

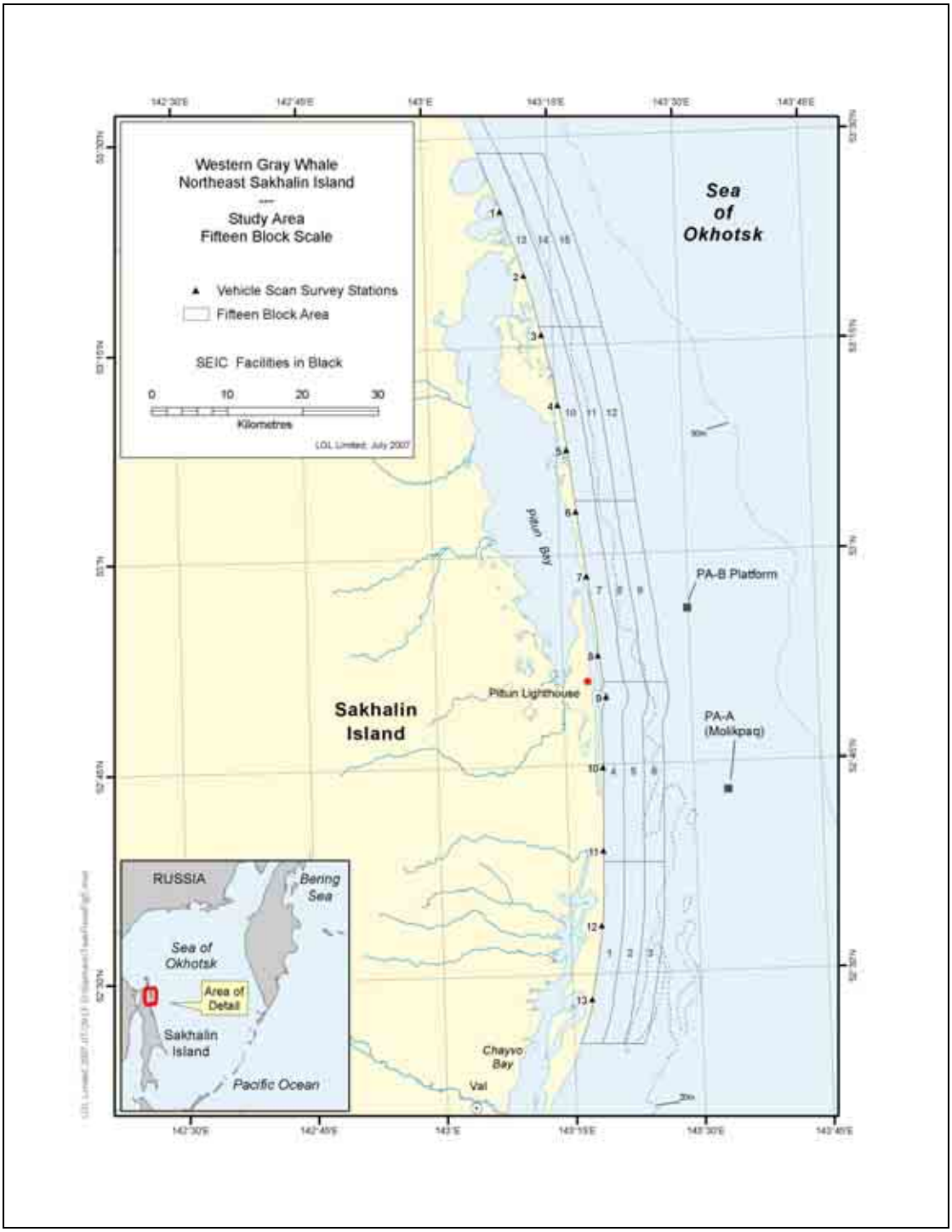

Fig. 6.2. The Piltun feeding area divided into 15 blocks. Blocks 7 to 12 were used to delineate a study area for the WGW density analysis sensitivity tests.

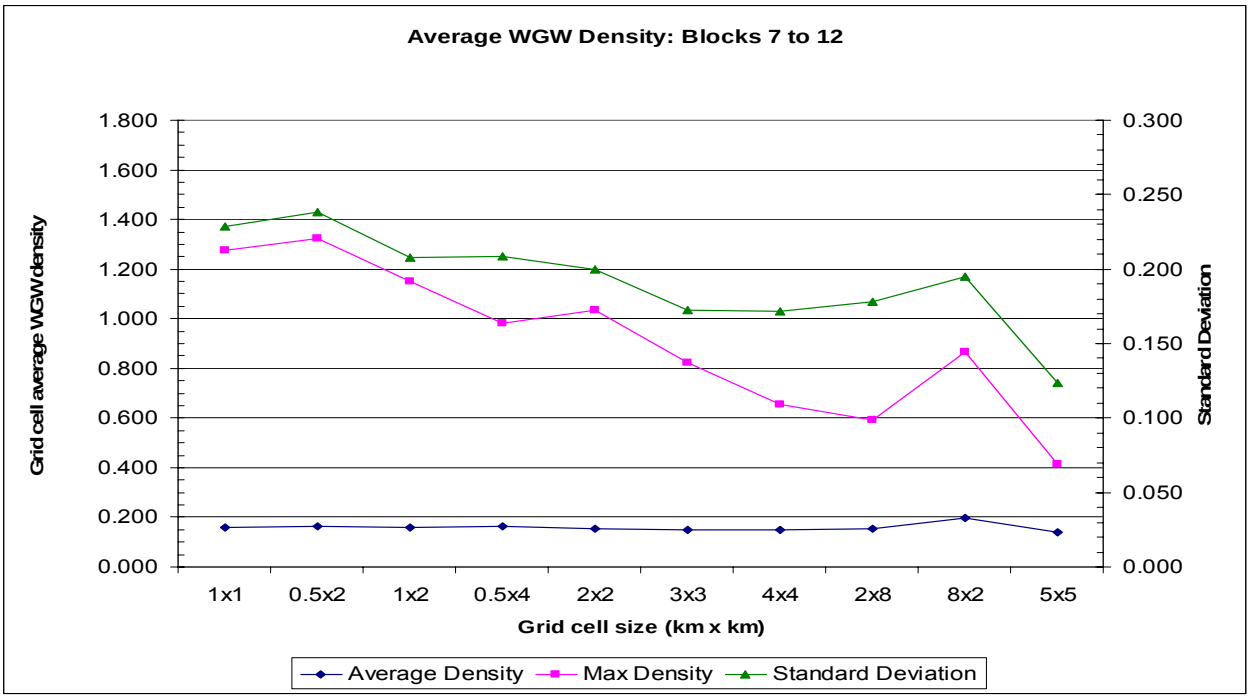

Fig. 6.3. Average, maximum and standard deviation of the grid cell average estimated density calculated across all grid cells for a given cell size and shape. Ten grid cell configurations ranging from 1 to 25 km^2 in area were tested. Two shapes (square and rectangle) of grid cells were tested. The first digit in the grid cell size is the east/west length of the cell in km. The second digit in the grid cell size is the north/south length of the cell in km. For example, 0.5 x 2 is a grid cell that is 0.5 km in the east/west direction and 2 km in the north/south direction.

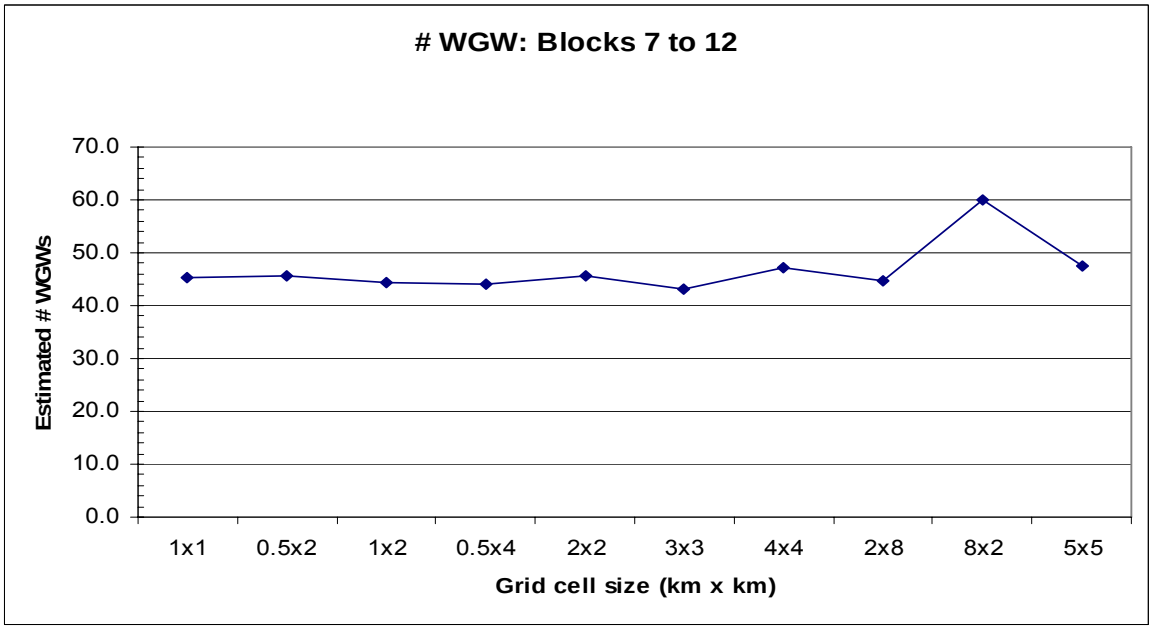

Fig. 6.4. The number of WGWs estimated with the study area calculated across all grid cells for a given cell size and shape. Ten grid cell configurations ranging from 1 to 25 km^2 in area were tested. Two shapes (square and rectangle) of grid cells were tested. The first digit in the grid cell size is the east/west length of the cell in km. The second digit in the grid cell size is the north/south length of the cell in km. For example, 0.5 x 2 is a grid cell that is 0.5 km in the east/west direction and 2 km in the north/south direction.

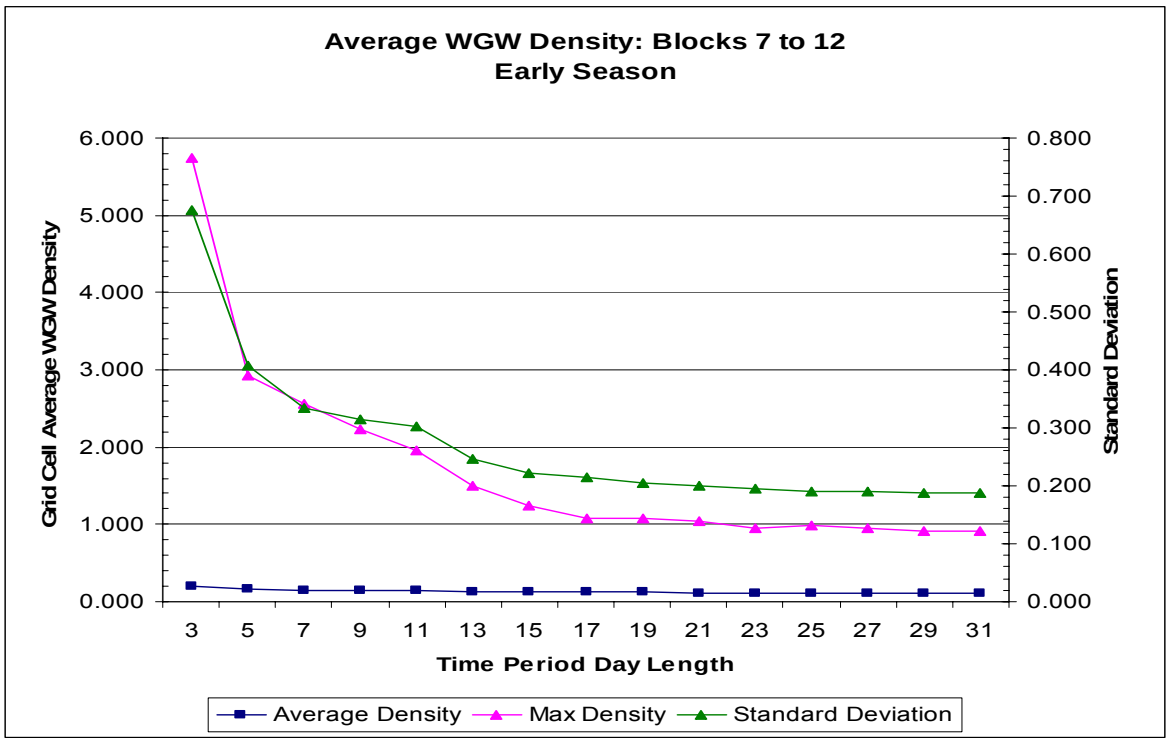

Fig. 6.5. Average, maximum and standard deviation of the grid cell average estimated density calculated across all grid cells for increasing time intervals during the early season when the WGW population is increasing in the Piltun area. Time periods were centred on 7 July, with successive time periods constructed by adding 1 day to each end of the current time period.

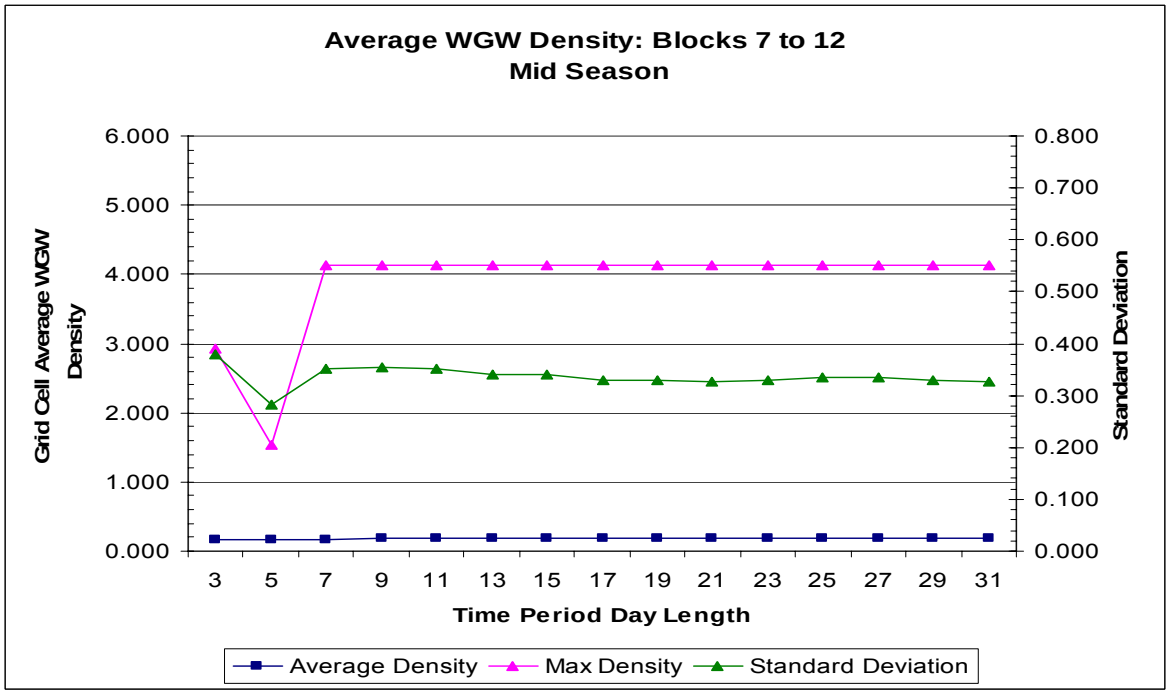

Fig. 6.6. Average, maximum and standard deviation of the grid cell average estimated density calculated across all grid cells for increasing time period lengths during the mid season when the WGW population is stable in the Piltun area. Time periods were centred on 21 August, with successive time periods constructed by adding 1 day to each end of the current time period.

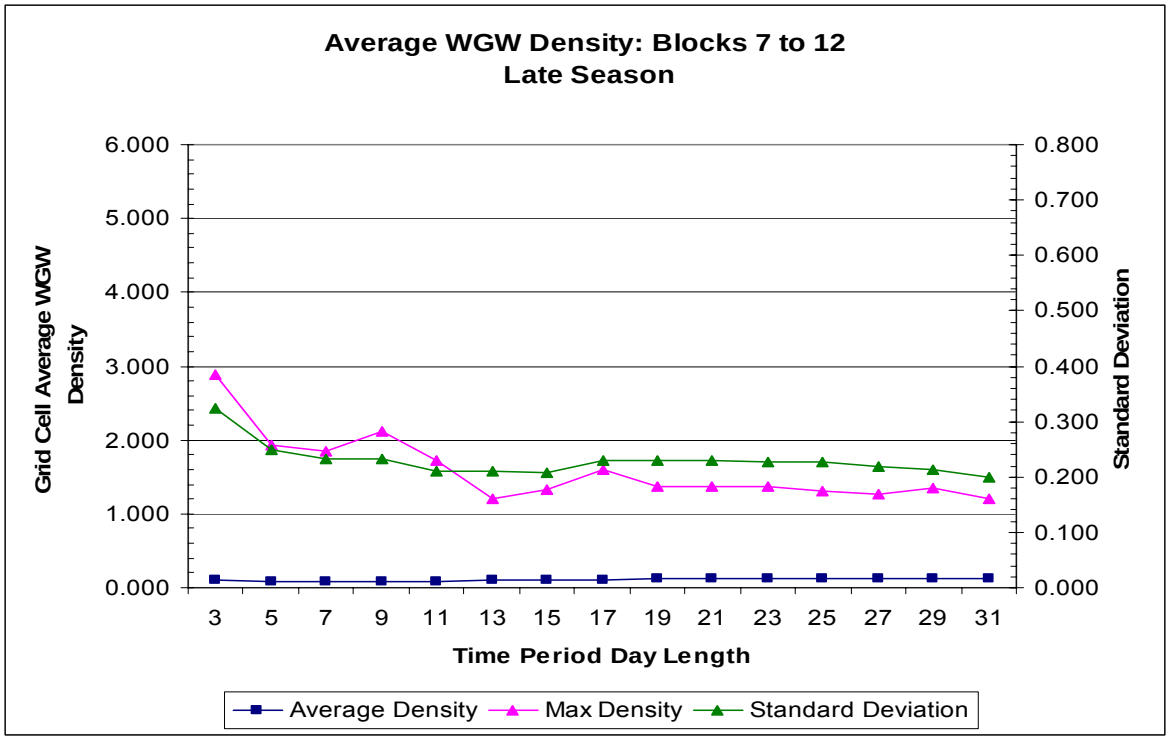

Fig. 6.7. Average, maximum and standard deviation of the grid cell average estimated density calculated across all grid cells for increasing time period lengths during the late season when the WGW population is decreasing in the Piltun area. Time periods were centred on 1 October, with successive time periods constructed by adding 1 day to each end of the current time period.

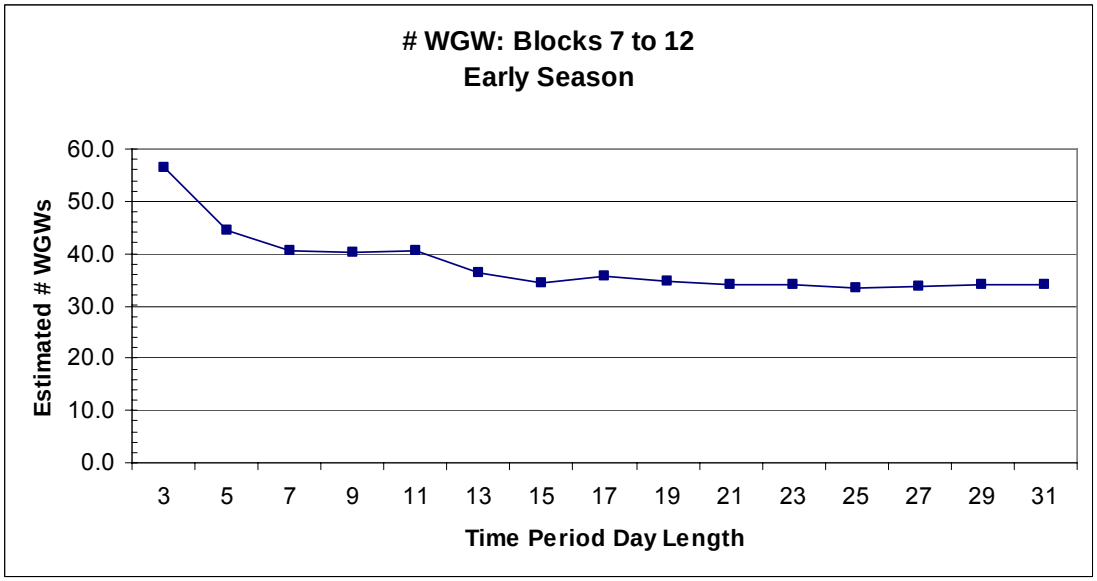

Fig. 6.8. The number of WGWs estimated with the study area for increasing time period lengths during the early season when the WGW population is increasing in the Piltun area. Time periods were centred on 7 July, with successive time periods constructed by adding 1 day to each end of the current time period.

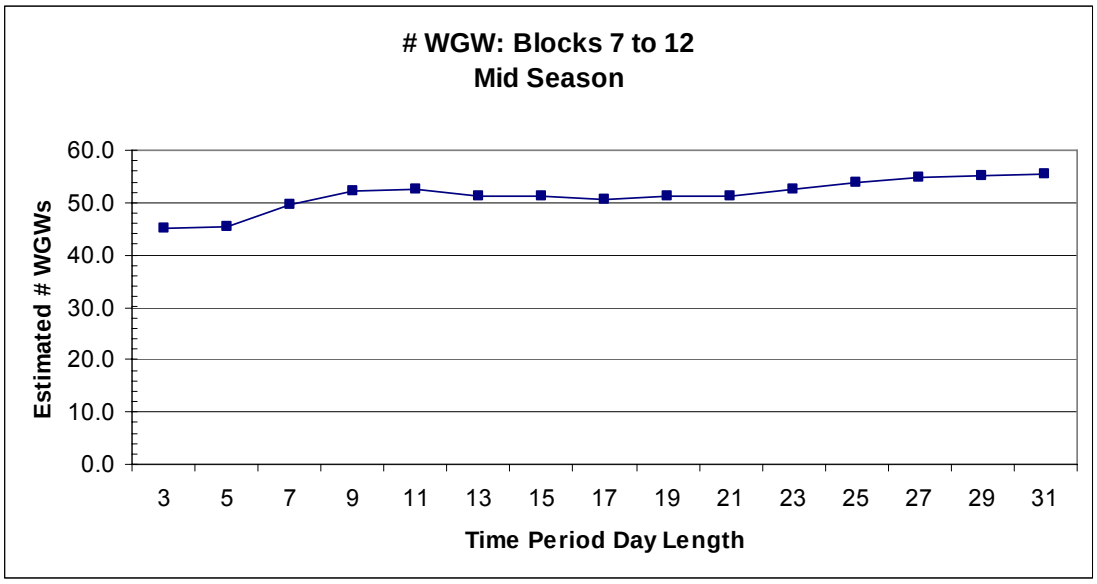

Fig. 6.9. The number of WGWs estimated with the study area for increasing time period lengths during the mid season when the WGW population is stable in the Piltun area. Time periods were centred on 21 August, with successive time periods constructed by adding 1 day to each end of the current time period.

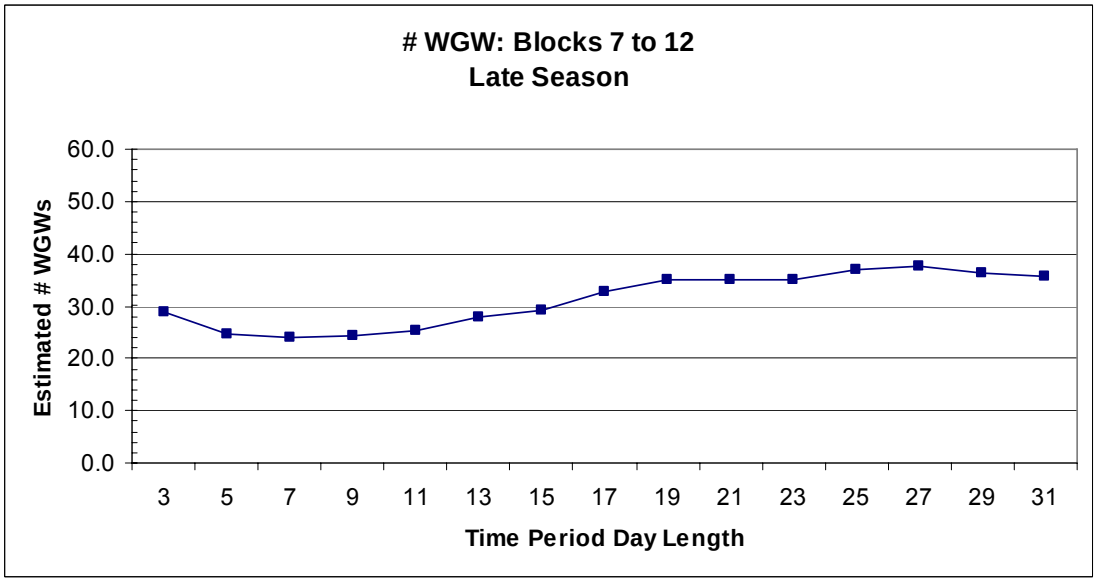

Fig. 6.10. The number of WGWs estimated with the study area for increasing time period lengths during the late season when the WGW population is decreasing in the Piltun area. Time periods were centred on 1 October, with successive time periods constructed by adding 1 day to each end of the current time period.

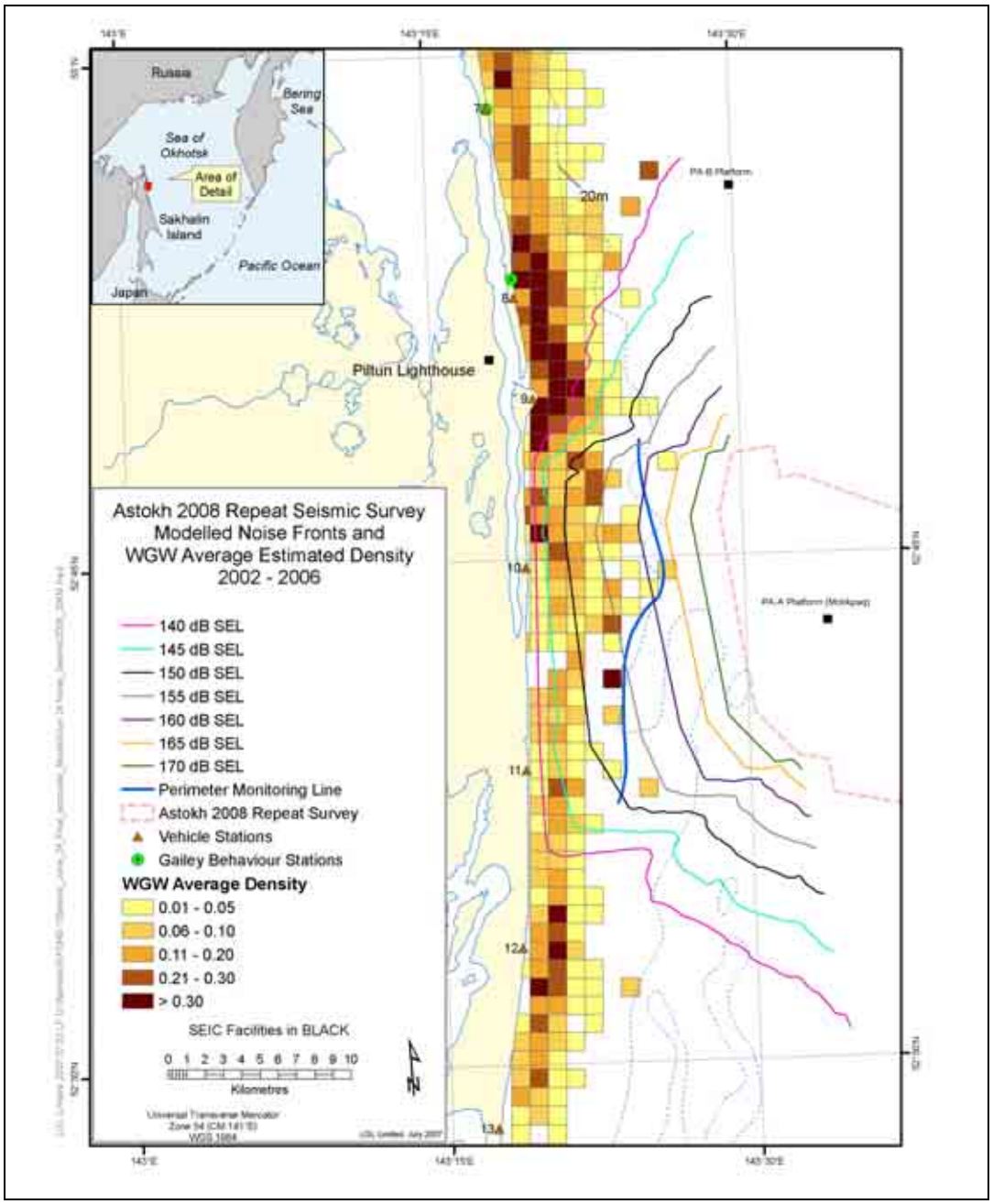

Figure 6.11. WGW average density based on 2002 to 2006 aerial, vessel and shore-based scan survey (behavior and vehicle) data is shown overlaid with the 2008 seismic survey area and the nearshore predicted noise fronts at 5 dB increments from 140 to 170 dB SEL per pulse. The Piltun feeding area perimeter monitoring line for acoustic receivers was delineated by first deriving a 95% kernel density contour for the 2002 to 2006 average estimated densities, manually smoothing the contour to reduce the effect of isolated non-zero density grid cells, and then extracting the offshore segment of the smoothed contour that extended 10 km north and 10 km south of the shot area center.

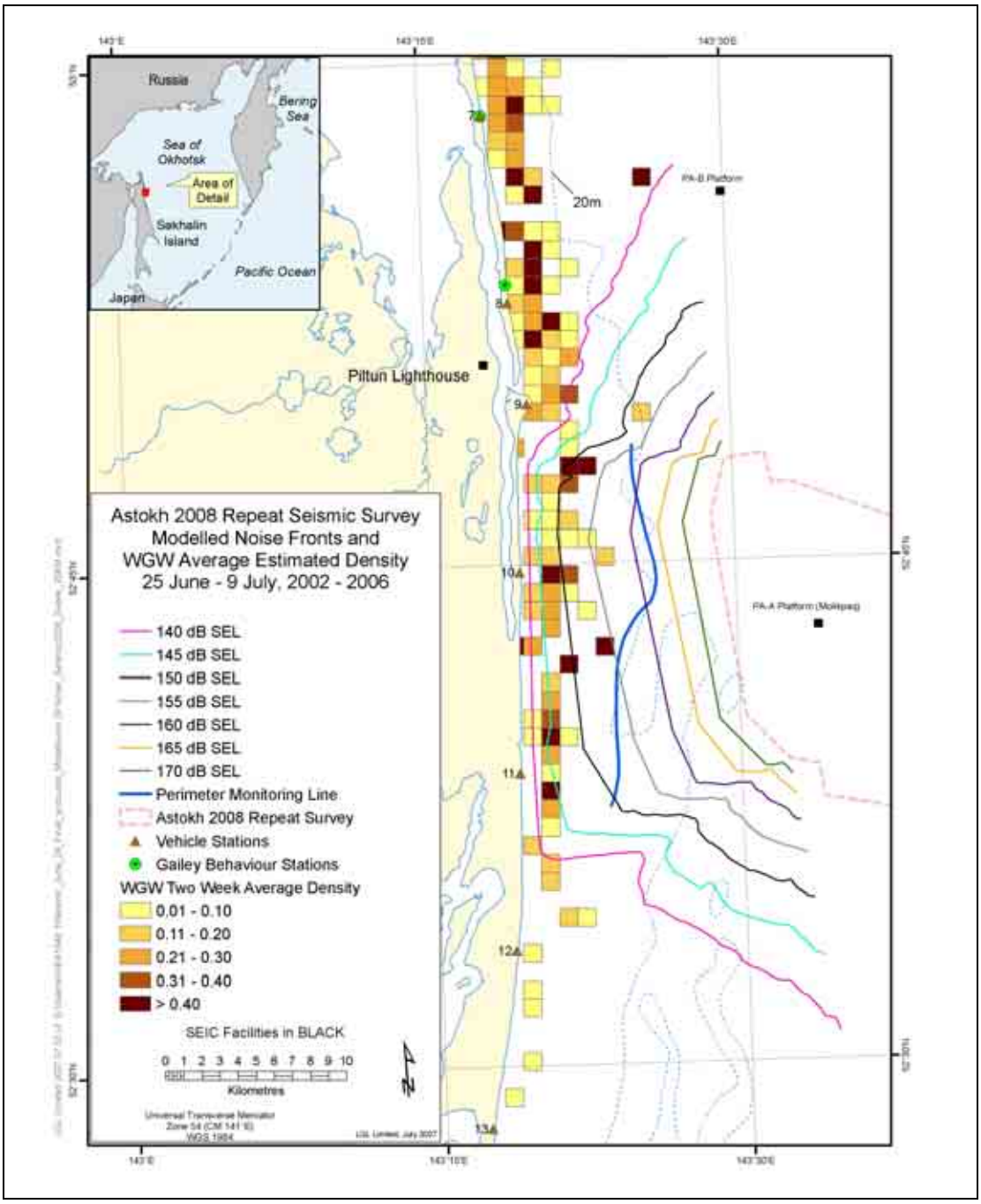

Figure 6.12. WGW average estimated densities based on aerial, vessel, shore-based behavior scan and shore-based vehicle scan survey data during the 2 week time interval of 25 June to 9 July, 2002 to 2006 is shown overlaid with the 2008 seismic survey area, the nearshore predicted noise fronts at 5 dB increments from 140 to 170 dB SEL per pulse and the proposed perimeter monitoring line for acoustic receivers

7 MONITORING AND MITIGATION

7.1 Objectives and targets

The Task Force noted that, in an ideal situation, one or more specific conservation targets would be provided, such as a maximum number of whales that may be exposed to sound above a certain level. Its task would then be to devise mitigation measures to ensure that these objectives were met (with sufficiently high probability), and to specify monitoring arrangements that would help to verify the extent to which the targets were met.

However, as discussed in section 4, the Task Force had not, in the time available, been able to determine specific maximum acceptable level of sound exposure. The Task Force therefore settled for the scientifically less satisfactory but more pragmatic approach of:

i) specifying mitigation measures that the Task Force agrees are reasonable and practical;

ii) providing an indication of the likely effect of the proposed measures in terms of limiting or reducing the exposure of WGWs to different sound levels.

In practice, item (ii) can require considerable analysis, and possibly additional data. In the time available, the Task Force could in some cases merely outline a possible approach to estimating the effectiveness of a proposed measure.

The Task Force used current best practice as the starting point for its recommendations on mitigation methods, but looked for incremental enhancements to current practice in areas where current practice has clear weaknesses. An example of the latter is the issue of seismic surveying in periods of darkness or fog where the utility of looking out for whales is small or zero.

The general objectives of the mitigation strategy are twofold:

(a) to reduce the risk of exposure of whales encountered anywhere in the survey area to dangerously high noise levels that might cause auditory injury;

(b) to limit the exposure to noise of whales on the feeding ground, with the aim of limiting adverse behavioural consequences of noise exposure that might reduce feeding success, especially for mothers with calves.

With respect to objective (a), the Task Force agreed that, in line with current practice, an exclusion zone based on the 180 dB_{RMS} re 1 μPa isopleth be implemented throughout the survey (such that shut down occurs when a whale is detected in this zone), and that additional measures be implemented for survey taken in night or fog when whales cannot be detected directly.

With respect to objective (b), the Task Force proposed that additional mitigation measures be taken when real-time monitoring indicated that received sound levels may exceed 165 dB_{SEL} re 1 $(\mu Pa)^2s$ per pulse in any part of the feeding ground (as delineated by the boundary defined in section 6.4) while whales are present there.

The Task Force recognised that there are insufficient scientific data to confidently apply a precautionary measure that should be applied to surveys offshore of Sakhalin. The Task Force has however directly linked the use of the 165 dB_{SEL} measure to a suite of mitigation measures.

The monitoring measures proposed by the task force fall into two categories: :

(i) Real-time monitoring required to detect when the above threshold is exceeded;
(ii) Additional monitoring (involving the collection of data which need not necessarily be analysed in real time) to obtain data on the effects of the seismic survey on whales, especially WGW, to add to the existing knowledge base, and to contribute to the design of mitigation strategies for future seismic surveys.

7.2 Consideration of main scientific and operational issues

7.2.1 General issues

Conducting the survey as early in the season as ice conditions permit, before the majority of the population has arrived on the feeding grounds, will help to minimise the number of whales affected by the survey. In addition, the spatial coverage of the survey is limited so as to reduce the overlap of its acoustic footprint with the WGW feeding ground to the greatest extent possible consistent with achieving the survey technical objectives.

However, because some whales will be present on, and in transit to, the feeding ground during the proposed time window for the survey, further mitigation is needed.

The proposed mitigation measures fall into two categories:

(i) Those that apply to the entire survey, in order to meet objective (a) (to protect whales from possible auditory injury);
(ii) Special measures for those survey lines that potentially will cause disturbance to WGW on their feeding ground (i.e. in order to meet objective (b)).

7.2.2 Mitigation measures with respect to objective (a) (applicable to the entire survey)

The standard procedure is that operations are not started, or are shut down, if a whale is detected within a specified action radius of the seismic vessel, or is detected with a location and heading such that it is expected to enter the action radius. The action radius should be broader than any "danger zone" (where sound levels might be injurious), such that the risk of an animal entering the danger zone during shooting is kept small.

The effectiveness of a given action radius, such as 1.5km, can be expressed in terms of the risk that a whale will enter a danger zone (however this is defined) undetected. This probability depends on a number of factors, including:

- The number and efficiency of observers
- Sighting conditions (sea state, light intensity, visibility)
- Speed of the vessel
- Swimming speed of the whale and its direction relative to the vessel
- Surfacing/diving behaviour of the whale.

In standard line transect analysis, the probability of detecting a whale is calculated as a function of its perpendicular distance from the trackline (the distance when the vessel passes abeam of the whale). In the current case, the probability of interest is the probability that a whale is detected

before it enters a given radius around the sound source. This requires a somewhat different calculation from that made in standard line transect analysis.

Muir presented results of line transect analysis of surveys of WGWs conducted during 2002-06 from vessels travelling at about 10 knots. These indicated that the perpendicular detection probability function was approximately flat (and assumed to be 100%) out to a perpendicular distance of about 800m. The detection function would be expected to have a somewhat broader shoulder for the slower-moving (~5 knots) seismic vessel for the same level of observer effort.

In order to determine the detection radius, a radial detection functions were fitted to these data, as detailed in Annex B. However, it was not possible from these data to determine the absolute level of the detection function uniquely, and the detection rate at short range needed to be assumed. On the assumption that whales in the seismic survey area would be travelling, and surfacing only for respiration, then a respiration rate in the range 30-60 per hour and a detection probability (for a previously unseen WGW) in the range 0.25-0.75 per exhalation would imply a mean detection time for solitary whales of 80-480s. The mean time to detection of groups of 2 or more whales would be less, because of the greater number of exhalations.

Calculations were then performed, as detailed in Annex B, on the "risk" that a (solitary) whale in the survey area would approach within specific ranges of the seismic array during operation, assuming either (i) no mitigation response or (ii) shutdown when the whale is sighted within 1.5km, or on a course to come closer than 1.5km from the gun array. The whales were assumed to be located and oriented randomly relative to the survey lines. If the whales respond evasively to the seismic vessel, the number of incidents will tend to be fewer than predicted. The calculations also provide estimates of the expected number of times that shutdown will be triggered.

Assumed values or ranges of other parameters involved in the risk calculations were as follows: seismic vessel speed 5 knots; survey line spacing 300m; whale swimming speed 0-5 knots; gun array towed 100-400m behind the vessel.

The "risk" is expressed as the expected number of times that a whale, which remains in the survey area for the duration of the survey, would pass within the given distance of the operating gun array before a shutdown is triggered. In reality, it is unlikely that an individual whale would remain in the survey area for the duration, but the risk can also be interpreted as follows. If the risk for a given approach distance is estimated to be ρ, and if the average number of whales present in the (entire) survey area at any one time is n, then the expected total number of "close encounter incidents" (whales passing within the given distance of the array during operation) is $n\rho$. The probability that at least one such incident occurs is $1 - e^{-n\rho}$.

For example, if there are an average of 2 WGWs in the area at any one time, and if the computed risk of passing within 100m of the operating gun array is 0.27, then this means that the expected number of incidents of whales passing within this distance is 0.54, which corresponds to a probability of 0.14 that at least one such incident will occur.

The expected number of WGWs present in the survey area at any one time is expected to be low, but it is difficult to quantify from the available data exactly how low (see section 6). If one assumes an average density of 0.01 WGW km^{-2} in the survey area (~ 200 km^2) then the expected number of close (<100m) encounters based on the results in Annex B is about 1.5 without the shutdown rule; this would be reduced by 50% or more by the shutdown rule. Similar

calculations for other closest approach distances can be made using the results given in Annex B Table 3.

A low whale density in the survey area implies that the expected number of close encounters would be fairly low, even without mitigation, but it also implies that the expected number of shutdowns (for the purpose of protecting WGWs) would also be low, such that the mitigation will not be costly.

The Task Force **emphasised** that these calculations of risk are subject to considerable uncertainty, and are presented for illustrative purposes only. It agreed, however, that analyses of this kind should in general form part of the process of assessing the risk to whales of a seismic survey. The Task Force **recommends** that a more careful analysis be conducted before the survey is carried out (recognising that there is probably insufficient time to do so before the deadline for submission of the Environmental Assessment). The Task Force noted that the risk estimate is most sensitive to the mean time to detection, and agreed that efforts **should be made** to narrow the plausible range for this parameter, through additional analysis or data.

Table 4 in Annex B provides further results from the same trials, but expressed in terms of the sound energy received by each whale (in units of dB_{SEL}). The results show that even with the shutdown criterion, most whales in the seismic survey area would be exposed to sound energy levels (calculated for a single pass of the seismic vessel) exceeding 190 dB_{SEL} on at least one occasion, and thus potentially subject to TTS (see section 4). However, no whales would be expected to receive more than 215 dB_{SEL}. For exposure levels in the range 195-215 $dB_{SEL,}$ the shutdown criterion is estimated to reduce the expected number of such exposure cases by 44-99%. Although the Task Force had no reason to believe that exposures in the range 195-215 dB_{SEL} would be permanently injurious to gray whales, it noted that such exposures were beyond the range that could be assumed to be safe. It therefore **recommends** that all practical means to reduce the numbers of whales exposed to these levels should be employed, as detailed below.

The effectiveness of the shutdown criterion is a function of, among other factors, of the number of marine mammal observers (MMOs). The Task Force did not have specific information on how many MMOs the seismic vessel would be able to carry, but **recommends** that there be at least least two MMOs on watch on the seismic vessel at any one time, before (duration specified below) and during each line shooting, in good sightings conditions (defined as sea state ≤ 3, visibility of WGW $\geq$ 1.5km) with a provision for shutdown (or non-startup) if whales are seen within 1.5 km, or with a position and heading such that they are expected to pass within 1.5 km of the seismic array (as determined by the MMOs) These provisions have been incorporated into the recommended mitigation schema given in section 7.5. For times when these conditions are not met, additional precautions are recommended, as discussed below.

With respect to periods when conditions do not permit reliable visual detection (using the above criteria, the Task Force took into account the following factors:

Seismic operations will not be conducted in sea states greater than 3, when gray whale detectability is poor.

Sunset to sunrise is about 7 hours in midsummer, with about 6 hours of darkness. Depending on cloud cover, the light can be too poor for reliable visual survey for up to an hour before sunset or after sunrise. There may also be periods of fog when visual observation is not possible.

Neither night-vision binoculars or thermal imaging can provide effective mitigation at night or during fog.

The Task Force noted that a prohibition on night shooting could increase the survey duration by up to 50%, which would be undesirable, both in terms of increased costs and in terms of extending the duration of the seismic survey into the period of peak whale abundance. It therefore agreed that night shooting or shooting during fog or poor light should only be conducted when the line has been surveyed (either by a separate "scout" vessel or while shooting an adjacent line) in good conditions during the preceding 6 hours and no gray whales have been sighted within this period. This would be the first time such a measure has been tried: the period of 6 hours, while considered practical to implement, remains, in the absence an analysis of the effectiveness of the measure for different choices of period, arbitrary.

7.2.3 Mitigation measures with respect to objective (b) (applicable to survey lines potentially affecting whales in the feeding area)

The objective is that no whales in the feeding area (as defined by the boundary shown in Fig. 6.11) should be exposed to more than 165 dB_{SEL} per pulse.

According to the acoustic model predictions (section 5), noise levels are not predicted to exceed this threshold within the feeding area. However, because the acoustic model does not necessarily take account of all sources of uncertainty, the possibility cannot be excluded that levels will exceed 165 dB_{SEL} per pulse in part of the feeding ground during shooting of lines closest to the feeding ground. Therefore, real-time monitoring of sound levels along the boundary of the feeding ground is required, with contingency plans for additional mitigation measures that would come into effect in the event that noise levels greater than 165 dB_{SEL} per pulse occur.

The contingency plans should ensure that in this event, lines would not be shot when whales are present in the part of the feeding ground that the line in question would ensonify with more than 165 dB_{SEL} per pulse. Implementation of this approach will require:

(i) Real-time monitoring of sound levels at the edge of the feeding ground to ensure that (a) times when the target level is exceeded in the feeding ground are detected or inferred, and (b) the approximate overlap of the impact area (defined as the area estimated to be exposed to sound levels >165dB_{SEL} per pulse during the line in question) with the feeding ground is delineated;

(ii) Real-time monitoring of whale occurrence in the overlap of the impact area with the feeding ground such that lines are not shot when whales are present.

Acoustic receivers should be stationed along the boundary of the feeding ground (as defined by the Task Force – see section 6.4) with sufficiently close spacing to determine the extent, if any, that the sound threshold is observed or predicted to be exceeded (and with some allowance for redundancy in the event of equipment failure). The Task Force agreed that 9 buoys with a spacing of 2.5 km would be sufficient, provided that any malfunctioning receiver was rapidly

replaced such that the gap between functioning receivers would never exceed 5 km, which was considered to be the range of reliable model-based interpolation of recorded sound levels.

Overall, the survey should start by shooting lines away from the feeding ground to calibrate the acoustic model. The recorded and model-predicted sound levels should be compared. In the event that recorded sound levels exceed the predictions, the model should be retuned to fit the observations. The lines, or parts of lines, if any, which are expected to ensonify part of the feeding ground with $\geq 165 dB_{SEL}$, per pulse are to be designated 'A'-lines. The updating of the model to account for recorded sound levels should be conducted as often as necessary and appropriate, to ensure that the overlap between the impact area and the feeding ground is reliably delineated.

Acquisition of A-lines should be contingent on verifying that there are no whales in the overlap of the impact area and the feeding ground. This requires:

- Shore-based monitoring teams are in place and have not detected gray whales in the overlap area for that line within the last 6 hours;
- No acquisition at night or in poor visibility;
- No acquisition when fog obscures visibility either from the shore-based monitoring platform or from the seismic vessel;.
- If part of the overlap area is out of the range of visibility of both the shore-based platforms and the seismic vessel, the intervening area must be surveyed by an additional (possibly stationary) vessel and verified to be free of gray whales.

The failure to detect whales in the overlap area does not necessarily imply that none are present. It does, however, ensure that there are unlikely to be significant numbers present. Detection of no whales in the overlap area, when conditions and observation levels are adequate, is an operational criterion designed to meet the objective of not exposing a significant number of feeding gray whales to sound levels greater than 165 dB_{SEL} per pulse.

A "significant number" is defined pragmatically in this context as a number large enough that it would be unlikely that none of them would be detected (in good sighting conditions).

In the event that received sound levels at the edge of the feeding ground do not exceed the model predictions, there will be no overlap area, and none of the above contingency mitigation measures will be triggered.

7.2.4 Additional monitoring

In addition to the above mitigation-linked monitoring activities, the following additional monitoring in the feeding ground should be conducted for the purpose of obtaining data on the effects of this survey on gray whales, including possible effects on gray whales of sound levels below the 165 dB_{SEL} threshold. These additional data should be collected even if noise levels in the feeding area never exceed 165 dB_{SEL} per pulse. The data can be of use in refining mitigation strategies for future surveys. These additional monitoring activities do not provide data that would be used to trigger survey shutdown, hence the data gathered do not need to be analysed in real time.

(i) Shore-based observation of whales in the part of the feeding ground facing the seismic survey area. The observations should start as early as possible, be as continuous as possible, and provide for complete coverage of the relevant section of coastline.

(ii) Subject to discussions between the Task Force and Glenn Gailey with respect to the utility of such data (i.e. in view of issues such as likely low sample sizes, etc.), behavioural data using the Gailey protocols (tracking of whales etc.) should be collected from at least one shore station in the area of concern.

(iii) Noise levels from the seismic survey should be measured at at least two appropriately spaced locations well within the edge of the part of the feeding ground facing the seismic action area (for example using bottom-sited recorders, not necessarily additional to those already in place for other purposes).

7.3 Recommended monitoring and mitigation protocol

7.3.1 Monitoring of Received Sound Levels

Along the Perimeter of the Feeding Area

- Real time monitoring of acoustic levels using sea-bottom receivers will be undertaken during all periods of seismic source activity.
- A total of 9 receivers will be positioned with at 2500m intervals along the edge of the feeding area (Fig. 6.11) to ensure adequate redundancy – never more than 5000m between active buoys.
- Receivers will be in place and verified to be functioning properly before activity starts and for the duration of the survey.
- There will be a direct radio link between the real-time monitoring acoustician and the Senior MMO on the active seismic vessel.

Within the Feeding Area

- All necessary efforts will be made to obtain archival acoustic data within the feeding area using bottom-mounted receivers.
- Besides the existing "Joint Study" buoys, two additional archival receivers will be positioned on the sea bottom.

7.3.2 Visual Monitoring of Whales

Within the Feeding Area (Shore-based)

- Shore-based scan surveys (i.e., 'whale distribution surveys') will be undertaken from the 4 existing observation locations west of the survey area.

- Glenn Gailey will be consulted regarding the value of supplementing the scan surveys with onshore behavioral monitoring stations.

Within the Feeding Area (Vessel-based)

- Behavioral observation from a moored vessel positioned along the perimeter and immediately outside the feeding area will be implemented if possible; this platform should be located in the area of maximum predicted ensonification.

- The vessel will be mobilized along the perimeter of the feeding area only in poor visibility conditions (e.g. fog) or if the calibration indicates that the165dB$_{SEL}$ per pulse threshold has been exceeded at the perimeter.

- The observation vessel will have a direct radio link to the Senior MMO on the active seismic vessel.

Within the Proximity of the Active Vessel(s)

- An extended visual search (20 minutes) will be conducted prior to start-up of the seismic source.

- Trained MMOs will be stationed on all vessels for the full duration of the survey.

- There will be a minimum of two MMOs on watch on the seismic vessel at any given time during ramp-up, shooting and for the 20 minutes before start of ramp-up.

- MMOs will be limited to a maximum 4-hour continuous shift with a minimum break of 2 hours between shifts

- Single-point authority for operational shutdown will lie with the Senior MMO on the seismic vessel.

- All vessels and real-time acousticians will have direct radio access to the Senior MMO.

- Occurrence and behavior of sighted whales will be documented in accordance with existing MMPP and MMO procedures.

7.3.3 Mitigation Measures Applicable to the Entire Survey

Timing and Duration

- The seismic survey will be commenced as early in the season as logistically possible. Logistics includes ensuring that all mitigation and monitoring procedures are in place.

- The duration of the seismic survey will be as short as technically and logistically feasible. Logistics includes ensuring that all mitigation and monitoring procedures are in place.

Within the Proximity of the Active Seismic Vessel

- After more than 20 minutes of inactive source a ramp-up procedure will be adopted whereby the individual air guns will be activated in a progressively larger combination over a period of several minutes.

- The Senior MMO will initiate source shutdown if a gray whale is observed within a 1,500m safety radius of the source array.

- The Senior MMO will initiate a precautionary shutdown if a gray whale is observed to be on a course that will result in its entering the safety radius.

- A single source of the smallest possible volume will be activated during line changes.

Operations in conditions that preclude effective visual monitoring of the defined safety radius (e.g. night, fog, poor visibility)

- Operations will not be conducted for shot lines designated as 'A' lines (see below).

- Prior to acquisition, lines will be scouted not more than 6 hours in advance (if necessary using a second vessel) to ensure there are no gray whales in the vicinity.

- Operations will shut down for the night period if whales are sighted in the pre-dusk scan.

- After more than 20 minutes of source inactivity, operations will not be re-commenced, due to the inability to conduct an adequate visual scan.

- "Poor visibility" means any conditions under which the visibilitiy of WGW is ≤ 1.5 km

7.3.4 Definition and Updating of the A and B Zones

- Initially, the entire survey area is considered B zone for which the additional mitigation measures below do not apply.

- Before any lines within 9 km (i.e., the currently predicted range to 160 dB_{RMS}) of the feeding ground are shot, received sound levels on the edge of the feeding area will be compared with model predictions. If received sound levels exceed model predictions, then the model shall be retuned to match the observed levels. Based on the updated model predictions, lines for which an overlap is predicted between the 165 dB_{SEL} per pulse contour and the feeding area will be reclassified as A lines, for which the additional mitigation measures specified below apply

- The comparison between observed and expected sound levels at the edge of the feeding ground, and where indicated, retuning of the acoustic model, shall be repeated at regular intervals during the survey.

- In the event that the 165 dB_{SEL} per pulse threshold is unexpectedly exceeded at any receiver on the edge of the feeding ground while shooting a B line, operations shall be

suspended immediately or shifted away from the feeding ground until a recalibration exercise has been conducted as described above, and the lines have been reclassified accordingly.

7.3.5 Special Mitigation Measures for Parts of the Seismic Survey Potentially Having an Impact in the Feeding Area (A Zone)

Shooting of lines designated as A lines are subject to the following additional restrictions for those parts where overlap is predicted between the 165 dB_{SEL} per pulse contour and the feeding area.

- No acquisition during periods of poor visibility within the feeding area.
- No acquisition during night time (see above for definition).
- Area of predicted overlap between 165 dB_{SEL} per pulse contour and Feeding Area shall be within effective sighting distance of a shore station or an additional vessel.
- No acquisition if any gray whales have been observed in the area of overlap over the preceding 6 hours.
- No acquisition if mother-calf pairs have been observed in the area of overlap in the preceding 12 hours.

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ANNEX A: TERMS OF REFERENCE FOR THE ASTOKH 4D SEISMIC TASK FORCE

Background

Sakhalin Energy's (SEIC) preliminary plans for carrying out a 4D seismic survey in the vicinity of the Molikpaq during the summer of 2008 were presented and reviewed by the WGWAP during its meeting in St Petersburg. There it was agreed to establish a WGWAP Task Force that would provide independent expert advice to the company as it prepares the required comprehensive Environmental Impact Assessment that outlines the mitigation and monitoring measures intended to ensure minimal environmental impact whilst meeting the survey's technical objectives.

Objectives

A task force is proposed to review and analyze (as a contribution to the EIA) noise predictions and estimated whale densities for the proposed 2008 Astokh seismic operations in the light of potential effects on gray whales, and make recommendations on mitigation and monitoring.

Regular and prompt communication between SEIC staff and selected Task Force members is essential for timely delivery of the Task Force recommendations. Please refer to the WGWAP Task Forces Communication Procedures Guidance Note Agreed by IUCN and SEIC (attachment).

The task force will consist of the following individuals:

WGWAP
Randall Reeves (ex oficio)
Greg Donovan (workshop Chair)[1]
Douglas Nowacek
Alexander Vedenev
[1]Due to incapacity, Greg Donovan was replaced as workshop chair by Justin Cooke

SEIC
Matthew Angelatos
Martijn van Haaster
Roberto Racca
Doug Bell
Judy Muir

Associate Scientists
Ann Bowles
Konstantin Avilov

IUCN
Julian Roberts
Sarah Gotheil

Task Force Focal Points

- Sarah Gotheil, IUCN, Programme Associate

- Matthew Angelatos, SEIC, Project Leader

Workplan and Timing

The task force's work will be based upon data that are available at the commencement of a workshop to be held in late June 2007. However, during the workshop additional analyses will likely be conducted in response to issues and questions raised by the task force. Success of the task force is dependent upon prompt delivery of the following:

Task	Description	Due	Notes
1	Draft TOR distributed	8 May 2007	SEIC Draft available
2	Final TOR + Workshop Agenda Distributed	Mon 14th May 2007	TBC
3	Task Force Progress Telecon	Wed 20th May?	
3	Modeling + WGW Density Results	Start June	
4	Sound level Impact Compilation	Start June	Doug N
5	Best Practice Mitigation Measures	Start June	Doug N
6	SEIC Acquisition in Winter Feasibility Doc	Start June	Matt
7	Task-Force Workshop	Late June	4 days Den Haag
8	Report finalized and circulated	End July	
9	SEIC EIA Complete	End August	

A key input to the June workshop will be the provision of simulation results addressing the uncertainty in model predictions of both acoustic contours and whale density distributions. One component of this work, specified by the task force (see below), will be undertaken by JASCO and LGL and provided in advance of a 4-day workshop to be held in time for the work to be incorporated in the EIA (due date end August). Another component of the work will be an independent set of noise prediction simulations by Vedenev and Avilov using input data provided by SEIC as well as some experimental TL data obtained by Vedenev and colleagues in 2004. Data transfer from JASCO (Racca) to Vedenev will need to be worked out through the good offices of IUCN to obtain SEIC permission and ensure that appropriate safeguards are in place (see below). Ideally, the results of these independent simulations will be available by the time of the workshop. Otherwise, they need to be available in advance of the completion of the task force's report.

Practical considerations mean that the workshop cannot be held before mid-June.

Specification of trial structure:

Noise footprint information – See Appendix 1

Whale density distribution sensitivity tests – See Appendix 2

For incorporation into the planned 2008 Seismic EIA, whale densities will be calculated for 10 km^2 grid cells (5 km parallel to shore X 2 km perpendicular) for the area from shore out to the 20 m isobath and cover the same area as WGWAP-2/INF.11, at least for blocks 1-9 in that document, and pending results of sensitivity tests. As discussed in the WGWAP-2 report (section 10), whale densities will be calculated with a 1-day average and reported in whales/km^2.

Safeguards

Data providers' rights will be protected. No use of the data will be made without the express permission of the data providers. Any use of the data by the WGWAP will protect the data providers' rights in accordance with paragraph 3(e) of the WGWAP TOR. Any other use of the data will be subject to agreement between the scientists and institutions providing and using the data. The rights of any third parties contributing additional data will be similarly respected. Any external experts engaged to assist with the modelling shall assent to these conditions.

Appendix 1 – SEIC/JASCO strategy for modeling the noise footprint from the seismic surveys

Suggested 'trials' for acoustic contour modelling (all to produce contours for 140-170 dB_{SEL} per pulse in 3dB steps). The design principles are as follows: (1) develop a 'base case' of 'default' values that Racca has already chosen; (2) based on what is known about the variables within a suitable window of expected dates in the area, choose plausible ranges for each parameter, recognizing the need to take a realistic yet precautionary approach – in doing so change one variable at a time to help with interpretation; (3) develop a number of appropriate 'combination' trials. JASCO plans to test each of the parameters included in the table below using a 'minimum-to-maximum' approach, i.e., each parameter is varied from end to end within a plausible range. The range to be tested for those parameters deemed to be of 'high' influence is either shown in Table 1 or should be determined in consultation with geophysicists. Within this plausible range, parameters should be evaluated for at least 4 values (i.e., quartiles), and for those parameters that are expected to have significant influence, higher resolution analyses should be pursued. While testing one parameter, the others will be held at 'average' values. The presentation format of this multi-variate analysis is being developed, but should include tabulated results as well as figures showing the sound level contours (*sensu* WGWAP-2/INF.11 Maps 4-14) from the various model runs.

Empirical results of TL work carried out in the Piltun-Astokh area between 2001-2006 will be key to validation of the modeled results. Therefore, data from the TL experiments directed/commissioned in whole or in part by SEIC should be used to inform these analyses. Some relevant experimental TL data from Vedenev's expedition in 2004 also should be used. A timeline for the distribution of these data among the interested parties in the Task Force should be agreed upon as soon as possible.

Finally, the appropriate metric for considering the noise impinging on whales from seismic surveys is not RMS or SEL but peak-to-peak pressures and energy flux density given the impulsive nature of these signals (Madsen 2005). Madsen (2005) argues that the RMS metric relies heavily upon choosing the size of averaging window for the squared pressures. The size of this window is not standardized, and variations in its size can lead to ≥10 dB differences in RMS sound pressure for the same wave forms. RMS pressure does not represent the energy of the noise pulse and it does not prevent exposure to high peak pressures. Levels for transients, such as seismic airgun pulses, should therefore be given as peak–peak sound pressure and energy flux density instead of RMS sound pressure level. As estimation of peak-to-peak pressures requires fine resolution frequency modeling for received pulse shape synthesis, which is very computation intensive, full-area noise footprint maps will be modeled only for SEL (which is effectively equivalent to energy flux density for a single airgun shot) while peak-to-peak modeling will be performed along a set of key radials from each shot point with special emphasis on propagation into the feeding area.

As indicated in Table 1, airgun parameters (i.e., source characteristics) are critical and therefore they need to be specified, and plausible ranges in the parameters to be tested are required if variation is expected. Variation in airgun types, volumes and/or arrangements will be modeled within the pre-defined ranges of technical feasibility. This will be evaluated in an effort to determine the optimal balance between achieving success in the surveys while minimizing exposure of the whales to seismic noise.

Table 1 – Parameters to be tested in the analysis of noise potentially affecting gray whales during planned 2008 Astokh seismic surveys.

Bottom parameters (assuming 2 layer model)

Parameter	Influence	Notes	Effect	Uncertainty	Values used in preliminary modelling	Proposed range for sensitivity analysis
P-wave speed	High	The sound speed in the bottom is probably the most important parameter influencing sound propagation in shallow water. This is because the sound speed at the water/bottom interface controls the critical angle and hence the total amount of sound energy trapped in the water column. The sound speed in the bottom also controls the cutoff frequency in shallow water which is especially important for modeling low frequency sources like airguns. The current value used in the modeling was derived by fitting model predictions to *in situ* TL measurements.	high values -> low TL	Unknown. Review any available geological information to determine natural variation in bottom type and refer to Hamilton (1980) to determine range of values	1652 m/s- 2152 m/s (0-500m) 2152 m/s (>500m)	Preliminary values ok.
P-wave gradient	Med	At mid to high frequencies, sound propagation in shallow water is generally dominated by water-borne energy. The gradient in the sub-bottom should only have a significant influence at low frequencies where a significant amount of energy also travels via the sub-bottom.	High values -> low TL (low freqs)	Unknown. Review Hamilton (1980) to determine reasonable range of values.		Consult geophysicists
S-wave speed	Med	The shear wave speed primarily influences long-range sound propagation (the effect at short range is negligible). Shear conversion at the seabed slowly strips sound energy from the water column. The shear-wave speed in the bottom is very difficult to estimate, however, and so the corresponding uncertainty is large. Note also that the complex bottom density [?]approximation is limited to low shear speed values; one must be careful not to exceed the approximation limits, or else the	High values -> high TL	Unknown.	150 m/s	OK

		properties of the seafloor will not be physically reasonable.				
Density	Low	The density in the sub-bottom is much less important than the P-wave speed for determining the amount of energy trapped in the sub-bottom. The density is also related to porosity, and hence the P-wave speed, so the range of values used in a sensitivity analysis will be more or less determined by the compression speed.	High values -> low TL	Related to P-wave speed.	1.772 g/cm^3	OK
P-wave attenuation	Med	P-wave attenuation results in imperfect reflection at the seabed for trapped modes (similar to S-wave speed). The effect of this parameter should be similar to that of S-wave speed.	High values -> high TL	Unknown.	0.14 dB/λ	OK
S-wave attenuation	Expected to be low	The S-wave attenuation in the sub-bottom is a very difficult parameter to estimate. The uncertainty in this parameter is large and its effect is difficult to decouple from that of S-wave speed.	Not well known	High. Range of values not well known. Related to S-wave speed.	13.6 dB/λ	OK
Basement depth	Low	This parameter only influences very low frequencies which propagate deep into the sub-bottom. However, the depth to the basement should be easy to determine from seismic survey data.	Shallow -> low TL (low freqs)	Low; can be obtained from any available seismic data.		OK
Basement speed	Low	Sound speed in the basement is probably not a very influential parameter except at the very lowest frequencies. The effect of this parameter depends on the basement depth.	High -> low TL (low freqs)	Unknown.		OK
Note that most of the bottom parameters are related so it is more reasonable to vary the overall bottom type rather than to vary the individual parameters separately.						

Water column parameters

Parameter	**Influence**	**Notes**	**Effect**	**Uncertainty**		

Sound speed profile gradient	High	The sound speed profile in shallow water is usually one of three types: down-refracting, up-refracting, or isovelocity. An up-refracting profile (+ve gradient) creates a surface duct which traps higher frequencies near the sea-surface resulting in lower TL (this is neglecting scattering from surface roughness which RAM doesn't account for). A down-refracting profile (-ve gradient) results in more interaction of sound with the seabed and generally higher transmission loss. The strength of the gradient would have to be determined by checking historical sound speed profile measurements.	+ve : Low TL -ve: High TL	Unknown. Check historical SVP measurements.	0m: 1482m/s 6m: 1481 m/s 10m: 1480m/s 30m: 1462m/s	Values given result in gradient of -0.66. Range to test: -0.7 to 0
Water depth	High	The water depth influences the intensity of the sound near the source, especially at the 190 dB and 180 dB contour levels. In shallow water, the 190 dB radius will be greater because the transition from spherical to ducted transmission loss occurs at shorter range. Conversely, at longer range, the transmission loss is higher in shallow water due to the more prominent bottom interaction and waveguide cutoff effects.	Shallow water -> low TL at short ranges, high TL at long ranges	Generally low. May need to take into account tidal variations and small-scale bottom depth features especially in very shallow areas.	From GIS database (varies over modeling area)	Base case should be an upslope, using the gradient along the direct path from the survey area – small scale features are likely to affect a very small area

Airgun array parameters

Parameter	**Influence**	**Notes**	**Effect**	**Uncertainty**		
Airgun injection rate coefficient	High	The injection rate of the airguns determines how fast air is released from the gun chamber and consequently the loudness of the initial peak. This air injection rate depends primarily on the airgun design (ie., the gun port area). Currently only data for Bolt 600/B airguns are available to JASCO; however, a range of values can be estimated from the optimization used for tuning the current version of the JASCO source model. Gun array will replicate that used in the original, pre-production 1997 survey – specifics TBC.	High -> greater SL	Can be estimated. Standard ranges of values for different airgun types are available.	0.091145	Values will replicate the original 1997 pre-production survey – still under discussion.

Airgun firing pressure	Med	The firing pressure also controls the air injection rate, as well as the bubble pulse duration. However, the uncertainty of this parameter is quite low since the firing pressure is controlled by the survey technicians to ensure a repeatable signature.	High -> greater SL	Low. Known from prescribed airgun operating conditions.	2000 psi	Ok to use a single value if this is to be controlled by SEIC. If alternatives are being considered, then a plausible range of psi values needs to be incorporated.
Airgun firing depth	High	The firing depth of the airgun has a large influence on transmission loss, due to surface ghost cancellation. The deeper the airgun array, the more energy that is trapped in the waveguide.	Deeper -> lower TL	Low, as it is a prescribed operational parameter. Nominal value, however, may be affected by sea conditions as well as by working restrictions due to icing etc.	6.0 m	Range: 4-10 m in 1-m steps.
Array beam pattern/geometry – frequency range	High	The transmission pattern of the array at the frequencies emitted will affect propagation of the signals towards and into the feeding area. The beam pattern, for example, affects the critical angle of transmission as the sound energy interacts with the bottom; the importance of critical angle is described under 'P-wave speed' above.	High – particularly given the strong lobes at relevant frequencies (50-500 Hz)			Maximum resolution possible for 50-2000 Hz range. Ideally, this would be 1 Hz resolution to estimate received pulse shape. 1/3 octave bands for rest of range.

Appendix 2 – WGW Density Analysis Sensitivity Tests

The estimated number of WGWs within a predefined study area during a specific time period is a useful metric for a variety of management applications. SEIC presently derives this metric using average WGW densities estimated at a 1 km^2 resolution from systematic aerial, vessel and shore-based survey data collected from 2002 to 2006. Estimation is a 4-step process, as follows: (1) A WGW density is estimated for each grid cell that has been sampled by a given survey; (2) The density estimates from all surveys within a time period of interest are averaged for each grid cell in the study area; (3) The number of WGWs within each grid cell is estimated by multiplying the cell area by the average density in that cell; (4) Estimated numbers of WGWs are summed across all grid cells to determine the number of WGWs in the study area.

This task will investigate the potential effects of parameter values, specifically grid cell size, grid cell shape, length of the time period used to sample the survey data, survey platform and interpolation methods for missing data, on density estimates and consequently the number of WGWs determined to be within a study area for the years 2004 to 2006. All tests will use the same spatial and temporal boundaries. The number of WGWs will be estimated within a study area delineated by blocks 7 to 12 at the 15-block spatial scale of the Piltun nearshore feeding area (approximately 385 km^2, Map 1). We will use only survey data for the month of September, when weather conditions are usually good, surveys have been conducted frequently, and WGW densities generally have been high. Tests will be conducted using survey data pooled across all 3 years, and separately for each year. Only the data from shore-based vehicle surveys will be used for the tests involving grid cell size and shape. The results of these tests will then be used to select a single grid cell size and shape for use in the tests for effects of time period length and different survey platforms. The following statistics will be provided for each test described in objectives 1 to 4:

1) Average, maximum and standard deviation of the average WGW density for each grid cell in the study area pooled across all three years (2004 to 2006) and for each year separately.
2) Average, maximum and standard deviation of the number of WGWs within the entire study area estimated by each test pooled across all three years (2004 to 2006) and for each year separately.

Objective 1: Test the effect of the grid cell size. WGW densities will be estimated for square grid cells of the following sizes:

- 1 km^2 (current method)
- 4 km^2 (2 km x 2 km)
- 9 km^2 (3 km x 3 km)
- 16 km^2 (4 km x 4 km)

Objective 2: Test the effect of grid cell shape. WGW densities will be estimated for the following 16 km^2 grid cells.

- 4 km x 4 km square grid cell (tested in Objective 1).
- 2 km east-west by 8 km north-south (along shore) rectangular grid cell.
- 8 km east-west by 2 km north-south rectangular grid cell.

Objective 3: Test the effect of the survey data time period length that is used for estimating grid cell average densities. Three temporal intervals during the feeding season that have different WGW population trends in the Piltun feeding area will be tested. WGW densities for each temporal interval will be estimated using time periods at 1 day increments from 3 to 31 days. Time periods will be centred on the day indicated below for each temporal interval, with successive time periods constructed by adding 1 day to each end of the current time period:

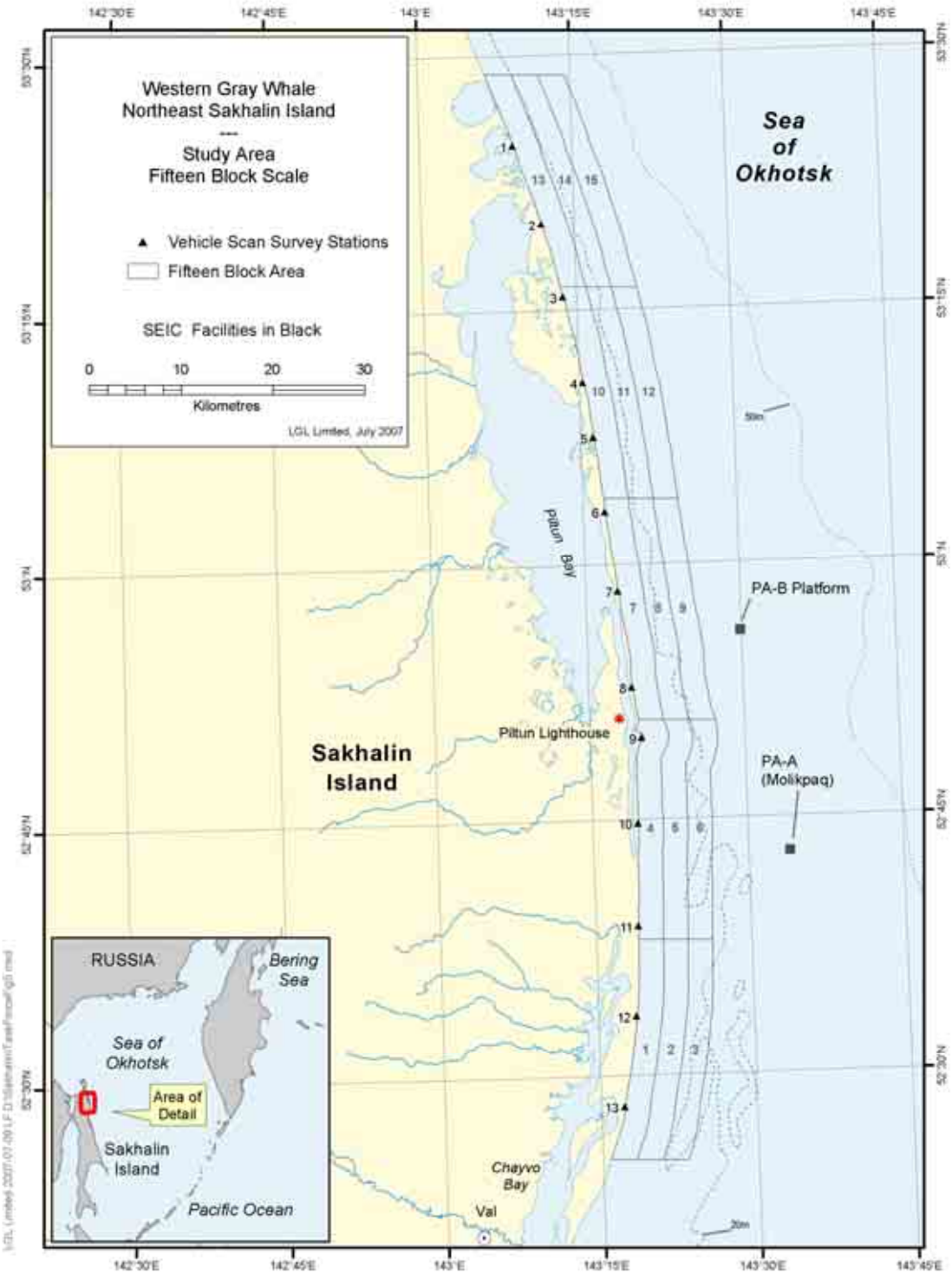
- Early July when the WGW population size in the Piltun area is increasing. Time window centred about 7 July.
- Late August when the the WGW population size in the Piltun area has stabilized. Time window centred about 21 August.
- Early October when the WGW population size in the Piltun area is decreasing. Time window centred about 1 October.

Objective 4: Test the effect on the number of WGWs based on density estimates from single survey platforms (shore-based vehicle, shore-based behaviour, aerial, vessel) versus the following combinations of survey platforms:

- Both shore-based surveys (behaviour and vehicle)
- Both shore-based and vessel surveys
- Vessel and aerial surveys
- All survey platforms (shore-based, vessel, aerial)

Objective 5: Test methods of data gap ‘correction’:

This will depend on results from Objective 3, above, and may be unnecessary. If combining surveys across different platforms is supported, then there are likely no gaps in density estimates in waters with non-zero WGW density estimates. Most, if not all, gaps will be in areas farther offshore where systematic surveys have recorded no gray whales, i.e. all cells (within a few km) surrounding the gaps will have estimated densities of zero. Consequently different methods of data gap correction will likely all interpolate zero densities within data gaps. This objective will be reconsidered after tests for Objectives 1 to 3 have been completed.


Western Gray Whale
Northeast Sakhalin Island

Study Area
Fifteen Block Scale
Vehicle Scan Survey Stations
Fifteen Block Area
SEIC Facilities in Black
0 10 20 30
Kilometres
LGL Limited, July 2007
Sea of Okhotsk
Piltun Bay
PA-B Platform
Piltun Lighthouse
Sakhalin Island
PA-A (Molikpaq)
Chayvo Bay
Val
RUSSIA
Bering Sea
Sea of Okhotsk
Area of Detail
Sakhalin Island
Pacific Ocean
142°30'E
142°45'E
143°E
143°15'E
143°30'E
143°45'E
53°30'N
53°15'N
53°N
52°45'N
52°30'N

ANNEX B: ILLUSTRATIVE CALCULATIONS OF EFFECTIVENESS OF SHUTDOWN CRITERIA FOR REDUCING SOUND EXPOSURE RISK

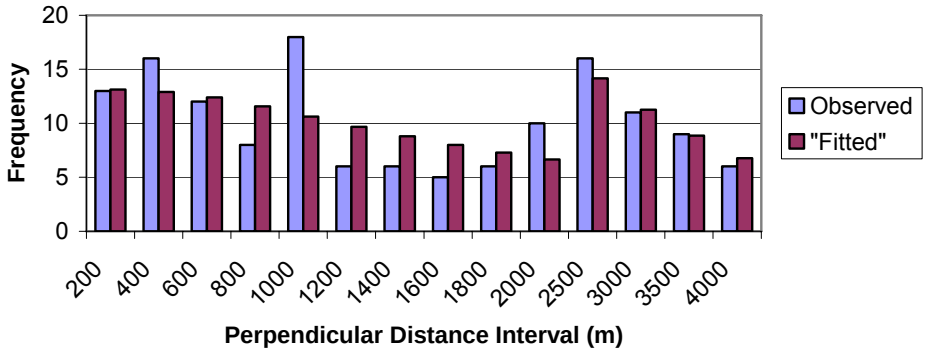
The purpose of this Annex is to illustrate an approach to estimating the expected effectiveness of mitigation methods based on the use of visual observations of the proximity of WGW to trigger shutdown of the gun array. The results should not necessarily be taken at face value, but they provide a guide to a possible approach, and may help to identify the parameters that cause greatest uncertainty.

Analysis of data relating to the detection function for WGW from shipborne platforms

Data from shipboard sighting surveys conducted during 2002-06 supplied by Judy Muir were examined with a view to estimating a radial detection function. In standard line transect the detection probability as a function of perpendicular distance from the trackline is the item of interest, but for the current purpose the detection rate as a function of radial distance is required.

From 2003 onwards, the data nominally collected were the angle and distance to the sightings, but it appears that the position recorded was not necessarily the position of the first sighting: some observers tended to wait until the whale was roughly abeam before estimating the distance. It was therefore decided not to use the radial distances and angles as given, but to fit the calculated perpendicular distances. These should be roughly independent of whether the first or a subsequent observation of each whale was used, because the speed of the vessel averaged about 10.5 kn, much faster than typical whale swimming speeds. The distribution of perpendicular distances is shown in Fig. B1 for the data from 2002-06.

Fig. B1. Fit to survey vessel sighting distances



The instantaneous sighting hazard for a previously unseen group of whales is modelled with the usual hazard-rate function:

$$f(r;s) = cs\left(1 - \exp\left(-(a/r)^b\right)\right) \qquad \text{(A.1)}$$

Where a, b, and c are parameters, and s denotes group size. The parameter a represents roughly the width of the "shoulder" in the hazard function; the parameter b determines how steeply the hazard declines with distance beyond the shoulder. The parameter c, which determines the

hazard rate at short distances, cannot be well estimated from these data, because it doesn't have a strong influence on the shape of the distribution of distances to sightings. Its estimation would require duplicate observations from independent platforms.

The radial hazard function relates to the detection probability as a function of perpendicular distance as follows:

$$g(y;s) = 1 - \exp\left(-\tfrac{1}{v}\int_{x=0}^{\infty} f\left(\sqrt{x^2+y^2}\right)dx\right) \qquad \text{(A.2)}$$

where v is the speed of the vessel, on the assumption that the angular distribution of sighting effort is uniform from ahead to abeam.

Plausible values of the parameter c depend on the level of observer effort and the rate at which the whales generate sighting cues. If the main sighting cues are respirations, then a rate in the range 30-60 cues per hour would be realistic by analogy with other baleen whales. The probability of sighting a cue at short distance depends on the level of observer effort and the nature of the searching. If there are two observers, each searching a 90° sector by naked eye, then if each observer takes 5-10s to scan his/her sector, and if the cues remain visible for 3-5s, then the probability of seeing a cue at short distance could be in the range 30-100%.

If binoculars are used, cues can be seen out to much greater distances, but the probability of seeing a nearby cue is reduced by the narrower field of view and slower angular scanning speed. It was not clear to what extent binoculars were used in the collection of these data: observers had binoculars available, but there were no specific protocols as to their use. According to an anecdotal report, binoculars were mainly used to obtain a closer look at whales already sighted, while most of the primary scanning was by naked eye.

It would be desirable to collect specific field data relating to cue sighting probability at short distance, but for the purpose of these illustrative calculations, a range of 0.25-0.75 was used. Coupled with a range of 30-60 cues per hour, this implies a range of 0.00208-0.0125s^{-1} for the parameter c (80-480s for $1/c$).

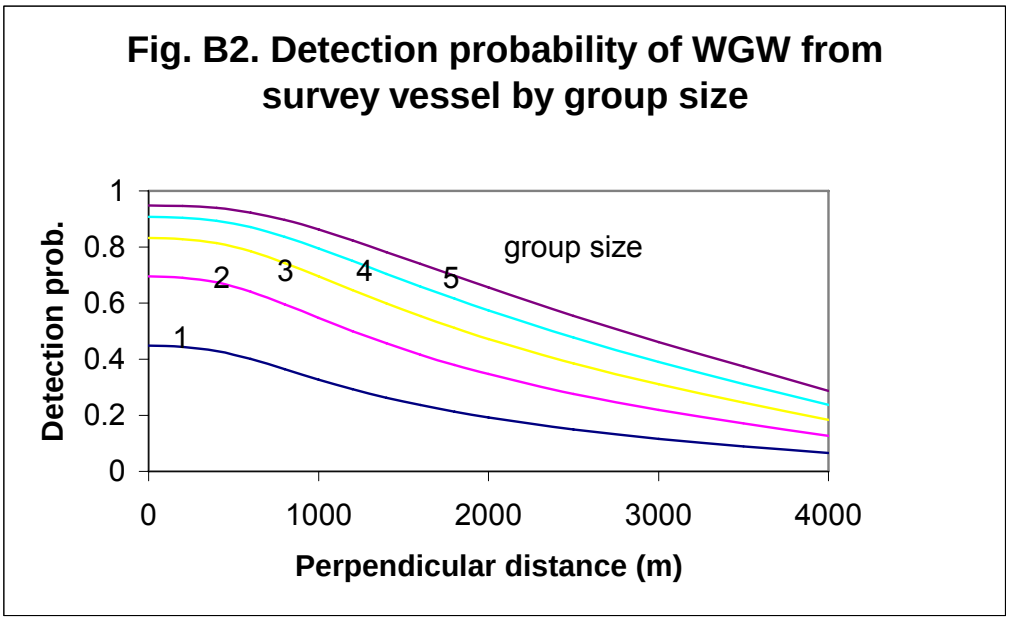
The results of fitting the model are shown in Table B1 for different values of c. The model fit, expressed as AIC, is best for the lowest value of c, but the differences are not statistically significant. Furthermore, the model fits are liable to be compromised by incorrect assumptions (such as a uniform angular distribution of search effort) and imprecise data (the angles and distances to whales were guessed by eye rather than measured instrumentally).

Table B1. Fits of radial hazard-rate model to shipborne survey data

c s-1	1/c s	*am*	CV(a)	*b*	SE(b)	AIC
0.0125	80	670	0.55	-2.18	0.66	2324.59
0.00625	160	817	0.58	-2.09	0.71	2324.35
0.003125	320	914	0.66	-1.94	0.73	2324.06
0.00208333	480	930	0.74	-1.83	0.73	2323.91

Fig. B1 shows the fitted distribution of perpendicular sightings distances compared with the observed distribution. Fig. B2 shows the estimated detection probability as a function of perpendicular distance and group size, for the lowest value of c. For this value of c, the probability of detection on the trackline – often called g(0) – ranges from about 0.45 for solitary animals to about 0.95 for groups of five animals. Assuming that the parameters a, b and c keep the same values, the corresponding range of g(0) values for the slower-moving seismic vessel (5

knots as opposed to 10.5 knots) would be 0.71 to1.00. In the analysis below, only solitary whales are considered, these being those most at risk.



It should be emphasised that the purpose of the analysis of these data is to gain only a very rough impression of the sightability of WGW. The data collection protocols for the visual surveys were insufficiently specific to ensure that any particular interpretation of the data is reliable. It is also unclear how the level and nature of observer effort on these surveys would relate to the level and nature of observer effort on a seismic survey vessel.

Modelling the effect of the shutdown rule on the risk of close encounters

The mitigation strategy assumed for the seismic survey is that operations would be shut down when a whale is detected within 1.5km of the gun array, or on a course that would bring it into this zone.

The expected number of close encounters during the seismic survey, and the expected proportion for which mitigation action would be taken, was estimated by simulation. Whales were generated at random positions and assumed to be swimming in straight lines, with a random orientation relative to the trackline. The form of the visual detection function was assumed to be given by equation (A.1). The seismic vessel was assumed to be moving at a constant speed of 5 knots. The seismic survey was assumed to cover the entire survey area with survey lines spaced 400m apart.

The values used for relevant parameters are listed in Table B2. Three alternative values were used for the distance of the array behind the ship: 100m, 200m and 400m. Three alternative values were used for whale swimming speed: 0, 2.5 and 5.0 knots. For each selected value of the *c* parameter, the corresponding values of the *a* and *b* parameters were taken from Table B1. In addition, one case (Case 9) was run with the *a* parameter halved to simulate the effect of operation under reduced visibility.

Table B2. Parameters used for the simulation analysis

Case	*a* M	*b*	*c* s^{-1}	1/*c* S	Array offset m	Whale speed Knots
1	930	-1.827	0.00208	480	200	2.5
2	914	-1.938	0.00313	320	200	2.5
3	817	-2.091	0.00625	160	200	2.5
4	670	-2.183	0.01250	80	200	2.5
5	930	-1.827	0.00208	480	200	0
6	930	-1.827	0.00208	480	200	5
7	930	-1.827	0.00208	480	100	2.5
8	930	-1.827	0.00208	480	400	2.5
9	465	-1.827	0.00208	480	400	2.5

The results are shown in Table B3 in terms of the expected number of close encounters (to within various distances) per unit whale abundance, where whale abundance is expressed in terms of the average number of whales present in the seismic survey area at a random time during the survey. By expressing the results in this way, neither the total area of the seismic survey nor the total duration of the survey need enter the calculations. The only parameters of the seismic survey that enter the calculations are the speed of the seismic vessel, the spacing of the tracklines, and the distance of the gun array behind the seismic vessel. End effects, including the possibility of start-ups in the middle of a survey line, are ignored. The results are generated on the assumption that each survey line is surveyed without interruption, except when a WGW is sighted.

For each case, one million potential encounters were simulated, so that the results, to the number of significant digits displayed, are not subject to sampling variability. The results for each distance are cumulative: the encounters to within 100m are included in those within 200m, etc. For example, the results of Case 1 imply that if there are an average of 2 whales in the seismic survey area, then the expected number of encounters closer than 100m is 0.54 without the shutdown measure and 0.16 with the shutdown measure. The probability of at least one such close encounter would be 0.42 (= 1 – exp(-0.54)) without the shutdown measure and 0.15 with the shutdown measure.

Table B3. Results of simulation study of mitigation effectiveness in terms of distance of closest approach

Case	Expected numbers of close encounters	Distance of closest approach to operating array (m) 100	200	300	400	500	600	800	1000	1500
1	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.08	0.16	0.25	0.36	0.48	0.62	0.96	1.36	2.55
	Effectiveness %	70.4	70.1	68.6	66.6	64.1	61.4	55.5	49.6	36.7
2	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.05	0.10	0.16	0.24	0.33	0.43	0.72	1.07	2.21
	Effectiveness %	81.4	81.3	79.9	78.0	75.7	73.0	66.8	60.1	45.2
3	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.02	0.04	0.06	0.09	0.14	0.20	0.40	0.69	1.74
	Effectiveness %	93.6	93.4	92.6	91.4	89.6	87.4	81.3	74.3	56.8
4	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.00	0.01	0.02	0.03	0.05	0.09	0.24	0.48	1.47
	Effectiveness %	98.6	98.5	98.1	97.3	96.1	94.3	89.1	82.1	63.7
5	No mitigation	0.25	0.50	0.75	1.00	1.25	1.50	2.01	2.51	3.76
	With mitigation	0.07	0.14	0.23	0.32	0.44	0.57	0.89	1.27	2.40
	Effectiveness %	71.1	71.0	69.6	67.6	65.1	62.2	55.7	49.4	36.1
6	No mitigation	0.76	1.46	2.02	2.53	2.99	3.42	4.20	4.90	6.36
	With mitigation	0.34	0.62	0.87	1.12	1.38	1.65	2.21	2.81	4.31
	Effectiveness %	55.8	57.3	56.9	55.6	53.9	51.9	47.4	42.7	32.2
7	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.08	0.17	0.27	0.38	0.51	0.66	1.01	1.42	2.62
	Effectiveness %	70.8	69.1	67.0	64.7	61.9	59.1	53.0	47.2	35.0
8	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.08	0.17	0.25	0.34	0.44	0.57	0.87	1.24	2.41
	Effectiveness %	69.4	69.1	68.8	68.4	66.9	64.9	59.7	54.0	40.4
9	No mitigation	0.27	0.54	0.81	1.07	1.34	1.61	2.15	2.69	4.03
	With mitigation	0.14	0.29	0.44	0.60	0.79	1.00	1.51	2.04	3.42
	Effectiveness %	46.1	45.7	45.0	44.2	41.4	37.7	30.1	24.2	15.2

An alternative to the "distance of closest approach" as a measure of risk, is the total sound exposure (in dB_{SEL}) from the shooting of a seismic line. Approximate levels were computed as follows:

The results shown in Fig. 5.3 indicate that, excluding the extreme nearshore area, the received energy from a pulse declines roughly as $\exp(-br)/r$, where r is distance from the source. This corresponds to 2-D spreading with an effective absorption rate (b) of about 1.5 dB per km

(0.0015 dB m^{-1}). Directional effects were ignored, and the received SEL at a distance *r* km from a pulse was taken to be 171 – 1.5*r* – ln*r* dB. The received sound energy was summed across all pulses on the seismic line assuming a pulse spacing of 18.75m and a line length of 15.4 km.

The results are shown in Table B4. These results show that most whales in the seismic survey area will be exposed to more than 190 dB_{SEL} (and thus potentially subject to TTS – see section 4) whether or not the shutdown criterion is used. No whales are predicted to be exposed to more than 215 dB_{SEL} whether or not the shutdown criterion is used. The effect of the shutdown criterion is most felt in the range 195-215 dB_{SEL}, where it reduces the number of WGW exposed to this level of noise by 44-99%.

Table B4. Results of simulation study of mitigation effectiveness in terms of sound exposure level

Case	Expected number of exposures exceeding	dB SEL 180	185	190	195	200	205	210	215	220
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
1	With mitigation	9.5	8.0	2.5	0.2	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	4.5	13.4	46.2	77.6	87.6	100.0			
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
2	With mitigation	9.4	7.7	2.1	0.1	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	5.5	16.8	55.3	87.5	94.5	100.0			
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
3	With mitigation	9.2	7.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	6.8	21.5	66.1	96.2	99.0	100.0			
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
4	With mitigation	9.2	7.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	7.6	24.4	71.2	99.1	99.9	100.0			
	No mitigation	9.9	9.6	4.3	0.7	0.0	0.0	0.0	0.0	0.0
5	With mitigation	9.5	8.5	2.1	0.2	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	4.1	11.9	51.4	70.9	70.7				
	No mitigation	9.9	8.8	5.4	2.2	0.7	0.2	0.0	0.0	0.0
6	With mitigation	8.9	6.9	2.9	0.9	0.3	0.1	0.0	0.0	0.0
	Effectiveness %	9.9	22.2	47.3	59.2	58.9	44.3	15.5	60.0	100.0
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
7	With mitigation	9.5	8.1	2.6	0.2	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	4.2	12.7	45.4	78.0	87.9	100.0			
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
8	With mitigation	9.4	7.9	2.5	0.2	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	5.1	14.9	47.2	76.7	87.1	100.0			
	No mitigation	9.9	9.2	4.7	1.0	0.0	0.0	0.0	0.0	0.0
9	With mitigation	9.7	8.7	3.6	0.5	0.0	0.0	0.0	0.0	0.0
	Effectiveness %	1.8	5.5	24.1	50.2	66.5	100.0			